Tanya DeRivi
Senior Director, California Climate and Fuels

November 22, 2024

California Air Resources Board
1001 I Street
Sacramento, CA 95814

Submitted via email to MSS@arb.ca.gov

Re: WSPA Comments on the CARB 2025 Mobile Source Strategy Discussion Draft

The Western States Petroleum Association (WSPA) appreciates the opportunity to comment on the 2025 Mobile Source Strategy (MSS) Discussion Draft (released October 11, 2024), as requested by the California Air Resources Board (CARB) at its October 23, 2024, public workshop. WSPA is a non-profit trade association that represents companies that import and export, produce, refine, transport and market petroleum, petroleum products, natural gas, and other energy supplies in California and four other western states, and has been an active participant in air quality planning issues for over 30 years.

WSPA recognizes the challenges that California faces in meeting its air quality improvement and greenhouse gas emission reduction goals and acknowledges that the transportation sector is integral in any solution. CARB should recognize in any actions it takes to further these goals, including the Mobile Source Strategy, must strike an appropriate balance between environmental protection, and affordability and reliability. While WSPA continues to work with the California Energy Commission (CEC) and CARB to address energy supply and cost concerns, we are concerned that California's transportation and energy policies are attempting to reduce affordable and reliable energy supplies faster than consumers can afford. Ignoring affordability and reliability leads to volatile markets and higher prices, especially for economically disadvantaged individuals. All technologies should have a seat at the table to determine what is the most cost effective and diverse mobile source strategy to meet California's emission reduction goals.

WSPA wants to work with CARB and stakeholders to develop a credible 2025 MSS, which must, at a minimum, address the following:

1. **Technology feasibility:** As directed by Executive Order (EO) N-79-20[1] and California Senate Bill (SB) 44,[2] CARB must develop regulations and strategies to achieve the State's overarching goals and "act consistently with technological feasibility and cost effectiveness." To be credible, the MSS must provide a more in-depth assessment of commercially available technologies and the feasibility of adopting these technologies at the scale and pace of proposed control scenarios. The assessment should evaluate all feasible emission-reducing technologies (e.g., combustion vs. zero tailpipe) so policy makers, stakeholders, and the public can meaningfully comment on or decide amongst control scenarios. Selecting an infeasible control scenario risks impeding the movement of goods and services in California, exacerbating projected challenges due to critical infrastructure constraints for the transportation energy supply chain.[3] CARB must not underestimate the impacts this could

[1] Executive Order N-79-20. Available at: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf. Accessed: November 2024.
[2] Senate Bill 44. Available at: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB44. Accessed: November 2024.
[3] Turner, Mason, & Company. 2024. Transportation Energy Supply Chain Infrastructure and Investment Study (TESCII). Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=259251&DocumentContentId=95338.

impose on communities already experiencing higher living costs. Please refer to **Attachment A** (**Item A.1**) for more detailed comments regarding technology feasibility.

2. **Affordability and cost-effectiveness:** The MSS must include scenarios with a full range of feasible low-emitting technologies/fuels to provide policymakers with credible options to find the lowest cost and most cost-effective emission reduction pathways. WSPA recommends that CARB utilize available methodologies and stakeholder studies to assess costs, emission reductions, and implementation barriers (which affect emissions reduction timelines). In particular, CARB should consider the impact of any technology mandate on the cost to move goods and services in California, and the effect of these higher costs on communities already experiencing higher living costs. Previous studies[4,5,6] have shown that a technology-neutral approach that considers a full suite of low-emitting technologies/fuels (as opposed to a technology forcing approach) can not only achieve the State's emission reduction targets, but do so more cost-effectively. The Governor's directive "to help curb rising electricity costs and provide electric bill relief" and CARB's Proposed Low Carbon Fuel Standard Board Resolution[7] emphasize that CARB's policies, plans, and regulations need greater analysis and transparency related to energy/fuel prices and affordability. Please refer to **Attachment A** (**Item A.2**) for more detailed comments regarding affordability and cost-effectiveness.

3. **Implementation barriers affecting baseline and other scenarios:** The 2025 MSS and scenarios developed under this strategy must account for known implementation barriers (e.g., local power availability, charging infrastructure, vehicle/equipment availability, etc.). CARB should adjust its "baseline" scenario to account for these barriers by realistically modeling affected implementation timelines and incorporating additional technology/fuel options that have lower implementation barriers into the modeled scenarios. WSPA has repeatedly highlighted these implementation barriers and potential solutions to addressing these barriers in prior comment letters on the 2020 MSS, the Advanced Clean Fleets (ACF) regulation, the Advanced Clean Cars II (ACC II) regulation, and the 2022 Scoping Plan Update. As evidenced by recent stakeholder meetings for various regulatory programs including the Advanced Clean Truck (ACT) regulation, ACF regulation, Ocean-Going Vessels (OGV) At-Berth regulation, and Commercial Harbor Craft (CHC) regulation, as well the most recent 2025 MSS presentation, these implementation barriers have not been addressed, even as implementation requirements increase. Please refer to **Attachment A**, **Item A.3** for more detailed comments regarding implementation barriers. In order for the 2025 MSS to be a credible planning document, stakeholders must be apprised of the effects of these known barriers in the baseline scenario modeling. At the very least, CARB should include modeling scenarios with use of known, feasible, lower-emission combustion technologies that do not have these implementation barriers. These scenarios should then be analyzed for affordability, cost-effectiveness, and the ability to credibly reduce emissions as the current suite of mobile source policy implementation barriers are reduced over time.

4. **Further uncertainties affecting the baseline and other scenarios:** Failing to account for implementation challenges and other uncertainties may impact the longevity of the 2025

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4 Ramboll. 2021. Multi-Technology Pathways to Achieve California's Air Quality and Greenhouse gas Goals: Heavy-Heavy-Duty Truck Case Study. Available at: https://www.wspa.org/wp-content/uploads/Multi-technology-Truck-Emission-Reduction-Scenarios-White-Paper-FINAL.pdf. Accessed: November 2024.

5 Ramboll. 2022. Multi-Technology Pathways to Achieve California's Greenhouse Gas Goals: Light-Duty Auto Case Study. Available as Attachment D at: https://www.arb.ca.gov/lists/com-attach/477-accii2022-AHcAdQBxBDZSeVc2.pdf. Accessed: November 2024.

6 NERA Economic Consulting. Economic Impact Analysis of California's 2022 Draft Scoping Plan's "Proposed Scenario". Available as Attachment D at: https://www.arb.ca.gov/lists/com-attach/4416-scopingplan2022-BnEAdVQlBTdRCAZn.pdf. Accessed: November 2024.

7 CARB 2024 Amendments to the LCFS was approved November 8, 2024. Available at https://ww2.arb.ca.gov/sites/default/files/barcu/board/books/2024/11070824/24-14prores.pdf. Accessed: November 2024.

MSS as a planning document. For instance, CARB is currently adjusting requirements under previously adopted regulations to address the implementation challenges outlined above. In addition to these challenges, there is now additional uncertainty related to the status of United States Environmental Protection Agency (EPA) waivers for key adopted rules (e.g., Advanced Clean Fleets, Heavy-Duty Omnibus, Transport Refrigeration Units, Commercial Harbor Craft, In-Use Off-Road Diesel-Fueled Fleet, Small Off-Road Engines, Advanced Clean Cars II, and In-Use Locomotive rules), that needs to be reflected in the baseline as well as alternate scenarios. It is imperative that CARB develop scenarios that remove the assumption that existing and proposed regulations can feasibly be implemented on the adopted implementation schedules. CARB needs to conduct a workshop to discuss how these implementation barriers, including the uncertainties around the EPA waivers, will be accounted for in the development of the 2025 MSS scenarios. Refer to **Attachment A**, **Item A.4** for more detailed comments regarding these uncertainties affecting the baseline and other scenarios.

In summary, WSPA believes that in developing the 2025 MSS, CARB must consider all feasible emission-reducing technology/fuel combinations and identify the most credible and cost-effective scenarios to maximize possible emission reductions. A 2025 MSS that merely focuses on expanding zero emission (ZE) technology mandates is not credible because the baseline assumptions for the currently adopted rules (e.g., ACT, ACF, ACCII, and Off-Road ZE technology Rules) have been challenged. These challenges include issues related to the EPA waivers and implementation barriers highlighted above.

WSPA strongly encourages CARB to work with stakeholders to develop a modified baseline that reflects the known implementation barriers and the use of feasible and cost-effective emission-reducing technologies that WSPA and other stakeholders have proposed in studies and comments on the 2020 MSS and related rulemakings. CARB should hold an immediate 2025 MSS workshop focused on adjustments needed for the baseline scenario to credibly reflect the affordability and implementation issues outlined above and take stakeholder suggestions on feasible emission-reducing technologies that must be included in model scenarios so that policy makers, stakeholders, and the public can trust that the 2025 MSS contains a range of feasible and affordable emission-reduction scenarios that can be compared for feasibility and affordability as California pursues its air quality and climate change goals.

Thank you for considering our comments. WSPA would welcome the opportunity to discuss these comments and recommendations in more detail with CARB staff; I can be reached at tderivi@wspa.org.

Sincerely,

Tanya DeRivi

Tanya DeRivi
Senior Director, California Climate and Fuels

Attachment A: Detailed Comments on the 2025 Mobile Source Strategy Discussion Draft
Attachment B: Referenced Non-CARB Documents

ATTACHMENT A
Detailed Comments on the 2025 Mobile Source Strategy Discussion Draft

Detailed Comments on the 2025 Mobile Source Strategy Discussion Draft

In the October 23, 2024, Public Workshop, CARB staff solicited stakeholder comment on the 2025 MSS Discussion Draft, requesting input on the following questions:

- Are there any category current controls or emission reduction potential that [CARB] overlooked?
- Are there concepts/scenarios that you strongly support, or don't think are necessary?
- What additional ideas or concepts would you like CARB to explore or consider?

WSPA offers the following comments in response to the above questions and provides further elaboration on the four key comments concerning the 2025 MSS highlighted in the main comment letter.

A.1 Technology Feasibility: As directed by Executive Order N-79-20[8] and California Senate Bill (SB) 44,[9] CARB must develop regulations and strategies to achieve the State's overarching goals and "act consistently with technological feasibility and cost effectiveness." To be credible as a broad planning document, the MSS must provide an in-depth assessment of commercially available technologies and the ability to adopt these technologies at the scale and pace of proposed control scenarios. The assessment should evaluate all feasible emission-reducing technologies (e.g., combustion vs. zero tailpipe) so policymakers, stakeholders, and the public can meaningfully comment on or decide amongst control scenarios. Selecting an infeasible control scenario risks impeding the movement of goods and services in California, exacerbating projected challenges due to critical infrastructure constraints for the transportation energy supply chain. CARB must not underestimate the impacts this could impose on communities already experiencing higher living costs.

WSPA encourages CARB to take a technology-neutral approach, rather than a technology-forcing approach, in its scenario development. CARB should develop sensitivity scenarios under which specific technologies are unable to meet the cost effectiveness or operational requirements of a specific mobile source category. Additionally, CARB should provide further details on how technology feasibility will be incorporated into scenario analysis.

The 2025 MSS Discussion Draft offers limited detail on how vehicle technology feasibility will be assessed. While CARB acknowledges deployment challenges associated with zero emission (ZE) infrastructure, the 2025 MSS Discussion Draft does not detail how it plans to consider these challenges. Further, CARB does not specify how these challenges might factor into the Agency's decision-making as to which scenarios to model and ultimately select as the State's strategy.

Staff should not push for solutions under which safety, operability, or affordability is sacrificed, nor should exemptions, extensions, or payment-related provisions act as a substitute. For many mobile categories, zero exhaust emission technology is not ready to meet the duty cycle requirements of use, or may not be available at the desired pace. Such control scenarios endanger California's economy because they effectively reduce the ability for stakeholders to move goods and services within the State, phasing out existing modes of transporting goods and services without a viable replacement, and without reducing emissions using the most cost effective technology. For example,

8 Executive Order N-79-20. Available at: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf. Accessed: November 2024

9 Senate Bill 44. Available at: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB44. Accessed: November 2024.

please see specific technology feasibility concerns with the State's implementation of Ocean-Going Vessel At-Berth Regulation and Commercial Harbor Craft (CHC) Regulation highlighted in **Item A.3.1.**

WSPA recommends that CARB incorporate full life cycle assessments (LCA) and model the use of alternative fuels to address technology feasibility concerns listed above.

A.1.1 Full Life Cycle Assessment: As WSPA has explained in previous comments on the 2020 MSS, Advanced Clean Fleets (ACF), and Advanced Clean Cars (ACC II) regulations, CARB must analyze greenhouse gas (GHG) benefits on a life cycle basis (including upstream processes such as battery production) and assess impacts on individual particulate matter (PM) sources separately (e.g., tail pipe, tire wear, brake wear, and entrained road dust). Different technologies have varied effects on these individual sources, and these effects should be accounted for in CARB's selection of scenarios and preferred strategy. In addition to a GHG LCA analysis, CARB should also conduct a full environmental LCA to capture sustainability impacts that would arise from the mining of critical minerals to support production of key battery components (e.g., lithium, cobalt, etc.). This analysis should explore the environmental impacts of these mining processes on air, water, and local communities across the supply chain. This LCA should also include the end-of-life disposal of these batteries, which have considerable environmental implications, as recycling is not at scale and is only available for certain types of batteries.

While the 2025 MSS Discussion Draft provides estimates for the tailpipe PM emissions in year 2020 and projected emissions for years 2031 and 2050, this assessment does not account for the full lifecycle of emissions potential. While staff notes that PM emissions from non-exhaust sources (like tire wear and brake wear) are areas of active research, it is unclear if these non-exhaust PM emissions will be evaluated to understand the total PM impacts of the ZE on-road vehicle transition that is proposed by the 2025 MSS. WSPA encourages CARB to evaluate a broader range of impacts, rather than focus on tank to wheel emissions.

A.1.2 Alternative Fuels: WSPA believes that CARB should model scenarios for on-road heavy duty and off-road mobile sources that consider and use alternative liquid and gaseous fuels as pathways to meet the State's GHG goals and air pollution targets. Alternative low emission fuel/mobile source technologies are currently available and are not subject to the implementation barriers described in **Item A.3**.

- CARB's reliance on consequential analysis (*i.e.*, indirect land use changes) unreasonably attributes environmental consequences that have not been directly observed and gives a disproportionate penalty to crop-based fuel technology due to indirect risks. Technology decisions should instead be prioritized with attributional analysis. Under this analysis, alternative fuel technology solutions remain a feasible reduction pathway, and CARB should fully consider alternative fuels in the scenario development process.
- CARB should model scenarios for on-road heavy duty and off-road mobile sources under which an increased use of renewable liquid and gaseous fuels in Low NO_X engines and other technologies is evaluated as a pathway to reducing GHG emissions. This includes combustion technologies that utilize compressed natural gas and/or hydrogen. This would align with the Low Carbon Fuel Standard program and other related efforts to promote production of these renewable fuels.
- A shift to a complete electrified-focused fleet would strand existing investments in renewable fuel feedstocks and infrastructure, while also incurring significant

additional costs to consumers. While the 2025 MSS Discussion Draft briefly mentions the consideration and use of alternative and/or renewable fuels for the off-road sector (e.g., renewable diesel for several off-road categories, sustainable aviation fuel for aircraft, and alternative fuels for OGVs), CARB continues to focus on a ZE technology-forcing approach for the on-road sector. At minimum, CARB should develop one scenario in which alternative fuels are explored as a primary option for achieving the State's decarbonization goals.

A.2 Affordability and cost-effectiveness: As directed by EO N-79-20[10] and SB 44,[11] the 2025 MSS must include scenarios that evaluate a full range of low-emitting technologies/fuels to provide policy makers credible options to find the most cost-effective emission reduction pathways. A complete assessment of costs, emission reductions, and implementation barriers (which affect emissions reduction timelines) can be done based on available methodologies and stakeholder studies. However, the current discussion draft does not meaningfully assess cost effectiveness, only mentioning the directive to consider cost effectiveness once in the document.

- CARB staff should provide details on how the Agency plans to calculate and assess the cost effectiveness of each mechanism considered in the 2025 MSS to reduce emissions from a specific mobile source category, and explain how CARB will take into account the cost effectiveness of each mechanism in its development of the proposed scenarios. CARB should also establish a methodology for estimating the overall cost effectiveness of proposed scenarios and indicate how that metric would be used to select the preferred scenario.
- Additionally, as part of this analysis, CARB staff should consider the variability and range in cost assumptions over time for key implementation aspects (total cost of vehicle ownership including fuel and infrastructure). This would include details such as potential increases in vehicle miles traveled (VMT) associated with fleet electrification and subsequently associated increases in cost to consumers.
- Developing a plan that fails to adequately analyze affordability and reliability risks creates a more volatile market that will likely increase consumer prices – which is likely to have the most significant impact for economically disadvantaged communities. CARB must strike an appropriate balance between affordability, reliability, and environmental protection, to avoid these unintended consequences. In addition, CARB must ensure that any cost effectiveness analysis also includes a thorough assessment of the cost implications on consumers in order to ensure that CARB's policies do not reduce the affordability and reliability of supply faster than the consumer's ability to afford it.
- In addition to these cost concerns, CARB should also assess other economic and environmental trade-offs, such as leakage of GHG emissions due to a shifting of business operations to regions outside California.

A.3 Implementation barriers affecting baseline and other scenarios: The MSS and its scenarios must account for known implementation barriers (e.g., local power availability, charging infrastructure, vehicle/equipment availability, etc.). This should be done for the "baseline" scenario by realistically modeling affected implementation timelines and by incorporating additional technology/fuel options that have lower implementation barriers into the modeled scenarios. CARB should conduct a regulatory effectiveness assessment and model scenarios under which technology feasibility, cost-effectiveness,

[10] Executive Order N-79-20. Available at: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf. Accessed: November 2024

[11] Senate Bill 44. Available at: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB44. Accessed: November 2024.

and the ability to enact and enforce regulations would hinder regulations from achieving full compliance.

WSPA has repeatedly highlighted these implementation barriers and potential solutions to addressing these barriers in prior comment letters on the 2022 MSS, the ACF regulation, the ACC II regulation, and the 2022 Scoping Plan Update. WSPA lists a number of those implementation barriers below.

A.3.1 Category-Specific Implementation Barriers

WSPA has identified a number of concerns regarding CARB's 2020 OGV At-Berth Regulation[12] and CARB's 2022 CHC Regulation amendments.[13] These concerns remain applicable to the development of the 2025 MSS. WSPA reiterates a number of these concerns below:

- **OGV At-Berth Regulation:** CARB's 2020 amendments to its OGV At-Berth Regulation will impose new requirements on marine terminal operations. It requires tanker terminals and operators, starting January 1, 2025, to reduce emissions from crude oil and product tankers by capturing stack emissions or by electrification of the at-berth operations using shore-based power, with limited exemptions. Absent the ability to implement one of these options, tankers will generally not be legally permitted to berth at California ports and marine terminals after applicable deadlines. At this time, the vast majority of the tankers that berth at California ports and terminals are not equipped to utilize shore power. Moreover, no stack emissions capture system has been approved for use by tankers, and vendors have provided no date certain for the approval and implementation of such a system, even if feasible. Finally, there are no currently applicable regulatory exemptions allowing tankers lacking shore power or emissions controls to dock at California ports after January 1. As a result, at this time, that At-Berth Regulation provides no clear path for tankers to meet the regulation's OGV emission control requirements to berth at the Port of Long Beach and Port of Los Angeles by the compliance deadline of January 1, 2025.
- **CHC Regulation:** As with OGVs, there is currently no existing equipment or technology approved by the maritime industry to safely supply shore power to petrochemical tank barges or tugs while operating in an electrically classified or hazardous area. Guidance documents (including design recommendations) for certain types of vessels are under development but have not yet been issued. There are also possible issues (including possible physical constraints) with matching up ship-to-shore connections.

A.3.2 Infrastructure Availability and Grid Readiness:

CARB should develop sensitivity scenarios with varying degrees of zero-emission infrastructure availability, also accounting for grid readiness.

- While the 2025 MSS Discussion Draft highlights ZE infrastructure needs (Chapter 5), this discussion simply summarizes existing ZE infrastructure efforts in the State and does not evaluate timing for infrastructure readiness. The 2025 MSS scenario will require significant increases in ZE infrastructure availability as compared to the 2020 MSS, as CARB is proposing electrification of several off-road categories and considering deployment of ZE locomotives and airplanes. CARB should plan to

[12] CARB 2020 At Berth Regulation. Available at: https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation. Accessed: November 2024

[13] CARB 2022 CHC Amendments. Available at: https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft. Accessed: November 2024.

model various sensitivity scenarios for cases where the State cannot meet the increasing demand for ZE mobile sources in both the on-road and off-road sector.

- In addition to infrastructure availability, CARB should work with relevant State agencies to assess power distribution, grid readiness, and the ability to build power stations to support charging centers, and develop a geographic assessment of available ZE charging infrastructure. This analysis should also include an assessment of incremental electricity demand and the emissions associated with the increased daily peak power requirements.

A.4 Further Uncertainties affecting the baseline scenario and other scenarios: Failing to account for implementation challenges and other uncertainties may impact the longevity of the 2025 MSS as a planning document. For instance, CARB is currently adjusting requirements under previously adopted regulations to address the implementation challenges outlined above. It is imperative that CARB develop scenarios that question the baseline assumption that existing and proposed regulations can meet their mandated targets. There is now additional uncertainty related to the status of United States Environmental Protection Agency (EPA) waivers for key adopted rules that needs to be reflected in the baseline as well as alternate scenarios. WSPA encourages CARB to conduct a workshop to discuss how these uncertainties regarding the EPA waivers will be better incorporated into its 2025 MSS.

Per CARB staff responses to a public comment in the October 23rd Public Workshop, CARB is currently assuming 100% compliance with all proposed regulations in the baseline emission projections. CARB should conduct a regulatory effectiveness assessment and model scenarios under which technology feasibility, cost-effectiveness, and the ability to enact and enforce regulations would hinder regulations from achieving full compliance.

CARB's "regulatory effectiveness" assessment should also calculate regulatory effectiveness at interim and milestone years resulting from a lack of electrical generation and related charging infrastructure barriers (see **Item A.3.2**). CARB should address these issues by including scenarios that evaluate alternate fuel/technology options that could reduce emissions and do not have these constraints.

In addition to regulatory effectiveness, the 2025 MSS relies on several State mandates that require users to buy new equipment, but many of these mandates have not been realized. CARB should consider sensitivity scenarios in which these mandates are not realized.

A.5 Additional Comments

A.5.1 Selection Criteria: CARB should specify the criteria for selecting the final 2025 MSS scenario before staff begins scenario modeling.

- CARB has not specified the criteria for selecting the final scenario. WSPA requests that CARB provide information on how factors such as cost-effectiveness, emission benefits, and technology feasibility will be considered, as well as how will CARB address the synergies and trade-offs among different scenarios. Additionally, CARB has not provided estimates of oxides of nitrogen (NO_X), PM, or GHG emission reductions to the future baseline that are necessary to achieve State targets and mandates.

A.5.2 Inventory Years: CARB should consider a baseline year of 2019 and provide 2037 baseline inventories. The current discussion draft uses a baseline year of 2020, which is an inflection point for energy usage and the economy. The justification for this selection is "to best compare and review the progress made since the 2020 MSS." However, CARB also states that "[i]t is important to note that emissions estimates shown for 2020, 2031, and 2050 generally do not reflect the impacts of the COVID-19 pandemic. Differences between them are due to impacts of adopted CARB regulations, policies, and natural turnover."[14] Given these considerations, CARB should consider a baseline year of 2019 instead of 2020. We also note that CARB has not included a 2037 baseline emission estimates, which should be provided.

14 CARB 2025 Discussion Draft Mobile Source Strategy. Page 14. Available at: https://ww2.arb.ca.gov/sites/default/files/2024-10/Discussion_Draft_2025_Mobile_Source_Strategy.pdf. Accessed: November 2024.

ATTACHMENT B
Referenced Non-CARB Documents

EXECUTIVE DEPARTMENT
STATE OF CALIFORNIA

EXECUTIVE ORDER N-79-20

WHEREAS the climate change crisis is happening now, impacting California in unprecedented ways, and affecting the health and safety of too many Californians; and

WHEREAS we must accelerate our actions to mitigate and adapt to climate change, and more quickly move toward our low-carbon, sustainable and resilient future; and

WHEREAS the COVID-19 pandemic has disrupted the entire transportation sector, bringing a sharp decline in demand for fuels and adversely impacting public transportation; and

WHEREAS as our economy recovers, we must accelerate the transition to a carbon neutral future that supports the retention and creation of high-road, high-quality jobs; and

WHEREAS California's long-term economic resilience requires bold action to eliminate emissions from transportation, which is the largest source of emissions in the State; and

WHEREAS the State must prioritize clean transportation solutions that are accessible to all Californians, particularly those who are low-income or experience a disproportionate share of pollution; and

WHEREAS zero emissions technologies, especially trucks and equipment, reduce both greenhouse gas emissions and toxic air pollutants that disproportionately burden our disadvantaged communities of color; and

WHEREAS California is a world leader in manufacturing and deploying zero-emission vehicles and chargers and fueling stations for cars, trucks, buses and freight-related equipment; and

WHEREAS passenger rail, transit, bicycle and pedestrian infrastructure, and micro-mobility options are critical components to the State achieving carbon neutrality and connecting communities, requiring coordination of investments and work with all levels of governments including rail and transit agencies to support these mobility options; and

WHEREAS California's policies have contributed to an on-going reduction in in-state oil extraction, which has declined by over 60 percent since 1985, but demand for oil has not correspondingly declined over the same period of time; and

WHEREAS California is already working to decarbonize the transportation fuel sector through the Low Carbon Fuel Standard, which recognizes the full life cycle of carbon in transportation emissions including transport into the State; and

WHEREAS clean renewable fuels play a role as California transitions to a decarbonized transportation sector; and

WHEREAS to protect the health and safety of our communities and workers the State must focus on the impacts of oil extraction as it transitions away from fossil fuel, by working to end the issuance of new hydraulic fracturing permits by 2024; and

WHEREAS a sustainable and inclusive economic future for California will require retaining and creating high-road, high-quality jobs through sustained engagement with communities, workers and industries in changing and growing industries.

NOW THEREFORE, I, GAVIN NEWSOM, Governor of the State of California by virtue of the power and authority vested in me by the Constitution and the statutes of the State of California, do hereby issue the following Order to pursue actions necessary to combat the climate crisis.

IT IS HEREBY ORDERED THAT:

1. It shall be a goal of the State that 100 percent of in-state sales of new passenger cars and trucks will be zero-emission by 2035. It shall be a further goal of the State that 100 percent of medium- and heavy-duty vehicles in the State be zero-emission by 2045 for all operations where feasible and by 2035 for drayage trucks. It shall be further a goal of the State to transition to 100 percent zero-emission off-road vehicles and equipment by 2035 where feasible.

2. The State Air Resources Board, to the extent consistent with State and federal law, shall develop and propose:

    a) Passenger vehicle and truck regulations requiring increasing volumes of new zero-emission vehicles sold in the State towards the target of 100 percent of in-state sales by 2035.

    b) Medium- and heavy-duty vehicle regulations requiring increasing volumes of new zero-emission trucks and buses sold and operated in the State towards the target of 100 percent of the fleet transitioning to zero-emission vehicles by 2045 everywhere feasible and for all drayage trucks to be zero-emission by 2035.

    c) Strategies, in coordination with other State agencies, U.S. Environmental Protection Agency and local air districts, to achieve 100 percent zero-emission from off-road vehicles and equipment operations in the State by 2035.

    In implementing this Paragraph, the State Air Resources Board shall act consistently with technological feasibility and cost-effectiveness.

3. The Governor's Office of Business and Economic Development, in consultation with the State Air Resources Board, Energy Commission, Public Utilities Commission, State Transportation Agency, the

Department of Finance and other State agencies, local agencies and the private sector, shall develop a Zero-Emissions Vehicle Market Development Strategy by January 31, 2021, and update every three years thereafter, that:

a) Ensures coordinated and expeditious implementation of the system of policies, programs and regulations necessary to achieve the goals and orders established by this Order.

b) Outlines State agencies' actions to support new and used zero-emission vehicle markets for broad accessibility for all Californians.

4. The State Air Resources Board, the Energy Commission, Public Utilities Commission and other relevant State agencies, shall use existing authorities to accelerate deployment of affordable fueling and charging options for zero-emission vehicles, in ways that serve all communities and in particular low-income and disadvantaged communities, consistent with State and federal law.

5. The Energy Commission, in consultation with the State Air Resources Board and the Public Utilities Commission, shall update the biennial statewide assessment of zero-emission vehicle infrastructure required by Assembly Bill 2127 (Chapter 365, Statues of 2018) to support the levels of electric vehicle adoption required by this Order.

6. The State Transportation Agency, the Department of Transportation and the California Transportation Commission, in consultation with the Department of Finance and other State agencies, shall by July 15, 2021 identify near term actions, and investment strategies, to improve clean transportation, sustainable freight and transit options, while continuing a "fix-it-first" approach to our transportation system, including where feasible:

   a) Building towards an integrated, statewide rail and transit network, consistent with the California State Rail Plan, to provide seamless, affordable multimodal travel options for all.

   b) Supporting bicycle, pedestrian, and micro-mobility options, particularly in low-income and disadvantaged communities in the State, by incorporating safe and accessible infrastructure into projects where appropriate.

   c) Supporting light, medium, and heavy duty zero-emission vehicles and infrastructure as part of larger transportation projects, where appropriate.

7. The Labor and Workforce Development Agency and the Office of Planning and Research, in consultation with the Department of Finance and other State agencies, shall develop by July 15, 2021 and expeditiously implement a Just Transition Roadmap, consistent with the recommendations in the "Putting California on the High Road: A Jobs and Climate Action Plan for 2030" report pursuant to Assembly Bill 398 (Chapter 135, Statutes of 2017).

8. To support the transition away from fossil fuels consistent with the goals established in this Order and California's goal to achieve carbon neutrality by no later than 2045, the California Environmental Protection Agency and the California Natural Resources Agency, in consultation with other State, local and federal agencies, shall expedite regulatory processes to repurpose and transition upstream and downstream oil production facilities, while supporting community participation, labor standards, and protection of public health, safety and the environment. The agencies shall report on progress and provide an action plan, including necessary changes in regulations, laws or resources, by July 15, 2021.

9. The State Air Resources Board, in consultation with other State agencies, shall develop and propose strategies to continue the State's current efforts to reduce the carbon intensity of fuels beyond 2030 with consideration of the full life cycle of carbon.

10. The California Environmental Protection Agency and the California Natural Resources Agency, in consultation with the Office of Planning and Research, the Department of Finance, the Governor's Office of Business and Economic Development and other local and federal agencies, shall develop strategies, recommendations and actions by July 15, 2021 to manage and expedite the responsible closure and remediation of former oil extraction sites as the State transitions to a carbon-neutral economy.

11. The Department of Conservation's Geologic Energy Management Division and other relevant State agencies shall strictly enforce bonding requirements and other regulations to ensure oil extraction operators are responsible for the proper closure and remediation of their sites.

12. The Department of Conservation's Geologic Energy Management Division shall:

    a) Propose a significantly strengthened, stringent, science-based health and safety draft rule that protects communities and workers from the impacts of oil extraction activities by December 31, 2020.

    b) Post on its website for public review and consultation a draft rule at least 60 days before submitting to the Office of Administrative Law.

IT IS FURTHER ORDERED that as soon as hereafter possible, the Order be filed in the Office of the Secretary of State and that widespread publicity and notice be given of this Order.

This Order is not intended to, and does not, create any rights or benefits, substantive or procedural, enforceable at law or in equity, against the State of California, its agencies, departments, entities, officers, employees, or any other person.

IN WITNESS WHEREOF I have hereunto set my hand and caused the Great Seal of the State of California to be affixed this 23rd day of September 2020.

GAVIN NEWSOM
Governor of California

ATTEST:

ALEX PADILLA
Secretary of State

SB-44 Medium- and heavy-duty vehicles: comprehensive strategy. (2019-2020)

Date Published: 09/23/2019 09:00 PM

Senate Bill No. 44

CHAPTER 297

An act to add Section 43024.2 to the Health and Safety Code, relating to vehicular air pollution.

[Approved by Governor September 20, 2019. Filed with Secretary of State September 20, 2019.]

LEGISLATIVE COUNSEL'S DIGEST

SB 44, Skinner. Medium- and heavy-duty vehicles: comprehensive strategy.

The California Global Warming Solutions Act of 2006 designates the State Air Resources Board as the state agency charged with monitoring and regulating sources of emissions of greenhouse gases.

The California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program funds zero- and near-zero-emission truck, bus, and off-road vehicle and equipment technologies and related projects, including, but not limited to, technology development, demonstration, precommercial pilots, and early commercial deployments of zero- and near-zero-emission medium- and heavy-duty truck technology.

This bill would require the state board, no later than January 1, 2021, and at least every 5 years thereafter, in consultation with the Department of Transportation, the State Energy Resources Conservation and Development Commission, and the Governor's Office of Business and Economic Development and in collaboration with relevant stakeholders, to update the state board's 2016 mobile source strategy to include a comprehensive strategy for the deployment of medium-duty and heavy-duty vehicles in the state for the purpose of bringing the state into compliance with federal ambient air quality standards and reducing motor vehicle greenhouse gas emissions from the medium-duty and heavy-duty vehicle sector. The bill would require the state board to recommend reasonable and achievable goals, based on specified factors, for reducing emissions from medium-duty and heavy-duty vehicles by 2030 and 2050, respectively, as part of the comprehensive strategy. The bill also would require the state board to include other specified information in the updates to the 2016 mobile source strategy. The bill would authorize the state board to establish a process to identify medium-duty and heavy-duty vehicle segments that can more quickly reduce motor vehicle emissions, consistent with the California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program, with a beachhead market analysis.

Vote: majority   Appropriation: no   Fiscal Committee: yes   Local Program: no

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

SECTION 1. The Legislature finds and declares all of the following:

(a) Diesel-fueled trucks are responsible for 33 percent of statewide oxides of nitrogen emissions annually. These same trucks emit more particulate matter than all of the state’s powerplants.

(b) People who live near freeways and busy roadways are at high risk for exposure to these health-threatening air pollutants emitted by these medium- and heavy-duty vehicles.

(c) In 1998, the State Air Resources Board identified diesel particulate matter as a toxic air contaminant based on published evidence of a relationship between diesel exhaust exposure and lung cancer.

(d) Diesel particulate matter also contributes to noncancer health effects, like premature death, hospitalizations, and emergency department visits for exacerbated chronic heart and lung disease, including asthma, increased respiratory symptoms, and decreased lung function in children.

(e) Children are particularly vulnerable to the negative effect of diesel because they have higher respiration rates than adults and this can increase their exposure to air pollutants relative to their body weight.

(f) Children exposed to high levels of diesel exhaust are five times more likely than other children to have underdeveloped lungs.

(g) Increased respiratory symptoms, such as cough wheeze, runny nose, and doctor-diagnosed asthma, have been linked to traffic exposure.

(h) Studies have shown that children who live in high-density traffic areas have higher rates of doctor visits for asthma and increased use of asthma medication than children who live near low-density traffic areas.

(i) Reducing emissions of these pollutants can have an immediate beneficial impact on air quality and on public health.

(j) The largest source of the state’s greenhouse gas emissions comes from the transportation sector, accounting for nearly 50 percent of statewide emissions.

(k) While diesel-fueled trucks and buses make up just 3 percent of the vehicles on the state’s roads, they produce 23 percent of greenhouse gas emissions from the transportation sector.

(l) Nearly all of the diesel-related air quality challenges can be attributed to old diesel-fueled trucks still operating on California’s roads, which has prompted the State Air Resources Board to take actions to address these air quality challenges, making some progress in moving California toward cleaner medium- and heavy-duty vehicles, including, but not limited to, the following measures:

(1) The On-Road Heavy-Duty Diesel Vehicles (In-Use) Regulation (Section 2025 of Title 13 of the California Code of Regulations), adopted on September 28, 2006, requires nearly all diesel-fueled trucks and buses that operate in California to be upgraded or replaced with 2010 model year engines or equivalent by January 1, 2023.

(2) The In-Use Off-Road Diesel-Fueled Fleets Regulation (Section 2025 of Title 13 of the California Code of Regulations), adopted on July 26, 2007, aims to reduce diesel particulate matter and oxides of nitrogen emissions from existing off-road heavy-duty diesel vehicles operating in California, such as vehicles used in construction, mining, and industrial operations.

(m) However, the state must take additional actions to immediately reduce health-threatening criteria air pollution and climate-threatening greenhouse gas emissions by outlining a clear path to convert medium- and heavy-duty vehicle segments, as well as off-road equipment, to cleaner technologies and fuels.

(n) Actions to reduce pollution and greenhouse gas emissions may include, but are not limited to, vehicle replacement, improved engine efficiency, fuels replacement, mode shifting, and operational efficiencies, including changes to vehicle deployment schedules.

(o) Providing consistent, multiyear funding is imperative to reduce emissions of criteria air pollutants and greenhouse gases associated with medium- and heavy-duty vehicles where this technology is commercially available but still costs a premium and to help support commercialization paths for new technologies that are not currently market ready.

SEC. 2. Section 43024.2 is added to the Health and Safety Code, to read:

43024.2. (a) (1) No later than January 1, 2021, and at least every five years thereafter, the state board, in consultation with the Department of Transportation, the State Energy Resources Conservation and Development

Commission, and the Governor's Office of Business and Economic Development and in collaboration with relevant stakeholders, shall update the state board's 2016 mobile source strategy to include a comprehensive strategy for the deployment of medium duty and heavy-duty vehicles in the state for the purpose of bringing the state into compliance with federal ambient air quality standards and reducing motor vehicle greenhouse gas emissions from the medium duty and heavy-duty vehicle sector. The state board shall recommend reasonable and achievable goals for reducing emissions from medium duty and heavy-duty vehicles by 2030 and 2050, respectively, as part of the comprehensive strategy based on factors that include, but are not limited to, the state's overarching emissions reduction goal established in Section 38566, the goals established in the California Sustainable Freight Action Plan completed in response to Executive Order No. B-32-15, technological feasibility, and cost-effectiveness.

(2) The state board's updates to the mobile source strategy shall include both of the following:

(A) An identification of policies that provide advantages to fleets that reduce greenhouse gas emissions earlier than required by law.

(B) The coordination of plans for the attainment of federal ambient air quality standards with relevant greenhouse gas emissions reduction goals.

(b) In developing the comprehensive strategy, the state board shall do all of the following:

(1) Seek to maximize the reduction of criteria air pollutants.

(2) Identify regulation that could improve market acceptance, spur technology advancements, reduce technology costs, and support the commercialization and deployment of medium duty and heavy-duty vehicles that reduce emissions of greenhouse gases.

(3) Identify research needs to address any data gaps.

(4) Identify areas where the state should coordinate with other state agencies, districts, utilities providers, and technology providers to implement measures identified as part of the comprehensive strategy.

(5) Identify benefits to low-income communities and communities disproportionally impacted by diesel pollution.

(6) Identify policies that provide advantages to fleets that reduce greenhouse gas emissions early.

(c) The state board, through a public process, may establish a process to identify medium duty and heavy-duty vehicle segments that can more quickly reduce motor vehicle emissions, consistent with the state board's three-year heavy-duty vehicle investment strategy required pursuant to the California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program, established pursuant to Section 39719.2, with a beachhead market analysis.

(d) The state board shall submit the updated mobile source strategy to the relevant policy and fiscal committees of the Legislature.

DOCKETED

Docket Number:	23-SB-02
Project Title:	SB X1-2 Implementation
TN #:	259251
Document Title:	Turner Mason & Company Comments - Transportation Energy Supply Chain Infrastructure and Investment Study (TESCII) – Turner, Mason & Company – June 15, 2024
Description:	N/A
Filer:	System
Organization:	Turner Mason & Company
Submitter Role:	Public
Submission Date:	9/22/2024 1:58:57 PM
Docketed Date:	9/23/2024

Comment Received From: Turner Mason & Company
Submitted On: 9/22/2024
Docket Number: 23-SB-02

Transportation Energy Supply Chain Infrastructure and Investment Study (TESCII) â€“ Turner, Mason & Company â€“ June 15, 2024

This study analyzes the stability of the existing road liquid transportation fuel supply chain and identifies key risks to its viability under a number of policy combination scenarios.

Additional submitted attachment is included below.

TESCII STUDY REPORT

POTENTIAL IMPACTS OF CALIFORNIA REGULATIONS & POLICY ON THE TRANSPORTATION FUELS SUPPLY CHAIN

JUNE 15, 2024

Turner, Mason & Company
energy consulting & advisory

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Associate Consultant

- Turner Mason & Company (TM&C) conducted a study of the California transportation fuel system (upstream, refining, logistics, regulatory) with a focus on identifying potential "pinch-points" that could significantly impact the ability of the system to meet future transportation fuel demand in the State.
- Founded in 1971, TM&C provides technical, commercial and strategic consulting services to worldwide clients in the crude oil, midstream, refining, refined products, biofuels and renewable fuels industries.
- Core competencies – Market Analysis, Refinery Strategic Studies, Feasibility Studies / Project Independent Assessments & Due Diligence, M&A / Transaction Support & Due Diligence, Crude / Feedstock Valuation, Asset / Fair Market Value Assessments, Industry Studies, Regulatory Support, Fuels Compliance, Litigation Support.
- TM&C engagement team collectively has over 120 years of experience in the industry across integrated oil companies, independent refiners, and energy consulting firms.

EXECUTIVE SUMMARY

PREFACE

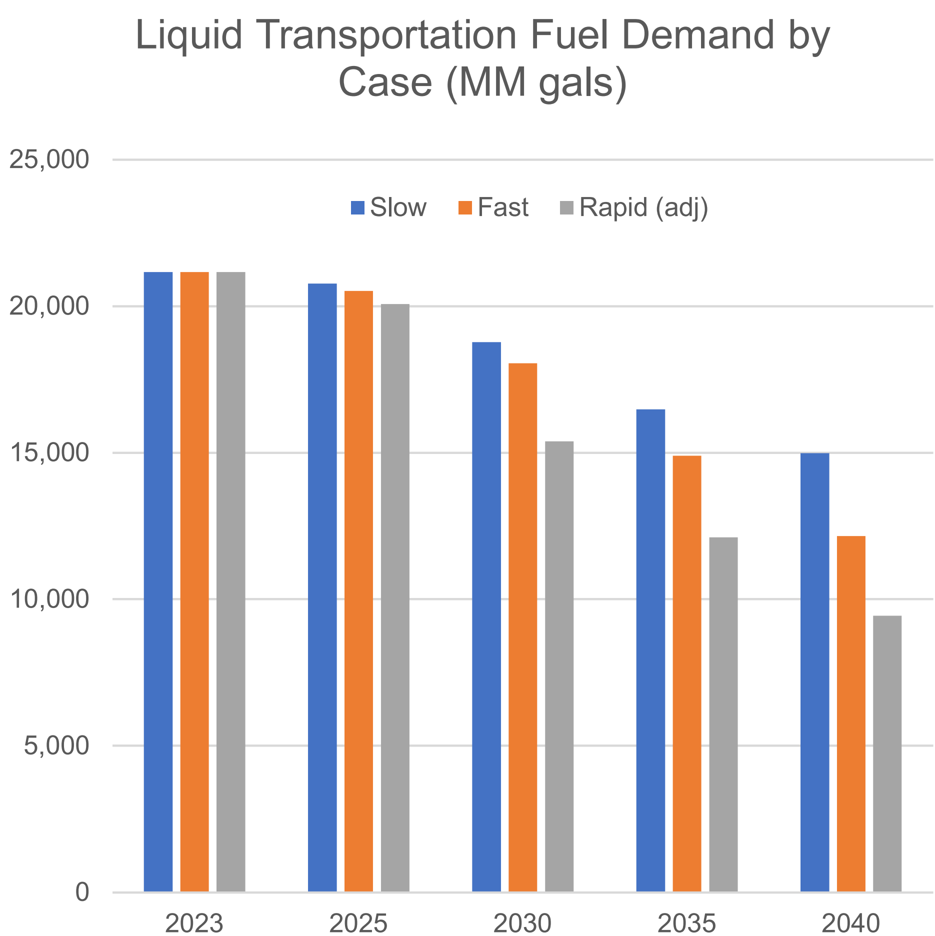
- There are three main tasks assigned to the CEC in SB X1-2
  - Providing a transportation fuels assessment, including an evaluation of oil and gas extraction.
  - Assessing if a refining gross margin cap "likely benefits to consumers outweigh the potential costs to consumers."
  - Develop a process for refiners to report planned maintenance and turnaround schedules.
- This study is a holistic view of potential impacts on the petroleum supply chain
  - CEC's gasoline demand is taken as given (e.g., policies are implemented that achieve the "Slow", "Fast", or "Rapid" cases).
  - Our focus is on risks for the liquid transportation fuels supply chain across those cases.
  - We also look at risks to the system from other factors, such as California crude oil production profiles, crude oil pipeline operating limitations, and marine logistics constraints.
- Several prospective policies are not included in the analysis because we lack sufficient definition at this time to model them:
  - Gross Margin Cap
  - A tighter LCFS carbon intensity
  - A tighter Cap and Trade carbon intensity
- Our results are based entirely on public information and TM&C analysis
  - We leverage public information to calculate state-level supply/demand balances.
  - Where public data are not available, we make assumptions based on our collective experience, industry interviews, and sensitivity analysis.

Note: CEC is California Energy Commission
SB X1-2 refers to California Senate Bill 2 which was signed in to law by Governor Gavin Newsom on March 28, 2023
LCFS is Low Carbon Fuel Standard

KEY FINDINGS

- California crude oil production is in terminal decline
  - Recent production declines are approaching an annualized rate of ~15%, which is about 50% *faster* than gasoline demand declines in the CEC's most aggressive Transportation Fuels Assessment ("Rapid") case.
  - Risk of decline rates accelerating given recent slowing in pace of drilling permit approvals.
  - Setback rule (SB 1137) could shut-in ~20% of current production.
- California refineries could be approaching critical infrastructure constraints
  - Crude oil pipelines are at increasing risk of falling to minimum throughput levels.
  - Central District pipelines serving the San Francisco Bay area appear to have the greater risk.
  - If pipelines close, refineries become more dependent on waterborne crude oil imports.
  - Marine facilities could face a limit on vessel movements before limits on flows or emissions.
  - Marine logistics limits could come from combinations of constraints rather than imposing a single constraint.
- There are several refineries, in the North and South estimated to be on the verge of reaching these logistical constraints of challenged pipeline flows and lack of marine options.
- CARB's "At-Berth" regulation could critically impair marine logistics in the liquid transportation supply chain.
- It is not a question of "if", but "when" refiners could be forced into difficult decisions. The ability of a refinery to adapt to major shifts in crude supply or product demand could be limited without major investments.

Liquid Transportation Fuel Decline Estimated to be 11% to 27% by 2030



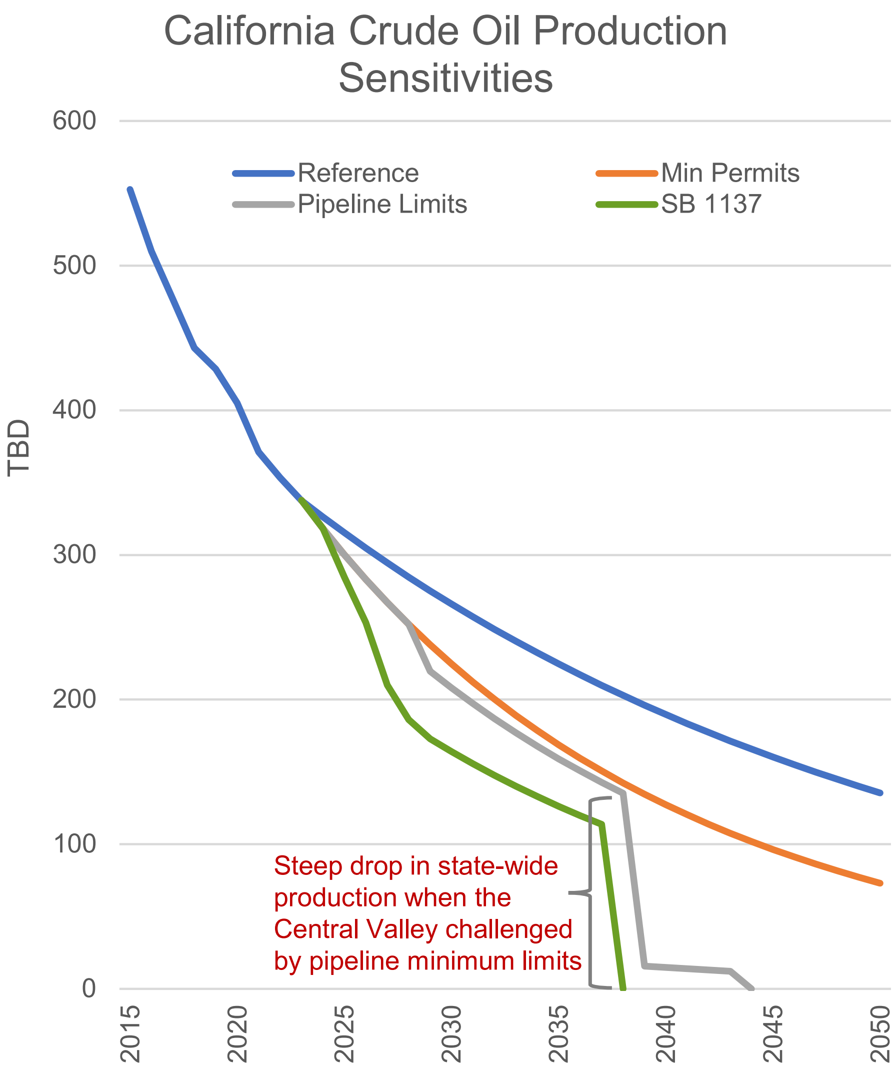
- CEC's draft Transportation Fuel Assessment only examines gasoline
- TM&C uses CEC's draft Transportation Fuel Assessment scenarios to map non-gasoline transportation fuels:
  - "Slow" = 2023 IEPR Baseline
  - "Fast" = AATE3 in the 2023 IEPR
  - "Rapid" = CARB 2022 Scoping Plan
- TM&C adopts the CARB Scoping Plan assumption on aviation fuel
  - CARB uses the same demand profile (+1.7% p.a.) across all scenarios due to aviation's decarbonization challenges
  - Aviation fuel continues to grow even though total liquid road transportation fuel demand declines

Source: Turner Mason analysis, CEC Draft Fuels Assessment, CARB 2022 Scoping Plan

Note: CARB is California Air Resources Board

TM&C adjusts diesel demand in CARB's 2022 Scoping Plan to 2023 actuals (from CEC data) and preserves the plan's rate of demand decline

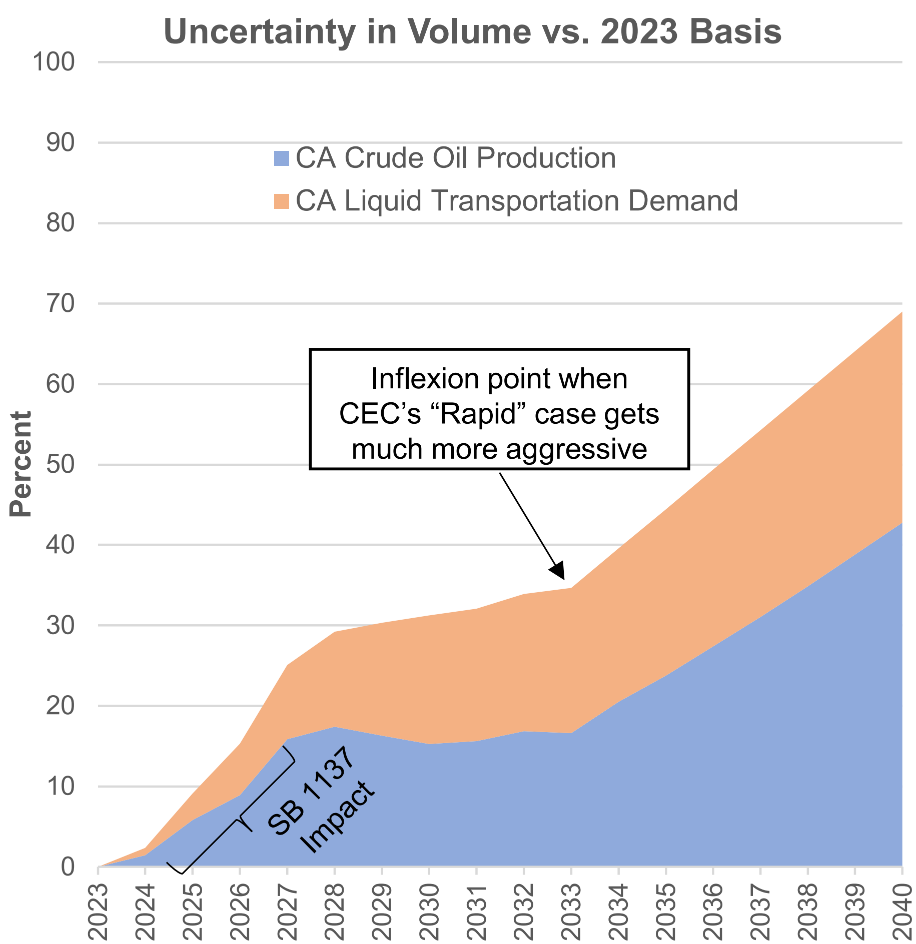
SEVERAL FACTORS COULD IMPACT FUTURE CALIFORNIA CRUDE OIL PRODUCTION



- **Reference**: Production of crude oil in California declines at the 2000-23 rate (3.4% p.a.), which assumes there is a recovery from recent upstream activity, i.e., early-2024 decline rates have accelerated to -15% on an annualized basis.
- **Minimum permits**: Production declines at the 2019-23 rate (5.8% p.a.) driven by the slowing pace of drilling permit approvals.
- **Pipeline limits**: Step changes in production declines caused by shutdowns of pipelines due to minimum throughputs; we assume trucking is not a viable transportation alternative.
- **Setback limit (SB 1137)**: Implementation would accelerate decline across the entire state. The LA Basin could be entirely shut-in by the early-2030s.

Source: CalGEM (California Geologic Energy Management Division), Catalyst Environmental, EIA (US Department of Energy, Energy Information Agency), TM&C analysis

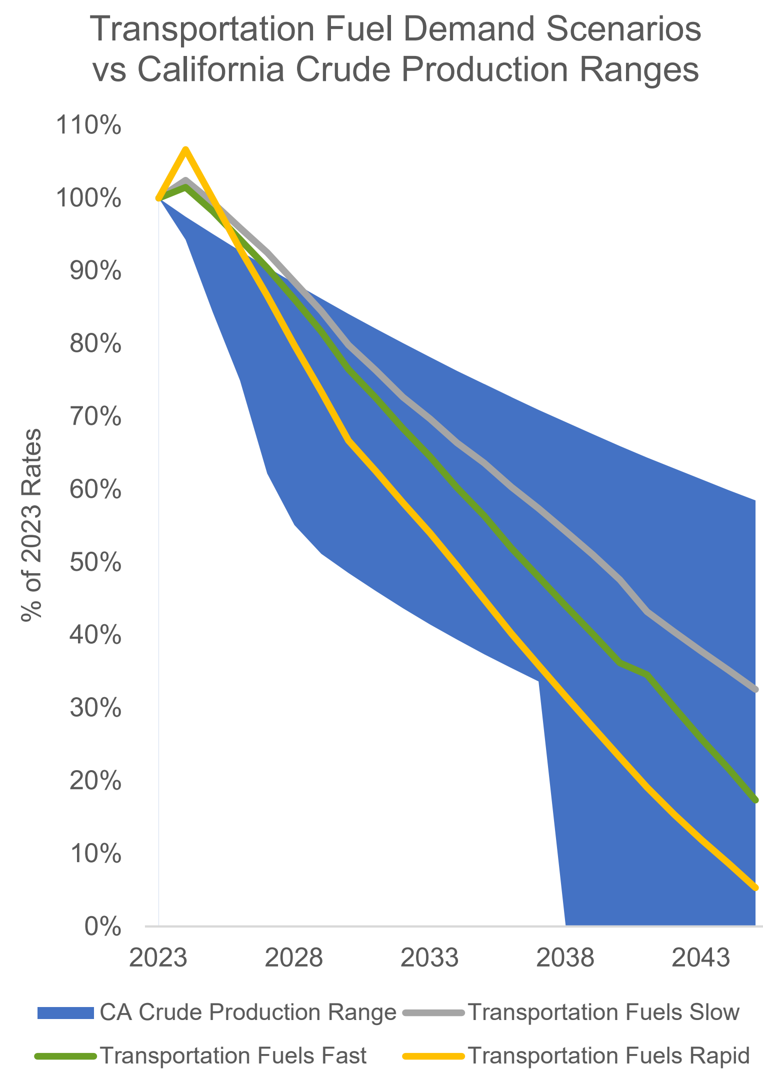
GROWING MARKET UNCERTAINTY MAKES INVESTMENT DECISIONS INCREASING MORE CHALLENGING



- Crude oil producers and pipeline operators would have to contend with the uncertainty of the blue shaded area when making business decisions.
- Refiners must contend with the uncertainty of both sourcing crude and fulfilling demand:
  - How to source crude oil supply? (blue area)
  - Where product markets might be? (tan area)
  - What projects might improve the ability to adapt?
- Combining these uncertainties could exacerbate the challenges of decision-making ("the whole is greater than the sum of the parts").
- The increase in uncertainty looks to be greatest in next 5 to 7 years, when determining the long-term viability of the supply chain will be most critical.
- How this uncertainty impacts the competitiveness of California assets for corporate capital relative to other assets is likely to vary across companies.

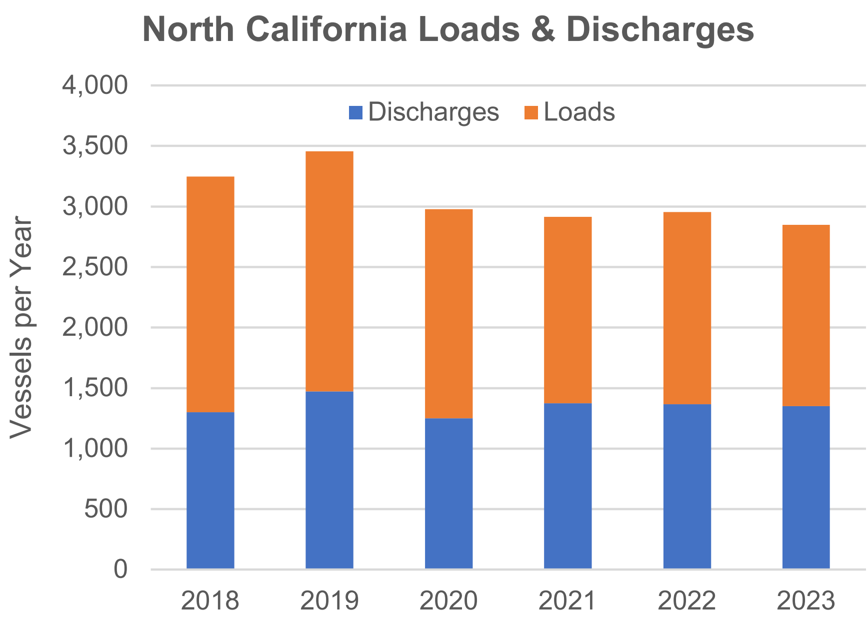
REFINERY OPERATIONS DRIVEN BY SHIFTS IN SUPPLY-DEMAND DYNAMICS

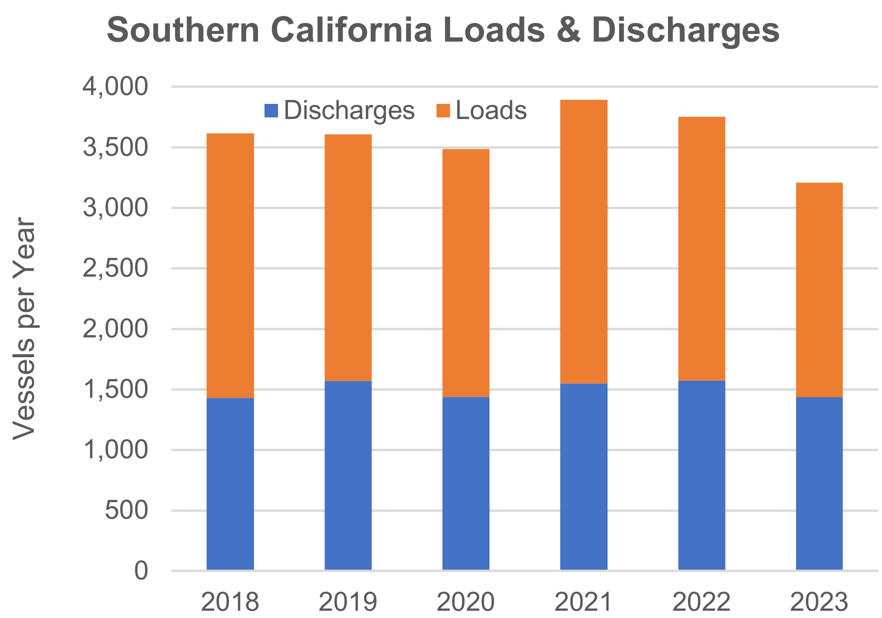
- As product demand declines, refineries would increase product exports, reduce crude oil runs, or eventually shut-down
- Exports must compete in the global market against other refiners with potentially lower costs
- If exports are not economically competitive, or reach logistic / permitting constraints, refineries may then reduce runs or shut-down
- There is a great deal of uncertainty in both future California crude oil production and transportation fuel demand, which may lead to a variety of business decisions as refiners compete within California and across a global market
- The decline of crude oil production relative to transportation fuel demand opens a range of marine logistics decisions (increasing imports/exports) to maintain, slow down, or cease operations. Each refiner may respond differently based on these uncertainties and additional business factors, such as, ability to acquire necessary permits.



Source: TM&C Analysis Refinery Scenarios (Supply-Demand), CalGEM, CEC, CARB

TOTAL MARINE TRAFFIC HAS DECLINED AS CRUDE VESSEL DECLINE IS FASTER THAN PRODUCT VESSEL GROWTH



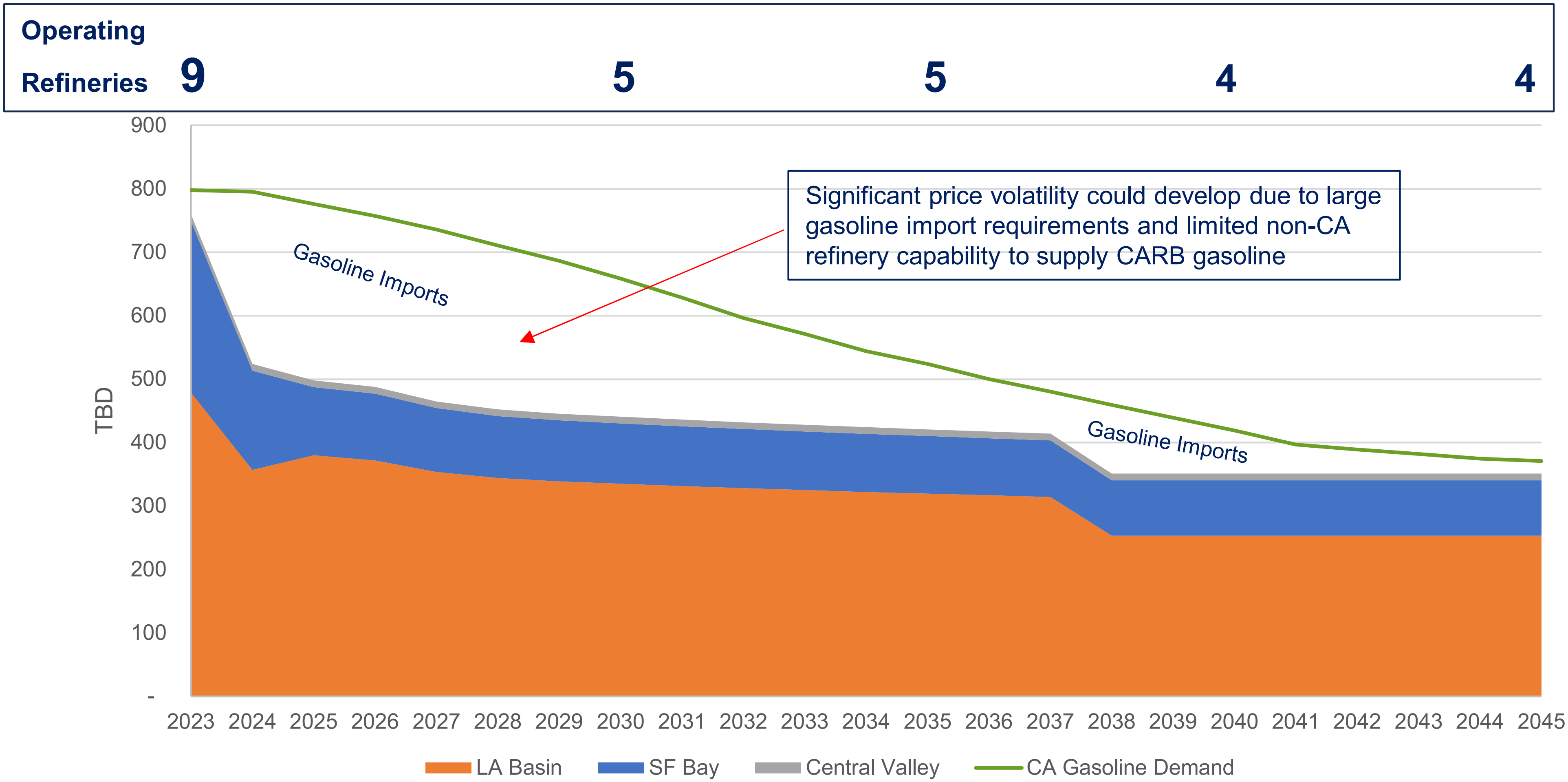


- Crude oil discharges are down in the North from pre-pandemic levels and expected to drop further with recent refinery shutdowns.
- However, product discharges are growing in the North and South resulting from a mix of growing imports of petroleum products and renewable feedstock cargos.
- It takes 3 to 5 product vessels to replace a crude oil tanker on a product volume equivalent basis.
- Product loads are declining in both the North and South; declines in fuel oil loads in response to new IMO regulations on sulfur content is masking increasing diesel loads (exports) in the South.

Source: California State Lands Commission, TM&C analysis
Note: Discharges and Loads refer to volumes received from/loaded to a vessel. These volumes could originate from/destined to another location within California so should not be confused with exports/imports

Risk of significant immediate refinery shutdowns if refiners face CARB "At-Berth" crude restrictions

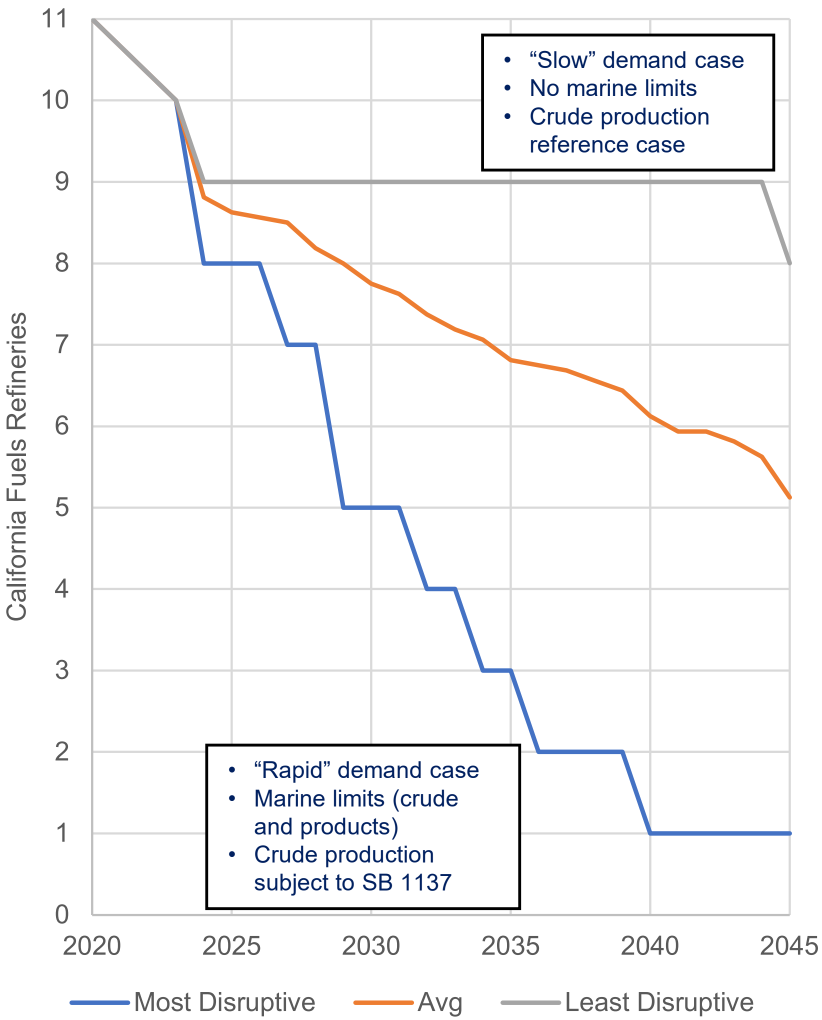
- CEC "Slow" fuels demand case
- CARB "At-Berth" limiting crude imports
- California crude oil production at SB1137 case
- Refinery utilization falls to 65% before shut-down



Source: TM&C analysis

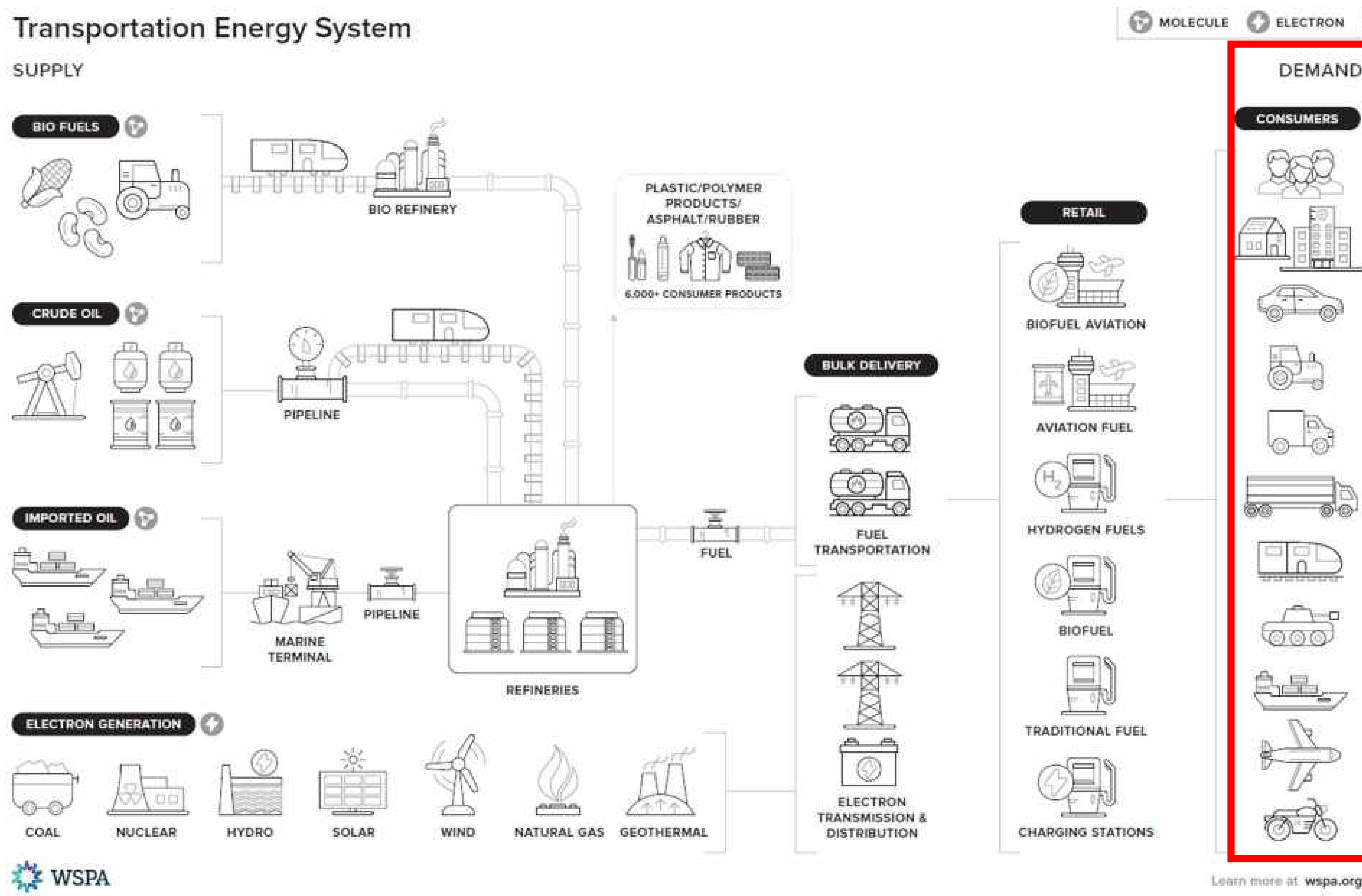
Refinery closure risk is highly dependent on scenarios

- TM&C evaluated potential refinery closures across 16 scenarios covering combinations of:
  - Transportation fuel demand cases,
  - Crude oil production profiles,
  - Logistics constraints,
  - Refining operating environments.
- Across all scenarios, on average, about half of California's fuels refineries could close by 2045.
- In the most disruptive scenario, only one fuels refinery remains by 2040.
- Even in least disruptive scenario refineries could close
  - Major shifts in business (increases in exports) and operations required.
  - Assumes no new limitations to importing crude and exporting products.
  - Requires exports to be globally competitive.
- If onshore power is unavailable or on-ship capture is infeasible, full enforcement of "At-Berth" restrictions could close 3-4 refineries almost immediately.
- **Refineries may close faster than demand declines, which could put pressure on marine logistics and vessel traffic limits.**



Source: TM&C Analysis
Note: Refinery utilization falls to 65% before shut-down

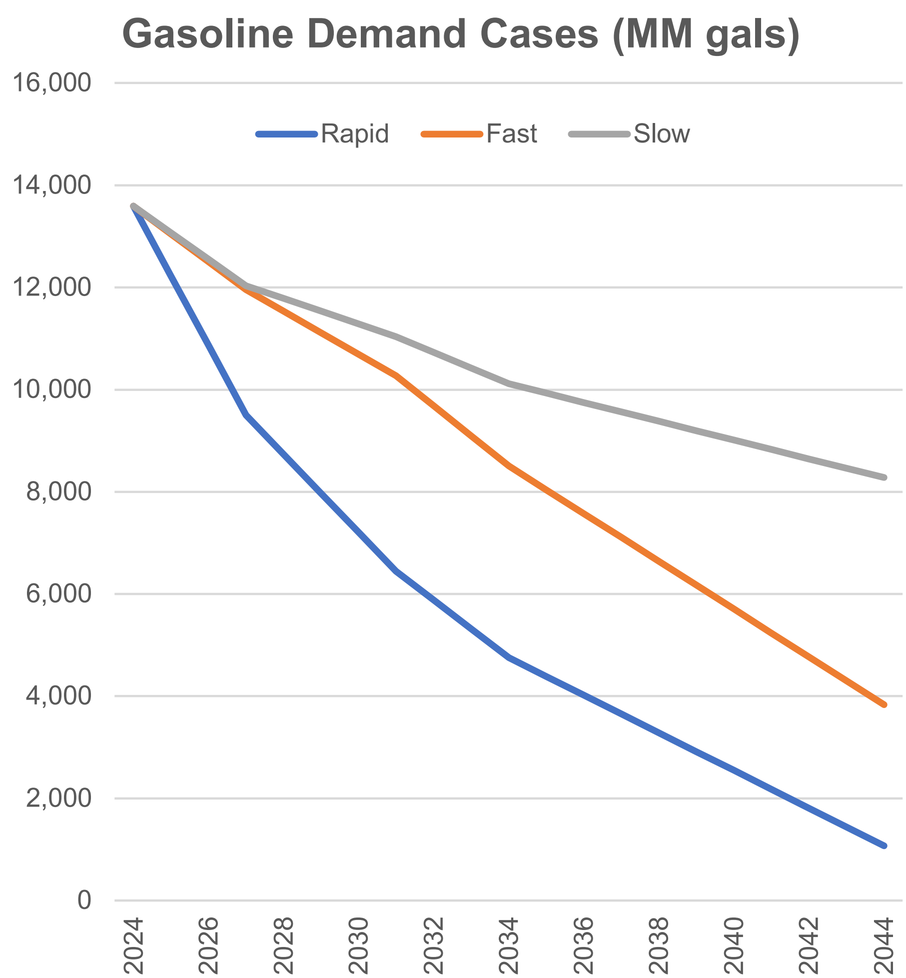
Transportation Energy System: Fuel Demand



DEMAND SUMMARY

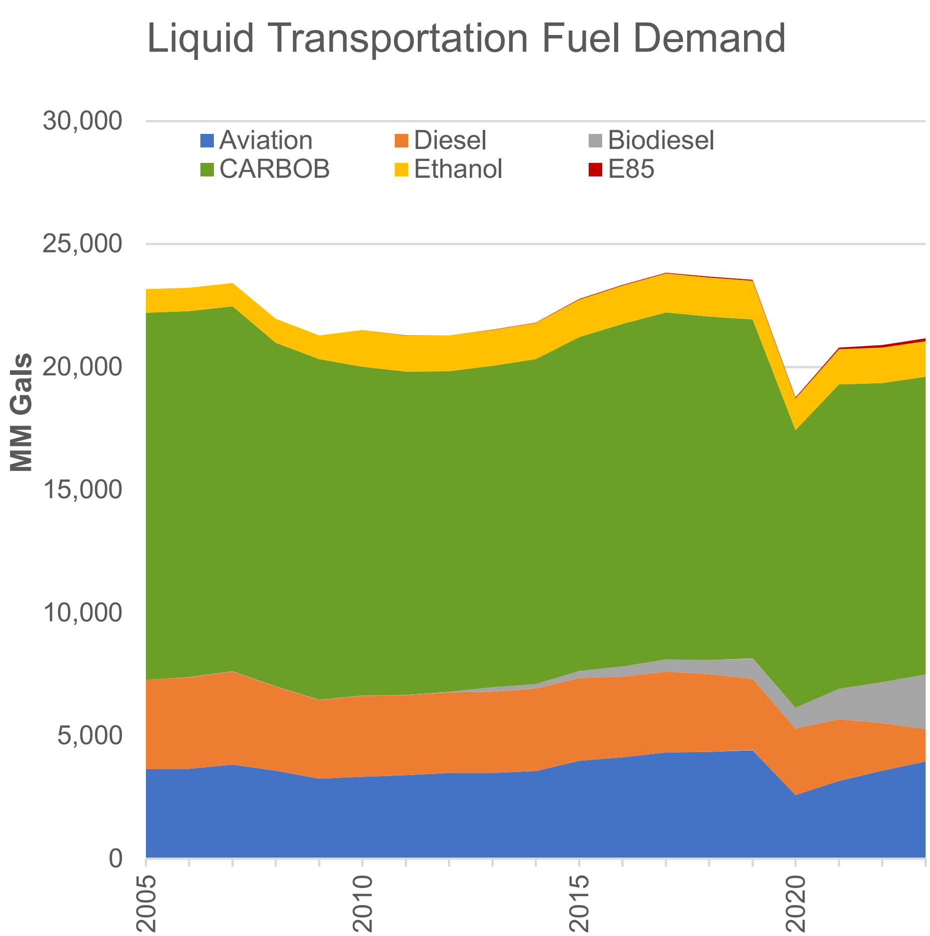
- California liquid transportation fuel demand has declined ~9% since 2005
- No liquid fuel, except renewable diesel, has recovered from COVID-19 demand destruction
- Across all future demand cases aviation fuel continues to grow even though total liquid transportation fuel demand declines
- In 2023 biomass-based diesel (BBD) was 63% of California's diesel supply, which is greater than at any point in in the future under CARB's Scoping Plan. TM&C's view is that BBD could completely displace petroleum-based diesel as early as 2026.

CEC's draft Fuels Transportation Assessment shows a variety of gasoline demand scenarios



- "Slow" scenario
  - 2023 IEPR Baseline
  - Demand declines at 2.4% p.a.
- "Fast"
  - AATE3 case in the 2023 IEPR
  - Demand declines at 6.1% p.a.
- "Rapid"
  - CARB 2022 Scoping Plan
  - Demand declines at 11.9% p.a.
- For historical reference: demand decline (2005 – 2023) = 0.8% p.a.

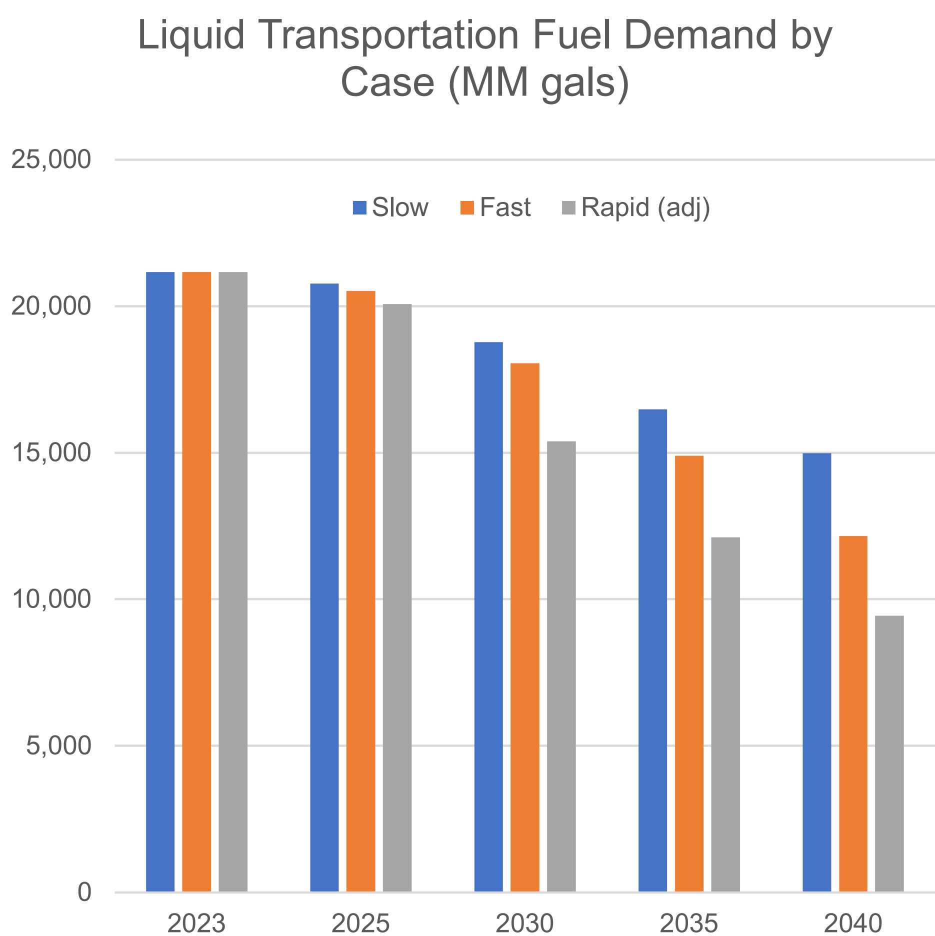
California liquid transportation fuel demand has declined 8.6% since 2005



- No liquid fuel, except renewable diesel, has recovered from COVID-19 demand destruction
- Total diesel demand has declined 2.3% since 2005
  - Petroleum diesel has declined over 60% (-5.5% p.a.)
  - Renewable diesel grew over *45% p.a.*
- Gasoline demand declined 14% from 2005
  - Decline from EV penetration and improving fuel efficiency has been gradual (-0.8% p.a.)
  - Recovery from COVID-19 destruction has been about 50%
- Aviation fuel demand has grown 8.5% since 2005 and has recovered about 75% of its COVID-19 destruction

Source: California Energy Commission

LIQUID TRANSPORTATION FUEL COULD DECLINE 11-27% BY 2030

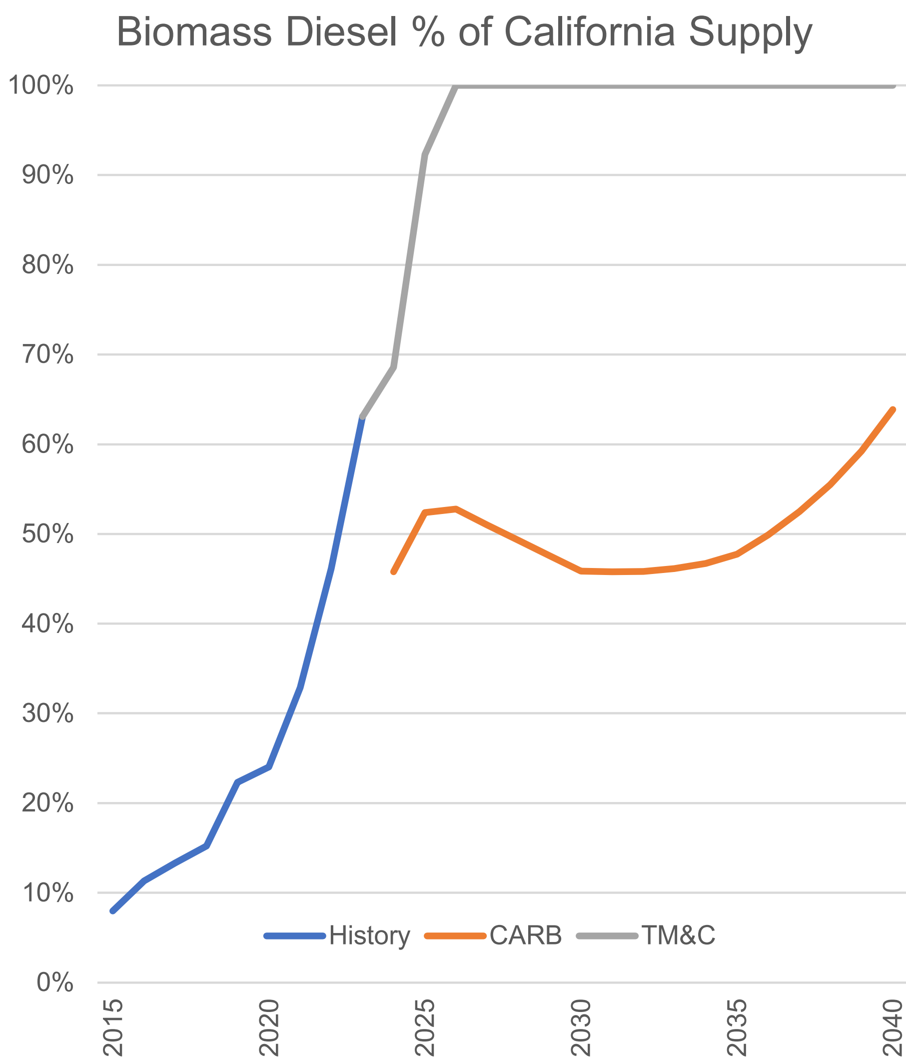


- TM&C maps non-gasoline fuels demands to CEC's draft Transportation Fuel Assessment scenarios in the following way:
  - "Slow" = 2023 IEPR Baseline
  - "Fast" = AATE3 in the 2023 IEPR
  - "Rapid" = CARB 2022 Scoping Plan
- Aviation fuel continues to grow even though total liquid transportation fuel demand declines
- TM&C adopts the CARB Scoping Plan assumption that aviation fuel has the same demand profile (+1.7% p.a.) across all scenarios due to its decarbonization challenges

Turner, Mason & Company
energy consulting & advisory

Source: Turner Mason analysis, CEC Draft Fuels Assessment, CARB 2022 Scoping Plan
Note: Turner Mason adjusts diesel demand in CARB's 2022 Scoping Plan to 2023 actuals (from CEC data) and preserves the plan's rate of demand decline

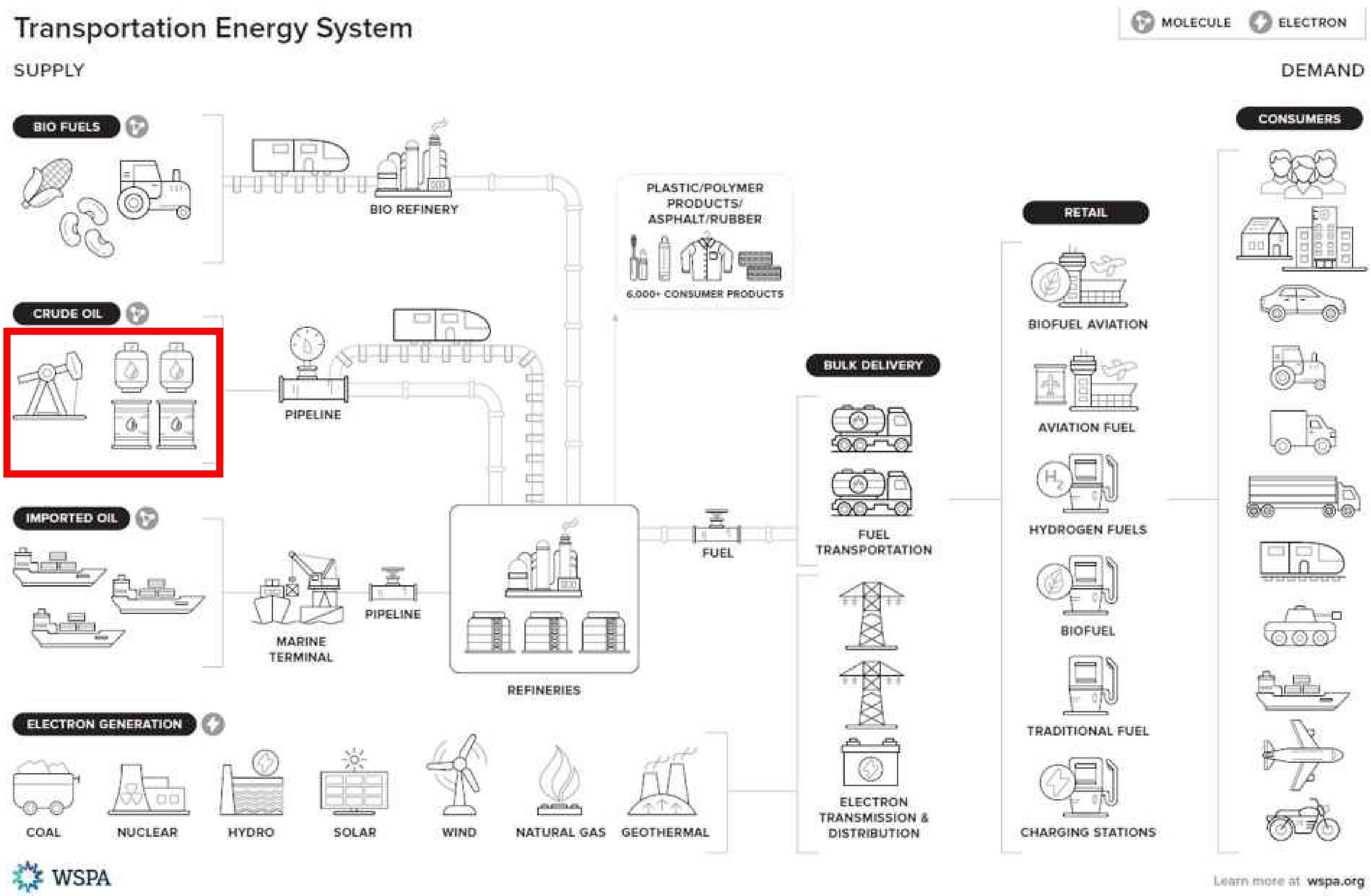
Rapid penetration of biomass-based diesel can put significant pressure on refinery product yields



- In 2023 BBD was 63% of California's diesel supply.
- CARB's Scoping Plan from 2022 already understates BBD penetration into California's diesel supply
- Focus is shifting towards RD (renewable diesel) given its cash margin advantage over biodiesel.
- Imports from out of state could fill the gap of credits needed to comply with increased LCFS compliance targets until all petroleum diesel is displaced.
- TM&C's view is that BBD could completely displace petroleum-based diesel as early as 2026.

Source: CEC, CARB, TM&C analysis
Note: LCFS is Low Carbon Fuel Standard

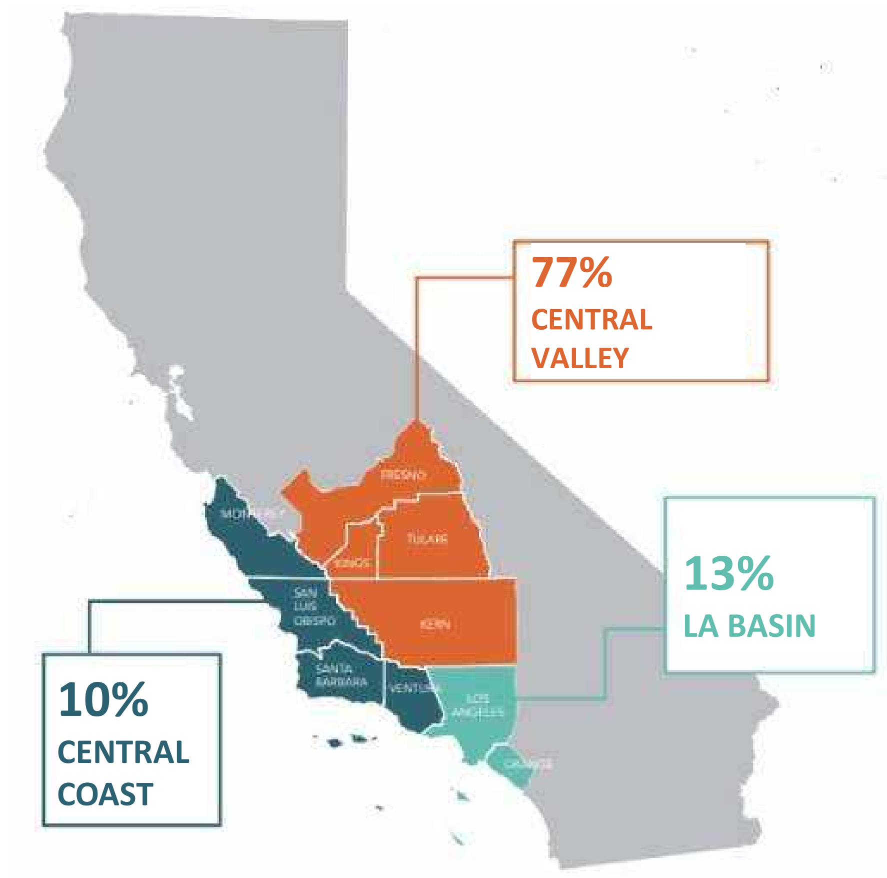
Transportation Energy System: Crude Oil Production



UPSTREAM SUMMARY

- California crude oil production has fallen over 50% since 2000
- Decline rates have accelerated over time; especially post-COVID
- Wellhead production is at risk of being shut-in, while still economic, because pipelines cannot operate below minimum throughput levels
- Alaska production could see some recovery with new projects, but eventually decline would return; California refineries would continue to compete with Washington refineries, which offer better economics to Alaska producers

California crude oil production is divided into three regions and dominated by the Central Valley

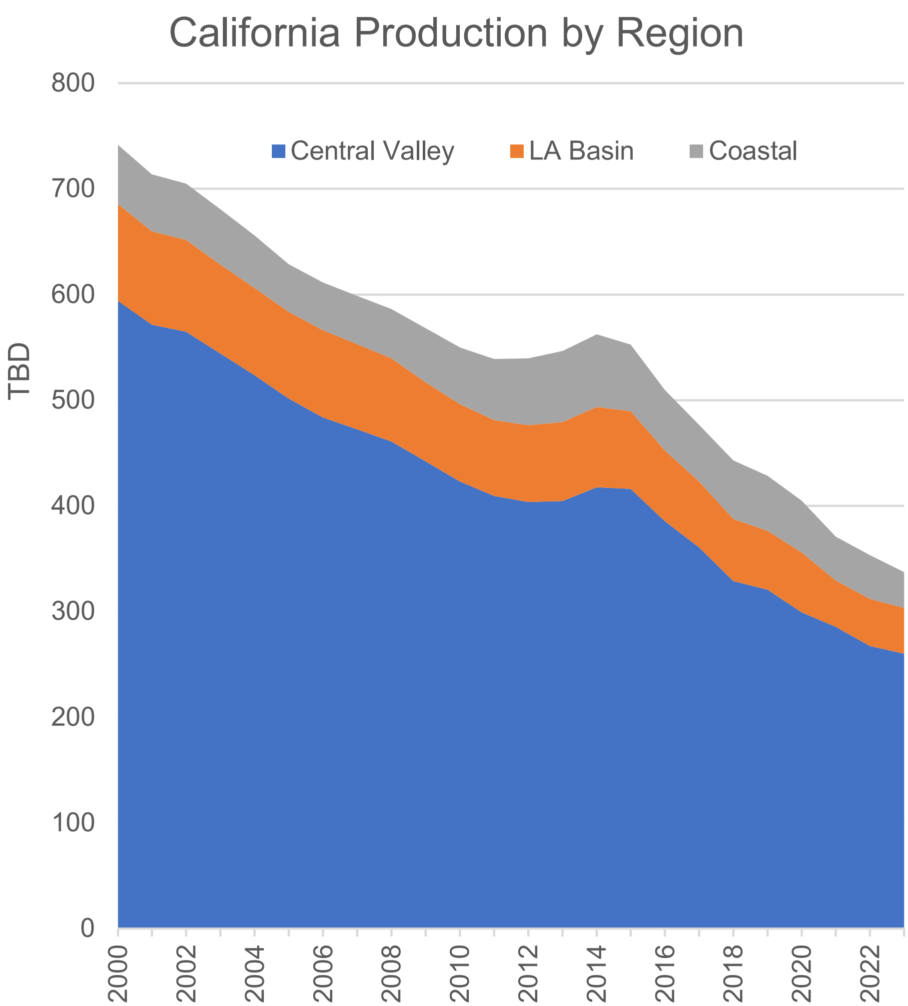


Location	2023 Production (TBD)	2019-23 Decline (% p.a.)
Central Coast	34	-9.9
Central Valley	260	-5.1
LA Basin	43	-6.1
California Total	338	-5.8

- Majority of production in Central Valley.
- Central Valley and LA Basin production face significant regulatory (setback) hurdles in addition to declining production.

Source: CalGEM

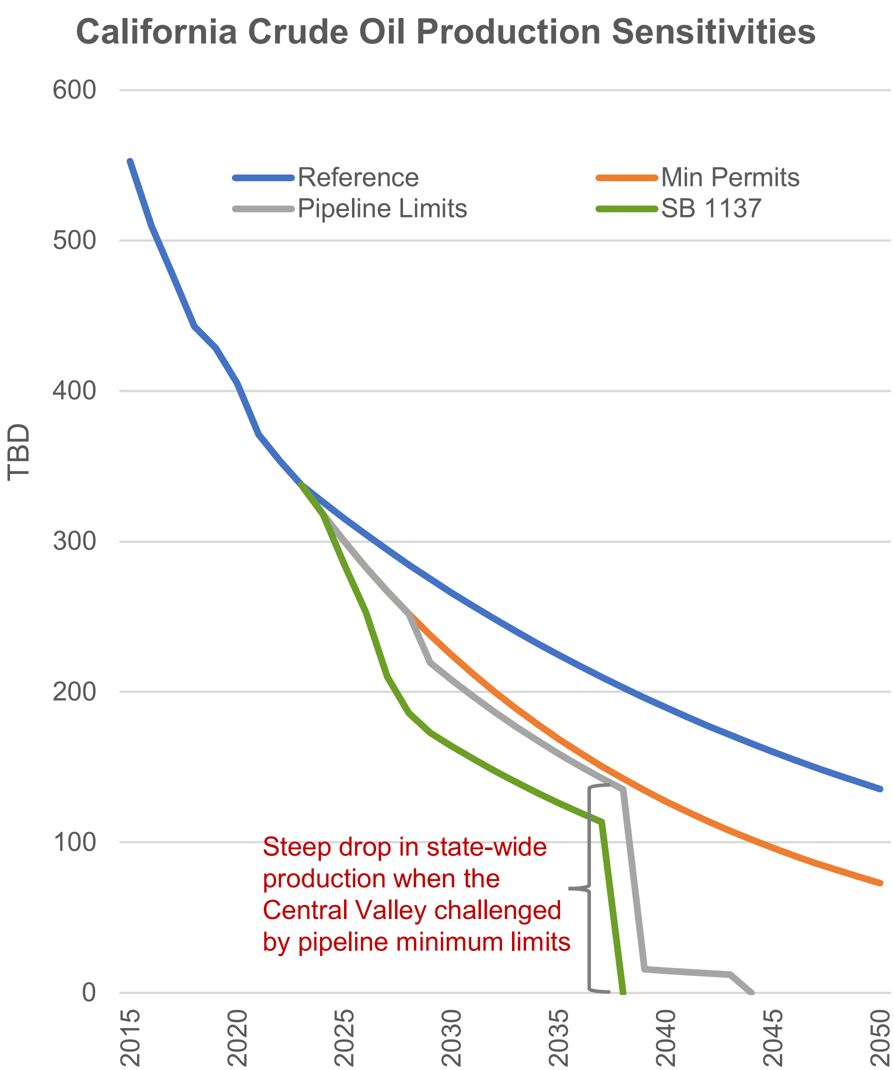
California crude oil production has fallen over 50% since 2000



- Decline rates have accelerated over time; especially post-COVID
- Most of the decline (both by volume and percent) was in the Central Valley (San Joaquin Valley)
- Coastal district production is challenged increasingly by pipeline access

Source: CalGEM

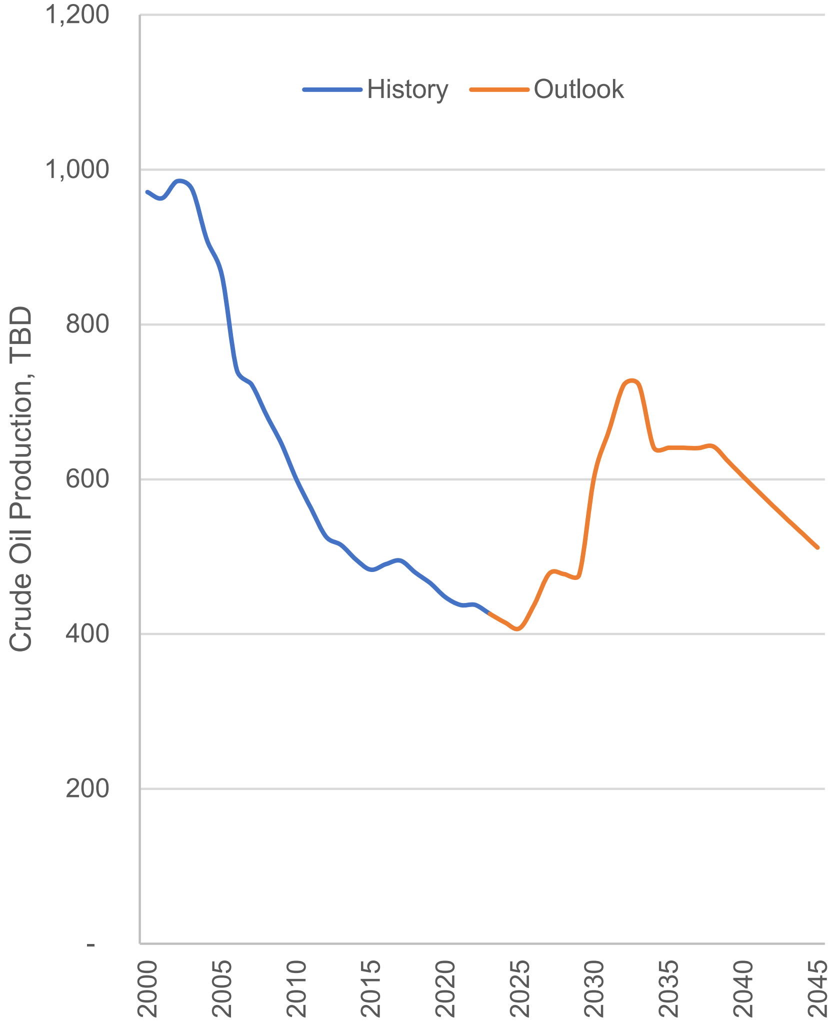
Several factors could impact future California Production



- **Reference**: Production declines at the 2000-23 rate (3.4% p.a.), which assumes there is a recovery in upstream activity, i.e., early-2024 decline rates have accelerated to -15% on an annualized basis
- **Minimum permits**: Production declines at the 2019-23 rate (5.8% p.a.) driven by a slowing pace of drilling permit approvals
- **Pipeline limits**: Step changes in production caused by shutdowns of pipelines due to minimum throughputs
- **Setback limit (SB 1137)**: Implementation would accelerate decline, particularly in the LA Basin, which could see the entire basin shut-in by the early-2030s

Source: CalGEM, Catalyst Environmental, EIA, TM&C analysis

Alaska Production recovers with Piko and Willow projects, but eventually returns to decline



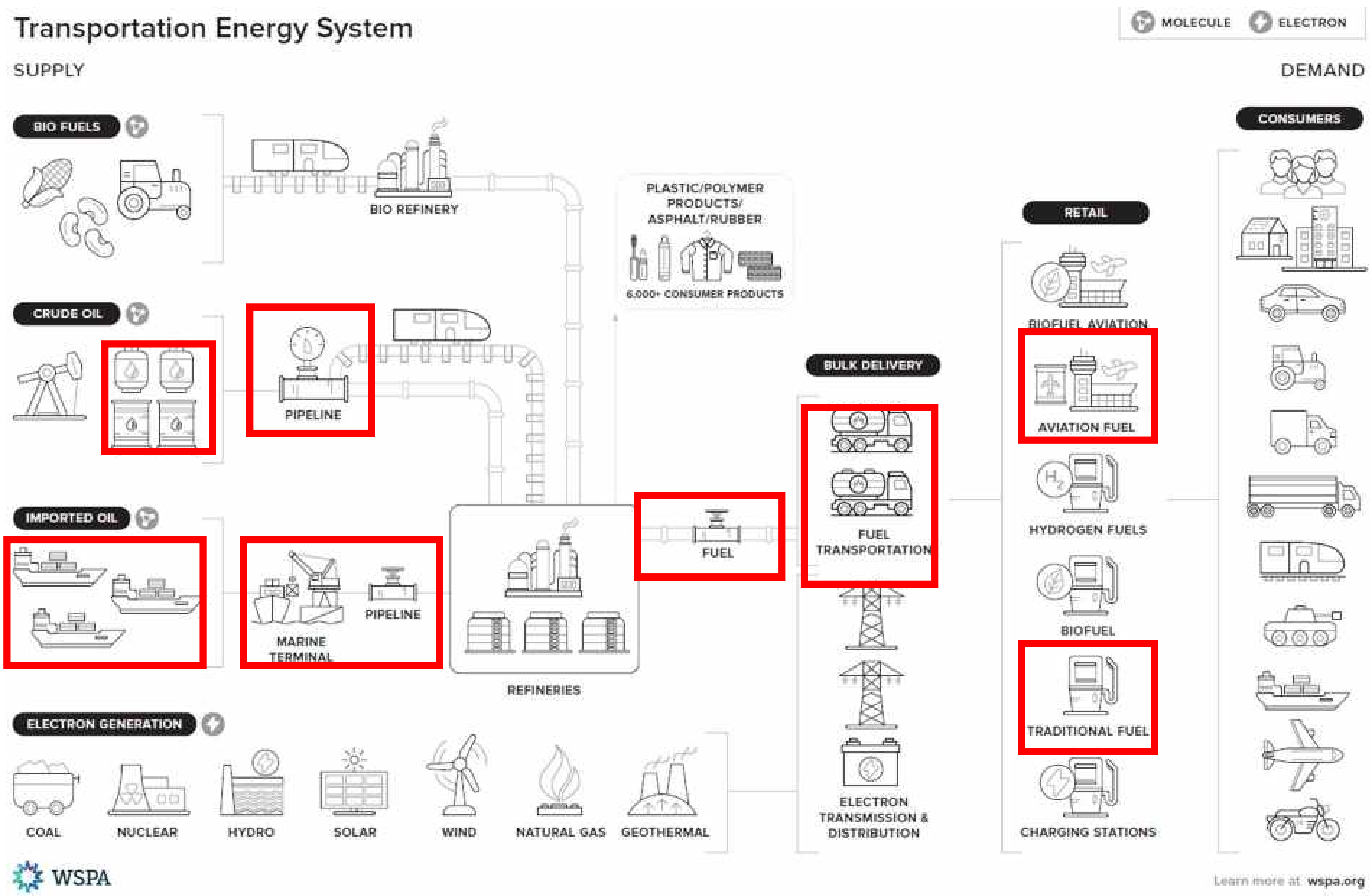
- Production peaked at 2,017 TBD in 1988 and has since been in decline (-4.3% p.a.)
- Santos expects to start its Pika project (80 TBD) in 2026
- ConocoPhillips intends to start-up its Willow project in 2029, eventually adding 180 TBD of new production
- These projects extend the useful life of the TAPS (Trans-Alaska Pipeline System)
- California competes with Washington area refineries for Alaska crude oil via marine vessels
- California's future consumption of Alaska crude oil is assumed to decline due to Washington refineries maintaining their consumption and offering better economics to Alaskan crude producers

IMPACTS OF TMX PIPELINE

- The Trans Mountain Expansion (TMX) pipeline (590 TBD) runs from Edmonton, Alberta to the port in Burnaby, just east of Vancouver, British Columbia. The new pipeline runs parallel to the existing Trans Mountain pipeline (300 TBD).
- TMX is started-up in May 2024 and eventually has the potential for up to 590 TBD of waterborne exports of Canadian crude oil
  - Increases WCS (Western Canadian Select) to global crude markets, particularly US West Coast and Asia
  - Could help replace heavy California grades that are in decline
  - Would reduce need for other foreign imports into California, though WCS would still enter California via marine ports
- Full ramp-up of TMX is a multi-step process and may take 2-3 years
- Some TMX specifications (e.g., vapor pressure, TAN) are so wide some California refiners are concerned they might not be able to buy crude oil shipped on the pipeline.

Source: https://www.transmountain.com/, Argus Media
Note: TAN is Total Acid Number
WCS is Western Canadian Select

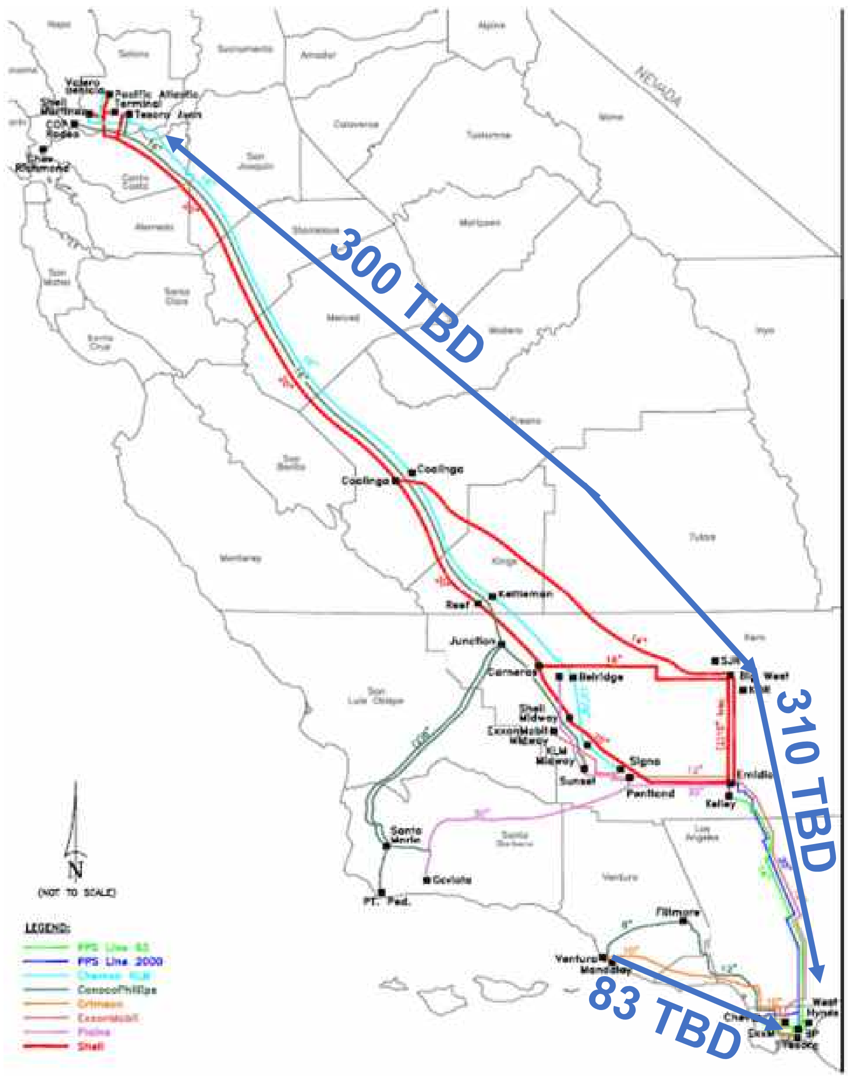
TRANSPORTATION ENERGY SYSTEM: LOGISTICS



Logistics Summary

- CARB's "At-Berth" regulation could critically impair marine logistics in the liquid transportation supply chain
- Multiple pipelines connect crude oil producing areas to refining centers, with throughput appearing to be reaching critical minimum volume for several pipelines
- With the closure of refineries in northern California, the Bay Area appears to be more at risk of pipeline closures
- Crude imports have not increased to fully offset California crude production declines, resulting in refinery capacity slowly declining
- The North is a net exporter of petroleum products, while the South is a net importer
- As refineries shut down, crude oil discharges decrease, but product movements increase to keep demand supplied
- Product cargos tend to be much smaller than crude oil cargos, so as product cargos rise, vessel traffic would greatly increase.
- Very little crude oil is brought in by rail because of high transportation costs. We do not expect rail to play a major role in California's future crude oil supply.

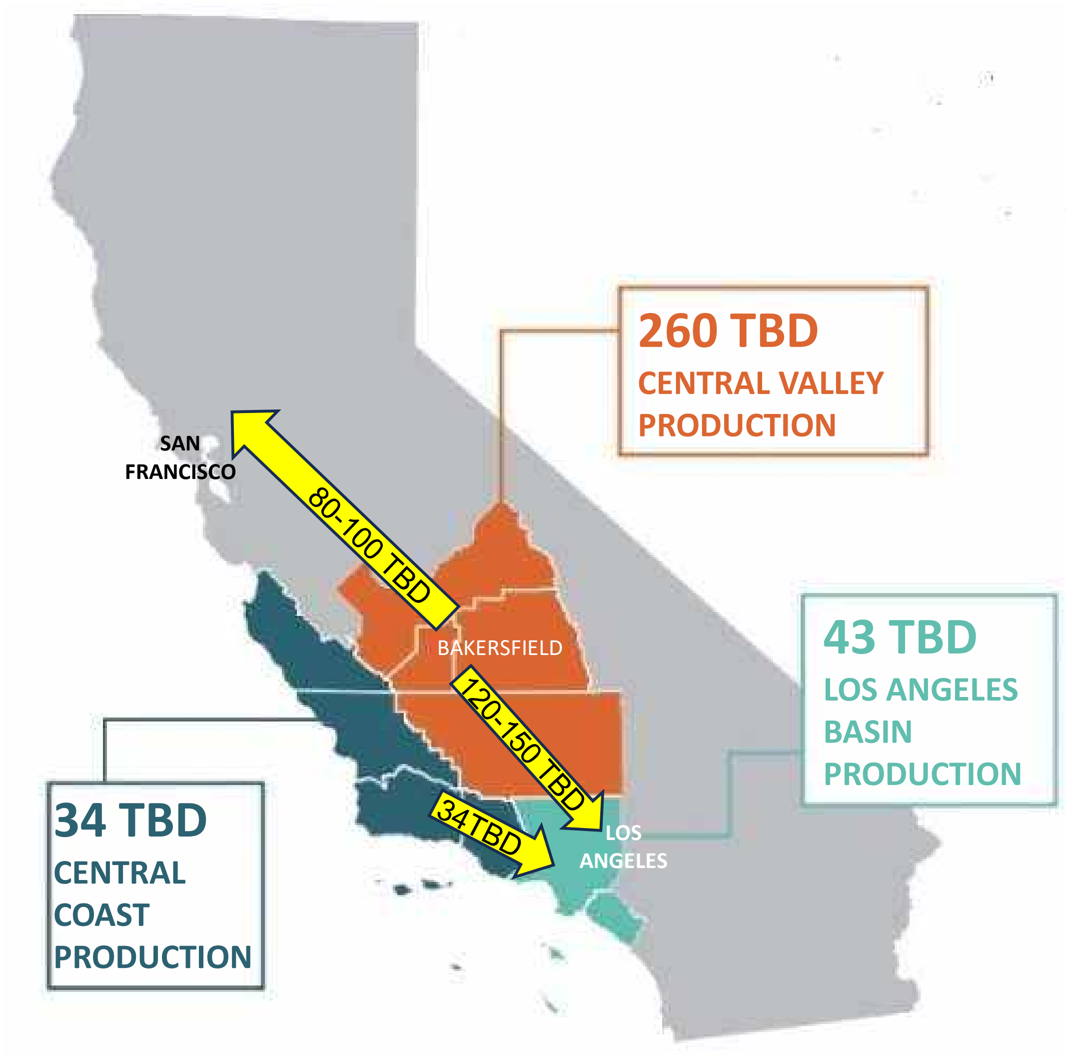
MULTIPLE PIPELINES CONNECT CRUDE OIL PRODUCING AREAS TO REFINING CENTERS



Regional Movement	Pipeline Name	Current Capacity (TBD)	Estimated Minimum Throughput (TBD)
Central Valley to San Francisco	KLM Pipeline	90	30
	San Pablo Bay Pipeline	210	60
Central Valley to Los Angeles	Line 63	60	20
	Line 2000	110	30
	M-70 Pipeline	110	30
	Chevron	30	10
Central Coast to Los Angeles	Texaco	28	10
	Southern California Pipeline System	55	20

Source: California Coastal Commission, CPUC (California Public Utilities Commission), BOEM (Bureau of Ocean Energy Management), *Oil & Gas Journal*, company websites

THROUGHPUT APPEARS TO BE REACHING CRITICAL MINIMUM VOLUME FOR SEVERAL CRUDE OIL PIPELINES



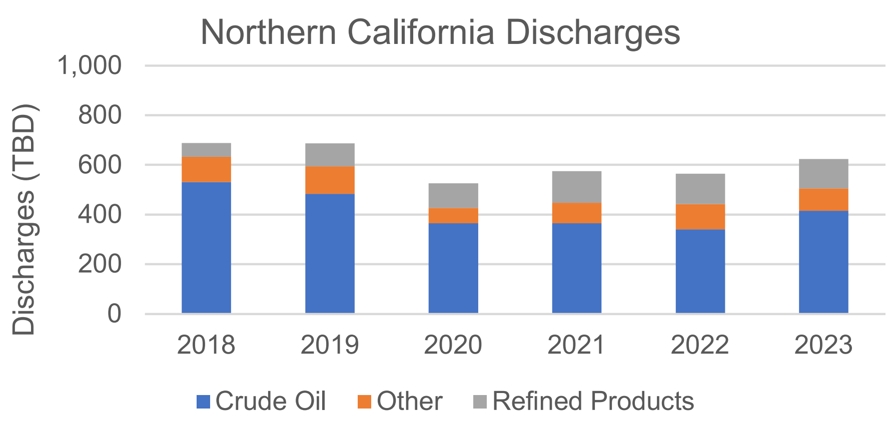
Regional Movement	Pipeline Name	Current Capacity (TBD)	Estimated Minimum Throughput (TBD)	Current Throughput (TBD)
Central Valley to San Francisco	KLM Pipeline	90	30-35	80-100
	San Pablo Bay Pipeline	210	60-65	
Central Valley to Los Angeles	Line 63	60	20-25	120-150
	Line 2000	110	30-35	
	M-70 Pipeline	110	30-35	
	Chevron	30	10-15	
Central Coast to Los Angeles	Texaco	28	10-15	34
	Southern California Pipeline System	55	20-25	

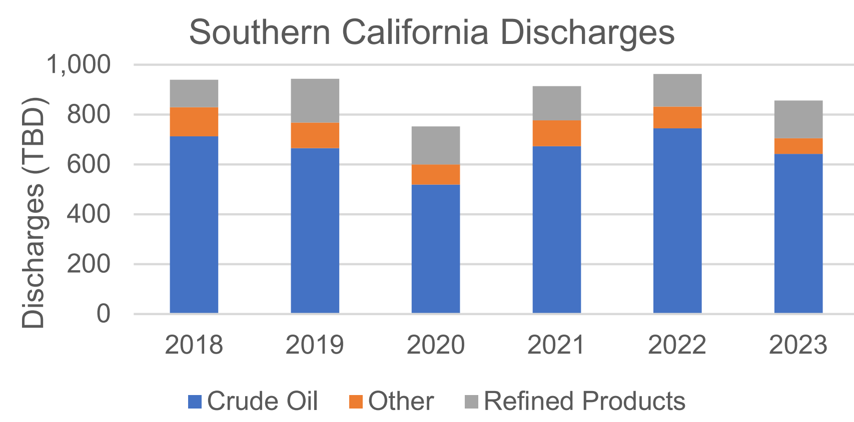
Source: CalGEM, CEC, California State Lands Commission, TM&C analysis

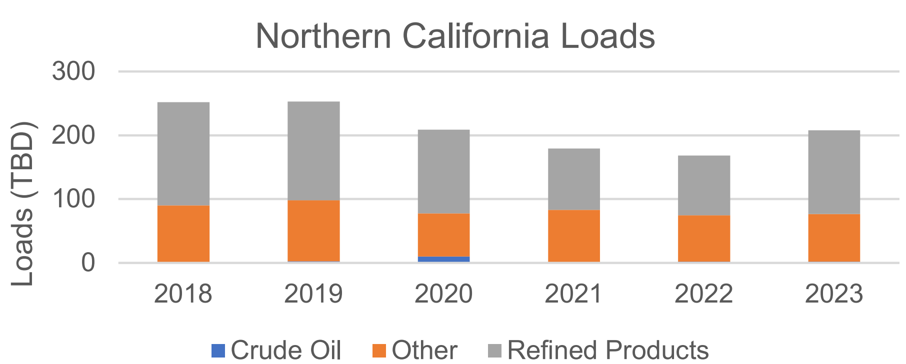
Crude Logistics - Pipeline

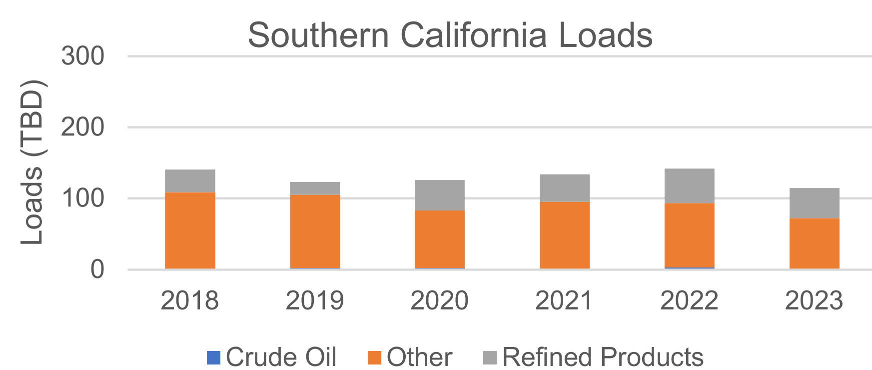
- We estimate pipelines need to operate at ~30% capacity to maintain continuous flow
- This minimum flow constraint can be mitigated with tankage as volume can be built up and shipped in batches
- We assume once a pipeline is shut down it does not return to service, due to the significant hurdle of securing necessary permits and re-start costs
- With closure of refineries in northern California, the two remaining pipelines are more at risk of shutting down if flow reductions continue than the South
- Closure of pipelines and denial of permits to restart them or to allow trucking of crude oil makes it difficult to get central coast crude oil production to market. This could accelerate further production declines.

Marine Logistics Summary







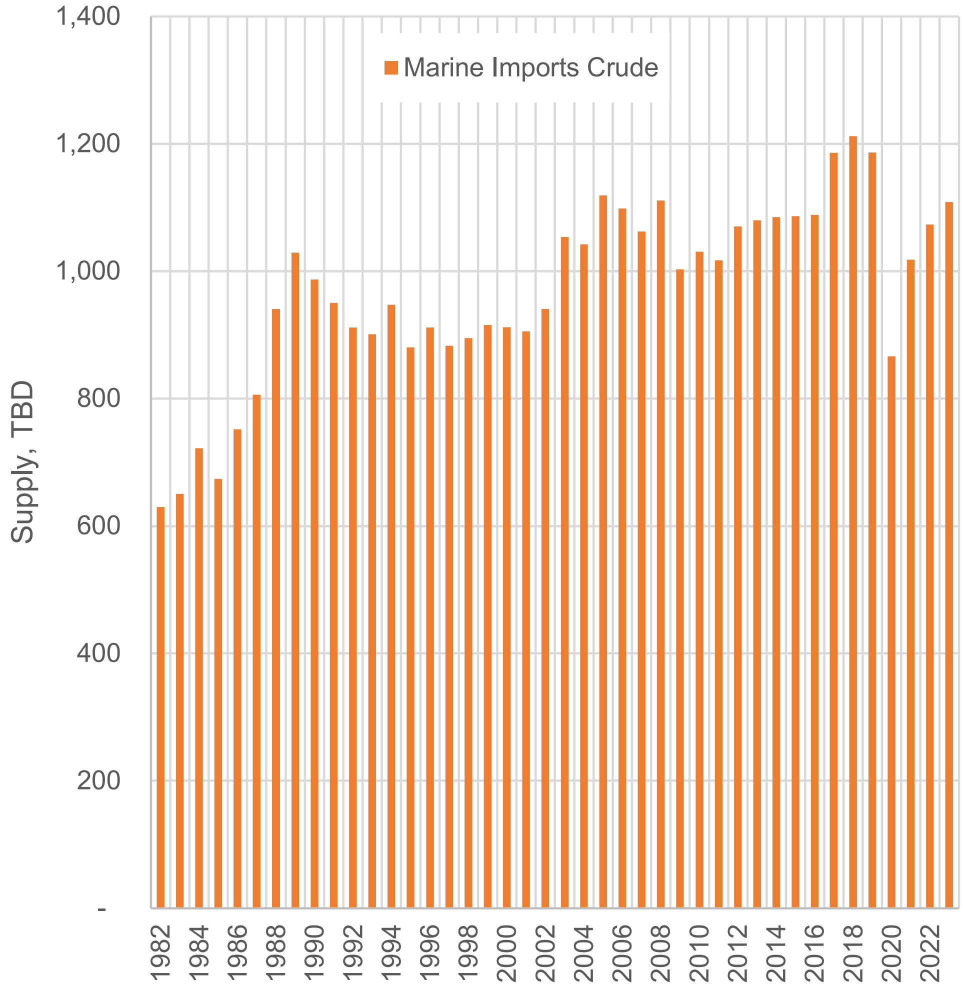


- Discharges and Loads refer to volumes being received from or loaded onto a vessel. These should not be confused with imports and exports as much of the volume originates from or is destined for another location within California.
- Northern crude oil discharges are down from pre-pandemic levels. These volumes are expected to drop even further with recent refinery shutdowns.

Source: California State Lands Commission, TM&C analysis

Potential Crude Oil Marine Limits

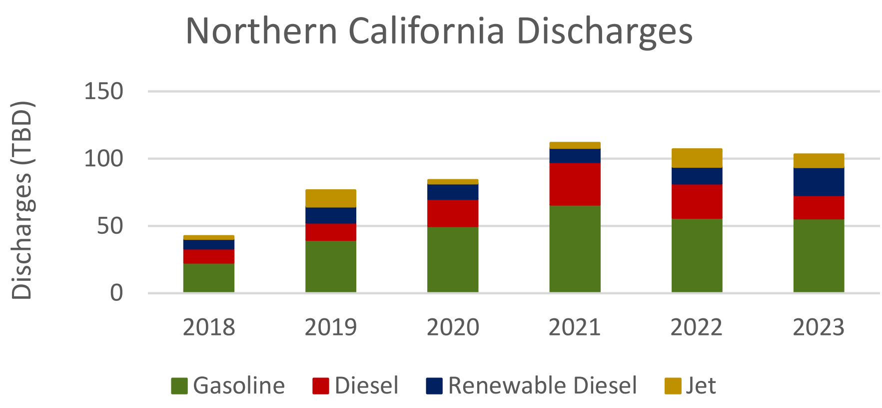
- Crude marine import limit is set at 1,150 TBD based on historical volumes
  - Apart from COVID-19, marine crude imports have exceeded 1,000 TBD since 2003
  - However, only once has marine crude imports exceeded 1,200 TBD (2018)
- Region specific marine import history
  - SF Bay ~ 430 TBD (160 million barrels/yr.)
  - P66 Rodeo and Marathon Martinez already converted to renewable fuels operations; we assume their marine crude oil import capacity is not available to industry
  - LA Basin ~ 715 TBD (260 million barrels/yr.)
  - Marine logistics availability assumptions
    - Marine import capacity dedicated to a refinery shuts when the refinery closes
    - Marine import capacity separate from refinery would remain available to the industry as refineries close
- Crude imports have not increased to fully offset California crude production declines, resulting in refinery capacity slowly declining

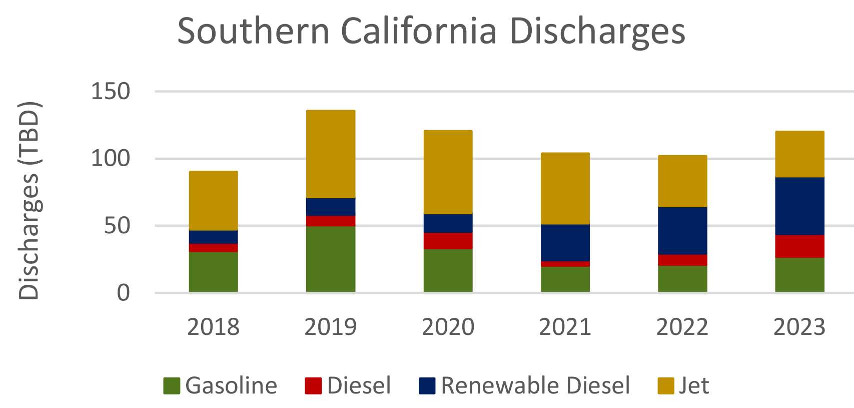


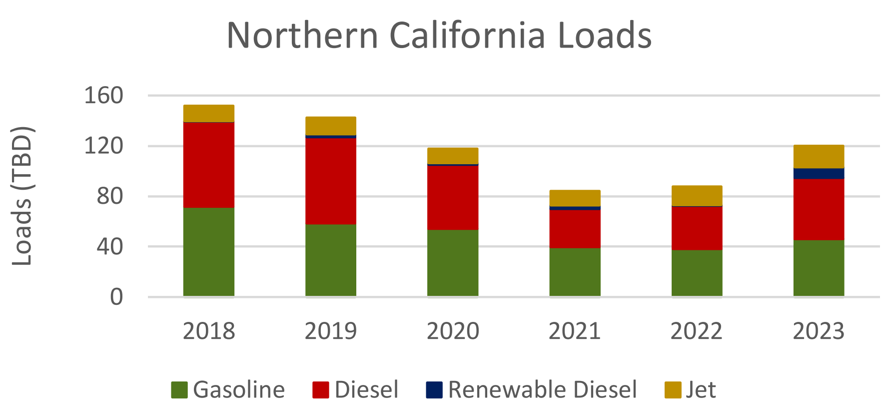
Turner, Mason & Company
energy consulting & advisory

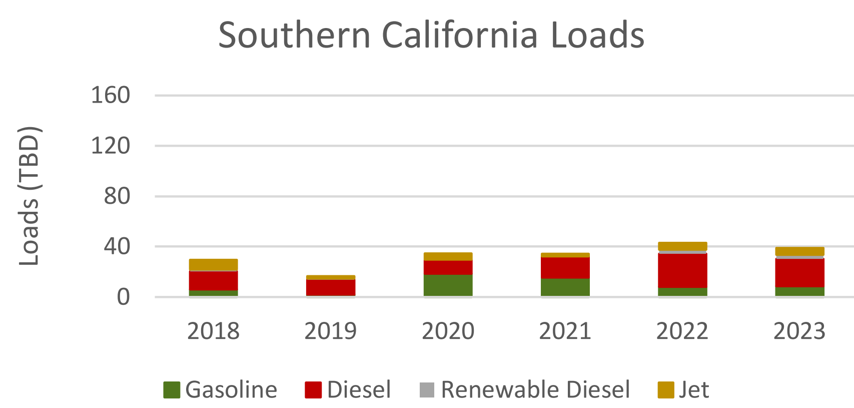
Source: EIA, TM&C Analysis

PRODUCT LOGISTICS - MARINE





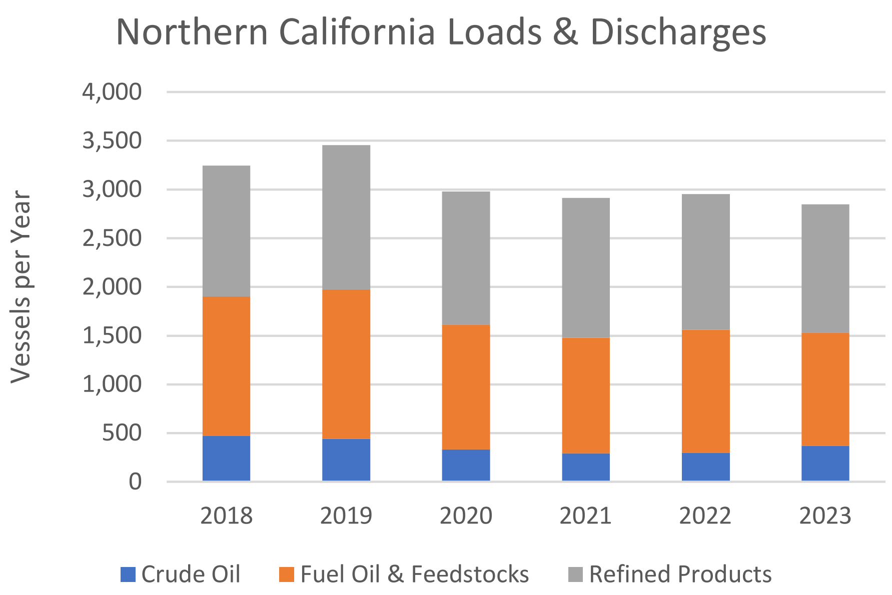


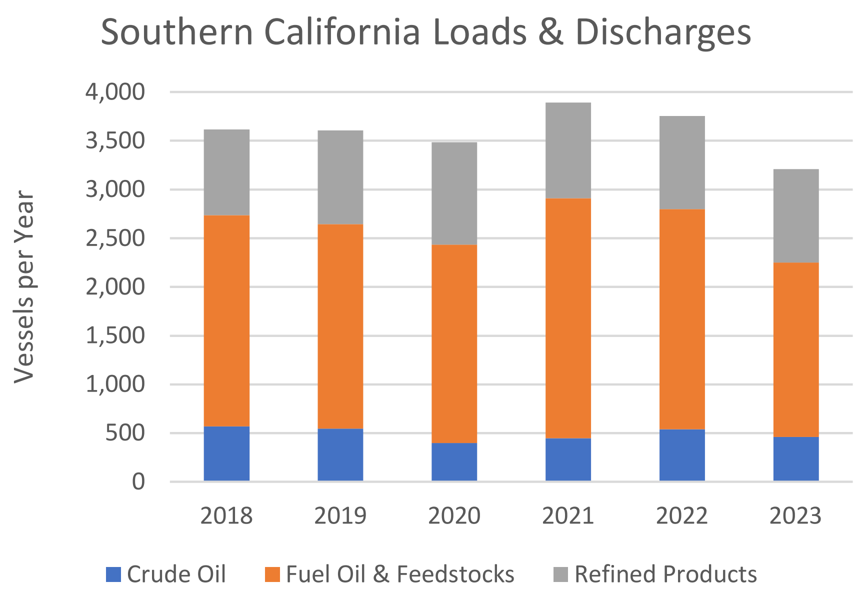


- Discharges and Loads refer to volumes being received from or loaded onto a vessel. These should not be confused with imports and exports as much of the volume originates from or is destined for another location within California.
- **Northern California is a net exporter, while the South is a net Importer of refined products and blend stocks.**

Source: California State Lands Commission, TM&C analysis

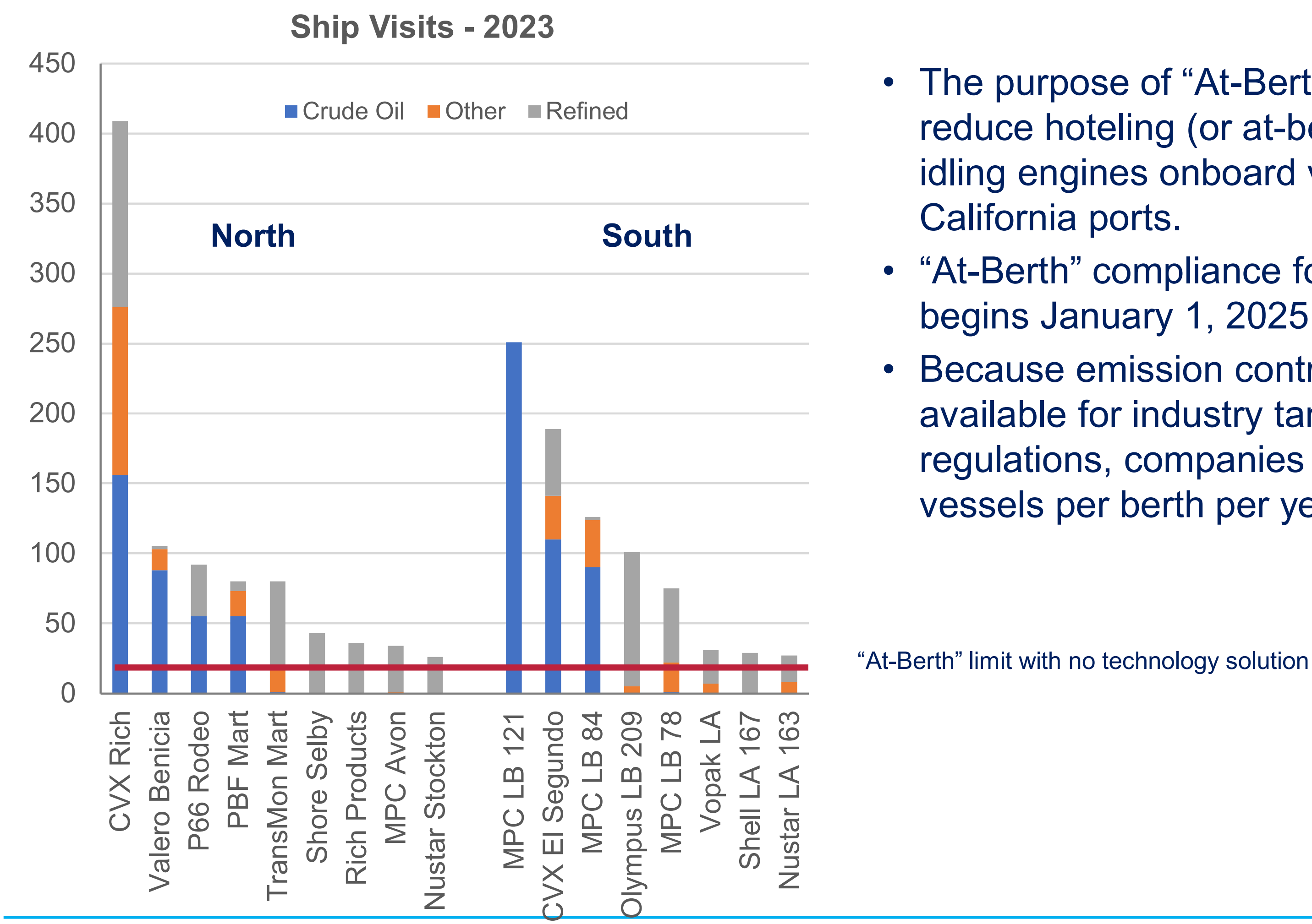
MARINE LOGISTICS - VESSELS





- Discharges and Loads refer to volumes being received from or loaded onto a ship or barge. These should not be confused with imports and exports as much of the volume originates from or is destined for another location within California.
- The total number of ships, both loads and discharges, that are visiting Northern or Southern points is depicted on these graphs.
- Total number of ships in the North has been relatively constant since 2020
- However, in the South there was an increase in ship calls in 2021, which has tapered off

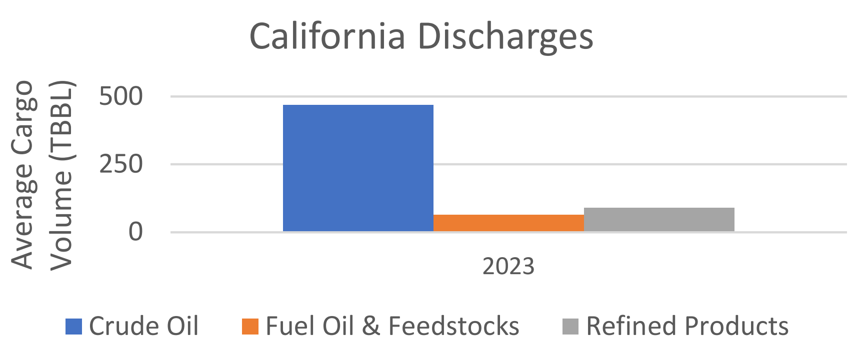
CARB's "At-Berth" regulation could critically impair marine logistics in the liquid transportation supply chain

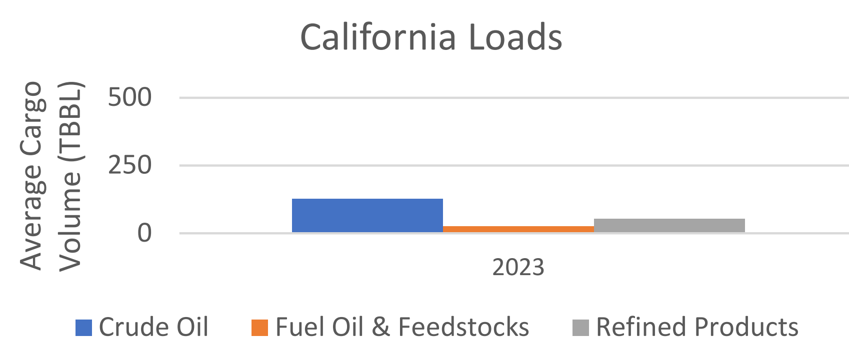


- The purpose of "At-Berth" regulations is reduce hoteling (or at-berth) emissions from idling engines onboard vessels docked at California ports.
- "At-Berth" compliance for tanker vessels begins January 1, 2025
- Because emission control technology is not available for industry tankers, to comply with regulations, companies will be limited to 20 vessels per berth per year.

Product Logistics - Marine

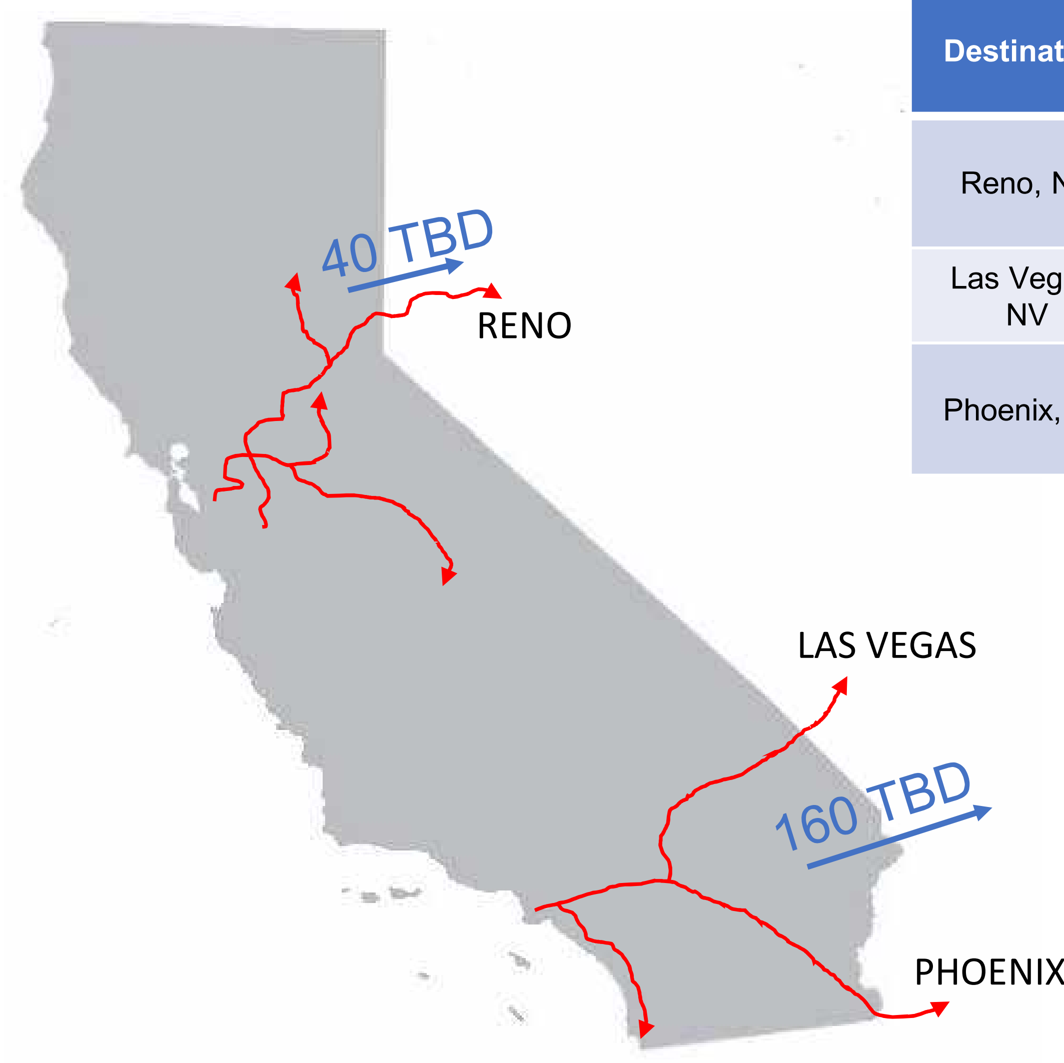
- The volume of products being loaded and discharged were highest in 2023.
- As refineries shut down, product discharges have increased, while loads have decreased
  - Jet is a significant portion of the discharges in the south as airlines are increasingly sourcing their fuel internationally.
  - Product cargos tend to be smaller than crude oil cargos. As product cargos rise, vessel traffic would greatly increase.
- These trends point to higher shipping traffic, especially among products, in the future.
- As renewable diesel grows its share of the California market, refiners increasingly rely on marine capacity to bring in renewable diesel finished fuel, renewable feedstock, and gasoline plus loading ships with fossil diesel to keep the market balanced.
- If refineries reach a marine logistic limit or saturate commercially attractive markets, they could be forced to cut refinery crude oil runs, which could reduce the supply of several products and especially gasoline production.





Source: California State Lands Commission, TM&C analysis

PRODUCT LOGISTICS – PIPELINE (ARIZONA, NEVADA)



Destination	Pipeline Name	Capacity (TBD)	Throughput (TBD)	Minimum Throughput (TBD)
Reno, NV	SFPP Northern Region	40	40	10-15
Las Vegas, NV	CalNev Pipeline	128	60	35-40
Phoenix, AZ	SFPP Southern Region	100	100	25-30

- California's refining centers deliver transportation fuels to the Arizona and Nevada markets via pipelines.
- The northern pipeline system is not connected to the southern system. Any fuel moved between the North and South refining centers must move via ocean going vessel.
- California refineries are major transportation fuels suppliers to markets in Arizona (88%) and Nevada (45%), so disruptions in fuels production in California would impact all three states.

Crude Logistics - Rail

- Refineries have the capability to bring in small volumes of crude by rail if needed.
- Very little crude oil is brought in by rail. With high transportation costs, crude by rail is not very competitive in California.
  - A decade ago, crude by rail was a growing industry in California, with several facilities expanding their capabilities to offload crude oil from railcars.
  - The crude by rail was driven by discounted crude oil in Canada and North Dakota.
  - Within a few years, many of the incentives that had driven acquiring crude oil from this source had dissipated.
    - Pipeline infrastructure in the Bakken (North Dakota) was built up to take crude oil to market, reducing the financial incentive to deliver crude oil by rail.
    - Reduced fuel demand cause by the pandemic, and the shutdown of refineries in California, reduced the demand for crude oil.
    - By 2021, only 1.7 million barrels of crude oil (5 TBD) entered California by rail (less than 0.5% of all crude oil imports), all of which went to Bakersfield.
    - The completion of the Trans Mountain Pipeline expansion (bringing crude from Alberta, Canada to the Pacific Coast) further reduces the incentive to bring Canadian crude oil to California by rail.
- Crude by rail is not expected to play a major role in California's future crude oil supply.
- Product by rail is also unlikely as it takes 3 to 5 unit trains (100 cars) to equal one typical tanker

Source: CEC, EIA

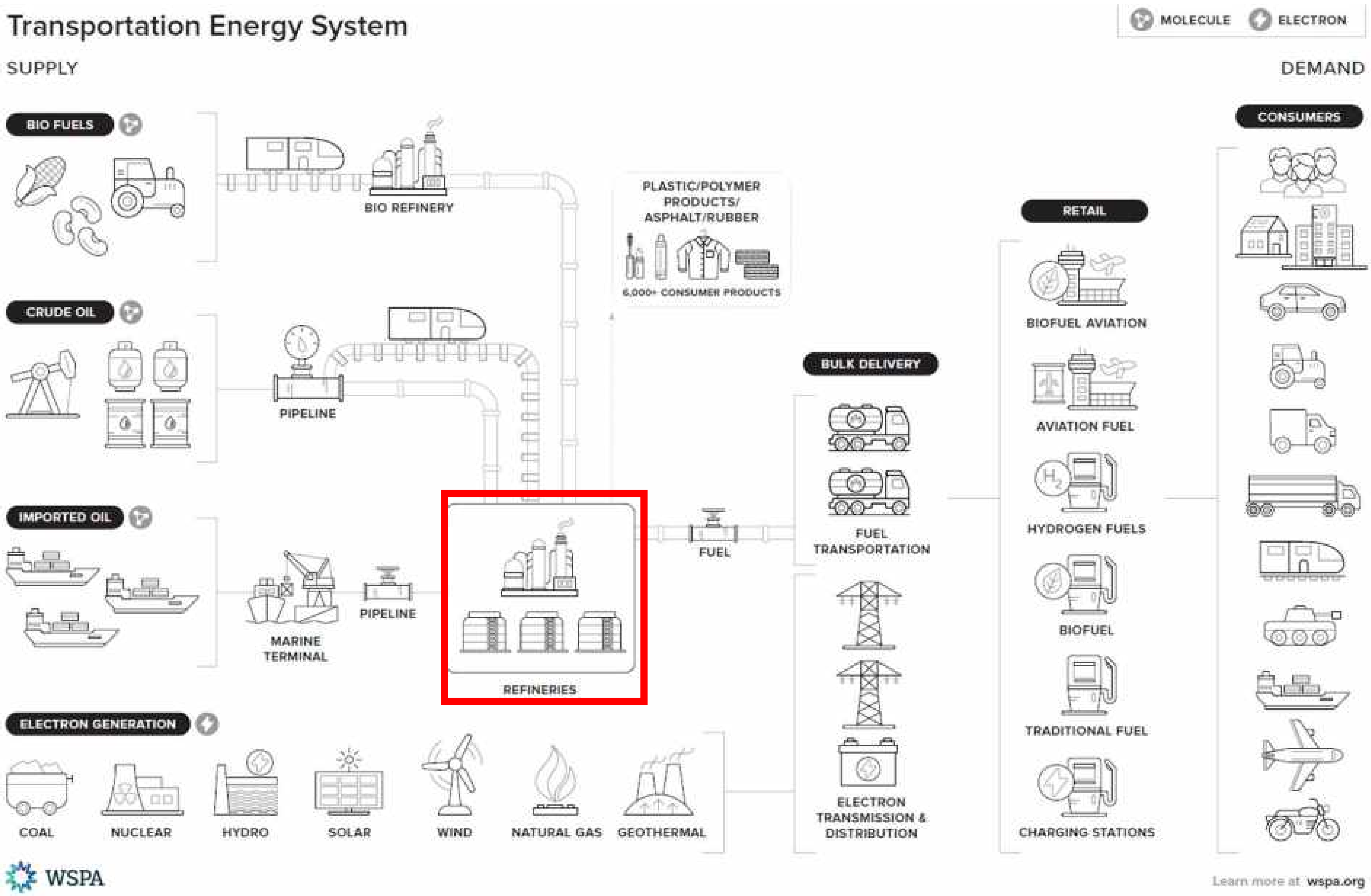
PRODUCT LOGISTICS – RAIL

- Largely renewable fuels, like ethanol or biodiesel, or liquid petroleum gases like butane or propane
- Stockton (1) & Colton (2) are main ethanol hubs
- These facilities are unlikely to be an option for any significant quantity of imported gasoline or diesel as renewable fuels continue to be imported

POTENTIAL PRODUCT LIMITS

- As transportation fuel demand in California declines, product pipelines may face the same type of turndown concerns as the crude pipelines. This could lead to difficult business decisions on how to operate pipelines at reduced rates to meet demands of the California consumer.
- Product pipeline exports to AZ and NV may be potentially impacted.
  - From SF Bay – 40 TBD to Reno
  - From LA Basin – 160 TBD to Las Vegas/Phoenix
- Demand decline may lead to increased need of importing or exporting transportation fuel, increasing vessel calls in the north and the south.
- Additional constraints on product pipeline operations or vessel movements may contribute to further price volatility.

TRANSPORTATION ENERGY SYSTEM: REFINING

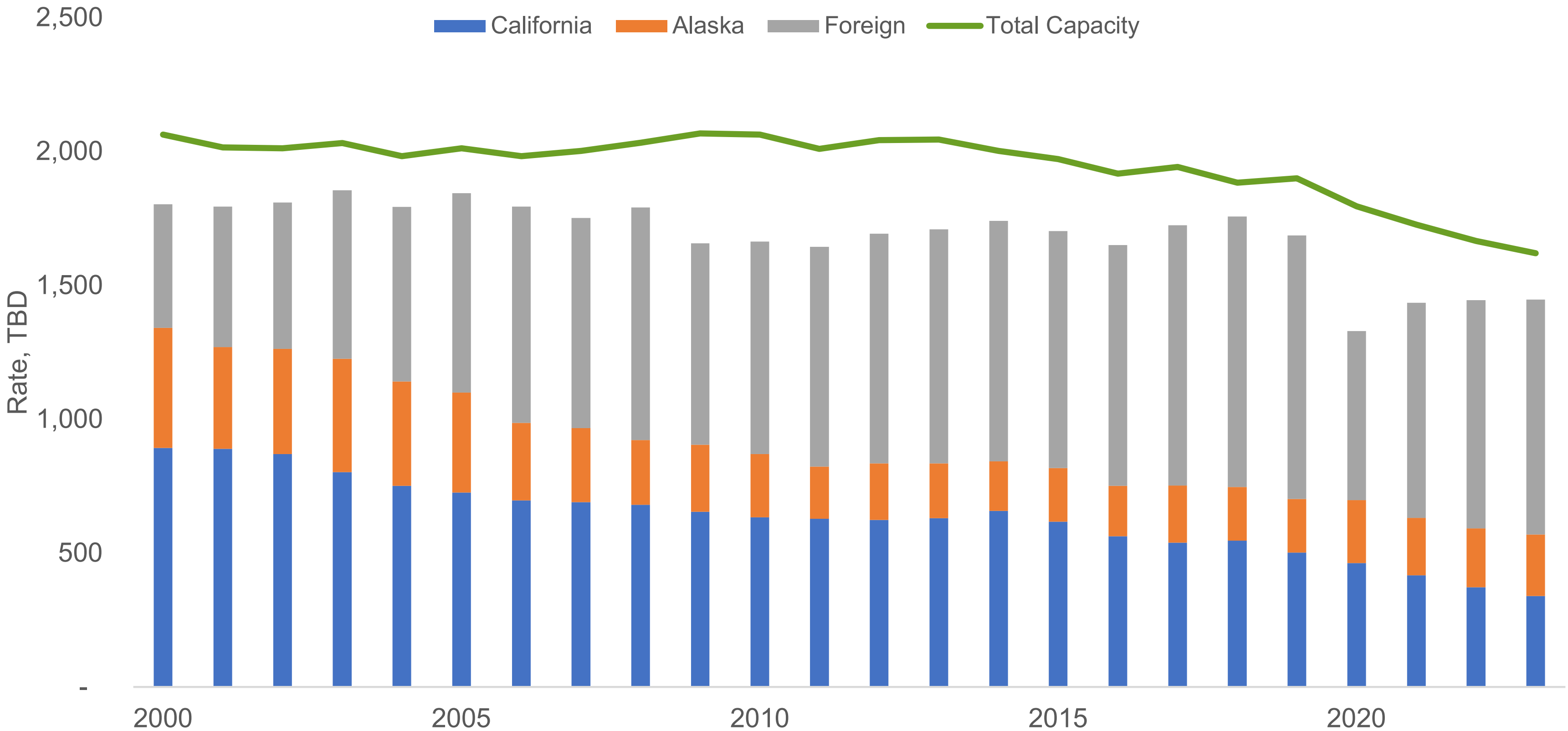


Refining Summary

- As California crude production declines, refineries have become more dependent on marine imports of crude oil to maintain refinery throughput
- Future declines in California crude production coupled with import logistic constraints could limit the ability of refineries to maintain operating rates
- Conversion of crude oil fuels refineries to renewables results in a net loss of total fuels production. These conversions are not a 1:1 change in transportation fuels.
- The amount of each fuel a refiner produces is a function of the installed hardware at a refinery, the crude slate chosen to maximize overall profit, and the operating conditions within the refinery.
- There are a limited number of refineries in California that supply transportation fuels to the state. As demand declines, refiners may face difficult business decisions to export their production, curtail their operations, or shut down.

California refineries have a history of declining capacity and crude oil runs

- Foreign crude oil imports have grown to meet refinery supply needs as California and Alaska crude production declines
- Overall crude oil runs declined with recent refinery closures or site conversions to renewable fuels



After the most recent closures there are nine fuels refineries remaining in California

Asphalt vs Fuels Refiners (May 2024)

Area	Asphalt	Fuels
Number of Facilities (#)	4	9
Crude Distillation (TBD)	44	1,664

Regional Distribution of Refiners (May 2024)

Area	LA Basin	Central	SF Bay
Number of Facilities (#)	7	3	3
Crude Distillation (TBD)	1,089	54	564
Fuels Production Capability* (TBD)	845	8	419

* Actual fuels production may exceed fuels production capability due to imports of blend components and finished products

- California has a limited number of refineries supplying transportation fuels to the state.
- As demand declines, refiners may face difficult business decisions, such as exporting production to other markets, curtailing operations, or shutting down facilities (which could be converted to alternative fuels facilities, terminals, or permanently closed).

Conversion to renewables causes net loss of transportation fuel supply

Marathon Martinez
- Refinery capacity = 166 TBD crude (2,550 MMGY)
- Renewable diesel capacity = 730 MMGY

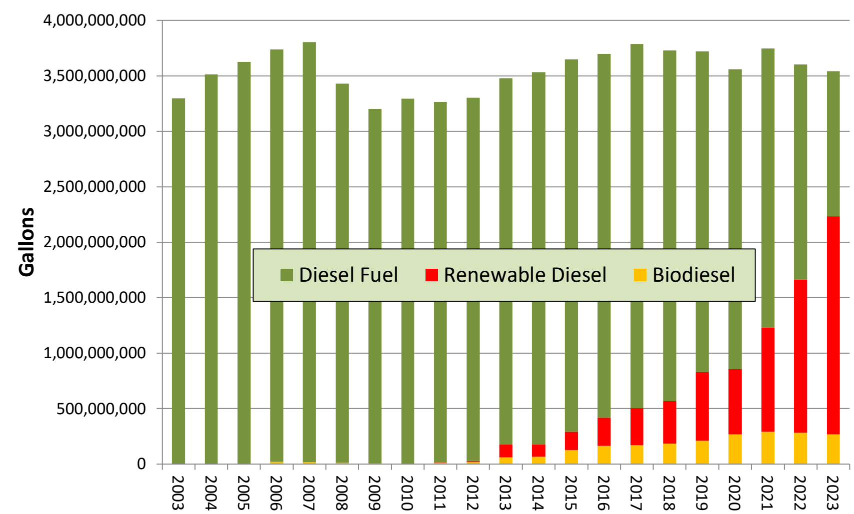
P66 Rodeo
- Refinery capacity = 120 TBD crude (1,840 MMGY)
- Renewable diesel capacity = 800 MMGY

Conversion to renewables results in a net loss of total fuels production – not 1:1 change
- Net increase in diesel production competing for space among other diesel supplies
- Decrease in gasoline production, which cannot be made up by yield shifts in other refineries
- Could require an increase in gasoline and jet imports to satisfy demand

LCFS compliance is displacing fossil ULSD
- ULSD supply is down 103 TBD since 2019 (-54%)
- Pressuring refiners with higher yields of fossil ULSD

	Net Production Change (TBD)	% Change North CA capability
Gasoline	-148	-55%
Jet	-31	-42%
Diesel	27	+25%
Total	**-152**	**-36%**

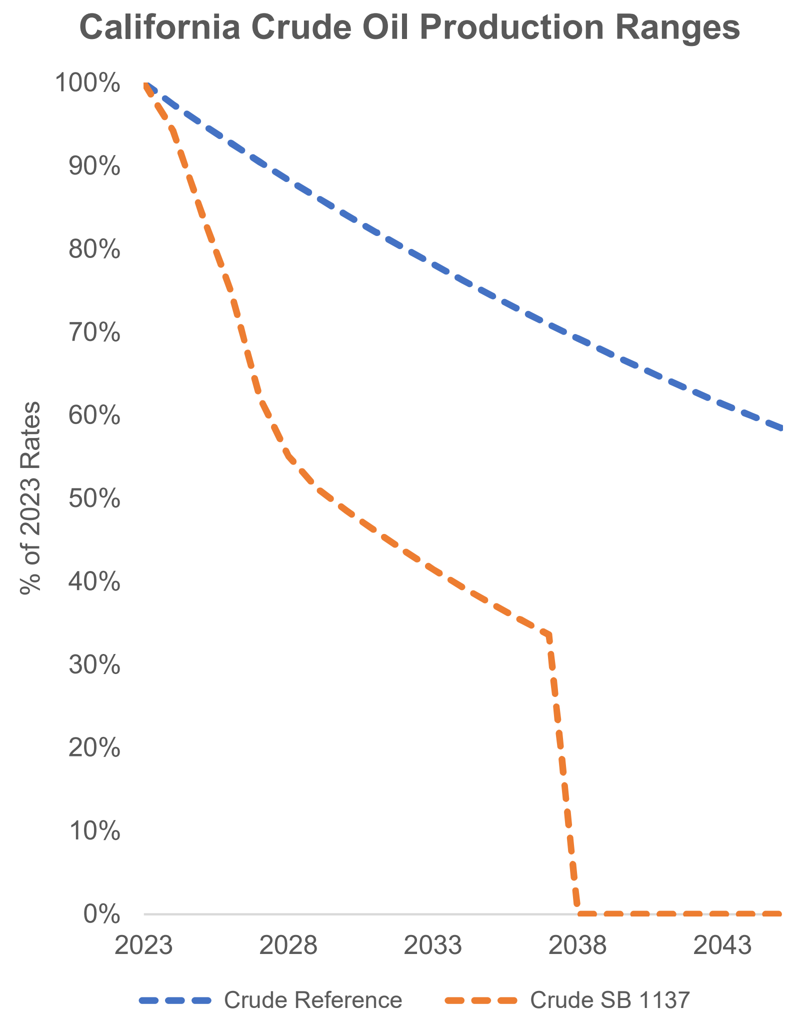
California Diesel, Biodiesel & Renewable Diesel Demand 2003 - 2023



Source: EIA, company websites, CEC, TM&C Analysis

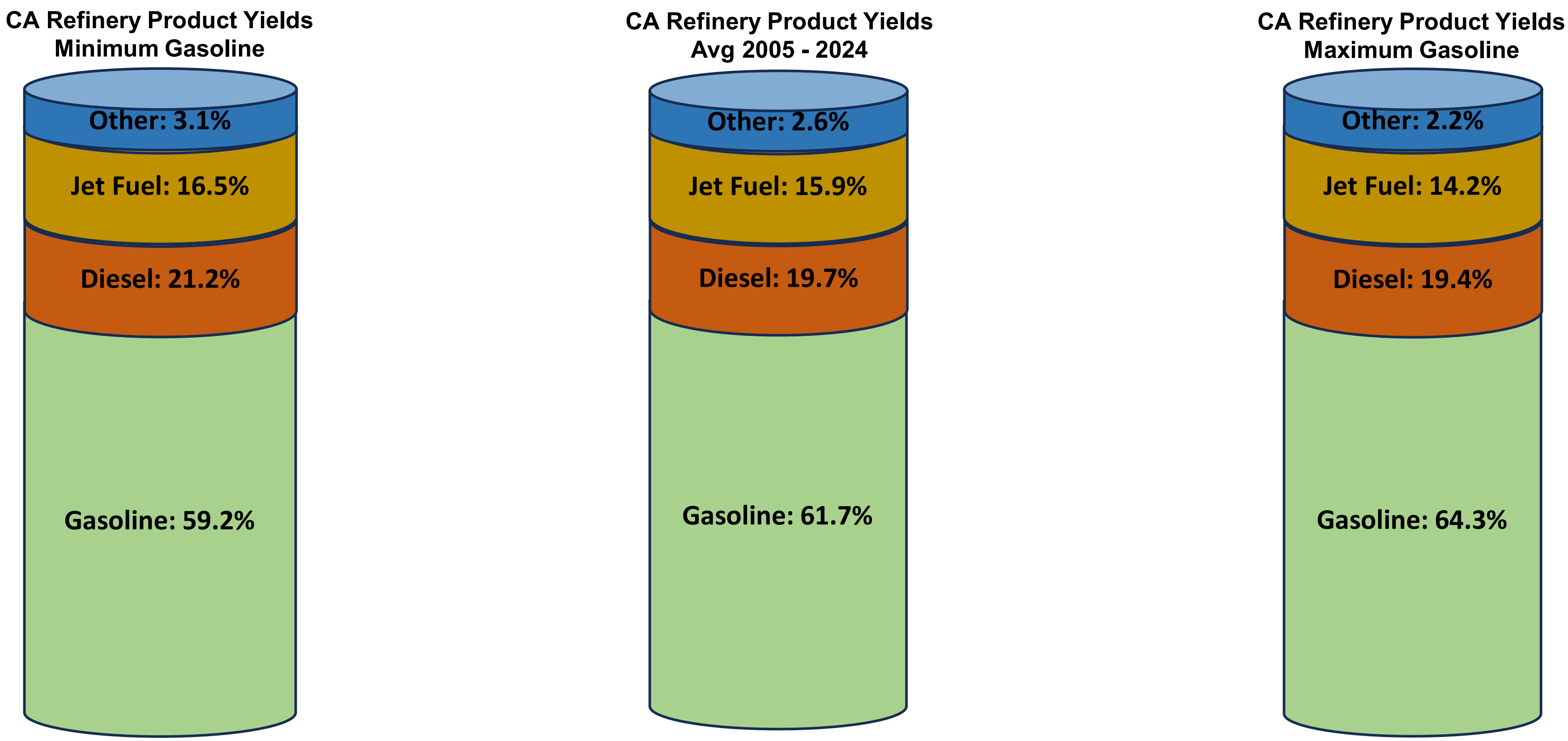
REFINERS ARE BEING FORCED TO ADAPT TO DECLINING CRUDE OIL AVAILABILITY

- Range of decline rates of California crude oil production is highly uncertain and varies across basins.
- The pace of approving permits and regulations, such as SB 1137, can also have material impacts on the production profile of California crude oil basins.
- Regulations, such as "At-Berth", could impact the ability to import crude oil.
- California policies could impact not only where and how refineries source crude oil, but also the overall operating rate of a refinery.



Source: TM&C Analysis, CalGEM

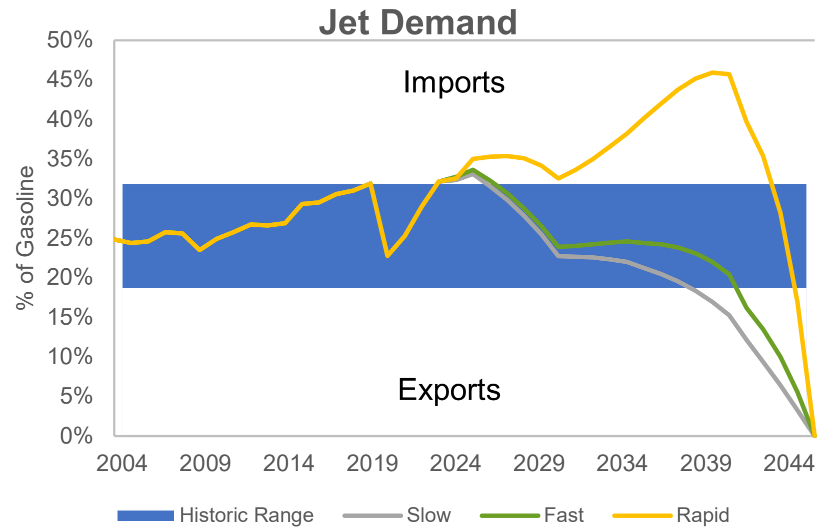
THE CALIFORNIA REFINING SYSTEM CAN ONLY FLEX ITS GASOLINE YIELD 5%

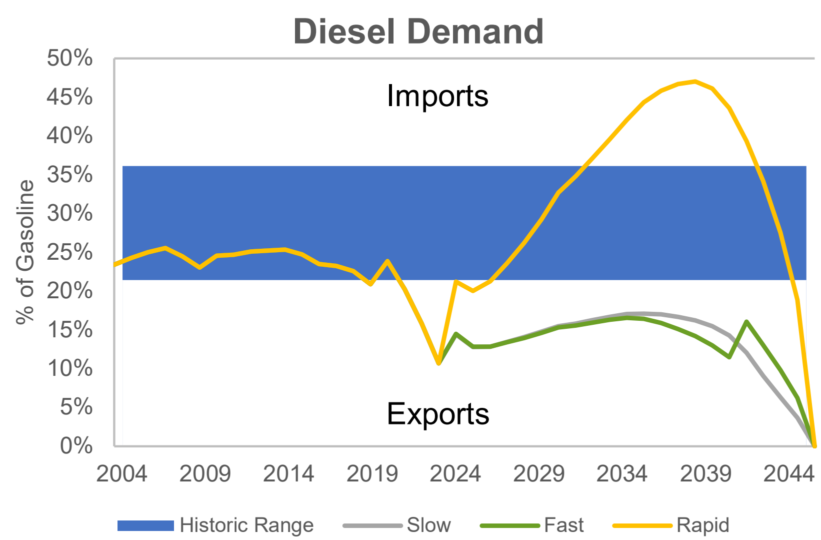


- Recent data shows refiners trying to minimize diesel in favor of jet (jet has increased from 12% in 2020 to 20% in 2024)
- Additional significant increase in jet yield eventually would require a major shift in the crude oils processed and probably capital projects

A CHANGE IN DEMAND FOR ONE PRODUCT HAS MULTI-PRODUCT IMPLICATIONS FOR A REFINER

- The amount of each product each refinery can make is a function of the installed hardware and the crude slate chosen to maximize overall profit within the constraints of the facility.
- As demand for jet or petroleum diesel shifts (relative to gasoline) – there is a limited ability to shift refining operations to produce more or less of a particular fuel.
- The petroleum diesel chart on the right shows some refineries are struggling to balance through yield adjustments. However, because the refinery does not know what the future holds (e.g., yellow vs. green lines), it is difficult to plan, permit, invest, and build necessary changes in the configuration.
- A refiner could have to export or import products to maintain balances while meeting demands.
- Uncertainty in future demand shifts limit the ability to make investment decisions, such as committing capital for the installation of new hardware to adapt to *potential* changes in product mix.



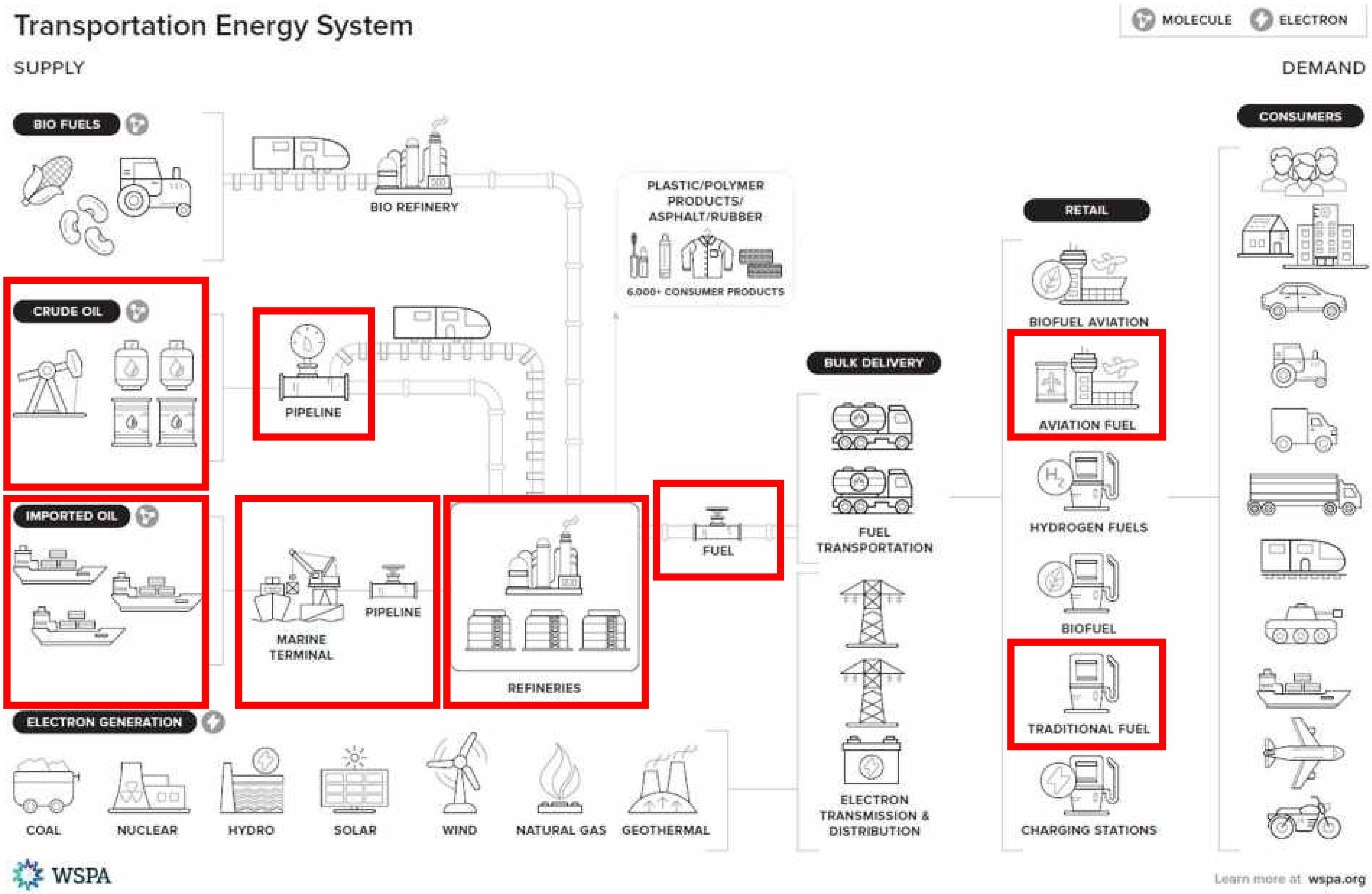


Source: CEC Weekly Production, CEC, CARB, TM&C Analysis

Potential logistics impacts of refinery shutdowns

- Terminal Conversion
  - Logistics still available to industry
  - Site owners would be able to defer site decommissioning and remediation costs as site would still be operating (as a terminal)
- Renewable Fuels Plant (Bio-Refinery) Conversion
  - Logistics fully (or partially) repurposed for renewable operations
    - Renewable plant logistics generally not available to fossil industry as they are used for renewable feedstock imports and product exports
    - Importing of renewable feedstock
  - Potential exporting of products after meeting California demand
  - Limited opportunities for additional sites to convert to renewable fuels production as market nears saturation
    - RD currently is 60% of California diesel supply
    - TM&C market outlook expects RD saturation could be as early as 2026
    - Newer markets in Oregon, Washington and Canada, but may favor locations closer due to logistical constraints
- Complete Site Shutdown
  - Logistics not available to industry
  - Site owners would incur costs associated with site decommissioning and remediation

SCENARIOS



Transportation Energy System
MOLECULE
ELECTRON
SUPPLY
DEMAND
BIO FUELS
BIO REFINERY
PLASTIC/POLYMER PRODUCTS/ ASPHALT/RUBBER
6,000+ CONSUMER PRODUCTS
CONSUMERS
RETAIL
BIOFUEL AVIATION
CRUDE OIL
PIPELINE
AVIATION FUEL
BULK DELIVERY
HYDROGEN FUELS
IMPORTED OIL
FUEL
FUEL TRANSPORTATION
MARINE TERMINAL
PIPELINE
REFINERIES
BIOFUEL
TRADITIONAL FUEL
ELECTRON GENERATION
COAL
NUCLEAR
HYDRO
SOLAR
WIND
NATURAL GAS
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Scenario Summary

- The California refining industry faces numerous constraints that could impact their future ability to continue operations and supply transportation fuels to the state
- Major potential physical constraints include minimum refinery utilization, both crude and product pipeline throughputs minimums, crude oil marine imports, product marine exports, upstream crude oil production declines and permitting restrictions
- The industry also faces declining transportation product demand within California, with limited ability to alter operations to significantly shift their product yields
- Economic factors including profitability, capital requirements, and global competition in markets where they potentially would need to increase exports of products could impact whether a specific crude oil production well, refinery, or pipeline continues operations
- TM&C evaluated scenarios primarily focused on the impact of physical constraints (utilizations, marine limits, pipeline limits) faced by the industry under various crude oil supply and product demand cases.
- Refineries in these scenarios close for technical or operational reasons. However, they could close sooner for other reasons, e.g., inability to obtain required permits, structurally negative margins, not competitive in their corporate portfolio.
- Across all scenarios, on average, about half of California's fuels refineries close by 2045. In the most disruptive scenario, only one fuels refinery remains by 2040. Even in the least disruptive scenario refineries could close.

Overview of Potential Constraints

- Physical Utilization Minimum (65%)
  - Difficult to continually run crude units below 65% utilization
  - More exact constraints would require confidential business information from each site
- Economic Utilization Minimum (80%)
  - Estimate of crude unit utilization below which a refinery may financially struggle due to very high unit fixed costs
  - Overall corporate financial health determines how long a specific refinery could operate with negative financials
- Bay Area has a product pipeline to Nevada, while LA Basin has product pipelines supplying Arizona and Nevada
  - 40 TBD limit from Bay Area to NV
  - 160 TBD limit from LA Basin to AZ + NV
- Marine crude oil import limit of 1,200 TBD for entire state, but decreased slightly to 1,150 TBD due to Marathon Martinez and P66 Rodeo conversions to renewable fuels production
- Marine product loading limit of 670 TBD for entire state
- Key marine logistics assumptions
  - Marine import capacity dedicated to a refinery shuts with refinery closure
  - Marine import capacity separate from refinery still available to the industry as refineries close
  - Potential for limit to decline in future due to regulatory / permitting change
- Black swan events (e.g., COVID) do not demonstrate sustainable (physically / economically) operating potential

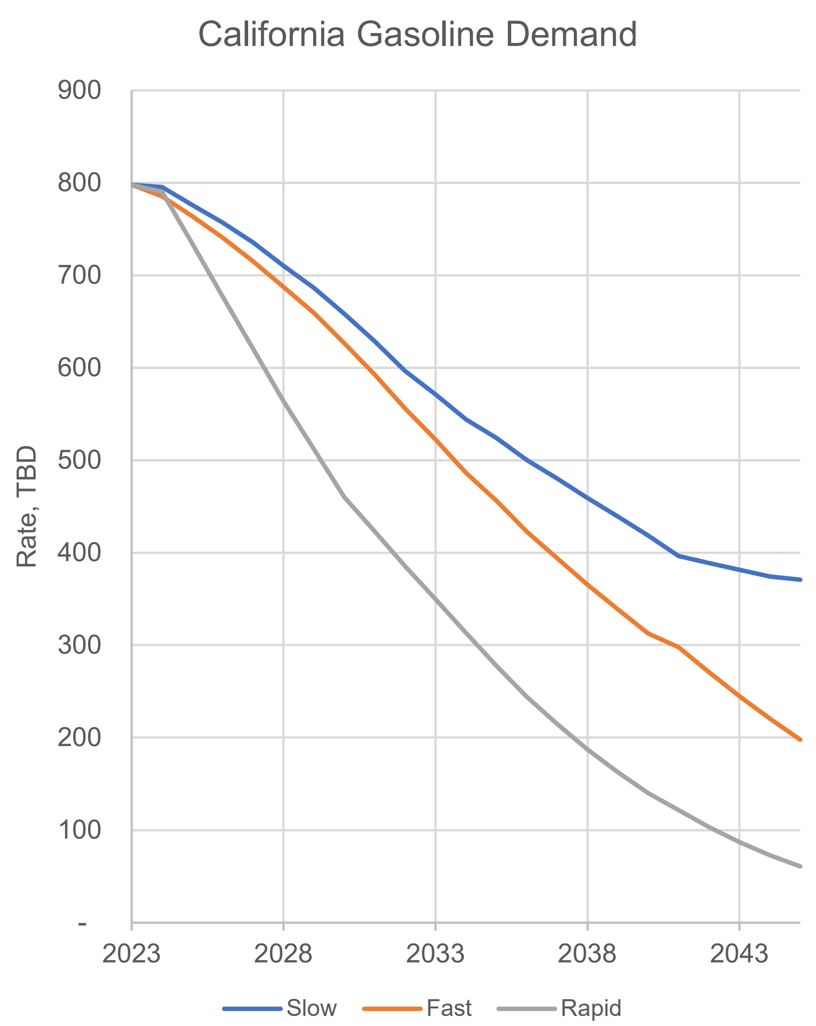
Plausible Scenarios

We crafted these scenarios to understand how plausible constraints could expose potential dislocations in the entire system. These are not a forecast of decision-making at individual assets (e.g., wellheads, pipelines, berths, refineries). Decisions made by asset owners at specific sites could involve several factors that could vary on a case-by-case basis.

Reference	Scenario Name	Description / Constraints	Potential Impacts
A	Open Constraints	• No discontinuities	• System remains operable with no limits or disruptions
B	Refinery runs to satisfy CA gasoline demand	• Refinery turndown limit • No pipeline gasoline to AZ/NV, fill pipeline with diesel/jet	• Only satisfy local (CA) demand for gasoline, can import CARB components if necessary • Renewable diesel for local demand • Export petroleum diesel • Reach refinery turndown limits sooner, causing some refiners to shut down more quickly
C	Marine constraints	• Crude inbound limit (1,150 TBD) • Product (inbound/outbound) limit (VOC emissions) • Physical Utilization Min (65%)	• Crude marine limit prevents marine volume from full replacement of declining California production • Product outbound limit as declining CA transportation fuel demand forces growing product exports; impacting refinery crude runs • Reaching physical refinery turndown limits results in refinery closures to maintain minimum throughput at remaining refineries.
D	Turn-arounds become Refinery closures	• Decision to close rather than spend capital when a refinery reaches a major turn-around	• System becomes more reliant on product imports
E	Marine constraints with Economic Utilization	• Similar to Marine Constraint Scenario but with more restrictive utilization constraint (80%)	• Economic Utilization constraint results in two additional potential refinery closures under all gasoline demand scenarios
F	Crude production	• Different CA crude production profiles, with marine constraints • Slow CA gasoline demand profile	• As CA production more rapidly decreases in different scenarios, crude marine limit could have a greater impact on operations than in the Marine constraints case
G	Fully Enforced “At-Berth” Emissions Limits	• Limit to 20 vessel/berth (effective Crude import limit 700 TBD) • Physical Utilization Min (65%) • SB1137 Crude production profile • Slow/Rapid product demand profiles	• Rapid initial closure of refineries due to crude production declines and “At-Berth” emissions limit • Increased marine product imports due to refinery closures • Marine product constraint, even if filling AZ/NV pipelines is not limiting

CARB Gasoline Demand Cases

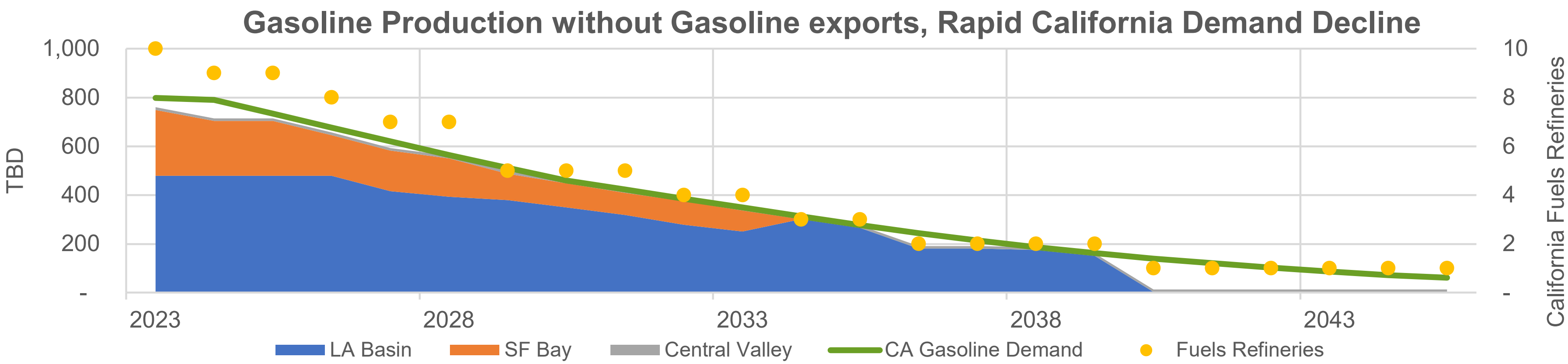
- Studied three CARB gasoline cases from CEC Transportation Fuels Assessment – Slow, Fast, Rapid decline in demand.
- Imposed same three demand curves in each scenario.

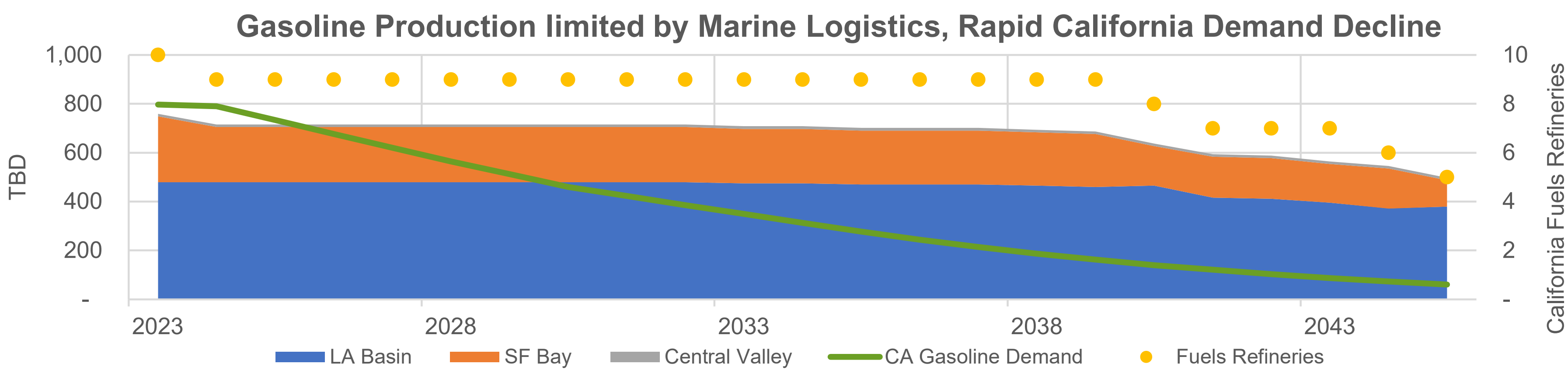


Source: CEC Transportation Fuels Assessment,
TM&C Modeling

California gasoline production under different constraint scenarios

- Limiting exports of gasoline may cause rapid shutdown of refineries as excess production has no disposition, requiring imports to balance demand.
- Potential for price volatility due to transitioning between imports and exports, can impact business decisions.
- Exports must compete in global market; imports must meet strict California product specifications.

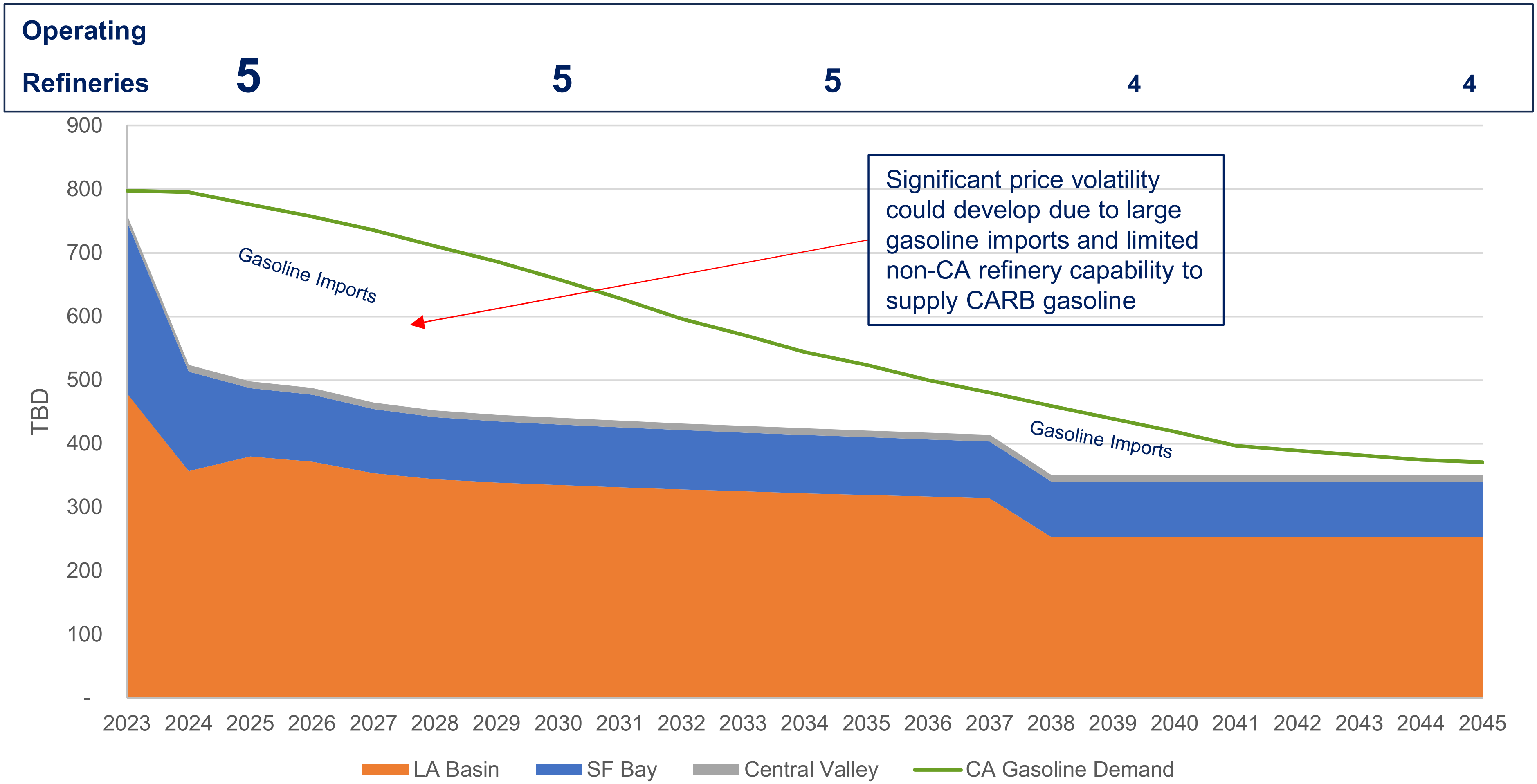




Source: TM&C Modeling

Risk of significant immediate refinery shutdowns if refiners face CARB "At-Berth" crude restrictions

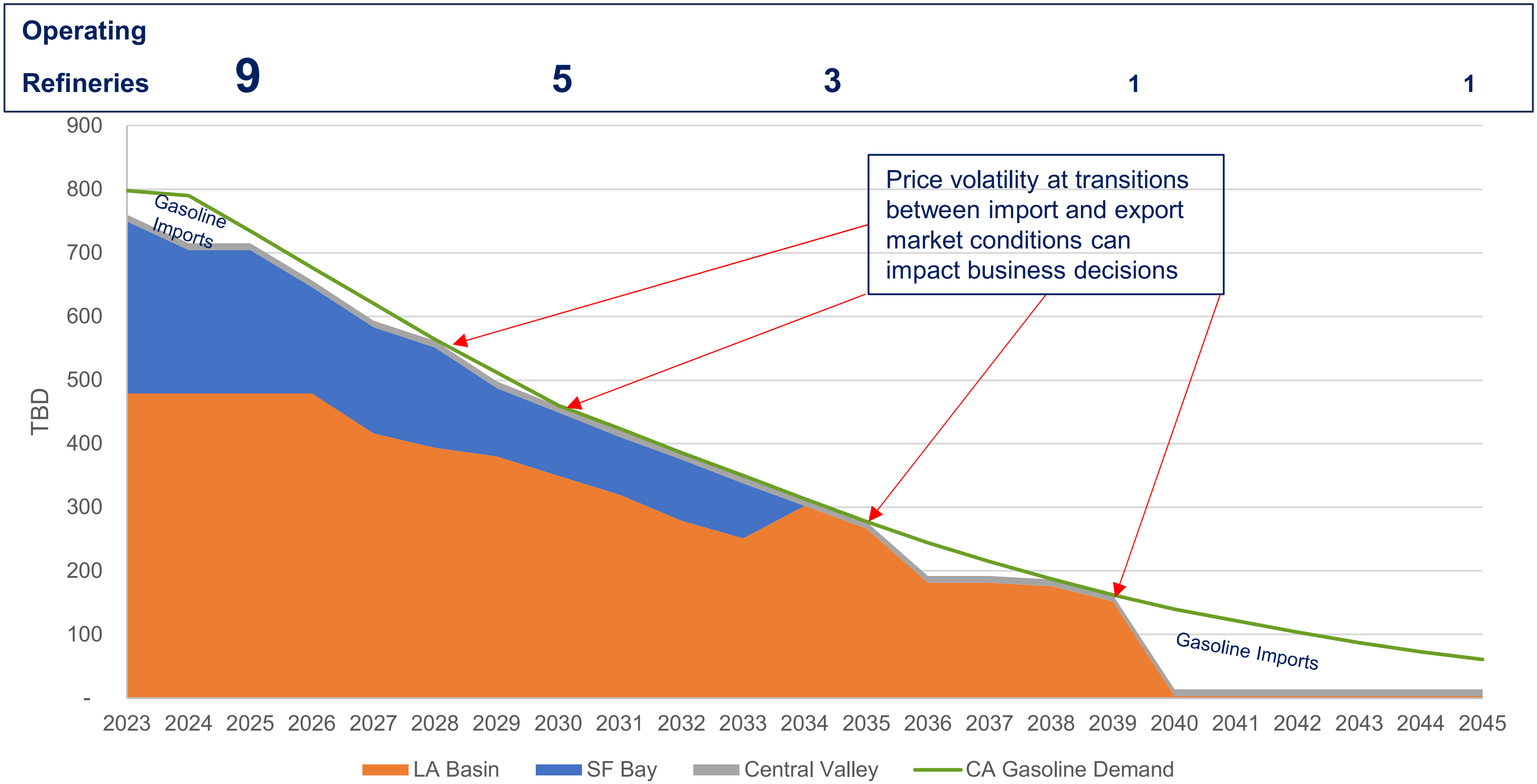
- CEC "Slow" fuels demand case
- CARB "At-Berth" limiting crude imports
- California crude oil production at SB1137 case
- Refinery utilization falls to 65% before shut-down



Source: TM&C analysis

If California refineries could not export products, the risk of refinery shutdowns could accelerate

- CEC "Rapid" fuels demand case
- Limited non-CARB product exports (e.g., CARB "At-Berth")
- California crude oil production at reference case
- Refinery utilization falls to 65% before shut-down

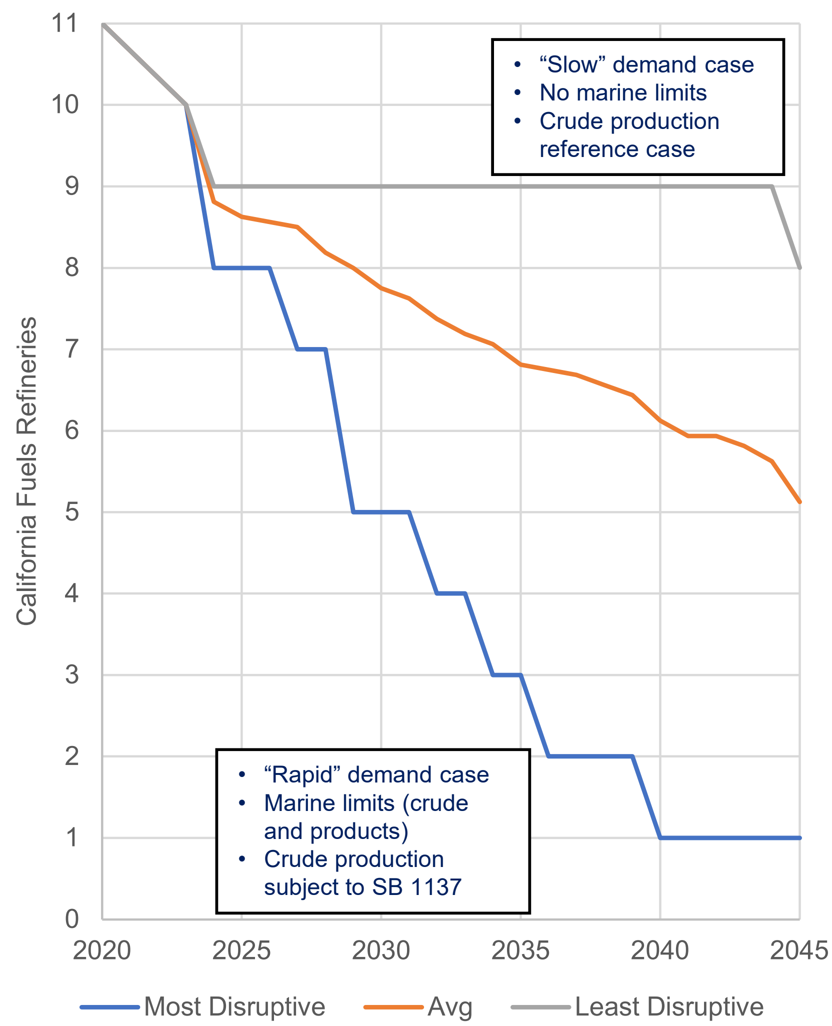


Source: TM&C analysis

Turner, Mason & Company
energy consulting & advisory

REFINERY CLOSURE RISK IS HIGHLY DEPENDENT ON SCENARIOS

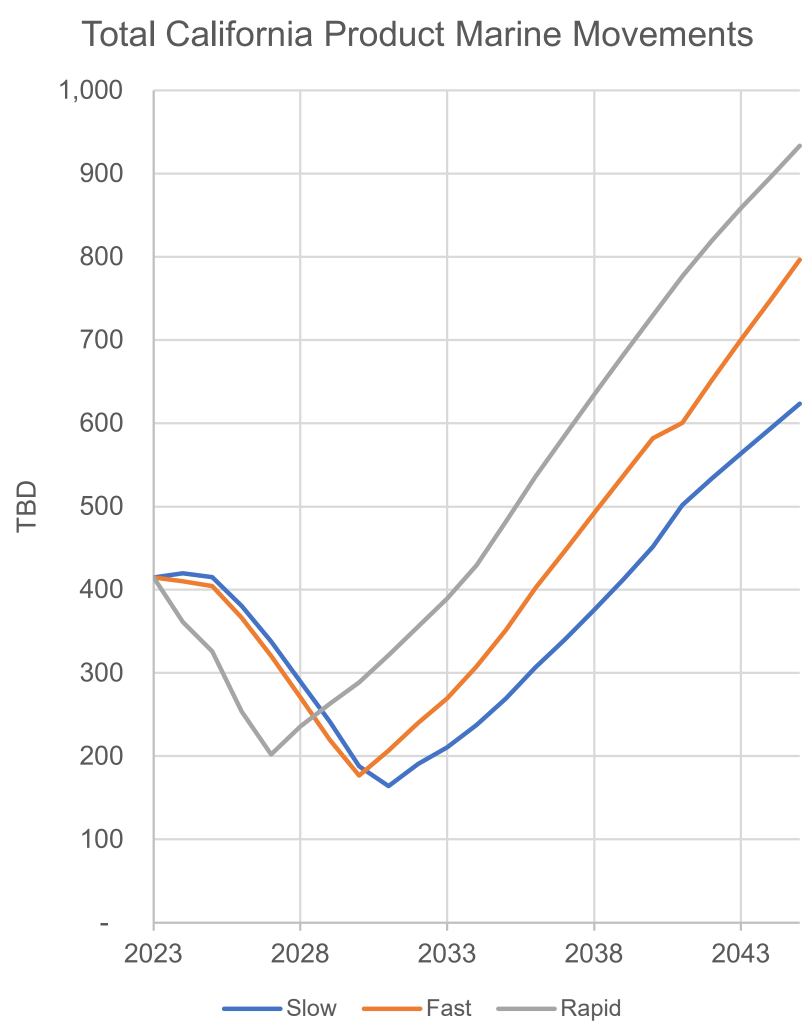
- TM&C evaluated potential refinery closures across 16 scenarios covering combinations of:
  - Transportation fuel demand cases
  - Crude oil production profiles
  - Logistics constraints
  - Refining operating environments
- Across all scenarios, on average, about half of California's fuels refineries could close by 2045
- In the most disruptive scenario, only one fuels refinery remains by 2040
- Even in least disruptive scenario refineries could close
  - Major shifts in business (increases in exports) and operations required
  - Assumes no new limitations to importing crude and exporting products
  - Requires exports to be globally competitive
- If onshore power is unavailable or on-ship capture is infeasible, full enforcement of "At-Berth" restrictions could close 3-4 refineries almost immediately
- Refineries may close faster than demand declines, which could put pressure on marine logistics and vessel traffic limits



Source: TM&C Analysis
Note: Refinery utilization falls to 65% before shut-down

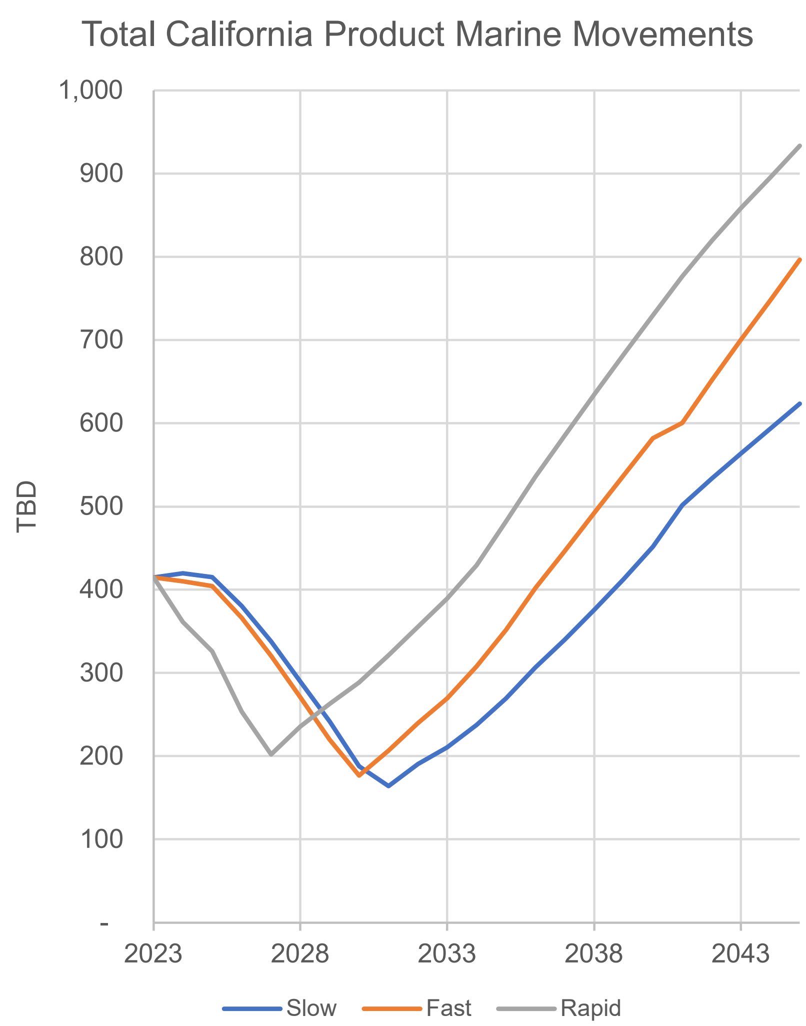
A. Open Constraints

- Current system remains operating in nearly identical state as today (P66 Rodeo refinery fully converted to renewable diesel in 2024)
- Declining California crude oil production requires increase in import crude volumes to maintain refinery throughput
- Declining California transportation fuel demand requires increase in product export volumes to maintain refinery throughput
- No constraints on marine movements (crude or product) imposed
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand



A. Open Constraints

- Current system remains operating in nearly identical state as today (P66 Rodeo refinery fully converted to renewable diesel in 2024)
- Declining California crude production requires increase in import crude volumes to maintain refinery throughput
- Declining California transportation fuel demand requires increase in product export volumes to maintain refinery throughput
- No constraints on marine movements (crude or product) imposed
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand

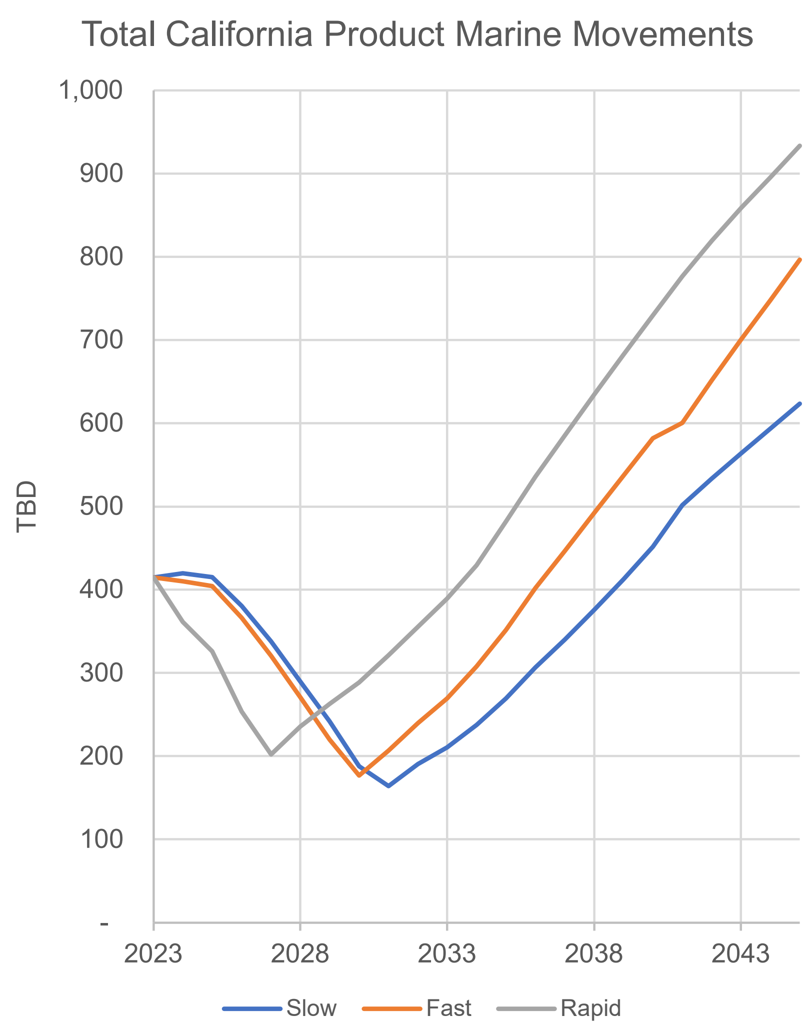


A. Open Constraints (cont.)

- Current system remains operating in nearly identical state as today (P66 Rodeo refinery fully converted to renewable diesel in 2024)
- Shows impact of declining California crude production and necessary increase in import crude volumes to maintain refinery throughput
- Shows impact of declining California transportation fuel demand, and necessary increase in product export volumes to maintain refinery throughput
- No constraints on marine movements (crude or product) imposed
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand

A. Open Constraints Results (cont.)

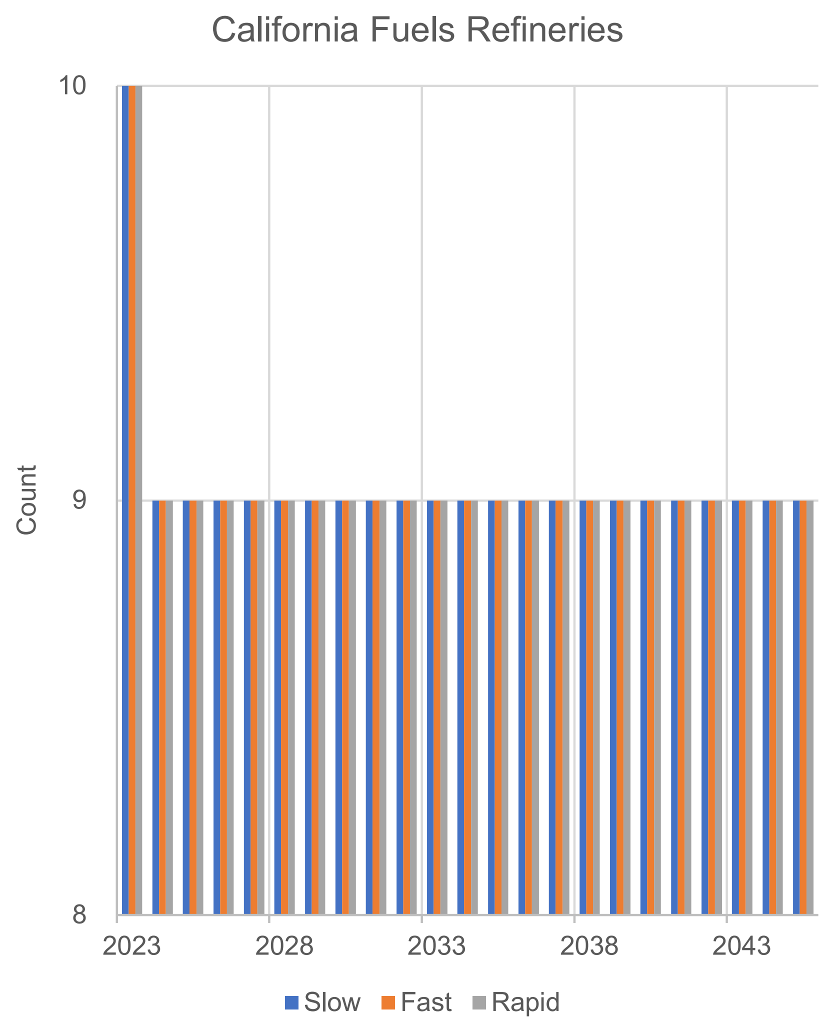
- Total product marine movements (gasoline, jet, diesel).
- Changes due to changes in California CARB gasoline demand curves (Slow, Fast, Rapid).
- No constraints imposed on total product marine movements.
- Switch from importing gasoline and jet in early years to eventual exporting both products
- Total product marine movements would continue to grow due to decline in California demand for transportation products.



Source: TM&C Modeling

A. Open Constraints Results (cont.)

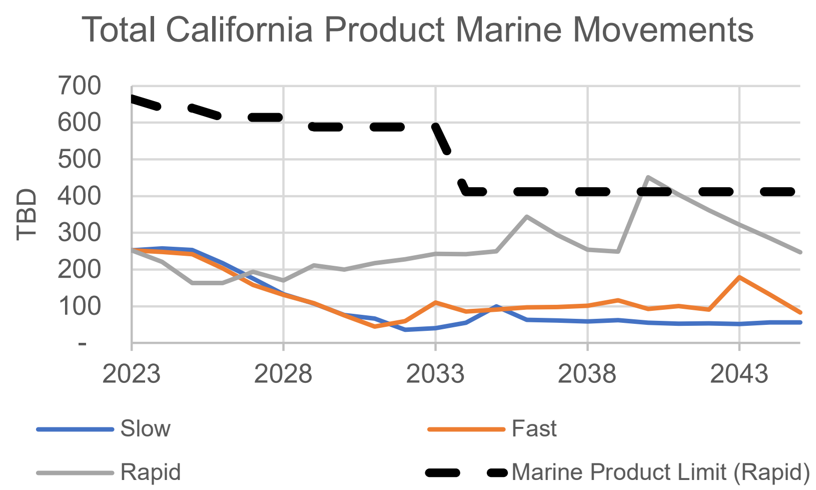
- Total number of fuels refineries remains unchanged since there are no constraints on system, particularly exporting of product.
- P66 Rodeo refinery converted to renewable fuels production in 2024.
- Number of fuels refineries the same regardless of California CARB demand forecast (Slow, Fast, Rapid) because the system is unconstrained.

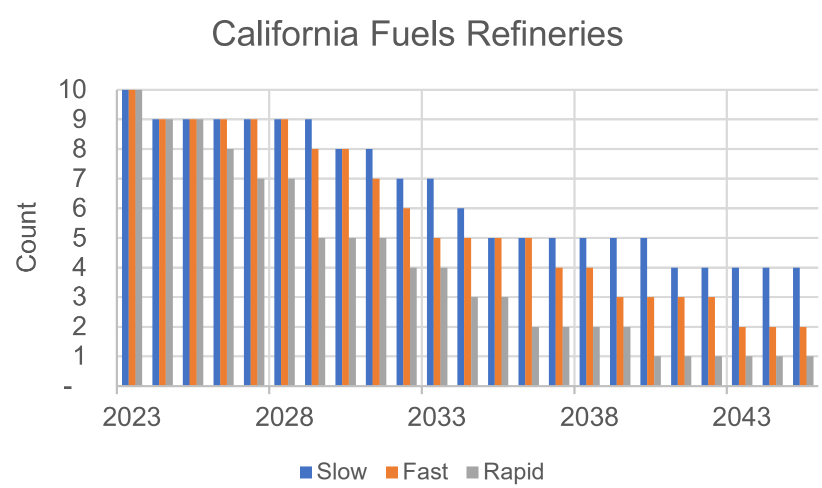


Source: TM&C Modeling

B. Satisfy California Gasoline Demand only

- Imposing CEC product demand curves on system, while not allowing export of gasoline (pipeline or marine)
- Under more aggressive declining California product demand curves, significant refinery closures are needed to maintain minimum refinery utilization
- Crude imports decline rapidly due to refinery closures
- Refinery closures under more restrictive demand scenarios can require significant jet and diesel exports
- Potential for infeasibility in Rapid scenario due to hitting marine product export limit





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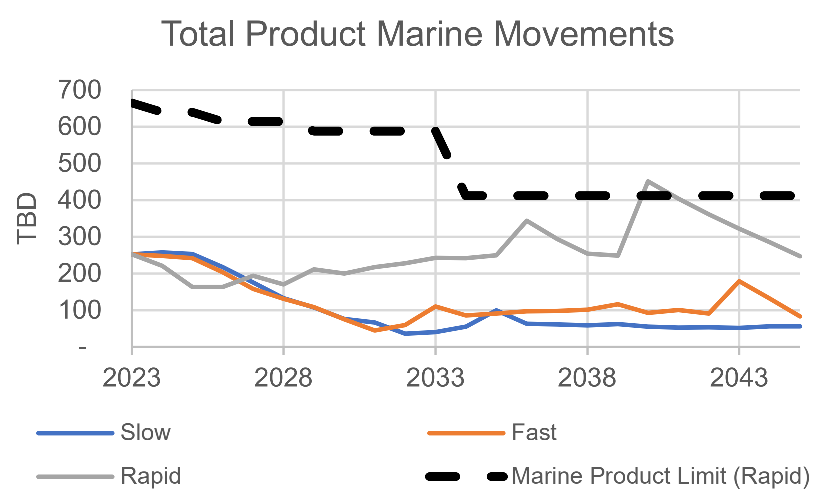
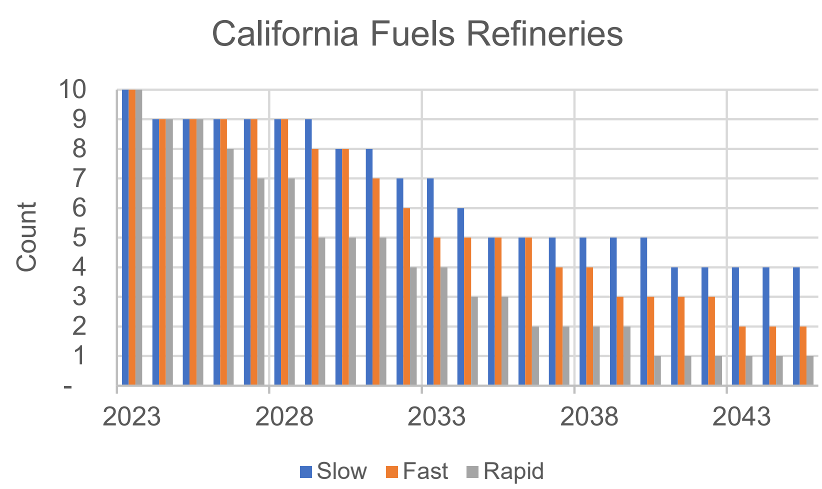
- Imposing CEC product demand curves on system, while not allowing export of gasoline (pipeline or marine)
- Under more aggressive declining California product demand curves, significant refinery closures are needed to maintain minimum refinery utilization
- Crude imports decline rapidly due to refinery closures
- Refinery closures under more restrictive demand scenarios can require significant Jet and Diesel exports
- Slight potential for infeasibility in Rapid scenario due to hitting marine product limit





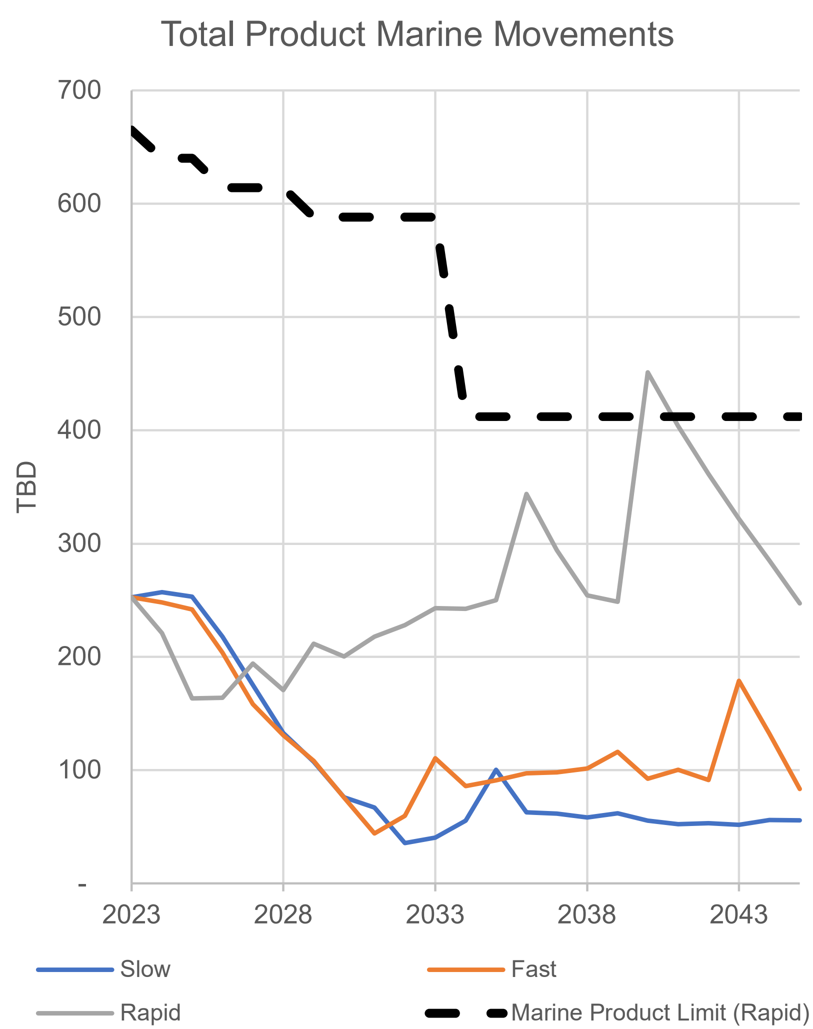
Source: TM&C Modeling

B. SATISFY CALIFORNIA GASOLINE DEMAND ONLY

- Imposing CEC product demand curves on system, while not allowing export of gasoline (pipeline or marine)
- Imports of gasoline allowed to meet California demand only
- No pipeline exports of gasoline to AZ / NV allowed
- Allow import / export of diesel and jet fuel as necessary
- Represents bookend case of California system under most stress
- Under more aggressive California product demand curves, refinery closures are significant to maintain minimum refinery utilization

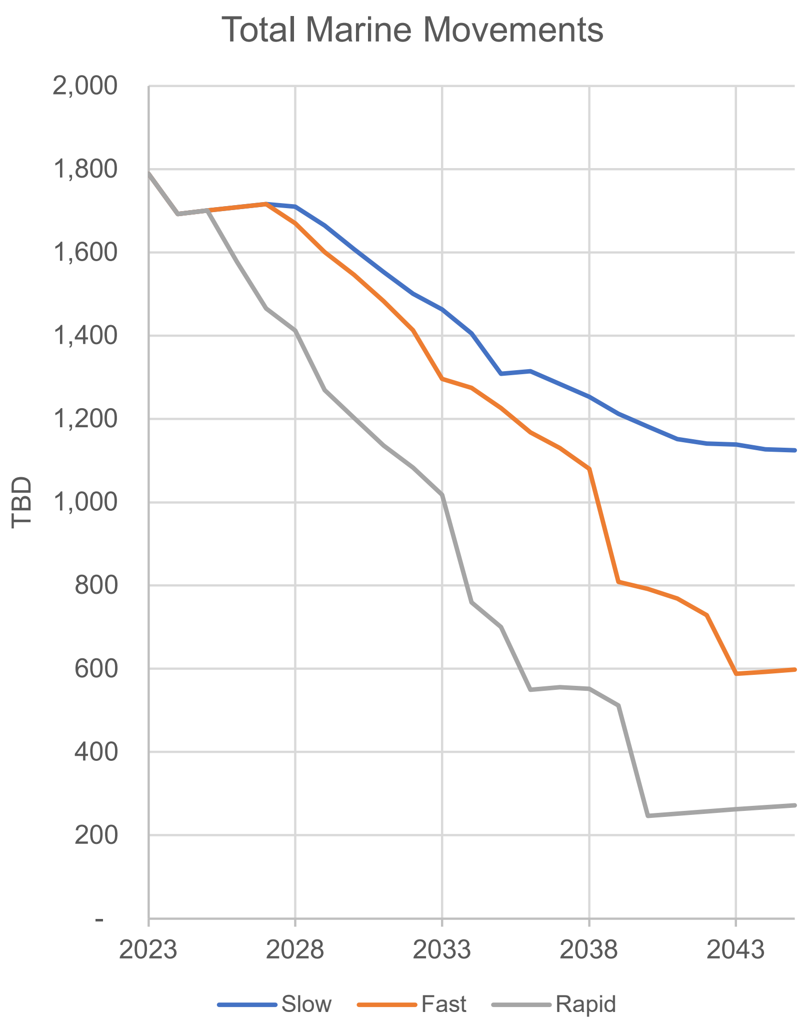
B. Satisfy California Gasoline Demand Only(cont.)

- Total product marine movements (gasoline, jet, diesel).
- Changes in California CEC gasoline demand curves (Slow, Fast, Rapid).
- Under Slow scenario, jet goes from import to export, while diesel remains steady export.
- Under Fast scenario, jet goes from import to steady export, while diesel exports steadily decline and become imports due to refinery closures.
- Under Rapid scenario, refinery closures cause diesel to go from export to large import.
- Slight potential for infeasibility in Rapid scenario due to hitting marine product movements limits



B. Satisfy California Gasoline Demand Only(cont.)

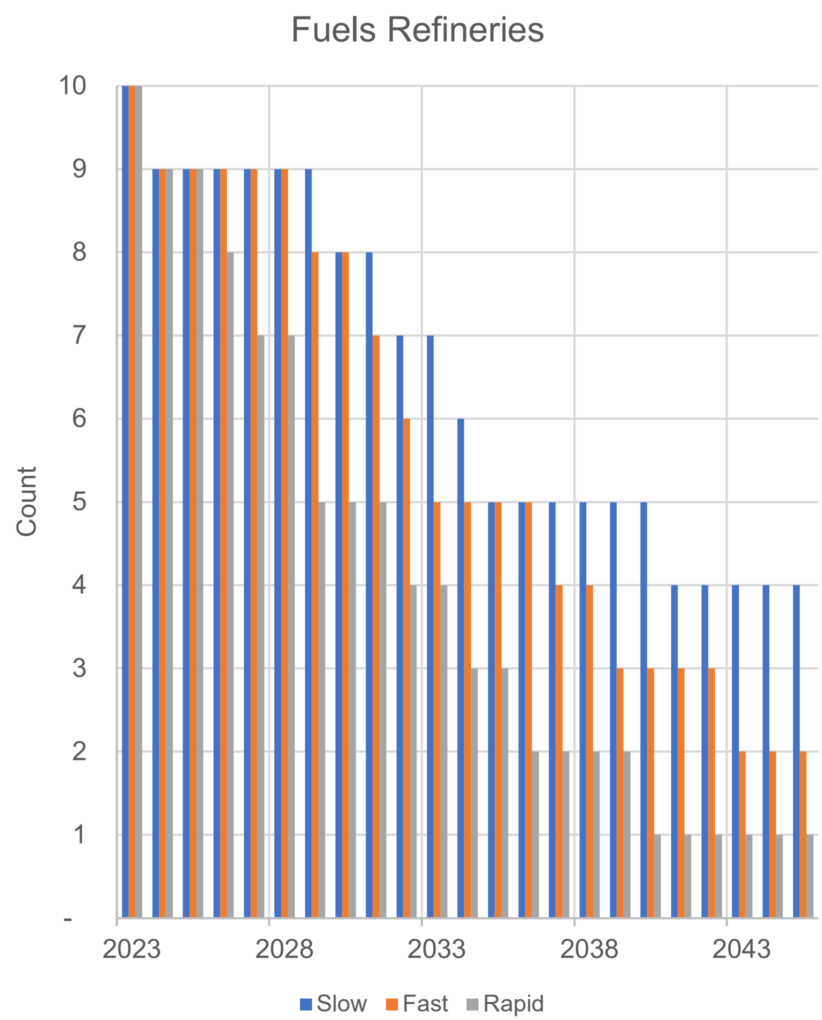
- Total marine movements (crude, gasoline, jet, diesel).
- Changes in California CEC gasoline demand curves (Slow, Fast, Rapid).
- Crude imports constrained in Slow scenario, while crude imports rapidly decline due to refinery closures in Fast and Rapid scenarios.



Source: TM&C Modeling

B. Satisfy California Gasoline Demand Only (cont.)

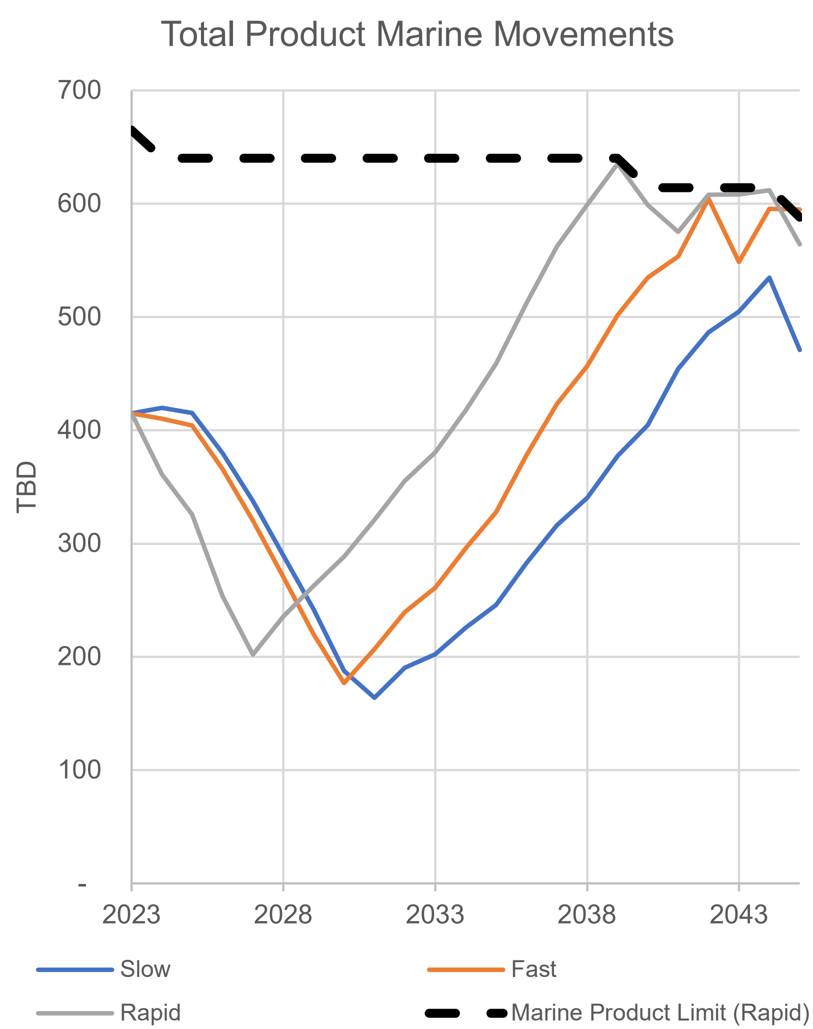
- P66 Rodeo refinery fully converted to renewable fuels production in 2024.
- Slow scenario sees refinery closures begin in 2030.
- Fast scenario sees one large fuels refinery operating by 2045, and one structurally advantaged small fuels refinery.
- Rapid scenario sees one fuels refinery operating by 2045.



Source: TM&C Modeling

C. Crude and Product Marine Limited

- Imposing crude marine import limits and product marine movement limits on system, in additional to the minimum refinery utilization limits.
- Marine Logistics
  - Marine import capacity dedicated to a refinery shuts with refinery closure
  - Marine import capacity separate from refinery still available to the industry as refineries close
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand
- Enough room in system, via California product demand and AZ/NV pipeline to keep system running through 2040 in all California gasoline demand scenarios, but one refinery closure could be required in 2045 under the Rapid demand decline scenario
- Under all scenarios, jet goes from import to export, while diesel remains steady export
- Gasoline goes from import to export in more aggressive California CARB gasoline demand scenarios but remains an import in the Slow scenario
- Crude oil imports constrained in all scenarios, except in later years for the Fast and Rapid scenarios where the product marine export limit dominates.



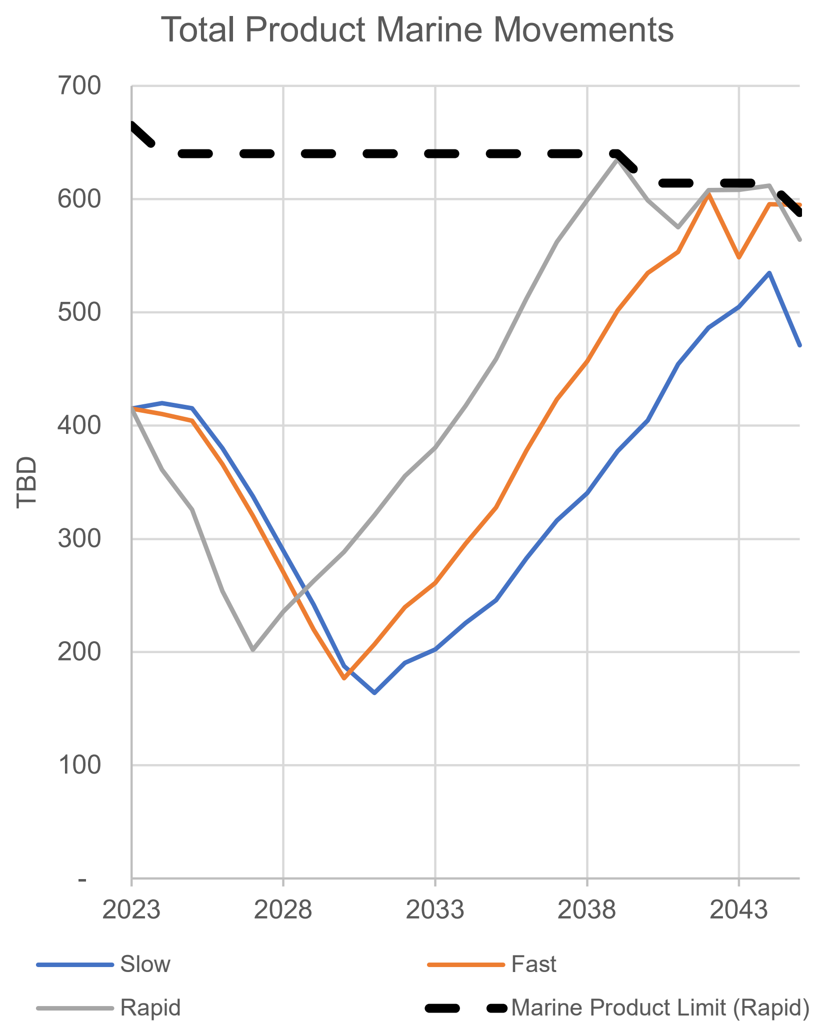
Source: TM&C Modeling

C. Crude and Product Marine Limited (cont.)

- Imposing crude marine import limit (1,150 TBD) and product marine movement limit (670 TBD) on system, in additional to the normal minimum refinery utilization limit
- Marine Logistics
  - Marine import capacity dedicated to a refinery shuts with refinery closure
  - Marine import capacity separate from refinery still available to the industry as refineries close
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand
- Enough room in system, via California product demand and AZ/NV pipeline to keep system running through 2040 in all California gasoline demand scenarios, but one refinery closure could be required in 2045 under the Rapid demand decline scenario

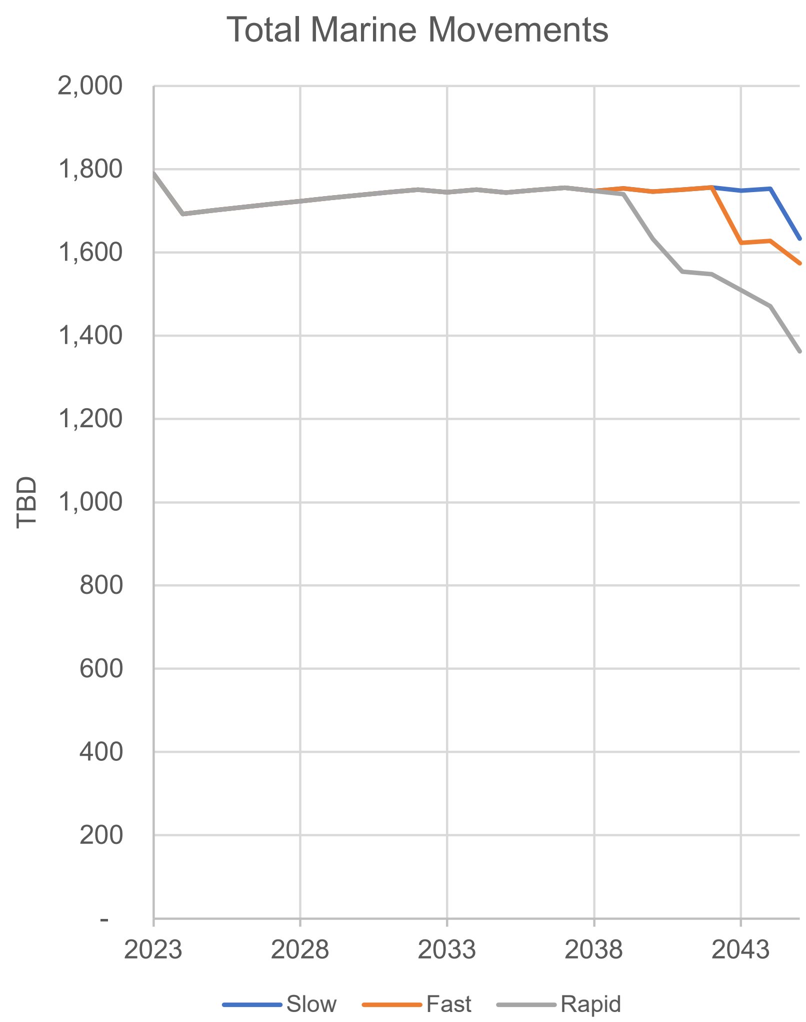
C. Marine Limited (cont.)

- Total product marine movements (gasoline, jet, diesel).
- Changes in California CCEC gasoline demand curves (Slow, Fast, Rapid).
- 670 TBD limit on total product marine movements imposed and reduced as refineries shutdown.
- Under all scenarios, jet goes from import to export, while diesel remains steady export.
- Gasoline goes from import to export in more aggressive California CARB gasoline demand scenarios but remains an import in the Slow scenario.



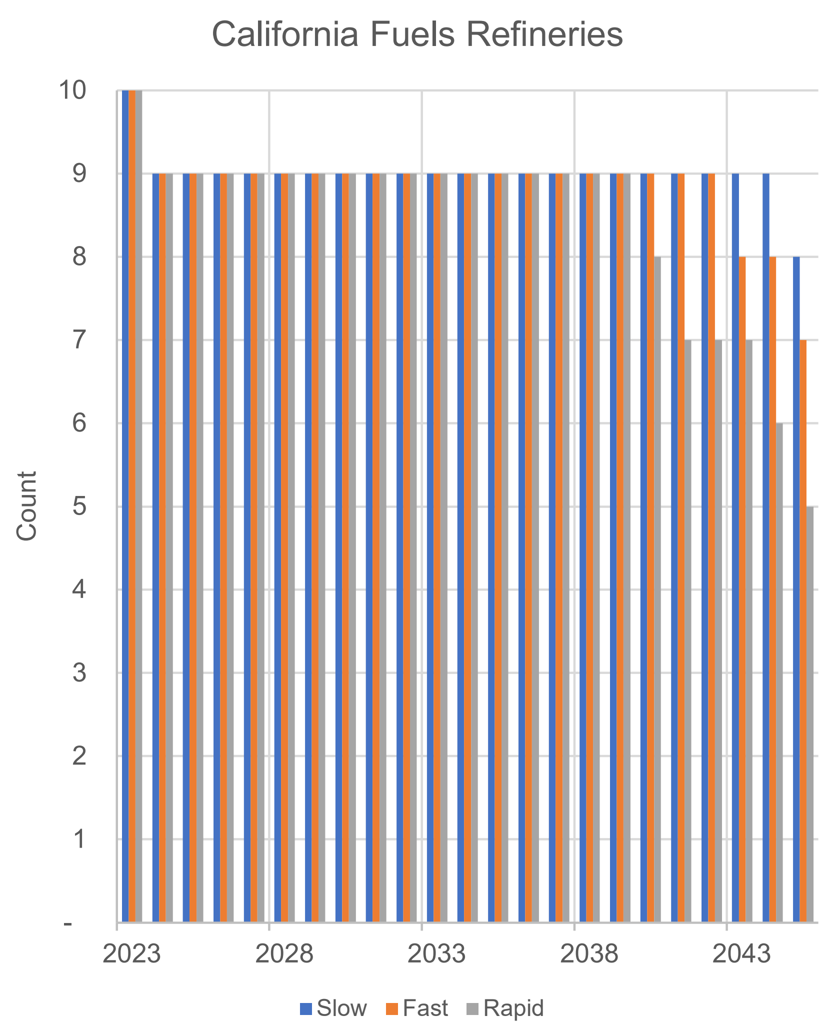
C. Marine Limited (cont.)

- Total marine movements (crude, gasoline, jet, diesel).
- Changes in California CEC gasoline demand curves (Slow, Fast, Rapid).
- Crude imports constrained in all scenarios, except in later years for the Fast and Rapid scenarios where the Product Marine Export Limit dominates.
- One refinery could close in 2045 under Rapid scenario causing total marine movements to decline.



C. Marine Limited (cont.)

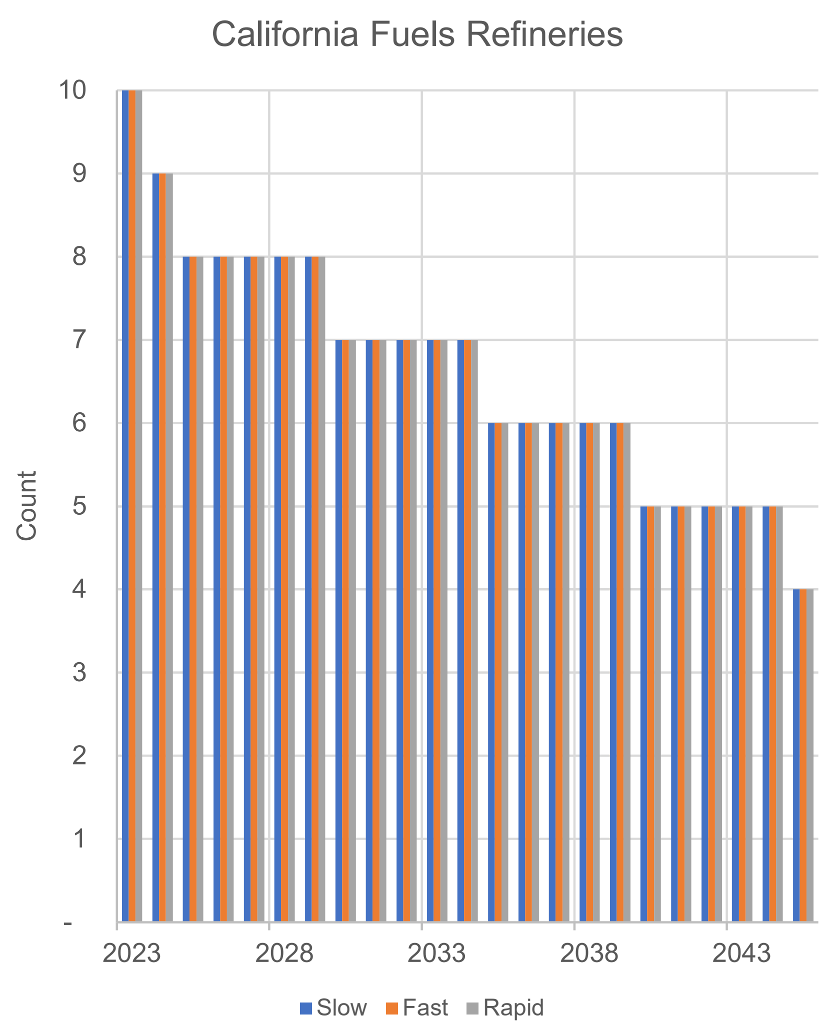
- P66 Rodeo refinery fully converted to renewable fuels production in 2024.
- Slow scenario could see first refinery closure after 2040, while Fast scenario could see first refinery closure before 2040.
- Rapid scenario could see five refinery closures by 2045.



Source: TM&C Modeling

D. Refinery turnarounds become shutdowns

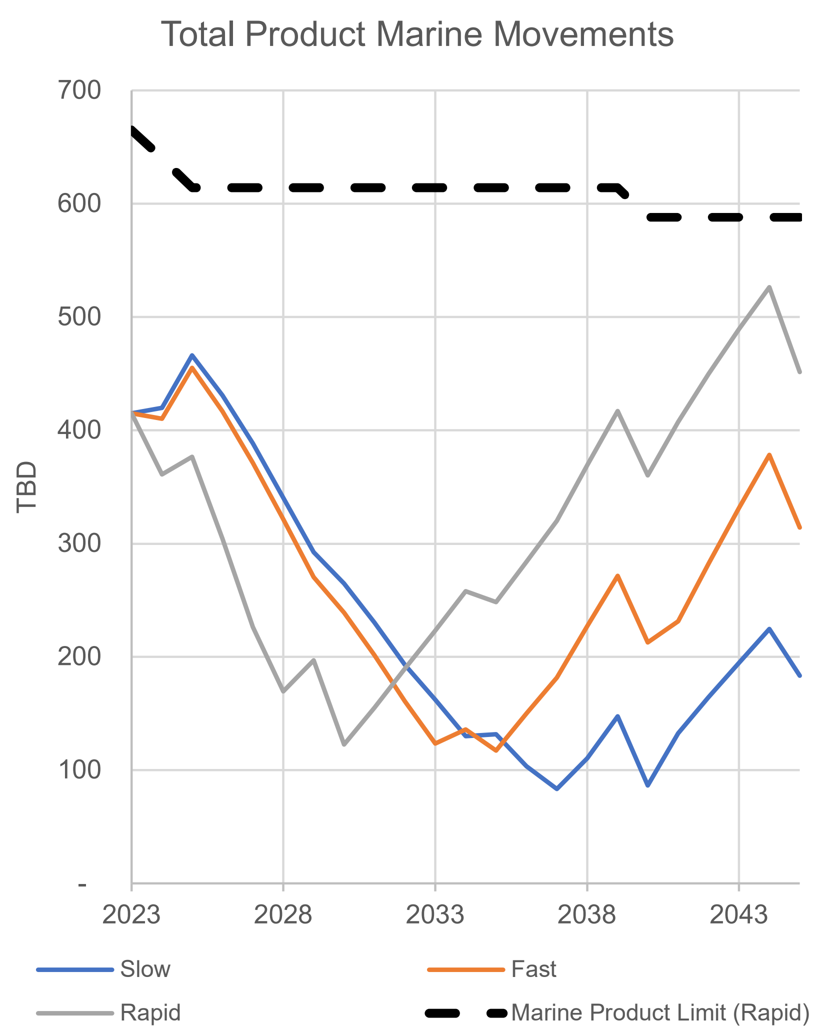
- Imposing crude marine import limit (1,150 TBD) and product marine movement limit (670 TBD) on system, in addition to the minimum refinery utilization limit
- At each turnaround (2025, 2030, 2035, 2040, 2045) one refinery is modeled to shutdown rather than incur large turnaround costs. Refinery shutdown according to seriatim
- Due to one refinery shutdown every five years, system is not constrained by crude or product marine export limits
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand
- Under all scenarios, jet goes from import to export, while diesel remains steady export
- Gasoline goes from import to export in more aggressive declining California CARB gasoline demand scenarios, but still requires imports in the Slow scenario



Source: TM&C Modeling

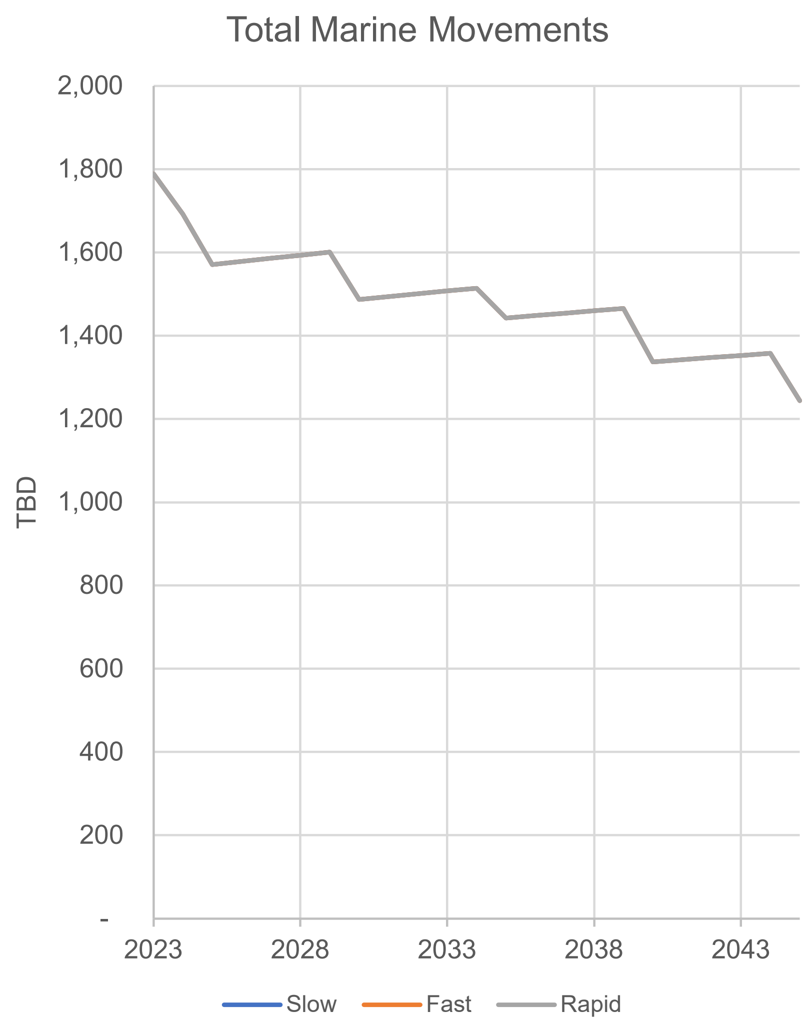
D. Refinery Turnaround becomes a Shutdown (cont.)

- Total product marine movements (gasoline, jet, diesel).
- Changes in California CEC gasoline demand curves (Slow, Fast, Rapid).
- 670 TBD limit on total product marine movements imposed and reduced as refineries close.
- Under all scenarios, Jet goes from import to export, while diesel remains steady export.
- Gasoline goes from import to export in more aggressive California CARB gasoline demand scenarios, but remains an import in the Slow scenario.



D. Refinery Turnaround becomes a Shutdown (cont.)

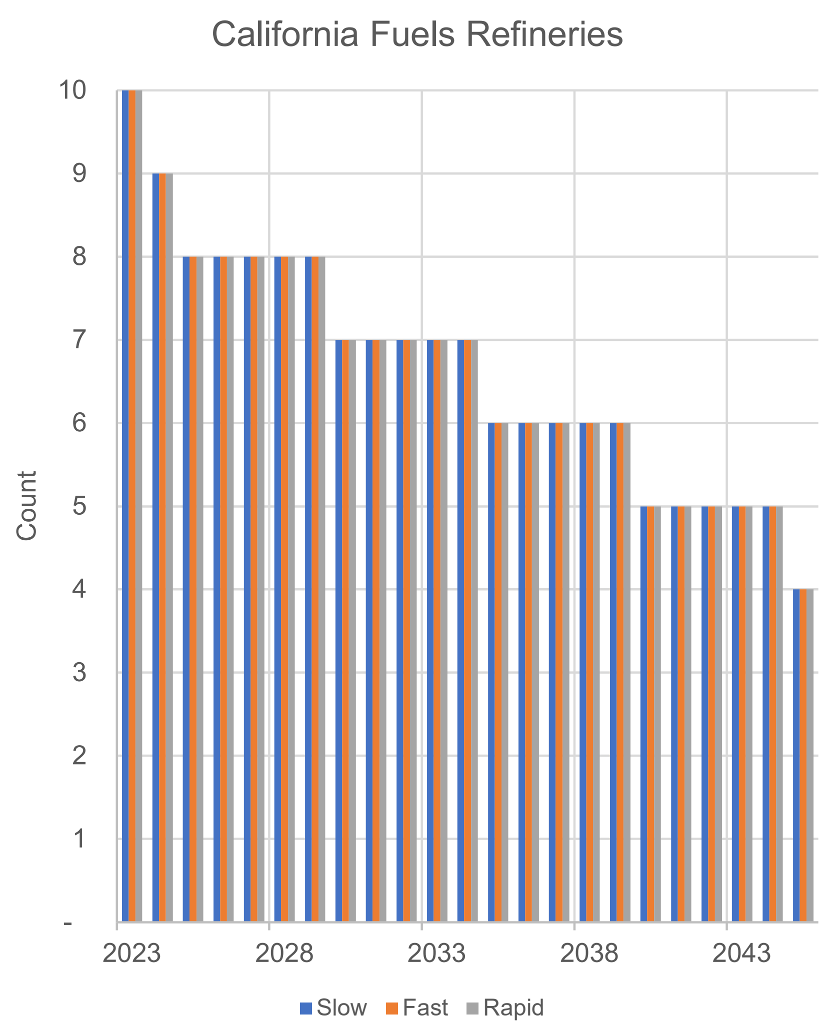
- Total marine movements (crude, gasoline, jet, diesel).
- Changes in California CEC gasoline demand curves (Slow, Fast, Rapid).
- Crude unconstrained in all scenarios due to refinery shutdowns.
- Product marine export limit also not a factor.
- Follow same curve due to same operations in all demand curves



Source: TM&C Modeling

D. Refinery Turnaround becomes a Shutdown (cont.)

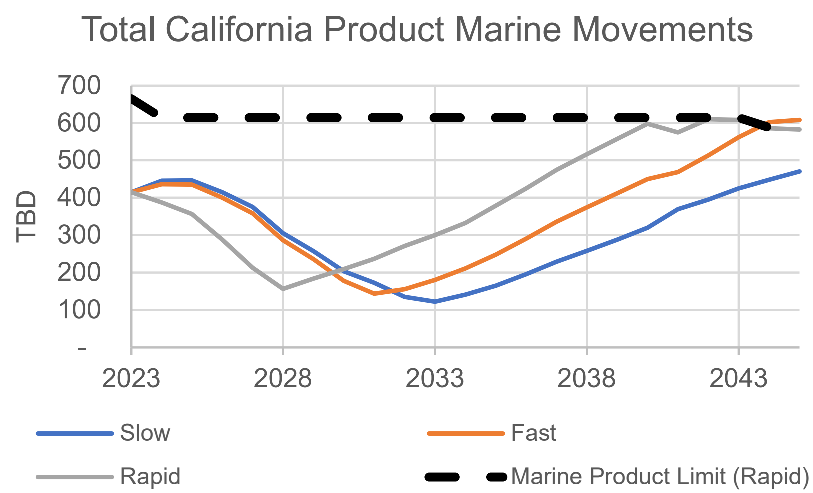
- P66 Rodeo refinery fully converted to renewable fuels production in 2024.
- One refinery shutdown every five years. No other refinery shutdowns look to be required to keep system in balance.

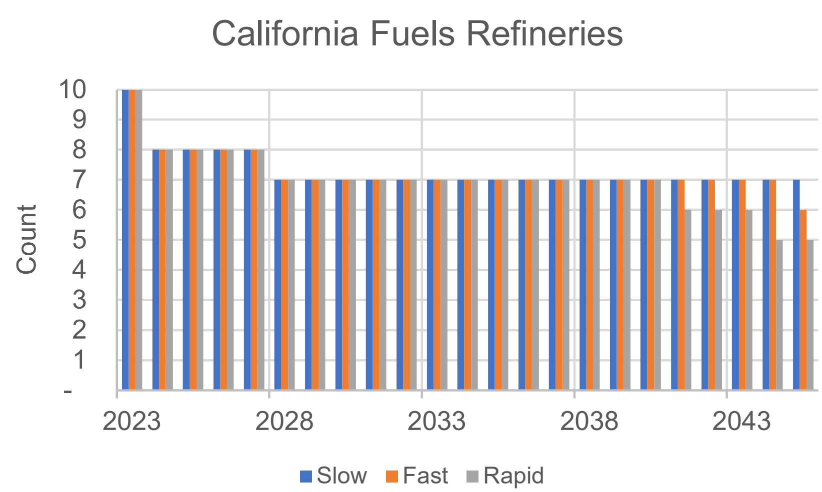


Source: TM&C Modeling

E. Crude and Product Marine Limited (Economic Utilization)

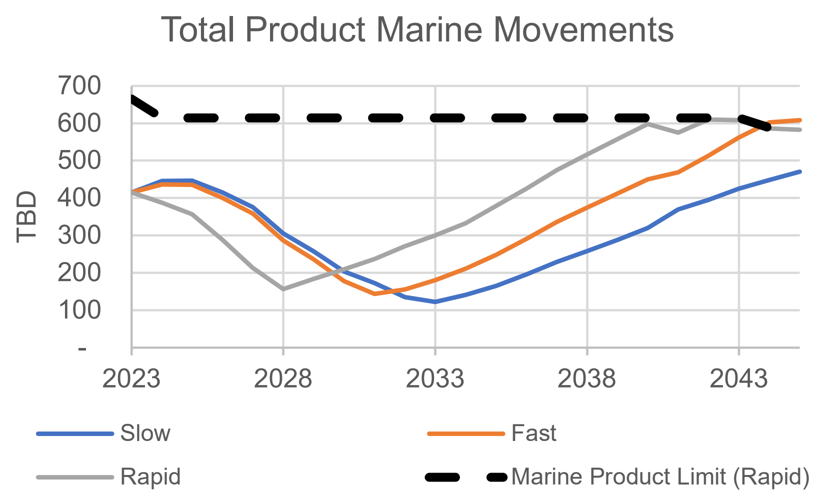
- Imposing crude marine import limit and product marine movement limit on system, but with an economic utilization (80%) instead of the physical refinery utilization limit
- Economic utilization limit increases the number of refinery closures to two under all gasoline demand scenarios. One by 2035, another by 2040. In the prior physical utilization limit (65%) scenario, only one refinery closes by 2045, and only under the rapid gasoline demand scenario
- Early refinery closures (before 2030) due to low utilization in base operations
- Under all scenarios, Jet goes from import to export, while diesel remains steady export
- Gasoline goes from import to export in more aggressive California CARB gasoline demand scenarios but remains an import in the Slow scenario
- Crude imports constrained in all scenarios, except in later years for the Fast and Rapid scenarios where the product marine export limit dominates
- Total marine movements expected to remain steady under California demand destruction until 2040 when refinery closures begin to limit total crude runs

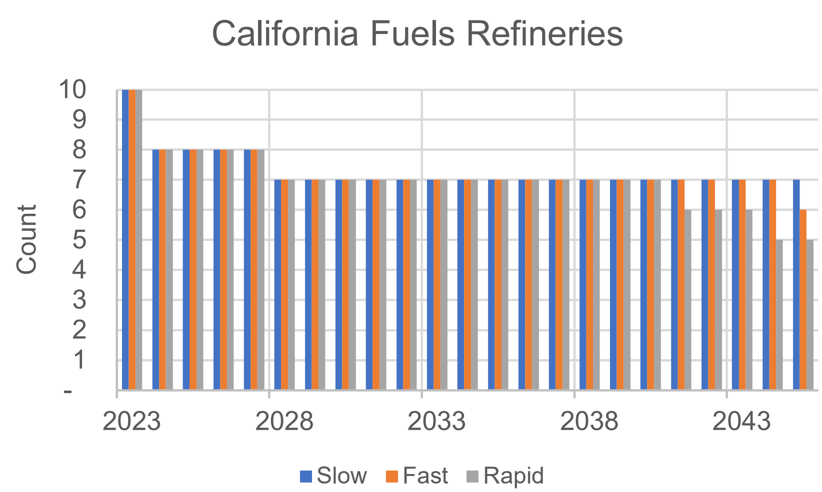




E. Crude and Product Marine Limited (Economic Utilization)

- Imposing crude marine import limit and product marine movement limit on system, but with an economic utilization (80%) instead of the physical refinery utilization limit
- Economic utilization limit increases the number of refinery closures to two under all gasoline demand scenarios. One by 2035, another by 2040. In the prior physical utilization limit (65%) scenario, only one refinery closes by 2045, and only under the rapid gasoline demand scenario
- Early refinery closures (before 2030) due to low utilization in base operations
- Under all scenarios, Jet goes from import to export, while diesel remains steady export
- Gasoline goes from import to export in more aggressive California CARB gasoline demand scenarios but remains an import in the Slow scenario
- Crude imports constrained in all scenarios, except in later years for the Fast and Rapid scenarios where the product marine export limit dominates
- Total marine movements expected to remain steady under California demand declines until 2040 when refinery closures begin to limit total crude runs



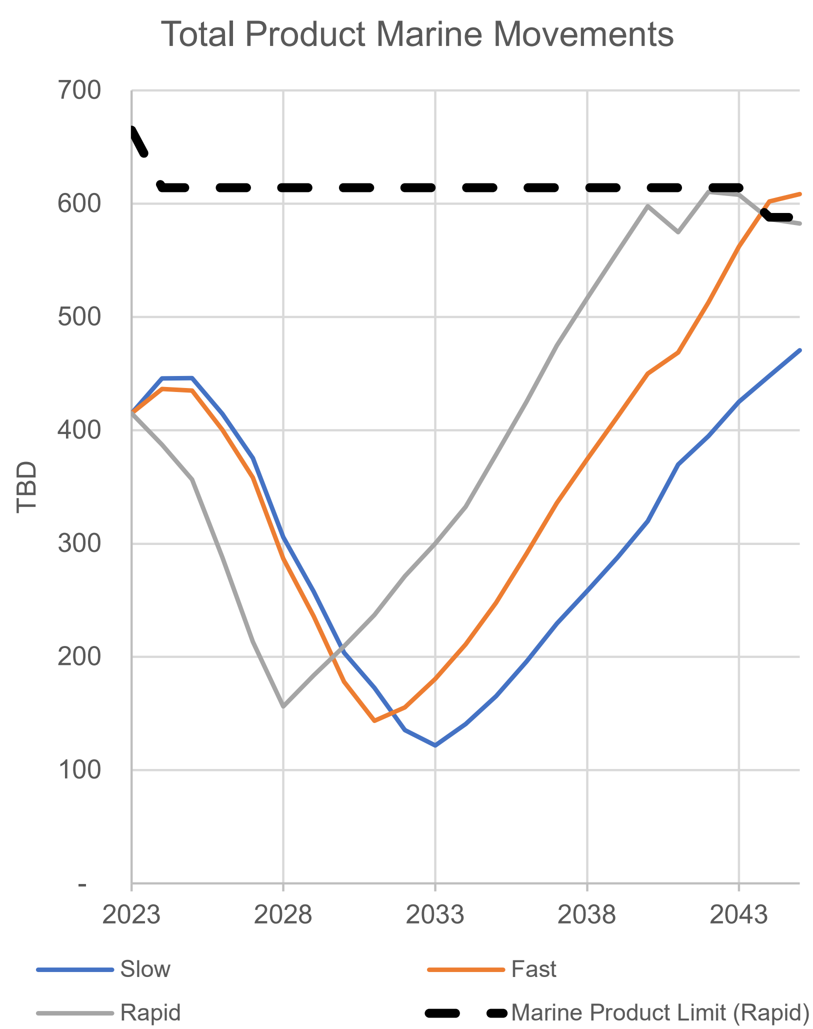


E. Crude and Product Marine Limited (Economic Utilization)

- Similar to early utilization limiting scenario, we impose a crude marine import limit (1,150 TBD) and product marine movement limit (670 TBD) on system. However, in this scenario, the crude distillation unit utilization is assumed to have a minimum economic utilization of 80% instead of the previous technical minimum refinery utilization limit of 65%.
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand
- Economic utilization limit increases to the number of refinery closures under all gasoline demand scenarios to two: one by 2035 and another by 2040. In the prior physical utilization limit (65%) scenario, only one refinery closes by 2045, and only under the rapid gasoline demand scenario.

E. ECONOMIC UTILIZATION LIMITED (CONT.)

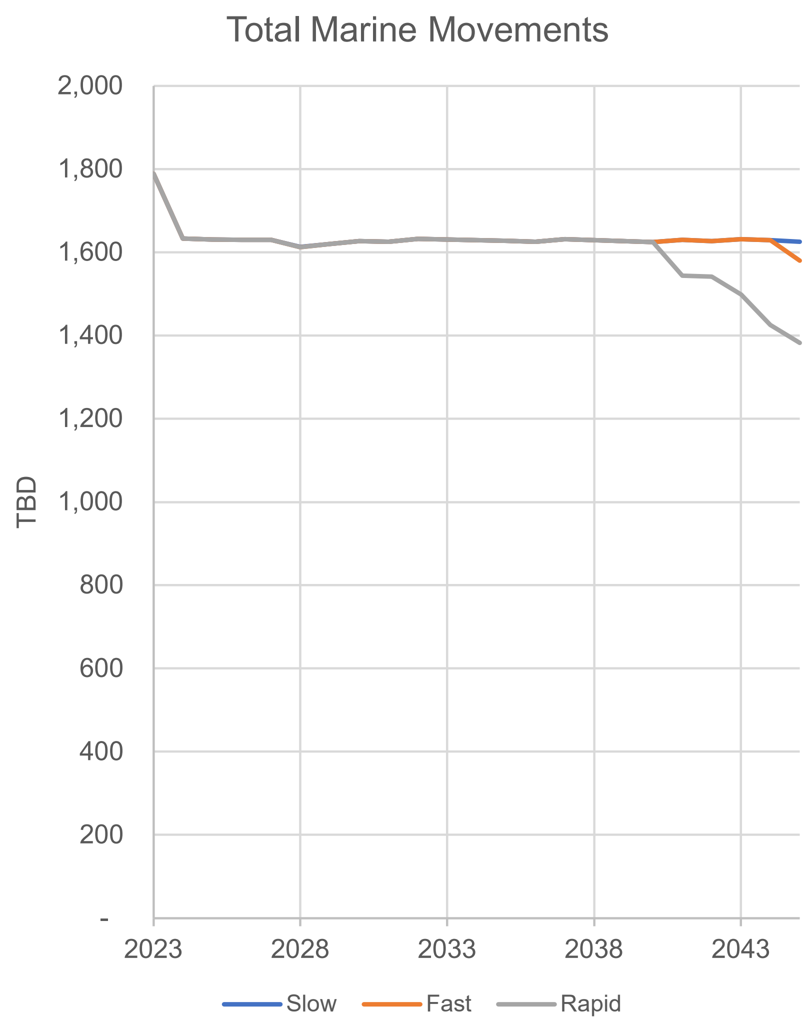
- Total product marine movements (gasoline, jet, diesel).
- Changes in California CEC gasoline demand curves (Slow, Fast, Rapid).
- 670 TBD limit on total product marine movements imposed and reduced as refineries close.
- Under all scenarios, jet goes from import to export, while diesel remains steady export.
- Gasoline goes from import to export in more aggressive California CARB gasoline demand scenarios but remains an import in the Slow scenario.



Source: TM&C Modeling

E. Economic Utilization Limited (cont.)

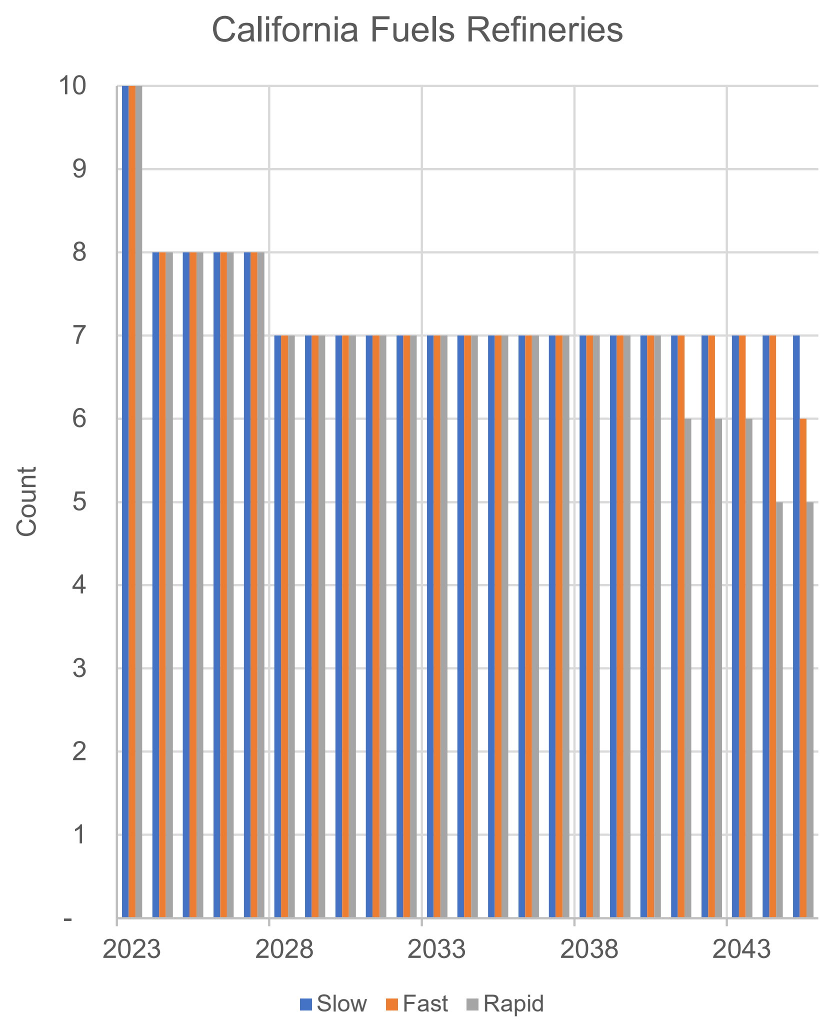
- Total marine movements (crude, gasoline, jet, diesel).
- Changes in California CEC gasoline demand curves (Slow, Fast, Rapid).
- Crude imports constrained in all scenarios, except in later years for the Fast and Rapid scenarios where the product marine export limit dominates.
- Total marine movements expected to remain steady under California demand destruction until 2040 when potential refinery closures could begin to limit total crude runs.



Source: TM&C Modeling

E. Economic Utilization Limited (cont.)

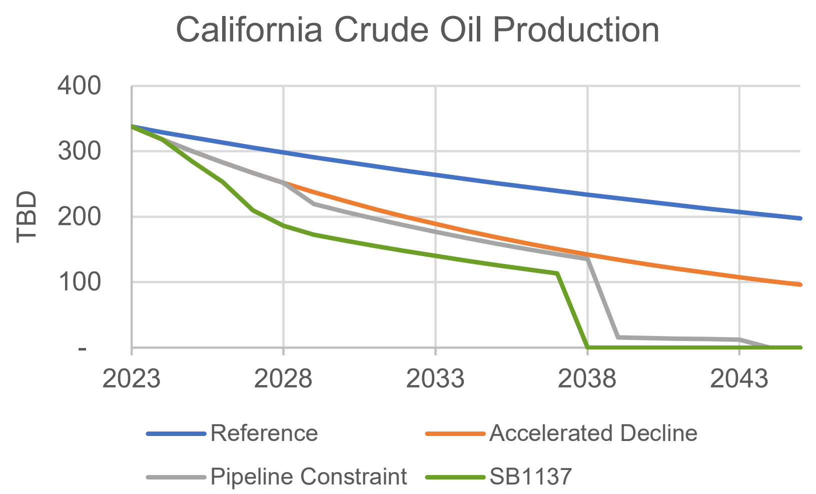
- P66 Rodeo refinery fully converted to renewable fuels production in 2024.
- Early refinery closures (before 2030) due to low utilization in base operations.
- More refineries could close than under the Physical Utilization Limited scenario.

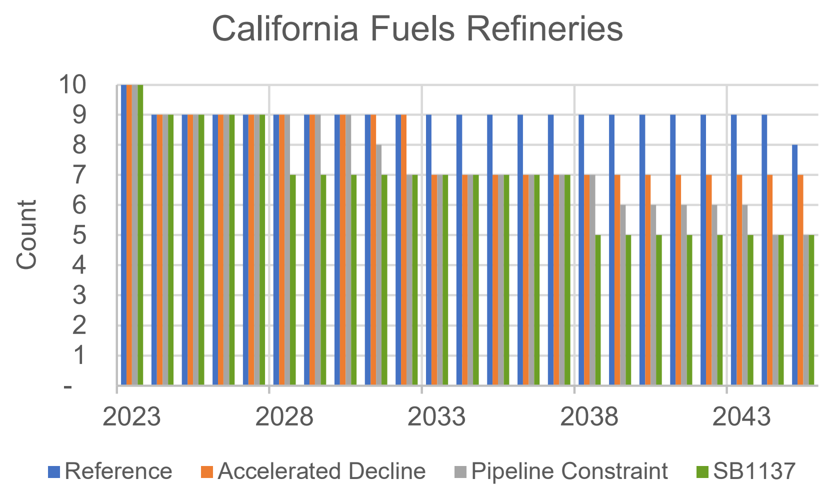


Source: TM&C Modeling

F. Crude Production Alternatives

- Apply different California crude oil production scenarios on system, under the "Slow" product demand scenario. Crude marine import limits become a more prominent driver as California crude oil production declines.
- In all California gasoline demand scenarios (and including AZ/NV pipeline demand), there is enough capacity in system through 2040.
- However, in the "Rapid" scenario demand declines enough to result in the closure of a California refinery by 2045.



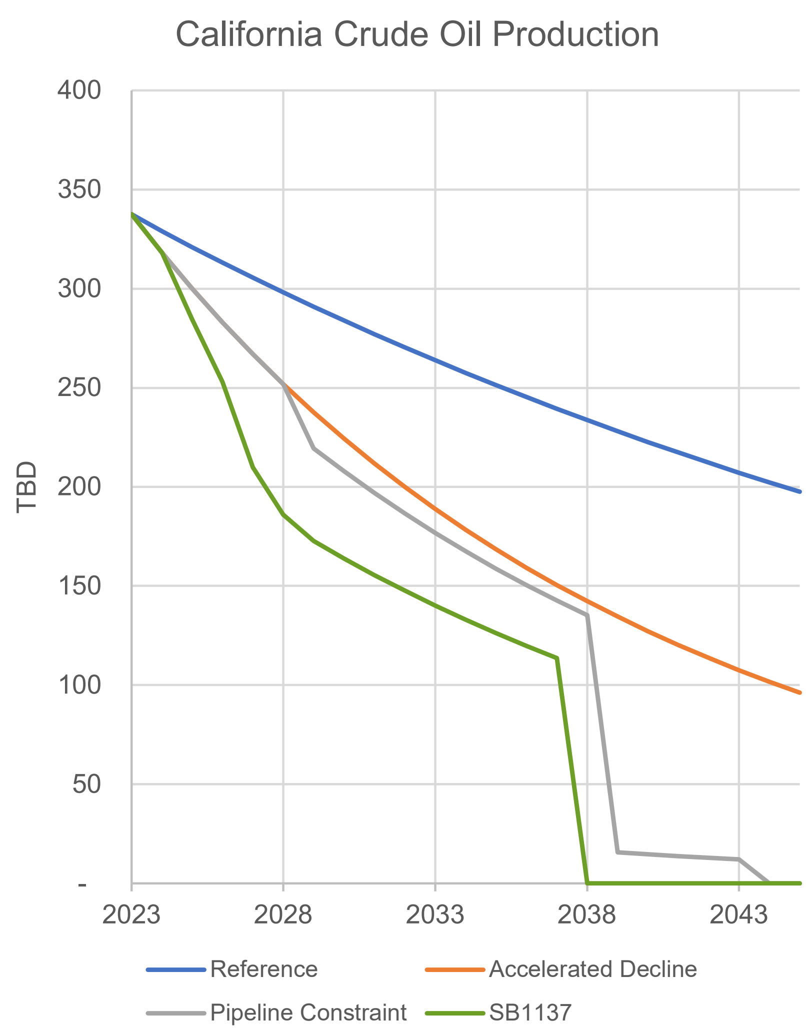


F. Crude Production Alternatives

- Apply different California Crude Production scenarios on system, under Slow Product Demand scenario. Crude marine import limit becomes a more prominent driver as California production declines.
- Imposing crude marine import limit (1,150 TBD) and product marine movement limit (670 TBD) on system, in addition to the normal minimum refinery utilization limit
- Product pipelines supplying AZ and NV are filled, potentially requiring additional imports of products to meet demand
- Enough room in system, via California product demand and AZ/NV pipeline to keep system running through 2040 in all California gasoline demand scenarios, but one refinery could close in 2045 under the Rapid demand decline scenario

F. CRUDE PRODUCTION LIMITED (CONT..)

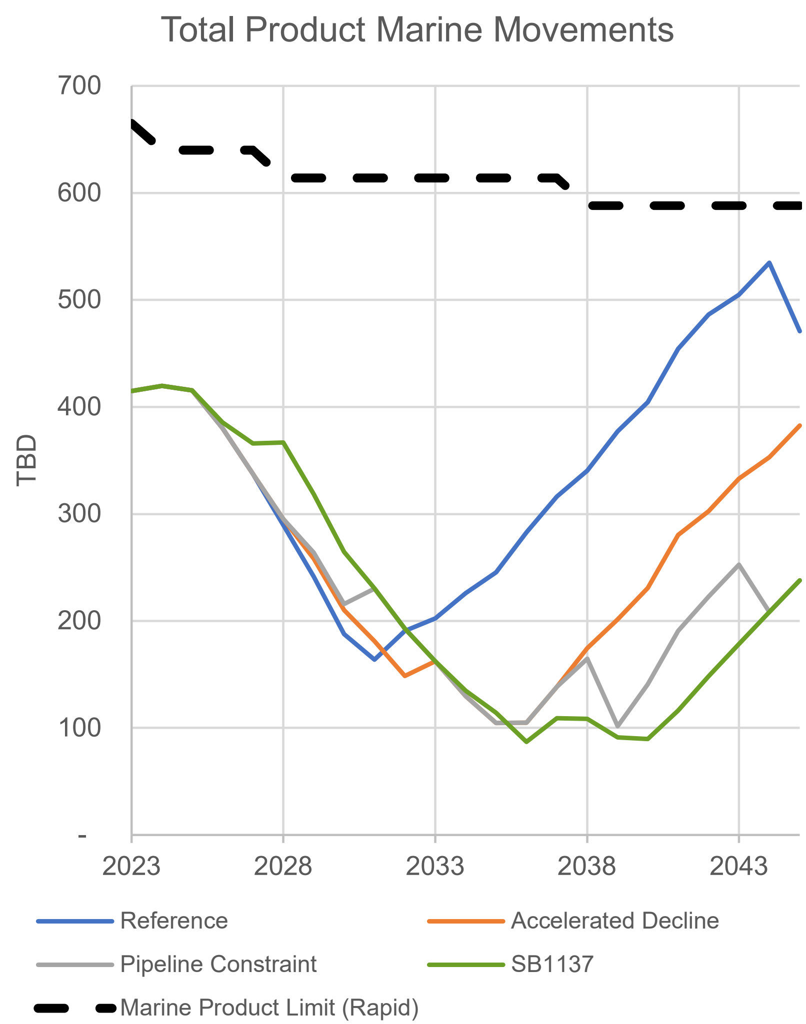
- Reference: Production declines continue based on recent decline rates
- Accelerated Decline: Production declines driven by a slowing pace of drilling permit approvals
- Pipeline Constraint: Once a pipeline reaches minimum throughput, the pipeline and production that filled it are both shutdown; trucking the production out of the field is assumed to not be an option.
- SB1137: Setback limits shut-in production in urban areas first, eventually across state.



Source: CalGEM, Catalyst Environmental, EIA, Turner Mason analysis

F. Crude Production Limited (cont.)

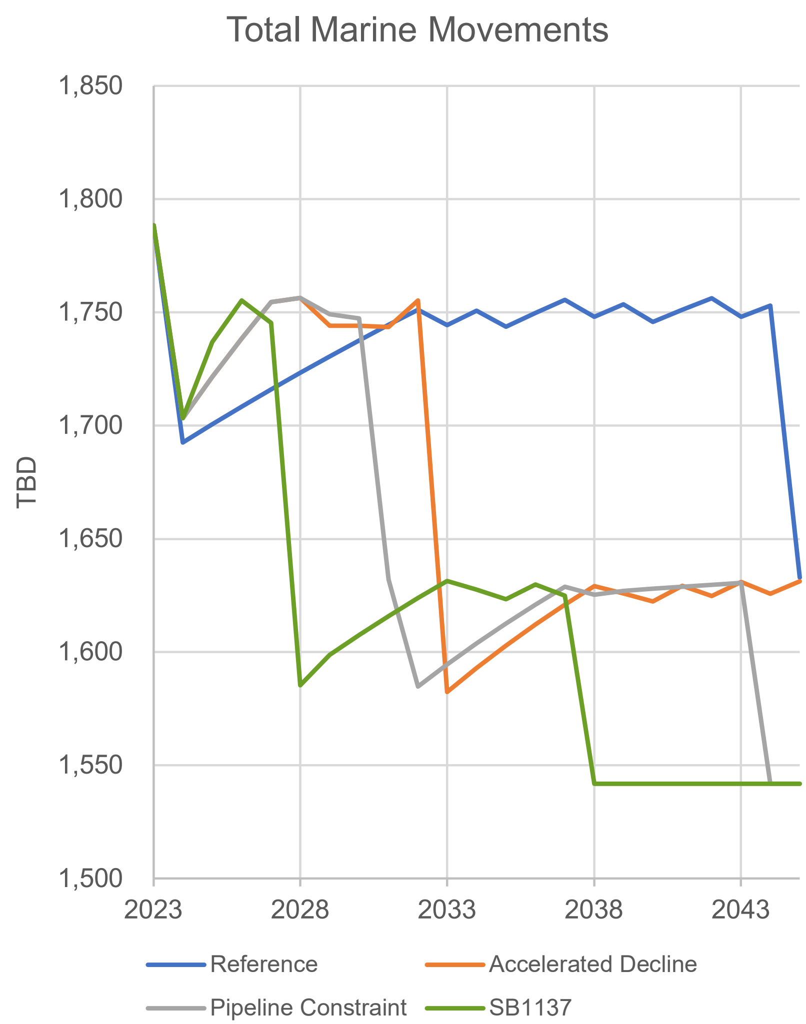
- Total product marine movements (gasoline, jet, diesel).
- Changes in California Crude Production profiles.
- 670 TBD limit on total product marine movements imposed and reduced as refineries shutdown.
- Marine import limit is not constraining.
- Under all scenarios, gasoline and jet goes from import to export, while diesel remains steady export.



Source: TM&C Modeling

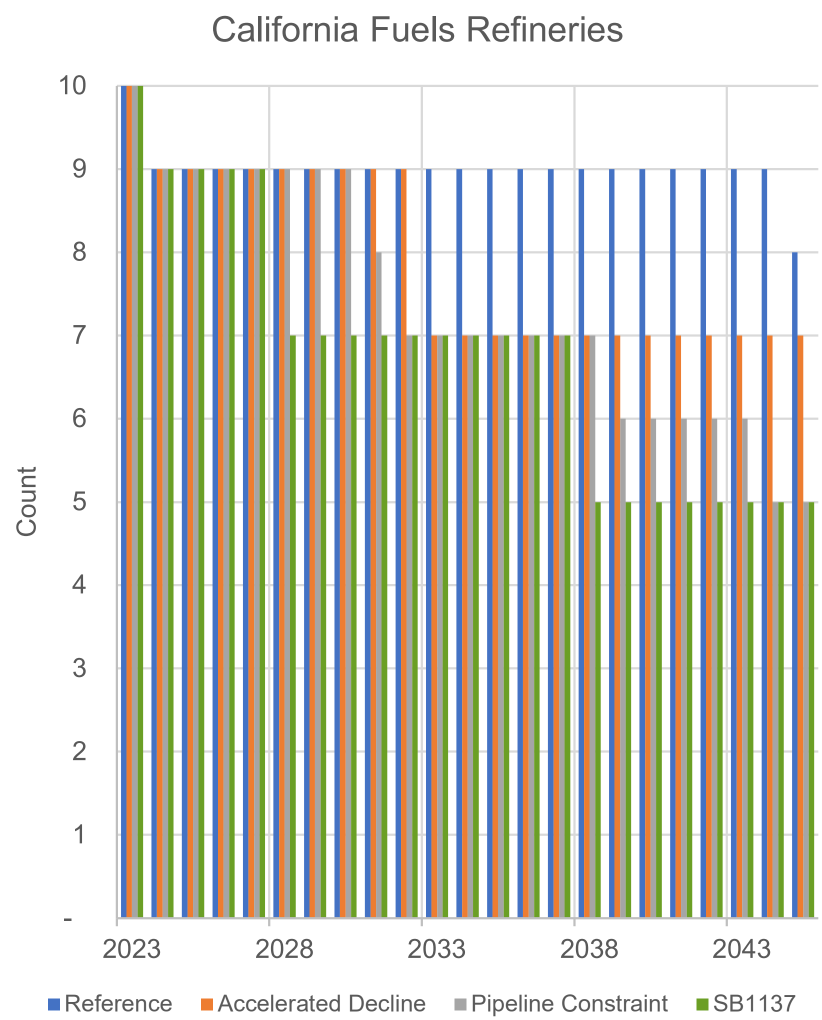
F. Crude Production Limited (cont..)

- Total marine movements (crude, gasoline, jet, diesel).
- Changes in California Crude Production profiles.
- Crude imports constrained in all scenarios due to rapid decline in crude production.



F. Crude Production Limited (cont..)

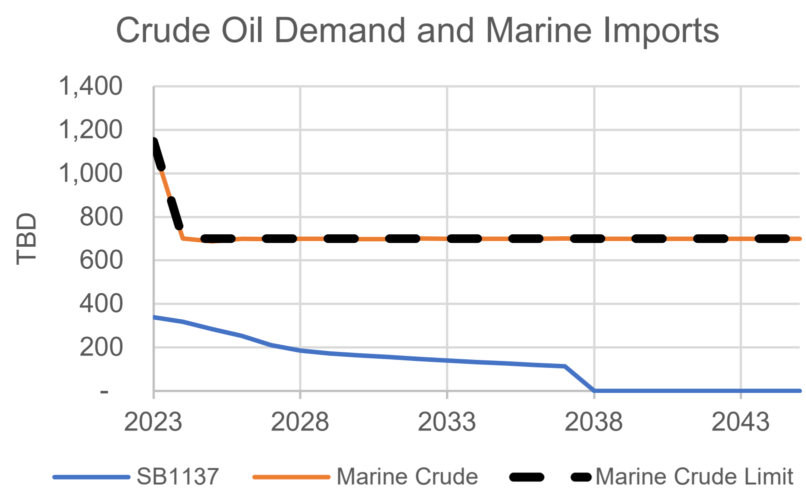
- P66 Rodeo refinery fully converted to renewable fuels production in 2024.
- All crude production scenarios expected to see refinery closures.
- Pipeline Constraint and SB1137 may force half of California refineries to close by 2045.

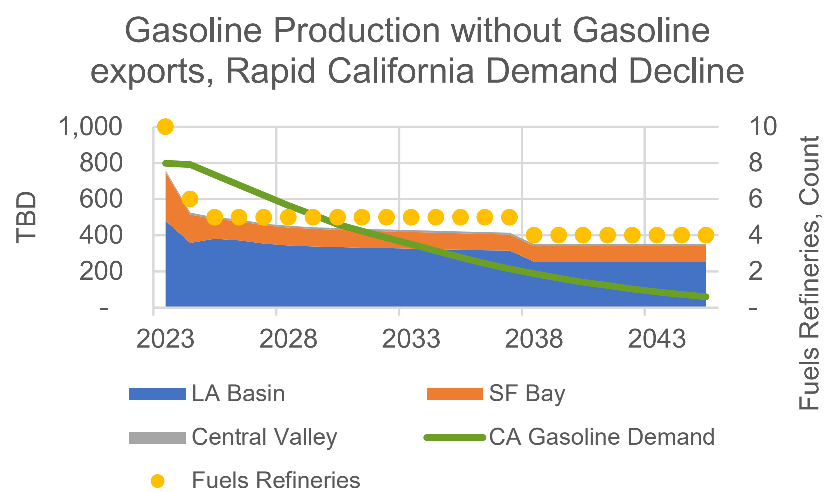


Source: TM&C Modeling

G. Fully Enforced "At-Berth" Emissions Limits

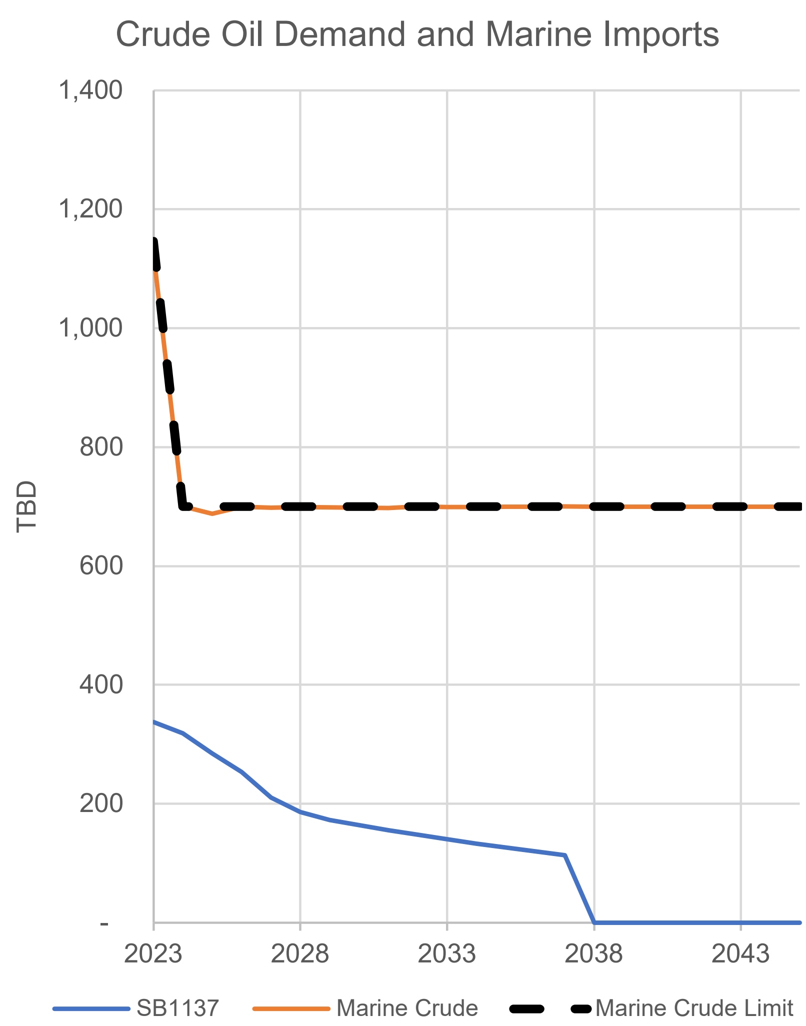
- Marine system is rendered infeasible if 20 vessel/berth per year limit is applied to total ship visits
- To make the system feasible, we assume there is a waiver in some way:
  - If 20 vessel/berth per year limit is applied to crude oil, it creates an effective crude marine import limit of 700 TBD, vs 1,150 TBD in other scenarios
  - Product marine import limit nearly unchanged with 20 vessel/berth per year limit (670 TBD)
- Under SB1137 California crude oil production decline and "At-Berth" constraints, see rapid initial closure of refineries
- Timing of implementation of "At-Berth" constraints uncertain, which would change impacts on system
- Increased marine product imports due to refinery closures
- If importers use largest available product vessels, California **demand must decline rapidly** for marine product berths to not be constrained.
- Imports of gasoline required in early years due to rapid shutdown of refineries that are "At-Berth" constrained on crude oil
- As California demand rapidly declines, eventually move to exports of gasoline required (Rapid demand) but continued imports required (Slow demand)





G. Fully Enforced "At-Berth" Emissions Limits (cont..)

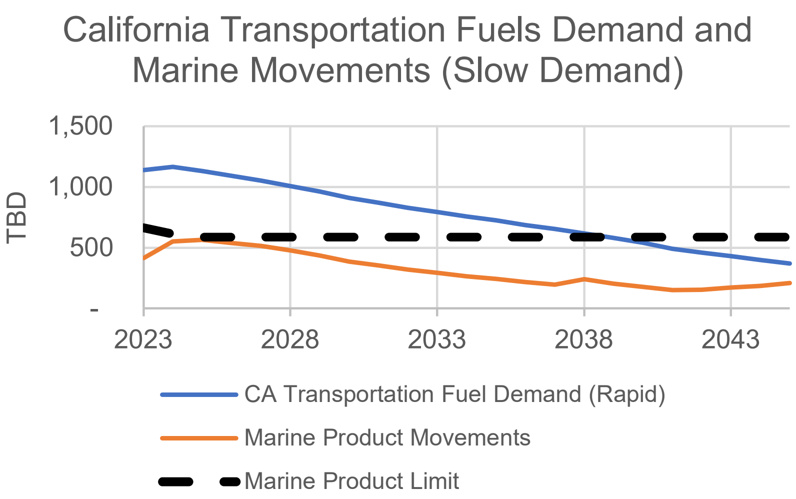
- SB1137 Demand: Setback limits shut-in production in urban areas first, eventually across state.
- 20 vessel/berth per year limit creates effectively 700 TBD crude marine import limit.

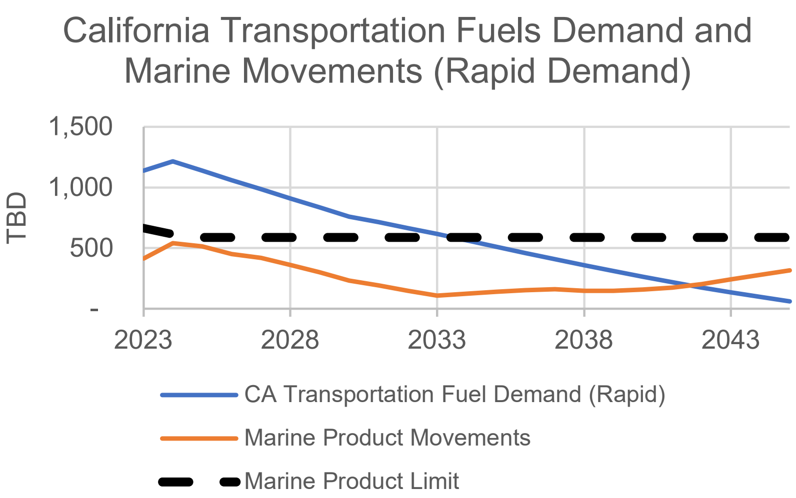


Source: TM&C Modeling

G. Fully Enforced "At-Berth" Emissions Limits (cont)

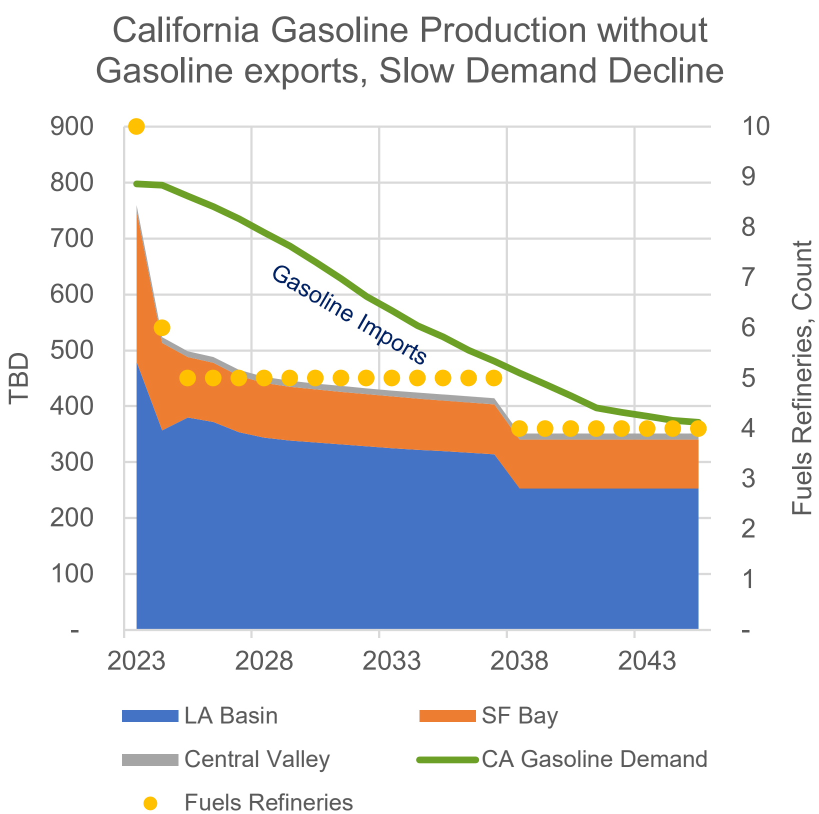
- Total product marine movements (gasoline, jet, diesel).
- Slow and Rapid California Transportation Fuel Demand Scenario
- 670 TBD limit on total product marine movements imposed and reduced as refineries shutdown.
- Total product marine limit is not limiting in either scenario.

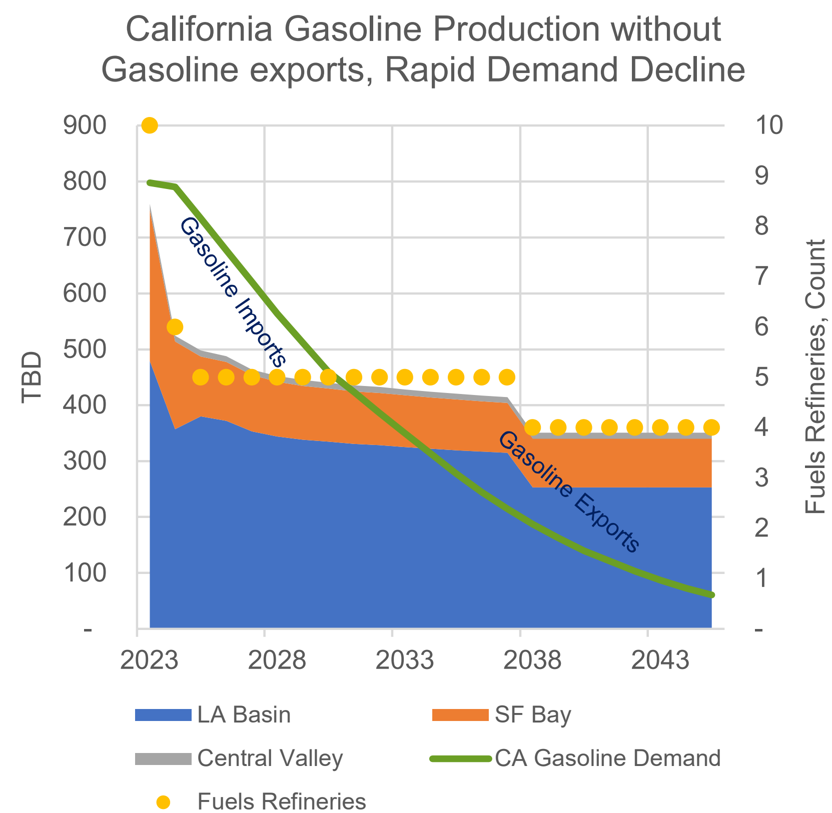




G. Fully Enforced "At-Berth" Emissions Limits (cont)

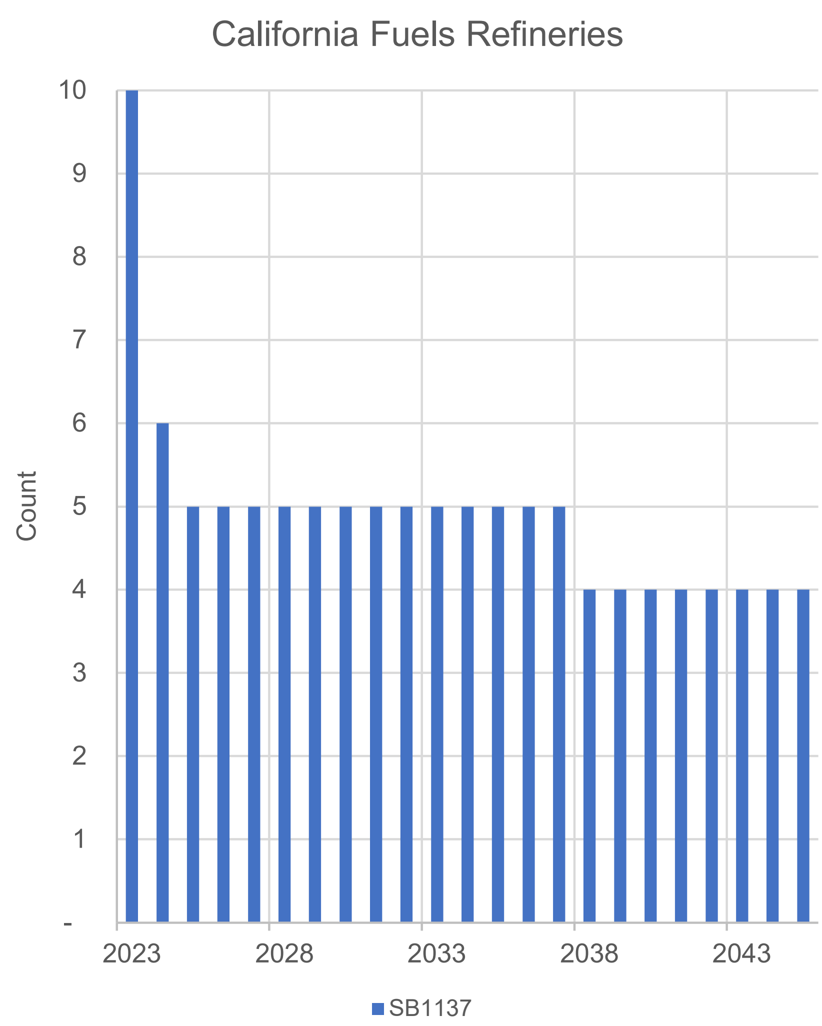
- California refineries could rapidly shut-down if crude oil availability is limited locally by SB 1137 and by water by the "At-Berth" regulation.
- With slow demand decline, California could perpetually require imports
- Imports of gasoline required in early years due to rapid shutdown of refineries ("At-Berth" constrained).
- As California demand rapidly declines, eventually exports of gasoline could be required.
- Moving from imports to exports could induce price volatility





G. Fully Enforced "At-Berth" Emissions Limits (cont.)

- P66 Rodeo refinery fully converted to renewable fuels production in 2024.
- Under SB1137 California Crude Production decline and "At-Berth" constraints, see rapid initial closure of refineries to meet "At-Berth" constraint, and two additional closures in later years as California production continues to decline.
- Pace of refinery closures the same under either CA product demand scenario (Slow or Rapid).



APPENDIX

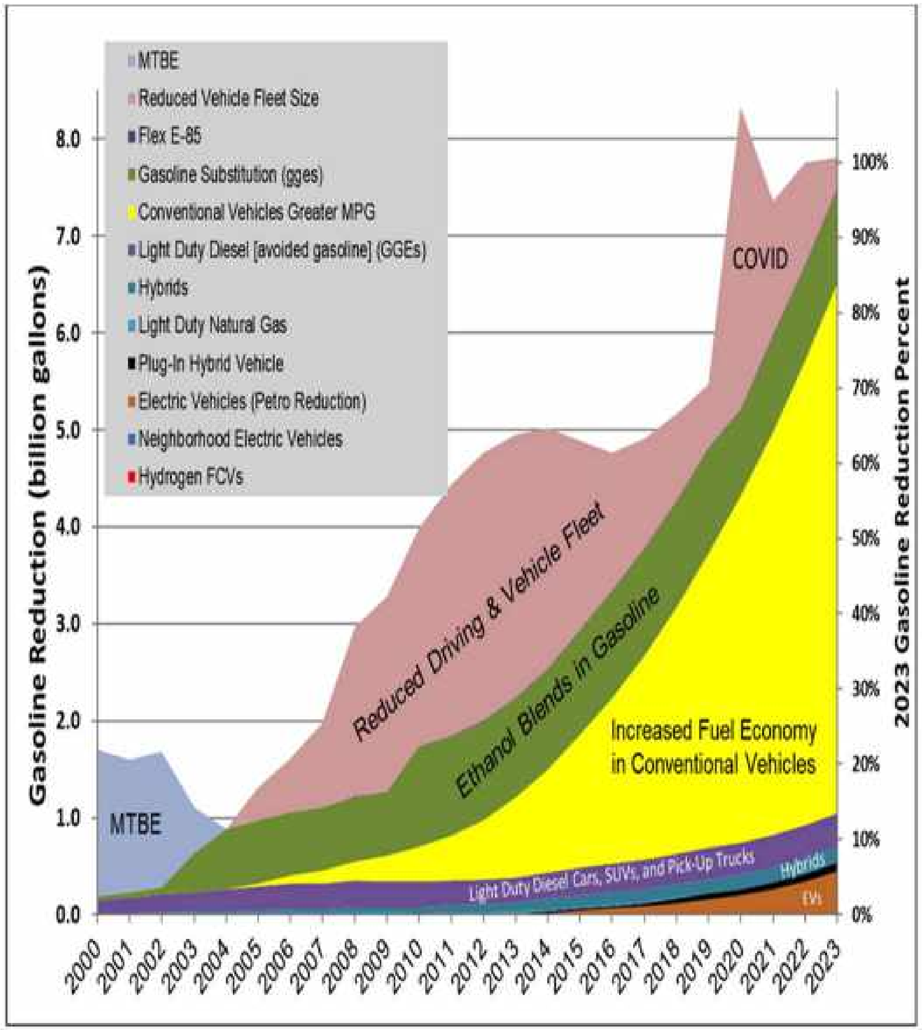
Glossary

AATE3	Additional Achievable Transportation Electrification
AZ	State of Arizona
BBD	Biomass-based Diesel
BOEM	Bureau of Ocean Energy Management (US Department of Interior)
CBI	Confidential Business Information
CalGEM	California Geologic Energy Management Division
CARB	California Air Resources Board
CEC	California Energy Commission
CPUC	California Public Utilities Commission
EIA	Energy Information Agency (US Department of Energy)
EVs	Electric Vehicles
IEPR	Integrated Energy Policy Report
KRV	Kern River Valley
LCFS	Low Carbon Fuel Standard
MM Gals	Million Gallons
MMGY	Million Gallons per Year
NV	Nevada
RD	Renewable Diesel
SJV	San Joaquin Valley
TAN	Total Acid Number
TBD	Thousand Barrels per Day
TESCII	Transportation Energy Supply Chain Infrastructure and Investment
TMX	Trans Mountain Pipeline Expansion
ULSD	Ultra Low Sulfur Diesel
WCS	Western Canadian Select

THE SCOPE OF OUR APPROACH TO THE TESCII STUDY

- This study is based entirely on public information and TM&C analysis. We leveraged this public information on crude oil and refined products to calculate state-level supply/demand balances using State of California projections for future demand.
- Our primary analytical efforts included:
    - Studied recent domestic crude oil production trends and estimated future production declines for major onshore and offshore California production.
    - Mapped crude supply logistics from production fields to refineries along major trunkline networks, including identifying major injection and destination points. Additionally, studied import crude logistics, including major docks/berths capacity and pathways to refineries.
    - Developed representative models of each individual refinery in California using our proprietary Turner Mason Modeling System (TMMS). These configurations were used in an assessment of the viability and risk to the California refinery network at a state level under expected crude supply, product demands, and logistic constraints.
    - Studied existing logistic systems (pipelines, marine, rail) and identified potential developments that could impact these systems in the future.
    - Reviewed expected changes in the regulatory outlook, including proposed rules, permitting bans, executive orders, and new standards. Assessed potential impact of these initiatives on the viability of the transportation fuel delivery system.
- Summarized assessments and results.

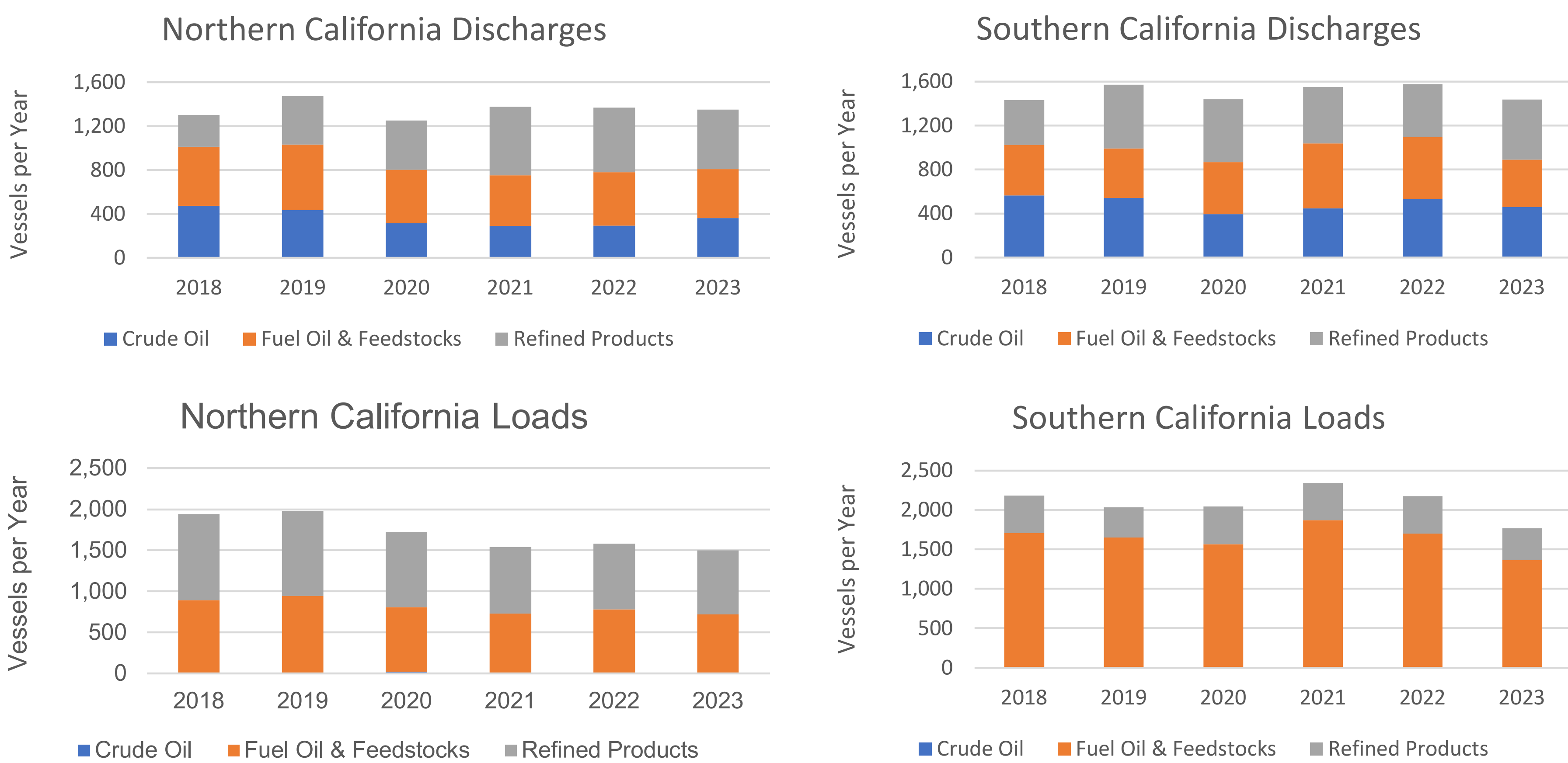
EVs ARE NOT THE ONLY WAY TO REDUCE GASOLINE DEMAND



- Over the last 20 years, California has reduced fossil fuel consumption in the state by 7.8 billion gallons compared to the projected trend (extrapolated from the historic trendline)
- California's population growth (1940-2003) was the dominant factor in gasoline demand growth, but population growth has slowed significantly since 2003
- The chart on the left shows the purchase of conventional vehicles (with improving fuel economy since 2003) are responsible for ~75% of gasoline consumption in 2023
- CARB's zero emission vehicle (ZEV) mandate program is estimated to reduce ~7% of 2023 gasoline consumption

Source: Stillwater & Associates

Marine Logistics



Discharges and Loads refer to volumes being received from or loaded onto a ship or barge. These should not be confused with imports and exports as much of the volume originates from or is destined to another location within California.

SCENARIO MODELING BASIS / ASSUMPTIONS

- Modeled each refinery in TMMS
  - Additional feedstock purchases held constant to represent typical operation
  - No change in configuration over time
- Held operation of four (small) asphalt refineries constant
  - Easiest access to California crude
  - Demand for product not declining
  - Even with shift to EV's and RD, asphalt demand not expected to decline
- Operations of one small fuels refinery held constant
  - Structural advantage of access to crude oil and captive product market
  - Assume niche position keeps refinery economic
- Distribution of California crude production
  - Asphalt refiners running KRV crude (heavier than SJV) at constant rates
  - Distribution of remaining California crude production to SF Bay vs LA Basin
- Distribution of other crudes
  - Alaska crude oil
  - Other grades available within defined min / max limits
  - Marginal grade (Arab Medium) to fill crude units to desired rate as needed
- Years modeled
  - 2023 through 2045
  - CEC transportation fuel demand curves end in 2045
- Refinery shutdown impacts
  - Conversion of P66 Rodeo to renewable fuels production (along with Marathon Martinez) modeled as scenario where crude marine import capability removed from system
  - SF Bay refinery marine logistics associated with individual refineries and not available to rest of circuit after shutdown
  - LA Basin marine logistics separate from individual refineries so still available to rest of circuit as refineries shutdown

METHOD FOR APPLYING SCENARIO CONSTRAINTS

- Crude marine limit / product marine limit
  - Causes utilization to drop
- Physical/Economic utilization minimum
  - Triggers refinery shutdown
- California only demand case
  - Triggers refinery shutdown to reduce gasoline production
- Apply refinery shutdown seriatim
  - Based on size / complexity / resiliency
  - Once shutdown, don’t reopen site in later (more constrained) years
- Scaling operating refinery runs to meet marine limits as necessary
  - Can cause utilization to drop
- Iterative process
  - Applying marine limits, utilization limits, California demand limits with adjustments to scaling / shutdowns
- After iterative process, including refinery shutdowns, recast crude slates to remaining refineries based on scaled operations / utilization and re-run refinery models
  - Ensures utilization of full California crude that would have been lost in iterative process due to shutdowns / scaling
  - Minimum impact to product yields

Who We Are

Founded in 1971, Turner, Mason & Company provides technical, commercial and strategic consulting services to worldwide clients in the crude oil, midstream, refining, refined products, biofuels and renewable fuels industries.

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Founded: 1971

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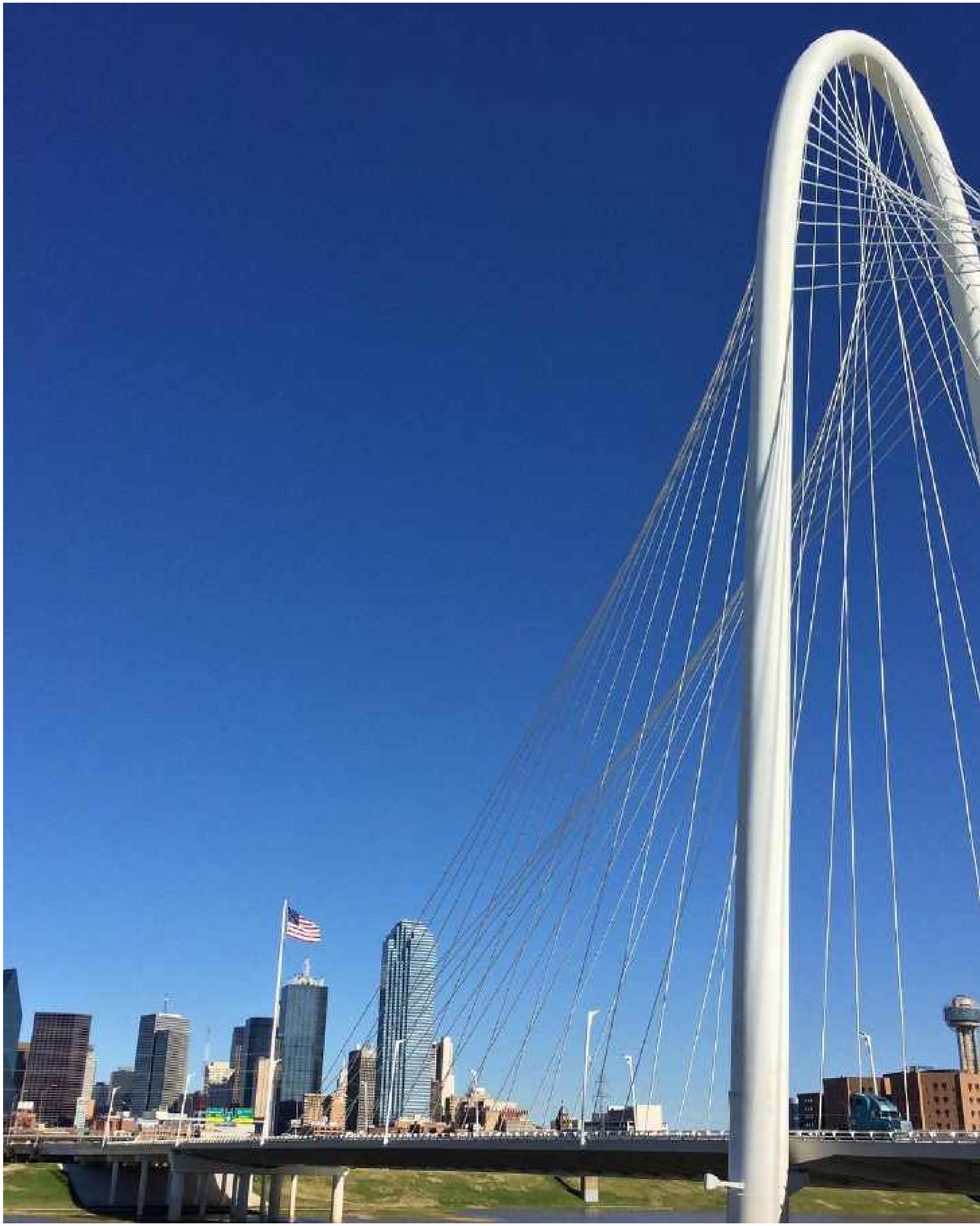

Prepared for
Western States Petroleum Association

Prepared by
Ramboll US Consulting, Inc.
Los Angeles, California

Project Number
1690017786-001

Date
February 1, 2021

MULTI-TECHNOLOGY PATHWAYS TO ACHIEVE CALIFORNIA'S AIR QUALITY AND GREENHOUSE GAS GOALS:

HEAVY-HEAVY-DUTY TRUCK CASE STUDY

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Los Angeles, California 90071

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FIGURES

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ACRONYMS AND ABBREVIATIONS

ACT:	Advanced Clean Truck
AC Transit:	Alameda Contra Costa Transit District
AEO:	Annual Energy Outlook
AG:	agriculture
AW:	dairy digester/animal waste
AQMP:	Air Quality Management Plan
BD:	biodiesel
BEB:	battery electric bus
BEV:	battery electric vehicle
CAA:	Clean Air Act
CA-GREET:	California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
CARB:	California Air Resources Board
CEC:	California Energy Commission
CI:	carbon intensity
DSL:	diesel
EER:	energy economy ratio
EMA:	Energy Marketers of America
EMFAC2017:	Emission Factor Model
EV:	electric vehicle
GHG:	greenhouse gases
g/bhp-hr:	grams per brake horsepower hour
HDV:	heavy-duty vehicle
HHDT:	heavy-heavy-duty truck
ICCT:	International Council on Clean Transportation
ICT:	Innovative Clean Transit
ISOR:	Initial Statement of Reasons
kWh:	kilowatt hour
LCFS:	Low Carbon Fuel Standard
LFG:	landfill gas
MHDV:	medium- and heavy- duty vehicle
META Tool:	Mobile Emissions Toolkit for Analysis

MSS:	Mobile Source Strategy
MY:	model year
NG:	natural gas
NO_X:	oxides of nitrogen
PM:	particulate matter
$PM_{2.5}$:	particulate matter less than 2.5 microns in diameter
RNG:	renewable natural gas
RNWD/RD:	renewable diesel
SB 44:	Senate Bill 44
SCAB:	South Coast Air Basin
SCAQMD:	South Coast Air Quality Management District
SIP:	State Implementation Plan
SJV:	San Joaquin Valley
SJVAPCD:	San Joaquin Valley Air Pollution Control District
SWCV:	solid waste collection vehicles
TCO:	total cost of ownership
T&D:	transmission and distribution
US EIA:	United States Energy Information Administration
USEPA:	United States Environmental Protection Agency
WWTP:	wastewater treatment plants
ZEB:	zero emission bus
ZEV:	zero emission vehicle

EXECUTIVE SUMMARY

California Senate Bill 44[1] (SB 44) requires the California Air Resources Board (CARB) to "update the 2016 mobile source strategy to include a comprehensive strategy for the deployment of medium-duty and heavy-duty vehicles in the state for the purpose of bringing the state into compliance with federal ambient air quality standards and reducing motor vehicle greenhouse gas emissions from the medium-duty and heavy-duty vehicle sector." In response, CARB developed the 2020 Draft Mobile Source Strategy (MSS)[2], which delivered a single electrification-centric approach that has failed to meet the 2023 and 2031 air quality goals, abandoned its 2016 MSS commitments, did not analyze for any alternatives, and failed to look at cost and feasibility as SB 44 required. Further, CARB does not deliver pre-2032 near-term (or short-term) reductions required for non-attainment areas to meet 2023 and 2031 federal health standard deadlines, which were promised to these impacted communities. It also ignored the potential role of renewable liquid and gaseous fuels in meeting longer-term (post-2032) greenhouse gas reduction goals.

As on-road truck emissions are a primary control measure category in non-attainment areas, Ramboll conducted an analysis of one specific sector within the MSS, California's heavy-heavy- duty truck (HHDT) fleet, to identify multiple vehicle technology and fuel pathways that could achieve these near-term air quality goals while being consistent with the meeting of the state's long-term climate goals. The multi-technology analysis of the HHDT sector in this report began in June 2020 after the original CARB 2020 MSS presentation in March 2020.[3] The main conclusions of our analysis are summarized below:

CARB's 2020 Mobile Source Strategy **did not deliver** pre-2032 near-term (or short-term) reductions required for non-attainment areas to meet 2023 and 2031 federal health standard deadlines. Ramboll's analysis of **multi-technology pathways**, which include a combination of low-emission (75% to 100% lower) vehicle technologies and fuel mixes (including lower carbon intensity liquid and gaseous fuels), demonstrates that there are faster paths to meeting near-term federal health requirements, making progress on state climate goals and achieving greater reductions per dollar spent.

- Expanded implementation of zero-emission and Low-NO_X vehicles, coupled with increased introduction of renewable liquid and gaseous fuels, can deliver earlier (as shown in **Figure ES-1**) and more cost-effective benefits than a zero-emission vehicle (ZEV)-only approach.
- As advanced low-emitting trucks are commercially available[4] to deliver benefits to communities sooner, multi-technology pathways can help achieve emission reductions without reliance on infrastructure and technology upgrades that will take years to resolve.
- There is a growing potential for renewable fuels, including those with negative carbon intensity, to meet achieve GHG reductions, which CARB has not acknowledged fully in the MSS nor assessed

[1] California Senate Bill 44. Available at: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB44. Accessed January 2021.

[2] CARB Mobile Source Strategy. Available at: https://ww2.arb.ca.gov/resources/documents/2020-mobile-source-strategy. Accessed January 2021.

[3] CARB Mobile Source Strategy March 2020 Presentation. Available at: https://ww3.arb.ca.gov/planning/sip/2020mss/pres_marwbnr.pdf. Accessed January 2021.

[4] Optional Low NO_X Certified Heavy-Duty Engines. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/msprog/onroad/optionnox/optional_low_nox_certified_hd_engines.pdf. Accessed: January 2021.

the potential for early and cost-effective GHG reductions through these multi-technology vehicle pathways.

- Low-emission heavy-heavy-duty trucks are cost-competitive with (or cheaper than) battery electric vehicles (BEVs). This is true even though battery technology promises (such as greater energy density/lower cost) have not been adequately demonstrated and related transmission/distribution infrastructure cost have not been included in the state's analyses.

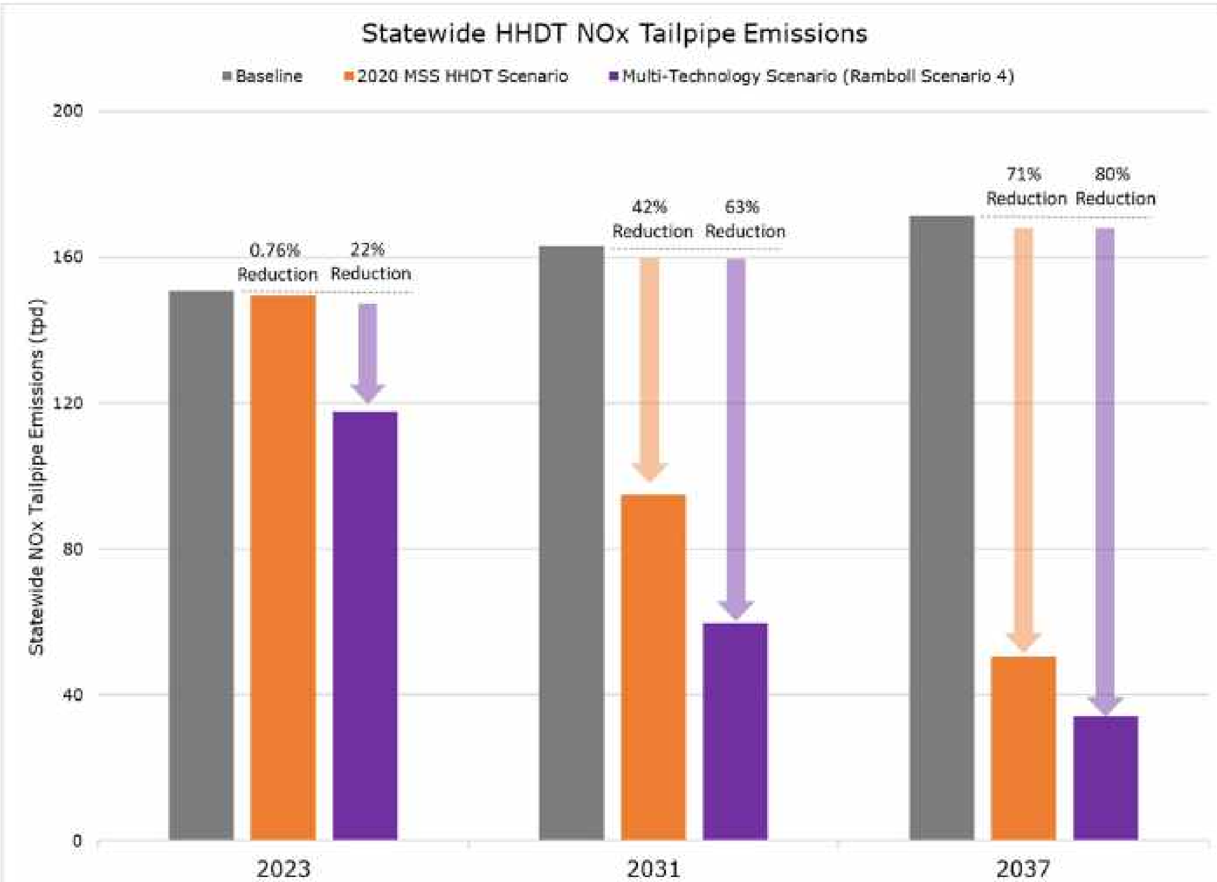

Figure ES-1. Statewide NO_X HHDT Tailpipe Emissions

These conclusions emphasize the need for CARB to conduct a similar analyses across all mobile source sectors, not just the heavy-heavy-duty truck sector, in order to identify existing opportunities to meet state emission reduction commitments consistent with the federal Clean Air Act, fulfill SB 44 requirements, and comprehensively assess the costs and timelines for potential GHG reduction strategies. The analysis also identified information gaps, unsupported technical and cost assumptions, and areas of future research. The lack of citations and/or justifications for the analysis assumptions and inputs used in CARB's Mobile Emissions Toolkit for Analysis (META Tool) needs to be remedied as CARB revises the 2020 MSS and develops future rulemaking on Advanced Clean Cars 2, Advanced Clean Fleets and other rules.

Taking the Next Steps

Several commenters[5] have agreed that the 2020 MSS (and its development process, technical analyses, public process) were inadequate when compared with SB 44 requirements and the previous 2016 MSS. The South Coast Air Quality Management District (SCAQMD) comments[6] noted that "[T]he lack of discussion of the 2023 8-hour ozone attainment date in the South Coast Air Basin in the draft Mobile Source Strategy is very disturbing and likely unlawful[.]" and "given the need for both short-term and long-term reductions, ***considerations must be given for both technologies that are commercially available today (e.g., near-zero technologies) as well as technologies that are being developed and demonstrated (e.g., zero-emission technologies)***." The San Joaquin Valley Air Pollution Control District (SJVAPCD) comments[7] noted that "given the need for both short-term and long-term reductions, considerations must be given for both technologies that are commercially available today (e.g., near-zero technologies) as well as technologies that are being developed and demonstrated (e.g., zero-emission technologies)[.]" and "the District recommends that CARB more clearly articulate the existing commitments included in the 2018 Supplement and 2018 PM2.5 Plan that calls for ***the deployment of a combination of zero and near-zero technology as the most effective and achievable strategy for securing the needed near-term emissions reductions in the San Joaquin Valley and South Coast***."

Based on the results of this study and concerns raised by the local air quality districts, this paper offers the following recommendations:

- CARB should revise the 2020 MSS to include scenarios that assess the increased use of renewable liquid and gaseous fuels and low-NO_X technologies, as well as the expanded use of market-based emission reduction strategies, to achieve emission reductions consistent with SB44 requirements.
- Each scenario must be evaluated for technical feasibility, and as such would require an analysis of future fueling infrastructure availability.
- CARB should assess the associated cost of each MSS scenario in order to identify cost-effective pathways to achieving the state's emission goals, including citations and justifications for assumptions of projected costs and range of potential costs (when uncertainty is high).
- A robust economic analysis is needed of the economic impacts on affected stakeholders (and the public, who ultimately pays). The public, stakeholders, and the legislature need this information to make informed decisions about the path to achieving California's emission goals.

CARB must be transparent and unbiased in the rulemaking process. CARB should conduct technical working groups to foster stakeholder participation in scenario development and assessment, address cost data gaps identified in this study, and ensure that reasonable and achievable strategies are developed that meet SB 44 requirements. Multi-technology pathways can help the state achieve faster and more certain emission reductions to fulfil its commitment to non-attainment communities while expanding ways to reduce greenhouse gas emissions.

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5 Public Comments on the Workshop Discussion Draft 2020 Mobile Source Strategy. Available at: https://ww2.arb.ca.gov/resources/documents/workshop-discussion-draft-2020-mobile-source-strategy-comments-received. Accessed: January 2021.

6 South Coast Air Quality Management District Comments on the Draft 2020 Mobile Source Strategy dated October 20, 2020. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-11/SouthCoastAQMD_Comment-WorkshopDiscussionDraft2020MSS.pdf. Accessed: January 2021.

7 San Joaquin Valley Air Pollution Control District Comments on the Draft 2020 Mobile Source Strategy dated October 21, 2020. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-11/SJVAPCD_Comment-WorkshopDiscussionDraft2020MSS.pdf. Accessed: January 2021.

1. INTRODUCTION

1.1 CARB 2020 MSS Summary

The California Air Resources Board (CARB) first released the Mobile Source Strategy (MSS) in 2016,[8] which introduced a set of measures to reduce emissions from mobile sources to meet the State's air quality and climate goals over the subsequent fifteen years. A list of proposed policy measures coupled with CARB action dates and estimated emission reductions was provided in the 2016 MSS. In 2019, California Senate Bill 44 (SB 44) directed CARB to update the 2016 MSS by January 1, 2021 to bring the state in compliance with federal air quality standards and reduce greenhouse gas (GHG) emissions from the medium- and heavy-duty vehicle sector. CARB released a Workshop Discussion Draft of the 2020 MSS[9] on September 30th, 2020 followed by a Draft 2020 MSS[10] on November 24th, 2020 to inform and provide direction on future CARB rulemaking to meet the State's air quality and climate goals and to meet SB 44 requirements.

1.2 Purpose of this Study

The 2020 MSS draft is focused on meeting the State's long-term climate goals through the exploration of electrification concepts and scenarios across the mobile source sectors. There is, however, an immediate need to assess multiple vehicle/fuel technology pathways for significantly reducing oxides of nitrogen (NO_X) emissions from mobile sources, particularly heavy-heavy-duty trucks (HHDTs),[11] in order to meet the upcoming federal Clean Air Act (CAA) ozone attainment deadlines in 2023 and 2031 for South Coast Air Basin (SCAB) and San Joaquin Valley (SJV). While the 2016 MSS identified near-zero technologies such as Low NO_X natural gas (NG) engines and plug in hybrid vehicle (PHEV) technologies as potential pathways to help achieve these near-term NO_X reductions, the 2020 MSS does not address these much needed near-term NO_X reductions; instead it focuses on a vehicle electrification pathways to achieve the State's long-term climate goals.

Since the 2020 MSS does not address the NO_X reductions needed to the State's near-term air quality goals, Ramboll conducted an analysis of California's HHDT fleet to identify multiple vehicle technology and fuel pathways that could help achieve these near-term air quality goals while still meeting the long-term climate goals. This white paper provides a summary of the methodology, results, and conclusions of Ramboll's analysis. The results of these analyses can be used as a basis for further discussion with CARB, air districts, and stakeholders to amend the deficiencies in the current 2020 MSS and its related feasibility, cost, and socioeconomic analyses.

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8 CARB. 2016. Mobile Source Strategy. May. Available at: https://ww3.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf. Accessed: January 2021.

9 CARB. 2020. Workshop Discussion Draft 2020 Mobile Source Strategy. September 30. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-09/Workshop_Discussion_Draft_2020_Mobile_Source_Strategy.pdf. Accessed: January 2021.

10 CARB. 2020. Draft 2020 Mobile Source Strategy. November 24. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-11/Draft_2020_Mobile_Source_Strategy.pdf. Accessed: January 2021.

11 HHDTs make up the largest portion of mobile source NO_X emissions in the SCAB and SJV as shown in the 2020 NO_X mobile source emission inventories for these areas. Available at: https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php. Accessed: January 2021.

2. MULTI-TECHNOLOGY SCENARIOS: HEAVY-HEAVY-DUTY TRUCK SECTOR EXAMPLE

The 2020 MSS assumes an aggressive penetration rate for zero emission vehicles (ZEVs) in the heavy-duty vehicle (HDV) sector which includes an ambitious phase-in for newer vehicles and an accelerated turnover of older and higher emitting vehicles in order to meet California's long-term climate goals. **Figure 2-1** below presents the vehicle technology fleet mix of the statewide HDV population proposed in the 2020 MSS ("CARB's 2020 MSS Scenario") at CARB's March 2020 Presentation. As shown in the figure, this scenario assumes that the fraction of ZEV in the HDV fleet will increase from ~0% in 2020 to 21% in 2031, 44% in 2037, 76% in 2045, and 80% in 2050.[12] While the 2020 MSS Workshop Discussion Draft briefly evaluates an alternative Low-NO_X "concept" that assumes an accelerated turnover to Low-NO_X vehicles, CARB does not consider or access other scenarios that use a mix of alternative vehicle and fuel technologies to achieve the California's long-term climate goals.

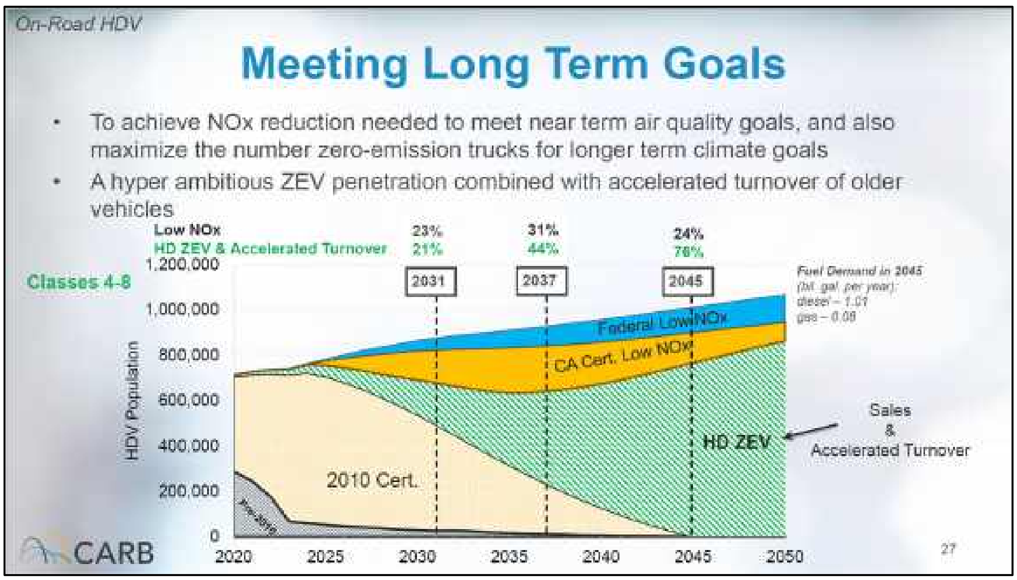

Figure 2-1. Heavy-Duty Vehicle Fleet Mix for 2020 MSS[13]

Ramboll's analysis presented in this report evaluates the emission benefits of a series of multi-technology scenarios for a sub-set of the statewide HDV fleet consisting of diesel heavy-heavy-duty trucks (HHDTs) excluding solid waste collection vehicles (SWCV). The purpose of this analysis is to evaluate if there are other vehicle/fuel technology pathways besides CARB's 2020 MSS Scenario that could achieve the State's long-term climate goals while also meeting the near-term air quality goals. CARB does not provide a breakdown between the types of heavy-duty ZEVs modeled in its

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[12] On November 24, 2020, CARB released the Draft 2020 MSS with fleet mix assumptions that differ slightly from those seen in Figure 3-1. The heavy-duty ZEV fleet mix Draft 2020 MSS are as follows: 24% in 2031, 48% in 2037, and 77% in 2045 (obtained from Draft META tool that accompanies the Draft 2020 MSS. Available at: https://ww3.arb.ca.gov/planning/sip/2020mss/draft_META.zip. Accessed: January 2021.). As Ramboll's analysis was conducted before the Draft 2020 MSS was released, it uses fleet mix percentages from the March 2020 presentation.

[13] CARB, 2020. Long-term strategy for 2020 MSS. CARB 2020 Mobile Source Strategy Public Webinar, March 25, 2020. Available at: https://ww3.arb.ca.gov/planning/sip/2020mss/pres_marwbnr.pdf. Accessed: January 2021.

long-term scenarios. As CARB assumes that the heavy-duty ZEV population will be predominately battery electric vehicles[14] (BEVs), Ramboll's scenario analysis models ZEVs as BEVs only.

A brief description of the analyzed scenarios is presented below. **Figure 2-2** presents vehicle technology fleet mixes for these scenarios. A detailed matrix of all scenarios can be found in **Appendix A.**

- **S1 - CARB Long-Term Scenario**: As shown in **Figure 2-2**, the fleet mix for this scenario assumes an aggressive penetration rate for BEV with an accelerated turnover of pre-2024 vehicles to achieve the following fractions of BEV in future calendar years that are similar to the CARB 2020 MSS Scenario: 44% in 2037, 76% in 2045, and 80% in 2050. The fraction of California Low NO_X diesel (CA Low NO_X DSL) vehicles and Federal Low NO_X diesel (Federal Low NO_X DSL) vehicles in future years is also maintained at values similar to the CARB 2020 MSS Scenario.
- **S2 – Low NO_X NG with ACT**: In this scenario, Ramboll assumed that the sales fractions of BEV in HHDTs for model year 2024 and beyond are equal to the purchase mandate stated in CARB's Advanced Clean Truck (ACT) Regulation[15] and that the fraction of Federal Low NO_X DSL HHDTs in the statewide fleet is maintained at values similar to the CARB 2020 MSS Scenario. All other new (model year [MY] 2024 and beyond) vehicles are assumed to be Low NO_X natural gas (Low NO_X NG) vehicles that are commercially available in the market today. Note, an accelerated turnover of pre-2024 vehicles, at a rate similar to the CARB 2020 MSS Scenario, is also assumed with these vehicles turning over to newer alternative technology vehicles (e.g., Federal Low NO_X DSL, Low NO_X NG, and BEV).
- **S3 – Low NO_X NG without ACT**: This scenario is identical to scenario S2 with the following exception: all BEV in S2 are replaced with Low NO_X NG vehicles.
- **S4 – Low NO_X NG with SCAQMD 2016 AQMP & ACT**: This scenario is similar to scenario S2, but assumes early adoption of Low NO_X NG HHDTs to meet or exceed South Coast Air Quality Management District's (SCAQMD's) 2016 Air Quality Management Plan (AQMP) projections for NG truck population in calendar years 2023 and 2031.[16] The conventional DSL fleet is adjusted to accommodate the early adoption of Low NO_X NG HHDTs while the sales fraction of BEVs for model year 2024 and beyond remains equal to the purchase mandate stated in CARB's ACT Regulation. Accelerated turnover of older vehicles is included as described in S2.
- **S5 – CA Low NO_X DSL with ACT**: This scenario is identical to scenario S2 with the following exception: CA Low NO_X DSL HHDTs are used to replace the Low NO_X NG HHDTs in S2.
- **S6 – CA Low NO_X DSL without ACT**: This scenario is identical to scenario S3 with the following exception: CA Low NO_X DSL vehicles are used to replace the Low NO_X NG in S3.

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[14] CARB 2020 MSS Discussion Draft assumes that roughly 90% of the light-duty ZEV population in 2030 are BEVs and 75% in 2045.

[15] Available at: https://ww3.arb.ca.gov/regact/2019/act2019/30dayatta.pdf. Accessed: January 2021.

[16] SCAQMD 2016 AQMP Final Socioeconomic Report Appendix 2-A. Available at: https://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/final/appfinal_030817.pdf?sfvrsn=2. Accessed: January 2021.

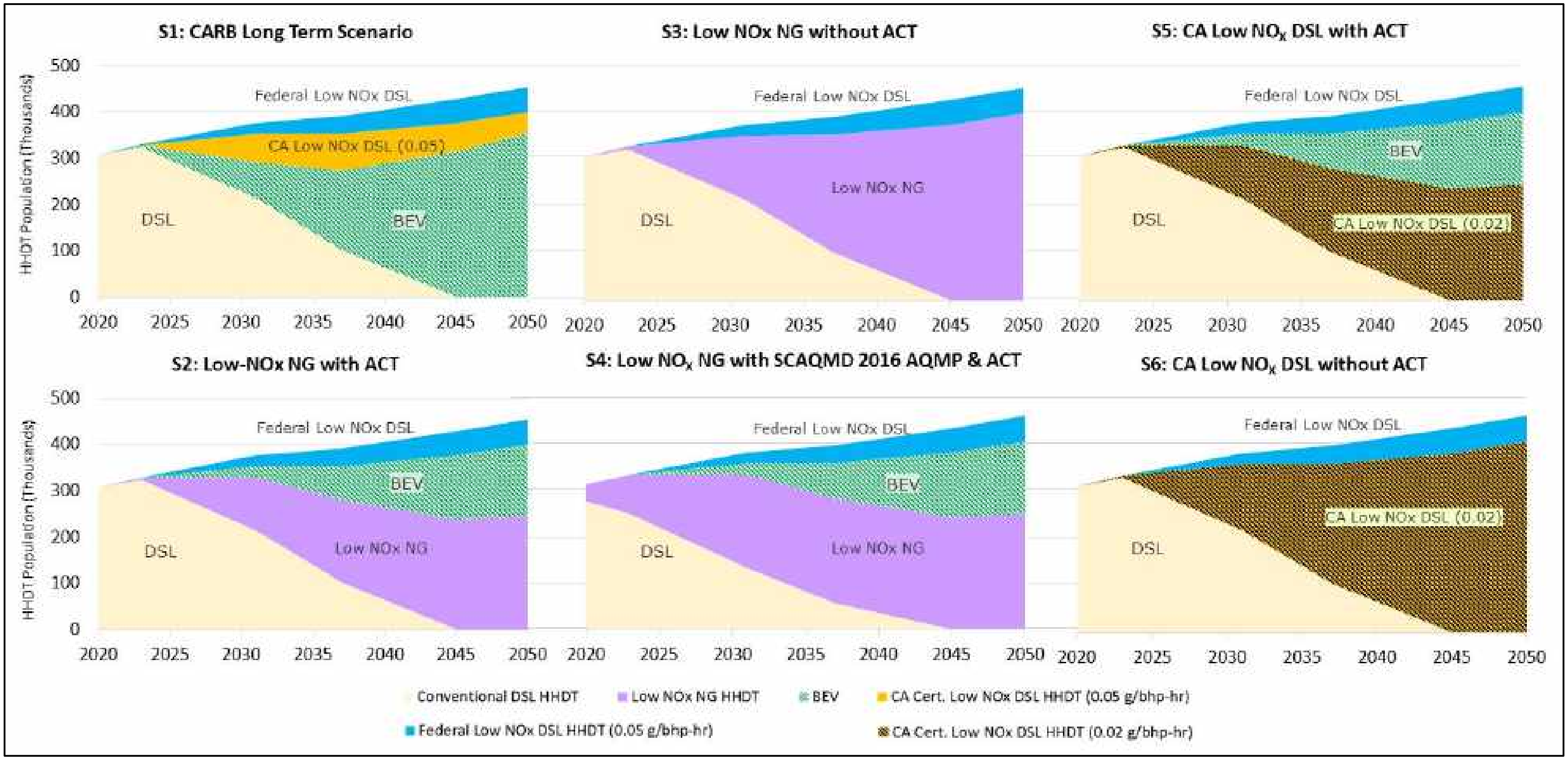

Figure 2-2. Diesel Heavy-Heavy-Duty Truck Fleet Mixes for Ramboll Scenario Analysis

- Ramboll also analyzed a baseline scenario **S0 – Baseline EMFAC2017** which represents the default fleet mix for HHDTs in the EMFAC2017 model,[17] which assumes that all new trucks will meet the 2010 United States Environmental Agency (USEPA) standard.[18] This scenario is used as a baseline to evaluate incremental emission benefits in this analysis.

Besides evaluating the above mentioned scenarios for NO_X and GHG emissions benefits, Ramboll also performed an comparative analysis of the projected total cost of ownership (TCO) and vehicle lifetime emissions of five heavy-heavy-duty truck (HHDT) technologies: Conventional diesel HHDT, Federal Low NO_X diesel HHDT, CA Low NO_X HHDT, Low NO_X NG HHDT, and Battery Electric HHDT. Details on the methodologies used for the scenario and TCO analysis are presented in **Section 4** and **Section 5**.

[17] CARB EMFAC 2017 v1.02. Available at: https://arb.ca.gov/emfac/2017/. Accessed December 2020.

[18] Available at: http://www.meca.org/regulation/us-epa-20072010-heavyduty-engine-and-vehicle-standards-and-highway-diesel-fuel-sulfur-control-requirements. Accessed: December 2020.

3. SCENARIO ANALYSIS METHODOLOGY

This Section describes the methodology used for Ramboll's scenario analysis. Detailed modeling inputs, outputs, and methodology are provided in **Appendix A.**

3.1 Renewable Fuel Sub-Scenarios

Ramboll analyzed four versions of scenarios S1 through S6 to explore the use of renewable fuels to achieve greenhouse gas emission reductions. These sub-scenarios are summarized in **Table 3-1** below.

Table 3-1. Renewable Fuels Sub-Scenarios

Sub-Scenarios	Sub-Scenario Descriptions
"A1" Sub-Scenarios	"A1" Scenarios assume that conventional diesel and conventional NG from fossil fuels are used to fuel 100% of the diesel and Low-NO_X NG vehicle populations, respectively, in future calendar years.
"B1" Sub-Scenarios	"B1" Scenarios assume that renewable diesel (RD) from tallow and renewable NG from landfill gas (RNG-LFG) are used to fuel 100% of the diesel and Low-NO_X NG vehicle populations, respectively, in future calendar years.
"C1" Sub-Scenarios	"C1" Scenarios are hypothetical scenarios that assume a composite mix of renewable fuels are used to fuel 100% of the diesel and Low-NO_X NG vehicle populations. For these scenarios, Ramboll assumed that the carbon intensity (CI) of renewable diesel would be an average across all renewable diesel and biodiesel CIs reported in the Low Carbon Fuel Standard (LCFS) Fuel Pathway Table.[19] Ramboll also assumed that source mix for RNG would be 50% LFG, 25% wastewater treatment plants (WWTP), and 25% agriculture (AG). "C1" scenarios are only calculated for calendar year 2045.
"C2" Sub-Scenarios	"C2" Scenarios are hypothetical scenarios that assume conventional diesel and conventional NG are used to fuel 50% of the diesel and Low-NO_X NG vehicle populations, respectively. The remaining 50% of each vehicle population is assumed to be fueled with a composite mix of renewable fuels as described in scenario C1. "C2" scenarios are only calculated for calendar year 2045.

3.2 Tailpipe (Tank-to-Wheel) Emissions

CARB's EMFAC2017 model[20] was used to estimate tailpipe emissions for NO_X and GHGs for all HHDT vehicle types included in this analysis. Specifically, EMFAC2017 was queried at the statewide level for scenario analysis years 2020, 2023, 2031, 2037, 2045 and 2050 to obtain total exhaust emissions, population, and fuel consumption data for HHDTs by model year. Tailpipe emissions for alternative technology HHDTs were calculated based on EMFAC2017 data and the assumptions in **Table 3-2**. Further details regarding tailpipe emission estimation methodology, including EMFAC2017 inputs and outputs, can be found in **Appendix A**.

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[19] CARB LCFS Fuel Pathway Table. Available at: https://ww3.arb.ca.gov/fuels/lcfs/fuelpathways/current-pathways_all.xlsx. Accessed: January 2021.

[20] Available at: https://arb.ca.gov/emfac/2017/. Accessed: January 2021

Table 3-2. Tailpipe Emission Assumptions

Vehicle Type	Tailpipe NO_X	Tailpipe GHG
Conventional Diesel HHDT	Default EMFAC Output	Default EMFAC Output
Federal Low-NO_X Diesel HHDT	**75% NO_X** reduction from conventional diesel HHDT based on 0.05 grams per brake horsepower hour (g/bhp-hr) NOx certification	Default EMFAC Output
California Certified Low-NO_X Diesel HHDT	Scenario S1: **75% NO_X** reduction from conventional diesel HHDT based on 0.05 g/bhp-hr NOx certification Scenario S5 and Scenario S6: **90% NO_X** reduction from conventional diesel HHDT based on 0.02 g/bhp-hr NO_X certification	Default EMFAC Output
Low-NO_X Natural Gas HHDT	**90% NO_X** reduction from conventional diesel HHDT based on 0.02 g/bhp-hr NO_X certification	Default EMFAC Output
Battery Electric HHDT	Zero NO_x tailpipe emissions	Zero GHG tailpipe emissions

3.3 Upstream (Well-to-Tank) Emissions

Ramboll estimated well-to-tank (i.e., “upstream”) NO_X and GHG emissions associated with fuel production and distribution for each analyzed fuel type (electricity, diesel, natural gas, renewable diesel from tallow, and renewable natural gas from landfill gas) using emission factors obtained from the CA-GREET 3.0 model.[21] Developed from Argonne National Laboratory’s GREET 2016 model,[22] the CA-GREET 3.0 model is used by CARB to calculate well-to-wheel (i.e., “lifecycle”) emissions from transportation fuels under the California LCFS Program. Hence, use of this model to estimate upstream emissions is consist with the CARB methodologies.

For purposes of this analysis, Ramboll adjusted the electricity grid mix inputs to the CA-GREET 3.0 model based on California Energy Commission (CEC) current grid mix data[23] and projections for each of the modeled calendar years 2020, 2023, 2031, 2037, 2045 and 2050.[24] Ramboll also updated the

[21] CA-GREET 3.0 Model. Available at: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm. Accessed: January 2021.

[22] Available at: https://greet.es.anl.gov/publication-greet-model. Accessed: January 2021.

[23] California Energy Commission 2018 Grid Mix Data. Available at: https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2018-total-system-electric-generation. Accessed: January 2021.

[24] CEC 2018. Deep Decarbonization in a High Renewables Future - Implications for Renewable Integration and Electric System Flexibility, Docket 18-IEPR-06 - 223869, Slide 10. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=223869&DocumentContentId=54081. Accessed: January 2021.

default assumptions for renewable fuels transportation distances within CA-GREET 3.0 to more accurately represent distribution within California. Further details regarding CA-GREET 3.0 model inputs and outputs can be found in **Appendix A**.

Emission factors from CA-GREET 3.0 are obtained per unit of energy consumed for each fuel type. In order to calculate total upstream emissions for each scenario, the total amount of energy consumed of each fuel type is calculated using Energy Economy Ratios (EERs). EERs are dimensionless values that represent the efficiency of a fuel as used in a powertrain as compared to a reference fuel used in the same powertrain.[25] The conventional diesel fuel energy derived from EMFAC2017 for the proportion of vehicles assumed to be turned over to electric of natural gas vehicles was adjusted by the appropriate EERs for heavy-duty vehicles to obtain natural gas or electricity energy consumption. A summary of EER values used in this analysis are provided in **Appendix A**.

[25] CARB 2020. Low Carbon Fuel Standard Regulation. Available online at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf Accessed: January 2021.

4. COST ANALYSIS METHODOLOGY

As discussed in Section 2, Ramboll conducted a total cost of ownership (TCO) analysis and cost-effectiveness analysis for five HHDT technologies: Conventional diesel HHDT, Federal Low NO_X diesel HHDT, CA Low NO_X HHDT, Low NO_X NG HHDT, and Battery Electric HHDT.

The TCO analysis includes an assessment of capital and operational costs with cost values presented in 2018 dollars. The analysis assumes the purchase of a model year (MY) 2024 truck and conducts a TCO calculation for both a 10-year (435,000 miles) and 15-year (909,900 miles) useful truck life. Where possible, cost assumptions are derived from CARB sources including the CARB ACT Regulation.[26]

Capital costs are calculated as a sum of the vehicle purchase cost and charger/charging infrastructure cost, where applicable (i.e., for battery electric trucks). Vehicle purchase costs used in this analysis do not include financing costs or incentives available from various federal, state, and local funding programs. Low-NO_X diesel truck capital costs were estimated by adding the incremental low-NO_X engine and aftertreatment to the cost of a conventional diesel truck. Vehicle purchase costs for BEVs are highly dependent on the future cost projections for batteries. Given the variability in these cost projections,[27] HHDT BEV total cost of ownership was analyzed for a MY2018 and a MY2024 vehicle. Further details regarding battery cost assumptions are provided in **Section 6.3.1** and **Appendix B.** Costs associated with the new and/or enhanced electric generation and transmission infrastructure required for deployment of BEVs are not included in this analysis.

Operational costs are calculated as a sum of fuel costs and operation & maintenance (O&M) costs. Fuel cost projections are derived from United States Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2019.[28] Potential revenue from CARB LCFS credits[29] are not included in this cost analysis. CARB ACT ISOR[27] assumes that a diesel engine rebuild is not needed for an operational life of 600,000 miles. As such, Ramboll Cost analysis does not assume any midlife overhaul costs for a diesel HHDT. As consistent with CARB ACT ISOR[27], a midlife overhaul is required for HHDT BEVs, which consists of a battery replacement in year 8 of operation.

Ramboll calculated cost-effectiveness for each HHDT technology as a ratio of the incremental total cost of ownership (compared to conventional diesel HHDT) divided by incremental tailpipe NO_X emission reductions over the vehicle lifetime (compared to a conventional diesel HHDT). Ramboll estimated tailpipe NO_X emissions for each HHDT technology using EMFAC2017 outputs for a conventional diesel HHDT and the assumptions listed in **Table 3-2**.

Refer to **Appendix B** for additional information on the methodology and assumptions used for the TCO and cost-effectiveness analysis**.**

[26] Refer to **Appendix B** for a complete list of sources.

[27] CARB ACT ISOR[25] Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

[28] EIA AEO 2019. Table 3 Fuel Prices for the Pacific Region. Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2019&region=1-9&cases=ref2019&start=2017&end=2050&f=A&linechart=ref2019-d111618a.3-3-AEO2019.1-9&map=ref2019-d111618a.4-3-AEO2019.1-9&sourcekey=0. Accessed: January 2021.

[29] LCFS Credit Generation Opportunities. Available at: https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/lcfs-credit-generation-opportunities. Accessed: December 2020.

5. SCENARIO ANALYSIS EMISSIONS RESULTS

5.1 Tailpipe NO_X Emissions

Figure 5-1 below presents the estimated total NO_X tailpipe (vehicle exhaust) emissions from the statewide HHDTs excluding SWCVs for calendar year 2020 to 2050 for each modeled scenario: S0 - Baseline EMFAC2017 (represented by black line), S1 – CARB Long-Term Scenario (represented by the orange line), S2 - Low NO_X NG with ACT (represented by blue line), S3 – Low NO_X NG without ACT (represented by green line), S4 – Low NO_X NG with SCAQMD 2016 AQMP & ACT (represented by purple line), S5 – CA Low NO_X DSL with ACT (represented by yellow line), and S5 – CA Low NO_X DSL with ACT (represented by grey line). Renewable fuels are not expected to change NO_X tailpipe emissions relative to the corresponding conventional fuels they displace; therefore "A1" and "B1" sub-scenarios show the same tailpipe NO_X emission estimates for each modeled scenario.

The results of the scenario analysis demonstrate that all modeled scenarios with Low NO_X engines (S2 through S6) can achieve similar NO_X reductions (compared to the baseline Scenario S0) as the CARB Long-Term Scenario (S1) presented in the 2020 MSS. In fact, as seen in **Figure 5-1** and **Figure 5-2** Scenario S4, which assumes the early adoption of Low-NO_X NG HHDTs to meet or exceed fleet mix requirements from the SCAQMD's 2016 AQMP, achieves greater NO_X reductions (compared to the baseline Scenario S0) sooner than CARB's Long-Term Scenario (S1). The CARB scenario (S1) achieves only 3% of the tailpipe NO_X emission reductions (compared to Baseline Scenario 0) that a multi-technology deployment of near-zero emission HHDTs consistent with the 2016 MSS SIP (S4) would have achieved in 2023; even by 2031, the CARB scenario only achieves 66% of the tailpipe NO_X reductions Scenario 4 would have achieved in 2031. Strategies that fail to deploy early adoption of near-zero emission trucks as CARB committed to in the 2016 MSS SIP (a key component of the SCAQMD's 2016 AQMP[30] and SJVAPCD's 2016 San Joaquin Valley SIP[31] and 2018 supplements[32]) forgo necessary near-term NO_X emission reductions needed to meet 2023 and 2031 ozone attainment deadlines in South Coast Air Basin and San Joaquin Valley.

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[30] SCAQMD. Final 2016 AQMP-CARB/EPA/SIP Submittal. Available at: https://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan/final-2016-aqmp. Accessed: January 2021.

[31] SJVAPCD. 2016 Plan for the 2008 8-Hour Ozone Standard. Available at: https://www.valleyair.org/Air_Quality_Plans/Ozone-Plan-2016.htm. Accessed: January 2021.

[32] SJVAPCD. 2018 PM 2.5 Plan for the San Joaquin Valley. Available at: https://www.valleyair.org/pmplans/. Accessed: January 2021.

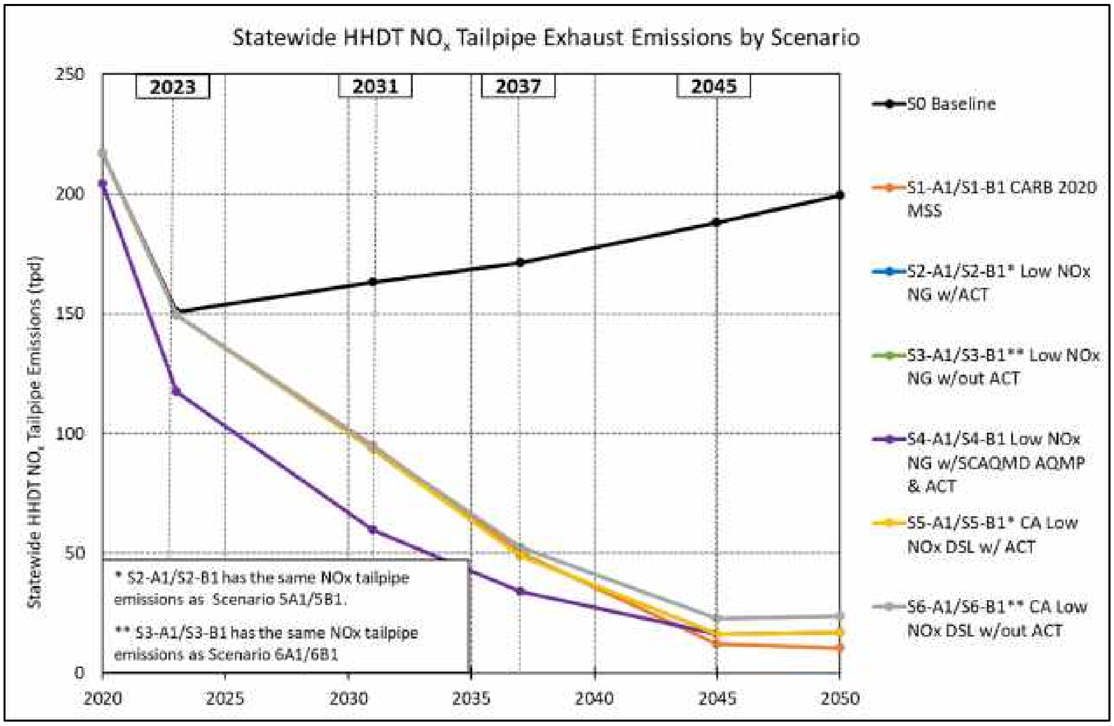

Figure 5-1. Statewide HHDT NO_X Tailpipe Exhaust Emissions by Scenario

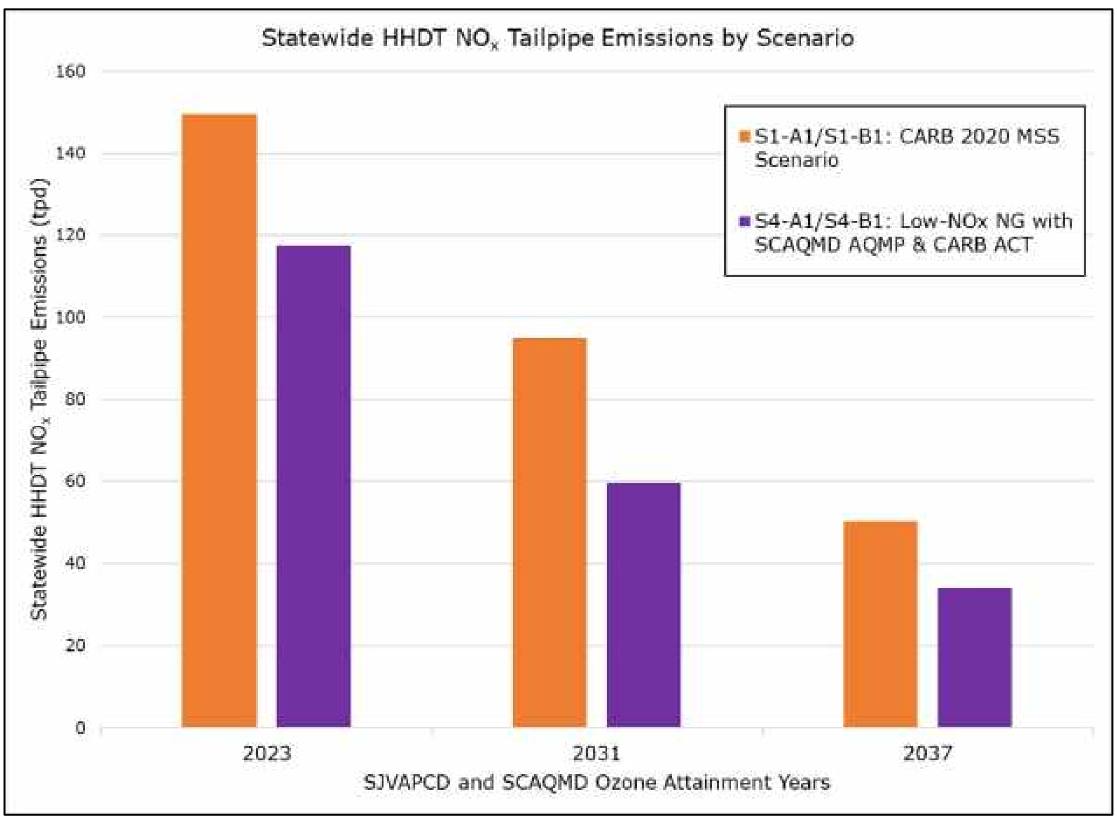

Figure 5-2. Statewide HHDT NO_X Emissions Comparison by Scenario

5.2 GHG Emissions

Figure 5-3 provides a comparison of well-to-wheel ("lifecycle") GHG emissions associated with the statewide HHDT fleet excluding the SWCVs in calendar year 2045 for the following modeled scenarios: S1 – CARB Long-Term Scenario (represented by the orange bar), S2 - Low NO_X NG with ACT (represented by blue bar), S3 – Low NO_X NG without ACT (represented by green bar), S5 – CA Low NO_X DSL with ACT (represented by yellow bar), and S5 – CA Low NO_X DSL with ACT (represented by grey bar) . As summarized previously in **Table 3-1**, sub-scenarios B1, C1, and C2 explore the use of renewable fuels to generate GHG emission reductions needed to meet the State's long-term climate goals. The results presented in **Figure 5-3** show that the use of renewable fuels (sub-scenarios B1, C1, and C2) along with near-zero vehicle technologies (Scenarios S2, S3, S5, and S6) such as Low NO_X NG and Low NO_X DSL engines can generate GHG reductions similar to CARB Long-Term Scenario (S1). Further, Scenarios S2-C1 and S3-C1, which model an accelerated turnover of the statewide HHDT fleet (excluding SWVCs) to Low-NO_X NG vehicles fueled by a composite mix of renewable NG, could result negative lifecycle GHG emissions.

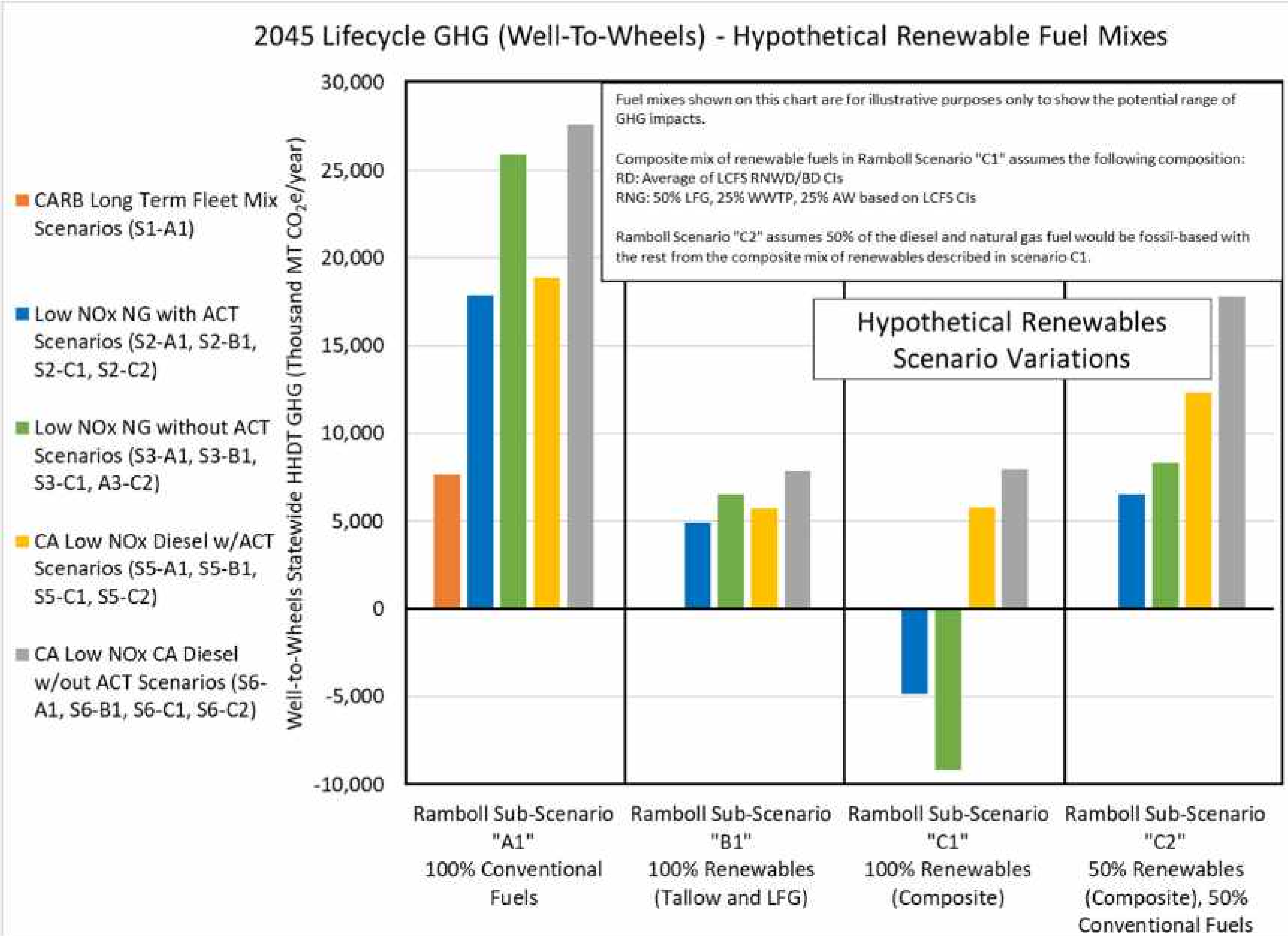

Figure 5-3. 2045 Well-to-Wheels GHG Emissions

5.3 Summary of Scenario Analysis Results

The tailpipe NO_X and lifecycle GHG emissions results of Ramboll's scenario analysis presented in Sections 5.1 and 5.2 clearly indicate that CARB can develop a multi vehicle/fuel technology pathway for mobile sources that not only achieves the much needed near-term NO_X reductions in SCAB and SJV by early adoption of Low NO_X vehicle technologies, but also achieves sufficient GHG reductions to meet the State's long-term climate goals through the increased use of liquid and gaseous renewable fuels.

6. COST ANALYSIS RESULTS

6.1 Total Cost of Ownership Results

The results of Ramboll's cost analysis demonstrate that Low-NO_X HHDTs can deliver equivalent operational cost savings as BEVs, with a lower purchase cost and without additional infrastructure investments. **Figures 6-1 and 6-2** show the projected total cost of ownership for a 10- and 15-year useful life analysis for each truck technology: Conventional Diesel HHDT (light yellow), Federal Low-NO_X Diesel HHDT (blue), CA Low-NO_X Diesel HHDT (Orange), Low-NO_X NG HHDT (purple), MY2018 BEV (green) and MY2024 BEV (green). Costs associated with charger and installation are show in hatched dark green. With the exception of BEV-2018 costs, all vehicles analyzed are MY2024 vehicles. As stated previously, Ramboll assessed the cost of both a MY2018 and MY2024 BEV given the variability in HD battery cost projections. These concerns are further elaborated in **Section 6.3.1** of this report. While the inclusion of LCFS credits for electric charging may result in up to $88,000 of revenue for a 10-year truck lifetime (up to $181,000 of revenue for a 15-year truck lifetime), the earnings from this potential revenue have not been included in the Ramboll cost analysis given uncertainties in future market conditions and availability of credit deficits in the LCFS program in future years. From these results, under both a 10-year and 15-year useful life analysis, the total projected cost of ownership for low-NO_X trucks is below that of BEVs, even without accounting for vehicle replacement ratio differences.

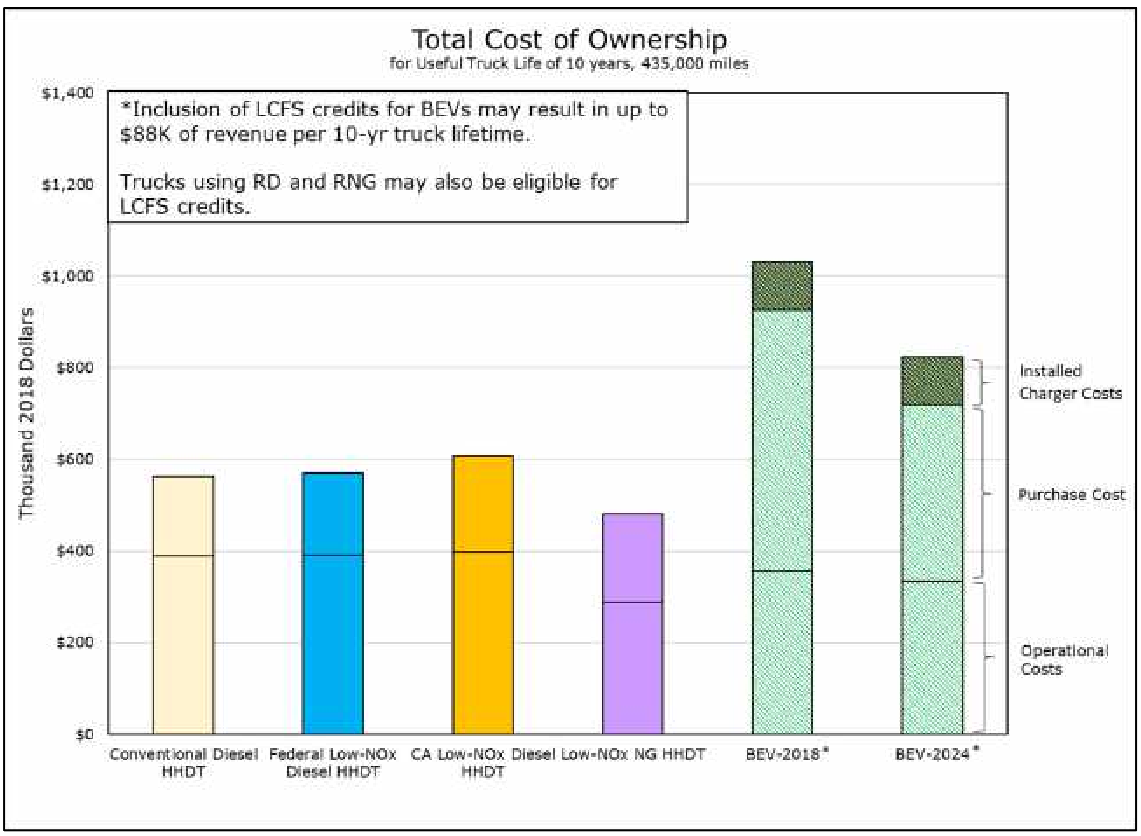

Figure 6-1. Total Cost of Ownership Results for a 10-year Useful Life

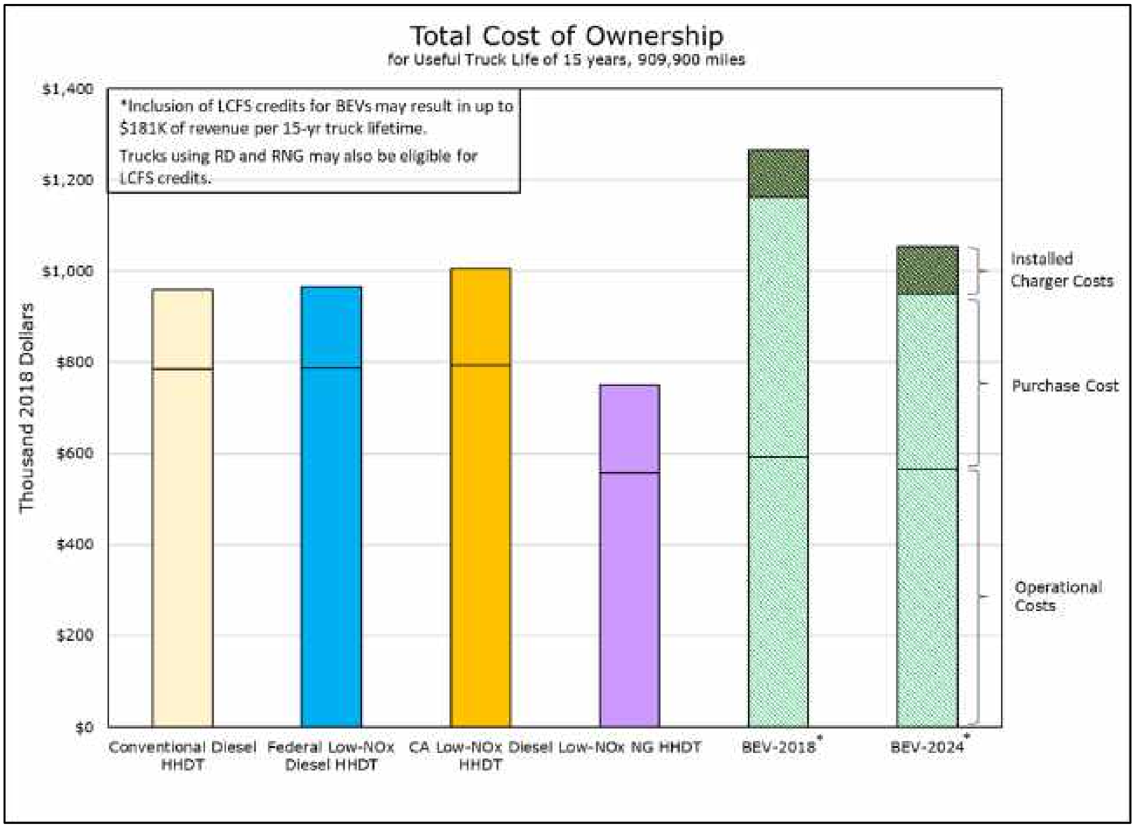

Figure 6-2. Total Cost of Ownership Results for a 15-year Useful Life

Figure 6-3 provides a comparison between the TCO analysis for conventional diesel HHDT, BEV-2018 and BEV-2024 from CARB Advanced Clean Truck (ACT) Regulation[33] and the Ramboll Analysis. Total cost of ownership is broken down by vehicle purchase cost (gray), financing costs (light blue), charger and infrastructure costs (green), and total operational costs (dark blue). Where possible, Ramboll analysis used cost assumptions from the CARB ACT regulation, nonetheless, due to the following key differences between both analyses, CARB's TCO results for BEVs (labelled as ACT ISOR 12-yr TCO in graph) are much lower than the Ramboll BEV TCO results:

- CARB's analysis reduces BEV operational costs by $130,000 to $170,000 to account for revenues generated from LCFS credits. As described earlier, Ramboll's analysis does not account for these credits.
- CARB's costs are discounted to net present value, while Ramboll's analysis reports costs in 2018 dollars.
- CARB's analysis includes financing costs for the purchase of the vehicle and charger while the Ramboll's analysis does not include this cost.
- CARB's analysis does not include infrastructure upgrade and maintenance costs in its final TCO calculation even though these assumptions are provided in the CARB ACT ISOR. Ramboll uses the cost assumptions in CARB ACT ISOR to estimate infrastructure upgrade costs.

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[33] CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

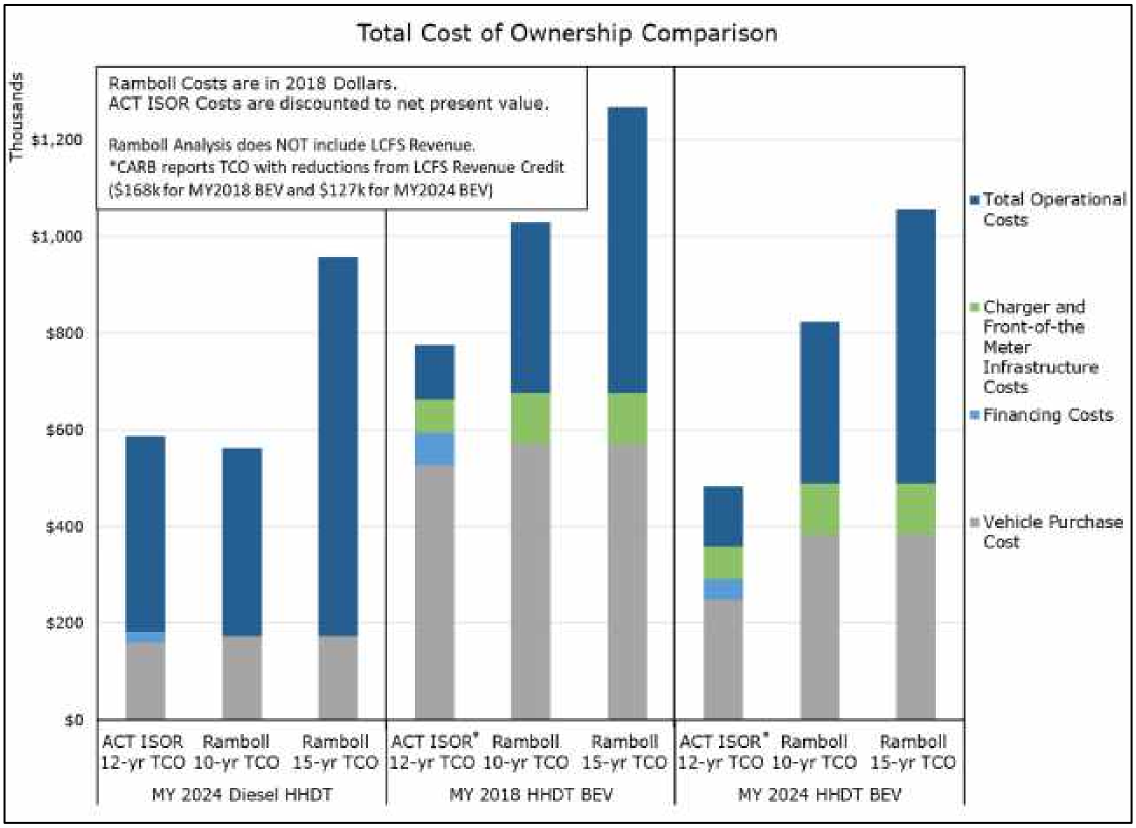

Figure 6-3. Comparison between Ramboll and CARB ACT TCO Analyses

Among the above-mentioned differences in CARB's and Ramboll's analysis approach, the primary driver for the significantly lower TCO for BEV's in CARB's analysis is the revenue generated from LCFS credits. CARB has potentially under-represented BEV operational costs by assuming significant LCFS credit offsets and projecting electricity prices up to 10% lower than those presented in the US Department of Energy's (US DOE) Annual Energy Outlook (AEO) 2018.[34] CARB estimates that LCFS credit revenues of roughly $130,000 to $170,000 per truck can be used to offset already low electricity fuel costs. This assumption fails to consider that LCFS credit revenue depends on future market conditions and availability of credit deficits from the production of higher carbon intensity fuels. Availability of LCFS credits out to the 10-15-year lifetime of a truck has not been demonstrated. Further, with the large-scale electrification of trucks that CARB is considering in the 2020 MSS, BEV truck operators who do not have the real estate to install chargers at their facility will likely charge their vehicles at private/public charging stations. There operators would; therefore, be unable to reap the benefits of LCFS credits which would go the charging station owners.

CARB's economic analysis assumes a 1:1 BEV to diesel vehicle replacement ratio, an assumption that ignores the operational implications of BEV usage in the HDT sector and provides a favorable TCO for HD BEVs compared to the diesel HDT that they replace. Previous studies on HD BEVs, specifically bus fleet operations, have shown that due to increased vehicle weight, limited battery range, long

[34] EIA AEO 2018. Table 3 Fuel Prices for the Pacific Region. Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2018&region=1-9&cases=ref2018&start=2016&end=2050&f=A&linechart=ref2018-d121317a.3-3-AEO2018.1-9&map=ref2018-d121317a.4-3-AEO2018.1-9&sourcekey=0. Accessed: January 2021.

charging times and unfavorable charging windows, more than one battery electric bus (BEB) will be needed to replace a conventional diesel bus. For example, some transit agencies have found that BEBs are unable to be used on many of their "route blocks" (a route block is a vehicle schedule, the daily assignment for an individual bus). The Victor Valley Transit Agency found that BEBs can only be used on 15 of their 56 route blocks, with the optimistic assumption that BEBs are able to achieve ranges of 250 miles.[35]

Lastly, CARB's economic analysis uses highly optimistic vehicle price projections for BEVs in 2024 and beyond. As described in more detail in **Section 5.3**, these price projections rely on optimistic battery price assumptions from Bloomberg Energy's light duty vehicle battery costs,[36] and as such may overestimate the cost savings from the purchase of BEVs.

6.2 Cost Effectiveness Results

Cost-effectiveness is the measure of the cost (in dollars) of a projected vehicle technology for each ton of emissions reduced. In Ramboll's TCO analysis, NO_X tailpipe cost effectiveness is calculated by dividing the incremental TCO of a vehicle (compared to a conventional diesel HHDT) by the total lifetime tailpipe NO_X emissions reductions (compared to that of a conventional diesel HHDT). A negative cost effectiveness indicates that an HHDT technology has a lower cost compared to that of a conventional diesel HHDT and, as such, is highly cost effective in achieving emission reductions.

Figure 6-4 and Figure 6-5 show the NO_X tailpipe cost effectiveness for analyzed HHDT technology types for a 10-year and 15-year truck life, respectively. The red line illustrates the typical maximum regulatory cost effectiveness of roughly $50,000/ton of NO_x reductions.[37] The cost-effectiveness values for Low NO_X Diesel and Low NO_X NG HHDT are well below this value when considering a 10-year or 15-year truck life and are <u>always</u> more cost-effective than the BEVs. The BEV-2018 is 2 to almost 8 times less cost-effective than the typical maximum regulatory threshold of $50,000/ton of NO_X reductions (15-year and 10-year truck life, respectively). If battery costs drop as assumed by CARB 2016 HD battery paper, operational cost savings materialize (given the concerns raised above about realizing the LCFS credits), and additional behind-the-meter electrical infrastructure costs are not accounted for, the BEV-2024 cost-effectiveness is below $50,000/ton of NO_X reductions for a 15-year truck life because of the increased operational cost benefits and NO_X reductions achieved over

[35] Presentation by the Victor Valley Transit Agency at the 2019 California Desert Air Working Group. Available at: https://www.mdaqmd.ca.gov/home/showdocument?id=6973. Accessed December 2020.

[36] Bloomberg 2019 Better Batteries Report. Available at: https://www.bloomberg.com/quicktake/batteries. Accessed: December 2020.

[37] This value was estimated based on a review of the following documents:

- Cost effectiveness values for CARB's on-road heavy-duty mobile source measures reported in the SCAQMD's 2016 AQMP range from a negative value to $296,000. Available at: http://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/final/sociofinal_030817.pdf?sfvrsn=2. Accessed: January 2021.
- CARB's Carl Moyer Program uses a maximum cost effectiveness limit of $30,000 per weighted ton of emission reductions to evaluate funding eligibility. Available at: https://ww3.arb.ca.gov/msprog/moyer/guidelines/2017gl/2017_cmp_gl_volume_1.pdf. Accessed: January 2021.
- SCAQMD's guidance for evaluating Best Available Control Technology (BACT) uses a maximum cost effectiveness value of ~$29,000 per ton of NO_x reductions. Available at: http://www.aqmd.gov/docs/default-source/bact/cost-effectiveness-values/bact-cost-effectiveness-4th-qtr-2019.pdf. Accessed: January 2021.

the additional 5-year truck life, but is still less cost-effective than the other low-emission trucks by a factor of 2 or greater.

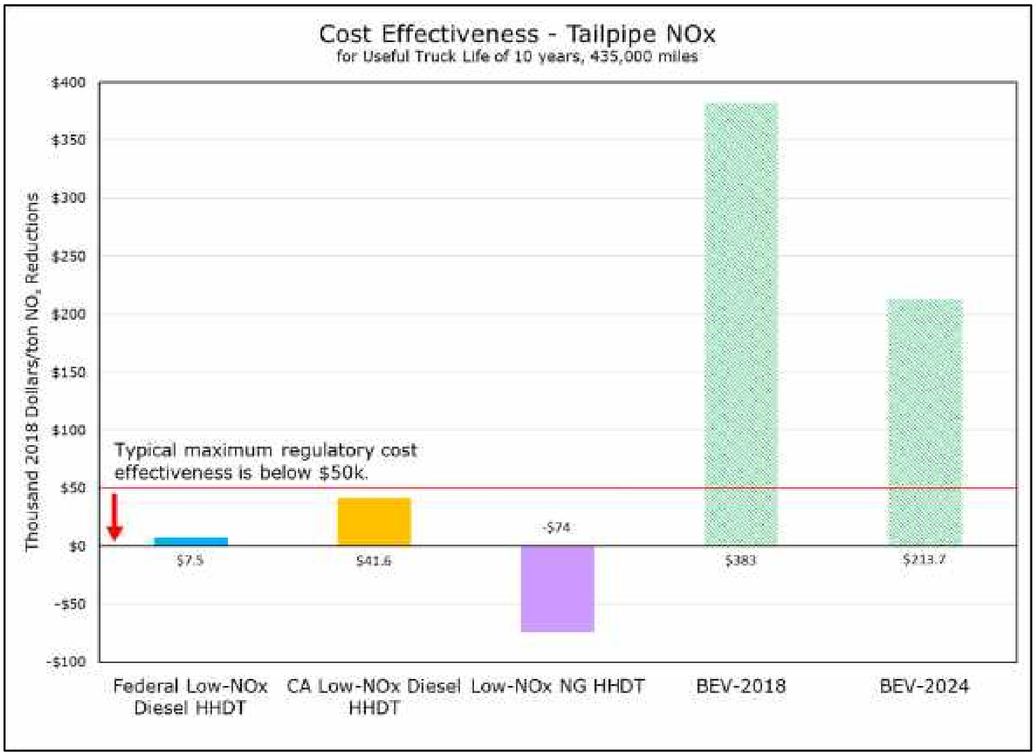

Figure 6-4. Tailpipe NO_X Cost-Effectiveness for a 10-year Truck Life

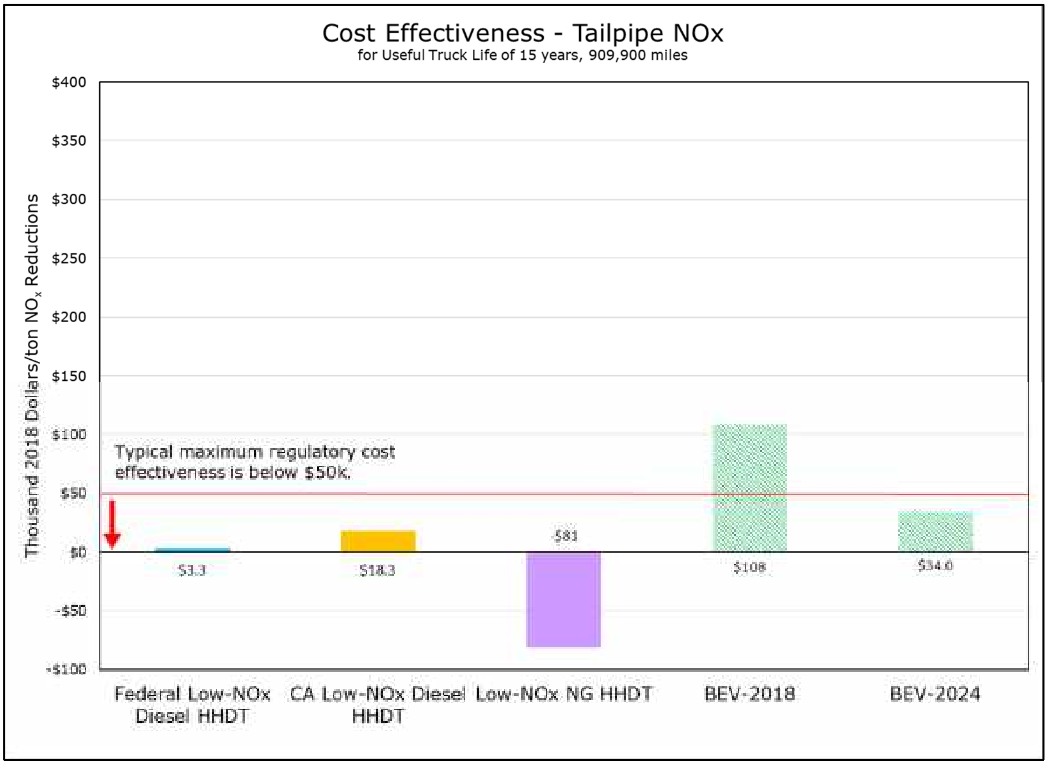

Figure 6-5. Tailpipe NO_X Cost Effectiveness for a 15-year Truck Life

6.3 Data Gaps and Key Concerns

There are a number of data gaps and concerns surrounding the assumptions used in the TCO analysis. These are discussed briefly in the following sub-sections.

6.3.1 Battery Costs and Availability

As shown in **Table 6-1** below, the CARB ACT regulation provided four data sources to future cost projections of batteries used in HHDTs. For the economic analysis that CARB performed for the ACT regulation, they used the data point that was most favorable to BEVs, Bloomberg Energy's light-duty (LD) battery cost assumptions[38] with a five-year delay, that projects a 52% decline in HHDT BEV purchase costs by 2024 as compared to 2018. As shown in **Figure 6-6**, by using the Bloomberg "5-year LD delay" projections, heavy-duty battery costs would be comparable to light-duty battery costs by 2024. This assumption that HD battery costs will see similar price declines as LD batteries has not been substantiated by existing HD battery reports. According to US DOE's 2019 Report[39] on medium- and heavy-duty vehicle (MHDV) electrification, while LDV battery costs have reduced substantially, these reductions have not been realized in the MHDV sector due to low volume purchases and customized pack specifications. The report states that MHDV-specific requirements such as high lifetime mileage, deeper discharges per cycle, overall ruggedness, and resistance to temperature extremes, along with low sales volumes are likely result in incremental vehicle costs as high as 50%-100% of the price of a conventional truck. Given these considerations, Ramboll TCO

[38] Bloomberg 2019 Better Batteries Report. Available at: https://www.bloomberg.com/quicktake/batteries. Accessed: December 2020.

[39] US DOE Medium- and Heavy-Duty Vehicle Electrification Report. Available at: https://info.ornl.gov/sites/publications/Files/Pub136575.pdf. Accessed: January 2021.

analysis conservatively uses battery cost assumptions from CARB's HD Battery Report,[40] rather than the Bloomberg "5-year LD delay" projections, to calculate the purchase cost of a MY2024 BEV. Note, for MY2018 BEV, Ramboll Analysis used purchase cost assumptions from the Bloomberg "5-year LD delay" to be consistent with CARB assumptions. BEV purchase costs used in the Ramboll TCO analysis are bolded in **Table 6-1** below.

Table 6-1. BEV Purchase Cost (without tax) by Battery Cost Source

	CARB HD Battery Paper[1]	**CARB ACT ISOR[2] (Bloomberg 5-yr LD Delay)**	**ICCT HD Battery Estimate[1]**	**Bloomberg LD Projection[1]**
2018 HHDT BEV Purchase Cost[3]	$437,706	**$474,930**	$288,368	$238,944
2024 HHDT BEV Purchase Cost[3]	**$320,374**	$232,155	$236,111	$193,251

Notes:

[1] These purchase costs are pulled from the CARB ACT Draft Cost Calculator, which is an attachment to the ACT ISOR rulemaking documents. Available at: https://ww2.arb.ca.gov/sites/default/files/2019-05/190508tcocalc_2.xlsx. Accessed: December 2020.

[2] These purchase costs are pulled from Table 5 of the CARB ACT ISOR Appendix H (Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: November 2020.). Note, these values are slightly different from outputs in the CARB ACT Draft Cost Calculator.

[3] These costs assume the purchase of a 510 kWh BEV and do not include tax.

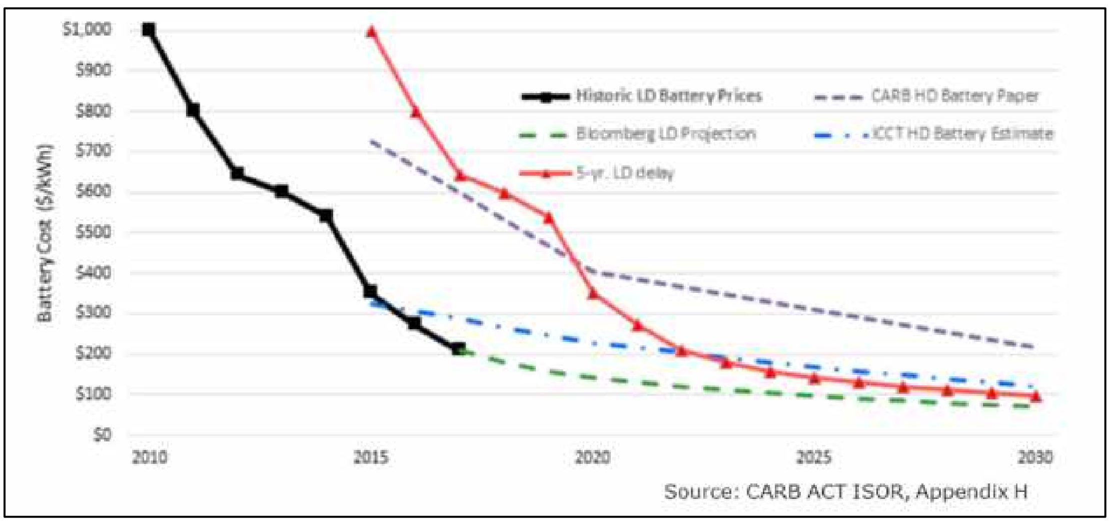

Figure 6-6. Battery Cost Projections from the CARB ACT ISOR[41]

[40] CARB 2016 Battery Cost for Heavy-Duty Electric Vehicles. Available at: https://www.arb.ca.gov/msprog/bus/battery_cost.pdf. Accessed: December 2020.

[41] CARB ACT ISOR Appendix H. Available at: Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: November 2020.

6.3.2 Government Electricity Price Projections

The CARB ACT ISOR[25] projects electricity prices at rates lower than those reported by the US Energy Information Administration (EIA) Annual Energy Outlooks (AEO) for 2018[34] and 2019[42] for the Pacific Region. As shown in **Figure 6-7** below, CARB ACT ISOR[25] sources its electricity prices from EIA AEO 2018 report and adjusts prices to be roughly $0.02/kWh lower than those reported in the 2018 report. Since CARB ACT ISOR[25] has not substantiated these lower electricity cost projections, the Ramboll Cost Analysis uses electricity prices from the most recent AEO released in 2019. **Appendix B** provides more information regarding fuel prices used in the Ramboll Cost Analysis.

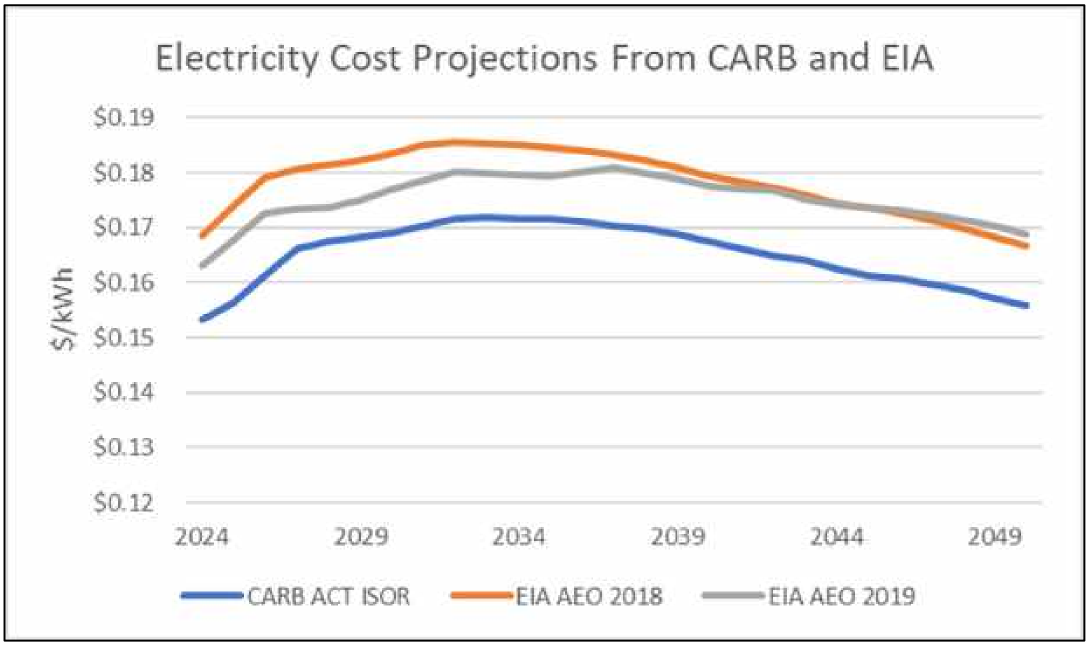

Figure 6-7. Electricity Cost Projections

6.3.3 Lack of Publicly Available Information to Make Renewable Fuel Availability and Price Projections

Due to limited literature surrounding projections of renewable fuel production and prices, Ramboll was unable to analyze the availability of renewable fuels needed to meet the fuel volumes of the renewable fuel scenarios (Scenarios "B1", "C1" and "C2"). Existing literature reports recent growth in California renewable fuel usage, with biodiesel usage tripling between 2015 and 2019 and RNG increasing by 475% in the same time frame.[43] In 2019, roughly 80% of California transportation NG usage was comprised of RNG. US RNG production is expected to grow by a factor of ten between 2025 and

[42] EIA AEO 2019. Table 3 Fuel Prices for the Pacific Region. Available at: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2019&region=1-9&cases=ref2019&start=2017&end=2050&f=A&linechart=ref2019-d111618a.3-3-AEO2019.1-9&map=ref2019-d111618a.4-3-AEO2019.1-9&sourcekey=0. Accessed: December 2020.

[43] GNA, 2020. The State of Sustainable Fleets 2020. Available at: https://www.stateofsustainablefleets.com/. Accessed: January 2021.

2040.[44] While research reports promise the growth of renewable fuels, more detailed data on fuel production and price projections are needed to access the feasibility and cost effectiveness of the renewable scenarios presented in the Ramboll Scenario and Cost analysis. Current retail prices for renewable diesel are available from the US DOE,[45] nonetheless, these reports do not provide price projections.

6.3.4 Other Unaccounted-for Costs

Additional data gaps include the need to estimate costs of increased grid generating capacity, expanded transmission and distribution (T&D), and grid impacts due to increased renewables demand in order to meet increasing electricity usage that would result from electrification of the mobile sector.

While infrastructure needed for gaseous fuel production is not expected to expand significantly, electrification strategies would require additional infrastructure upgrades. This would include, for example, the addition of in-route charging facilities for point-to-point delivery. Analyzing these additional charging infrastructure costs, among other grid related improvements, would require close collaboration with other government agencies in order to estimate and prepare for such a transition.

In 2020, Energy Marketers of America (EMA) conducted a national utility infrastructure study which concluded that EV transmission and distribution (T&D) infrastructure costs would be roughly $5,100 per EV for an average 10-year vehicle life.[46] This study reviewed three nation-wide 2030 electrification scenarios of light-duty EVs and on-road freight EVs. Depending on the EV penetration scenario, total T&D investments can range from $35–$146 billion by 2030. If these costs were borne solely by EV owners, each owner would have to pay more than $500 a year per EV or $9 every time they completely charge their 75-kWh battery vehicle. Given the results of this study, further research is needed to estimate the cost of new EV infrastructure in California.

Lastly, recent regulatory reporting by California transit agencies strongly cautions against uncritically accepting CARB's estimates of electric vehicle and related infrastructure costs. Recent reports from transit agencies[47,48,49,50] have shown that CARB projections[51] in the Innovative Clean Transit (ICT) regulation are significantly different from real world experiences. As seen in the graph below, these reports have demonstrated that Transit operators face BEV charging infrastructure costs significantly higher than CARB ICT estimates. some transit agencies have found that zero emission buses (ZEBs)

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[44] American Gas Foundation, 2019. Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment, Figure 6. Available at: https://gasfoundation.org/2019/12/18/renewable-sources-of-natural-gas/. Accessed: January 2021.

[45] US Department of Energy Alternative Fuels Data Center, Alternative Fuel Price Report. Available online at: https://afdc.energy.gov/fuels/prices.html. Accessed: January 2021.

[46] EMA Utility Investments and Consumer Costs of Electric Vehicle Charging Infrastructure. Available at: https://www.energymarketersofamerica.org/ema_today/attachments/Energy_Marketers_of_America_Study-Utility_Infrastructure_for_EVs.pdf. Accessed: January 2021.

[47] AC Transit Rollout Plan. Available at: http://www.actransit.org/wp-content/uploads/AC-Transit-ZEB-Rollout-Plan_06102020.pdf. Accessed: January 2021.

[48] Foothill Transit Rollout Plan. Available at: http://foothilltransit.org/wp-content/uploads/2014/05/Burns-McDonnell-In-Depot-Charging-and-Planning-Study.pdf. Accessed: January 2021.

[49] Long Beach Transit ZEB Rollout Plan. Available at: https://cafcp.org/sites/default/files/Long-Beach-Transit-Zero-Emission-Rollout-Plan.pdf. Accessed: January 2021.

[50] Omnitrans ZEB Rollout Plan. Available at: https://www.gosbcta.com/wp-content/uploads/2020/05/Final-Omnitrans-Rollout-Plan.pdf. Accessed: January 2021.

[51] CARB ICT Cost Calculator. Available at: https://ww2.arb.ca.gov/resources/documents/battery-electric-truck-and-bus-charging-cost-calculator. Accessed: January 2021.

are unable to be used on many of their "route blocks" (a route block is a vehicle schedule, the daily assignment for an individual bus). Further, the Victor Valley Transit Agency found that ZEBs can only be used on 15 of their 56 route blocks, with the optimistic assumption that ZEBs are able to achieve ranges of 250 miles.[52] These concerns may also affect medium- and heavy-duty fleets. For example, this may result in:

- the need for fleets to purchase more ZEVs to meet the same operating capacity as the vehicles they are replacing;
- fleet operators finding that portions of their fleet cannot run their full routes; and
- infrastructure costs significantly higher than cost estimates.

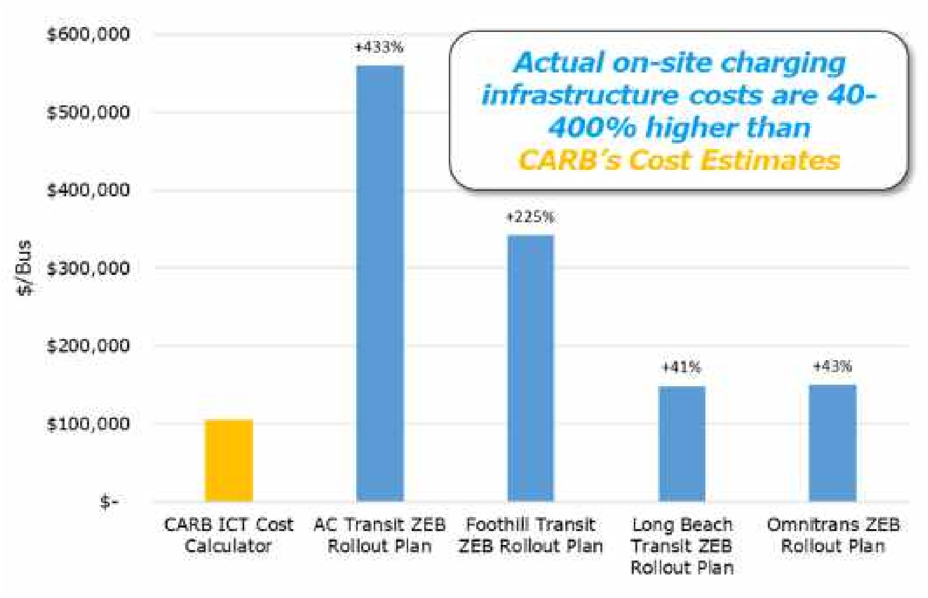

Figure 6-8. Zero Emission Bus (ZEB) Depot Charging Infrastructure Costs

[52] Presentation by the Victor Valley Transit Agency at the 2019 California Desert Air Working Group. Available at: https://www.mdaqmd.ca.gov/home/showdocument?id=6973. Accessed October 2020.

7. CONCLUSIONS

7.1 Summary of Analysis Conclusions

Ramboll's analysis suggests that expanded implementation of zero-emission and low-NO_X vehicles, coupled with increased introduction of renewable liquid and gaseous fuels, can deliver earlier and more cost-effective benefits than a ZEV only approach. As advanced low-emitting trucks are commercially available to deliver benefits to communities sooner, with greater certainty, multi-technology pathways can help achieve emission reductions without reliance on infrastructure and technology upgrades that will take years to resolve. The main conclusions of our analysis are summarized below:

Meeting Emission Goals

- Near-term NO_X reductions and long-term GHG goals can be achieved with a mix of advanced low-emitting trucks and renewable fuels;
- A ZEV-only strategy will not deliver required near-term NO_X reductions needed in at-risk environmental justice communities;
- BEV technology has potential for longer-term emission benefits, but relies upon technology and infrastructure developments outside CARB's control or ability to incentivize; and
- There is a growing potential for renewable fuels, including those with negative carbon intensity, to meet long-term GHG reductions.

Achieving Cost effectiveness

- Low-emission heavy-heavy-duty trucks are cost-competitive with (or cheaper than) BEVs;
- Battery technology promises (greater energy density/lower cost) have been assumed but have not been demonstrated; and
- Low-emission heavy-heavy-duty trucks are currently certified and commercially available at scale today.[53]

These conclusions emphasize the need for CARB to conduct a similar analysis across all mobile source sectors, not just the heavy-heavy-duty truck sector, in order to identify existing opportunities to meet state emission goals earlier and more cost effectively.

7.2 Next Steps- Technical

By focusing on a strategy that relies on only on ZEVs, CARB's Mobile Source Strategy falls short of its Clean Air Act commitments to deliver ready, dependable near-term benefits. As such robust scenario analysis coupled with a fleet wide cost-benefit analysis should instead be conducted to develop a reasonable and achievable strategy for California's mobile source sector to meet state emission goals. Such an analysis should build out and evaluate multiple scenarios beyond the singular pathway proposed in the current MSS draft. This includes scenarios that assess the increased use of renewable liquid and gaseous fuels and low-NO_X technologies, as well as the use of market-based emission reduction strategies like Cap-and-Trade, to achieve emission reductions. Further, each scenario must be evaluated for technical feasibility, and as such would require an analysis of future fueling

[53] Optional Low NO_X Certified Heavy-Duty Engines. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/msprog/onroad/optionnox/optional_low_nox_certified_hd_engines.pdf. Accessed: January 2021.

availability. This would include an assessment of electric grid reliability and availability of infrastructure that would be needed to support a potential transition to a larger ZEV fleet.

In addition to the exploration of multiple scenarios, CARB should assess all associated cost of each MSS scenario in order to identify cost-effective pathways to achieving the state's emission goals. This would include providing citations and justifications for assumptions of projected costs and, as necessary, include a range of potential costs when uncertainty is determined to be high. Further, a robust economic analysis is needed to identity the economic impacts on affected stakeholders.

Performing a robust feasibility and cost analysis as laid out in this section will help to provide the public, stakeholders, and the legislature with sufficient information to make informed decisions about the path to achieving California's emission goals.

7.3 Next Steps- Regulatory

In conducting technical analysis that will inform policy decisions, CARB should remain transparent and unbiased in the rulemaking process. As part of this process, CARB should conduct technical working groups to foster stakeholder participation in scenario development and assessment. Such coordination will help to address cost data gaps identified in **Section 5.3.** and ensure that reasonable and achievable strategies are developed in accordance with SB 44 requirements.

Our analysis confirms that a ZEV-centric approach that only focuses on long-term reductions will not provide the necessary near-term reductions needed to attain federal health standards in the most affected communities in California. With the urgency to achieve near-term criteria pollutant emission reductions, CARB must explore a variety of multi-technology pathways that can help the state achieve faster and surer emission reductions to fulfil its commitment to AB 617 communities and non-attainment areas. For longer-term greenhouse gas reduction goals, CARB should consider a variety of multi-technology pathways to broaden the use of lower carbon-intensity fuels and carbon capture technologies to complement electrification (with attendant statewide infrastructure improvement costs and delays) to reduce greenhouse gas emissions.

APPENDIX A
SCENARIO ANALYSIS ASSUMPTIONS AND DETAILED METHODOLOGY

This Appendix describes the methodology used to calculate tailpipe and upstream emissions for the Ramboll scenario analysis. A list of all tables accompanying this appendix is located after this analysis description. Refer to **Table A-1** provides a list of the analysed scenarios. Refer to **Section 2** of the main document for further details on the scenarios.

Tailpipe Emissions

CARB's EMFAC2017 model[1] was used to estimate tailpipe emissions for oxides of nitrogen (NO_X) and greenhouse gases (GHGs) for all heavy-heavy duty trucks (HHDT) types included in this analysis. Because Ramboll's analysis considers a sub-set of the statewide heavy duty vehicle (HDV) fleet consisting of diesel HHDTs excluding solid waste collection vehicles (SWCV), EMFAC2017 was queried separately for all HHDTs and for SWCVs. First, EMFAC2017 was queried at the statewide level for scenario analysis years 2020, 2023, 2031, 2037, 2045 and 2050 to obtain total exhaust emissions, population, and fuel consumption data for all diesel HHDTs by model year. Specific inputs used in this query are as follows:

- Run Mode: Emissions
- Region Type: Statewide
- Region: California
- Calendar Year: 2020, 2023, 2031, 2037, 2045 and 2050
- Season: Annual
- Vehicle Category: EMFAC2007 Categories - HHDT
- Model Year: All Model Years
- Speed: Aggregated
- Fuel: DSL

Subsequently, EMFAC2017 was queried for all calendar years listed above using the same configuration but for T7 SWCVs using EMFAC2011 vehicle categories. All EMFAC outputs are included in **Table A-2 through Table A-43.**

To obtain data for the adjusted statewide HHDT fleet considered in this analysis, EMFAC outputs for diesel T7 SWCVs were subtracted from corresponding EMFAC outputs for all diesel HHDTs (which included diesel T7 SWCV) for each calendar year. The resulting data, representative of total exhaust emissions, population, and fuel consumption for the statewide diesel HHDT fleet excluding T7 SWCVs, was used to determine emissions and fuel consumption in the baseline scenario S0.

For the other scenarios considered in this analysis, tailpipe emissions for alternative technology HHDTs were calculated based on the adjusted EMFAC2017 data, fleet mix percentages, and the tailpipe emissions assumptions in **Table 3-2** of the main document. Specifically, total NO_X emissions for each calendar year in each scenario were determined using the percentage of the fleet comprised of each HHDT type in each model year and the percentage reduction in NO_X emissions relative to conventional diesel HHDT for each

[1] EMFAC2017 Database v1.0.2. Note this analysis was conducted before the release of EMFAC2017 v.1.0.3. Available at: https://arb.ca.gov/emfac/2017/. Accessed January 2021.

alternative HHDT technology type. Thus, tailpipe emissions were determined first on a per model year basis to account for the population of each HHDT type in each model year and the reduction in tailpipe NO_X emissions achieved by each HHDT type, and total emissions in each calendar year were calculated as the sum of tailpipe emissions across all HHDT types and all model years in that calendar year.

The fleet mix composition for each model year in each calendar year was determined based on the specific technology penetration assumptions for each scenario, as described in **Section 2** of the main document and shown in **Table A-1**. Similar to the 2020 MSS, accelerated turnover of older model year HHDTs to newer vehicles is assumed in all scenarios for calendar years 2031, 2037, 2045, and 2050, and calendar year 2023 for Scenario S4. Specifically, Ramboll's analysis assumes that a fraction of pre-2024 model year (i.e., all model years up to and including 2023) diesel HHDTs are retired and replaced with newer model year alternative HHDT technologies (i.e., low-NOx diesel, low-NOx NG, BEVs) in order to achieve 2020 MSS targets for conventional diesel HHDTs (i.e., Pre-2010 and 2010 Cert.) and the required penetration of newer, alternative HHDT technologies specific to each scenario in the target calendar years. The following describes the procedure used to implement accelerated turnover:

- First, the percentage of the EMFAC-derived HHDT population comprised of pre-2024 vehicles is determined for each target calendar year and compared to the percentage given in CARB's 2020 MSS Long Term Fleet Mix.
- The ratio of these to percentages provides the scaling factor that is used to determine the number of HHDTs in each pre-2024 model year that should be retired, and the population of HHDTs in all model years up to and including 2023 is adjusted accordingly.
- Next, the scaling factor for newer model year HHDTs is determined to ensure that the same number of trucks retried are allocated to the newer model years. This scaling factor is then applied to the EMFAC-derived population of all post-2023 model year HHDTs to obtain the adjusted population data.
- The resulting adjusted HHDT population data for each model year is then used as the basis to determine the fleet mix composition, which are based on the specific technology penetration assumptions for each scenario.

Accelerated turnover calculations are carried out separately for each calendar year but consistently across all scenarios, such that the scaling factors and number of trucks turned over varies between calendar years but is the same across all scenarios in a given calendar year. The resulting fleet mix population data for each scenario, aggregated by model year, is presented in **Figure 3-2** of the main document. Detailed population breakdown by HHDT technology type and model year for each calendar year are presented in **Table A-2 through Table A-43.**

Tailpipe emissions for GHGs are calculated using the same general methodology as tailpipe NO_X emissions. Note however that only BEVs provide a reduction in tailpipe GHG emissions and all other HHDT types are assumed to have the same tailpipe GHG emissions as conventional diesel HHDTs, as described in **Table 3-2** of the main document. Specifically, BEVs are assumed to have zero tailpipe emissions of CO_2, CH_4, and N_2O. GHG emissions are reported in units of carbon dioxide equivalent (CO_2e). CO_2e is calculated based on CO_2, CH_4, and N_2O emissions, using global warming potentials (GWPs) from the International Panel on

Climate Change (IPCC) Fourth Assessment Report (AR4).[2] The GWPs used for CO_2, CH_4, and N_2O are 1, 25, and 298, respectively.

GREET Model Inputs and Assumptions

Ramboll estimated well-to-tank (i.e., "upstream") NO_X and GHG emissions associated with fuel production and distribution for each analyzed fuel type (electricity, diesel, natural gas, renewable diesel from tallow, and renewable natural gas from landfill gas) using emission factors obtained from the CA-GREET 3.0 model. A summary of these emission factors is provided in **Table A-44**.

For purposes of this analysis, Ramboll adjusted the electricity grid mix inputs to the CA-GREET 3.0 model based on California Energy Commission (CEC) current grid mix data[3] and projections for each of the modeled calendar years 2020, 2023, 2031, 2037, 2045 and 2050.[4] **Table A-45** summarizes electricity grid mix inputs into the GREET model.

Ramboll also updated the default assumptions for renewable fuels transportation distances within CA-GREET 3.0 to more accurately represent fuel production and distribution within California. RNG pipeline distance is taken from CARB CA-GREET NG distribution assumptions.[5] Tallow and renewable diesel transportation distances are updated based on biodiesel rendering and retail facilities in California, as reported by Argonne National Laboratory[6] (ANL) and the Environmental Defense Fund.[7] Details regarding the adjusted metrics are provided in **Table A-46**.

As the conventional fuels are not expected to be sourced by in-state feedstock only, this analysis assumes that feedstock electricity mix for conventional fuels comes from a U.S. average grid mix. Electricity grid mix for production and processing of all fuels was assumed to come from a California grid-average electricity mix (CAMx).

Emission factors from CA-GREET 3.0 are obtained per unit of energy consumed for each fuel type. In order to calculate total upstream emissions for each scenario, the total amount of energy consumed of each fuel type is calculated using Energy Economy Ratios (EERs). EERs are dimensionless values that represent the efficiency of a fuel as used in a powertrain as compared to a reference fuel used in the same powertrain. A summary of EER values used in this analysis are provided in **Table A-47**. EER values for Low-NOx Diesel and NG trucks were

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[2] Greenhouse Gas Protocol. Available at: https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf. Accessed January 2021

[3] California Energy Commission 2018 Grid Mix Data. Available at: https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2018-total-system-electric-generation. Accessed December 2020.

[4] CEC 2018. Deep Decarbonization in a High Renewables Future - Implications for Renewable Integration and Electric System Flexibility, Docket 18-IEPR-06 - 223869, Slide 10. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=223869&DocumentContentId=54081. Accessed: December 2020.

[5] CA-GREET3.0 Lookup Table Pathways Technical Support Documentation. Available at: https://ww2.arb.ca.gov/sites/default/files/classic//fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: August 2020.

[6] ANL Tallow-Based Diesel Pathway in GREET. Available at: https://greet.es.anl.gov/publication-tallow-13. Accessed: August 2020.

[7] EDF Biodiesel in California. Available at: https://www.edf.org/sites/default/files/sites/default/files/content/Biodiesel%20Value%20Chain%20-%20August%202013.pdf. Accessed: August 2020.

sourced from CARB Low Carbon Fuel Standard.[8] EER values for battery electric trucks were adjusted to be consistent with HHDT BEV fuel economies reported in the CARB ACT regulation.[9]

[8] LCFS Regulation, 2019. Table 5. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed November 2020.

[9] CARB ACT Cost Calculator. Available at: https://ww2.arb.ca.gov/sites/default/files/2019-05/190508tcocalc_2.xlsx. Accessed November 2020.

APPENDIX A TABLES
SCENARIO ANALYSIS ASSUMPTIONS AND DETAILED METHODOLOGY

APPENDIX A TABLES

Ramboll HHDT Scenarios

Scenario #	Scenario Name	Assumptions	Conventional DSL	Federal Low NO_x DSL	CA Cert. Low NO_x DSL	Low NO_x NG	BEV	Fuel Pathway For Diesel and NG	Scenario Description
0	Baseline EMFAC2017	**Fleet Mix**	EMFAC2017					100% Fossil	Fleet mixes and emissions will match EMFAC2017 Baseline projections.
		Tailpipe Emission Standard							
S1-A1	CARB Long Term Fleet Mix (includes Accelerated ZEV Turnover) - Fossil Fuel	**Fleet Mix**	CARB Long-Term Fleet Mix (0% starting 2045)[1]	CARB Long-Term Fleet Mix (12% by 2050)	CARB Long-Term Fleet Mix (8% by 2050)	CARB Long-Term Fleet Mix (Assume 0% of Fleet for all years)	CARB Long-Term Fleet Mix (81% by 2050)	100% Fossil	Fleet Mixes will match CARB Long-Term Scenario.[2] Low-NO_x Diesel tailpipe emissions standards are based on CARB 2019 Proposed Standards.[3]
		Tailpipe Emission Standard	EMFAC2017	0.05 g/bhp-hr	0.05 g/bhp-hr		No Tailpipe Emissions		
S1-B1	CARB Long Term Fleet Mix (includes Accelerated ZEV Turnover) - Renewable Fuel	**Fleet Mix**	Same as 1A					100% Renewable[4] (DSL-Tallow; CNG-LFG)	
		Tailpipe Emission Standard							
S2-A1	Low NO_x CNG with ACT - Fossil Fuel	**Fleet Mix**	CARB Long-Term Fleet Mix (0% starting 2045)[1]	CARB Long-Term Fleet Mix (12% by 2050)	Assume 0% of Fleet for all Calendar Years	Remaining Fleet Mix	ACT Mandate for CA Trucks (40% by 2050)	100% Fossil	BEV fleet mixes will meet ACT ZEV Mandates[5]. Low-NO_x Diesel tailpipe emissions standards based on CARB 2019 Proposed Standards.[3] Low NOx NG standards based on CARB 2016 MSS.[6]
		Tailpipe Emission Standard	EMFAC2017	0.05 g/bhp-hr		0.02 g/bhp-hr	No Tailpipe Emissions		
S2-B1	Low NO_x CNG with ACT - Renewable Fuel	**Fleet Mix**	Same as 2A					100% Renewable[4] (DSL-Tallow; CNG-LFG)	
		Tailpipe Emission Standard							
S3-A1	Low NO_x CNG - Fossil Fuel	**Fleet Mix**	CARB Long-Term Fleet Mix (0% starting 2045)[1]	CARB Long-Term Fleet Mix (12% by 2050)	Assume 0% of Fleet for all Calendar Years	Remaining Fleet Mix	Assume 0% of Fleet for all Calendar Years	100% Fossil	No penetration of BEVs for all calendar years. Low-NO_x Diesel tailpipe emissions standards based on CARB 2019 Proposed Standards.[3] Low NO_x NG standards based on 2016 MSS.[6]
		Tailpipe Emission Standard	EMFAC2017	0.05 g/bhp-hr		0.02 g/bhp-hr			
S3-B1	Low NO_x CNG - Renewable Fuels	**Fleet Mix**	Same as 3A					100% Renewable[4] (DSL-Tallow; CNG-LFG)	
		Tailpipe Emission Standard							
S4-A1	Scenario 2 with 2016 SCAQMD AQMP - Fossil Fuel	**Fleet Mix**	CARB Long-Term Fleet Mix (0% starting 2045)[1]	CARB Long-Term Fleet Mix (12% by 2050)	Assume 0% of Fleet for all Calendar Years	2016 AQMP Fleet Mix (82,300 CNG Trucks by 2023)	ACT Mandate for CA Trucks (40% by 2050)	100% Fossil	Same as Scenario 2, but assumes early adoption of Low NOx NG vehicles to meet or exceed SCAQMD 2016 AQMP projections for 2023 and 2031.[7] Conventional DSL fleet is adjusted to accommodate early adoption of NG vehicles. BEV penetration will meet ACT ZEV Mandates.[5]
		Tailpipe Emission Standard	EMFAC2017	0.05 g/bhp-hr		0.02 g/bhp-hr	No Tailpipe Emissions		
S4-B1	Scenario 2 with 2016 SCAQMD AQMP - Renewable Fuel	**Fleet Mix**	Same as 4A					100% Renewable[4] (DSL-Tallow; CNG-LFG)	
		Tailpipe Emission Standard							
S5-A1	Low NO_x CA Diesel with ACT - Fossil Fuel	**Fleet Mix**	CARB Long-Term Fleet Mix (0% starting 2045)[1]	CARB Long-Term Fleet Mix (12% by 2050)	Remaining Fleet Mix	Assume 0% of Fleet for all Calendar Years	ACT Mandate for CA Trucks (40% by 2050)	100% Fossil	BEV fleet mixes will meet ACT ZEV Mandates[5]. No penetration of Low-NO_x NG for all calendar years. CA Low-NO_x Diesel tailpipe emissions assume 0.02 g/bhp-hr standards are achieved.
		Tailpipe Emission Standard	EMFAC2017	0.05 g/bhp-hr	0.02 g/bhp-hr		No Tailpipe Emissions		
S5-B1	Low NOx CA Diesel with ACT- Renewable Fuel	**Fleet Mix**	Same as 2A					100% Renewable[4] (DSL-Tallow; CNG-LFG)	
		Tailpipe Emission Standard							
S6-A1	Low NOx CA Diesel without ACT - Fossil Fuel	**Fleet Mix**	CARB Long-Term Fleet Mix (0% starting 2045)[1]	CARB Long-Term Fleet Mix (12% by 2050)	Remaining Fleet Mix	Assume 0% of Fleet for all Calendar Years	Assume 0% of Fleet for all Calendar Years	100% Fossil	No penetration of BEVs or Low-NO_x NG for all calendar years. CA Low-NOx Diesel tailpipe emissions assume 0.02 g/bhp-hr standards are achieved.
		Tailpipe Emission Standard	EMFAC2017	0.05 g/bhp-hr	0.02 g/bhp-hr				
S6-B1	Low NOx CA Diesel without ACT - Renewable Fuels	**Fleet Mix**	Same as 3A					100% Renewable[4] (DSL-Tallow; CNG-LFG)	
		Tailpipe Emission Standard							

Notes:

[1] All scenarios except Scenario 0 include an accelerated fleet turnover assumption similar to CARB Long Term Fleet Mix that results in 0% conventional DSL starting in 2045 and 12% Federal Low NOx DSL in 2050

[2] CARB 2020 Mobile Source Strategy March 25, 2020 Webinar Presentation. Available at: https://ww3.arb.ca.gov/planning/sip/2020mss/pres_marwbnr.pdf. Accessed: July 2020.

[3] CARB Heavy-Duty Low NOx Program September 2019 Workshop. Available at: https://ww2.arb.ca.gov/sites/default/files/classic//msprog/hdlownox/files/workgroup_20190926/staff/01_hde_standards.pdf?_ga=2.98823766.992508391.1594658953-836277372.1571089290. Accessed: July 2020.

[4] Renewable diesel and natural gas are assumed to have zero tailpipe CO_2 emissions.

[5] CARB Advanced Clean Truck Rule. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/30dayattb.pdf. Accessed: July 2020.

[6] CARB 2016 Mobile Source Strategy. Available at: https://ww2.arb.ca.gov/resources/documents/2016-mobile-source-strategy. Accessed: July 2020.

[7] SCAQMD 2016 AQMP Final Socioeconomic Report Appendix 2-A. Available at: https://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/final/appfinal_030817.pdf?sfvrsn=2. Accessed: July 2020.

Abbreviations:

ACT - Advanced Clean Truck Rule
AQMP - Air Quality Management Plan
BEV - battery electric vehicle
bhp-hr - break horsepower hour
CA Cert. - California certified
CARB - California Air Resources Board
CNG - compressed natural gas
CO_2 - carbon dioxide
DSL - diesel
g - gram
HHDT - heavy-heavy-duty truck
LFG - landfill gas
MSS - Mobile Source Strategy
NG - natural gas
NOx - oxides of nitrogen
SCAQMD - South Coast Air Quality Management District
ZEV - zero emission vehicle

Model Year	EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	29	0.02	1.7	0.000	0.000	0.15	100%	29	19,871
1977	34	0.02	2.3	0.000	0.000	0.20	100%	34	27,331
1978	66	0.04	3.9	0.000	0.001	0.35	100%	66	47,207
1979	94	0.05	5.0	0.000	0.001	0.44	100%	94	59,761
1980	87	0.05	5.1	0.000	0.001	0.45	100%	87	61,143
1981	258	0.15	15	0.000	0.002	1.3	100%	258	180,361
1982	236	0.13	13	0.000	0.002	1.2	100%	236	156,209
1983	219	0.13	13	0.000	0.002	1.1	100%	219	151,257
1984	274	0.18	18	0.000	0.003	1.6	100%	274	214,575
1985	404	0.25	25	0.000	0.004	2.2	100%	404	301,188
1986	396	0.25	25	0.000	0.004	2.2	100%	396	301,092
1987	426	0.29	27	0.000	0.004	2.4	100%	426	324,223
1988	484	0.34	32	0.000	0.005	2.9	100%	484	387,591
1989	567	0.40	38	0.000	0.006	3.4	100%	567	454,438
1990	539	0.39	37	0.000	0.006	3.3	100%	539	446,862
1991	475	0.34	28	0.000	0.004	2.5	100%	475	335,098
1992	399	0.31	25	0.000	0.004	2.2	100%	399	301,877
1993	363	0.29	25	0.000	0.004	2.2	100%	363	295,585
1994	379	0.31	28	0.000	0.004	2.5	100%	379	330,512
1995	507	0.41	37	0.000	0.006	3.3	100%	507	443,837
1996	1,142	1.8	150	0.006	0.02	13	100%	1,142	1,800,897
1997	1,167	1.8	149	0.006	0.02	13	100%	1,167	1,790,241
1998	1,370	2.2	192	0.008	0.03	17	100%	1,370	2,305,455
1999	1,972	4.1	291	0.01	0.05	26	100%	1,972	3,484,066
2000	4,067	9.0	641	0.02	0.10	57	100%	4,067	7,683,603
2001	3,153	6.6	476	0.02	0.07	42	100%	3,153	5,706,180
2002	2,427	4.6	338	0.01	0.05	30	100%	2,427	4,046,083
2003	2,907	3.5	425	0.01	0.07	38	100%	2,907	5,088,912
2004	2,913	3.0	421	0.01	0.07	38	100%	2,913	5,047,803
2005	4,812	5.1	719	0.02	0.11	64	100%	4,812	8,613,212
2006	5,968	6.9	972	0.03	0.15	87	100%	5,968	11,650,876
2007	8,303	9.5	1,454	0.03	0.23	130	100%	8,303	17,419,576
2008	12,274	13	2,417	0.02	0.38	215	100%	12,274	28,960,284
2009	14,354	16	3,080	0.03	0.48	275	100%	14,354	36,913,677
2010	11,383	13	2,653	0.02	0.42	236	100%	11,383	31,795,323
2011	13,627	10	3,166	0.01	0.50	282	100%	13,627	37,940,166
2012	39,297	19	6,724	0.01	1.1	599	100%	39,297	80,581,115
2013	21,084	14	5,397	0.010	0.85	481	100%	21,084	64,680,893
2014	23,061	12	5,525	0.01	0.87	492	100%	23,061	66,207,976
2015	28,916	14	7,779	0.02	1.2	693	100%	28,916	93,222,050
2016	41,998	22	12,488	0.02	2.0	1,113	100%	41,998	149,658,452
2017	16,101	6.6	3,944	0.008	0.62	351	100%	16,101	47,265,405
2018	12,688	5.9	3,720	0.007	0.58	332	100%	12,688	44,579,225
2019	12,851	5.6	3,844	0.007	0.60	343	100%	12,851	46,069,473
2020	8,537	3.3	2,461	0.004	0.39	219	100%	8,537	29,496,897
2021	4,246	1.1	575	0.002	0.09	51	100%	4,246	6,891,960

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	0%	0	0	0%	0	0	0%	0	0
1977	0%	0	0	0%	0	0	0%	0	0
1978	0%	0	0	0%	0	0	0%	0	0
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
1976	0%	0	0	0.02	1.7	0.000	0.000
1977	0%	0	0	0.02	2.3	0.000	0.000
1978	0%	0	0	0.04	3.9	0.000	0.001
1979	0%	0	0	0.05	5.0	0.000	0.001
1980	0%	0	0	0.05	5.1	0.000	0.001
1981	0%	0	0	0.15	15	0.000	0.002
1982	0%	0	0	0.13	13	0.000	0.002
1983	0%	0	0	0.13	13	0.000	0.002
1984	0%	0	0	0.18	18	0.000	0.003
1985	0%	0	0	0.25	25	0.000	0.004
1986	0%	0	0	0.25	25	0.000	0.004
1987	0%	0	0	0.29	27	0.000	0.004
1988	0%	0	0	0.34	32	0.000	0.005
1989	0%	0	0	0.40	38	0.000	0.006
1990	0%	0	0	0.39	37	0.000	0.006
1991	0%	0	0	0.34	28	0.000	0.004
1992	0%	0	0	0.31	25	0.000	0.004
1993	0%	0	0	0.29	25	0.000	0.004
1994	0%	0	0	0.31	28	0.000	0.004
1995	0%	0	0	0.41	37	0.000	0.006
1996	0%	0	0	1.8	150	0.006	0.02
1997	0%	0	0	1.8	149	0.006	0.02
1998	0%	0	0	2.2	192	0.008	0.03
1999	0%	0	0	4.1	291	0.01	0.05
2000	0%	0	0	9.0	641	0.02	0.10
2001	0%	0	0	6.6	476	0.02	0.07
2002	0%	0	0	4.6	338	0.01	0.05
2003	0%	0	0	3.5	425	0.01	0.07
2004	0%	0	0	3.0	421	0.01	0.07
2005	0%	0	0	5.1	719	0.02	0.11
2006	0%	0	0	6.9	972	0.03	0.15
2007	0%	0	0	9.5	1,454	0.03	0.23
2008	0%	0	0	13	2,417	0.02	0.38
2009	0%	0	0	16	3,080	0.03	0.48
2010	0%	0	0	13	2,653	0.02	0.42
2011	0%	0	0	10	3,166	0.01	0.50
2012	0%	0	0	19	6,724	0.01	1.1
2013	0%	0	0	14	5,397	0.010	0.85
2014	0%	0	0	12	5,525	0.01	0.87
2015	0%	0	0	14	7,779	0.02	1.2
2016	0%	0	0	22	12,488	0.02	2.0
2017	0%	0	0	6.6	3,944	0.008	0.62
2018	0%	0	0	5.9	3,720	0.007	0.58
2019	0%	0	0	5.6	3,844	0.007	0.60
2020	0%	0	0	3.3	2,461	0.004	0.39
2021	0%	0	0	1.1	575	0.002	0.09

Notes:

[1] EMFAC data shown here are obtained directly from EMFAC2017.

[2] Fleet mix percentages in this scenario are obtained directly from EMFAC2017.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the EMFAC data.

[4] Energy consumption is calculated based on EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are obtained directly from EMFAC2017 in this scenario.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	53	0.03	2.9	0.000	0.000	0.26	100%	53	35,019
1980	64	0.04	3.7	0.000	0.001	0.33	100%	64	44,086
1981	209	0.12	12	0.000	0.002	1.1	100%	209	142,790
1982	208	0.11	11	0.000	0.002	1.0	100%	208	134,214
1983	196	0.11	11	0.000	0.002	1.0	100%	196	131,088
1984	241	0.15	15	0.000	0.002	1.3	100%	241	176,822
1985	357	0.21	21	0.000	0.003	1.9	100%	357	252,082
1986	331	0.20	20	0.000	0.003	1.8	100%	331	243,579
1987	345	0.22	21	0.000	0.003	1.9	100%	345	253,082
1988	370	0.26	24	0.000	0.004	2.2	100%	370	290,997
1989	420	0.29	28	0.000	0.004	2.5	100%	420	332,355
1990	382	0.28	27	0.000	0.004	2.4	100%	382	319,401
1991	331	0.24	20	0.000	0.003	1.8	100%	331	238,471
1992	279	0.22	18	0.000	0.003	1.6	100%	279	214,037
1993	235	0.20	17	0.000	0.003	1.5	100%	235	202,566
1994	257	0.21	19	0.000	0.003	1.7	100%	257	228,163
1995	341	0.29	26	0.000	0.004	2.3	100%	341	308,497
1996	354	0.29	26	0.000	0.004	2.3	100%	354	309,827
1997	358	0.27	24	0.000	0.004	2.2	100%	358	292,799
1998	350	0.29	27	0.000	0.004	2.4	100%	350	324,850
1999	484	0.48	38	0.000	0.006	3.4	100%	484	458,610
2000	570	0.55	44	0.000	0.007	3.9	100%	570	522,449
2001	630	0.52	42	0.000	0.007	3.7	100%	630	502,288
2002	683	0.50	41	0.000	0.006	3.7	100%	683	490,906
2003	607	0.31	41	0.000	0.006	3.7	100%	607	491,836
2004	588	0.27	39	0.000	0.006	3.4	100%	588	462,594
2005	722	0.33	48	0.000	0.008	4.3	100%	722	579,188
2006	789	0.37	53	0.000	0.008	4.7	100%	789	635,640
2007	1,010	0.43	69	0.000	0.01	6.1	100%	1,010	822,391
2008	958	0.24	51	0.000	0.008	4.5	100%	958	608,971
2009	1,054	0.24	57	0.000	0.009	5.1	100%	1,054	681,595
2010	516	0.11	28	0.000	0.004	2.5	100%	516	336,250
2011	601	0.08	32	0.000	0.005	2.8	100%	601	381,333
2012	36,456	15	5,160	0.010	0.81	460	100%	36,456	61,840,416
2013	23,385	13	4,715	0.009	0.74	420	100%	23,385	56,503,770
2014	25,954	12	4,907	0.01	0.77	437	100%	25,954	58,805,403
2015	43,313	18	8,476	0.02	1.3	755	100%	43,313	101,582,009
2016	51,092	25	12,180	0.03	1.9	1,086	100%	51,092	145,975,230
2017	45,093	20	10,301	0.02	1.6	918	100%	45,093	123,455,483
2018	15,699	7.6	3,880	0.008	0.61	346	100%	15,699	46,494,284
2019	15,755	7.5	4,119	0.008	0.65	367	100%	15,755	49,364,115
2020	14,758	7.0	4,076	0.008	0.64	363	100%	14,758	48,851,177
2021	13,866	6.3	3,442	0.008	0.54	307	100%	13,866	41,250,943
2022	13,999	6.1	3,590	0.008	0.56	320	100%	13,999	43,027,237
2023	9,671	3.7	2,395	0.005	0.38	213	100%	9,671	28,707,076
2024	4,843	1.3	599	0.003	0.09	53	100%	4,843	7,172,863

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
1979	0%	0	0	0.03	2.9	0.000	0.000
1980	0%	0	0	0.04	3.7	0.000	0.001
1981	0%	0	0	0.12	12	0.000	0.002
1982	0%	0	0	0.11	11	0.000	0.002
1983	0%	0	0	0.11	11	0.000	0.002
1984	0%	0	0	0.15	15	0.000	0.002
1985	0%	0	0	0.21	21	0.000	0.003
1986	0%	0	0	0.20	20	0.000	0.003
1987	0%	0	0	0.22	21	0.000	0.003
1988	0%	0	0	0.26	24	0.000	0.004
1989	0%	0	0	0.29	28	0.000	0.004
1990	0%	0	0	0.28	27	0.000	0.004
1991	0%	0	0	0.24	20	0.000	0.003
1992	0%	0	0	0.22	18	0.000	0.003
1993	0%	0	0	0.20	17	0.000	0.003
1994	0%	0	0	0.21	19	0.000	0.003
1995	0%	0	0	0.29	26	0.000	0.004
1996	0%	0	0	0.29	26	0.000	0.004
1997	0%	0	0	0.27	24	0.000	0.004
1998	0%	0	0	0.29	27	0.000	0.004
1999	0%	0	0	0.48	38	0.000	0.006
2000	0%	0	0	0.55	44	0.000	0.007
2001	0%	0	0	0.52	42	0.000	0.007
2002	0%	0	0	0.50	41	0.000	0.006
2003	0%	0	0	0.31	41	0.000	0.006
2004	0%	0	0	0.27	39	0.000	0.006
2005	0%	0	0	0.33	48	0.000	0.008
2006	0%	0	0	0.37	53	0.000	0.008
2007	0%	0	0	0.43	69	0.000	0.01
2008	0%	0	0	0.24	51	0.000	0.008
2009	0%	0	0	0.24	57	0.000	0.009
2010	0%	0	0	0.11	28	0.000	0.004
2011	0%	0	0	0.08	32	0.000	0.005
2012	0%	0	0	15	5,160	0.010	0.81
2013	0%	0	0	13	4,715	0.009	0.74
2014	0%	0	0	12	4,907	0.01	0.77
2015	0%	0	0	18	8,476	0.02	1.3
2016	0%	0	0	25	12,180	0.03	1.9
2017	0%	0	0	20	10,301	0.02	1.6
2018	0%	0	0	7.6	3,880	0.008	0.61
2019	0%	0	0	7.5	4,119	0.008	0.65
2020	0%	0	0	7.0	4,076	0.008	0.64
2021	0%	0	0	6.3	3,442	0.008	0.54
2022	0%	0	0	6.1	3,590	0.008	0.56
2023	0%	0	0	3.7	2,395	0.005	0.38
2024	0%	0	0	1.3	599	0.003	0.09

Notes:

[1] EMFAC data shown here are obtained directly from EMFAC2017.

[2] Fleet mix percentages in this scenario are obtained directly from EMFAC2017.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the EMFAC data.

[4] Energy consumption is calculated based on EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are obtained directly from EMFAC2017 in this scenario.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	175	0.10	9.4	0.000	0.001	0.84	100%	175	112,374
1988	235	0.13	13	0.000	0.002	1.1	100%	235	151,922
1989	294	0.17	16	0.000	0.002	1.4	100%	294	189,030
1990	270	0.16	15	0.000	0.002	1.3	100%	270	177,527
1991	233	0.15	12	0.000	0.002	1.1	100%	233	142,277
1992	183	0.12	10	0.000	0.002	0.87	100%	183	116,485
1993	140	0.09	7.9	0.000	0.001	0.71	100%	140	95,261
1994	138	0.09	8.0	0.000	0.001	0.71	100%	138	96,100
1995	170	0.11	10	0.000	0.002	0.91	100%	170	122,715
1996	167	0.11	10	0.000	0.002	0.90	100%	167	120,764
1997	163	0.11	10	0.000	0.002	0.85	100%	163	114,460
1998	153	0.11	10	0.000	0.002	0.90	100%	153	120,608
1999	208	0.18	14	0.000	0.002	1.3	100%	208	169,415
2000	246	0.21	17	0.000	0.003	1.5	100%	246	198,328
2001	281	0.21	17	0.000	0.003	1.5	100%	281	204,106
2002	317	0.22	18	0.000	0.003	1.6	100%	317	211,549
2003	287	0.14	18	0.000	0.003	1.6	100%	287	211,008
2004	291	0.12	18	0.000	0.003	1.6	100%	291	209,839
2005	372	0.16	23	0.000	0.004	2.0	100%	372	273,985
2006	425	0.19	27	0.000	0.004	2.4	100%	425	319,695
2007	573	0.24	37	0.000	0.006	3.3	100%	573	445,598
2008	595	0.15	31	0.000	0.005	2.8	100%	595	371,545
2009	690	0.15	36	0.000	0.006	3.2	100%	690	433,363
2010	356	0.07	19	0.000	0.003	1.7	100%	356	222,974
2011	441	0.05	22	0.000	0.004	2.0	100%	441	267,310
2012	19,805	6.6	2,242	0.004	0.35	200	100%	19,805	26,866,514
2013	11,462	5.5	2,037	0.003	0.32	182	100%	11,462	24,410,727
2014	13,052	5.1	2,102	0.004	0.33	187	100%	13,052	25,194,573
2015	23,841	8.4	3,662	0.007	0.58	326	100%	23,841	43,882,716
2016	26,961	10	4,078	0.01	0.64	363	100%	26,961	48,868,299
2017	31,181	10	4,244	0.009	0.67	378	100%	31,181	50,860,206
2018	10,710	4.0	1,675	0.004	0.26	149	100%	10,710	20,074,268
2019	12,144	4.7	1,963	0.005	0.31	175	100%	12,144	23,528,898
2020	13,758	5.7	2,379	0.006	0.37	212	100%	13,758	28,508,004
2021	15,079	6.5	2,397	0.006	0.38	214	100%	15,079	28,725,379
2022	17,317	8.0	2,991	0.008	0.47	267	100%	17,317	35,843,367
2023	23,269	12	4,495	0.01	0.71	401	100%	23,269	53,863,869
2024	20,136	10	3,698	0.01	0.58	330	100%	20,136	44,323,511
2025	20,975	11	4,195	0.01	0.66	374	100%	20,975	50,271,835
2026	20,497	11	4,412	0.01	0.69	393	100%	20,497	52,879,863
2027	20,024	11	4,331	0.01	0.68	386	100%	20,024	51,907,076
2028	18,309	9.4	4,128	0.01	0.65	368	100%	18,309	49,470,673
2029	17,211	8.4	3,970	0.010	0.62	354	100%	17,211	47,574,498
2030	16,613	7.6	3,900	0.010	0.61	348	100%	16,613	46,733,779
2031	10,661	4.3	2,402	0.006	0.38	214	100%	10,661	28,788,156
2032	5,437	1.4	644	0.003	0.10	57	100%	5,437	7,713,862

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	0%	0	0	0%	0	0	0%	0	0
2025	0%	0	0	0%	0	0	0%	0	0
2026	0%	0	0	0%	0	0	0%	0	0
2027	0%	0	0	0%	0	0	0%	0	0
2028	0%	0	0	0%	0	0	0%	0	0
2029	0%	0	0	0%	0	0	0%	0	0
2030	0%	0	0	0%	0	0	0%	0	0
2031	0%	0	0	0%	0	0	0%	0	0
2032	0	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1987	0%	0	0	0.10	9.4	0.000	0.001
1988	0%	0	0	0.13	13	0.000	0.002
1989	0%	0	0	0.17	16	0.000	0.002
1990	0%	0	0	0.16	15	0.000	0.002
1991	0%	0	0	0.15	12	0.000	0.002
1992	0%	0	0	0.12	10	0.000	0.002
1993	0%	0	0	0.09	7.9	0.000	0.001
1994	0%	0	0	0.09	8.0	0.000	0.001
1995	0%	0	0	0.11	10	0.000	0.002
1996	0%	0	0	0.11	10	0.000	0.002
1997	0%	0	0	0.11	10	0.000	0.002
1998	0%	0	0	0.11	10	0.000	0.002
1999	0%	0	0	0.18	14	0.000	0.002
2000	0%	0	0	0.21	17	0.000	0.003
2001	0%	0	0	0.21	17	0.000	0.003
2002	0%	0	0	0.22	18	0.000	0.003
2003	0%	0	0	0.14	18	0.000	0.003
2004	0%	0	0	0.12	18	0.000	0.003
2005	0%	0	0	0.16	23	0.000	0.004
2006	0%	0	0	0.19	27	0.000	0.004
2007	0%	0	0	0.24	37	0.000	0.006
2008	0%	0	0	0.15	31	0.000	0.005
2009	0%	0	0	0.15	36	0.000	0.006
2010	0%	0	0	0.07	19	0.000	0.003
2011	0%	0	0	0.05	22	0.000	0.004
2012	0%	0	0	6.6	2,242	0.004	0.35
2013	0%	0	0	5.5	2,037	0.003	0.32
2014	0%	0	0	5.1	2,102	0.004	0.33
2015	0%	0	0	8.4	3,662	0.007	0.58
2016	0%	0	0	10	4,078	0.01	0.64
2017	0%	0	0	10	4,244	0.009	0.67
2018	0%	0	0	4.0	1,675	0.004	0.26
2019	0%	0	0	4.7	1,963	0.005	0.31
2020	0%	0	0	5.7	2,379	0.006	0.37
2021	0%	0	0	6.5	2,397	0.006	0.38
2022	0%	0	0	8.0	2,991	0.008	0.47
2023	0%	0	0	12	4,495	0.01	0.71
2024	0%	0	0	10	3,698	0.01	0.58
2025	0%	0	0	11	4,195	0.01	0.66
2026	0%	0	0	11	4,412	0.01	0.69
2027	0%	0	0	11	4,331	0.01	0.68
2028	0%	0	0	9.4	4,128	0.01	0.65
2029	0%	0	0	8.4	3,970	0.010	0.62
2030	0%	0	0	7.6	3,900	0.010	0.61
2031	0%	0	0	4.3	2,402	0.006	0.38
2032	0%	0	0	1.4	644	0.003	0.10

Notes:

[1] EMFAC data shown here are obtained directly from EMFAC2017.

[2] Fleet mix percentages in this scenario are obtained directly from EMFAC2017.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the EMFAC data.

[4] Energy consumption is calculated based on EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are obtained directly from EMFAC2017 in this scenario.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
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gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	75	0.05	3.9	0.000	0.001	0.35	100%	75	47,317
1994	94	0.05	4.8	0.000	0.001	0.42	100%	94	57,084
1995	130	0.07	6.7	0.000	0.001	0.59	100%	130	79,873
1996	134	0.08	6.8	0.000	0.001	0.61	100%	134	81,980
1997	131	0.07	6.6	0.000	0.001	0.59	100%	131	79,331
1998	117	0.07	6.4	0.000	0.001	0.57	100%	117	76,415
1999	150	0.11	8.5	0.000	0.001	0.76	100%	150	101,977
2000	166	0.12	10	0.000	0.002	0.85	100%	166	114,626
2001	181	0.12	10	0.000	0.002	0.88	100%	181	118,851
2002	193	0.13	10	0.000	0.002	0.90	100%	193	121,512
2003	164	0.07	9.3	0.000	0.001	0.83	100%	164	111,673
2004	161	0.06	9.1	0.000	0.001	0.81	100%	161	108,865
2005	200	0.08	12	0.000	0.002	1.0	100%	200	139,150
2006	227	0.10	13	0.000	0.002	1.2	100%	227	160,976
2007	306	0.12	19	0.000	0.003	1.7	100%	306	225,401
2008	329	0.08	17	0.000	0.003	1.5	100%	329	201,692
2009	389	0.09	20	0.000	0.003	1.8	100%	389	239,857
2010	206	0.04	10	0.000	0.002	0.94	100%	206	125,743
2011	263	0.03	13	0.000	0.002	1.1	100%	263	153,971
2012	8,969	2.7	905	0.002	0.14	81	100%	8,969	10,850,749
2013	4,884	2.3	844	0.001	0.13	75	100%	4,884	10,111,625
2014	5,575	2.3	920	0.002	0.14	82	100%	5,575	11,024,466
2015	10,887	4.2	1,802	0.003	0.28	161	100%	10,887	21,597,772
2016	11,839	4.2	1,806	0.004	0.28	161	100%	11,839	21,639,565
2017	15,963	4.4	1,940	0.004	0.30	173	100%	15,963	23,245,601
2018	5,542	1.9	779	0.002	0.12	69	100%	5,542	9,330,010
2019	6,531	2.2	908	0.002	0.14	81	100%	6,531	10,880,678
2020	7,555	2.6	1,064	0.002	0.17	95	100%	7,555	12,750,708
2021	8,675	3.0	1,060	0.003	0.17	94	100%	8,675	12,701,740
2022	10,535	3.8	1,347	0.004	0.21	120	100%	10,535	16,143,648
2023	13,855	5.9	2,024	0.005	0.32	180	100%	13,855	24,261,600
2024	13,533	5.3	1,724	0.005	0.27	154	100%	13,533	20,662,715
2025	15,085	6.2	2,019	0.006	0.32	180	100%	15,085	24,194,862
2026	16,881	7.2	2,375	0.007	0.37	212	100%	16,881	28,459,718
2027	18,671	8.3	2,646	0.008	0.42	236	100%	18,671	31,706,518
2028	20,424	10	3,093	0.009	0.49	276	100%	20,424	37,072,964
2029	21,972	11	3,583	0.01	0.56	319	100%	21,972	42,935,501
2030	23,020	12	4,027	0.01	0.63	359	100%	23,020	48,263,523
2037	23,699	12	4,465	0.01	0.70	398	100%	23,699	53,515,434
2032	23,052	12	4,643	0.01	0.73	414	100%	23,052	55,644,560
2033	22,627	12	4,837	0.01	0.76	431	100%	22,627	57,966,231
2034	20,981	11	4,668	0.01	0.73	416	100%	20,981	55,937,866
2035	19,875	10	4,533	0.01	0.71	404	100%	19,875	54,328,050
2036	18,831	8.6	4,372	0.01	0.69	390	100%	18,831	52,390,503
2037	11,862	4.7	2,651	0.006	0.42	236	100%	11,862	31,768,688
2038	6,109	1.6	710	0.003	0.11	63	100%	6,109	8,512,215

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	0%	0	0	0%	0	0	0%	0	0
2025	0%	0	0	0%	0	0	0%	0	0
2026	0%	0	0	0%	0	0	0%	0	0
2027	0%	0	0	0%	0	0	0%	0	0
2028	0%	0	0	0%	0	0	0%	0	0
2029	0%	0	0	0%	0	0	0%	0	0
2030	0%	0	0	0%	0	0	0%	0	0
2037	0%	0	0	0%	0	0	0%	0	0
2032	0%	0	0	0%	0	0	0%	0	0
2033	0%	0	0	0%	0	0	0%	0	0
2034	0%	0	0	0%	0	0	0%	0	0
2035	0%	0	0	0%	0	0	0%	0	0
2036	0%	0	0	0%	0	0	0%	0	0
2037	0%	0	0	0%	0	0	0%	0	0
2038	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1993	0%	0	0	0.05	3.9	0.000	0.001
1994	0%	0	0	0.05	4.8	0.000	0.001
1995	0%	0	0	0.07	6.7	0.000	0.001
1996	0%	0	0	0.08	6.8	0.000	0.001
1997	0%	0	0	0.07	6.6	0.000	0.001
1998	0%	0	0	0.07	6.4	0.000	0.001
1999	0%	0	0	0.11	8.5	0.000	0.001
2000	0%	0	0	0.12	10	0.000	0.002
2001	0%	0	0	0.12	10	0.000	0.002
2002	0%	0	0	0.13	10	0.000	0.002
2003	0%	0	0	0.07	9.3	0.000	0.001
2004	0%	0	0	0.06	9.1	0.000	0.001
2005	0%	0	0	0.08	12	0.000	0.002
2006	0%	0	0	0.10	13	0.000	0.002
2007	0%	0	0	0.12	19	0.000	0.003
2008	0%	0	0	0.08	17	0.000	0.003
2009	0%	0	0	0.09	20	0.000	0.003
2010	0%	0	0	0.04	10	0.000	0.002
2011	0%	0	0	0.03	13	0.000	0.002
2012	0%	0	0	2.7	905	0.002	0.14
2013	0%	0	0	2.3	844	0.001	0.13
2014	0%	0	0	2.3	920	0.002	0.14
2015	0%	0	0	4.2	1,802	0.003	0.28
2016	0%	0	0	4.2	1,806	0.004	0.28
2017	0%	0	0	4.4	1,940	0.004	0.30
2018	0%	0	0	1.9	779	0.002	0.12
2019	0%	0	0	2.2	908	0.002	0.14
2020	0%	0	0	2.6	1,064	0.002	0.17
2021	0%	0	0	3.0	1,060	0.003	0.17
2022	0%	0	0	3.8	1,347	0.004	0.21
2023	0%	0	0	5.9	2,024	0.005	0.32
2024	0%	0	0	5.3	1,724	0.005	0.27
2025	0%	0	0	6.2	2,019	0.006	0.32
2026	0%	0	0	7.2	2,375	0.007	0.37
2027	0%	0	0	8.3	2,646	0.008	0.42
2028	0%	0	0	10	3,093	0.009	0.49
2029	0%	0	0	11	3,583	0.01	0.56
2030	0%	0	0	12	4,027	0.01	0.63
2037	0%	0	0	12	4,465	0.01	0.70
2032	0%	0	0	12	4,643	0.01	0.73
2033	0%	0	0	12	4,837	0.01	0.76
2034	0%	0	0	11	4,668	0.01	0.73
2035	0%	0	0	10	4,533	0.01	0.71
2036	0%	0	0	8.6	4,372	0.01	0.69
2037	0%	0	0	4.7	2,651	0.006	0.42
2038	0%	0	0	1.6	710	0.003	0.11

Notes:

[1] EMFAC data shown here are obtained directly from EMFAC2017.

[2] Fleet mix percentages in this scenario are obtained directly from EMFAC2017.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the EMFAC data.

[4] Energy consumption is calculated based on EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are obtained directly from EMFAC2017 in this scenario.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Table A-6. NOx and GHG Tailpipe Emissions for Scenario 0 in Calendar Year 2045

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	92	0.06	4.7	0.000	0.001	0.42	100%	92	55,864
2002	126	0.08	6.1	0.000	0.001	0.55	100%	126	73,692
2003	117	0.05	5.8	0.000	0.001	0.52	100%	117	69,583
2004	117	0.04	5.8	0.000	0.001	0.52	100%	117	69,938
2005	141	0.05	7.1	0.000	0.001	0.63	100%	141	84,978
2006	149	0.06	7.7	0.000	0.001	0.68	100%	149	91,926
2007	186	0.07	10	0.000	0.002	0.89	100%	186	119,191
2008	190	0.05	9.4	0.000	0.001	0.84	100%	190	113,113
2009	208	0.05	10	0.000	0.002	0.93	100%	208	124,512
2010	103	0.02	5.1	0.000	0.001	0.45	100%	103	60,761
2011	124	0.01	5.8	0.000	0.001	0.52	100%	124	69,981
2012	3,164	0.88	279	0.001	0.04	25	100%	3,164	3,344,913
2013	1,607	0.74	266	0.000	0.04	24	100%	1,607	3,183,366
2014	1,758	0.74	291	0.001	0.05	26	100%	1,758	3,492,142
2015	3,339	1.4	569	0.001	0.09	51	100%	3,339	6,824,423
2016	3,387	1.2	514	0.001	0.08	46	100%	3,387	6,158,622
2017	4,827	1.2	537	0.001	0.08	48	100%	4,827	6,430,112
2018	1,762	0.58	238	0.001	0.04	21	100%	1,762	2,851,512
2019	2,149	0.69	284	0.001	0.04	25	100%	2,149	3,404,717
2020	2,509	0.83	339	0.001	0.05	30	100%	2,509	4,060,186
2021	2,963	1.0	350	0.001	0.06	31	100%	2,963	4,200,368
2022	3,605	1.2	440	0.001	0.07	39	100%	3,605	5,271,072
2023	4,481	1.5	550	0.001	0.09	49	100%	4,481	6,596,556
2024	5,241	1.7	576	0.002	0.09	51	100%	5,241	6,908,530
2025	6,104	2.0	676	0.002	0.11	60	100%	6,104	8,100,000
2026	7,152	2.4	794	0.002	0.12	71	100%	7,152	9,515,611
2027	8,184	2.8	872	0.003	0.14	78	100%	8,184	10,447,069
2028	9,405	3.2	1,001	0.003	0.16	89	100%	9,405	11,995,147
2029	10,888	3.8	1,166	0.004	0.18	104	100%	10,888	13,973,007
2030	12,611	4.4	1,359	0.004	0.21	121	100%	12,611	16,288,180
2045	14,300	5.4	1,661	0.005	0.26	148	100%	14,300	19,910,222
2032	16,271	6.5	2,006	0.006	0.32	179	100%	16,271	24,038,562
2033	18,271	7.6	2,358	0.007	0.37	210	100%	18,271	28,256,371
2034	20,665	9.0	2,802	0.008	0.44	250	100%	20,665	33,577,632
2035	22,814	10	3,274	0.010	0.51	292	100%	22,814	39,232,932
2036	24,632	12	3,762	0.01	0.59	335	100%	24,632	45,082,949
2037	26,123	13	4,272	0.01	0.67	381	100%	26,123	51,193,009
2038	26,997	14	4,724	0.01	0.74	421	100%	26,997	56,619,599
2039	27,480	14	5,157	0.01	0.81	460	100%	27,480	61,800,167
2040	26,050	14	5,193	0.01	0.82	463	100%	26,050	62,236,336
2041	25,105	13	5,312	0.01	0.83	473	100%	25,105	63,663,029
2042	22,635	11	4,974	0.01	0.78	443	100%	22,635	59,613,985
2043	21,270	10	4,789	0.01	0.75	427	100%	21,270	57,388,548
2044	20,106	9.0	4,590	0.01	0.72	409	100%	20,106	55,011,066
2045	12,634	5.0	2,768	0.007	0.44	247	100%	12,634	33,169,181
2046	6,495	1.7	741	0.004	0.12	66	100%	6,495	8,884,377

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	0%	0	0	0%	0	0	0%	0	0
2025	0%	0	0	0%	0	0	0%	0	0
2026	0%	0	0	0%	0	0	0%	0	0
2027	0%	0	0	0%	0	0	0%	0	0
2028	0%	0	0	0%	0	0	0%	0	0
2029	0%	0	0	0%	0	0	0%	0	0
2030	0%	0	0	0%	0	0	0%	0	0
2045	0%	0	0	0%	0	0	0%	0	0
2032	0%	0	0	0%	0	0	0%	0	0
2033	0%	0	0	0%	0	0	0%	0	0
2034	0%	0	0	0%	0	0	0%	0	0
2035	0%	0	0	0%	0	0	0%	0	0
2036	0%	0	0	0%	0	0	0%	0	0
2037	0%	0	0	0%	0	0	0%	0	0
2038	0%	0	0	0%	0	0	0%	0	0
2039	0%	0	0	0%	0	0	0%	0	0
2040	0%	0	0	0%	0	0	0%	0	0
2041	0%	0	0	0%	0	0	0%	0	0
2042	0%	0	0	0%	0	0	0%	0	0
2043	0%	0	0	0%	0	0	0%	0	0
2044	0%	0	0	0%	0	0	0%	0	0
2045	0%	0	0	0%	0	0	0%	0	0
2046	0%	0	0	0%	0	0	0%	0	0

	BEV			Tailpipe Emission Estimates[5] (tons/day)			
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2001	0%	0	0	0.06	4.7	0.000	0.001
2002	0%	0	0	0.08	6.1	0.000	0.001
2003	0%	0	0	0.05	5.8	0.000	0.001
2004	0%	0	0	0.04	5.8	0.000	0.001
2005	0%	0	0	0.05	7.1	0.000	0.001
2006	0%	0	0	0.06	7.7	0.000	0.001
2007	0%	0	0	0.07	10	0.000	0.002
2008	0%	0	0	0.05	9.4	0.000	0.001
2009	0%	0	0	0.05	10	0.000	0.002
2010	0%	0	0	0.02	5.1	0.000	0.001
2011	0%	0	0	0.01	5.8	0.000	0.001
2012	0%	0	0	0.88	279	0.001	0.04
2013	0%	0	0	0.74	266	0.000	0.04
2014	0%	0	0	0.74	291	0.001	0.05
2015	0%	0	0	1.4	569	0.001	0.09
2016	0%	0	0	1.2	514	0.001	0.08
2017	0%	0	0	1.2	537	0.001	0.08
2018	0%	0	0	0.58	238	0.001	0.04
2019	0%	0	0	0.69	284	0.001	0.04
2020	0%	0	0	0.83	339	0.001	0.05
2021	0%	0	0	1.0	350	0.001	0.06
2022	0%	0	0	1.2	440	0.001	0.07
2023	0%	0	0	1.5	550	0.001	0.09
2024	0%	0	0	1.7	576	0.002	0.09
2025	0%	0	0	2.0	676	0.002	0.11
2026	0%	0	0	2.4	794	0.002	0.12
2027	0%	0	0	2.8	872	0.003	0.14
2028	0%	0	0	3.2	1,001	0.003	0.16
2029	0%	0	0	3.8	1,166	0.004	0.18
2030	0%	0	0	4.4	1,359	0.004	0.21
2045	0%	0	0	5.4	1,661	0.005	0.26
2032	0%	0	0	6.5	2,006	0.006	0.32
2033	0%	0	0	7.6	2,358	0.007	0.37
2034	0%	0	0	9.0	2,802	0.008	0.44
2035	0%	0	0	10	3,274	0.010	0.51
2036	0%	0	0	12	3,762	0.01	0.59
2037	0%	0	0	13	4,272	0.01	0.67
2038	0%	0	0	14	4,724	0.01	0.74
2039	0%	0	0	14	5,157	0.01	0.81
2040	0%	0	0	14	5,193	0.01	0.82
2041	0%	0	0	13	5,312	0.01	0.83
2042	0%	0	0	11	4,974	0.01	0.78
2043	0%	0	0	10	4,789	0.01	0.75
2044	0%	0	0	9.0	4,590	0.01	0.72
2045	0%	0	0	5.0	2,768	0.007	0.44
2046	0%	0	0	1.7	741	0.004	0.12

Notes:

[1] EMFAC data shown here are obtained directly from EMFAC2017.

[2] Fleet mix percentages in this scenario are obtained directly from EMFAC2017.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the EMFAC data.

[4] Energy consumption is calculated based on EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are obtained directly from EMFAC2017 in this scenario.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	EMFAC2017 Output[1]						Conventional DSL		
Model Year	**Population**	**NOx_TOTEX (tons/day)**	**CO2_TOTEX (tons/day)**	**CH4_TOTEX (tons/day)**	**N2O_TOTEX (tons/day)**	**Fuel Consumption (1000 gal/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
2006	82	0.03	4.1	0.000	0.001	0.37	100%	82	49,174
2007	132	0.04	6.6	0.000	0.001	0.59	100%	132	79,672
2008	156	0.04	7.6	0.000	0.001	0.68	100%	156	90,995
2009	181	0.04	8.9	0.000	0.001	0.79	100%	181	106,208
2010	90	0.02	4.4	0.000	0.001	0.39	100%	90	52,143
2011	106	0.01	4.8	0.000	0.001	0.43	100%	106	57,864
2012	1,478	0.33	101	0.000	0.02	9.0	100%	1,478	1,207,021
2013	750	0.28	99	0.000	0.02	8.9	100%	750	1,192,404
2014	777	0.30	115	0.000	0.02	10	100%	777	1,374,836
2015	1,536	0.62	252	0.000	0.04	22	100%	1,536	3,021,320
2016	1,630	0.59	241	0.001	0.04	21	100%	1,630	2,889,636
2017	2,386	0.59	251	0.001	0.04	22	100%	2,386	3,002,314
2018	887	0.29	116	0.000	0.02	10	100%	887	1,390,448
2019	1,087	0.35	139	0.000	0.02	12	100%	1,087	1,669,054
2020	1,265	0.41	166	0.000	0.03	15	100%	1,265	1,987,822
2021	1,465	0.48	169	0.000	0.03	15	100%	1,465	2,020,660
2022	1,760	0.59	209	0.001	0.03	19	100%	1,760	2,502,994
2023	2,161	0.73	259	0.001	0.04	23	100%	2,161	3,102,175
2024	2,493	0.83	270	0.001	0.04	24	100%	2,493	3,239,609
2025	2,909	1.0	317	0.001	0.05	28	100%	2,909	3,802,943
2026	3,483	1.1	378	0.001	0.06	34	100%	3,483	4,525,444
2027	4,089	1.3	422	0.001	0.07	38	100%	4,089	5,058,290
2028	4,861	1.6	505	0.001	0.08	45	100%	4,861	6,057,599
2029	5,793	1.9	607	0.002	0.10	54	100%	5,793	7,272,512
2030	6,787	2.3	713	0.002	0.11	64	100%	6,787	8,549,670
2050	7,893	2.7	837	0.002	0.13	75	100%	7,893	10,032,270
2032	9,119	3.1	976	0.003	0.15	87	100%	9,119	11,701,451
2033	10,570	3.6	1,130	0.003	0.18	101	100%	10,570	13,541,512
2034	12,402	4.3	1,331	0.004	0.21	119	100%	12,402	15,952,622
2035	14,345	5.1	1,555	0.005	0.24	139	100%	14,345	18,633,374
2036	16,120	6.1	1,885	0.006	0.30	168	100%	16,120	22,588,671
2037	17,993	7.2	2,237	0.007	0.35	199	100%	17,993	26,803,159
2038	19,907	8.4	2,593	0.008	0.41	231	100%	19,907	31,070,008
2039	22,021	10	3,013	0.009	0.47	269	100%	22,021	36,113,252
2040	24,085	11	3,476	0.01	0.55	310	100%	24,085	41,659,449
2041	26,029	12	3,991	0.01	0.63	356	100%	26,029	47,825,120
2042	27,606	14	4,519	0.01	0.71	403	100%	27,606	54,152,315
2043	28,488	15	4,980	0.01	0.78	444	100%	28,488	59,679,625
2044	28,931	15	5,411	0.02	0.85	482	100%	28,931	64,850,659
2045	27,286	14	5,420	0.02	0.85	483	100%	27,286	64,956,609
2046	26,307	14	5,542	0.01	0.87	494	100%	26,307	66,420,856
2047	23,687	12	5,184	0.01	0.81	462	100%	23,687	62,130,013
2048	22,283	11	5,001	0.01	0.79	446	100%	22,283	59,930,609
2049	21,009	9.4	4,781	0.01	0.75	426	100%	21,009	57,302,967
2050	13,154	5.2	2,874	0.007	0.45	256	100%	13,154	34,442,748
2051	6,775	1.8	1,178	0.004	0.19	105	100%	6,775	14,114,877

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	0%	0	0	0%	0	0	0%	0	0
2025	0%	0	0	0%	0	0	0%	0	0
2026	0%	0	0	0%	0	0	0%	0	0
2027	0%	0	0	0%	0	0	0%	0	0
2028	0%	0	0	0%	0	0	0%	0	0
2029	0%	0	0	0%	0	0	0%	0	0
2030	0%	0	0	0%	0	0	0%	0	0
2050	0%	0	0	0%	0	0	0%	0	0
2032	0%	0	0	0%	0	0	0%	0	0
2033	0%	0	0	0%	0	0	0%	0	0
2034	0%	0	0	0%	0	0	0%	0	0
2035	0%	0	0	0%	0	0	0%	0	0
2036	0%	0	0	0%	0	0	0%	0	0
2037	0%	0	0	0%	0	0	0%	0	0
2038	0%	0	0	0%	0	0	0%	0	0
2039	0%	0	0	0%	0	0	0%	0	0
2040	0%	0	0	0%	0	0	0%	0	0
2041	0%	0	0	0%	0	0	0%	0	0
2042	0%	0	0	0%	0	0	0%	0	0
2043	0%	0	0	0%	0	0	0%	0	0
2044	0%	0	0	0%	0	0	0%	0	0
2045	0%	0	0	0%	0	0	0%	0	0
2046	0%	0	0	0%	0	0	0%	0	0
2047	0%	0	0	0%	0	0	0%	0	0
2048	0%	0	0	0%	0	0	0%	0	0
2049	0%	0	0	0%	0	0	0%	0	0
2050	0%	0	0	0%	0	0	0%	0	0
2051	0%	0	0	0%	0	0	0%	0	0

	BEV			Tailpipe Emission Estimates[5] (tons/day)			
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2006	0%	0	0	0.03	4.1	0.000	0.001
2007	0%	0	0	0.04	6.6	0.000	0.001
2008	0%	0	0	0.04	7.6	0.000	0.001
2009	0%	0	0	0.04	8.9	0.000	0.001
2010	0%	0	0	0.02	4.4	0.000	0.001
2011	0%	0	0	0.01	4.8	0.000	0.001
2012	0%	0	0	0.33	101	0.000	0.02
2013	0%	0	0	0.28	99	0.000	0.02
2014	0%	0	0	0.30	115	0.000	0.02
2015	0%	0	0	0.62	252	0.000	0.04
2016	0%	0	0	0.59	241	0.001	0.04
2017	0%	0	0	0.59	251	0.001	0.04
2018	0%	0	0	0.29	116	0.000	0.02
2019	0%	0	0	0.35	139	0.000	0.02
2020	0%	0	0	0.41	166	0.000	0.03
2021	0%	0	0	0.48	169	0.000	0.03
2022	0%	0	0	0.59	209	0.001	0.03
2023	0%	0	0	0.73	259	0.001	0.04
2024	0%	0	0	0.83	270	0.001	0.04
2025	0%	0	0	1.0	317	0.001	0.05
2026	0%	0	0	1.1	378	0.001	0.06
2027	0%	0	0	1.3	422	0.001	0.07
2028	0%	0	0	1.6	505	0.001	0.08
2029	0%	0	0	1.9	607	0.002	0.10
2030	0%	0	0	2.3	713	0.002	0.11
2050	0%	0	0	2.7	837	0.002	0.13
2032	0%	0	0	3.1	976	0.003	0.15
2033	0%	0	0	3.6	1,130	0.003	0.18
2034	0%	0	0	4.3	1,331	0.004	0.21
2035	0%	0	0	5.1	1,555	0.005	0.24
2036	0%	0	0	6.1	1,885	0.006	0.30
2037	0%	0	0	7.2	2,237	0.007	0.35
2038	0%	0	0	8.4	2,593	0.008	0.41
2039	0%	0	0	10	3,013	0.009	0.47
2040	0%	0	0	11	3,476	0.01	0.55
2041	0%	0	0	12	3,991	0.01	0.63
2042	0%	0	0	14	4,519	0.01	0.71
2043	0%	0	0	15	4,980	0.01	0.78
2044	0%	0	0	15	5,411	0.02	0.85
2045	0%	0	0	14	5,420	0.02	0.85
2046	0%	0	0	14	5,542	0.01	0.87
2047	0%	0	0	12	5,184	0.01	0.81
2048	0%	0	0	11	5,001	0.01	0.79
2049	0%	0	0	9.4	4,781	0.01	0.75
2050	0%	0	0	5.2	2,874	0.007	0.45
2051	0%	0	0	1.8	1,178	0.004	0.19

Notes:

[1] EMFAC data shown here are obtained directly from EMFAC2017.

[2] Fleet mix percentages in this scenario are obtained directly from EMFAC2017.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the EMFAC data.

[4] Energy consumption is calculated based on EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are obtained directly from EMFAC2017 in this scenario.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	29	0.02	1.7	0.000	0.000	0.15	100%	29	19,871
1977	34	0.02	2.3	0.000	0.000	0.20	100%	34	27,331
1978	66	0.04	3.9	0.000	0.001	0.35	100%	66	47,207
1979	94	0.05	5.0	0.000	0.001	0.44	100%	94	59,761
1980	87	0.05	5.1	0.000	0.001	0.45	100%	87	61,143
1981	258	0.15	15	0.000	0.002	1.3	100%	258	180,361
1982	236	0.13	13	0.000	0.002	1.2	100%	236	156,209
1983	219	0.13	13	0.000	0.002	1.1	100%	219	151,257
1984	274	0.18	18	0.000	0.003	1.6	100%	274	214,575
1985	404	0.25	25	0.000	0.004	2.2	100%	404	301,188
1986	396	0.25	25	0.000	0.004	2.2	100%	396	301,092
1987	426	0.29	27	0.000	0.004	2.4	100%	426	324,223
1988	484	0.34	32	0.000	0.005	2.9	100%	484	387,591
1989	567	0.40	38	0.000	0.006	3.4	100%	567	454,438
1990	539	0.39	37	0.000	0.006	3.3	100%	539	446,862
1991	475	0.34	28	0.000	0.004	2.5	100%	475	335,098
1992	399	0.31	25	0.000	0.004	2.2	100%	399	301,877
1993	363	0.29	25	0.000	0.004	2.2	100%	363	295,585
1994	379	0.31	28	0.000	0.004	2.5	100%	379	330,512
1995	507	0.41	37	0.000	0.006	3.3	100%	507	443,837
1996	1,142	1.8	150	0.006	0.02	13	100%	1,142	1,800,897
1997	1,167	1.8	149	0.006	0.02	13	100%	1,167	1,790,241
1998	1,370	2.2	192	0.008	0.03	17	100%	1,370	2,305,455
1999	1,972	4.1	291	0.01	0.05	26	100%	1,972	3,484,066
2000	4,067	9.0	641	0.02	0.10	57	100%	4,067	7,683,603
2001	3,153	6.6	476	0.02	0.07	42	100%	3,153	5,706,180
2002	2,427	4.6	338	0.01	0.05	30	100%	2,427	4,046,083
2003	2,907	3.5	425	0.01	0.07	38	100%	2,907	5,088,912
2004	2,913	3.0	421	0.01	0.07	38	100%	2,913	5,047,803
2005	4,812	5.1	719	0.02	0.11	64	100%	4,812	8,613,212
2006	5,968	6.9	972	0.03	0.15	87	100%	5,968	11,650,876
2007	8,303	9.5	1,454	0.03	0.23	130	100%	8,303	17,419,576
2008	12,274	13	2,417	0.02	0.38	215	100%	12,274	28,960,284
2009	14,354	16	3,080	0.03	0.48	275	100%	14,354	36,913,677
2010	11,383	13	2,653	0.02	0.42	236	100%	11,383	31,795,323
2011	13,627	10	3,166	0.01	0.50	282	100%	13,627	37,940,166
2012	39,297	19	6,724	0.01	1.1	599	100%	39,297	80,581,115
2013	21,084	14	5,397	0.010	0.85	481	100%	21,084	64,680,893
2014	23,061	12	5,525	0.01	0.87	492	100%	23,061	66,207,976
2015	28,916	14	7,779	0.02	1.2	693	100%	28,916	93,222,050
2016	41,998	22	12,488	0.02	2.0	1,113	100%	41,998	149,658,452
2017	16,101	6.6	3,944	0.008	0.62	351	100%	16,101	47,265,405
2018	12,688	5.9	3,720	0.007	0.58	332	100%	12,688	44,579,225
2019	12,851	5.6	3,844	0.007	0.60	343	100%	12,851	46,069,473
2020	8,537	3.3	2,461	0.004	0.39	219	100%	8,537	29,496,897
2021	4,246	1.1	575	0.002	0.09	51	100%	4,246	6,891,960

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	0%	0	0	0%	0	0	0%	0	0
1977	0%	0	0	0%	0	0	0%	0	0
1978	0%	0	0	0%	0	0	0%	0	0
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV Fleet Mix[2] (%)	BEV Population[3]	BEV Energy Consumption[4] (MJ/day)	Tailpipe Emission Estimates[5] (tons/day) NO_X	CO_2	CH_4	N_2O
1976	0%	0	0	0.02	1.7	0.000	0.000
1977	0%	0	0	0.02	2.3	0.000	0.000
1978	0%	0	0	0.04	3.9	0.000	0.001
1979	0%	0	0	0.05	5.0	0.000	0.001
1980	0%	0	0	0.05	5.1	0.000	0.001
1981	0%	0	0	0.15	15	0.000	0.002
1982	0%	0	0	0.13	13	0.000	0.002
1983	0%	0	0	0.13	13	0.000	0.002
1984	0%	0	0	0.18	18	0.000	0.003
1985	0%	0	0	0.25	25	0.000	0.004
1986	0%	0	0	0.25	25	0.000	0.004
1987	0%	0	0	0.29	27	0.000	0.004
1988	0%	0	0	0.34	32	0.000	0.005
1989	0%	0	0	0.40	38	0.000	0.006
1990	0%	0	0	0.39	37	0.000	0.006
1991	0%	0	0	0.34	28	0.000	0.004
1992	0%	0	0	0.31	25	0.000	0.004
1993	0%	0	0	0.29	25	0.000	0.004
1994	0%	0	0	0.31	28	0.000	0.004
1995	0%	0	0	0.41	37	0.000	0.006
1996	0%	0	0	1.8	150	0.006	0.02
1997	0%	0	0	1.8	149	0.006	0.02
1998	0%	0	0	2.2	192	0.008	0.03
1999	0%	0	0	4.1	291	0.01	0.05
2000	0%	0	0	9.0	641	0.02	0.10
2001	0%	0	0	6.6	476	0.02	0.07
2002	0%	0	0	4.6	338	0.01	0.05
2003	0%	0	0	3.5	425	0.01	0.07
2004	0%	0	0	3.0	421	0.01	0.07
2005	0%	0	0	5.1	719	0.02	0.11
2006	0%	0	0	6.9	972	0.03	0.15
2007	0%	0	0	9.5	1,454	0.03	0.23
2008	0%	0	0	13	2,417	0.02	0.38
2009	0%	0	0	16	3,080	0.03	0.48
2010	0%	0	0	13	2,653	0.02	0.42
2011	0%	0	0	10	3,166	0.01	0.50
2012	0%	0	0	19	6,724	0.01	1.1
2013	0%	0	0	14	5,397	0.010	0.85
2014	0%	0	0	12	5,525	0.01	0.87
2015	0%	0	0	14	7,779	0.02	1.2
2016	0%	0	0	22	12,488	0.02	2.0
2017	0%	0	0	6.6	3,944	0.008	0.62
2018	0%	0	0	5.9	3,720	0.007	0.58
2019	0%	0	0	5.6	3,844	0.007	0.60
2020	0%	0	0	3.3	2,461	0.004	0.39
2021	0%	0	0	1.1	575	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	53	0.03	2.9	0.000	0.000	0.26	100%	53	35,019
1980	64	0.04	3.7	0.000	0.001	0.33	100%	64	44,086
1981	209	0.12	12	0.000	0.002	1.1	100%	209	142,790
1982	208	0.11	11	0.000	0.002	1.0	100%	208	134,214
1983	196	0.11	11	0.000	0.002	1.0	100%	196	131,088
1984	241	0.15	15	0.000	0.002	1.3	100%	241	176,822
1985	357	0.21	21	0.000	0.003	1.9	100%	357	252,082
1986	331	0.20	20	0.000	0.003	1.8	100%	331	243,579
1987	345	0.22	21	0.000	0.003	1.9	100%	345	253,082
1988	370	0.26	24	0.000	0.004	2.2	100%	370	290,997
1989	420	0.29	28	0.000	0.004	2.5	100%	420	332,355
1990	382	0.28	27	0.000	0.004	2.4	100%	382	319,401
1991	331	0.24	20	0.000	0.003	1.8	100%	331	238,471
1992	279	0.22	18	0.000	0.003	1.6	100%	279	214,037
1993	235	0.20	17	0.000	0.003	1.5	100%	235	202,566
1994	257	0.21	19	0.000	0.003	1.7	100%	257	228,163
1995	341	0.29	26	0.000	0.004	2.3	100%	341	308,497
1996	354	0.29	26	0.000	0.004	2.3	100%	354	309,827
1997	358	0.27	24	0.000	0.004	2.2	100%	358	292,799
1998	350	0.29	27	0.000	0.004	2.4	100%	350	324,850
1999	484	0.48	38	0.000	0.006	3.4	100%	484	458,610
2000	570	0.55	44	0.000	0.007	3.9	100%	570	522,449
2001	630	0.52	42	0.000	0.007	3.7	100%	630	502,288
2002	683	0.50	41	0.000	0.006	3.7	100%	683	490,906
2003	607	0.31	41	0.000	0.006	3.7	100%	607	491,836
2004	588	0.27	39	0.000	0.006	3.4	100%	588	462,594
2005	722	0.33	48	0.000	0.008	4.3	100%	722	579,188
2006	789	0.37	53	0.000	0.008	4.7	100%	789	635,640
2007	1,010	0.43	69	0.000	0.01	6.1	100%	1,010	822,391
2008	958	0.24	51	0.000	0.008	4.5	100%	958	608,971
2009	1,054	0.24	57	0.000	0.009	5.1	100%	1,054	681,595
2010	516	0.11	28	0.000	0.004	2.5	100%	516	336,250
2011	601	0.08	32	0.000	0.005	2.8	100%	601	381,333
2012	36,456	15	5,160	0.010	0.81	460	100%	36,456	61,840,416
2013	23,385	13	4,715	0.009	0.74	420	100%	23,385	56,503,770
2014	25,954	12	4,907	0.01	0.77	437	100%	25,954	58,805,403
2015	43,313	18	8,476	0.02	1.3	755	100%	43,313	101,582,009
2016	51,092	25	12,180	0.03	1.9	1,086	100%	51,092	145,975,230
2017	45,093	20	10,301	0.02	1.6	918	100%	45,093	123,455,483
2018	15,699	7.6	3,880	0.008	0.61	346	100%	15,699	46,494,284
2019	15,755	7.5	4,119	0.008	0.65	367	100%	15,755	49,364,115
2020	14,758	7.0	4,076	0.008	0.64	363	100%	14,758	48,851,177
2021	13,866	6.3	3,442	0.008	0.54	307	100%	13,866	41,250,943
2022	13,999	6.1	3,590	0.008	0.56	320	100%	13,999	43,027,237
2023	9,671	3.7	2,395	0.005	0.38	213	100%	9,671	28,707,076
2024	4,843	1.3	599	0.003	0.09	53	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	484	717,286	25%	1,211	1,793,216	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1979	0%	0	0	0.03	2.9	0.000	0.000
1980	0%	0	0	0.04	3.7	0.000	0.001
1981	0%	0	0	0.12	12	0.000	0.002
1982	0%	0	0	0.11	11	0.000	0.002
1983	0%	0	0	0.11	11	0.000	0.002
1984	0%	0	0	0.15	15	0.000	0.002
1985	0%	0	0	0.21	21	0.000	0.003
1986	0%	0	0	0.20	20	0.000	0.003
1987	0%	0	0	0.22	21	0.000	0.003
1988	0%	0	0	0.26	24	0.000	0.004
1989	0%	0	0	0.29	28	0.000	0.004
1990	0%	0	0	0.28	27	0.000	0.004
1991	0%	0	0	0.24	20	0.000	0.003
1992	0%	0	0	0.22	18	0.000	0.003
1993	0%	0	0	0.20	17	0.000	0.003
1994	0%	0	0	0.21	19	0.000	0.003
1995	0%	0	0	0.29	26	0.000	0.004
1996	0%	0	0	0.29	26	0.000	0.004
1997	0%	0	0	0.27	24	0.000	0.004
1998	0%	0	0	0.29	27	0.000	0.004
1999	0%	0	0	0.48	38	0.000	0.006
2000	0%	0	0	0.55	44	0.000	0.007
2001	0%	0	0	0.52	42	0.000	0.007
2002	0%	0	0	0.50	41	0.000	0.006
2003	0%	0	0	0.31	41	0.000	0.006
2004	0%	0	0	0.27	39	0.000	0.006
2005	0%	0	0	0.33	48	0.000	0.008
2006	0%	0	0	0.37	53	0.000	0.008
2007	0%	0	0	0.43	69	0.000	0.01
2008	0%	0	0	0.24	51	0.000	0.008
2009	0%	0	0	0.24	57	0.000	0.009
2010	0%	0	0	0.11	28	0.000	0.004
2011	0%	0	0	0.08	32	0.000	0.005
2012	0%	0	0	15	5,160	0.010	0.81
2013	0%	0	0	13	4,715	0.009	0.74
2014	0%	0	0	12	4,907	0.01	0.77
2015	0%	0	0	18	8,476	0.02	1.3
2016	0%	0	0	25	12,180	0.03	1.9
2017	0%	0	0	20	10,301	0.02	1.6
2018	0%	0	0	7.6	3,880	0.008	0.61
2019	0%	0	0	7.5	4,119	0.008	0.65
2020	0%	0	0	7.0	4,076	0.008	0.64
2021	0%	0	0	6.3	3,442	0.008	0.54
2022	0%	0	0	6.1	3,590	0.008	0.56
2023	0%	0	0	3.7	2,395	0.005	0.38
2024	65%	3,148	1,539,490	0.11	209	0.001	0.03

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	166	0.09	8.9	0.000	0.001	0.79	100%	166	106,532
1988	223	0.13	12	0.000	0.002	1.1	100%	223	144,024
1989	279	0.16	15	0.000	0.002	1.3	100%	279	179,202
1990	256	0.15	14	0.000	0.002	1.3	100%	256	168,297
1991	221	0.14	11	0.000	0.002	1.0	100%	221	134,880
1992	173	0.11	9.2	0.000	0.001	0.82	100%	173	110,429
1993	132	0.09	7.5	0.000	0.001	0.67	100%	132	90,308
1994	131	0.08	7.6	0.000	0.001	0.68	100%	131	91,104
1995	161	0.11	10	0.000	0.002	0.87	100%	161	116,335
1996	159	0.11	10	0.000	0.002	0.85	100%	159	114,485
1997	155	0.10	9.1	0.000	0.001	0.81	100%	155	108,509
1998	145	0.10	10	0.000	0.001	0.85	100%	145	114,337
1999	197	0.17	13	0.000	0.002	1.2	100%	197	160,607
2000	233	0.20	16	0.000	0.002	1.4	100%	233	188,016
2001	267	0.20	16	0.000	0.003	1.4	100%	267	193,494
2002	300	0.21	17	0.000	0.003	1.5	100%	300	200,551
2003	272	0.13	17	0.000	0.003	1.5	100%	272	200,037
2004	276	0.12	17	0.000	0.003	1.5	100%	276	198,929
2005	353	0.15	22	0.000	0.003	1.9	100%	353	259,740
2006	403	0.18	25	0.000	0.004	2.3	100%	403	303,073
2007	543	0.22	35	0.000	0.006	3.1	100%	543	422,431
2008	564	0.14	29	0.000	0.005	2.6	100%	564	352,228
2009	654	0.15	34	0.000	0.005	3.1	100%	654	410,832
2010	337	0.07	18	0.000	0.003	1.6	100%	337	211,381
2011	419	0.05	21	0.000	0.003	1.9	100%	419	253,413
2012	18,775	6.3	2,125	0.004	0.33	189	100%	18,775	25,469,698
2013	10,866	5.2	1,931	0.003	0.30	172	100%	10,866	23,141,590
2014	12,373	4.9	1,993	0.004	0.31	178	100%	12,373	23,884,682
2015	22,601	8.0	3,471	0.007	0.55	309	100%	22,601	41,601,211
2016	25,559	9.1	3,866	0.010	0.61	345	100%	25,559	46,327,589
2017	29,560	9.2	4,023	0.009	0.63	359	100%	29,560	48,215,934
2018	10,153	3.8	1,588	0.004	0.25	142	100%	10,153	19,030,587
2019	11,512	4.5	1,861	0.004	0.29	166	100%	11,512	22,305,607
2020	13,043	5.4	2,255	0.005	0.35	201	100%	13,043	27,025,846
2021	14,295	6.2	2,272	0.006	0.36	203	100%	14,295	27,231,919
2022	16,417	7.5	2,835	0.007	0.45	253	100%	16,417	33,979,835
2023	22,059	12	4,261	0.010	0.67	380	100%	22,059	51,063,434
2024	21,715	11	3,988	0.01	0.63	355	0%	0	0
2025	22,619	12	4,524	0.01	0.71	403	0%	0	0
2026	22,104	12	4,758	0.01	0.75	424	0%	0	0
2027	21,594	11	4,671	0.01	0.73	416	0%	0	0
2028	19,744	10	4,452	0.01	0.70	397	0%	0	0
2029	18,560	9.0	4,281	0.01	0.67	382	0%	0	0
2030	17,915	8.2	4,205	0.01	0.66	375	0%	0	0
2031	11,497	4.6	2,590	0.006	0.41	231	0%	0	0
2032	5,864	1.6	694	0.003	0.11	62	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	2,171	4,779,835	25%	5,429	11,949,588	0%	0	0
2025	10%	2,262	5,421,301	30%	6,786	16,263,902	0%	0	0
2026	10%	2,210	5,702,550	35%	7,736	19,958,924	0%	0	0
2027	15%	3,239	8,396,467	35%	7,558	19,591,756	0%	0	0
2028	15%	2,962	8,002,355	40%	7,898	21,339,614	0%	0	0
2029	20%	3,712	10,260,841	45%	8,352	23,086,893	0%	0	0
2030	20%	3,583	10,079,515	50%	8,958	25,198,789	0%	0	0
2031	20%	2,299	6,209,013	45%	5,174	13,970,280	0%	0	0
2032	10%	586	831,861	40%	2,345	3,327,443	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1987	0%	0	0	0.09	8.9	0.000	0.001
1988	0%	0	0	0.13	12	0.000	0.002
1989	0%	0	0	0.16	15	0.000	0.002
1990	0%	0	0	0.15	14	0.000	0.002
1991	0%	0	0	0.14	11	0.000	0.002
1992	0%	0	0	0.11	9.2	0.000	0.001
1993	0%	0	0	0.09	7.5	0.000	0.001
1994	0%	0	0	0.08	7.6	0.000	0.001
1995	0%	0	0	0.11	10	0.000	0.002
1996	0%	0	0	0.11	10	0.000	0.002
1997	0%	0	0	0.10	9.1	0.000	0.001
1998	0%	0	0	0.10	10	0.000	0.001
1999	0%	0	0	0.17	13	0.000	0.002
2000	0%	0	0	0.20	16	0.000	0.002
2001	0%	0	0	0.20	16	0.000	0.003
2002	0%	0	0	0.21	17	0.000	0.003
2003	0%	0	0	0.13	17	0.000	0.003
2004	0%	0	0	0.12	17	0.000	0.003
2005	0%	0	0	0.15	22	0.000	0.003
2006	0%	0	0	0.18	25	0.000	0.004
2007	0%	0	0	0.22	35	0.000	0.006
2008	0%	0	0	0.14	29	0.000	0.005
2009	0%	0	0	0.15	34	0.000	0.005
2010	0%	0	0	0.07	18	0.000	0.003
2011	0%	0	0	0.05	21	0.000	0.003
2012	0%	0	0	6.3	2,125	0.004	0.33
2013	0%	0	0	5.2	1,931	0.003	0.30
2014	0%	0	0	4.9	1,993	0.004	0.31
2015	0%	0	0	8.0	3,471	0.007	0.55
2016	0%	0	0	9.1	3,866	0.010	0.61
2017	0%	0	0	9.2	4,023	0.009	0.63
2018	0%	0	0	3.8	1,588	0.004	0.25
2019	0%	0	0	4.5	1,861	0.004	0.29
2020	0%	0	0	5.4	2,255	0.005	0.35
2021	0%	0	0	6.2	2,272	0.006	0.36
2022	0%	0	0	7.5	2,835	0.007	0.45
2023	0%	0	0	12	4,261	0.010	0.67
2024	65%	14,114	10,258,817	1.0	1,396	0.004	0.22
2025	60%	13,572	10,740,531	1.2	1,809	0.005	0.28
2026	55%	12,157	10,356,256	1.3	2,141	0.006	0.34
2027	50%	10,797	9,241,582	1.4	2,335	0.006	0.37
2028	45%	8,885	7,927,023	1.4	2,448	0.006	0.38
2029	35%	6,496	5,929,144	1.5	2,783	0.007	0.44
2030	30%	5,375	4,992,314	1.4	2,944	0.007	0.46
2031	35%	4,024	3,587,828	0.75	1,684	0.004	0.26
2032	50%	2,932	1,373,383	0.19	347	0.002	0.05

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	66	0.04	3.5	0.000	0.001	0.31	100%	66	42,043
1994	83	0.05	4.2	0.000	0.001	0.38	100%	83	50,721
1995	115	0.07	5.9	0.000	0.001	0.53	100%	115	70,970
1996	119	0.07	6.1	0.000	0.001	0.54	100%	119	72,842
1997	117	0.06	5.9	0.000	0.001	0.52	100%	117	70,488
1998	104	0.06	5.7	0.000	0.001	0.50	100%	104	67,898
1999	133	0.10	7.6	0.000	0.001	0.67	100%	133	90,610
2000	147	0.11	8.5	0.000	0.001	0.76	100%	147	101,850
2001	161	0.11	8.8	0.000	0.001	0.79	100%	161	105,603
2002	172	0.11	9.0	0.000	0.001	0.80	100%	172	107,968
2003	146	0.06	8.3	0.000	0.001	0.74	100%	146	99,226
2004	143	0.06	8.1	0.000	0.001	0.72	100%	143	96,731
2005	178	0.07	10	0.000	0.002	0.92	100%	178	123,640
2006	202	0.09	12	0.000	0.002	1.1	100%	202	143,033
2007	272	0.11	17	0.000	0.003	1.5	100%	272	200,277
2008	292	0.07	15	0.000	0.002	1.3	100%	292	179,211
2009	346	0.08	18	0.000	0.003	1.6	100%	346	213,122
2010	183	0.04	9.3	0.000	0.001	0.83	100%	183	111,727
2011	234	0.03	11	0.000	0.002	1.0	100%	234	136,809
2012	7,969	2.4	804	0.002	0.13	72	100%	7,969	9,641,296
2013	4,340	2.0	750	0.001	0.12	67	100%	4,340	8,984,556
2014	4,954	2.0	817	0.001	0.13	73	100%	4,954	9,795,650
2015	9,674	3.7	1,601	0.003	0.25	143	100%	9,674	19,190,427
2016	10,519	3.7	1,604	0.004	0.25	143	100%	10,519	19,227,562
2017	14,184	3.9	1,723	0.004	0.27	154	100%	14,184	20,654,585
2018	4,924	1.7	692	0.002	0.11	62	100%	4,924	8,290,062
2019	5,803	1.9	807	0.002	0.13	72	100%	5,803	9,667,889
2020	6,713	2.3	945	0.002	0.15	84	100%	6,713	11,329,480
2021	7,708	2.6	942	0.003	0.15	84	100%	7,708	11,285,971
2022	9,361	3.4	1,197	0.003	0.19	107	100%	9,361	14,344,235
2023	12,311	5.2	1,799	0.004	0.28	160	100%	12,311	21,557,339
2024	14,157	5.5	1,804	0.005	0.28	161	0%	0	0
2025	15,781	6.4	2,112	0.006	0.33	188	0%	0	0
2026	17,659	7.5	2,484	0.007	0.39	221	0%	0	0
2027	19,532	8.7	2,768	0.008	0.44	247	0%	0	0
2028	21,365	10	3,236	0.010	0.51	288	0%	0	0
2029	22,985	11	3,748	0.01	0.59	334	0%	0	0
2030	24,081	12	4,213	0.01	0.66	375	0%	0	0
2037	24,791	13	4,671	0.01	0.73	416	0%	0	0
2032	24,114	13	4,857	0.01	0.76	433	0%	0	0
2033	23,670	12	5,060	0.01	0.80	451	0%	0	0
2034	21,948	11	4,883	0.01	0.77	435	0%	0	0
2035	20,791	10	4,742	0.01	0.75	423	0%	0	0
2036	19,699	9.0	4,573	0.01	0.72	408	0%	0	0
2037	12,409	5.0	2,773	0.007	0.44	247	0%	0	0
2038	6,391	1.7	743	0.003	0.12	66	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	1,416	2,161,542	25%	3,539	5,403,855	0%	0	0
2025	10%	1,578	2,531,043	30%	4,734	7,593,128	0%	0	0
2026	10%	1,766	2,977,192	35%	6,181	10,420,173	0%	0	0
2027	15%	2,930	4,975,264	35%	6,836	11,608,949	0%	0	0
2028	15%	3,205	5,817,346	40%	8,546	15,512,922	0%	0	0
2029	20%	4,597	8,983,030	45%	10,343	20,211,817	0%	0	0
2030	20%	4,816	10,097,767	50%	12,040	25,244,417	0%	0	0
2037	12%	2,975	6,717,948	5%	1,240	2,799,145	0%	0	0
2032	10%	2,411	5,821,019	40%	9,646	23,284,077	0%	0	0
2033	10%	2,367	6,063,891	35%	8,285	21,223,618	0%	0	0
2034	10%	2,195	5,851,702	30%	6,585	17,555,106	0%	0	0
2035	12%	2,495	6,819,958	5%	1,040	2,841,649	0%	0	0
2036	12%	2,364	6,576,732	5%	985	2,740,305	0%	0	0
2037	12%	1,489	3,988,015	5%	620	1,661,673	0%	0	0
2038	12%	767	1,068,563	5%	320	445,235	0%	0	0

Table A-11. NOx and GHG Tailpipe Emissions for Scenario 1 in Calendar Year 2037
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1993	0%	0	0	0.04	3.5	0.000	0.001
1994	0%	0	0	0.05	4.2	0.000	0.001
1995	0%	0	0	0.07	5.9	0.000	0.001
1996	0%	0	0	0.07	6.1	0.000	0.001
1997	0%	0	0	0.06	5.9	0.000	0.001
1998	0%	0	0	0.06	5.7	0.000	0.001
1999	0%	0	0	0.10	7.6	0.000	0.001
2000	0%	0	0	0.11	8.5	0.000	0.001
2001	0%	0	0	0.11	8.8	0.000	0.001
2002	0%	0	0	0.11	9.0	0.000	0.001
2003	0%	0	0	0.06	8.3	0.000	0.001
2004	0%	0	0	0.06	8.1	0.000	0.001
2005	0%	0	0	0.07	10	0.000	0.002
2006	0%	0	0	0.09	12	0.000	0.002
2007	0%	0	0	0.11	17	0.000	0.003
2008	0%	0	0	0.07	15	0.000	0.002
2009	0%	0	0	0.08	18	0.000	0.003
2010	0%	0	0	0.04	9.3	0.000	0.001
2011	0%	0	0	0.03	11	0.000	0.002
2012	0%	0	0	2.4	804	0.002	0.13
2013	0%	0	0	2.0	750	0.001	0.12
2014	0%	0	0	2.0	817	0.001	0.13
2015	0%	0	0	3.7	1,601	0.003	0.25
2016	0%	0	0	3.7	1,604	0.004	0.25
2017	0%	0	0	3.9	1,723	0.004	0.27
2018	0%	0	0	1.7	692	0.002	0.11
2019	0%	0	0	1.9	807	0.002	0.13
2020	0%	0	0	2.3	945	0.002	0.15
2021	0%	0	0	2.6	942	0.003	0.15
2022	0%	0	0	3.4	1,197	0.003	0.19
2023	0%	0	0	5.2	1,799	0.004	0.28
2024	65%	9,202	4,639,253	0.48	631	0.002	0.10
2025	60%	9,469	5,014,432	0.64	845	0.002	0.13
2026	55%	9,712	5,406,804	0.85	1,118	0.003	0.18
2027	50%	9,766	5,476,031	1.1	1,384	0.004	0.22
2028	45%	9,614	5,762,582	1.4	1,780	0.005	0.28
2029	35%	8,045	5,190,771	1.8	2,436	0.007	0.38
2030	30%	7,224	5,001,354	2.1	2,949	0.008	0.46
2037	83%	20,577	15,342,795	0.55	794	0.002	0.12
2032	50%	12,057	9,610,369	1.6	2,429	0.007	0.38
2033	55%	13,019	11,012,479	1.4	2,277	0.006	0.36
2034	60%	13,169	11,593,231	1.1	1,953	0.005	0.31
2035	83%	17,257	15,575,770	0.43	806	0.002	0.13
2036	83%	16,350	15,020,279	0.38	777	0.002	0.12
2037	83%	10,300	9,108,035	0.21	471	0.001	0.07
2038	83%	5,305	2,440,439	0.07	126	0.001	0.02

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	**Population**	**NOx_TOTEX (tons/day)**	**CO2_TOTEX (tons/day)**	**CH4_TOTEX (tons/day)**	**N2O_TOTEX (tons/day)**	**Fuel Consumption (1000 gal/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
2001	0	0	0	0	0	0	0%	0	0
2002	0	0	0	0	0	0	0%	0	0
2003	0	0	0	0	0	0	0%	0	0
2004	0	0	0	0	0	0	0%	0	0
2005	0	0	0	0	0	0	0%	0	0
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	5,738	1.9	631	0.002	0.10	56	0%	0	0
2025	6,682	2.2	740	0.002	0.12	66	0%	0	0
2026	7,830	2.6	869	0.002	0.14	77	0%	0	0
2027	8,960	3.0	954	0.003	0.15	85	0%	0	0
2028	10,297	3.5	1,096	0.003	0.17	98	0%	0	0
2029	11,921	4.1	1,276	0.004	0.20	114	0%	0	0
2030	13,807	4.8	1,488	0.005	0.23	133	0%	0	0
2045	15,655	5.9	1,819	0.006	0.29	162	0%	0	0
2032	17,813	7.1	2,196	0.007	0.35	196	0%	0	0
2033	20,003	8.3	2,581	0.008	0.41	230	0%	0	0
2034	22,623	10	3,067	0.009	0.48	273	0%	0	0
2035	24,976	11	3,584	0.01	0.56	319	0%	0	0
2036	26,967	13	4,118	0.01	0.65	367	0%	0	0
2037	28,599	14	4,677	0.01	0.74	417	0%	0	0
2038	29,556	15	5,172	0.01	0.81	461	0%	0	0
2039	30,085	16	5,646	0.02	0.89	503	0%	0	0
2040	28,520	15	5,685	0.02	0.89	507	0%	0	0
2041	27,485	14	5,816	0.02	0.91	518	0%	0	0
2042	24,780	12	5,446	0.01	0.86	485	0%	0	0
2043	23,286	11	5,243	0.01	0.82	467	0%	0	0
2044	22,012	10	5,025	0.01	0.79	448	0%	0	0
2045	13,831	5.5	3,030	0.007	0.48	270	0%	0	0
2046	7,111	1.9	812	0.004	0.13	72	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	574	756,340	25%	1,434	1,890,850	0%	0	0
2025	10%	668	886,781	30%	2,005	2,660,344	0%	0	0
2026	10%	783	1,041,761	35%	2,741	3,646,164	0%	0	0
2027	15%	1,344	1,715,605	35%	3,136	4,003,078	0%	0	0
2028	15%	1,544	1,969,828	40%	4,119	5,252,875	0%	0	0
2029	20%	2,384	3,059,507	45%	5,364	6,883,890	0%	0	0
2030	20%	2,761	3,566,433	50%	6,903	8,916,082	0%	0	0
2045	12%	1,879	2,615,706	5%	783	1,089,877	0%	0	0
2032	10%	1,781	2,631,722	40%	7,125	10,526,888	0%	0	0
2033	10%	2,000	3,093,484	35%	7,001	10,827,195	0%	0	0
2034	10%	2,262	3,676,051	30%	6,787	11,028,154	0%	0	0
2035	12%	2,997	5,154,227	5%	1,249	2,147,595	0%	0	0
2036	12%	3,236	5,922,773	5%	1,348	2,467,822	0%	0	0
2037	12%	3,432	6,725,482	5%	1,430	2,802,284	0%	0	0
2038	12%	3,547	7,438,400	5%	1,478	3,099,333	0%	0	0
2039	12%	3,610	8,118,998	5%	1,504	3,382,916	0%	0	0
2040	12%	3,422	8,176,299	5%	1,426	3,406,791	0%	0	0
2041	12%	3,298	8,363,731	5%	1,374	3,484,888	0%	0	0
2042	12%	2,974	7,831,788	5%	1,239	3,263,245	0%	0	0
2043	12%	2,794	7,539,421	5%	1,164	3,141,425	0%	0	0
2044	12%	2,641	7,227,079	5%	1,101	3,011,283	0%	0	0
2045	12%	1,660	4,357,601	5%	692	1,815,667	0%	0	0
2046	12%	853	1,167,185	5%	356	486,327	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
2001	0%	0	0	0	0	0	0
2002	0%	0	0	0	0	0	0
2003	0%	0	0	0	0	0	0
2004	0%	0	0	0	0	0	0
2005	0%	0	0	0	0	0	0
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	65%	3,730	1,623,310	0.17	221	0.001	0.03
2025	60%	4,009	1,756,867	0.22	296	0.001	0.05
2026	55%	4,307	1,891,916	0.30	391	0.001	0.06
2027	50%	4,480	1,888,283	0.38	477	0.001	0.08
2028	45%	4,633	1,951,285	0.48	603	0.002	0.09
2029	35%	4,172	1,767,911	0.67	830	0.003	0.13
2030	30%	4,142	1,766,430	0.85	1,042	0.003	0.16
2045	83%	12,994	5,973,883	0.25	309	0.001	0.05
2032	50%	8,906	4,344,912	0.89	1,098	0.003	0.17
2033	55%	11,002	5,617,998	0.94	1,162	0.003	0.18
2034	60%	13,574	7,282,892	1.0	1,227	0.004	0.19
2035	83%	20,730	11,771,489	0.48	609	0.002	0.10
2036	83%	22,383	13,526,734	0.54	700	0.002	0.11
2037	83%	23,737	15,360,002	0.60	795	0.002	0.12
2038	83%	24,531	16,988,202	0.64	879	0.002	0.14
2039	83%	24,971	18,542,585	0.66	960	0.003	0.15
2040	83%	23,671	18,673,453	0.63	967	0.003	0.15
2041	83%	22,813	19,101,520	0.60	989	0.003	0.16
2042	83%	20,568	17,886,641	0.53	926	0.002	0.15
2043	83%	19,327	17,218,918	0.47	891	0.002	0.14
2044	83%	18,270	16,505,576	0.42	854	0.002	0.13
2045	83%	11,480	9,952,115	0.23	515	0.001	0.08
2046	83%	5,902	2,665,677	0.08	138	0.001	0.02

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	**Population**	**NOx_TOTEX (tons/day)**	**CO2_TOTEX (tons/day)**	**CH4_TOTEX (tons/day)**	**N2O_TOTEX (tons/day)**	**Fuel Consumption (1000 gal/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	2,595	0.86	281	0.001	0.04	25	0%	0	0
2025	3,028	1.0	330	0.001	0.05	29	0%	0	0
2026	3,626	1.2	393	0.001	0.06	35	0%	0	0
2027	4,257	1.4	439	0.001	0.07	39	0%	0	0
2028	5,060	1.7	526	0.001	0.08	47	0%	0	0
2029	6,031	2.0	632	0.002	0.10	56	0%	0	0
2030	7,066	2.4	743	0.002	0.12	66	0%	0	0
2050	8,217	2.8	872	0.003	0.14	78	0%	0	0
2032	9,494	3.2	1,017	0.003	0.16	91	0%	0	0
2033	11,004	3.8	1,176	0.004	0.18	105	0%	0	0
2034	12,911	4.5	1,386	0.004	0.22	124	0%	0	0
2035	14,935	5.3	1,619	0.005	0.25	144	0%	0	0
2036	16,783	6.4	1,962	0.006	0.31	175	0%	0	0
2037	18,732	7.5	2,328	0.007	0.37	208	0%	0	0
2038	20,725	8.7	2,699	0.008	0.42	241	0%	0	0
2039	22,925	10	3,137	0.009	0.49	280	0%	0	0
2040	25,074	11	3,619	0.01	0.57	323	0%	0	0
2041	27,099	13	4,155	0.01	0.65	370	0%	0	0
2042	28,740	14	4,704	0.01	0.74	419	0%	0	0
2043	29,658	15	5,184	0.01	0.81	462	0%	0	0
2044	30,119	16	5,634	0.02	0.89	502	0%	0	0
2045	28,407	15	5,643	0.02	0.89	503	0%	0	0
2046	27,387	14	5,770	0.02	0.91	514	0%	0	0
2047	24,660	12	5,397	0.01	0.85	481	0%	0	0
2048	23,198	11	5,206	0.01	0.82	464	0%	0	0
2049	21,872	10	4,978	0.01	0.78	444	0%	0	0
2050	13,695	5.4	2,992	0.007	0.47	267	0%	0	0
2051	7,053	1.8	1,226	0.004	0.19	109	0%	0	0

Table A-13. NOx and GHG Tailpipe Emissions for Scenario 1 in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	260	337,270	25%	649	843,175	0%	0	0
2025	10%	303	395,918	30%	908	1,187,754	0%	0	0
2026	10%	363	471,136	35%	1,269	1,648,977	0%	0	0
2027	15%	639	789,915	35%	1,490	1,843,135	0%	0	0
2028	15%	759	945,969	40%	2,024	2,522,585	0%	0	0
2029	20%	1,206	1,514,257	45%	2,714	3,407,079	0%	0	0
2030	20%	1,413	1,780,183	50%	3,533	4,450,457	0%	0	0
2050	12%	986	1,253,331	5%	411	522,221	0%	0	0
2032	10%	949	1,218,218	40%	3,797	4,872,872	0%	0	0
2033	10%	1,100	1,409,784	35%	3,851	4,934,242	0%	0	0
2034	10%	1,291	1,660,800	30%	3,873	4,982,400	0%	0	0
2035	12%	1,792	2,327,866	5%	747	969,944	0%	0	0
2036	12%	2,014	2,822,001	5%	839	1,175,834	0%	0	0
2037	12%	2,248	3,348,517	5%	937	1,395,215	0%	0	0
2038	12%	2,487	3,881,574	5%	1,036	1,617,323	0%	0	0
2039	12%	2,751	4,511,626	5%	1,146	1,879,844	0%	0	0
2040	12%	3,009	5,204,512	5%	1,254	2,168,547	0%	0	0
2041	12%	3,252	5,974,789	5%	1,355	2,489,495	0%	0	0
2042	12%	3,449	6,765,245	5%	1,437	2,818,852	0%	0	0
2043	12%	3,559	7,455,772	5%	1,483	3,106,572	0%	0	0
2044	12%	3,614	8,101,789	5%	1,506	3,375,745	0%	0	0
2045	12%	3,409	8,115,025	5%	1,420	3,381,260	0%	0	0
2046	12%	3,286	8,297,953	5%	1,369	3,457,480	0%	0	0
2047	12%	2,959	7,761,898	5%	1,233	3,234,124	0%	0	0
2048	12%	2,784	7,487,127	5%	1,160	3,119,636	0%	0	0
2049	12%	2,625	7,158,856	5%	1,094	2,982,857	0%	0	0
2050	12%	1,643	4,302,930	5%	685	1,792,888	0%	0	0
2051	12%	846	1,763,371	5%	353	734,738	0%	0	0

	BEV			Tailpipe Emission Estimates[5] (tons/day)			
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	65%	1,687	723,873	0.08	98	0.000	0.02
2025	60%	1,817	784,381	0.10	132	0.000	0.02
2026	55%	1,994	855,619	0.13	177	0.000	0.03
2027	50%	2,128	869,421	0.18	220	0.001	0.03
2028	45%	2,277	937,064	0.23	289	0.001	0.05
2029	35%	2,111	875,001	0.33	411	0.001	0.06
2030	30%	2,120	881,712	0.41	520	0.001	0.08
2050	83%	6,820	2,862,421	0.12	148	0.000	0.02
2032	50%	4,747	2,011,250	0.40	508	0.001	0.08
2033	55%	6,052	2,560,272	0.42	529	0.002	0.08
2034	60%	7,747	3,290,331	0.45	554	0.002	0.09
2035	83%	12,396	5,316,501	0.22	275	0.001	0.04
2036	83%	13,929	6,445,032	0.27	334	0.001	0.05
2037	83%	15,547	7,647,515	0.32	396	0.001	0.06
2038	83%	17,202	8,864,939	0.37	459	0.001	0.07
2039	83%	19,028	10,303,884	0.43	533	0.002	0.08
2040	83%	20,812	11,886,333	0.49	615	0.002	0.10
2041	83%	22,492	13,645,531	0.55	706	0.002	0.11
2042	83%	23,855	15,450,815	0.61	800	0.002	0.13
2043	83%	24,616	17,027,875	0.64	881	0.002	0.14
2044	83%	24,999	18,503,282	0.66	958	0.003	0.15
2045	83%	23,578	18,533,512	0.63	959	0.003	0.15
2046	83%	22,732	18,951,293	0.60	981	0.003	0.15
2047	83%	20,468	17,727,023	0.52	918	0.002	0.14
2048	83%	19,254	17,099,486	0.47	885	0.002	0.14
2049	83%	18,154	16,349,764	0.42	846	0.002	0.13
2050	83%	11,367	9,827,254	0.23	509	0.001	0.08
2051	83%	5,854	4,027,277	0.08	208	0.001	0.03

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	29	0.02	1.7	0.000	0.000	0.15	100%	29	19,871
1977	34	0.02	2.3	0.000	0.000	0.20	100%	34	27,331
1978	66	0.04	3.9	0.000	0.001	0.35	100%	66	47,207
1979	94	0.05	5.0	0.000	0.001	0.44	100%	94	59,761
1980	87	0.05	5.1	0.000	0.001	0.45	100%	87	61,143
1981	258	0.15	15	0.000	0.002	1.3	100%	258	180,361
1982	236	0.13	13	0.000	0.002	1.2	100%	236	156,209
1983	219	0.13	13	0.000	0.002	1.1	100%	219	151,257
1984	274	0.18	18	0.000	0.003	1.6	100%	274	214,575
1985	404	0.25	25	0.000	0.004	2.2	100%	404	301,188
1986	396	0.25	25	0.000	0.004	2.2	100%	396	301,092
1987	426	0.29	27	0.000	0.004	2.4	100%	426	324,223
1988	484	0.34	32	0.000	0.005	2.9	100%	484	387,591
1989	567	0.40	38	0.000	0.006	3.4	100%	567	454,438
1990	539	0.39	37	0.000	0.006	3.3	100%	539	446,862
1991	475	0.34	28	0.000	0.004	2.5	100%	475	335,098
1992	399	0.31	25	0.000	0.004	2.2	100%	399	301,877
1993	363	0.29	25	0.000	0.004	2.2	100%	363	295,585
1994	379	0.31	28	0.000	0.004	2.5	100%	379	330,512
1995	507	0.41	37	0.000	0.006	3.3	100%	507	443,837
1996	1,142	1.8	150	0.006	0.02	13	100%	1,142	1,800,897
1997	1,167	1.8	149	0.006	0.02	13	100%	1,167	1,790,241
1998	1,370	2.2	192	0.008	0.03	17	100%	1,370	2,305,455
1999	1,972	4.1	291	0.01	0.05	26	100%	1,972	3,484,066
2000	4,067	9.0	641	0.02	0.10	57	100%	4,067	7,683,603
2001	3,153	6.6	476	0.02	0.07	42	100%	3,153	5,706,180
2002	2,427	4.6	338	0.01	0.05	30	100%	2,427	4,046,083
2003	2,907	3.5	425	0.01	0.07	38	100%	2,907	5,088,912
2004	2,913	3.0	421	0.01	0.07	38	100%	2,913	5,047,803
2005	4,812	5.1	719	0.02	0.11	64	100%	4,812	8,613,212
2006	5,968	6.9	972	0.03	0.15	87	100%	5,968	11,650,876
2007	8,303	9.5	1,454	0.03	0.23	130	100%	8,303	17,419,576
2008	12,274	13	2,417	0.02	0.38	215	100%	12,274	28,960,284
2009	14,354	16	3,080	0.03	0.48	275	100%	14,354	36,913,677
2010	11,383	13	2,653	0.02	0.42	236	100%	11,383	31,795,323
2011	13,627	10	3,166	0.01	0.50	282	100%	13,627	37,940,166
2012	39,297	19	6,724	0.01	1.1	599	100%	39,297	80,581,115
2013	21,084	14	5,397	0.010	0.85	481	100%	21,084	64,680,893
2014	23,061	12	5,525	0.01	0.87	492	100%	23,061	66,207,976
2015	28,916	14	7,779	0.02	1.2	693	100%	28,916	93,222,050
2016	41,998	22	12,488	0.02	2.0	1,113	100%	41,998	149,658,452
2017	16,101	6.6	3,944	0.008	0.62	351	100%	16,101	47,265,405
2018	12,688	5.9	3,720	0.007	0.58	332	100%	12,688	44,579,225
2019	12,851	5.6	3,844	0.007	0.60	343	100%	12,851	46,069,473
2020	8,537	3.3	2,461	0.004	0.39	219	100%	8,537	29,496,897
2021	4,246	1.1	575	0.002	0.09	51	100%	4,246	6,891,960

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	0%	0	0	0%	0	0	0%	0	0
1977	0%	0	0	0%	0	0	0%	0	0
1978	0%	0	0	0%	0	0	0%	0	0
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1976	0%	0	0	0.02	1.7	0.000	0.000
1977	0%	0	0	0.02	2.3	0.000	0.000
1978	0%	0	0	0.04	3.9	0.000	0.001
1979	0%	0	0	0.05	5.0	0.000	0.001
1980	0%	0	0	0.05	5.1	0.000	0.001
1981	0%	0	0	0.15	15	0.000	0.002
1982	0%	0	0	0.13	13	0.000	0.002
1983	0%	0	0	0.13	13	0.000	0.002
1984	0%	0	0	0.18	18	0.000	0.003
1985	0%	0	0	0.25	25	0.000	0.004
1986	0%	0	0	0.25	25	0.000	0.004
1987	0%	0	0	0.29	27	0.000	0.004
1988	0%	0	0	0.34	32	0.000	0.005
1989	0%	0	0	0.40	38	0.000	0.006
1990	0%	0	0	0.39	37	0.000	0.006
1991	0%	0	0	0.34	28	0.000	0.004
1992	0%	0	0	0.31	25	0.000	0.004
1993	0%	0	0	0.29	25	0.000	0.004
1994	0%	0	0	0.31	28	0.000	0.004
1995	0%	0	0	0.41	37	0.000	0.006
1996	0%	0	0	1.8	150	0.006	0.02
1997	0%	0	0	1.8	149	0.006	0.02
1998	0%	0	0	2.2	192	0.008	0.03
1999	0%	0	0	4.1	291	0.01	0.05
2000	0%	0	0	9.0	641	0.02	0.10
2001	0%	0	0	6.6	476	0.02	0.07
2002	0%	0	0	4.6	338	0.01	0.05
2003	0%	0	0	3.5	425	0.01	0.07
2004	0%	0	0	3.0	421	0.01	0.07
2005	0%	0	0	5.1	719	0.02	0.11
2006	0%	0	0	6.9	972	0.03	0.15
2007	0%	0	0	9.5	1,454	0.03	0.23
2008	0%	0	0	13	2,417	0.02	0.38
2009	0%	0	0	16	3,080	0.03	0.48
2010	0%	0	0	13	2,653	0.02	0.42
2011	0%	0	0	10	3,166	0.01	0.50
2012	0%	0	0	19	6,724	0.01	1.1
2013	0%	0	0	14	5,397	0.010	0.85
2014	0%	0	0	12	5,525	0.01	0.87
2015	0%	0	0	14	7,779	0.02	1.2
2016	0%	0	0	22	12,488	0.02	2.0
2017	0%	0	0	6.6	3,944	0.008	0.62
2018	0%	0	0	5.9	3,720	0.007	0.58
2019	0%	0	0	5.6	3,844	0.007	0.60
2020	0%	0	0	3.3	2,461	0.004	0.39
2021	0%	0	0	1.1	575	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	53	0.03	2.9	0.000	0.000	0.26	100%	53	35,019
1980	64	0.04	3.7	0.000	0.001	0.33	100%	64	44,086
1981	209	0.12	12	0.000	0.002	1.1	100%	209	142,790
1982	208	0.11	11	0.000	0.002	1.0	100%	208	134,214
1983	196	0.11	11	0.000	0.002	1.0	100%	196	131,088
1984	241	0.15	15	0.000	0.002	1.3	100%	241	176,822
1985	357	0.21	21	0.000	0.003	1.9	100%	357	252,082
1986	331	0.20	20	0.000	0.003	1.8	100%	331	243,579
1987	345	0.22	21	0.000	0.003	1.9	100%	345	253,082
1988	370	0.26	24	0.000	0.004	2.2	100%	370	290,997
1989	420	0.29	28	0.000	0.004	2.5	100%	420	332,355
1990	382	0.28	27	0.000	0.004	2.4	100%	382	319,401
1991	331	0.24	20	0.000	0.003	1.8	100%	331	238,471
1992	279	0.22	18	0.000	0.003	1.6	100%	279	214,037
1993	235	0.20	17	0.000	0.003	1.5	100%	235	202,566
1994	257	0.21	19	0.000	0.003	1.7	100%	257	228,163
1995	341	0.29	26	0.000	0.004	2.3	100%	341	308,497
1996	354	0.29	26	0.000	0.004	2.3	100%	354	309,827
1997	358	0.27	24	0.000	0.004	2.2	100%	358	292,799
1998	350	0.29	27	0.000	0.004	2.4	100%	350	324,850
1999	484	0.48	38	0.000	0.006	3.4	100%	484	458,610
2000	570	0.55	44	0.000	0.007	3.9	100%	570	522,449
2001	630	0.52	42	0.000	0.007	3.7	100%	630	502,288
2002	683	0.50	41	0.000	0.006	3.7	100%	683	490,906
2003	607	0.31	41	0.000	0.006	3.7	100%	607	491,836
2004	588	0.27	39	0.000	0.006	3.4	100%	588	462,594
2005	722	0.33	48	0.000	0.008	4.3	100%	722	579,188
2006	789	0.37	53	0.000	0.008	4.7	100%	789	635,640
2007	1,010	0.43	69	0.000	0.01	6.1	100%	1,010	822,391
2008	958	0.24	51	0.000	0.008	4.5	100%	958	608,971
2009	1,054	0.24	57	0.000	0.009	5.1	100%	1,054	681,595
2010	516	0.11	28	0.000	0.004	2.5	100%	516	336,250
2011	601	0.08	32	0.000	0.005	2.8	100%	601	381,333
2012	36,456	15	5,160	0.010	0.81	460	100%	36,456	61,840,416
2013	23,385	13	4,715	0.009	0.74	420	100%	23,385	56,503,770
2014	25,954	12	4,907	0.01	0.77	437	100%	25,954	58,805,403
2015	43,313	18	8,476	0.02	1.3	755	100%	43,313	101,582,009
2016	51,092	25	12,180	0.03	1.9	1,086	100%	51,092	145,975,230
2017	45,093	20	10,301	0.02	1.6	918	100%	45,093	123,455,483
2018	15,699	7.6	3,880	0.008	0.61	346	100%	15,699	46,494,284
2019	15,755	7.5	4,119	0.008	0.65	367	100%	15,755	49,364,115
2020	14,758	7.0	4,076	0.008	0.64	363	100%	14,758	48,851,177
2021	13,866	6.3	3,442	0.008	0.54	307	100%	13,866	41,250,943
2022	13,999	6.1	3,590	0.008	0.56	320	100%	13,999	43,027,237
2023	9,671	3.7	2,395	0.005	0.38	213	100%	9,671	28,707,076
2024	4,843	1.3	599	0.003	0.09	53	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	484	717,286	0%	0	0	86%	4,141	6,814,220

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1979	0%	0	0	0.03	2.9	0.000	0.000
1980	0%	0	0	0.04	3.7	0.000	0.001
1981	0%	0	0	0.12	12	0.000	0.002
1982	0%	0	0	0.11	11	0.000	0.002
1983	0%	0	0	0.11	11	0.000	0.002
1984	0%	0	0	0.15	15	0.000	0.002
1985	0%	0	0	0.21	21	0.000	0.003
1986	0%	0	0	0.20	20	0.000	0.003
1987	0%	0	0	0.22	21	0.000	0.003
1988	0%	0	0	0.26	24	0.000	0.004
1989	0%	0	0	0.29	28	0.000	0.004
1990	0%	0	0	0.28	27	0.000	0.004
1991	0%	0	0	0.24	20	0.000	0.003
1992	0%	0	0	0.22	18	0.000	0.003
1993	0%	0	0	0.20	17	0.000	0.003
1994	0%	0	0	0.21	19	0.000	0.003
1995	0%	0	0	0.29	26	0.000	0.004
1996	0%	0	0	0.29	26	0.000	0.004
1997	0%	0	0	0.27	24	0.000	0.004
1998	0%	0	0	0.29	27	0.000	0.004
1999	0%	0	0	0.48	38	0.000	0.006
2000	0%	0	0	0.55	44	0.000	0.007
2001	0%	0	0	0.52	42	0.000	0.007
2002	0%	0	0	0.50	41	0.000	0.006
2003	0%	0	0	0.31	41	0.000	0.006
2004	0%	0	0	0.27	39	0.000	0.006
2005	0%	0	0	0.33	48	0.000	0.008
2006	0%	0	0	0.37	53	0.000	0.008
2007	0%	0	0	0.43	69	0.000	0.01
2008	0%	0	0	0.24	51	0.000	0.008
2009	0%	0	0	0.24	57	0.000	0.009
2010	0%	0	0	0.11	28	0.000	0.004
2011	0%	0	0	0.08	32	0.000	0.005
2012	0%	0	0	15	5,160	0.010	0.81
2013	0%	0	0	13	4,715	0.009	0.74
2014	0%	0	0	12	4,907	0.01	0.77
2015	0%	0	0	18	8,476	0.02	1.3
2016	0%	0	0	25	12,180	0.03	1.9
2017	0%	0	0	20	10,301	0.02	1.6
2018	0%	0	0	7.6	3,880	0.008	0.61
2019	0%	0	0	7.5	4,119	0.008	0.65
2020	0%	0	0	7.0	4,076	0.008	0.64
2021	0%	0	0	6.3	3,442	0.008	0.54
2022	0%	0	0	6.1	3,590	0.008	0.56
2023	0%	0	0	3.7	2,395	0.005	0.38
2024	5%	218	106,580	0.14	572	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	166	0.09	8.9	0.000	0.001	0.79	100%	166	106,532
1988	223	0.13	12	0.000	0.002	1.1	100%	223	144,024
1989	279	0.16	15	0.000	0.002	1.3	100%	279	179,202
1990	256	0.15	14	0.000	0.002	1.3	100%	256	168,297
1991	221	0.14	11	0.000	0.002	1.0	100%	221	134,880
1992	173	0.11	9.2	0.000	0.001	0.82	100%	173	110,429
1993	132	0.09	7.5	0.000	0.001	0.67	100%	132	90,308
1994	131	0.08	7.6	0.000	0.001	0.68	100%	131	91,104
1995	161	0.11	10	0.000	0.002	0.87	100%	161	116,335
1996	159	0.11	10	0.000	0.002	0.85	100%	159	114,485
1997	155	0.10	9.1	0.000	0.001	0.81	100%	155	108,509
1998	145	0.10	10	0.000	0.001	0.85	100%	145	114,337
1999	197	0.17	13	0.000	0.002	1.2	100%	197	160,607
2000	233	0.20	16	0.000	0.002	1.4	100%	233	188,016
2001	267	0.20	16	0.000	0.003	1.4	100%	267	193,494
2002	300	0.21	17	0.000	0.003	1.5	100%	300	200,551
2003	272	0.13	17	0.000	0.003	1.5	100%	272	200,037
2004	276	0.12	17	0.000	0.003	1.5	100%	276	198,929
2005	353	0.15	22	0.000	0.003	1.9	100%	353	259,740
2006	403	0.18	25	0.000	0.004	2.3	100%	403	303,073
2007	543	0.22	35	0.000	0.006	3.1	100%	543	422,431
2008	564	0.14	29	0.000	0.005	2.6	100%	564	352,228
2009	654	0.15	34	0.000	0.005	3.1	100%	654	410,832
2010	337	0.07	18	0.000	0.003	1.6	100%	337	211,381
2011	419	0.05	21	0.000	0.003	1.9	100%	419	253,413
2012	18,775	6.3	2,125	0.004	0.33	189	100%	18,775	25,469,698
2013	10,866	5.2	1,931	0.003	0.30	172	100%	10,866	23,141,590
2014	12,373	4.9	1,993	0.004	0.31	178	100%	12,373	23,884,682
2015	22,601	8.0	3,471	0.007	0.55	309	100%	22,601	41,601,211
2016	25,559	9.1	3,866	0.010	0.61	345	100%	25,559	46,327,589
2017	29,560	9.2	4,023	0.009	0.63	359	100%	29,560	48,215,934
2018	10,153	3.8	1,588	0.004	0.25	142	100%	10,153	19,030,587
2019	11,512	4.5	1,861	0.004	0.29	166	100%	11,512	22,305,607
2020	13,043	5.4	2,255	0.005	0.35	201	100%	13,043	27,025,846
2021	14,295	6.2	2,272	0.006	0.36	203	100%	14,295	27,231,919
2022	16,417	7.5	2,835	0.007	0.45	253	100%	16,417	33,979,835
2023	22,059	12	4,261	0.010	0.67	380	100%	22,059	51,063,434
2024	21,715	11	3,988	0.01	0.63	355	0%	0	0
2025	22,619	12	4,524	0.01	0.71	403	0%	0	0
2026	22,104	12	4,758	0.01	0.75	424	0%	0	0
2027	21,594	11	4,671	0.01	0.73	416	0%	0	0
2028	19,744	10	4,452	0.01	0.70	397	0%	0	0
2029	18,560	9.0	4,281	0.01	0.67	382	0%	0	0
2030	17,915	8.2	4,205	0.01	0.66	375	0%	0	0
2031	11,497	4.6	2,590	0.006	0.41	231	0%	0	0
2032	5,864	1.6	694	0.003	0.11	62	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	2,171	4,779,835	0%	0	0	86%	18,566	45,408,434
2025	10%	2,262	5,421,301	0%	0	0	84%	18,932	50,418,096
2026	10%	2,210	5,702,550	0%	0	0	81%	17,904	51,322,947
2027	15%	3,239	8,396,467	0%	0	0	72%	15,602	44,936,647
2028	15%	2,962	8,002,355	0%	0	0	68%	13,426	40,308,160
2029	20%	3,712	10,260,841	0%	0	0	60%	11,136	34,202,804
2030	20%	3,583	10,079,515	0%	0	0	56%	10,032	31,358,493
2031	20%	2,299	6,209,013	0%	0	0	52%	5,979	17,937,150
2032	10%	586	831,861	0%	0	0	54%	3,166	4,991,164

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1987	0%	0	0	0.09	8.9	0.000	0.001
1988	0%	0	0	0.13	12	0.000	0.002
1989	0%	0	0	0.16	15	0.000	0.002
1990	0%	0	0	0.15	14	0.000	0.002
1991	0%	0	0	0.14	11	0.000	0.002
1992	0%	0	0	0.11	9.2	0.000	0.001
1993	0%	0	0	0.09	7.5	0.000	0.001
1994	0%	0	0	0.08	7.6	0.000	0.001
1995	0%	0	0	0.11	10	0.000	0.002
1996	0%	0	0	0.11	10	0.000	0.002
1997	0%	0	0	0.10	9.1	0.000	0.001
1998	0%	0	0	0.10	10	0.000	0.001
1999	0%	0	0	0.17	13	0.000	0.002
2000	0%	0	0	0.20	16	0.000	0.002
2001	0%	0	0	0.20	16	0.000	0.003
2002	0%	0	0	0.21	17	0.000	0.003
2003	0%	0	0	0.13	17	0.000	0.003
2004	0%	0	0	0.12	17	0.000	0.003
2005	0%	0	0	0.15	22	0.000	0.003
2006	0%	0	0	0.18	25	0.000	0.004
2007	0%	0	0	0.22	35	0.000	0.006
2008	0%	0	0	0.14	29	0.000	0.005
2009	0%	0	0	0.15	34	0.000	0.005
2010	0%	0	0	0.07	18	0.000	0.003
2011	0%	0	0	0.05	21	0.000	0.003
2012	0%	0	0	6.3	2,125	0.004	0.33
2013	0%	0	0	5.2	1,931	0.003	0.30
2014	0%	0	0	4.9	1,993	0.004	0.31
2015	0%	0	0	8.0	3,471	0.007	0.55
2016	0%	0	0	9.1	3,866	0.010	0.61
2017	0%	0	0	9.2	4,023	0.009	0.63
2018	0%	0	0	3.8	1,588	0.004	0.25
2019	0%	0	0	4.5	1,861	0.004	0.29
2020	0%	0	0	5.4	2,255	0.005	0.35
2021	0%	0	0	6.2	2,272	0.006	0.36
2022	0%	0	0	7.5	2,835	0.007	0.45
2023	0%	0	0	12	4,261	0.010	0.67
2024	5%	977	710,226	1.2	3,809	0.01	0.60
2025	6%	1,425	1,127,756	1.3	4,239	0.01	0.67
2026	9%	1,989	1,694,660	1.2	4,330	0.01	0.68
2027	13%	2,753	2,356,604	1.2	4,075	0.01	0.64
2028	17%	3,357	2,994,653	1.1	3,695	0.009	0.58
2029	20%	3,712	3,388,083	1.0	3,425	0.009	0.54
2030	24%	4,300	3,993,852	0.87	3,196	0.008	0.50
2031	28%	3,219	2,870,263	0.47	1,865	0.004	0.29
2032	36%	2,111	988,836	0.12	444	0.002	0.07

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
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gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	66	0.04	3.5	0.000	0.001	0.31	100%	66	42,043
1994	83	0.05	4.2	0.000	0.001	0.38	100%	83	50,721
1995	115	0.07	5.9	0.000	0.001	0.53	100%	115	70,970
1996	119	0.07	6.1	0.000	0.001	0.54	100%	119	72,842
1997	117	0.06	5.9	0.000	0.001	0.52	100%	117	70,488
1998	104	0.06	5.7	0.000	0.001	0.50	100%	104	67,898
1999	133	0.10	7.6	0.000	0.001	0.67	100%	133	90,610
2000	147	0.11	8.5	0.000	0.001	0.76	100%	147	101,850
2001	161	0.11	8.8	0.000	0.001	0.79	100%	161	105,603
2002	172	0.11	9.0	0.000	0.001	0.80	100%	172	107,968
2003	146	0.06	8.3	0.000	0.001	0.74	100%	146	99,226
2004	143	0.06	8.1	0.000	0.001	0.72	100%	143	96,731
2005	178	0.07	10	0.000	0.002	0.92	100%	178	123,640
2006	202	0.09	12	0.000	0.002	1.1	100%	202	143,033
2007	272	0.11	17	0.000	0.003	1.5	100%	272	200,277
2008	292	0.07	15	0.000	0.002	1.3	100%	292	179,211
2009	346	0.08	18	0.000	0.003	1.6	100%	346	213,122
2010	183	0.04	9.3	0.000	0.001	0.83	100%	183	111,727
2011	234	0.03	11	0.000	0.002	1.0	100%	234	136,809
2012	7,969	2.4	804	0.002	0.13	72	100%	7,969	9,641,296
2013	4,340	2.0	750	0.001	0.12	67	100%	4,340	8,984,556
2014	4,954	2.0	817	0.001	0.13	73	100%	4,954	9,795,650
2015	9,674	3.7	1,601	0.003	0.25	143	100%	9,674	19,190,427
2016	10,519	3.7	1,604	0.004	0.25	143	100%	10,519	19,227,562
2017	14,184	3.9	1,723	0.004	0.27	154	100%	14,184	20,654,585
2018	4,924	1.7	692	0.002	0.11	62	100%	4,924	8,290,062
2019	5,803	1.9	807	0.002	0.13	72	100%	5,803	9,667,889
2020	6,713	2.3	945	0.002	0.15	84	100%	6,713	11,329,480
2021	7,708	2.6	942	0.003	0.15	84	100%	7,708	11,285,971
2022	9,361	3.4	1,197	0.003	0.19	107	100%	9,361	14,344,235
2023	12,311	5.2	1,799	0.004	0.28	160	100%	12,311	21,557,339
2024	14,157	5.5	1,804	0.005	0.28	161	0%	0	0
2025	15,781	6.4	2,112	0.006	0.33	188	0%	0	0
2026	17,659	7.5	2,484	0.007	0.39	221	0%	0	0
2027	19,532	8.7	2,768	0.008	0.44	247	0%	0	0
2028	21,365	10	3,236	0.010	0.51	288	0%	0	0
2029	22,985	11	3,748	0.01	0.59	334	0%	0	0
2030	24,081	12	4,213	0.01	0.66	375	0%	0	0
2037	24,791	13	4,671	0.01	0.73	416	0%	0	0
2032	24,114	13	4,857	0.01	0.76	433	0%	0	0
2033	23,670	12	5,060	0.01	0.80	451	0%	0	0
2034	21,948	11	4,883	0.01	0.77	435	0%	0	0
2035	20,791	10	4,742	0.01	0.75	423	0%	0	0
2036	19,699	9.0	4,573	0.01	0.72	408	0%	0	0
2037	12,409	5.0	2,773	0.007	0.44	247	0%	0	0
2038	6,391	1.7	743	0.003	0.12	66	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	1,416	2,161,542	0%	0	0	86%	12,104	20,534,650
2025	10%	1,578	2,531,043	0%	0	0	84%	13,209	23,538,696
2026	10%	1,766	2,977,192	0%	0	0	81%	14,304	26,794,732
2027	15%	2,930	4,975,264	0%	0	0	72%	14,112	26,626,876
2028	15%	3,205	5,817,346	0%	0	0	68%	14,528	29,302,186
2029	20%	4,597	8,983,030	0%	0	0	60%	13,791	29,943,433
2030	20%	4,816	10,097,767	0%	0	0	56%	13,485	31,415,274
2037	12%	2,975	6,717,948	0%	0	0	53%	13,090	32,843,299
2032	10%	2,411	5,821,019	0%	0	0	54%	13,022	34,926,115
2033	10%	2,367	6,063,891	0%	0	0	54%	12,782	36,383,345
2034	10%	2,195	5,851,702	0%	0	0	54%	11,852	35,110,212
2035	12%	2,495	6,819,958	0%	0	0	53%	10,978	33,342,015
2036	12%	2,364	6,576,732	0%	0	0	53%	10,401	32,152,911
2037	12%	1,489	3,988,015	0%	0	0	53%	6,552	19,496,964
2038	12%	767	1,068,563	0%	0	0	53%	3,375	5,224,086

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1993	0%	0	0	0.04	3.5	0.000	0.001
1994	0%	0	0	0.05	4.2	0.000	0.001
1995	0%	0	0	0.07	5.9	0.000	0.001
1996	0%	0	0	0.07	6.1	0.000	0.001
1997	0%	0	0	0.06	5.9	0.000	0.001
1998	0%	0	0	0.06	5.7	0.000	0.001
1999	0%	0	0	0.10	7.6	0.000	0.001
2000	0%	0	0	0.11	8.5	0.000	0.001
2001	0%	0	0	0.11	8.8	0.000	0.001
2002	0%	0	0	0.11	9.0	0.000	0.001
2003	0%	0	0	0.06	8.3	0.000	0.001
2004	0%	0	0	0.06	8.1	0.000	0.001
2005	0%	0	0	0.07	10	0.000	0.002
2006	0%	0	0	0.09	12	0.000	0.002
2007	0%	0	0	0.11	17	0.000	0.003
2008	0%	0	0	0.07	15	0.000	0.002
2009	0%	0	0	0.08	18	0.000	0.003
2010	0%	0	0	0.04	9.3	0.000	0.001
2011	0%	0	0	0.03	11	0.000	0.002
2012	0%	0	0	2.4	804	0.002	0.13
2013	0%	0	0	2.0	750	0.001	0.12
2014	0%	0	0	2.0	817	0.001	0.13
2015	0%	0	0	3.7	1,601	0.003	0.25
2016	0%	0	0	3.7	1,604	0.004	0.25
2017	0%	0	0	3.9	1,723	0.004	0.27
2018	0%	0	0	1.7	692	0.002	0.11
2019	0%	0	0	1.9	807	0.002	0.13
2020	0%	0	0	2.3	945	0.002	0.15
2021	0%	0	0	2.6	942	0.003	0.15
2022	0%	0	0	3.4	1,197	0.003	0.19
2023	0%	0	0	5.2	1,799	0.004	0.28
2024	5%	637	321,179	0.61	1,722	0.005	0.27
2025	6%	994	526,515	0.70	1,979	0.006	0.31
2026	9%	1,589	884,750	0.80	2,261	0.007	0.36
2027	13%	2,490	1,396,388	1.0	2,415	0.007	0.38
2028	17%	3,632	2,176,976	1.1	2,686	0.008	0.42
2029	20%	4,597	2,966,155	1.2	2,998	0.009	0.47
2030	24%	5,779	4,001,083	1.3	3,202	0.009	0.50
2037	35%	8,727	6,506,824	1.1	3,027	0.008	0.48
2032	36%	8,681	6,919,465	1.0	3,109	0.009	0.49
2033	36%	8,521	7,208,168	1.0	3,238	0.008	0.51
2034	36%	7,901	6,955,938	0.88	3,125	0.008	0.49
2035	35%	7,318	6,605,628	0.83	3,073	0.008	0.48
2036	35%	6,934	6,370,046	0.74	2,963	0.007	0.47
2037	35%	4,368	3,862,685	0.41	1,797	0.004	0.28
2038	35%	2,250	1,034,981	0.14	481	0.002	0.08

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0	0	0	0	0	0	0%	0	0
2002	0	0	0	0	0	0	0%	0	0
2003	0	0	0	0	0	0	0%	0	0
2004	0	0	0	0	0	0	0%	0	0
2005	0	0	0	0	0	0	0%	0	0
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	5,738	1.9	631	0.002	0.10	56	0%	0	0
2025	6,682	2.2	740	0.002	0.12	66	0%	0	0
2026	7,830	2.6	869	0.002	0.14	77	0%	0	0
2027	8,960	3.0	954	0.003	0.15	85	0%	0	0
2028	10,297	3.5	1,096	0.003	0.17	98	0%	0	0
2029	11,921	4.1	1,276	0.004	0.20	114	0%	0	0
2030	13,807	4.8	1,488	0.005	0.23	133	0%	0	0
2045	15,655	5.9	1,819	0.006	0.29	162	0%	0	0
2032	17,813	7.1	2,196	0.007	0.35	196	0%	0	0
2033	20,003	8.3	2,581	0.008	0.41	230	0%	0	0
2034	22,623	10	3,067	0.009	0.48	273	0%	0	0
2035	24,976	11	3,584	0.01	0.56	319	0%	0	0
2036	26,967	13	4,118	0.01	0.65	367	0%	0	0
2037	28,599	14	4,677	0.01	0.74	417	0%	0	0
2038	29,556	15	5,172	0.01	0.81	461	0%	0	0
2039	30,085	16	5,646	0.02	0.89	503	0%	0	0
2040	28,520	15	5,685	0.02	0.89	507	0%	0	0
2041	27,485	14	5,816	0.02	0.91	518	0%	0	0
2042	24,780	12	5,446	0.01	0.86	485	0%	0	0
2043	23,286	11	5,243	0.01	0.82	467	0%	0	0
2044	22,012	10	5,025	0.01	0.79	448	0%	0	0
2045	13,831	5.5	3,030	0.007	0.48	270	0%	0	0
2046	7,111	1.9	812	0.004	0.13	72	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	574	756,340	0%	0	0	86%	4,906	7,185,231
2025	10%	668	886,781	0%	0	0	84%	5,593	8,247,067
2026	10%	783	1,041,761	0%	0	0	81%	6,343	9,375,851
2027	15%	1,344	1,715,605	0%	0	0	72%	6,474	9,181,662
2028	15%	1,544	1,969,828	0%	0	0	68%	7,002	9,922,098
2029	20%	2,384	3,059,507	0%	0	0	60%	7,152	10,198,356
2030	20%	2,761	3,566,433	0%	0	0	56%	7,732	11,095,569
2045	12%	1,879	2,615,706	0%	0	0	53%	8,266	12,787,894
2032	10%	1,781	2,631,722	0%	0	0	54%	9,619	15,790,332
2033	10%	2,000	3,093,484	0%	0	0	54%	10,802	18,560,905
2034	10%	2,262	3,676,051	0%	0	0	54%	12,217	22,056,309
2035	12%	2,997	5,154,227	0%	0	0	53%	13,188	25,198,442
2036	12%	3,236	5,922,773	0%	0	0	53%	14,239	28,955,778
2037	12%	3,432	6,725,482	0%	0	0	53%	15,100	32,880,135
2038	12%	3,547	7,438,400	0%	0	0	53%	15,606	36,365,513
2039	12%	3,610	8,118,998	0%	0	0	53%	15,885	39,692,877
2040	12%	3,422	8,176,299	0%	0	0	53%	15,058	39,973,018
2041	12%	3,298	8,363,731	0%	0	0	53%	14,512	40,889,352
2042	12%	2,974	7,831,788	0%	0	0	53%	13,084	38,288,741
2043	12%	2,794	7,539,421	0%	0	0	53%	12,295	36,859,392
2044	12%	2,641	7,227,079	0%	0	0	53%	11,622	35,332,388
2045	12%	1,660	4,357,601	0%	0	0	53%	7,303	21,303,829
2046	12%	853	1,167,185	0%	0	0	53%	3,755	5,706,238

Table A-18. NOx and GHG Tailpipe Emissions for Scenario 2 in Calendar Year 2045

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2001	0%	0	0	0	0	0	0
2002	0%	0	0	0	0	0	0
2003	0%	0	0	0	0	0	0
2004	0%	0	0	0	0	0	0
2005	0%	0	0	0	0	0	0
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	5%	258	112,383	0.21	603	0.002	0.09
2025	6%	421	184,471	0.24	693	0.002	0.11
2026	9%	705	309,586	0.28	791	0.002	0.12
2027	13%	1,142	481,512	0.33	833	0.002	0.13
2028	17%	1,750	737,152	0.37	909	0.003	0.14
2029	20%	2,384	1,010,235	0.45	1,021	0.003	0.16
2030	24%	3,314	1,413,144	0.51	1,131	0.003	0.18
2045	35%	5,511	2,533,502	0.49	1,179	0.004	0.19
2032	36%	6,413	3,128,337	0.56	1,405	0.004	0.22
2033	36%	7,201	3,677,235	0.66	1,652	0.005	0.26
2034	36%	8,144	4,369,735	0.78	1,963	0.006	0.31
2035	35%	8,792	4,992,246	0.94	2,322	0.007	0.37
2036	35%	9,493	5,736,639	1.1	2,669	0.008	0.42
2037	35%	10,067	6,514,121	1.2	3,030	0.009	0.48
2038	35%	10,404	7,204,635	1.2	3,352	0.009	0.53
2039	35%	10,590	7,863,843	1.3	3,658	0.01	0.58
2040	35%	10,039	7,919,344	1.2	3,684	0.01	0.58
2041	35%	9,675	8,100,885	1.2	3,769	0.010	0.59
2042	35%	8,723	7,585,660	1.0	3,529	0.009	0.55
2043	35%	8,197	7,302,481	0.92	3,397	0.008	0.53
2044	35%	7,748	6,999,955	0.82	3,256	0.008	0.51
2045	35%	4,869	4,220,656	0.45	1,963	0.005	0.31
2046	35%	2,503	1,130,504	0.15	526	0.002	0.08

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	2,595	0.86	281	0.001	0.04	25	0%	0	0
2025	3,028	1.0	330	0.001	0.05	29	0%	0	0
2026	3,626	1.2	393	0.001	0.06	35	0%	0	0
2027	4,257	1.4	439	0.001	0.07	39	0%	0	0
2028	5,060	1.7	526	0.001	0.08	47	0%	0	0
2029	6,031	2.0	632	0.002	0.10	56	0%	0	0
2030	7,066	2.4	743	0.002	0.12	66	0%	0	0
2050	8,217	2.8	872	0.003	0.14	78	0%	0	0
2032	9,494	3.2	1,017	0.003	0.16	91	0%	0	0
2033	11,004	3.8	1,176	0.004	0.18	105	0%	0	0
2034	12,911	4.5	1,386	0.004	0.22	124	0%	0	0
2035	14,935	5.3	1,619	0.005	0.25	144	0%	0	0
2036	16,783	6.4	1,962	0.006	0.31	175	0%	0	0
2037	18,732	7.5	2,328	0.007	0.37	208	0%	0	0
2038	20,725	8.7	2,699	0.008	0.42	241	0%	0	0
2039	22,925	10	3,137	0.009	0.49	280	0%	0	0
2040	25,074	11	3,619	0.01	0.57	323	0%	0	0
2041	27,099	13	4,155	0.01	0.65	370	0%	0	0
2042	28,740	14	4,704	0.01	0.74	419	0%	0	0
2043	29,658	15	5,184	0.01	0.81	462	0%	0	0
2044	30,119	16	5,634	0.02	0.89	502	0%	0	0
2045	28,407	15	5,643	0.02	0.89	503	0%	0	0
2046	27,387	14	5,770	0.02	0.91	514	0%	0	0
2047	24,660	12	5,397	0.01	0.85	481	0%	0	0
2048	23,198	11	5,206	0.01	0.82	464	0%	0	0
2049	21,872	10	4,978	0.01	0.78	444	0%	0	0
2050	13,695	5.4	2,992	0.007	0.47	267	0%	0	0
2051	7,053	1.8	1,226	0.004	0.19	109	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	260	337,270	0%	0	0	86%	2,219	3,204,066
2025	10%	303	395,918	0%	0	0	84%	2,534	3,682,036
2026	10%	363	471,136	0%	0	0	81%	2,937	4,240,226
2027	15%	639	789,915	0%	0	0	72%	3,076	4,227,507
2028	15%	759	945,969	0%	0	0	68%	3,441	4,764,882
2029	20%	1,206	1,514,257	0%	0	0	60%	3,619	5,047,525
2030	20%	1,413	1,780,183	0%	0	0	56%	3,957	5,538,347
2050	12%	986	1,253,331	0%	0	0	53%	4,339	6,127,395
2032	10%	949	1,218,218	0%	0	0	54%	5,127	7,309,307
2033	10%	1,100	1,409,784	0%	0	0	54%	5,942	8,458,701
2034	10%	1,291	1,660,800	0%	0	0	54%	6,972	9,964,800
2035	12%	1,792	2,327,866	0%	0	0	53%	7,885	11,380,679
2036	12%	2,014	2,822,001	0%	0	0	53%	8,861	13,796,450
2037	12%	2,248	3,348,517	0%	0	0	53%	9,890	16,370,527
2038	12%	2,487	3,881,574	0%	0	0	53%	10,943	18,976,585
2039	12%	2,751	4,511,626	0%	0	0	53%	12,105	22,056,839
2040	12%	3,009	5,204,512	0%	0	0	53%	13,239	25,444,282
2041	12%	3,252	5,974,789	0%	0	0	53%	14,308	29,210,080
2042	12%	3,449	6,765,245	0%	0	0	53%	15,175	33,074,532
2043	12%	3,559	7,455,772	0%	0	0	53%	15,660	36,450,439
2044	12%	3,614	8,101,789	0%	0	0	53%	15,903	39,608,744
2045	12%	3,409	8,115,025	0%	0	0	53%	14,999	39,673,455
2046	12%	3,286	8,297,953	0%	0	0	53%	14,461	40,567,771
2047	12%	2,959	7,761,898	0%	0	0	53%	13,021	37,947,059
2048	12%	2,784	7,487,127	0%	0	0	53%	12,249	36,603,732
2049	12%	2,625	7,158,856	0%	0	0	53%	11,549	34,998,851
2050	12%	1,643	4,302,930	0%	0	0	53%	7,231	21,036,548
2051	12%	846	1,763,371	0%	0	0	53%	3,724	8,620,923

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	5%	117	50,114	0.10	269	0.001	0.04
2025	6%	191	82,360	0.11	310	0.001	0.05
2026	9%	326	140,010	0.13	358	0.001	0.06
2027	13%	543	221,702	0.15	383	0.001	0.06
2028	17%	860	354,002	0.18	437	0.001	0.07
2029	20%	1,206	500,001	0.22	505	0.001	0.08
2030	24%	1,696	705,370	0.25	564	0.002	0.09
2050	35%	2,892	1,213,943	0.23	565	0.002	0.09
2032	36%	3,418	1,448,100	0.26	651	0.002	0.10
2033	36%	3,961	1,675,814	0.30	753	0.002	0.12
2034	36%	4,648	1,974,199	0.35	887	0.003	0.14
2035	35%	5,257	2,254,709	0.44	1,049	0.003	0.16
2036	35%	5,907	2,733,315	0.53	1,272	0.004	0.20
2037	35%	6,594	3,243,284	0.62	1,509	0.005	0.24
2038	35%	7,295	3,759,589	0.72	1,749	0.005	0.27
2039	35%	8,070	4,369,840	0.84	2,033	0.006	0.32
2040	35%	8,826	5,040,951	1.0	2,345	0.007	0.37
2041	35%	9,539	5,787,020	1.1	2,692	0.008	0.42
2042	35%	10,117	6,552,635	1.2	3,048	0.009	0.48
2043	35%	10,440	7,221,460	1.3	3,359	0.009	0.53
2044	35%	10,602	7,847,175	1.3	3,651	0.01	0.57
2045	35%	9,999	7,859,995	1.2	3,657	0.01	0.57
2046	35%	9,640	8,037,175	1.2	3,739	0.010	0.59
2047	35%	8,680	7,517,967	1.0	3,497	0.009	0.55
2048	35%	8,166	7,251,830	0.91	3,374	0.008	0.53
2049	35%	7,699	6,933,876	0.81	3,226	0.008	0.51
2050	35%	4,821	4,167,703	0.45	1,939	0.005	0.30
2051	35%	2,483	1,707,953	0.15	795	0.002	0.12

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	29	0.02	1.7	0.000	0.000	0.15	100%	29	19,871
1977	34	0.02	2.3	0.000	0.000	0.20	100%	34	27,331
1978	66	0.04	3.9	0.000	0.001	0.35	100%	66	47,207
1979	94	0.05	5.0	0.000	0.001	0.44	100%	94	59,761
1980	87	0.05	5.1	0.000	0.001	0.45	100%	87	61,143
1981	258	0.15	15	0.000	0.002	1.3	100%	258	180,361
1982	236	0.13	13	0.000	0.002	1.2	100%	236	156,209
1983	219	0.13	13	0.000	0.002	1.1	100%	219	151,257
1984	274	0.18	18	0.000	0.003	1.6	100%	274	214,575
1985	404	0.25	25	0.000	0.004	2.2	100%	404	301,188
1986	396	0.25	25	0.000	0.004	2.2	100%	396	301,092
1987	426	0.29	27	0.000	0.004	2.4	100%	426	324,223
1988	484	0.34	32	0.000	0.005	2.9	100%	484	387,591
1989	567	0.40	38	0.000	0.006	3.4	100%	567	454,438
1990	539	0.39	37	0.000	0.006	3.3	100%	539	446,862
1991	475	0.34	28	0.000	0.004	2.5	100%	475	335,098
1992	399	0.31	25	0.000	0.004	2.2	100%	399	301,877
1993	363	0.29	25	0.000	0.004	2.2	100%	363	295,585
1994	379	0.31	28	0.000	0.004	2.5	100%	379	330,512
1995	507	0.41	37	0.000	0.006	3.3	100%	507	443,837
1996	1,142	1.8	150	0.006	0.02	13	100%	1,142	1,800,897
1997	1,167	1.8	149	0.006	0.02	13	100%	1,167	1,790,241
1998	1,370	2.2	192	0.008	0.03	17	100%	1,370	2,305,455
1999	1,972	4.1	291	0.01	0.05	26	100%	1,972	3,484,066
2000	4,067	9.0	641	0.02	0.10	57	100%	4,067	7,683,603
2001	3,153	6.6	476	0.02	0.07	42	100%	3,153	5,706,180
2002	2,427	4.6	338	0.01	0.05	30	100%	2,427	4,046,083
2003	2,907	3.5	425	0.01	0.07	38	100%	2,907	5,088,912
2004	2,913	3.0	421	0.01	0.07	38	100%	2,913	5,047,803
2005	4,812	5.1	719	0.02	0.11	64	100%	4,812	8,613,212
2006	5,968	6.9	972	0.03	0.15	87	100%	5,968	11,650,876
2007	8,303	9.5	1,454	0.03	0.23	130	100%	8,303	17,419,576
2008	12,274	13	2,417	0.02	0.38	215	100%	12,274	28,960,284
2009	14,354	16	3,080	0.03	0.48	275	100%	14,354	36,913,677
2010	11,383	13	2,653	0.02	0.42	236	100%	11,383	31,795,323
2011	13,627	10	3,166	0.01	0.50	282	100%	13,627	37,940,166
2012	39,297	19	6,724	0.01	1.1	599	100%	39,297	80,581,115
2013	21,084	14	5,397	0.010	0.85	481	100%	21,084	64,680,893
2014	23,061	12	5,525	0.01	0.87	492	100%	23,061	66,207,976
2015	28,916	14	7,779	0.02	1.2	693	100%	28,916	93,222,050
2016	41,998	22	12,488	0.02	2.0	1,113	100%	41,998	149,658,452
2017	16,101	6.6	3,944	0.008	0.62	351	100%	16,101	47,265,405
2018	12,688	5.9	3,720	0.007	0.58	332	100%	12,688	44,579,225
2019	12,851	5.6	3,844	0.007	0.60	343	100%	12,851	46,069,473
2020	8,537	3.3	2,461	0.004	0.39	219	100%	8,537	29,496,897
2021	4,246	1.1	575	0.002	0.09	51	100%	4,246	6,891,960

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	0%	0	0	0%	0	0	0%	0	0
1977	0%	0	0	0%	0	0	0%	0	0
1978	0%	0	0	0%	0	0	0%	0	0
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1976	0%	0	0	0.02	1.7	0.000	0.000
1977	0%	0	0	0.02	2.3	0.000	0.000
1978	0%	0	0	0.04	3.9	0.000	0.001
1979	0%	0	0	0.05	5.0	0.000	0.001
1980	0%	0	0	0.05	5.1	0.000	0.001
1981	0%	0	0	0.15	15	0.000	0.002
1982	0%	0	0	0.13	13	0.000	0.002
1983	0%	0	0	0.13	13	0.000	0.002
1984	0%	0	0	0.18	18	0.000	0.003
1985	0%	0	0	0.25	25	0.000	0.004
1986	0%	0	0	0.25	25	0.000	0.004
1987	0%	0	0	0.29	27	0.000	0.004
1988	0%	0	0	0.34	32	0.000	0.005
1989	0%	0	0	0.40	38	0.000	0.006
1990	0%	0	0	0.39	37	0.000	0.006
1991	0%	0	0	0.34	28	0.000	0.004
1992	0%	0	0	0.31	25	0.000	0.004
1993	0%	0	0	0.29	25	0.000	0.004
1994	0%	0	0	0.31	28	0.000	0.004
1995	0%	0	0	0.41	37	0.000	0.006
1996	0%	0	0	1.8	150	0.006	0.02
1997	0%	0	0	1.8	149	0.006	0.02
1998	0%	0	0	2.2	192	0.008	0.03
1999	0%	0	0	4.1	291	0.01	0.05
2000	0%	0	0	9.0	641	0.02	0.10
2001	0%	0	0	6.6	476	0.02	0.07
2002	0%	0	0	4.6	338	0.01	0.05
2003	0%	0	0	3.5	425	0.01	0.07
2004	0%	0	0	3.0	421	0.01	0.07
2005	0%	0	0	5.1	719	0.02	0.11
2006	0%	0	0	6.9	972	0.03	0.15
2007	0%	0	0	9.5	1,454	0.03	0.23
2008	0%	0	0	13	2,417	0.02	0.38
2009	0%	0	0	16	3,080	0.03	0.48
2010	0%	0	0	13	2,653	0.02	0.42
2011	0%	0	0	10	3,166	0.01	0.50
2012	0%	0	0	19	6,724	0.01	1.1
2013	0%	0	0	14	5,397	0.010	0.85
2014	0%	0	0	12	5,525	0.01	0.87
2015	0%	0	0	14	7,779	0.02	1.2
2016	0%	0	0	22	12,488	0.02	2.0
2017	0%	0	0	6.6	3,944	0.008	0.62
2018	0%	0	0	5.9	3,720	0.007	0.58
2019	0%	0	0	5.6	3,844	0.007	0.60
2020	0%	0	0	3.3	2,461	0.004	0.39
2021	0%	0	0	1.1	575	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	53	0.03	2.9	0.000	0.000	0.26	100%	53	35,019
1980	64	0.04	3.7	0.000	0.001	0.33	100%	64	44,086
1981	209	0.12	12	0.000	0.002	1.1	100%	209	142,790
1982	208	0.11	11	0.000	0.002	1.0	100%	208	134,214
1983	196	0.11	11	0.000	0.002	1.0	100%	196	131,088
1984	241	0.15	15	0.000	0.002	1.3	100%	241	176,822
1985	357	0.21	21	0.000	0.003	1.9	100%	357	252,082
1986	331	0.20	20	0.000	0.003	1.8	100%	331	243,579
1987	345	0.22	21	0.000	0.003	1.9	100%	345	253,082
1988	370	0.26	24	0.000	0.004	2.2	100%	370	290,997
1989	420	0.29	28	0.000	0.004	2.5	100%	420	332,355
1990	382	0.28	27	0.000	0.004	2.4	100%	382	319,401
1991	331	0.24	20	0.000	0.003	1.8	100%	331	238,471
1992	279	0.22	18	0.000	0.003	1.6	100%	279	214,037
1993	235	0.20	17	0.000	0.003	1.5	100%	235	202,566
1994	257	0.21	19	0.000	0.003	1.7	100%	257	228,163
1995	341	0.29	26	0.000	0.004	2.3	100%	341	308,497
1996	354	0.29	26	0.000	0.004	2.3	100%	354	309,827
1997	358	0.27	24	0.000	0.004	2.2	100%	358	292,799
1998	350	0.29	27	0.000	0.004	2.4	100%	350	324,850
1999	484	0.48	38	0.000	0.006	3.4	100%	484	458,610
2000	570	0.55	44	0.000	0.007	3.9	100%	570	522,449
2001	630	0.52	42	0.000	0.007	3.7	100%	630	502,288
2002	683	0.50	41	0.000	0.006	3.7	100%	683	490,906
2003	607	0.31	41	0.000	0.006	3.7	100%	607	491,836
2004	588	0.27	39	0.000	0.006	3.4	100%	588	462,594
2005	722	0.33	48	0.000	0.008	4.3	100%	722	579,188
2006	789	0.37	53	0.000	0.008	4.7	100%	789	635,640
2007	1,010	0.43	69	0.000	0.01	6.1	100%	1,010	822,391
2008	958	0.24	51	0.000	0.008	4.5	100%	958	608,971
2009	1,054	0.24	57	0.000	0.009	5.1	100%	1,054	681,595
2010	516	0.11	28	0.000	0.004	2.5	100%	516	336,250
2011	601	0.08	32	0.000	0.005	2.8	100%	601	381,333
2012	36,456	15	5,160	0.010	0.81	460	100%	36,456	61,840,416
2013	23,385	13	4,715	0.009	0.74	420	100%	23,385	56,503,770
2014	25,954	12	4,907	0.01	0.77	437	100%	25,954	58,805,403
2015	43,313	18	8,476	0.02	1.3	755	100%	43,313	101,582,009
2016	51,092	25	12,180	0.03	1.9	1,086	100%	51,092	145,975,230
2017	45,093	20	10,301	0.02	1.6	918	100%	45,093	123,455,483
2018	15,699	7.6	3,880	0.008	0.61	346	100%	15,699	46,494,284
2019	15,755	7.5	4,119	0.008	0.65	367	100%	15,755	49,364,115
2020	14,758	7.0	4,076	0.008	0.64	363	100%	14,758	48,851,177
2021	13,866	6.3	3,442	0.008	0.54	307	100%	13,866	41,250,943
2022	13,999	6.1	3,590	0.008	0.56	320	100%	13,999	43,027,237
2023	9,671	3.7	2,395	0.005	0.38	213	100%	9,671	28,707,076
2024	4,843	1.3	599	0.003	0.09	53	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	484	717,286	0%	0	0	90%	4,358	7,172,863

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1979	0%	0	0	0.03	2.9	0.000	0.000
1980	0%	0	0	0.04	3.7	0.000	0.001
1981	0%	0	0	0.12	12	0.000	0.002
1982	0%	0	0	0.11	11	0.000	0.002
1983	0%	0	0	0.11	11	0.000	0.002
1984	0%	0	0	0.15	15	0.000	0.002
1985	0%	0	0	0.21	21	0.000	0.003
1986	0%	0	0	0.20	20	0.000	0.003
1987	0%	0	0	0.22	21	0.000	0.003
1988	0%	0	0	0.26	24	0.000	0.004
1989	0%	0	0	0.29	28	0.000	0.004
1990	0%	0	0	0.28	27	0.000	0.004
1991	0%	0	0	0.24	20	0.000	0.003
1992	0%	0	0	0.22	18	0.000	0.003
1993	0%	0	0	0.20	17	0.000	0.003
1994	0%	0	0	0.21	19	0.000	0.003
1995	0%	0	0	0.29	26	0.000	0.004
1996	0%	0	0	0.29	26	0.000	0.004
1997	0%	0	0	0.27	24	0.000	0.004
1998	0%	0	0	0.29	27	0.000	0.004
1999	0%	0	0	0.48	38	0.000	0.006
2000	0%	0	0	0.55	44	0.000	0.007
2001	0%	0	0	0.52	42	0.000	0.007
2002	0%	0	0	0.50	41	0.000	0.006
2003	0%	0	0	0.31	41	0.000	0.006
2004	0%	0	0	0.27	39	0.000	0.006
2005	0%	0	0	0.33	48	0.000	0.008
2006	0%	0	0	0.37	53	0.000	0.008
2007	0%	0	0	0.43	69	0.000	0.01
2008	0%	0	0	0.24	51	0.000	0.008
2009	0%	0	0	0.24	57	0.000	0.009
2010	0%	0	0	0.11	28	0.000	0.004
2011	0%	0	0	0.08	32	0.000	0.005
2012	0%	0	0	15	5,160	0.010	0.81
2013	0%	0	0	13	4,715	0.009	0.74
2014	0%	0	0	12	4,907	0.01	0.77
2015	0%	0	0	18	8,476	0.02	1.3
2016	0%	0	0	25	12,180	0.03	1.9
2017	0%	0	0	20	10,301	0.02	1.6
2018	0%	0	0	7.6	3,880	0.008	0.61
2019	0%	0	0	7.5	4,119	0.008	0.65
2020	0%	0	0	7.0	4,076	0.008	0.64
2021	0%	0	0	6.3	3,442	0.008	0.54
2022	0%	0	0	6.1	3,590	0.008	0.56
2023	0%	0	0	3.7	2,395	0.005	0.38
2024	0%	0	0	0.14	599	0.003	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	166	0.09	8.9	0.000	0.001	0.79	100%	166	106,532
1988	223	0.13	12	0.000	0.002	1.1	100%	223	144,024
1989	279	0.16	15	0.000	0.002	1.3	100%	279	179,202
1990	256	0.15	14	0.000	0.002	1.3	100%	256	168,297
1991	221	0.14	11	0.000	0.002	1.0	100%	221	134,880
1992	173	0.11	9.2	0.000	0.001	0.82	100%	173	110,429
1993	132	0.09	7.5	0.000	0.001	0.67	100%	132	90,308
1994	131	0.08	7.6	0.000	0.001	0.68	100%	131	91,104
1995	161	0.11	10	0.000	0.002	0.87	100%	161	116,335
1996	159	0.11	10	0.000	0.002	0.85	100%	159	114,485
1997	155	0.10	9.1	0.000	0.001	0.81	100%	155	108,509
1998	145	0.10	10	0.000	0.001	0.85	100%	145	114,337
1999	197	0.17	13	0.000	0.002	1.2	100%	197	160,607
2000	233	0.20	16	0.000	0.002	1.4	100%	233	188,016
2001	267	0.20	16	0.000	0.003	1.4	100%	267	193,494
2002	300	0.21	17	0.000	0.003	1.5	100%	300	200,551
2003	272	0.13	17	0.000	0.003	1.5	100%	272	200,037
2004	276	0.12	17	0.000	0.003	1.5	100%	276	198,929
2005	353	0.15	22	0.000	0.003	1.9	100%	353	259,740
2006	403	0.18	25	0.000	0.004	2.3	100%	403	303,073
2007	543	0.22	35	0.000	0.006	3.1	100%	543	422,431
2008	564	0.14	29	0.000	0.005	2.6	100%	564	352,228
2009	654	0.15	34	0.000	0.005	3.1	100%	654	410,832
2010	337	0.07	18	0.000	0.003	1.6	100%	337	211,381
2011	419	0.05	21	0.000	0.003	1.9	100%	419	253,413
2012	18,775	6.3	2,125	0.004	0.33	189	100%	18,775	25,469,698
2013	10,866	5.2	1,931	0.003	0.30	172	100%	10,866	23,141,590
2014	12,373	4.9	1,993	0.004	0.31	178	100%	12,373	23,884,682
2015	22,601	8.0	3,471	0.007	0.55	309	100%	22,601	41,601,211
2016	25,559	9.1	3,866	0.010	0.61	345	100%	25,559	46,327,589
2017	29,560	9.2	4,023	0.009	0.63	359	100%	29,560	48,215,934
2018	10,153	3.8	1,588	0.004	0.25	142	100%	10,153	19,030,587
2019	11,512	4.5	1,861	0.004	0.29	166	100%	11,512	22,305,607
2020	13,043	5.4	2,255	0.005	0.35	201	100%	13,043	27,025,846
2021	14,295	6.2	2,272	0.006	0.36	203	100%	14,295	27,231,919
2022	16,417	7.5	2,835	0.007	0.45	253	100%	16,417	33,979,835
2023	22,059	12	4,261	0.010	0.67	380	100%	22,059	51,063,434
2024	21,715	11	3,988	0.01	0.63	355	0%	0	0
2025	22,619	12	4,524	0.01	0.71	403	0%	0	0
2026	22,104	12	4,758	0.01	0.75	424	0%	0	0
2027	21,594	11	4,671	0.01	0.73	416	0%	0	0
2028	19,744	10	4,452	0.01	0.70	397	0%	0	0
2029	18,560	9.0	4,281	0.01	0.67	382	0%	0	0
2030	17,915	8.2	4,205	0.01	0.66	375	0%	0	0
2031	11,497	4.6	2,590	0.006	0.41	231	0%	0	0
2032	5,864	1.6	694	0.003	0.11	62	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	2,171	4,779,835	0%	0	0	90%	19,543	47,798,351
2025	10%	2,262	5,421,301	0%	0	0	90%	20,358	54,213,007
2026	10%	2,210	5,702,550	0%	0	0	90%	19,894	57,025,496
2027	15%	3,239	8,396,467	0%	0	0	85%	18,355	52,866,643
2028	15%	2,962	8,002,355	0%	0	0	85%	16,783	50,385,200
2029	20%	3,712	10,260,841	0%	0	0	80%	14,848	45,603,739
2030	20%	3,583	10,079,515	0%	0	0	80%	14,332	44,797,846
2031	20%	2,299	6,209,013	0%	0	0	80%	9,198	27,595,615
2032	10%	586	831,861	0%	0	0	90%	5,277	8,318,607

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
1987	0%	0	0	0.09	8.9	0.000	0.001
1988	0%	0	0	0.13	12	0.000	0.002
1989	0%	0	0	0.16	15	0.000	0.002
1990	0%	0	0	0.15	14	0.000	0.002
1991	0%	0	0	0.14	11	0.000	0.002
1992	0%	0	0	0.11	9.2	0.000	0.001
1993	0%	0	0	0.09	7.5	0.000	0.001
1994	0%	0	0	0.08	7.6	0.000	0.001
1995	0%	0	0	0.11	10	0.000	0.002
1996	0%	0	0	0.11	10	0.000	0.002
1997	0%	0	0	0.10	9.1	0.000	0.001
1998	0%	0	0	0.10	10	0.000	0.001
1999	0%	0	0	0.17	13	0.000	0.002
2000	0%	0	0	0.20	16	0.000	0.002
2001	0%	0	0	0.20	16	0.000	0.003
2002	0%	0	0	0.21	17	0.000	0.003
2003	0%	0	0	0.13	17	0.000	0.003
2004	0%	0	0	0.12	17	0.000	0.003
2005	0%	0	0	0.15	22	0.000	0.003
2006	0%	0	0	0.18	25	0.000	0.004
2007	0%	0	0	0.22	35	0.000	0.006
2008	0%	0	0	0.14	29	0.000	0.005
2009	0%	0	0	0.15	34	0.000	0.005
2010	0%	0	0	0.07	18	0.000	0.003
2011	0%	0	0	0.05	21	0.000	0.003
2012	0%	0	0	6.3	2,125	0.004	0.33
2013	0%	0	0	5.2	1,931	0.003	0.30
2014	0%	0	0	4.9	1,993	0.004	0.31
2015	0%	0	0	8.0	3,471	0.007	0.55
2016	0%	0	0	9.1	3,866	0.010	0.61
2017	0%	0	0	9.2	4,023	0.009	0.63
2018	0%	0	0	3.8	1,588	0.004	0.25
2019	0%	0	0	4.5	1,861	0.004	0.29
2020	0%	0	0	5.4	2,255	0.005	0.35
2021	0%	0	0	6.2	2,272	0.006	0.36
2022	0%	0	0	7.5	2,835	0.007	0.45
2023	0%	0	0	12	4,261	0.010	0.67
2024	0%	0	0	1.3	3,988	0.01	0.63
2025	0%	0	0	1.4	4,524	0.01	0.71
2026	0%	0	0	1.3	4,758	0.01	0.75
2027	0%	0	0	1.4	4,671	0.01	0.73
2028	0%	0	0	1.2	4,452	0.01	0.70
2029	0%	0	0	1.2	4,281	0.01	0.67
2030	0%	0	0	1.1	4,205	0.01	0.66
2031	0%	0	0	0.60	2,590	0.006	0.41
2032	0%	0	0	0.18	694	0.003	0.11

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	66	0.04	3.5	0.000	0.001	0.31	100%	66	42,043
1994	83	0.05	4.2	0.000	0.001	0.38	100%	83	50,721
1995	115	0.07	5.9	0.000	0.001	0.53	100%	115	70,970
1996	119	0.07	6.1	0.000	0.001	0.54	100%	119	72,842
1997	117	0.06	5.9	0.000	0.001	0.52	100%	117	70,488
1998	104	0.06	5.7	0.000	0.001	0.50	100%	104	67,898
1999	133	0.10	7.6	0.000	0.001	0.67	100%	133	90,610
2000	147	0.11	8.5	0.000	0.001	0.76	100%	147	101,850
2001	161	0.11	8.8	0.000	0.001	0.79	100%	161	105,603
2002	172	0.11	9.0	0.000	0.001	0.80	100%	172	107,968
2003	146	0.06	8.3	0.000	0.001	0.74	100%	146	99,226
2004	143	0.06	8.1	0.000	0.001	0.72	100%	143	96,731
2005	178	0.07	10	0.000	0.002	0.92	100%	178	123,640
2006	202	0.09	12	0.000	0.002	1.1	100%	202	143,033
2007	272	0.11	17	0.000	0.003	1.5	100%	272	200,277
2008	292	0.07	15	0.000	0.002	1.3	100%	292	179,211
2009	346	0.08	18	0.000	0.003	1.6	100%	346	213,122
2010	183	0.04	9.3	0.000	0.001	0.83	100%	183	111,727
2011	234	0.03	11	0.000	0.002	1.0	100%	234	136,809
2012	7,969	2.4	804	0.002	0.13	72	100%	7,969	9,641,296
2013	4,340	2.0	750	0.001	0.12	67	100%	4,340	8,984,556
2014	4,954	2.0	817	0.001	0.13	73	100%	4,954	9,795,650
2015	9,674	3.7	1,601	0.003	0.25	143	100%	9,674	19,190,427
2016	10,519	3.7	1,604	0.004	0.25	143	100%	10,519	19,227,562
2017	14,184	3.9	1,723	0.004	0.27	154	100%	14,184	20,654,585
2018	4,924	1.7	692	0.002	0.11	62	100%	4,924	8,290,062
2019	5,803	1.9	807	0.002	0.13	72	100%	5,803	9,667,889
2020	6,713	2.3	945	0.002	0.15	84	100%	6,713	11,329,480
2021	7,708	2.6	942	0.003	0.15	84	100%	7,708	11,285,971
2022	9,361	3.4	1,197	0.003	0.19	107	100%	9,361	14,344,235
2023	12,311	5.2	1,799	0.004	0.28	160	100%	12,311	21,557,339
2024	14,157	5.5	1,804	0.005	0.28	161	0%	0	0
2025	15,781	6.4	2,112	0.006	0.33	188	0%	0	0
2026	17,659	7.5	2,484	0.007	0.39	221	0%	0	0
2027	19,532	8.7	2,768	0.008	0.44	247	0%	0	0
2028	21,365	10	3,236	0.010	0.51	288	0%	0	0
2029	22,985	11	3,748	0.01	0.59	334	0%	0	0
2030	24,081	12	4,213	0.01	0.66	375	0%	0	0
2037	24,791	13	4,671	0.01	0.73	416	0%	0	0
2032	24,114	13	4,857	0.01	0.76	433	0%	0	0
2033	23,670	12	5,060	0.01	0.80	451	0%	0	0
2034	21,948	11	4,883	0.01	0.77	435	0%	0	0
2035	20,791	10	4,742	0.01	0.75	423	0%	0	0
2036	19,699	9.0	4,573	0.01	0.72	408	0%	0	0
2037	12,409	5.0	2,773	0.007	0.44	247	0%	0	0
2038	6,391	1.7	743	0.003	0.12	66	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	1,416	2,161,542	0%	0	0	90%	12,741	21,615,421
2025	10%	1,578	2,531,043	0%	0	0	90%	14,203	25,310,426
2026	10%	1,766	2,977,192	0%	0	0	90%	15,893	29,771,924
2027	15%	2,930	4,975,264	0%	0	0	85%	16,602	31,325,736
2028	15%	3,205	5,817,346	0%	0	0	85%	18,160	36,627,733
2029	20%	4,597	8,983,030	0%	0	0	80%	18,388	39,924,577
2030	20%	4,816	10,097,767	0%	0	0	80%	19,265	44,878,963
2037	12%	2,975	6,717,948	0%	0	0	88%	21,816	54,738,832
2032	10%	2,411	5,821,019	0%	0	0	90%	21,703	58,210,191
2033	10%	2,367	6,063,891	0%	0	0	90%	21,303	60,638,909
2034	10%	2,195	5,851,702	0%	0	0	90%	19,754	58,517,021
2035	12%	2,495	6,819,958	0%	0	0	88%	18,296	55,570,025
2036	12%	2,364	6,576,732	0%	0	0	88%	17,335	53,588,185
2037	12%	1,489	3,988,015	0%	0	0	88%	10,920	32,494,941
2038	12%	767	1,068,563	0%	0	0	88%	5,624	8,706,809

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1993	0%	0	0	0.04	3.5	0.000	0.001
1994	0%	0	0	0.05	4.2	0.000	0.001
1995	0%	0	0	0.07	5.9	0.000	0.001
1996	0%	0	0	0.07	6.1	0.000	0.001
1997	0%	0	0	0.06	5.9	0.000	0.001
1998	0%	0	0	0.06	5.7	0.000	0.001
1999	0%	0	0	0.10	7.6	0.000	0.001
2000	0%	0	0	0.11	8.5	0.000	0.001
2001	0%	0	0	0.11	8.8	0.000	0.001
2002	0%	0	0	0.11	9.0	0.000	0.001
2003	0%	0	0	0.06	8.3	0.000	0.001
2004	0%	0	0	0.06	8.1	0.000	0.001
2005	0%	0	0	0.07	10	0.000	0.002
2006	0%	0	0	0.09	12	0.000	0.002
2007	0%	0	0	0.11	17	0.000	0.003
2008	0%	0	0	0.07	15	0.000	0.002
2009	0%	0	0	0.08	18	0.000	0.003
2010	0%	0	0	0.04	9.3	0.000	0.001
2011	0%	0	0	0.03	11	0.000	0.002
2012	0%	0	0	2.4	804	0.002	0.13
2013	0%	0	0	2.0	750	0.001	0.12
2014	0%	0	0	2.0	817	0.001	0.13
2015	0%	0	0	3.7	1,601	0.003	0.25
2016	0%	0	0	3.7	1,604	0.004	0.25
2017	0%	0	0	3.9	1,723	0.004	0.27
2018	0%	0	0	1.7	692	0.002	0.11
2019	0%	0	0	1.9	807	0.002	0.13
2020	0%	0	0	2.3	945	0.002	0.15
2021	0%	0	0	2.6	942	0.003	0.15
2022	0%	0	0	3.4	1,197	0.003	0.19
2023	0%	0	0	5.2	1,799	0.004	0.28
2024	0%	0	0	0.63	1,804	0.005	0.28
2025	0%	0	0	0.74	2,112	0.006	0.33
2026	0%	0	0	0.87	2,484	0.007	0.39
2027	0%	0	0	1.1	2,768	0.008	0.44
2028	0%	0	0	1.2	3,236	0.010	0.51
2029	0%	0	0	1.5	3,748	0.01	0.59
2030	0%	0	0	1.6	4,213	0.01	0.66
2037	0%	0	0	1.5	4,671	0.01	0.73
2032	0%	0	0	1.5	4,857	0.01	0.76
2033	0%	0	0	1.4	5,060	0.01	0.80
2034	0%	0	0	1.3	4,883	0.01	0.77
2035	0%	0	0	1.2	4,742	0.01	0.75
2036	0%	0	0	1.1	4,573	0.01	0.72
2037	0%	0	0	0.59	2,773	0.007	0.44
2038	0%	0	0	0.20	743	0.003	0.12

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0	0	0	0	0	0	0%	0	0
2002	0	0	0	0	0	0	0%	0	0
2003	0	0	0	0	0	0	0%	0	0
2004	0	0	0	0	0	0	0%	0	0
2005	0	0	0	0	0	0	0%	0	0
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	5,738	1.9	631	0.002	0.10	56	0%	0	0
2025	6,682	2.2	740	0.002	0.12	66	0%	0	0
2026	7,830	2.6	869	0.002	0.14	77	0%	0	0
2027	8,960	3.0	954	0.003	0.15	85	0%	0	0
2028	10,297	3.5	1,096	0.003	0.17	98	0%	0	0
2029	11,921	4.1	1,276	0.004	0.20	114	0%	0	0
2030	13,807	4.8	1,488	0.005	0.23	133	0%	0	0
2045	15,655	5.9	1,819	0.006	0.29	162	0%	0	0
2032	17,813	7.1	2,196	0.007	0.35	196	0%	0	0
2033	20,003	8.3	2,581	0.008	0.41	230	0%	0	0
2034	22,623	10	3,067	0.009	0.48	273	0%	0	0
2035	24,976	11	3,584	0.01	0.56	319	0%	0	0
2036	26,967	13	4,118	0.01	0.65	367	0%	0	0
2037	28,599	14	4,677	0.01	0.74	417	0%	0	0
2038	29,556	15	5,172	0.01	0.81	461	0%	0	0
2039	30,085	16	5,646	0.02	0.89	503	0%	0	0
2040	28,520	15	5,685	0.02	0.89	507	0%	0	0
2041	27,485	14	5,816	0.02	0.91	518	0%	0	0
2042	24,780	12	5,446	0.01	0.86	485	0%	0	0
2043	23,286	11	5,243	0.01	0.82	467	0%	0	0
2044	22,012	10	5,025	0.01	0.79	448	0%	0	0
2045	13,831	5.5	3,030	0.007	0.48	270	0%	0	0
2046	7,111	1.9	812	0.004	0.13	72	0%	0	0

	Federal Low NOx DSL			**CA Cert. Low NOx DSL**			**Low NOx NG**		
Model Year	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	574	756,340	0%	0	0	90%	5,164	7,563,401
2025	10%	668	886,781	0%	0	0	90%	6,014	8,867,814
2026	10%	783	1,041,761	0%	0	0	90%	7,047	10,417,613
2027	15%	1,344	1,715,605	0%	0	0	85%	7,616	10,801,955
2028	15%	1,544	1,969,828	0%	0	0	85%	8,752	12,402,622
2029	20%	2,384	3,059,507	0%	0	0	80%	9,536	13,597,807
2030	20%	2,761	3,566,433	0%	0	0	80%	11,045	15,850,813
2045	12%	1,879	2,615,706	0%	0	0	88%	13,777	21,313,157
2032	10%	1,781	2,631,722	0%	0	0	90%	16,032	26,317,219
2033	10%	2,000	3,093,484	0%	0	0	90%	18,003	30,934,842
2034	10%	2,262	3,676,051	0%	0	0	90%	20,361	36,760,514
2035	12%	2,997	5,154,227	0%	0	0	88%	21,979	41,997,404
2036	12%	3,236	5,922,773	0%	0	0	88%	23,731	48,259,631
2037	12%	3,432	6,725,482	0%	0	0	88%	25,167	54,800,225
2038	12%	3,547	7,438,400	0%	0	0	88%	26,009	60,609,188
2039	12%	3,610	8,118,998	0%	0	0	88%	26,475	66,154,795
2040	12%	3,422	8,176,299	0%	0	0	88%	25,097	66,621,697
2041	12%	3,298	8,363,731	0%	0	0	88%	24,187	68,148,920
2042	12%	2,974	7,831,788	0%	0	0	88%	21,807	63,814,568
2043	12%	2,794	7,539,421	0%	0	0	88%	20,492	61,432,320
2044	12%	2,641	7,227,079	0%	0	0	88%	19,370	58,887,313
2045	12%	1,660	4,357,601	0%	0	0	88%	12,172	35,506,382
2046	12%	853	1,167,185	0%	0	0	88%	6,258	9,510,397

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2001	0%	0	0	0	0	0	0
2002	0%	0	0	0	0	0	0
2003	0%	0	0	0	0	0	0
2004	0%	0	0	0	0	0	0
2005	0%	0	0	0	0	0	0
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	0%	0	0	0.22	631	0.002	0.10
2025	0%	0	0	0.26	740	0.002	0.12
2026	0%	0	0	0.30	869	0.002	0.14
2027	0%	0	0	0.37	954	0.003	0.15
2028	0%	0	0	0.43	1,096	0.003	0.17
2029	0%	0	0	0.54	1,276	0.004	0.20
2030	0%	0	0	0.63	1,488	0.005	0.23
2045	0%	0	0	0.70	1,819	0.006	0.29
2032	0%	0	0	0.82	2,196	0.007	0.35
2033	0%	0	0	1.0	2,581	0.008	0.41
2034	0%	0	0	1.1	3,067	0.009	0.48
2035	0%	0	0	1.3	3,584	0.01	0.56
2036	0%	0	0	1.5	4,118	0.01	0.65
2037	0%	0	0	1.7	4,677	0.01	0.74
2038	0%	0	0	1.8	5,172	0.01	0.81
2039	0%	0	0	1.8	5,646	0.02	0.89
2040	0%	0	0	1.7	5,685	0.02	0.89
2041	0%	0	0	1.7	5,816	0.02	0.91
2042	0%	0	0	1.5	5,446	0.01	0.86
2043	0%	0	0	1.3	5,243	0.01	0.82
2044	0%	0	0	1.2	5,025	0.01	0.79
2045	0%	0	0	0.64	3,030	0.007	0.48
2046	0%	0	0	0.22	812	0.004	0.13

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Table A-25. NOx and GHG Tailpipe Emissions for Scenario 3 in Calendar Year 2050

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	2,595	0.86	281	0.001	0.04	25	0%	0	0
2025	3,028	1.0	330	0.001	0.05	29	0%	0	0
2026	3,626	1.2	393	0.001	0.06	35	0%	0	0
2027	4,257	1.4	439	0.001	0.07	39	0%	0	0
2028	5,060	1.7	526	0.001	0.08	47	0%	0	0
2029	6,031	2.0	632	0.002	0.10	56	0%	0	0
2030	7,066	2.4	743	0.002	0.12	66	0%	0	0
2050	8,217	2.8	872	0.003	0.14	78	0%	0	0
2032	9,494	3.2	1,017	0.003	0.16	91	0%	0	0
2033	11,004	3.8	1,176	0.004	0.18	105	0%	0	0
2034	12,911	4.5	1,386	0.004	0.22	124	0%	0	0
2035	14,935	5.3	1,619	0.005	0.25	144	0%	0	0
2036	16,783	6.4	1,962	0.006	0.31	175	0%	0	0
2037	18,732	7.5	2,328	0.007	0.37	208	0%	0	0
2038	20,725	8.7	2,699	0.008	0.42	241	0%	0	0
2039	22,925	10	3,137	0.009	0.49	280	0%	0	0
2040	25,074	11	3,619	0.01	0.57	323	0%	0	0
2041	27,099	13	4,155	0.01	0.65	370	0%	0	0
2042	28,740	14	4,704	0.01	0.74	419	0%	0	0
2043	29,658	15	5,184	0.01	0.81	462	0%	0	0
2044	30,119	16	5,634	0.02	0.89	502	0%	0	0
2045	28,407	15	5,643	0.02	0.89	503	0%	0	0
2046	27,387	14	5,770	0.02	0.91	514	0%	0	0
2047	24,660	12	5,397	0.01	0.85	481	0%	0	0
2048	23,198	11	5,206	0.01	0.82	464	0%	0	0
2049	21,872	10	4,978	0.01	0.78	444	0%	0	0
2050	13,695	5.4	2,992	0.007	0.47	267	0%	0	0
2051	7,053	1.8	1,226	0.004	0.19	109	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	260	337,270	0%	0	0	90%	2,336	3,372,701
2025	10%	303	395,918	0%	0	0	90%	2,725	3,959,178
2026	10%	363	471,136	0%	0	0	90%	3,263	4,711,362
2027	15%	639	789,915	0%	0	0	85%	3,618	4,973,538
2028	15%	759	945,969	0%	0	0	85%	4,301	5,956,103
2029	20%	1,206	1,514,257	0%	0	0	80%	4,825	6,730,033
2030	20%	1,413	1,780,183	0%	0	0	80%	5,653	7,911,924
2050	12%	986	1,253,331	0%	0	0	88%	7,231	10,212,325
2032	10%	949	1,218,218	0%	0	0	90%	8,544	12,182,179
2033	10%	1,100	1,409,784	0%	0	0	90%	9,904	14,097,835
2034	10%	1,291	1,660,800	0%	0	0	90%	11,620	16,608,001
2035	12%	1,792	2,327,866	0%	0	0	88%	13,142	18,967,798
2036	12%	2,014	2,822,001	0%	0	0	88%	14,769	22,994,084
2037	12%	2,248	3,348,517	0%	0	0	88%	16,484	27,284,212
2038	12%	2,487	3,881,574	0%	0	0	88%	18,238	31,627,641
2039	12%	2,751	4,511,626	0%	0	0	88%	20,174	36,761,398
2040	12%	3,009	5,204,512	0%	0	0	88%	22,065	42,407,136
2041	12%	3,252	5,974,789	0%	0	0	88%	23,847	48,683,467
2042	12%	3,449	6,765,245	0%	0	0	88%	25,292	55,124,220
2043	12%	3,559	7,455,772	0%	0	0	88%	26,099	60,750,732
2044	12%	3,614	8,101,789	0%	0	0	88%	26,505	66,014,573
2045	12%	3,409	8,115,025	0%	0	0	88%	24,998	66,122,425
2046	12%	3,286	8,297,953	0%	0	0	88%	24,101	67,612,952
2047	12%	2,959	7,761,898	0%	0	0	88%	21,701	63,245,098
2048	12%	2,784	7,487,127	0%	0	0	88%	20,414	61,006,220
2049	12%	2,625	7,158,856	0%	0	0	88%	19,248	58,331,418
2050	12%	1,643	4,302,930	0%	0	0	88%	12,051	35,060,913
2051	12%	846	1,763,371	0%	0	0	88%	6,207	14,368,205

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	0%	0	0	0.10	281	0.001	0.04
2025	0%	0	0	0.12	330	0.001	0.05
2026	0%	0	0	0.14	393	0.001	0.06
2027	0%	0	0	0.17	439	0.001	0.07
2028	0%	0	0	0.21	526	0.001	0.08
2029	0%	0	0	0.26	632	0.002	0.10
2030	0%	0	0	0.31	743	0.002	0.12
2050	0%	0	0	0.33	872	0.003	0.14
2032	0%	0	0	0.37	1,017	0.003	0.16
2033	0%	0	0	0.43	1,176	0.004	0.18
2034	0%	0	0	0.52	1,386	0.004	0.22
2035	0%	0	0	0.62	1,619	0.005	0.25
2036	0%	0	0	0.75	1,962	0.006	0.31
2037	0%	0	0	0.89	2,328	0.007	0.37
2038	0%	0	0	1.0	2,699	0.008	0.42
2039	0%	0	0	1.2	3,137	0.009	0.49
2040	0%	0	0	1.4	3,619	0.01	0.57
2041	0%	0	0	1.5	4,155	0.01	0.65
2042	0%	0	0	1.7	4,704	0.01	0.74
2043	0%	0	0	1.8	5,184	0.01	0.81
2044	0%	0	0	1.8	5,634	0.02	0.89
2045	0%	0	0	1.7	5,643	0.02	0.89
2046	0%	0	0	1.7	5,770	0.02	0.91
2047	0%	0	0	1.5	5,397	0.01	0.85
2048	0%	0	0	1.3	5,206	0.01	0.82
2049	0%	0	0	1.2	4,978	0.01	0.78
2050	0%	0	0	0.64	2,992	0.007	0.47
2051	0%	0	0	0.22	1,226	0.004	0.19

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	29	0.02	1.7	0.000	0.000	0.15	100%	29	19,871
1977	34	0.02	2.3	0.000	0.000	0.20	100%	34	27,331
1978	66	0.04	3.9	0.000	0.001	0.35	100%	66	47,207
1979	94	0.05	5.0	0.000	0.001	0.44	100%	94	59,761
1980	87	0.05	5.1	0.000	0.001	0.45	100%	87	61,143
1981	258	0.15	15	0.000	0.002	1.3	100%	258	180,361
1982	236	0.13	13	0.000	0.002	1.2	100%	236	156,209
1983	219	0.13	13	0.000	0.002	1.1	100%	219	151,257
1984	274	0.18	18	0.000	0.003	1.6	100%	274	214,575
1985	404	0.25	25	0.000	0.004	2.2	100%	404	301,188
1986	396	0.25	25	0.000	0.004	2.2	100%	396	301,092
1987	426	0.29	27	0.000	0.004	2.4	100%	426	324,223
1988	484	0.34	32	0.000	0.005	2.9	100%	484	387,591
1989	567	0.40	38	0.000	0.006	3.4	100%	567	454,438
1990	539	0.39	37	0.000	0.006	3.3	100%	539	446,862
1991	475	0.34	28	0.000	0.004	2.5	100%	475	335,098
1992	399	0.31	25	0.000	0.004	2.2	100%	399	301,877
1993	363	0.29	25	0.000	0.004	2.2	100%	363	295,585
1994	379	0.31	28	0.000	0.004	2.5	100%	379	330,512
1995	507	0.41	37	0.000	0.006	3.3	100%	507	443,837
1996	1,142	1.8	150	0.006	0.02	13	100%	1,142	1,800,897
1997	1,167	1.8	149	0.006	0.02	13	100%	1,167	1,790,241
1998	1,370	2.2	192	0.008	0.03	17	100%	1,370	2,305,455
1999	1,972	4.1	291	0.01	0.05	26	100%	1,972	3,484,066
2000	4,067	9.0	641	0.02	0.10	57	100%	4,067	7,683,603
2001	3,153	6.6	476	0.02	0.07	42	100%	3,153	5,706,180
2002	2,427	4.6	338	0.01	0.05	30	100%	2,427	4,046,083
2003	2,907	3.5	425	0.01	0.07	38	100%	2,907	5,088,912
2004	2,913	3.0	421	0.01	0.07	38	100%	2,913	5,047,803
2005	4,812	5.1	719	0.02	0.11	64	100%	4,812	8,613,212
2006	5,968	6.9	972	0.03	0.15	87	100%	5,968	11,650,876
2007	8,303	9.5	1,454	0.03	0.23	130	100%	8,303	17,419,576
2008	12,274	13	2,417	0.02	0.38	215	100%	12,274	28,960,284
2009	14,354	16	3,080	0.03	0.48	275	100%	14,354	36,913,677
2010	11,383	13	2,653	0.02	0.42	236	100%	11,383	31,795,323
2011	13,627	10	3,166	0.01	0.50	282	100%	13,627	37,940,166
2012	39,297	19	6,724	0.01	1.1	599	100%	39,297	80,581,115
2013	21,084	14	5,397	0.010	0.85	481	100%	21,084	64,680,893
2014	23,061	12	5,525	0.01	0.87	492	100%	23,061	66,207,976
2015	28,916	14	7,779	0.02	1.2	693	100%	28,916	93,222,050
2016	41,998	22	12,488	0.02	2.0	1,113	100%	41,998	149,658,452
2017	16,101	6.6	3,944	0.008	0.62	351	100%	16,101	47,265,405
2018	12,688	5.9	3,720	0.007	0.58	332	25%	3,172	11,144,806
2019	12,851	5.6	3,844	0.007	0.60	343	10%	1,285	4,606,947
2020	8,537	3.3	2,461	0.004	0.39	219	0%	0	0
2021	4,246	1.1	575	0.002	0.09	51	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	0%	0	0	0%	0	0	0%	0	0
1977	0%	0	0	0%	0	0	0%	0	0
1978	0%	0	0	0%	0	0	0%	0	0
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	75%	9,516	37,149,354
2019	0%	0	0	0%	0	0	90%	11,566	46,069,473
2020	0%	0	0	0%	0	0	100%	8,537	32,774,330
2021	0%	0	0	0%	0	0	100%	4,246	7,657,733

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
1976	0%	0	0	0.02	1.7	0.000	0.000
1977	0%	0	0	0.02	2.3	0.000	0.000
1978	0%	0	0	0.04	3.9	0.000	0.001
1979	0%	0	0	0.05	5.0	0.000	0.001
1980	0%	0	0	0.05	5.1	0.000	0.001
1981	0%	0	0	0.15	15	0.000	0.002
1982	0%	0	0	0.13	13	0.000	0.002
1983	0%	0	0	0.13	13	0.000	0.002
1984	0%	0	0	0.18	18	0.000	0.003
1985	0%	0	0	0.25	25	0.000	0.004
1986	0%	0	0	0.25	25	0.000	0.004
1987	0%	0	0	0.29	27	0.000	0.004
1988	0%	0	0	0.34	32	0.000	0.005
1989	0%	0	0	0.40	38	0.000	0.006
1990	0%	0	0	0.39	37	0.000	0.006
1991	0%	0	0	0.34	28	0.000	0.004
1992	0%	0	0	0.31	25	0.000	0.004
1993	0%	0	0	0.29	25	0.000	0.004
1994	0%	0	0	0.31	28	0.000	0.004
1995	0%	0	0	0.41	37	0.000	0.006
1996	0%	0	0	1.8	150	0.006	0.02
1997	0%	0	0	1.8	149	0.006	0.02
1998	0%	0	0	2.2	192	0.008	0.03
1999	0%	0	0	4.1	291	0.01	0.05
2000	0%	0	0	9.0	641	0.02	0.10
2001	0%	0	0	6.6	476	0.02	0.07
2002	0%	0	0	4.6	338	0.01	0.05
2003	0%	0	0	3.5	425	0.01	0.07
2004	0%	0	0	3.0	421	0.01	0.07
2005	0%	0	0	5.1	719	0.02	0.11
2006	0%	0	0	6.9	972	0.03	0.15
2007	0%	0	0	9.5	1,454	0.03	0.23
2008	0%	0	0	13	2,417	0.02	0.38
2009	0%	0	0	16	3,080	0.03	0.48
2010	0%	0	0	13	2,653	0.02	0.42
2011	0%	0	0	10	3,166	0.01	0.50
2012	0%	0	0	19	6,724	0.01	1.1
2013	0%	0	0	14	5,397	0.010	0.85
2014	0%	0	0	12	5,525	0.01	0.87
2015	0%	0	0	14	7,779	0.02	1.2
2016	0%	0	0	22	12,488	0.02	2.0
2017	0%	0	0	6.6	3,944	0.008	0.62
2018	0%	0	0	1.9	3,720	0.007	0.58
2019	0%	0	0	1.1	3,844	0.007	0.60
2020	0%	0	0	0.33	2,461	0.004	0.39
2021	0%	0	0	0.11	575	0.002	0.09

Notes:

1 EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

2 Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

3 Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

4 Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

5 Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

6 Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	53	0.03	2.9	0.000	0.000	0.26	100%	53	35,019
1980	64	0.04	3.7	0.000	0.001	0.33	100%	64	44,086
1981	209	0.12	12	0.000	0.002	1.1	100%	209	142,790
1982	208	0.11	11	0.000	0.002	1.0	100%	208	134,214
1983	196	0.11	11	0.000	0.002	1.0	100%	196	131,088
1984	241	0.15	15	0.000	0.002	1.3	100%	241	176,822
1985	357	0.21	21	0.000	0.003	1.9	100%	357	252,082
1986	331	0.20	20	0.000	0.003	1.8	100%	331	243,579
1987	345	0.22	21	0.000	0.003	1.9	100%	345	253,082
1988	370	0.26	24	0.000	0.004	2.2	100%	370	290,997
1989	420	0.29	28	0.000	0.004	2.5	100%	420	332,355
1990	382	0.28	27	0.000	0.004	2.4	100%	382	319,401
1991	331	0.24	20	0.000	0.003	1.8	100%	331	238,471
1992	279	0.22	18	0.000	0.003	1.6	100%	279	214,037
1993	235	0.20	17	0.000	0.003	1.5	100%	235	202,566
1994	257	0.21	19	0.000	0.003	1.7	100%	257	228,163
1995	341	0.29	26	0.000	0.004	2.3	100%	341	308,497
1996	354	0.29	26	0.000	0.004	2.3	100%	354	309,827
1997	358	0.27	24	0.000	0.004	2.2	100%	358	292,799
1998	350	0.29	27	0.000	0.004	2.4	100%	350	324,850
1999	484	0.48	38	0.000	0.006	3.4	100%	484	458,610
2000	570	0.55	44	0.000	0.007	3.9	100%	570	522,449
2001	630	0.52	42	0.000	0.007	3.7	100%	630	502,288
2002	683	0.50	41	0.000	0.006	3.7	100%	683	490,906
2003	607	0.31	41	0.000	0.006	3.7	100%	607	491,836
2004	588	0.27	39	0.000	0.006	3.4	100%	588	462,594
2005	722	0.33	48	0.000	0.008	4.3	100%	722	579,188
2006	789	0.37	53	0.000	0.008	4.7	100%	789	635,640
2007	1,010	0.43	69	0.000	0.01	6.1	100%	1,010	822,391
2008	958	0.24	51	0.000	0.008	4.5	100%	958	608,971
2009	1,054	0.24	57	0.000	0.009	5.1	100%	1,054	681,595
2010	516	0.11	28	0.000	0.004	2.5	100%	516	336,250
2011	601	0.08	32	0.000	0.005	2.8	100%	601	381,333
2012	36,456	15	5,160	0.010	0.81	460	100%	36,456	61,840,416
2013	23,385	13	4,715	0.009	0.74	420	100%	23,385	56,503,770
2014	25,954	12	4,907	0.01	0.77	437	100%	25,954	58,805,403
2015	43,313	18	8,476	0.02	1.3	755	100%	43,313	101,582,009
2016	51,092	25	12,180	0.03	1.9	1,086	100%	51,092	145,975,230
2017	45,093	20	10,301	0.02	1.6	918	100%	45,093	123,455,483
2018	15,699	7.6	3,880	0.008	0.61	346	25%	3,925	11,623,571
2019	15,755	7.5	4,119	0.008	0.65	367	10%	1,575	4,936,412
2020	14,758	7.0	4,076	0.008	0.64	363	0%	0	0
2021	13,866	6.3	3,442	0.008	0.54	307	0%	0	0
2022	13,999	6.1	3,590	0.008	0.56	320	0%	0	0
2023	9,671	3.7	2,395	0.005	0.38	213	0%	0	0
2024	4,843	1.3	599	0.003	0.09	53	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	75%	11,774	38,745,237
2019	0%	0	0	0%	0	0	90%	14,179	49,364,115
2020	0%	0	0	0%	0	0	100%	14,758	54,279,085
2021	0%	0	0	0%	0	0	100%	13,866	45,834,381
2022	0%	0	0	0%	0	0	100%	13,999	47,808,041
2023	0%	0	0	0%	0	0	100%	9,671	31,896,751
2024	10%	484	717,286	0%	0	0	86%	4,141	6,814,220

Model Year	BEV Fleet Mix[2] (%)	BEV Population[3]	BEV Energy Consumption[4] (MJ/day)	Tailpipe Emission Estimates[5] (tons/day) NO_X	CO_2	CH_4	N_2O
1979	0%	0	0	0.03	2.9	0.000	0.000
1980	0%	0	0	0.04	3.7	0.000	0.001
1981	0%	0	0	0.12	12	0.000	0.002
1982	0%	0	0	0.11	11	0.000	0.002
1983	0%	0	0	0.11	11	0.000	0.002
1984	0%	0	0	0.15	15	0.000	0.002
1985	0%	0	0	0.21	21	0.000	0.003
1986	0%	0	0	0.20	20	0.000	0.003
1987	0%	0	0	0.22	21	0.000	0.003
1988	0%	0	0	0.26	24	0.000	0.004
1989	0%	0	0	0.29	28	0.000	0.004
1990	0%	0	0	0.28	27	0.000	0.004
1991	0%	0	0	0.24	20	0.000	0.003
1992	0%	0	0	0.22	18	0.000	0.003
1993	0%	0	0	0.20	17	0.000	0.003
1994	0%	0	0	0.21	19	0.000	0.003
1995	0%	0	0	0.29	26	0.000	0.004
1996	0%	0	0	0.29	26	0.000	0.004
1997	0%	0	0	0.27	24	0.000	0.004
1998	0%	0	0	0.29	27	0.000	0.004
1999	0%	0	0	0.48	38	0.000	0.006
2000	0%	0	0	0.55	44	0.000	0.007
2001	0%	0	0	0.52	42	0.000	0.007
2002	0%	0	0	0.50	41	0.000	0.006
2003	0%	0	0	0.31	41	0.000	0.006
2004	0%	0	0	0.27	39	0.000	0.006
2005	0%	0	0	0.33	48	0.000	0.008
2006	0%	0	0	0.37	53	0.000	0.008
2007	0%	0	0	0.43	69	0.000	0.01
2008	0%	0	0	0.24	51	0.000	0.008
2009	0%	0	0	0.24	57	0.000	0.009
2010	0%	0	0	0.11	28	0.000	0.004
2011	0%	0	0	0.08	32	0.000	0.005
2012	0%	0	0	15	5,160	0.010	0.81
2013	0%	0	0	13	4,715	0.009	0.74
2014	0%	0	0	12	4,907	0.01	0.77
2015	0%	0	0	18	8,476	0.02	1.3
2016	0%	0	0	25	12,180	0.03	1.9
2017	0%	0	0	20	10,301	0.02	1.6
2018	0%	0	0	2.5	3,880	0.008	0.61
2019	0%	0	0	1.4	4,119	0.008	0.65
2020	0%	0	0	0.70	4,076	0.008	0.64
2021	0%	0	0	0.63	3,442	0.008	0.54
2022	0%	0	0	0.61	3,590	0.008	0.56
2023	0%	0	0	0.37	2,395	0.005	0.38
2024	5%	218	106,580	0.14	572	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	166	0.09	8.9	0.000	0.001	0.79	100%	166	106,532
1988	223	0.13	12	0.000	0.002	1.1	100%	223	144,024
1989	279	0.16	15	0.000	0.002	1.3	100%	279	179,202
1990	256	0.15	14	0.000	0.002	1.3	100%	256	168,297
1991	221	0.14	11	0.000	0.002	1.0	100%	221	134,880
1992	173	0.11	9.2	0.000	0.001	0.82	100%	173	110,429
1993	132	0.09	7.5	0.000	0.001	0.67	100%	132	90,308
1994	131	0.08	7.6	0.000	0.001	0.68	100%	131	91,104
1995	161	0.11	10	0.000	0.002	0.87	100%	161	116,335
1996	159	0.11	10	0.000	0.002	0.85	100%	159	114,485
1997	155	0.10	9.1	0.000	0.001	0.81	100%	155	108,509
1998	145	0.10	10	0.000	0.001	0.85	100%	145	114,337
1999	197	0.17	13	0.000	0.002	1.2	100%	197	160,607
2000	233	0.20	16	0.000	0.002	1.4	100%	233	188,016
2001	267	0.20	16	0.000	0.003	1.4	100%	267	193,494
2002	300	0.21	17	0.000	0.003	1.5	100%	300	200,551
2003	272	0.13	17	0.000	0.003	1.5	100%	272	200,037
2004	276	0.12	17	0.000	0.003	1.5	100%	276	198,929
2005	353	0.15	22	0.000	0.003	1.9	100%	353	259,740
2006	403	0.18	25	0.000	0.004	2.3	100%	403	303,073
2007	543	0.22	35	0.000	0.006	3.1	100%	543	422,431
2008	564	0.14	29	0.000	0.005	2.6	100%	564	352,228
2009	654	0.15	34	0.000	0.005	3.1	100%	654	410,832
2010	337	0.07	18	0.000	0.003	1.6	100%	337	211,381
2011	419	0.05	21	0.000	0.003	1.9	100%	419	253,413
2012	18,775	6.3	2,125	0.004	0.33	189	100%	18,775	25,469,698
2013	10,866	5.2	1,931	0.003	0.30	172	100%	10,866	23,141,590
2014	12,373	4.9	1,993	0.004	0.31	178	100%	12,373	23,884,682
2015	22,601	8.0	3,471	0.007	0.55	309	100%	22,601	41,601,211
2016	25,559	9.1	3,866	0.010	0.61	345	100%	25,559	46,327,589
2017	29,560	9.2	4,023	0.009	0.63	359	100%	29,560	48,215,934
2018	10,153	3.8	1,588	0.004	0.25	142	25%	2,538	4,757,647
2019	11,512	4.5	1,861	0.004	0.29	166	10%	1,151	2,230,561
2020	13,043	5.4	2,255	0.005	0.35	201	0%	0	0
2021	14,295	6.2	2,272	0.006	0.36	203	0%	0	0
2022	16,417	7.5	2,835	0.007	0.45	253	0%	0	0
2023	22,059	12	4,261	0.010	0.67	380	0%	0	0
2024	21,715	11	3,988	0.01	0.63	355	0%	0	0
2025	22,619	12	4,524	0.01	0.71	403	0%	0	0
2026	22,104	12	4,758	0.01	0.75	424	0%	0	0
2027	21,594	11	4,671	0.01	0.73	416	0%	0	0
2028	19,744	10	4,452	0.01	0.70	397	0%	0	0
2029	18,560	9.0	4,281	0.01	0.67	382	0%	0	0
2030	17,915	8.2	4,205	0.01	0.66	375	0%	0	0
2031	11,497	4.6	2,590	0.006	0.41	231	0%	0	0
2032	5,864	1.6	694	0.003	0.11	62	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	75%	7,615	15,858,823
2019	0%	0	0	0%	0	0	90%	10,361	22,305,607
2020	0%	0	0	0%	0	0	100%	13,043	30,028,717
2021	0%	0	0	0%	0	0	100%	14,295	30,257,688
2022	0%	0	0	0%	0	0	100%	16,417	37,755,372
2023	0%	0	0	0%	0	0	100%	22,059	56,737,149
2024	10%	2,171	4,779,835	0%	0	0	86%	18,566	45,408,434
2025	10%	2,262	5,421,301	0%	0	0	84%	18,932	50,418,096
2026	10%	2,210	5,702,550	0%	0	0	81%	17,904	51,322,947
2027	15%	3,239	8,396,467	0%	0	0	72%	15,602	44,936,647
2028	15%	2,962	8,002,355	0%	0	0	68%	13,426	40,308,160
2029	20%	3,712	10,260,841	0%	0	0	60%	11,136	34,202,804
2030	20%	3,583	10,079,515	0%	0	0	56%	10,032	31,358,493
2031	20%	2,299	6,209,013	0%	0	0	52%	5,979	17,937,150
2032	10%	586	831,861	0%	0	0	54%	3,166	4,991,164

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1987	0%	0	0	0.09	8.9	0.000	0.001
1988	0%	0	0	0.13	12	0.000	0.002
1989	0%	0	0	0.16	15	0.000	0.002
1990	0%	0	0	0.15	14	0.000	0.002
1991	0%	0	0	0.14	11	0.000	0.002
1992	0%	0	0	0.11	9.2	0.000	0.001
1993	0%	0	0	0.09	7.5	0.000	0.001
1994	0%	0	0	0.08	7.6	0.000	0.001
1995	0%	0	0	0.11	10	0.000	0.002
1996	0%	0	0	0.11	10	0.000	0.002
1997	0%	0	0	0.10	9.1	0.000	0.001
1998	0%	0	0	0.10	10	0.000	0.001
1999	0%	0	0	0.17	13	0.000	0.002
2000	0%	0	0	0.20	16	0.000	0.002
2001	0%	0	0	0.20	16	0.000	0.003
2002	0%	0	0	0.21	17	0.000	0.003
2003	0%	0	0	0.13	17	0.000	0.003
2004	0%	0	0	0.12	17	0.000	0.003
2005	0%	0	0	0.15	22	0.000	0.003
2006	0%	0	0	0.18	25	0.000	0.004
2007	0%	0	0	0.22	35	0.000	0.006
2008	0%	0	0	0.14	29	0.000	0.005
2009	0%	0	0	0.15	34	0.000	0.005
2010	0%	0	0	0.07	18	0.000	0.003
2011	0%	0	0	0.05	21	0.000	0.003
2012	0%	0	0	6.3	2,125	0.004	0.33
2013	0%	0	0	5.2	1,931	0.003	0.30
2014	0%	0	0	4.9	1,993	0.004	0.31
2015	0%	0	0	8.0	3,471	0.007	0.55
2016	0%	0	0	9.1	3,866	0.010	0.61
2017	0%	0	0	9.2	4,023	0.009	0.63
2018	0%	0	0	1.2	1,588	0.004	0.25
2019	0%	0	0	0.85	1,861	0.004	0.29
2020	0%	0	0	0.54	2,255	0.005	0.35
2021	0%	0	0	0.62	2,272	0.006	0.36
2022	0%	0	0	0.75	2,835	0.007	0.45
2023	0%	0	0	1.2	4,261	0.010	0.67
2024	5%	977	710,226	1.2	3,809	0.01	0.60
2025	6%	1,425	1,127,756	1.3	4,239	0.01	0.67
2026	9%	1,989	1,694,660	1.2	4,330	0.01	0.68
2027	13%	2,753	2,356,604	1.2	4,075	0.01	0.64
2028	17%	3,357	2,994,653	1.1	3,695	0.009	0.58
2029	20%	3,712	3,388,083	1.0	3,425	0.009	0.54
2030	24%	4,300	3,993,852	0.87	3,196	0.008	0.50
2031	28%	3,219	2,870,263	0.47	1,865	0.004	0.29
2032	36%	2,111	988,836	0.12	444	0.002	0.07

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	**Population**	**NOx_TOTEX (tons/day)**	**CO2_TOTEX (tons/day)**	**CH4_TOTEX (tons/day)**	**N2O_TOTEX (tons/day)**	**Fuel Consumption (1000 gal/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
1993	66	0.04	3.5	0.000	0.001	0.31	100%	66	42,043
1994	83	0.05	4.2	0.000	0.001	0.38	100%	83	50,721
1995	115	0.07	5.9	0.000	0.001	0.53	100%	115	70,970
1996	119	0.07	6.1	0.000	0.001	0.54	100%	119	72,842
1997	117	0.06	5.9	0.000	0.001	0.52	100%	117	70,488
1998	104	0.06	5.7	0.000	0.001	0.50	100%	104	67,898
1999	133	0.10	7.6	0.000	0.001	0.67	100%	133	90,610
2000	147	0.11	8.5	0.000	0.001	0.76	100%	147	101,850
2001	161	0.11	8.8	0.000	0.001	0.79	100%	161	105,603
2002	172	0.11	9.0	0.000	0.001	0.80	100%	172	107,968
2003	146	0.06	8.3	0.000	0.001	0.74	100%	146	99,226
2004	143	0.06	8.1	0.000	0.001	0.72	100%	143	96,731
2005	178	0.07	10	0.000	0.002	0.92	100%	178	123,640
2006	202	0.09	12	0.000	0.002	1.1	100%	202	143,033
2007	272	0.11	17	0.000	0.003	1.5	100%	272	200,277
2008	292	0.07	15	0.000	0.002	1.3	100%	292	179,211
2009	346	0.08	18	0.000	0.003	1.6	100%	346	213,122
2010	183	0.04	9.3	0.000	0.001	0.83	100%	183	111,727
2011	234	0.03	11	0.000	0.002	1.0	100%	234	136,809
2012	7,969	2.4	804	0.002	0.13	72	100%	7,969	9,641,296
2013	4,340	2.0	750	0.001	0.12	67	100%	4,340	8,984,556
2014	4,954	2.0	817	0.001	0.13	73	100%	4,954	9,795,650
2015	9,674	3.7	1,601	0.003	0.25	143	100%	9,674	19,190,427
2016	10,519	3.7	1,604	0.004	0.25	143	100%	10,519	19,227,562
2017	14,184	3.9	1,723	0.004	0.27	154	100%	14,184	20,654,585
2018	4,924	1.7	692	0.002	0.11	62	25%	1,231	2,072,516
2019	5,803	1.9	807	0.002	0.13	72	10%	580	966,789
2020	6,713	2.3	945	0.002	0.15	84	0%	0	0
2021	7,708	2.6	942	0.003	0.15	84	0%	0	0
2022	9,361	3.4	1,197	0.003	0.19	107	0%	0	0
2023	12,311	5.2	1,799	0.004	0.28	160	0%	0	0
2024	14,157	5.5	1,804	0.005	0.28	161	0%	0	0
2025	15,781	6.4	2,112	0.006	0.33	188	0%	0	0
2026	17,659	7.5	2,484	0.007	0.39	221	0%	0	0
2027	19,532	8.7	2,768	0.008	0.44	247	0%	0	0
2028	21,365	10	3,236	0.010	0.51	288	0%	0	0
2029	22,985	11	3,748	0.01	0.59	334	0%	0	0
2030	24,081	12	4,213	0.01	0.66	375	0%	0	0
2037	24,791	13	4,671	0.01	0.73	416	0%	0	0
2032	24,114	13	4,857	0.01	0.76	433	0%	0	0
2033	23,670	12	5,060	0.01	0.80	451	0%	0	0
2034	21,948	11	4,883	0.01	0.77	435	0%	0	0
2035	20,791	10	4,742	0.01	0.75	423	0%	0	0
2036	19,699	9.0	4,573	0.01	0.72	408	0%	0	0
2037	12,409	5.0	2,773	0.007	0.44	247	0%	0	0
2038	6,391	1.7	743	0.003	0.12	66	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	75%	3,693	6,908,385
2019	0%	0	0	0%	0	0	90%	5,223	9,667,889
2020	0%	0	0	0%	0	0	100%	6,713	12,588,312
2021	0%	0	0	0%	0	0	100%	7,708	12,539,967
2022	0%	0	0	0%	0	0	100%	9,361	15,938,038
2023	0%	0	0	0%	0	0	100%	12,311	23,952,598
2024	10%	1,416	2,161,542	0%	0	0	86%	12,104	20,534,650
2025	10%	1,578	2,531,043	0%	0	0	84%	13,209	23,538,696
2026	10%	1,766	2,977,192	0%	0	0	81%	14,304	26,794,732
2027	15%	2,930	4,975,264	0%	0	0	72%	14,112	26,626,876
2028	15%	3,205	5,817,346	0%	0	0	68%	14,528	29,302,186
2029	20%	4,597	8,983,030	0%	0	0	60%	13,791	29,943,433
2030	20%	4,816	10,097,767	0%	0	0	56%	13,485	31,415,274
2037	12%	2,975	6,717,948	0%	0	0	53%	13,090	32,843,299
2032	10%	2,411	5,821,019	0%	0	0	54%	13,022	34,926,115
2033	10%	2,367	6,063,891	0%	0	0	54%	12,782	36,383,345
2034	10%	2,195	5,851,702	0%	0	0	54%	11,852	35,110,212
2035	12%	2,495	6,819,958	0%	0	0	53%	10,978	33,342,015
2036	12%	2,364	6,576,732	0%	0	0	53%	10,401	32,152,911
2037	12%	1,489	3,988,015	0%	0	0	53%	6,552	19,496,964
2038	12%	767	1,068,563	0%	0	0	53%	3,375	5,224,086

	BEV			Tailpipe Emission Estimates[5] (tons/day)			
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1993	0%	0	0	0.04	3.5	0.000	0.001
1994	0%	0	0	0.05	4.2	0.000	0.001
1995	0%	0	0	0.07	5.9	0.000	0.001
1996	0%	0	0	0.07	6.1	0.000	0.001
1997	0%	0	0	0.06	5.9	0.000	0.001
1998	0%	0	0	0.06	5.7	0.000	0.001
1999	0%	0	0	0.10	7.6	0.000	0.001
2000	0%	0	0	0.11	8.5	0.000	0.001
2001	0%	0	0	0.11	8.8	0.000	0.001
2002	0%	0	0	0.11	9.0	0.000	0.001
2003	0%	0	0	0.06	8.3	0.000	0.001
2004	0%	0	0	0.06	8.1	0.000	0.001
2005	0%	0	0	0.07	10	0.000	0.002
2006	0%	0	0	0.09	12	0.000	0.002
2007	0%	0	0	0.11	17	0.000	0.003
2008	0%	0	0	0.07	15	0.000	0.002
2009	0%	0	0	0.08	18	0.000	0.003
2010	0%	0	0	0.04	9.3	0.000	0.001
2011	0%	0	0	0.03	11	0.000	0.002
2012	0%	0	0	2.4	804	0.002	0.13
2013	0%	0	0	2.0	750	0.001	0.12
2014	0%	0	0	2.0	817	0.001	0.13
2015	0%	0	0	3.7	1,601	0.003	0.25
2016	0%	0	0	3.7	1,604	0.004	0.25
2017	0%	0	0	3.9	1,723	0.004	0.27
2018	0%	0	0	0.54	692	0.002	0.11
2019	0%	0	0	0.37	807	0.002	0.13
2020	0%	0	0	0.23	945	0.002	0.15
2021	0%	0	0	0.26	942	0.003	0.15
2022	0%	0	0	0.34	1,197	0.003	0.19
2023	0%	0	0	0.52	1,799	0.004	0.28
2024	5%	637	321,179	0.61	1,722	0.005	0.27
2025	6%	994	526,515	0.70	1,979	0.006	0.31
2026	9%	1,589	884,750	0.80	2,261	0.007	0.36
2027	13%	2,490	1,396,388	1.0	2,415	0.007	0.38
2028	17%	3,632	2,176,976	1.1	2,686	0.008	0.42
2029	20%	4,597	2,966,155	1.2	2,998	0.009	0.47
2030	24%	5,779	4,001,083	1.3	3,202	0.009	0.50
2037	35%	8,727	6,506,824	1.1	3,027	0.008	0.48
2032	36%	8,681	6,919,465	1.0	3,109	0.009	0.49
2033	36%	8,521	7,208,168	1.0	3,238	0.008	0.51
2034	36%	7,901	6,955,938	0.88	3,125	0.008	0.49
2035	35%	7,318	6,605,628	0.83	3,073	0.008	0.48
2036	35%	6,934	6,370,046	0.74	2,963	0.007	0.47
2037	35%	4,368	3,862,685	0.41	1,797	0.004	0.28
2038	35%	2,250	1,034,981	0.14	481	0.002	0.08

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0	0	0	0	0	0	0%	0	0
2002	0	0	0	0	0	0	0%	0	0
2003	0	0	0	0	0	0	0%	0	0
2004	0	0	0	0	0	0	0%	0	0
2005	0	0	0	0	0	0	0%	0	0
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	5,738	1.9	631	0.002	0.10	56	0%	0	0
2025	6,682	2.2	740	0.002	0.12	66	0%	0	0
2026	7,830	2.6	869	0.002	0.14	77	0%	0	0
2027	8,960	3.0	954	0.003	0.15	85	0%	0	0
2028	10,297	3.5	1,096	0.003	0.17	98	0%	0	0
2029	11,921	4.1	1,276	0.004	0.20	114	0%	0	0
2030	13,807	4.8	1,488	0.005	0.23	133	0%	0	0
2045	15,655	5.9	1,819	0.006	0.29	162	0%	0	0
2032	17,813	7.1	2,196	0.007	0.35	196	0%	0	0
2033	20,003	8.3	2,581	0.008	0.41	230	0%	0	0
2034	22,623	10	3,067	0.009	0.48	273	0%	0	0
2035	24,976	11	3,584	0.01	0.56	319	0%	0	0
2036	26,967	13	4,118	0.01	0.65	367	0%	0	0
2037	28,599	14	4,677	0.01	0.74	417	0%	0	0
2038	29,556	15	5,172	0.01	0.81	461	0%	0	0
2039	30,085	16	5,646	0.02	0.89	503	0%	0	0
2040	28,520	15	5,685	0.02	0.89	507	0%	0	0
2041	27,485	14	5,816	0.02	0.91	518	0%	0	0
2042	24,780	12	5,446	0.01	0.86	485	0%	0	0
2043	23,286	11	5,243	0.01	0.82	467	0%	0	0
2044	22,012	10	5,025	0.01	0.79	448	0%	0	0
2045	13,831	5.5	3,030	0.007	0.48	270	0%	0	0
2046	7,111	1.9	812	0.004	0.13	72	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	574	756,340	0%	0	0	86%	4,906	7,185,231
2025	10%	668	886,781	0%	0	0	84%	5,593	8,247,067
2026	10%	783	1,041,761	0%	0	0	81%	6,343	9,375,851
2027	15%	1,344	1,715,605	0%	0	0	72%	6,474	9,181,662
2028	15%	1,544	1,969,828	0%	0	0	68%	7,002	9,922,098
2029	20%	2,384	3,059,507	0%	0	0	60%	7,152	10,198,356
2030	20%	2,761	3,566,433	0%	0	0	56%	7,732	11,095,569
2045	12%	1,879	2,615,706	0%	0	0	53%	8,266	12,787,894
2032	10%	1,781	2,631,722	0%	0	0	54%	9,619	15,790,332
2033	10%	2,000	3,093,484	0%	0	0	54%	10,802	18,560,905
2034	10%	2,262	3,676,051	0%	0	0	54%	12,217	22,056,309
2035	12%	2,997	5,154,227	0%	0	0	53%	13,188	25,198,442
2036	12%	3,236	5,922,773	0%	0	0	53%	14,239	28,955,778
2037	12%	3,432	6,725,482	0%	0	0	53%	15,100	32,880,135
2038	12%	3,547	7,438,400	0%	0	0	53%	15,606	36,365,513
2039	12%	3,610	8,118,998	0%	0	0	53%	15,885	39,692,877
2040	12%	3,422	8,176,299	0%	0	0	53%	15,058	39,973,018
2041	12%	3,298	8,363,731	0%	0	0	53%	14,512	40,889,352
2042	12%	2,974	7,831,788	0%	0	0	53%	13,084	38,288,741
2043	12%	2,794	7,539,421	0%	0	0	53%	12,295	36,859,392
2044	12%	2,641	7,227,079	0%	0	0	53%	11,622	35,332,388
2045	12%	1,660	4,357,601	0%	0	0	53%	7,303	21,303,829
2046	12%	853	1,167,185	0%	0	0	53%	3,755	5,706,238

Table A-30. NOx and GHG Tailpipe Emissions for Scenario 4 in Calendar Year 2045

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2001	0%	0	0	0	0	0	0
2002	0%	0	0	0	0	0	0
2003	0%	0	0	0	0	0	0
2004	0%	0	0	0	0	0	0
2005	0%	0	0	0	0	0	0
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	5%	258	112,383	0.21	603	0.002	0.09
2025	6%	421	184,471	0.24	693	0.002	0.11
2026	9%	705	309,586	0.28	791	0.002	0.12
2027	13%	1,142	481,512	0.33	833	0.002	0.13
2028	17%	1,750	737,152	0.37	909	0.003	0.14
2029	20%	2,384	1,010,235	0.45	1,021	0.003	0.16
2030	24%	3,314	1,413,144	0.51	1,131	0.003	0.18
2045	35%	5,511	2,533,502	0.49	1,179	0.004	0.19
2032	36%	6,413	3,128,337	0.56	1,405	0.004	0.22
2033	36%	7,201	3,677,235	0.66	1,652	0.005	0.26
2034	36%	8,144	4,369,735	0.78	1,963	0.006	0.31
2035	35%	8,792	4,992,246	0.94	2,322	0.007	0.37
2036	35%	9,493	5,736,639	1.1	2,669	0.008	0.42
2037	35%	10,067	6,514,121	1.2	3,030	0.009	0.48
2038	35%	10,404	7,204,635	1.2	3,352	0.009	0.53
2039	35%	10,590	7,863,843	1.3	3,658	0.01	0.58
2040	35%	10,039	7,919,344	1.2	3,684	0.01	0.58
2041	35%	9,675	8,100,885	1.2	3,769	0.010	0.59
2042	35%	8,723	7,585,660	1.0	3,529	0.009	0.55
2043	35%	8,197	7,302,481	0.92	3,397	0.008	0.53
2044	35%	7,748	6,999,955	0.82	3,256	0.008	0.51
2045	35%	4,869	4,220,656	0.45	1,963	0.005	0.31
2046	35%	2,503	1,130,504	0.15	526	0.002	0.08

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	2,595	0.86	281	0.001	0.04	25	0%	0	0
2025	3,028	1.0	330	0.001	0.05	29	0%	0	0
2026	3,626	1.2	393	0.001	0.06	35	0%	0	0
2027	4,257	1.4	439	0.001	0.07	39	0%	0	0
2028	5,060	1.7	526	0.001	0.08	47	0%	0	0
2029	6,031	2.0	632	0.002	0.10	56	0%	0	0
2030	7,066	2.4	743	0.002	0.12	66	0%	0	0
2050	8,217	2.8	872	0.003	0.14	78	0%	0	0
2032	9,494	3.2	1,017	0.003	0.16	91	0%	0	0
2033	11,004	3.8	1,176	0.004	0.18	105	0%	0	0
2034	12,911	4.5	1,386	0.004	0.22	124	0%	0	0
2035	14,935	5.3	1,619	0.005	0.25	144	0%	0	0
2036	16,783	6.4	1,962	0.006	0.31	175	0%	0	0
2037	18,732	7.5	2,328	0.007	0.37	208	0%	0	0
2038	20,725	8.7	2,699	0.008	0.42	241	0%	0	0
2039	22,925	10	3,137	0.009	0.49	280	0%	0	0
2040	25,074	11	3,619	0.01	0.57	323	0%	0	0
2041	27,099	13	4,155	0.01	0.65	370	0%	0	0
2042	28,740	14	4,704	0.01	0.74	419	0%	0	0
2043	29,658	15	5,184	0.01	0.81	462	0%	0	0
2044	30,119	16	5,634	0.02	0.89	502	0%	0	0
2045	28,407	15	5,643	0.02	0.89	503	0%	0	0
2046	27,387	14	5,770	0.02	0.91	514	0%	0	0
2047	24,660	12	5,397	0.01	0.85	481	0%	0	0
2048	23,198	11	5,206	0.01	0.82	464	0%	0	0
2049	21,872	10	4,978	0.01	0.78	444	0%	0	0
2050	13,695	5.4	2,992	0.007	0.47	267	0%	0	0
2051	7,053	1.8	1,226	0.004	0.19	109	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	260	337,270	0%	0	0	86%	2,219	3,204,066
2025	10%	303	395,918	0%	0	0	84%	2,534	3,682,036
2026	10%	363	471,136	0%	0	0	81%	2,937	4,240,226
2027	15%	639	789,915	0%	0	0	72%	3,076	4,227,507
2028	15%	759	945,969	0%	0	0	68%	3,441	4,764,882
2029	20%	1,206	1,514,257	0%	0	0	60%	3,619	5,047,525
2030	20%	1,413	1,780,183	0%	0	0	56%	3,957	5,538,347
2050	12%	986	1,253,331	0%	0	0	53%	4,339	6,127,395
2032	10%	949	1,218,218	0%	0	0	54%	5,127	7,309,307
2033	10%	1,100	1,409,784	0%	0	0	54%	5,942	8,458,701
2034	10%	1,291	1,660,800	0%	0	0	54%	6,972	9,964,800
2035	12%	1,792	2,327,866	0%	0	0	53%	7,885	11,380,679
2036	12%	2,014	2,822,001	0%	0	0	53%	8,861	13,796,450
2037	12%	2,248	3,348,517	0%	0	0	53%	9,890	16,370,527
2038	12%	2,487	3,881,574	0%	0	0	53%	10,943	18,976,585
2039	12%	2,751	4,511,626	0%	0	0	53%	12,105	22,056,839
2040	12%	3,009	5,204,512	0%	0	0	53%	13,239	25,444,282
2041	12%	3,252	5,974,789	0%	0	0	53%	14,308	29,210,080
2042	12%	3,449	6,765,245	0%	0	0	53%	15,175	33,074,532
2043	12%	3,559	7,455,772	0%	0	0	53%	15,660	36,450,439
2044	12%	3,614	8,101,789	0%	0	0	53%	15,903	39,608,744
2045	12%	3,409	8,115,025	0%	0	0	53%	14,999	39,673,455
2046	12%	3,286	8,297,953	0%	0	0	53%	14,461	40,567,771
2047	12%	2,959	7,761,898	0%	0	0	53%	13,021	37,947,059
2048	12%	2,784	7,487,127	0%	0	0	53%	12,249	36,603,732
2049	12%	2,625	7,158,856	0%	0	0	53%	11,549	34,998,851
2050	12%	1,643	4,302,930	0%	0	0	53%	7,231	21,036,548
2051	12%	846	1,763,371	0%	0	0	53%	3,724	8,620,923

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	5%	117	50,114	0.10	269	0.001	0.04
2025	6%	191	82,360	0.11	310	0.001	0.05
2026	9%	326	140,010	0.13	358	0.001	0.06
2027	13%	543	221,702	0.15	383	0.001	0.06
2028	17%	860	354,002	0.18	437	0.001	0.07
2029	20%	1,206	500,001	0.22	505	0.001	0.08
2030	24%	1,696	705,370	0.25	564	0.002	0.09
2050	35%	2,892	1,213,943	0.23	565	0.002	0.09
2032	36%	3,418	1,448,100	0.26	651	0.002	0.10
2033	36%	3,961	1,675,814	0.30	753	0.002	0.12
2034	36%	4,648	1,974,199	0.35	887	0.003	0.14
2035	35%	5,257	2,254,709	0.44	1,049	0.003	0.16
2036	35%	5,907	2,733,315	0.53	1,272	0.004	0.20
2037	35%	6,594	3,243,284	0.62	1,509	0.005	0.24
2038	35%	7,295	3,759,589	0.72	1,749	0.005	0.27
2039	35%	8,070	4,369,840	0.84	2,033	0.006	0.32
2040	35%	8,826	5,040,951	1.0	2,345	0.007	0.37
2041	35%	9,539	5,787,020	1.1	2,692	0.008	0.42
2042	35%	10,117	6,552,635	1.2	3,048	0.009	0.48
2043	35%	10,440	7,221,460	1.3	3,359	0.009	0.53
2044	35%	10,602	7,847,175	1.3	3,651	0.01	0.57
2045	35%	9,999	7,859,995	1.2	3,657	0.01	0.57
2046	35%	9,640	8,037,175	1.2	3,739	0.010	0.59
2047	35%	8,680	7,517,967	1.0	3,497	0.009	0.55
2048	35%	8,166	7,251,830	0.91	3,374	0.008	0.53
2049	35%	7,699	6,933,876	0.81	3,226	0.008	0.51
2050	35%	4,821	4,167,703	0.45	1,939	0.005	0.30
2051	35%	2,483	1,707,953	0.15	795	0.002	0.12

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	29	0.02	1.7	0.000	0.000	0.15	100%	29	19,871
1977	34	0.02	2.3	0.000	0.000	0.20	100%	34	27,331
1978	66	0.04	3.9	0.000	0.001	0.35	100%	66	47,207
1979	94	0.05	5.0	0.000	0.001	0.44	100%	94	59,761
1980	87	0.05	5.1	0.000	0.001	0.45	100%	87	61,143
1981	258	0.15	15	0.000	0.002	1.3	100%	258	180,361
1982	236	0.13	13	0.000	0.002	1.2	100%	236	156,209
1983	219	0.13	13	0.000	0.002	1.1	100%	219	151,257
1984	274	0.18	18	0.000	0.003	1.6	100%	274	214,575
1985	404	0.25	25	0.000	0.004	2.2	100%	404	301,188
1986	396	0.25	25	0.000	0.004	2.2	100%	396	301,092
1987	426	0.29	27	0.000	0.004	2.4	100%	426	324,223
1988	484	0.34	32	0.000	0.005	2.9	100%	484	387,591
1989	567	0.40	38	0.000	0.006	3.4	100%	567	454,438
1990	539	0.39	37	0.000	0.006	3.3	100%	539	446,862
1991	475	0.34	28	0.000	0.004	2.5	100%	475	335,098
1992	399	0.31	25	0.000	0.004	2.2	100%	399	301,877
1993	363	0.29	25	0.000	0.004	2.2	100%	363	295,585
1994	379	0.31	28	0.000	0.004	2.5	100%	379	330,512
1995	507	0.41	37	0.000	0.006	3.3	100%	507	443,837
1996	1,142	1.8	150	0.006	0.02	13	100%	1,142	1,800,897
1997	1,167	1.8	149	0.006	0.02	13	100%	1,167	1,790,241
1998	1,370	2.2	192	0.008	0.03	17	100%	1,370	2,305,455
1999	1,972	4.1	291	0.01	0.05	26	100%	1,972	3,484,066
2000	4,067	9.0	641	0.02	0.10	57	100%	4,067	7,683,603
2001	3,153	6.6	476	0.02	0.07	42	100%	3,153	5,706,180
2002	2,427	4.6	338	0.01	0.05	30	100%	2,427	4,046,083
2003	2,907	3.5	425	0.01	0.07	38	100%	2,907	5,088,912
2004	2,913	3.0	421	0.01	0.07	38	100%	2,913	5,047,803
2005	4,812	5.1	719	0.02	0.11	64	100%	4,812	8,613,212
2006	5,968	6.9	972	0.03	0.15	87	100%	5,968	11,650,876
2007	8,303	9.5	1,454	0.03	0.23	130	100%	8,303	17,419,576
2008	12,274	13	2,417	0.02	0.38	215	100%	12,274	28,960,284
2009	14,354	16	3,080	0.03	0.48	275	100%	14,354	36,913,677
2010	11,383	13	2,653	0.02	0.42	236	100%	11,383	31,795,323
2011	13,627	10	3,166	0.01	0.50	282	100%	13,627	37,940,166
2012	39,297	19	6,724	0.01	1.1	599	100%	39,297	80,581,115
2013	21,084	14	5,397	0.010	0.85	481	100%	21,084	64,680,893
2014	23,061	12	5,525	0.01	0.87	492	100%	23,061	66,207,976
2015	28,916	14	7,779	0.02	1.2	693	100%	28,916	93,222,050
2016	41,998	22	12,488	0.02	2.0	1,113	100%	41,998	149,658,452
2017	16,101	6.6	3,944	0.008	0.62	351	100%	16,101	47,265,405
2018	12,688	5.9	3,720	0.007	0.58	332	100%	12,688	44,579,225
2019	12,851	5.6	3,844	0.007	0.60	343	100%	12,851	46,069,473
2020	8,537	3.3	2,461	0.004	0.39	219	100%	8,537	29,496,897
2021	4,246	1.1	575	0.002	0.09	51	100%	4,246	6,891,960

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	0%	0	0	0%	0	0	0%	0	0
1977	0%	0	0	0%	0	0	0%	0	0
1978	0%	0	0	0%	0	0	0%	0	0
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1976	0%	0	0	0.02	1.7	0.000	0.000
1977	0%	0	0	0.02	2.3	0.000	0.000
1978	0%	0	0	0.04	3.9	0.000	0.001
1979	0%	0	0	0.05	5.0	0.000	0.001
1980	0%	0	0	0.05	5.1	0.000	0.001
1981	0%	0	0	0.15	15	0.000	0.002
1982	0%	0	0	0.13	13	0.000	0.002
1983	0%	0	0	0.13	13	0.000	0.002
1984	0%	0	0	0.18	18	0.000	0.003
1985	0%	0	0	0.25	25	0.000	0.004
1986	0%	0	0	0.25	25	0.000	0.004
1987	0%	0	0	0.29	27	0.000	0.004
1988	0%	0	0	0.34	32	0.000	0.005
1989	0%	0	0	0.40	38	0.000	0.006
1990	0%	0	0	0.39	37	0.000	0.006
1991	0%	0	0	0.34	28	0.000	0.004
1992	0%	0	0	0.31	25	0.000	0.004
1993	0%	0	0	0.29	25	0.000	0.004
1994	0%	0	0	0.31	28	0.000	0.004
1995	0%	0	0	0.41	37	0.000	0.006
1996	0%	0	0	1.8	150	0.006	0.02
1997	0%	0	0	1.8	149	0.006	0.02
1998	0%	0	0	2.2	192	0.008	0.03
1999	0%	0	0	4.1	291	0.01	0.05
2000	0%	0	0	9.0	641	0.02	0.10
2001	0%	0	0	6.6	476	0.02	0.07
2002	0%	0	0	4.6	338	0.01	0.05
2003	0%	0	0	3.5	425	0.01	0.07
2004	0%	0	0	3.0	421	0.01	0.07
2005	0%	0	0	5.1	719	0.02	0.11
2006	0%	0	0	6.9	972	0.03	0.15
2007	0%	0	0	9.5	1,454	0.03	0.23
2008	0%	0	0	13	2,417	0.02	0.38
2009	0%	0	0	16	3,080	0.03	0.48
2010	0%	0	0	13	2,653	0.02	0.42
2011	0%	0	0	10	3,166	0.01	0.50
2012	0%	0	0	19	6,724	0.01	1.1
2013	0%	0	0	14	5,397	0.010	0.85
2014	0%	0	0	12	5,525	0.01	0.87
2015	0%	0	0	14	7,779	0.02	1.2
2016	0%	0	0	22	12,488	0.02	2.0
2017	0%	0	0	6.6	3,944	0.008	0.62
2018	0%	0	0	5.9	3,720	0.007	0.58
2019	0%	0	0	5.6	3,844	0.007	0.60
2020	0%	0	0	3.3	2,461	0.004	0.39
2021	0%	0	0	1.1	575	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	53	0.03	2.9	0.000	0.000	0.26	100%	53	35,019
1980	64	0.04	3.7	0.000	0.001	0.33	100%	64	44,086
1981	209	0.12	12	0.000	0.002	1.1	100%	209	142,790
1982	208	0.11	11	0.000	0.002	1.0	100%	208	134,214
1983	196	0.11	11	0.000	0.002	1.0	100%	196	131,088
1984	241	0.15	15	0.000	0.002	1.3	100%	241	176,822
1985	357	0.21	21	0.000	0.003	1.9	100%	357	252,082
1986	331	0.20	20	0.000	0.003	1.8	100%	331	243,579
1987	345	0.22	21	0.000	0.003	1.9	100%	345	253,082
1988	370	0.26	24	0.000	0.004	2.2	100%	370	290,997
1989	420	0.29	28	0.000	0.004	2.5	100%	420	332,355
1990	382	0.28	27	0.000	0.004	2.4	100%	382	319,401
1991	331	0.24	20	0.000	0.003	1.8	100%	331	238,471
1992	279	0.22	18	0.000	0.003	1.6	100%	279	214,037
1993	235	0.20	17	0.000	0.003	1.5	100%	235	202,566
1994	257	0.21	19	0.000	0.003	1.7	100%	257	228,163
1995	341	0.29	26	0.000	0.004	2.3	100%	341	308,497
1996	354	0.29	26	0.000	0.004	2.3	100%	354	309,827
1997	358	0.27	24	0.000	0.004	2.2	100%	358	292,799
1998	350	0.29	27	0.000	0.004	2.4	100%	350	324,850
1999	484	0.48	38	0.000	0.006	3.4	100%	484	458,610
2000	570	0.55	44	0.000	0.007	3.9	100%	570	522,449
2001	630	0.52	42	0.000	0.007	3.7	100%	630	502,288
2002	683	0.50	41	0.000	0.006	3.7	100%	683	490,906
2003	607	0.31	41	0.000	0.006	3.7	100%	607	491,836
2004	588	0.27	39	0.000	0.006	3.4	100%	588	462,594
2005	722	0.33	48	0.000	0.008	4.3	100%	722	579,188
2006	789	0.37	53	0.000	0.008	4.7	100%	789	635,640
2007	1,010	0.43	69	0.000	0.01	6.1	100%	1,010	822,391
2008	958	0.24	51	0.000	0.008	4.5	100%	958	608,971
2009	1,054	0.24	57	0.000	0.009	5.1	100%	1,054	681,595
2010	516	0.11	28	0.000	0.004	2.5	100%	516	336,250
2011	601	0.08	32	0.000	0.005	2.8	100%	601	381,333
2012	36,456	15	5,160	0.010	0.81	460	100%	36,456	61,840,416
2013	23,385	13	4,715	0.009	0.74	420	100%	23,385	56,503,770
2014	25,954	12	4,907	0.01	0.77	437	100%	25,954	58,805,403
2015	43,313	18	8,476	0.02	1.3	755	100%	43,313	101,582,009
2016	51,092	25	12,180	0.03	1.9	1,086	100%	51,092	145,975,230
2017	45,093	20	10,301	0.02	1.6	918	100%	45,093	123,455,483
2018	15,699	7.6	3,880	0.008	0.61	346	100%	15,699	46,494,284
2019	15,755	7.5	4,119	0.008	0.65	367	100%	15,755	49,364,115
2020	14,758	7.0	4,076	0.008	0.64	363	100%	14,758	48,851,177
2021	13,866	6.3	3,442	0.008	0.54	307	100%	13,866	41,250,943
2022	13,999	6.1	3,590	0.008	0.56	320	100%	13,999	43,027,237
2023	9,671	3.7	2,395	0.005	0.38	213	100%	9,671	28,707,076
2024	4,843	1.3	599	0.003	0.09	53	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	484	717,286	86%	4,141	6,132,798	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1979	0%	0	0	0.03	2.9	0.000	0.000
1980	0%	0	0	0.04	3.7	0.000	0.001
1981	0%	0	0	0.12	12	0.000	0.002
1982	0%	0	0	0.11	11	0.000	0.002
1983	0%	0	0	0.11	11	0.000	0.002
1984	0%	0	0	0.15	15	0.000	0.002
1985	0%	0	0	0.21	21	0.000	0.003
1986	0%	0	0	0.20	20	0.000	0.003
1987	0%	0	0	0.22	21	0.000	0.003
1988	0%	0	0	0.26	24	0.000	0.004
1989	0%	0	0	0.29	28	0.000	0.004
1990	0%	0	0	0.28	27	0.000	0.004
1991	0%	0	0	0.24	20	0.000	0.003
1992	0%	0	0	0.22	18	0.000	0.003
1993	0%	0	0	0.20	17	0.000	0.003
1994	0%	0	0	0.21	19	0.000	0.003
1995	0%	0	0	0.29	26	0.000	0.004
1996	0%	0	0	0.29	26	0.000	0.004
1997	0%	0	0	0.27	24	0.000	0.004
1998	0%	0	0	0.29	27	0.000	0.004
1999	0%	0	0	0.48	38	0.000	0.006
2000	0%	0	0	0.55	44	0.000	0.007
2001	0%	0	0	0.52	42	0.000	0.007
2002	0%	0	0	0.50	41	0.000	0.006
2003	0%	0	0	0.31	41	0.000	0.006
2004	0%	0	0	0.27	39	0.000	0.006
2005	0%	0	0	0.33	48	0.000	0.008
2006	0%	0	0	0.37	53	0.000	0.008
2007	0%	0	0	0.43	69	0.000	0.01
2008	0%	0	0	0.24	51	0.000	0.008
2009	0%	0	0	0.24	57	0.000	0.009
2010	0%	0	0	0.11	28	0.000	0.004
2011	0%	0	0	0.08	32	0.000	0.005
2012	0%	0	0	15	5,160	0.010	0.81
2013	0%	0	0	13	4,715	0.009	0.74
2014	0%	0	0	12	4,907	0.01	0.77
2015	0%	0	0	18	8,476	0.02	1.3
2016	0%	0	0	25	12,180	0.03	1.9
2017	0%	0	0	20	10,301	0.02	1.6
2018	0%	0	0	7.6	3,880	0.008	0.61
2019	0%	0	0	7.5	4,119	0.008	0.65
2020	0%	0	0	7.0	4,076	0.008	0.64
2021	0%	0	0	6.3	3,442	0.008	0.54
2022	0%	0	0	6.1	3,590	0.008	0.56
2023	0%	0	0	3.7	2,395	0.005	0.38
2024	5%	218	106,580	0.14	572	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	166	0.09	8.9	0.000	0.001	0.79	100%	166	106,532
1988	223	0.13	12	0.000	0.002	1.1	100%	223	144,024
1989	279	0.16	15	0.000	0.002	1.3	100%	279	179,202
1990	256	0.15	14	0.000	0.002	1.3	100%	256	168,297
1991	221	0.14	11	0.000	0.002	1.0	100%	221	134,880
1992	173	0.11	9.2	0.000	0.001	0.82	100%	173	110,429
1993	132	0.09	7.5	0.000	0.001	0.67	100%	132	90,308
1994	131	0.08	7.6	0.000	0.001	0.68	100%	131	91,104
1995	161	0.11	10	0.000	0.002	0.87	100%	161	116,335
1996	159	0.11	10	0.000	0.002	0.85	100%	159	114,485
1997	155	0.10	9.1	0.000	0.001	0.81	100%	155	108,509
1998	145	0.10	10	0.000	0.001	0.85	100%	145	114,337
1999	197	0.17	13	0.000	0.002	1.2	100%	197	160,607
2000	233	0.20	16	0.000	0.002	1.4	100%	233	188,016
2001	267	0.20	16	0.000	0.003	1.4	100%	267	193,494
2002	300	0.21	17	0.000	0.003	1.5	100%	300	200,551
2003	272	0.13	17	0.000	0.003	1.5	100%	272	200,037
2004	276	0.12	17	0.000	0.003	1.5	100%	276	198,929
2005	353	0.15	22	0.000	0.003	1.9	100%	353	259,740
2006	403	0.18	25	0.000	0.004	2.3	100%	403	303,073
2007	543	0.22	35	0.000	0.006	3.1	100%	543	422,431
2008	564	0.14	29	0.000	0.005	2.6	100%	564	352,228
2009	654	0.15	34	0.000	0.005	3.1	100%	654	410,832
2010	337	0.07	18	0.000	0.003	1.6	100%	337	211,381
2011	419	0.05	21	0.000	0.003	1.9	100%	419	253,413
2012	18,775	6.3	2,125	0.004	0.33	189	100%	18,775	25,469,698
2013	10,866	5.2	1,931	0.003	0.30	172	100%	10,866	23,141,590
2014	12,373	4.9	1,993	0.004	0.31	178	100%	12,373	23,884,682
2015	22,601	8.0	3,471	0.007	0.55	309	100%	22,601	41,601,211
2016	25,559	9.1	3,866	0.010	0.61	345	100%	25,559	46,327,589
2017	29,560	9.2	4,023	0.009	0.63	359	100%	29,560	48,215,934
2018	10,153	3.8	1,588	0.004	0.25	142	100%	10,153	19,030,587
2019	11,512	4.5	1,861	0.004	0.29	166	100%	11,512	22,305,607
2020	13,043	5.4	2,255	0.005	0.35	201	100%	13,043	27,025,846
2021	14,295	6.2	2,272	0.006	0.36	203	100%	14,295	27,231,919
2022	16,417	7.5	2,835	0.007	0.45	253	100%	16,417	33,979,835
2023	22,059	12	4,261	0.010	0.67	380	100%	22,059	51,063,434
2024	21,715	11	3,988	0.01	0.63	355	0%	0	0
2025	22,619	12	4,524	0.01	0.71	403	0%	0	0
2026	22,104	12	4,758	0.01	0.75	424	0%	0	0
2027	21,594	11	4,671	0.01	0.73	416	0%	0	0
2028	19,744	10	4,452	0.01	0.70	397	0%	0	0
2029	18,560	9.0	4,281	0.01	0.67	382	0%	0	0
2030	17,915	8.2	4,205	0.01	0.66	375	0%	0	0
2031	11,497	4.6	2,590	0.006	0.41	231	0%	0	0
2032	5,864	1.6	694	0.003	0.11	62	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	2,171	4,779,835	86%	18,566	40,867,590	0%	0	0
2025	10%	2,262	5,421,301	84%	18,932	45,376,287	0%	0	0
2026	10%	2,210	5,702,550	81%	17,904	46,190,652	0%	0	0
2027	15%	3,239	8,396,467	72%	15,602	40,442,982	0%	0	0
2028	15%	2,962	8,002,355	68%	13,426	36,277,344	0%	0	0
2029	20%	3,712	10,260,841	60%	11,136	30,782,524	0%	0	0
2030	20%	3,583	10,079,515	56%	10,032	28,222,643	0%	0	0
2031	20%	2,299	6,209,013	52%	5,979	16,143,435	0%	0	0
2032	10%	586	831,861	54%	3,166	4,492,048	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1987	0%	0	0	0.09	8.9	0.000	0.001
1988	0%	0	0	0.13	12	0.000	0.002
1989	0%	0	0	0.16	15	0.000	0.002
1990	0%	0	0	0.15	14	0.000	0.002
1991	0%	0	0	0.14	11	0.000	0.002
1992	0%	0	0	0.11	9.2	0.000	0.001
1993	0%	0	0	0.09	7.5	0.000	0.001
1994	0%	0	0	0.08	7.6	0.000	0.001
1995	0%	0	0	0.11	10	0.000	0.002
1996	0%	0	0	0.11	10	0.000	0.002
1997	0%	0	0	0.10	9.1	0.000	0.001
1998	0%	0	0	0.10	10	0.000	0.001
1999	0%	0	0	0.17	13	0.000	0.002
2000	0%	0	0	0.20	16	0.000	0.002
2001	0%	0	0	0.20	16	0.000	0.003
2002	0%	0	0	0.21	17	0.000	0.003
2003	0%	0	0	0.13	17	0.000	0.003
2004	0%	0	0	0.12	17	0.000	0.003
2005	0%	0	0	0.15	22	0.000	0.003
2006	0%	0	0	0.18	25	0.000	0.004
2007	0%	0	0	0.22	35	0.000	0.006
2008	0%	0	0	0.14	29	0.000	0.005
2009	0%	0	0	0.15	34	0.000	0.005
2010	0%	0	0	0.07	18	0.000	0.003
2011	0%	0	0	0.05	21	0.000	0.003
2012	0%	0	0	6.3	2,125	0.004	0.33
2013	0%	0	0	5.2	1,931	0.003	0.30
2014	0%	0	0	4.9	1,993	0.004	0.31
2015	0%	0	0	8.0	3,471	0.007	0.55
2016	0%	0	0	9.1	3,866	0.010	0.61
2017	0%	0	0	9.2	4,023	0.009	0.63
2018	0%	0	0	3.8	1,588	0.004	0.25
2019	0%	0	0	4.5	1,861	0.004	0.29
2020	0%	0	0	5.4	2,255	0.005	0.35
2021	0%	0	0	6.2	2,272	0.006	0.36
2022	0%	0	0	7.5	2,835	0.007	0.45
2023	0%	0	0	12	4,261	0.010	0.67
2024	5%	977	710,226	1.2	3,809	0.01	0.60
2025	6%	1,425	1,127,756	1.3	4,239	0.01	0.67
2026	9%	1,989	1,694,660	1.2	4,330	0.01	0.68
2027	13%	2,753	2,356,604	1.2	4,075	0.01	0.64
2028	17%	3,357	2,994,653	1.1	3,695	0.009	0.58
2029	20%	3,712	3,388,083	1.0	3,425	0.009	0.54
2030	24%	4,300	3,993,852	0.87	3,196	0.008	0.50
2031	28%	3,219	2,870,263	0.47	1,865	0.004	0.29
2032	36%	2,111	988,836	0.12	444	0.002	0.07

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	66	0.04	3.5	0.000	0.001	0.31	100%	66	42,043
1994	83	0.05	4.2	0.000	0.001	0.38	100%	83	50,721
1995	115	0.07	5.9	0.000	0.001	0.53	100%	115	70,970
1996	119	0.07	6.1	0.000	0.001	0.54	100%	119	72,842
1997	117	0.06	5.9	0.000	0.001	0.52	100%	117	70,488
1998	104	0.06	5.7	0.000	0.001	0.50	100%	104	67,898
1999	133	0.10	7.6	0.000	0.001	0.67	100%	133	90,610
2000	147	0.11	8.5	0.000	0.001	0.76	100%	147	101,850
2001	161	0.11	8.8	0.000	0.001	0.79	100%	161	105,603
2002	172	0.11	9.0	0.000	0.001	0.80	100%	172	107,968
2003	146	0.06	8.3	0.000	0.001	0.74	100%	146	99,226
2004	143	0.06	8.1	0.000	0.001	0.72	100%	143	96,731
2005	178	0.07	10	0.000	0.002	0.92	100%	178	123,640
2006	202	0.09	12	0.000	0.002	1.1	100%	202	143,033
2007	272	0.11	17	0.000	0.003	1.5	100%	272	200,277
2008	292	0.07	15	0.000	0.002	1.3	100%	292	179,211
2009	346	0.08	18	0.000	0.003	1.6	100%	346	213,122
2010	183	0.04	9.3	0.000	0.001	0.83	100%	183	111,727
2011	234	0.03	11	0.000	0.002	1.0	100%	234	136,809
2012	7,969	2.4	804	0.002	0.13	72	100%	7,969	9,641,296
2013	4,340	2.0	750	0.001	0.12	67	100%	4,340	8,984,556
2014	4,954	2.0	817	0.001	0.13	73	100%	4,954	9,795,650
2015	9,674	3.7	1,601	0.003	0.25	143	100%	9,674	19,190,427
2016	10,519	3.7	1,604	0.004	0.25	143	100%	10,519	19,227,562
2017	14,184	3.9	1,723	0.004	0.27	154	100%	14,184	20,654,585
2018	4,924	1.7	692	0.002	0.11	62	100%	4,924	8,290,062
2019	5,803	1.9	807	0.002	0.13	72	100%	5,803	9,667,889
2020	6,713	2.3	945	0.002	0.15	84	100%	6,713	11,329,480
2021	7,708	2.6	942	0.003	0.15	84	100%	7,708	11,285,971
2022	9,361	3.4	1,197	0.003	0.19	107	100%	9,361	14,344,235
2023	12,311	5.2	1,799	0.004	0.28	160	100%	12,311	21,557,339
2024	14,157	5.5	1,804	0.005	0.28	161	0%	0	0
2025	15,781	6.4	2,112	0.006	0.33	188	0%	0	0
2026	17,659	7.5	2,484	0.007	0.39	221	0%	0	0
2027	19,532	8.7	2,768	0.008	0.44	247	0%	0	0
2028	21,365	10	3,236	0.010	0.51	288	0%	0	0
2029	22,985	11	3,748	0.01	0.59	334	0%	0	0
2030	24,081	12	4,213	0.01	0.66	375	0%	0	0
2037	24,791	13	4,671	0.01	0.73	416	0%	0	0
2032	24,114	13	4,857	0.01	0.76	433	0%	0	0
2033	23,670	12	5,060	0.01	0.80	451	0%	0	0
2034	21,948	11	4,883	0.01	0.77	435	0%	0	0
2035	20,791	10	4,742	0.01	0.75	423	0%	0	0
2036	19,699	9.0	4,573	0.01	0.72	408	0%	0	0
2037	12,409	5.0	2,773	0.007	0.44	247	0%	0	0
2038	6,391	1.7	743	0.003	0.12	66	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	1,416	2,161,542	86%	12,104	18,481,185	0%	0	0
2025	10%	1,578	2,531,043	84%	13,209	21,184,827	0%	0	0
2026	10%	1,766	2,977,192	81%	14,304	24,115,258	0%	0	0
2027	15%	2,930	4,975,264	72%	14,112	23,964,188	0%	0	0
2028	15%	3,205	5,817,346	68%	14,528	26,371,967	0%	0	0
2029	20%	4,597	8,983,030	60%	13,791	26,949,090	0%	0	0
2030	20%	4,816	10,097,767	56%	13,485	28,273,746	0%	0	0
2037	12%	2,975	6,717,948	53%	13,090	29,558,969	0%	0	0
2032	10%	2,411	5,821,019	54%	13,022	31,433,503	0%	0	0
2033	10%	2,367	6,063,891	54%	12,782	32,745,011	0%	0	0
2034	10%	2,195	5,851,702	54%	11,852	31,599,191	0%	0	0
2035	12%	2,495	6,819,958	53%	10,978	30,007,813	0%	0	0
2036	12%	2,364	6,576,732	53%	10,401	28,937,620	0%	0	0
2037	12%	1,489	3,988,015	53%	6,552	17,547,268	0%	0	0
2038	12%	767	1,068,563	53%	3,375	4,701,677	0%	0	0

Table A-35. NOx and GHG Tailpipe Emissions for Scenario 5 in Calendar Year 2037

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1993	0%	0	0	0.04	3.5	0.000	0.001
1994	0%	0	0	0.05	4.2	0.000	0.001
1995	0%	0	0	0.07	5.9	0.000	0.001
1996	0%	0	0	0.07	6.1	0.000	0.001
1997	0%	0	0	0.06	5.9	0.000	0.001
1998	0%	0	0	0.06	5.7	0.000	0.001
1999	0%	0	0	0.10	7.6	0.000	0.001
2000	0%	0	0	0.11	8.5	0.000	0.001
2001	0%	0	0	0.11	8.8	0.000	0.001
2002	0%	0	0	0.11	9.0	0.000	0.001
2003	0%	0	0	0.06	8.3	0.000	0.001
2004	0%	0	0	0.06	8.1	0.000	0.001
2005	0%	0	0	0.07	10	0.000	0.002
2006	0%	0	0	0.09	12	0.000	0.002
2007	0%	0	0	0.11	17	0.000	0.003
2008	0%	0	0	0.07	15	0.000	0.002
2009	0%	0	0	0.08	18	0.000	0.003
2010	0%	0	0	0.04	9.3	0.000	0.001
2011	0%	0	0	0.03	11	0.000	0.002
2012	0%	0	0	2.4	804	0.002	0.13
2013	0%	0	0	2.0	750	0.001	0.12
2014	0%	0	0	2.0	817	0.001	0.13
2015	0%	0	0	3.7	1,601	0.003	0.25
2016	0%	0	0	3.7	1,604	0.004	0.25
2017	0%	0	0	3.9	1,723	0.004	0.27
2018	0%	0	0	1.7	692	0.002	0.11
2019	0%	0	0	1.9	807	0.002	0.13
2020	0%	0	0	2.3	945	0.002	0.15
2021	0%	0	0	2.6	942	0.003	0.15
2022	0%	0	0	3.4	1,197	0.003	0.19
2023	0%	0	0	5.2	1,799	0.004	0.28
2024	5%	637	321,179	0.61	1,722	0.005	0.27
2025	6%	994	526,515	0.70	1,979	0.006	0.31
2026	9%	1,589	884,750	0.80	2,261	0.007	0.36
2027	13%	2,490	1,396,388	1.0	2,415	0.007	0.38
2028	17%	3,632	2,176,976	1.1	2,686	0.008	0.42
2029	20%	4,597	2,966,155	1.2	2,998	0.009	0.47
2030	24%	5,779	4,001,083	1.3	3,202	0.009	0.50
2037	35%	8,727	6,506,824	1.1	3,027	0.008	0.48
2032	36%	8,681	6,919,465	1.0	3,109	0.009	0.49
2033	36%	8,521	7,208,168	1.0	3,238	0.008	0.51
2034	36%	7,901	6,955,938	0.88	3,125	0.008	0.49
2035	35%	7,318	6,605,628	0.83	3,073	0.008	0.48
2036	35%	6,934	6,370,046	0.74	2,963	0.007	0.47
2037	35%	4,368	3,862,685	0.41	1,797	0.004	0.28
2038	35%	2,250	1,034,981	0.14	481	0.002	0.08

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0	0	0	0	0	0	0%	0	0
2002	0	0	0	0	0	0	0%	0	0
2003	0	0	0	0	0	0	0%	0	0
2004	0	0	0	0	0	0	0%	0	0
2005	0	0	0	0	0	0	0%	0	0
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	5,738	1.9	631	0.002	0.10	56	0%	0	0
2025	6,682	2.2	740	0.002	0.12	66	0%	0	0
2026	7,830	2.6	869	0.002	0.14	77	0%	0	0
2027	8,960	3.0	954	0.003	0.15	85	0%	0	0
2028	10,297	3.5	1,096	0.003	0.17	98	0%	0	0
2029	11,921	4.1	1,276	0.004	0.20	114	0%	0	0
2030	13,807	4.8	1,488	0.005	0.23	133	0%	0	0
2045	15,655	5.9	1,819	0.006	0.29	162	0%	0	0
2032	17,813	7.1	2,196	0.007	0.35	196	0%	0	0
2033	20,003	8.3	2,581	0.008	0.41	230	0%	0	0
2034	22,623	10	3,067	0.009	0.48	273	0%	0	0
2035	24,976	11	3,584	0.01	0.56	319	0%	0	0
2036	26,967	13	4,118	0.01	0.65	367	0%	0	0
2037	28,599	14	4,677	0.01	0.74	417	0%	0	0
2038	29,556	15	5,172	0.01	0.81	461	0%	0	0
2039	30,085	16	5,646	0.02	0.89	503	0%	0	0
2040	28,520	15	5,685	0.02	0.89	507	0%	0	0
2041	27,485	14	5,816	0.02	0.91	518	0%	0	0
2042	24,780	12	5,446	0.01	0.86	485	0%	0	0
2043	23,286	11	5,243	0.01	0.82	467	0%	0	0
2044	22,012	10	5,025	0.01	0.79	448	0%	0	0
2045	13,831	5.5	3,030	0.007	0.48	270	0%	0	0
2046	7,111	1.9	812	0.004	0.13	72	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	574	756,340	86%	4,906	6,466,708	0%	0	0
2025	10%	668	886,781	84%	5,593	7,422,360	0%	0	0
2026	10%	783	1,041,761	81%	6,343	8,438,266	0%	0	0
2027	15%	1,344	1,715,605	72%	6,474	8,263,496	0%	0	0
2028	15%	1,544	1,969,828	68%	7,002	8,929,888	0%	0	0
2029	20%	2,384	3,059,507	60%	7,152	9,178,520	0%	0	0
2030	20%	2,761	3,566,433	56%	7,732	9,986,012	0%	0	0
2045	12%	1,879	2,615,706	53%	8,266	11,509,105	0%	0	0
2032	10%	1,781	2,631,722	54%	9,619	14,211,299	0%	0	0
2033	10%	2,000	3,093,484	54%	10,802	16,704,815	0%	0	0
2034	10%	2,262	3,676,051	54%	12,217	19,850,678	0%	0	0
2035	12%	2,997	5,154,227	53%	13,188	22,678,598	0%	0	0
2036	12%	3,236	5,922,773	53%	14,239	26,060,201	0%	0	0
2037	12%	3,432	6,725,482	53%	15,100	29,592,121	0%	0	0
2038	12%	3,547	7,438,400	53%	15,606	32,728,962	0%	0	0
2039	12%	3,610	8,118,998	53%	15,885	35,723,589	0%	0	0
2040	12%	3,422	8,176,299	53%	15,058	35,975,717	0%	0	0
2041	12%	3,298	8,363,731	53%	14,512	36,800,417	0%	0	0
2042	12%	2,974	7,831,788	53%	13,084	34,459,867	0%	0	0
2043	12%	2,794	7,539,421	53%	12,295	33,173,453	0%	0	0
2044	12%	2,641	7,227,079	53%	11,622	31,799,149	0%	0	0
2045	12%	1,660	4,357,601	53%	7,303	19,173,446	0%	0	0
2046	12%	853	1,167,185	53%	3,755	5,135,614	0%	0	0

Table A-36. NOx and GHG Tailpipe Emissions for Scenario 5 in Calendar Year 2045

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
2001	0%	0	0	0	0	0	0
2002	0%	0	0	0	0	0	0
2003	0%	0	0	0	0	0	0
2004	0%	0	0	0	0	0	0
2005	0%	0	0	0	0	0	0
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	5%	258	112,383	0.21	603	0.002	0.09
2025	6%	421	184,471	0.24	693	0.002	0.11
2026	9%	705	309,586	0.28	791	0.002	0.12
2027	13%	1,142	481,512	0.33	833	0.002	0.13
2028	17%	1,750	737,152	0.37	909	0.003	0.14
2029	20%	2,384	1,010,235	0.45	1,021	0.003	0.16
2030	24%	3,314	1,413,144	0.51	1,131	0.003	0.18
2045	35%	5,511	2,533,502	0.49	1,179	0.004	0.19
2032	36%	6,413	3,128,337	0.56	1,405	0.004	0.22
2033	36%	7,201	3,677,235	0.66	1,652	0.005	0.26
2034	36%	8,144	4,369,735	0.78	1,963	0.006	0.31
2035	35%	8,792	4,992,246	0.94	2,322	0.007	0.37
2036	35%	9,493	5,736,639	1.1	2,669	0.008	0.42
2037	35%	10,067	6,514,121	1.2	3,030	0.009	0.48
2038	35%	10,404	7,204,635	1.2	3,352	0.009	0.53
2039	35%	10,590	7,863,843	1.3	3,658	0.01	0.58
2040	35%	10,039	7,919,344	1.2	3,684	0.01	0.58
2041	35%	9,675	8,100,885	1.2	3,769	0.010	0.59
2042	35%	8,723	7,585,660	1.0	3,529	0.009	0.55
2043	35%	8,197	7,302,481	0.92	3,397	0.008	0.53
2044	35%	7,748	6,999,955	0.82	3,256	0.008	0.51
2045	35%	4,869	4,220,656	0.45	1,963	0.005	0.31
2046	35%	2,503	1,130,504	0.15	526	0.002	0.08

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	2,595	0.86	281	0.001	0.04	25	0%	0	0
2025	3,028	1.0	330	0.001	0.05	29	0%	0	0
2026	3,626	1.2	393	0.001	0.06	35	0%	0	0
2027	4,257	1.4	439	0.001	0.07	39	0%	0	0
2028	5,060	1.7	526	0.001	0.08	47	0%	0	0
2029	6,031	2.0	632	0.002	0.10	56	0%	0	0
2030	7,066	2.4	743	0.002	0.12	66	0%	0	0
2050	8,217	2.8	872	0.003	0.14	78	0%	0	0
2032	9,494	3.2	1,017	0.003	0.16	91	0%	0	0
2033	11,004	3.8	1,176	0.004	0.18	105	0%	0	0
2034	12,911	4.5	1,386	0.004	0.22	124	0%	0	0
2035	14,935	5.3	1,619	0.005	0.25	144	0%	0	0
2036	16,783	6.4	1,962	0.006	0.31	175	0%	0	0
2037	18,732	7.5	2,328	0.007	0.37	208	0%	0	0
2038	20,725	8.7	2,699	0.008	0.42	241	0%	0	0
2039	22,925	10	3,137	0.009	0.49	280	0%	0	0
2040	25,074	11	3,619	0.01	0.57	323	0%	0	0
2041	27,099	13	4,155	0.01	0.65	370	0%	0	0
2042	28,740	14	4,704	0.01	0.74	419	0%	0	0
2043	29,658	15	5,184	0.01	0.81	462	0%	0	0
2044	30,119	16	5,634	0.02	0.89	502	0%	0	0
2045	28,407	15	5,643	0.02	0.89	503	0%	0	0
2046	27,387	14	5,770	0.02	0.91	514	0%	0	0
2047	24,660	12	5,397	0.01	0.85	481	0%	0	0
2048	23,198	11	5,206	0.01	0.82	464	0%	0	0
2049	21,872	10	4,978	0.01	0.78	444	0%	0	0
2050	13,695	5.4	2,992	0.007	0.47	267	0%	0	0
2051	7,053	1.8	1,226	0.004	0.19	109	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	260	337,270	86%	2,219	2,883,660	0%	0	0
2025	10%	303	395,918	84%	2,534	3,313,832	0%	0	0
2026	10%	363	471,136	81%	2,937	3,816,203	0%	0	0
2027	15%	639	789,915	72%	3,076	3,804,757	0%	0	0
2028	15%	759	945,969	68%	3,441	4,288,394	0%	0	0
2029	20%	1,206	1,514,257	60%	3,619	4,542,772	0%	0	0
2030	20%	1,413	1,780,183	56%	3,957	4,984,512	0%	0	0
2050	12%	986	1,253,331	53%	4,339	5,514,655	0%	0	0
2032	10%	949	1,218,218	54%	5,127	6,578,377	0%	0	0
2033	10%	1,100	1,409,784	54%	5,942	7,612,831	0%	0	0
2034	10%	1,291	1,660,800	54%	6,972	8,968,320	0%	0	0
2035	12%	1,792	2,327,866	53%	7,885	10,242,611	0%	0	0
2036	12%	2,014	2,822,001	53%	8,861	12,416,805	0%	0	0
2037	12%	2,248	3,348,517	53%	9,890	14,733,474	0%	0	0
2038	12%	2,487	3,881,574	53%	10,943	17,078,926	0%	0	0
2039	12%	2,751	4,511,626	53%	12,105	19,851,155	0%	0	0
2040	12%	3,009	5,204,512	53%	13,239	22,899,854	0%	0	0
2041	12%	3,252	5,974,789	53%	14,308	26,289,072	0%	0	0
2042	12%	3,449	6,765,245	53%	15,175	29,767,079	0%	0	0
2043	12%	3,559	7,455,772	53%	15,660	32,805,395	0%	0	0
2044	12%	3,614	8,101,789	53%	15,903	35,647,870	0%	0	0
2045	12%	3,409	8,115,025	53%	14,999	35,706,110	0%	0	0
2046	12%	3,286	8,297,953	53%	14,461	36,510,994	0%	0	0
2047	12%	2,959	7,761,898	53%	13,021	34,152,353	0%	0	0
2048	12%	2,784	7,487,127	53%	12,249	32,943,359	0%	0	0
2049	12%	2,625	7,158,856	53%	11,549	31,498,966	0%	0	0
2050	12%	1,643	4,302,930	53%	7,231	18,932,893	0%	0	0
2051	12%	846	1,763,371	53%	3,724	7,758,831	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	5%	117	50,114	0.10	269	0.001	0.04
2025	6%	191	82,360	0.11	310	0.001	0.05
2026	9%	326	140,010	0.13	358	0.001	0.06
2027	13%	543	221,702	0.15	383	0.001	0.06
2028	17%	860	354,002	0.18	437	0.001	0.07
2029	20%	1,206	500,001	0.22	505	0.001	0.08
2030	24%	1,696	705,370	0.25	564	0.002	0.09
2050	35%	2,892	1,213,943	0.23	565	0.002	0.09
2032	36%	3,418	1,448,100	0.26	651	0.002	0.10
2033	36%	3,961	1,675,814	0.30	753	0.002	0.12
2034	36%	4,648	1,974,199	0.35	887	0.003	0.14
2035	35%	5,257	2,254,709	0.44	1,049	0.003	0.16
2036	35%	5,907	2,733,315	0.53	1,272	0.004	0.20
2037	35%	6,594	3,243,284	0.62	1,509	0.005	0.24
2038	35%	7,295	3,759,589	0.72	1,749	0.005	0.27
2039	35%	8,070	4,369,840	0.84	2,033	0.006	0.32
2040	35%	8,826	5,040,951	1.0	2,345	0.007	0.37
2041	35%	9,539	5,787,020	1.1	2,692	0.008	0.42
2042	35%	10,117	6,552,635	1.2	3,048	0.009	0.48
2043	35%	10,440	7,221,460	1.3	3,359	0.009	0.53
2044	35%	10,602	7,847,175	1.3	3,651	0.01	0.57
2045	35%	9,999	7,859,995	1.2	3,657	0.01	0.57
2046	35%	9,640	8,037,175	1.2	3,739	0.010	0.59
2047	35%	8,680	7,517,967	1.0	3,497	0.009	0.55
2048	35%	8,166	7,251,830	0.91	3,374	0.008	0.53
2049	35%	7,699	6,933,876	0.81	3,226	0.008	0.51
2050	35%	4,821	4,167,703	0.45	1,939	0.005	0.30
2051	35%	2,483	1,707,953	0.15	795	0.002	0.12

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

	Adjusted EMFAC2017 Output[1]						Conventional DSL		
Model Year	**Population**	**NOx_TOTEX (tons/day)**	**CO2_TOTEX (tons/day)**	**CH4_TOTEX (tons/day)**	**N2O_TOTEX (tons/day)**	**Fuel Consumption (1000 gal/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
1976	29	0.02	1.7	0.000	0.000	0.15	100%	29	19,871
1977	34	0.02	2.3	0.000	0.000	0.20	100%	34	27,331
1978	66	0.04	3.9	0.000	0.001	0.35	100%	66	47,207
1979	94	0.05	5.0	0.000	0.001	0.44	100%	94	59,761
1980	87	0.05	5.1	0.000	0.001	0.45	100%	87	61,143
1981	258	0.15	15	0.000	0.002	1.3	100%	258	180,361
1982	236	0.13	13	0.000	0.002	1.2	100%	236	156,209
1983	219	0.13	13	0.000	0.002	1.1	100%	219	151,257
1984	274	0.18	18	0.000	0.003	1.6	100%	274	214,575
1985	404	0.25	25	0.000	0.004	2.2	100%	404	301,188
1986	396	0.25	25	0.000	0.004	2.2	100%	396	301,092
1987	426	0.29	27	0.000	0.004	2.4	100%	426	324,223
1988	484	0.34	32	0.000	0.005	2.9	100%	484	387,591
1989	567	0.40	38	0.000	0.006	3.4	100%	567	454,438
1990	539	0.39	37	0.000	0.006	3.3	100%	539	446,862
1991	475	0.34	28	0.000	0.004	2.5	100%	475	335,098
1992	399	0.31	25	0.000	0.004	2.2	100%	399	301,877
1993	363	0.29	25	0.000	0.004	2.2	100%	363	295,585
1994	379	0.31	28	0.000	0.004	2.5	100%	379	330,512
1995	507	0.41	37	0.000	0.006	3.3	100%	507	443,837
1996	1,142	1.8	150	0.006	0.02	13	100%	1,142	1,800,897
1997	1,167	1.8	149	0.006	0.02	13	100%	1,167	1,790,241
1998	1,370	2.2	192	0.008	0.03	17	100%	1,370	2,305,455
1999	1,972	4.1	291	0.01	0.05	26	100%	1,972	3,484,066
2000	4,067	9.0	641	0.02	0.10	57	100%	4,067	7,683,603
2001	3,153	6.6	476	0.02	0.07	42	100%	3,153	5,706,180
2002	2,427	4.6	338	0.01	0.05	30	100%	2,427	4,046,083
2003	2,907	3.5	425	0.01	0.07	38	100%	2,907	5,088,912
2004	2,913	3.0	421	0.01	0.07	38	100%	2,913	5,047,803
2005	4,812	5.1	719	0.02	0.11	64	100%	4,812	8,613,212
2006	5,968	6.9	972	0.03	0.15	87	100%	5,968	11,650,876
2007	8,303	9.5	1,454	0.03	0.23	130	100%	8,303	17,419,576
2008	12,274	13	2,417	0.02	0.38	215	100%	12,274	28,960,284
2009	14,354	16	3,080	0.03	0.48	275	100%	14,354	36,913,677
2010	11,383	13	2,653	0.02	0.42	236	100%	11,383	31,795,323
2011	13,627	10	3,166	0.01	0.50	282	100%	13,627	37,940,166
2012	39,297	19	6,724	0.01	1.1	599	100%	39,297	80,581,115
2013	21,084	14	5,397	0.010	0.85	481	100%	21,084	64,680,893
2014	23,061	12	5,525	0.01	0.87	492	100%	23,061	66,207,976
2015	28,916	14	7,779	0.02	1.2	693	100%	28,916	93,222,050
2016	41,998	22	12,488	0.02	2.0	1,113	100%	41,998	149,658,452
2017	16,101	6.6	3,944	0.008	0.62	351	100%	16,101	47,265,405
2018	12,688	5.9	3,720	0.007	0.58	332	100%	12,688	44,579,225
2019	12,851	5.6	3,844	0.007	0.60	343	100%	12,851	46,069,473
2020	8,537	3.3	2,461	0.004	0.39	219	100%	8,537	29,496,897
2021	4,246	1.1	575	0.002	0.09	51	100%	4,246	6,891,960

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1976	0%	0	0	0%	0	0	0%	0	0
1977	0%	0	0	0%	0	0	0%	0	0
1978	0%	0	0	0%	0	0	0%	0	0
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1976	0%	0	0	0.02	1.7	0.000	0.000
1977	0%	0	0	0.02	2.3	0.000	0.000
1978	0%	0	0	0.04	3.9	0.000	0.001
1979	0%	0	0	0.05	5.0	0.000	0.001
1980	0%	0	0	0.05	5.1	0.000	0.001
1981	0%	0	0	0.15	15	0.000	0.002
1982	0%	0	0	0.13	13	0.000	0.002
1983	0%	0	0	0.13	13	0.000	0.002
1984	0%	0	0	0.18	18	0.000	0.003
1985	0%	0	0	0.25	25	0.000	0.004
1986	0%	0	0	0.25	25	0.000	0.004
1987	0%	0	0	0.29	27	0.000	0.004
1988	0%	0	0	0.34	32	0.000	0.005
1989	0%	0	0	0.40	38	0.000	0.006
1990	0%	0	0	0.39	37	0.000	0.006
1991	0%	0	0	0.34	28	0.000	0.004
1992	0%	0	0	0.31	25	0.000	0.004
1993	0%	0	0	0.29	25	0.000	0.004
1994	0%	0	0	0.31	28	0.000	0.004
1995	0%	0	0	0.41	37	0.000	0.006
1996	0%	0	0	1.8	150	0.006	0.02
1997	0%	0	0	1.8	149	0.006	0.02
1998	0%	0	0	2.2	192	0.008	0.03
1999	0%	0	0	4.1	291	0.01	0.05
2000	0%	0	0	9.0	641	0.02	0.10
2001	0%	0	0	6.6	476	0.02	0.07
2002	0%	0	0	4.6	338	0.01	0.05
2003	0%	0	0	3.5	425	0.01	0.07
2004	0%	0	0	3.0	421	0.01	0.07
2005	0%	0	0	5.1	719	0.02	0.11
2006	0%	0	0	6.9	972	0.03	0.15
2007	0%	0	0	9.5	1,454	0.03	0.23
2008	0%	0	0	13	2,417	0.02	0.38
2009	0%	0	0	16	3,080	0.03	0.48
2010	0%	0	0	13	2,653	0.02	0.42
2011	0%	0	0	10	3,166	0.01	0.50
2012	0%	0	0	19	6,724	0.01	1.1
2013	0%	0	0	14	5,397	0.010	0.85
2014	0%	0	0	12	5,525	0.01	0.87
2015	0%	0	0	14	7,779	0.02	1.2
2016	0%	0	0	22	12,488	0.02	2.0
2017	0%	0	0	6.6	3,944	0.008	0.62
2018	0%	0	0	5.9	3,720	0.007	0.58
2019	0%	0	0	5.6	3,844	0.007	0.60
2020	0%	0	0	3.3	2,461	0.004	0.39
2021	0%	0	0	1.1	575	0.002	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	53	0.03	2.9	0.000	0.000	0.26	100%	53	35,019
1980	64	0.04	3.7	0.000	0.001	0.33	100%	64	44,086
1981	209	0.12	12	0.000	0.002	1.1	100%	209	142,790
1982	208	0.11	11	0.000	0.002	1.0	100%	208	134,214
1983	196	0.11	11	0.000	0.002	1.0	100%	196	131,088
1984	241	0.15	15	0.000	0.002	1.3	100%	241	176,822
1985	357	0.21	21	0.000	0.003	1.9	100%	357	252,082
1986	331	0.20	20	0.000	0.003	1.8	100%	331	243,579
1987	345	0.22	21	0.000	0.003	1.9	100%	345	253,082
1988	370	0.26	24	0.000	0.004	2.2	100%	370	290,997
1989	420	0.29	28	0.000	0.004	2.5	100%	420	332,355
1990	382	0.28	27	0.000	0.004	2.4	100%	382	319,401
1991	331	0.24	20	0.000	0.003	1.8	100%	331	238,471
1992	279	0.22	18	0.000	0.003	1.6	100%	279	214,037
1993	235	0.20	17	0.000	0.003	1.5	100%	235	202,566
1994	257	0.21	19	0.000	0.003	1.7	100%	257	228,163
1995	341	0.29	26	0.000	0.004	2.3	100%	341	308,497
1996	354	0.29	26	0.000	0.004	2.3	100%	354	309,827
1997	358	0.27	24	0.000	0.004	2.2	100%	358	292,799
1998	350	0.29	27	0.000	0.004	2.4	100%	350	324,850
1999	484	0.48	38	0.000	0.006	3.4	100%	484	458,610
2000	570	0.55	44	0.000	0.007	3.9	100%	570	522,449
2001	630	0.52	42	0.000	0.007	3.7	100%	630	502,288
2002	683	0.50	41	0.000	0.006	3.7	100%	683	490,906
2003	607	0.31	41	0.000	0.006	3.7	100%	607	491,836
2004	588	0.27	39	0.000	0.006	3.4	100%	588	462,594
2005	722	0.33	48	0.000	0.008	4.3	100%	722	579,188
2006	789	0.37	53	0.000	0.008	4.7	100%	789	635,640
2007	1,010	0.43	69	0.000	0.01	6.1	100%	1,010	822,391
2008	958	0.24	51	0.000	0.008	4.5	100%	958	608,971
2009	1,054	0.24	57	0.000	0.009	5.1	100%	1,054	681,595
2010	516	0.11	28	0.000	0.004	2.5	100%	516	336,250
2011	601	0.08	32	0.000	0.005	2.8	100%	601	381,333
2012	36,456	15	5,160	0.010	0.81	460	100%	36,456	61,840,416
2013	23,385	13	4,715	0.009	0.74	420	100%	23,385	56,503,770
2014	25,954	12	4,907	0.01	0.77	437	100%	25,954	58,805,403
2015	43,313	18	8,476	0.02	1.3	755	100%	43,313	101,582,009
2016	51,092	25	12,180	0.03	1.9	1,086	100%	51,092	145,975,230
2017	45,093	20	10,301	0.02	1.6	918	100%	45,093	123,455,483
2018	15,699	7.6	3,880	0.008	0.61	346	100%	15,699	46,494,284
2019	15,755	7.5	4,119	0.008	0.65	367	100%	15,755	49,364,115
2020	14,758	7.0	4,076	0.008	0.64	363	100%	14,758	48,851,177
2021	13,866	6.3	3,442	0.008	0.54	307	100%	13,866	41,250,943
2022	13,999	6.1	3,590	0.008	0.56	320	100%	13,999	43,027,237
2023	9,671	3.7	2,395	0.005	0.38	213	100%	9,671	28,707,076
2024	4,843	1.3	599	0.003	0.09	53	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1979	0%	0	0	0%	0	0	0%	0	0
1980	0%	0	0	0%	0	0	0%	0	0
1981	0%	0	0	0%	0	0	0%	0	0
1982	0%	0	0	0%	0	0	0%	0	0
1983	0%	0	0	0%	0	0	0%	0	0
1984	0%	0	0	0%	0	0	0%	0	0
1985	0%	0	0	0%	0	0	0%	0	0
1986	0%	0	0	0%	0	0	0%	0	0
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	484	717,286	90%	4,358	6,455,577	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
1979	0%	0	0	0.03	2.9	0.000	0.000
1980	0%	0	0	0.04	3.7	0.000	0.001
1981	0%	0	0	0.12	12	0.000	0.002
1982	0%	0	0	0.11	11	0.000	0.002
1983	0%	0	0	0.11	11	0.000	0.002
1984	0%	0	0	0.15	15	0.000	0.002
1985	0%	0	0	0.21	21	0.000	0.003
1986	0%	0	0	0.20	20	0.000	0.003
1987	0%	0	0	0.22	21	0.000	0.003
1988	0%	0	0	0.26	24	0.000	0.004
1989	0%	0	0	0.29	28	0.000	0.004
1990	0%	0	0	0.28	27	0.000	0.004
1991	0%	0	0	0.24	20	0.000	0.003
1992	0%	0	0	0.22	18	0.000	0.003
1993	0%	0	0	0.20	17	0.000	0.003
1994	0%	0	0	0.21	19	0.000	0.003
1995	0%	0	0	0.29	26	0.000	0.004
1996	0%	0	0	0.29	26	0.000	0.004
1997	0%	0	0	0.27	24	0.000	0.004
1998	0%	0	0	0.29	27	0.000	0.004
1999	0%	0	0	0.48	38	0.000	0.006
2000	0%	0	0	0.55	44	0.000	0.007
2001	0%	0	0	0.52	42	0.000	0.007
2002	0%	0	0	0.50	41	0.000	0.006
2003	0%	0	0	0.31	41	0.000	0.006
2004	0%	0	0	0.27	39	0.000	0.006
2005	0%	0	0	0.33	48	0.000	0.008
2006	0%	0	0	0.37	53	0.000	0.008
2007	0%	0	0	0.43	69	0.000	0.01
2008	0%	0	0	0.24	51	0.000	0.008
2009	0%	0	0	0.24	57	0.000	0.009
2010	0%	0	0	0.11	28	0.000	0.004
2011	0%	0	0	0.08	32	0.000	0.005
2012	0%	0	0	15	5,160	0.010	0.81
2013	0%	0	0	13	4,715	0.009	0.74
2014	0%	0	0	12	4,907	0.01	0.77
2015	0%	0	0	18	8,476	0.02	1.3
2016	0%	0	0	25	12,180	0.03	1.9
2017	0%	0	0	20	10,301	0.02	1.6
2018	0%	0	0	7.6	3,880	0.008	0.61
2019	0%	0	0	7.5	4,119	0.008	0.65
2020	0%	0	0	7.0	4,076	0.008	0.64
2021	0%	0	0	6.3	3,442	0.008	0.54
2022	0%	0	0	6.1	3,590	0.008	0.56
2023	0%	0	0	3.7	2,395	0.005	0.38
2024	0%	0	0	0.14	599	0.003	0.09

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	166	0.09	8.9	0.000	0.001	0.79	100%	166	106,532
1988	223	0.13	12	0.000	0.002	1.1	100%	223	144,024
1989	279	0.16	15	0.000	0.002	1.3	100%	279	179,202
1990	256	0.15	14	0.000	0.002	1.3	100%	256	168,297
1991	221	0.14	11	0.000	0.002	1.0	100%	221	134,880
1992	173	0.11	9.2	0.000	0.001	0.82	100%	173	110,429
1993	132	0.09	7.5	0.000	0.001	0.67	100%	132	90,308
1994	131	0.08	7.6	0.000	0.001	0.68	100%	131	91,104
1995	161	0.11	10	0.000	0.002	0.87	100%	161	116,335
1996	159	0.11	10	0.000	0.002	0.85	100%	159	114,485
1997	155	0.10	9.1	0.000	0.001	0.81	100%	155	108,509
1998	145	0.10	10	0.000	0.001	0.85	100%	145	114,337
1999	197	0.17	13	0.000	0.002	1.2	100%	197	160,607
2000	233	0.20	16	0.000	0.002	1.4	100%	233	188,016
2001	267	0.20	16	0.000	0.003	1.4	100%	267	193,494
2002	300	0.21	17	0.000	0.003	1.5	100%	300	200,551
2003	272	0.13	17	0.000	0.003	1.5	100%	272	200,037
2004	276	0.12	17	0.000	0.003	1.5	100%	276	198,929
2005	353	0.15	22	0.000	0.003	1.9	100%	353	259,740
2006	403	0.18	25	0.000	0.004	2.3	100%	403	303,073
2007	543	0.22	35	0.000	0.006	3.1	100%	543	422,431
2008	564	0.14	29	0.000	0.005	2.6	100%	564	352,228
2009	654	0.15	34	0.000	0.005	3.1	100%	654	410,832
2010	337	0.07	18	0.000	0.003	1.6	100%	337	211,381
2011	419	0.05	21	0.000	0.003	1.9	100%	419	253,413
2012	18,775	6.3	2,125	0.004	0.33	189	100%	18,775	25,469,698
2013	10,866	5.2	1,931	0.003	0.30	172	100%	10,866	23,141,590
2014	12,373	4.9	1,993	0.004	0.31	178	100%	12,373	23,884,682
2015	22,601	8.0	3,471	0.007	0.55	309	100%	22,601	41,601,211
2016	25,559	9.1	3,866	0.010	0.61	345	100%	25,559	46,327,589
2017	29,560	9.2	4,023	0.009	0.63	359	100%	29,560	48,215,934
2018	10,153	3.8	1,588	0.004	0.25	142	100%	10,153	19,030,587
2019	11,512	4.5	1,861	0.004	0.29	166	100%	11,512	22,305,607
2020	13,043	5.4	2,255	0.005	0.35	201	100%	13,043	27,025,846
2021	14,295	6.2	2,272	0.006	0.36	203	100%	14,295	27,231,919
2022	16,417	7.5	2,835	0.007	0.45	253	100%	16,417	33,979,835
2023	22,059	12	4,261	0.010	0.67	380	100%	22,059	51,063,434
2024	21,715	11	3,988	0.01	0.63	355	0%	0	0
2025	22,619	12	4,524	0.01	0.71	403	0%	0	0
2026	22,104	12	4,758	0.01	0.75	424	0%	0	0
2027	21,594	11	4,671	0.01	0.73	416	0%	0	0
2028	19,744	10	4,452	0.01	0.70	397	0%	0	0
2029	18,560	9.0	4,281	0.01	0.67	382	0%	0	0
2030	17,915	8.2	4,205	0.01	0.66	375	0%	0	0
2031	11,497	4.6	2,590	0.006	0.41	231	0%	0	0
2032	5,864	1.6	694	0.003	0.11	62	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1987	0%	0	0	0%	0	0	0%	0	0
1988	0%	0	0	0%	0	0	0%	0	0
1989	0%	0	0	0%	0	0	0%	0	0
1990	0%	0	0	0%	0	0	0%	0	0
1991	0%	0	0	0%	0	0	0%	0	0
1992	0%	0	0	0%	0	0	0%	0	0
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	2,171	4,779,835	90%	19,543	43,018,516	0%	0	0
2025	10%	2,262	5,421,301	90%	20,358	48,791,706	0%	0	0
2026	10%	2,210	5,702,550	90%	19,894	51,322,947	0%	0	0
2027	15%	3,239	8,396,467	85%	18,355	47,579,979	0%	0	0
2028	15%	2,962	8,002,355	85%	16,783	45,346,680	0%	0	0
2029	20%	3,712	10,260,841	80%	14,848	41,043,365	0%	0	0
2030	20%	3,583	10,079,515	80%	14,332	40,318,062	0%	0	0
2031	20%	2,299	6,209,013	80%	9,198	24,836,053	0%	0	0
2032	10%	586	831,861	90%	5,277	7,486,747	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1987	0%	0	0	0.09	8.9	0.000	0.001
1988	0%	0	0	0.13	12	0.000	0.002
1989	0%	0	0	0.16	15	0.000	0.002
1990	0%	0	0	0.15	14	0.000	0.002
1991	0%	0	0	0.14	11	0.000	0.002
1992	0%	0	0	0.11	9.2	0.000	0.001
1993	0%	0	0	0.09	7.5	0.000	0.001
1994	0%	0	0	0.08	7.6	0.000	0.001
1995	0%	0	0	0.11	10	0.000	0.002
1996	0%	0	0	0.11	10	0.000	0.002
1997	0%	0	0	0.10	9.1	0.000	0.001
1998	0%	0	0	0.10	10	0.000	0.001
1999	0%	0	0	0.17	13	0.000	0.002
2000	0%	0	0	0.20	16	0.000	0.002
2001	0%	0	0	0.20	16	0.000	0.003
2002	0%	0	0	0.21	17	0.000	0.003
2003	0%	0	0	0.13	17	0.000	0.003
2004	0%	0	0	0.12	17	0.000	0.003
2005	0%	0	0	0.15	22	0.000	0.003
2006	0%	0	0	0.18	25	0.000	0.004
2007	0%	0	0	0.22	35	0.000	0.006
2008	0%	0	0	0.14	29	0.000	0.005
2009	0%	0	0	0.15	34	0.000	0.005
2010	0%	0	0	0.07	18	0.000	0.003
2011	0%	0	0	0.05	21	0.000	0.003
2012	0%	0	0	6.3	2,125	0.004	0.33
2013	0%	0	0	5.2	1,931	0.003	0.30
2014	0%	0	0	4.9	1,993	0.004	0.31
2015	0%	0	0	8.0	3,471	0.007	0.55
2016	0%	0	0	9.1	3,866	0.010	0.61
2017	0%	0	0	9.2	4,023	0.009	0.63
2018	0%	0	0	3.8	1,588	0.004	0.25
2019	0%	0	0	4.5	1,861	0.004	0.29
2020	0%	0	0	5.4	2,255	0.005	0.35
2021	0%	0	0	6.2	2,272	0.006	0.36
2022	0%	0	0	7.5	2,835	0.007	0.45
2023	0%	0	0	12	4,261	0.010	0.67
2024	0%	0	0	1.3	3,988	0.01	0.63
2025	0%	0	0	1.4	4,524	0.01	0.71
2026	0%	0	0	1.3	4,758	0.01	0.75
2027	0%	0	0	1.4	4,671	0.01	0.73
2028	0%	0	0	1.2	4,452	0.01	0.70
2029	0%	0	0	1.2	4,281	0.01	0.67
2030	0%	0	0	1.1	4,205	0.01	0.66
2031	0%	0	0	0.60	2,590	0.006	0.41
2032	0%	0	0	0.18	694	0.003	0.11

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	66	0.04	3.5	0.000	0.001	0.31	100%	66	42,043
1994	83	0.05	4.2	0.000	0.001	0.38	100%	83	50,721
1995	115	0.07	5.9	0.000	0.001	0.53	100%	115	70,970
1996	119	0.07	6.1	0.000	0.001	0.54	100%	119	72,842
1997	117	0.06	5.9	0.000	0.001	0.52	100%	117	70,488
1998	104	0.06	5.7	0.000	0.001	0.50	100%	104	67,898
1999	133	0.10	7.6	0.000	0.001	0.67	100%	133	90,610
2000	147	0.11	8.5	0.000	0.001	0.76	100%	147	101,850
2001	161	0.11	8.8	0.000	0.001	0.79	100%	161	105,603
2002	172	0.11	9.0	0.000	0.001	0.80	100%	172	107,968
2003	146	0.06	8.3	0.000	0.001	0.74	100%	146	99,226
2004	143	0.06	8.1	0.000	0.001	0.72	100%	143	96,731
2005	178	0.07	10	0.000	0.002	0.92	100%	178	123,640
2006	202	0.09	12	0.000	0.002	1.1	100%	202	143,033
2007	272	0.11	17	0.000	0.003	1.5	100%	272	200,277
2008	292	0.07	15	0.000	0.002	1.3	100%	292	179,211
2009	346	0.08	18	0.000	0.003	1.6	100%	346	213,122
2010	183	0.04	9.3	0.000	0.001	0.83	100%	183	111,727
2011	234	0.03	11	0.000	0.002	1.0	100%	234	136,809
2012	7,969	2.4	804	0.002	0.13	72	100%	7,969	9,641,296
2013	4,340	2.0	750	0.001	0.12	67	100%	4,340	8,984,556
2014	4,954	2.0	817	0.001	0.13	73	100%	4,954	9,795,650
2015	9,674	3.7	1,601	0.003	0.25	143	100%	9,674	19,190,427
2016	10,519	3.7	1,604	0.004	0.25	143	100%	10,519	19,227,562
2017	14,184	3.9	1,723	0.004	0.27	154	100%	14,184	20,654,585
2018	4,924	1.7	692	0.002	0.11	62	100%	4,924	8,290,062
2019	5,803	1.9	807	0.002	0.13	72	100%	5,803	9,667,889
2020	6,713	2.3	945	0.002	0.15	84	100%	6,713	11,329,480
2021	7,708	2.6	942	0.003	0.15	84	100%	7,708	11,285,971
2022	9,361	3.4	1,197	0.003	0.19	107	100%	9,361	14,344,235
2023	12,311	5.2	1,799	0.004	0.28	160	100%	12,311	21,557,339
2024	14,157	5.5	1,804	0.005	0.28	161	0%	0	0
2025	15,781	6.4	2,112	0.006	0.33	188	0%	0	0
2026	17,659	7.5	2,484	0.007	0.39	221	0%	0	0
2027	19,532	8.7	2,768	0.008	0.44	247	0%	0	0
2028	21,365	10	3,236	0.010	0.51	288	0%	0	0
2029	22,985	11	3,748	0.01	0.59	334	0%	0	0
2030	24,081	12	4,213	0.01	0.66	375	0%	0	0
2037	24,791	13	4,671	0.01	0.73	416	0%	0	0
2032	24,114	13	4,857	0.01	0.76	433	0%	0	0
2033	23,670	12	5,060	0.01	0.80	451	0%	0	0
2034	21,948	11	4,883	0.01	0.77	435	0%	0	0
2035	20,791	10	4,742	0.01	0.75	423	0%	0	0
2036	19,699	9.0	4,573	0.01	0.72	408	0%	0	0
2037	12,409	5.0	2,773	0.007	0.44	247	0%	0	0
2038	6,391	1.7	743	0.003	0.12	66	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
1993	0%	0	0	0%	0	0	0%	0	0
1994	0%	0	0	0%	0	0	0%	0	0
1995	0%	0	0	0%	0	0	0%	0	0
1996	0%	0	0	0%	0	0	0%	0	0
1997	0%	0	0	0%	0	0	0%	0	0
1998	0%	0	0	0%	0	0	0%	0	0
1999	0%	0	0	0%	0	0	0%	0	0
2000	0%	0	0	0%	0	0	0%	0	0
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	1,416	2,161,542	90%	12,741	19,453,879	0%	0	0
2025	10%	1,578	2,531,043	90%	14,203	22,779,383	0%	0	0
2026	10%	1,766	2,977,192	90%	15,893	26,794,732	0%	0	0
2027	15%	2,930	4,975,264	85%	16,602	28,193,162	0%	0	0
2028	15%	3,205	5,817,346	85%	18,160	32,964,959	0%	0	0
2029	20%	4,597	8,983,030	80%	18,388	35,932,119	0%	0	0
2030	20%	4,816	10,097,767	80%	19,265	40,391,066	0%	0	0
2037	12%	2,975	6,717,948	88%	21,816	49,264,949	0%	0	0
2032	10%	2,411	5,821,019	90%	21,703	52,389,172	0%	0	0
2033	10%	2,367	6,063,891	90%	21,303	54,575,018	0%	0	0
2034	10%	2,195	5,851,702	90%	19,754	52,665,319	0%	0	0
2035	12%	2,495	6,819,958	88%	18,296	50,013,022	0%	0	0
2036	12%	2,364	6,576,732	88%	17,335	48,229,366	0%	0	0
2037	12%	1,489	3,988,015	88%	10,920	29,245,447	0%	0	0
2038	12%	767	1,068,563	88%	5,624	7,836,129	0%	0	0

	BEV			Tailpipe Emission Estimates[5] (tons/day)			
Model Year	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_X	CO_2	CH_4	N_2O
1993	0%	0	0	0.04	3.5	0.000	0.001
1994	0%	0	0	0.05	4.2	0.000	0.001
1995	0%	0	0	0.07	5.9	0.000	0.001
1996	0%	0	0	0.07	6.1	0.000	0.001
1997	0%	0	0	0.06	5.9	0.000	0.001
1998	0%	0	0	0.06	5.7	0.000	0.001
1999	0%	0	0	0.10	7.6	0.000	0.001
2000	0%	0	0	0.11	8.5	0.000	0.001
2001	0%	0	0	0.11	8.8	0.000	0.001
2002	0%	0	0	0.11	9.0	0.000	0.001
2003	0%	0	0	0.06	8.3	0.000	0.001
2004	0%	0	0	0.06	8.1	0.000	0.001
2005	0%	0	0	0.07	10	0.000	0.002
2006	0%	0	0	0.09	12	0.000	0.002
2007	0%	0	0	0.11	17	0.000	0.003
2008	0%	0	0	0.07	15	0.000	0.002
2009	0%	0	0	0.08	18	0.000	0.003
2010	0%	0	0	0.04	9.3	0.000	0.001
2011	0%	0	0	0.03	11	0.000	0.002
2012	0%	0	0	2.4	804	0.002	0.13
2013	0%	0	0	2.0	750	0.001	0.12
2014	0%	0	0	2.0	817	0.001	0.13
2015	0%	0	0	3.7	1,601	0.003	0.25
2016	0%	0	0	3.7	1,604	0.004	0.25
2017	0%	0	0	3.9	1,723	0.004	0.27
2018	0%	0	0	1.7	692	0.002	0.11
2019	0%	0	0	1.9	807	0.002	0.13
2020	0%	0	0	2.3	945	0.002	0.15
2021	0%	0	0	2.6	942	0.003	0.15
2022	0%	0	0	3.4	1,197	0.003	0.19
2023	0%	0	0	5.2	1,799	0.004	0.28
2024	0%	0	0	0.63	1,804	0.005	0.28
2025	0%	0	0	0.74	2,112	0.006	0.33
2026	0%	0	0	0.87	2,484	0.007	0.39
2027	0%	0	0	1.1	2,768	0.008	0.44
2028	0%	0	0	1.2	3,236	0.010	0.51
2029	0%	0	0	1.5	3,748	0.01	0.59
2030	0%	0	0	1.6	4,213	0.01	0.66
2037	0%	0	0	1.5	4,671	0.01	0.73
2032	0%	0	0	1.5	4,857	0.01	0.76
2033	0%	0	0	1.4	5,060	0.01	0.80
2034	0%	0	0	1.3	4,883	0.01	0.77
2035	0%	0	0	1.2	4,742	0.01	0.75
2036	0%	0	0	1.1	4,573	0.01	0.72
2037	0%	0	0	0.59	2,773	0.007	0.44
2038	0%	0	0	0.20	743	0.003	0.12

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Table A-42. NOx and GHG Tailpipe Emissions for Scenario 6 in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0	0	0	0	0	0	0%	0	0
2002	0	0	0	0	0	0	0%	0	0
2003	0	0	0	0	0	0	0%	0	0
2004	0	0	0	0	0	0	0%	0	0
2005	0	0	0	0	0	0	0%	0	0
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	5,738	1.9	631	0.002	0.10	56	0%	0	0
2025	6,682	2.2	740	0.002	0.12	66	0%	0	0
2026	7,830	2.6	869	0.002	0.14	77	0%	0	0
2027	8,960	3.0	954	0.003	0.15	85	0%	0	0
2028	10,297	3.5	1,096	0.003	0.17	98	0%	0	0
2029	11,921	4.1	1,276	0.004	0.20	114	0%	0	0
2030	13,807	4.8	1,488	0.005	0.23	133	0%	0	0
2045	15,655	5.9	1,819	0.006	0.29	162	0%	0	0
2032	17,813	7.1	2,196	0.007	0.35	196	0%	0	0
2033	20,003	8.3	2,581	0.008	0.41	230	0%	0	0
2034	22,623	10	3,067	0.009	0.48	273	0%	0	0
2035	24,976	11	3,584	0.01	0.56	319	0%	0	0
2036	26,967	13	4,118	0.01	0.65	367	0%	0	0
2037	28,599	14	4,677	0.01	0.74	417	0%	0	0
2038	29,556	15	5,172	0.01	0.81	461	0%	0	0
2039	30,085	16	5,646	0.02	0.89	503	0%	0	0
2040	28,520	15	5,685	0.02	0.89	507	0%	0	0
2041	27,485	14	5,816	0.02	0.91	518	0%	0	0
2042	24,780	12	5,446	0.01	0.86	485	0%	0	0
2043	23,286	11	5,243	0.01	0.82	467	0%	0	0
2044	22,012	10	5,025	0.01	0.79	448	0%	0	0
2045	13,831	5.5	3,030	0.007	0.48	270	0%	0	0
2046	7,111	1.9	812	0.004	0.13	72	0%	0	0

Model Year	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2001	0%	0	0	0%	0	0	0%	0	0
2002	0%	0	0	0%	0	0	0%	0	0
2003	0%	0	0	0%	0	0	0%	0	0
2004	0%	0	0	0%	0	0	0%	0	0
2005	0%	0	0	0%	0	0	0%	0	0
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	574	756,340	90%	5,164	6,807,061	0%	0	0
2025	10%	668	886,781	90%	6,014	7,981,032	0%	0	0
2026	10%	783	1,041,761	90%	7,047	9,375,851	0%	0	0
2027	15%	1,344	1,715,605	85%	7,616	9,721,760	0%	0	0
2028	15%	1,544	1,969,828	85%	8,752	11,162,360	0%	0	0
2029	20%	2,384	3,059,507	80%	9,536	12,238,027	0%	0	0
2030	20%	2,761	3,566,433	80%	11,045	14,265,732	0%	0	0
2045	12%	1,879	2,615,706	88%	13,777	19,181,841	0%	0	0
2032	10%	1,781	2,631,722	90%	16,032	23,685,498	0%	0	0
2033	10%	2,000	3,093,484	90%	18,003	27,841,358	0%	0	0
2034	10%	2,262	3,676,051	90%	20,361	33,084,463	0%	0	0
2035	12%	2,997	5,154,227	88%	21,979	37,797,664	0%	0	0
2036	12%	3,236	5,922,773	88%	23,731	43,433,668	0%	0	0
2037	12%	3,432	6,725,482	88%	25,167	49,320,202	0%	0	0
2038	12%	3,547	7,438,400	88%	26,009	54,548,270	0%	0	0
2039	12%	3,610	8,118,998	88%	26,475	59,539,315	0%	0	0
2040	12%	3,422	8,176,299	88%	25,097	59,959,528	0%	0	0
2041	12%	3,298	8,363,731	88%	24,187	61,334,028	0%	0	0
2042	12%	2,974	7,831,788	88%	21,807	57,433,112	0%	0	0
2043	12%	2,794	7,539,421	88%	20,492	55,289,088	0%	0	0
2044	12%	2,641	7,227,079	88%	19,370	52,998,582	0%	0	0
2045	12%	1,660	4,357,601	88%	12,172	31,955,744	0%	0	0
2046	12%	853	1,167,185	88%	6,258	8,559,357	0%	0	0

Model Year	BEV			Tailpipe Emission Estimates[5] (tons/day)			
	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)	NO_x	CO_2	CH_4	N_2O
2001	0%	0	0	0	0	0	0
2002	0%	0	0	0	0	0	0
2003	0%	0	0	0	0	0	0
2004	0%	0	0	0	0	0	0
2005	0%	0	0	0	0	0	0
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	0%	0	0	0.22	631	0.002	0.10
2025	0%	0	0	0.26	740	0.002	0.12
2026	0%	0	0	0.30	869	0.002	0.14
2027	0%	0	0	0.37	954	0.003	0.15
2028	0%	0	0	0.43	1,096	0.003	0.17
2029	0%	0	0	0.54	1,276	0.004	0.20
2030	0%	0	0	0.63	1,488	0.005	0.23
2045	0%	0	0	0.70	1,819	0.006	0.29
2032	0%	0	0	0.82	2,196	0.007	0.35
2033	0%	0	0	1.0	2,581	0.008	0.41
2034	0%	0	0	1.1	3,067	0.009	0.48
2035	0%	0	0	1.3	3,584	0.01	0.56
2036	0%	0	0	1.5	4,118	0.01	0.65
2037	0%	0	0	1.7	4,677	0.01	0.74
2038	0%	0	0	1.8	5,172	0.01	0.81
2039	0%	0	0	1.8	5,646	0.02	0.89
2040	0%	0	0	1.7	5,685	0.02	0.89
2041	0%	0	0	1.7	5,816	0.02	0.91
2042	0%	0	0	1.5	5,446	0.01	0.86
2043	0%	0	0	1.3	5,243	0.01	0.82
2044	0%	0	0	1.2	5,025	0.01	0.79
2045	0%	0	0	0.64	3,030	0.007	0.48
2046	0%	0	0	0.22	812	0.004	0.13

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Table A-43. NOx and GHG Tailpipe Emissions for Scenario 6 in Calendar Year 2050

Model Year	Adjusted EMFAC2017 Output[1]						Conventional DSL		
	Population	NOx_TOTEX (tons/day)	CO2_TOTEX (tons/day)	CH4_TOTEX (tons/day)	N2O_TOTEX (tons/day)	Fuel Consumption (1000 gal/day)	Fleet Mix[2] (%)	Population[3]	Energy Consumption[4] (MJ/day)
2006	0	0	0	0	0	0	0%	0	0
2007	0	0	0	0	0	0	0%	0	0
2008	0	0	0	0	0	0	0%	0	0
2009	0	0	0	0	0	0	0%	0	0
2010	0	0	0	0	0	0	0%	0	0
2011	0	0	0	0	0	0	0%	0	0
2012	0	0	0	0	0	0	0%	0	0
2013	0	0	0	0	0	0	0%	0	0
2014	0	0	0	0	0	0	0%	0	0
2015	0	0	0	0	0	0	0%	0	0
2016	0	0	0	0	0	0	0%	0	0
2017	0	0	0	0	0	0	0%	0	0
2018	0	0	0	0	0	0	0%	0	0
2019	0	0	0	0	0	0	0%	0	0
2020	0	0	0	0	0	0	0%	0	0
2021	0	0	0	0	0	0	0%	0	0
2022	0	0	0	0	0	0	0%	0	0
2023	0	0	0	0	0	0	0%	0	0
2024	2,595	0.86	281	0.001	0.04	25	0%	0	0
2025	3,028	1.0	330	0.001	0.05	29	0%	0	0
2026	3,626	1.2	393	0.001	0.06	35	0%	0	0
2027	4,257	1.4	439	0.001	0.07	39	0%	0	0
2028	5,060	1.7	526	0.001	0.08	47	0%	0	0
2029	6,031	2.0	632	0.002	0.10	56	0%	0	0
2030	7,066	2.4	743	0.002	0.12	66	0%	0	0
2050	8,217	2.8	872	0.003	0.14	78	0%	0	0
2032	9,494	3.2	1,017	0.003	0.16	91	0%	0	0
2033	11,004	3.8	1,176	0.004	0.18	105	0%	0	0
2034	12,911	4.5	1,386	0.004	0.22	124	0%	0	0
2035	14,935	5.3	1,619	0.005	0.25	144	0%	0	0
2036	16,783	6.4	1,962	0.006	0.31	175	0%	0	0
2037	18,732	7.5	2,328	0.007	0.37	208	0%	0	0
2038	20,725	8.7	2,699	0.008	0.42	241	0%	0	0
2039	22,925	10	3,137	0.009	0.49	280	0%	0	0
2040	25,074	11	3,619	0.01	0.57	323	0%	0	0
2041	27,099	13	4,155	0.01	0.65	370	0%	0	0
2042	28,740	14	4,704	0.01	0.74	419	0%	0	0
2043	29,658	15	5,184	0.01	0.81	462	0%	0	0
2044	30,119	16	5,634	0.02	0.89	502	0%	0	0
2045	28,407	15	5,643	0.02	0.89	503	0%	0	0
2046	27,387	14	5,770	0.02	0.91	514	0%	0	0
2047	24,660	12	5,397	0.01	0.85	481	0%	0	0
2048	23,198	11	5,206	0.01	0.82	464	0%	0	0
2049	21,872	10	4,978	0.01	0.78	444	0%	0	0
2050	13,695	5.4	2,992	0.007	0.47	267	0%	0	0
2051	7,053	1.8	1,226	0.004	0.19	109	0%	0	0

	Federal Low NOx DSL			CA Cert. Low NOx DSL			Low NOx NG		
Model Year	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**	**Fleet Mix[2] (%)**	**Population[3]**	**Energy Consumption[4] (MJ/day)**
2006	0%	0	0	0%	0	0	0%	0	0
2007	0%	0	0	0%	0	0	0%	0	0
2008	0%	0	0	0%	0	0	0%	0	0
2009	0%	0	0	0%	0	0	0%	0	0
2010	0%	0	0	0%	0	0	0%	0	0
2011	0%	0	0	0%	0	0	0%	0	0
2012	0%	0	0	0%	0	0	0%	0	0
2013	0%	0	0	0%	0	0	0%	0	0
2014	0%	0	0	0%	0	0	0%	0	0
2015	0%	0	0	0%	0	0	0%	0	0
2016	0%	0	0	0%	0	0	0%	0	0
2017	0%	0	0	0%	0	0	0%	0	0
2018	0%	0	0	0%	0	0	0%	0	0
2019	0%	0	0	0%	0	0	0%	0	0
2020	0%	0	0	0%	0	0	0%	0	0
2021	0%	0	0	0%	0	0	0%	0	0
2022	0%	0	0	0%	0	0	0%	0	0
2023	0%	0	0	0%	0	0	0%	0	0
2024	10%	260	337,270	90%	2,336	3,035,431	0%	0	0
2025	10%	303	395,918	90%	2,725	3,563,261	0%	0	0
2026	10%	363	471,136	90%	3,263	4,240,226	0%	0	0
2027	15%	639	789,915	85%	3,618	4,476,184	0%	0	0
2028	15%	759	945,969	85%	4,301	5,360,493	0%	0	0
2029	20%	1,206	1,514,257	80%	4,825	6,057,030	0%	0	0
2030	20%	1,413	1,780,183	80%	5,653	7,120,732	0%	0	0
2050	12%	986	1,253,331	88%	7,231	9,191,092	0%	0	0
2032	10%	949	1,218,218	90%	8,544	10,963,961	0%	0	0
2033	10%	1,100	1,409,784	90%	9,904	12,688,052	0%	0	0
2034	10%	1,291	1,660,800	90%	11,620	14,947,200	0%	0	0
2035	12%	1,792	2,327,866	88%	13,142	17,071,018	0%	0	0
2036	12%	2,014	2,822,001	88%	14,769	20,694,676	0%	0	0
2037	12%	2,248	3,348,517	88%	16,484	24,555,791	0%	0	0
2038	12%	2,487	3,881,574	88%	18,238	28,464,877	0%	0	0
2039	12%	2,751	4,511,626	88%	20,174	33,085,259	0%	0	0
2040	12%	3,009	5,204,512	88%	22,065	38,166,423	0%	0	0
2041	12%	3,252	5,974,789	88%	23,847	43,815,120	0%	0	0
2042	12%	3,449	6,765,245	88%	25,292	49,611,798	0%	0	0
2043	12%	3,559	7,455,772	88%	26,099	54,675,659	0%	0	0
2044	12%	3,614	8,101,789	88%	26,505	59,413,116	0%	0	0
2045	12%	3,409	8,115,025	88%	24,998	59,510,183	0%	0	0
2046	12%	3,286	8,297,953	88%	24,101	60,851,657	0%	0	0
2047	12%	2,959	7,761,898	88%	21,701	56,920,588	0%	0	0
2048	12%	2,784	7,487,127	88%	20,414	54,905,598	0%	0	0
2049	12%	2,625	7,158,856	88%	19,248	52,498,276	0%	0	0
2050	12%	1,643	4,302,930	88%	12,051	31,554,822	0%	0	0
2051	12%	846	1,763,371	88%	6,207	12,931,384	0%	0	0

Model Year	BEV Fleet Mix[2] (%)	BEV Population[3]	BEV Energy Consumption[4] (MJ/day)	Tailpipe Emission Estimates[5] (tons/day) NO_X	CO_2	CH_4	N_2O
2006	0%	0	0	0	0	0	0
2007	0%	0	0	0	0	0	0
2008	0%	0	0	0	0	0	0
2009	0%	0	0	0	0	0	0
2010	0%	0	0	0	0	0	0
2011	0%	0	0	0	0	0	0
2012	0%	0	0	0	0	0	0
2013	0%	0	0	0	0	0	0
2014	0%	0	0	0	0	0	0
2015	0%	0	0	0	0	0	0
2016	0%	0	0	0	0	0	0
2017	0%	0	0	0	0	0	0
2018	0%	0	0	0	0	0	0
2019	0%	0	0	0	0	0	0
2020	0%	0	0	0	0	0	0
2021	0%	0	0	0	0	0	0
2022	0%	0	0	0	0	0	0
2023	0%	0	0	0	0	0	0
2024	0%	0	0	0.10	281	0.001	0.04
2025	0%	0	0	0.12	330	0.001	0.05
2026	0%	0	0	0.14	393	0.001	0.06
2027	0%	0	0	0.17	439	0.001	0.07
2028	0%	0	0	0.21	526	0.001	0.08
2029	0%	0	0	0.26	632	0.002	0.10
2030	0%	0	0	0.31	743	0.002	0.12
2050	0%	0	0	0.33	872	0.003	0.14
2032	0%	0	0	0.37	1,017	0.003	0.16
2033	0%	0	0	0.43	1,176	0.004	0.18
2034	0%	0	0	0.52	1,386	0.004	0.22
2035	0%	0	0	0.62	1,619	0.005	0.25
2036	0%	0	0	0.75	1,962	0.006	0.31
2037	0%	0	0	0.89	2,328	0.007	0.37
2038	0%	0	0	1.0	2,699	0.008	0.42
2039	0%	0	0	1.2	3,137	0.009	0.49
2040	0%	0	0	1.4	3,619	0.01	0.57
2041	0%	0	0	1.5	4,155	0.01	0.65
2042	0%	0	0	1.7	4,704	0.01	0.74
2043	0%	0	0	1.8	5,184	0.01	0.81
2044	0%	0	0	1.8	5,634	0.02	0.89
2045	0%	0	0	1.7	5,643	0.02	0.89
2046	0%	0	0	1.7	5,770	0.02	0.91
2047	0%	0	0	1.5	5,397	0.01	0.85
2048	0%	0	0	1.3	5,206	0.01	0.82
2049	0%	0	0	1.2	4,978	0.01	0.78
2050	0%	0	0	0.64	2,992	0.007	0.47
2051	0%	0	0	0.22	1,226	0.004	0.19

Notes:

[1] EMFAC data shown here are adjusted by subtracting data for T7 SWCVs from corresponding data for all HHDTs as described in Appendix A. Accelerated turnover adjustments are included in calendar years 2031, 2037, 2045, and 2050 as described in Appendix A.

[2] Fleet mix percentages for each alternative HHDT technology type are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[3] Population in each model year is calculated based on the fleet mix percentages for each HHDT type and the total population in the adjusted EMFAC data.

[4] Energy consumption is calculated based on adjusted EMFAC data, using the EER for each HHDT type shown in Table A-38.

[5] Emissions from vehicles in each model year are calculated based on the fleet mix composition and the reduction in tailpipe NOx emissions achieved by each HHDT type shown in Table 3-2. Total emissions in each calendar year are calculated as the sum of tailpipe emissions across all HHDT types and all model years in each calendar year.

[6] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CA Cert. - California certified
CH_4 - methane
CO_2 - carbon dioxide
DSL - diesel
EER - energy economy ratio
EMFAC2017 - Emission Factor Model
gal - gallon
HHDT - heavy heavy duty truck
MJ - megajoule
N_2O - nitrous oxide
NG - natural gas
NO_x - oxides of nitrogen
T7 SWCV - solid waste collection vehicles
TOTEX - total exhaust

Table A-44. Upstream Emission Factors
Appendix A Tables - Scenario Analysis
Assumptions and Detailed Methodology

Upstream Emission Factors by Fuel Type (g/MJ)						
Calendar Year	Diesel		CNG		Electricity	
	NO_x	CO_2e	NO_x	CO_2e	NO_x	CO_2e
2023	0.015	25.3	0.047	17.6	0.084	75.3
2024	0.015	25.2	0.047	17.4	0.080	71.7
2025	0.015	25.2	0.047	17.3	0.076	68.2
2026	0.015	25.2	0.047	17.2	0.071	64.6
2027	0.015	25.1	0.047	17.1	0.067	61.0
2028	0.015	25.1	0.047	17.0	0.063	57.4
2029	0.015	25.1	0.047	16.9	0.059	53.8
2030	0.015	25.0	0.047	16.8	0.055	50.2
2031	0.015	25.0	0.046	16.6	0.051	46.6
2032	0.015	25.0	0.046	16.6	0.047	44.2
2033	0.015	25.0	0.046	16.5	0.042	41.8
2034	0.015	25.0	0.046	16.4	0.038	39.4
2035	0.015	24.9	0.046	16.3	0.033	36.9
2036	0.015	24.9	0.046	16.3	0.029	34.5
2037	0.014	24.9	0.046	16.2	0.024	32.1
2038	0.014	24.9	0.046	16.1	0.023	30.2
2039	0.014	24.9	0.046	16.1	0.021	28.2
2040	0.014	24.8	0.046	16.0	0.020	26.3
2041	0.014	24.8	0.046	15.9	0.018	24.4
2042	0.014	24.8	0.046	15.9	0.016	22.5
2043	0.014	24.8	0.046	15.8	0.015	20.6
2044	0.014	24.8	0.046	15.8	0.013	18.6
2045	0.014	24.8	0.046	15.7	0.012	16.7
2046	0.014	24.8	0.045	15.7	0.011	15.6
2047	0.014	24.7	0.045	15.6	0.010	14.5
2048	0.014	24.7	0.045	15.6	0.009	13.4
2049	0.014	24.7	0.045	15.6	0.008	12.2
2050	0.014	24.7	0.045	15.5	0.007	11.1

Notes:

[1]Upstream emission factors for years 2023, 2031, 2037, 2045 and 2050 were derived from CA-GREET3.0 model. These values were used to interpolate emission factors for all other years. Details regarding model inputs and assumptions are provided in Appendix A.

Abbreviations:

CA-GREET - California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
CNG - compressed natural gas
CO_2e - carbon dioxide equivalent
g - gram
MJ - megajoule
NOx - nitrogen oxides

Table A-45. Electricity Grid Mix Assumptions
Appendix A Tables - Scenario Analysis
Assumptions and Detailed Methodology

Year[1,2]	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydro-electric	Geo-thermal	Wind	Solar
2020	0.16%	45.45%	3.30%	9.05%	2.35%	12.29%	4.54%	11.46%	11.40%
2023	0.00%	47.20%	0.00%	2.32%	3.03%	9.11%	6.97%	10.03%	21.35%
2031	0.00%	28.27%	0.00%	0.32%	1.96%	9.41%	9.85%	12.29%	37.91%
2037	0.00%	19.22%	0.00%	0.03%	0.12%	7.57%	8.98%	21.34%	42.74%
2045	0.00%	9.66%	0.00%	0.00%	0.00%	6.44%	6.71%	29.65%	47.54%
2050	0.00%	6.05%	0.00%	0.00%	0.00%	5.23%	6.64%	33.98%	48.11%

Notes:

[1] California electricity grid mix assumptions for year 2020 were taken from the most recently available CEC electricity mix data for 2018. Available at: https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2019-total-system-electric-generation/2018. Accessed December 2020.

[2] Electricity grid projections out to 2050 were sourced from Energy and Environmental Economics (E3) 2018 Deep Decarbonization report commissioned by the CEC. Available at: https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf. Accessed November 2020.

Abbreviations:

CEC - California Energy Commission

Table A-46. Renewable Fuel GREET 3.0 Transportation Assumptions

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Parameter	Ramboll Assumptions	Source
RNG Pipeline Distance (mi)	1,000	CARB CA- GREET3.0 NG Pipeline Distance[1]
Tallow Transport Distance (mi)	HD Truck - 100	ANL Tallow-based Pathway in GREET[2], EDF Biodiesel in CA[3]
Renewable Diesel Transport Distance (mi)	HD Truck - 100	EDF Biodiesel in CA[3]

Notes:

[1] CA-GREET3.0 Lookup Table Pathways Technical Support Documentation. Available at: https://ww2.arb.ca.gov/sites/default/files/classic//fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: August 2020.

[2] ANL Tallow-Based Diesel Pathway in GREET. Available at: https://greet.es.anl.gov/publication-tallow-13. Accessed: August 2020.

[3] EDF Biodiesel in California. Available at: https://www.edf.org/sites/default/files/sites/default/files/content/Biodiesel%20Value%20Chain%20-%20August%202013.pdf. Accessed: January 2020.

Abbreviations:

ANL - Argonne National Laboratory
CARB - California Air Resources Board
CA - California
EDF - Environmental Defense Fund
GREET - Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
HD - heavy-duty
mi - miles
NG - natural gas
RNG - Renewable Natural Gas

Table A-47. Energy Economy Ratios and Fuel Economy

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Truck Technology	EER value[1]	Fuel Economy (mi/DGE)	Source	Description
Conventional Diesel HHDT	1	7.03	CARB ACT ISOR, Appendix H[1]	Fuel Economy of a MY2024 Diesel HHDT.
Low NOx Diesel HHDT	1	7.03	CARB LCFS Regulation[2]	Diesel HHDT EER value from CARB LCFS regulation was used to calculate the fuel economy for a Low-NOx Diesel HHDT.
Low NOx NG HHDT	0.9	6.33	CARB LCFS Regulation[2]	Spark Ignition CNG EER value from CARB LCFS regulation was used to calculate a Low NOx NG HHDT fuel economy.
BEV HHDT	3.029	21.3	CARB ACT Cost Calculator[3]	Fuel Economy of a MY2024 BEV HHDT.

Notes:

[1]EER values are relative to conventional diesel

[1]CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed November 2020

[2]LCFS Regulation, 2019. Table 5. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed November 2020.

[3]CARB ACT Cost Calculator. Available at: https://ww2.arb.ca.gov/sites/default/files/2019-05/190508tcocalc_2.xlsx. Accessed November 2020.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
CNG - compressed natural gas
DGE - diesel gallon equivalent
EER - Energy Economy Ratio
HHDT - heavy-heavy-duty truck
ISOR - Initial Statement of Reason
LDV - light duty vehicle
LCFS - Low Carbon Fuel Standard
mi - miles
MY - model year
NG - Natural Gas
NOx - nitrogen oxides

APPENDIX B TABLES
COST ANALYSIS ASSUMPTIONS AND METHODOLOGY

APPENDIX B TABLES

Table B-1. Vehicle Purchase Cost Assumptions

Technology	Purchase Cost (with tax[1])	Source	Description
Conventional Diesel Truck	$172,921	CARB ACT ISOR, Appendix H[2]	Cost of a MY2024 Class 8 Day Cab, assuming compliance with GHG Phase 2 Standards.
Federal Low-NO_x Diesel Truck	$178,623	NREL Low-NOx Diesel Cost Study[3]	The NREL Low-NOx Study, commissioned by CARB, provides a range of incremental engine and aftertreatment costs for a 12-13L Truck. For a Federal Low-NOx diesel truck, the study assumes: - 0.02 g/bhp-hr Federal NOx Regulation begins MY 2023 - 10-year useful truck life (435,000 miles) - US wide implementation Ramboll Cost Analysis adds the average of high and low incremental cost values reported in the NREL Study to the baseline cost of a conventional diesel truck as reported by the CARB ACT Cost Calculator.
CA Low-NO_x Diesel Truck	$210,876	NREL Low-NO_x Diesel Cost Study[3,4]	The NREL Low-NOx Study, commissioned by CARB, provides a range of incremental engine and aftertreatment costs for a 12-13L Truck. For a CA Low-NOx diesel truck, the study assumes: - 0.02 g/bhp hr CA NOx regulation beginning MY 2027 - extended useful truck life (15 years) - extended warranty (800,000 miles) - CA only implementation Ramboll Cost Analysis adds the average of high and low incremental cost values reported in the NREL Study to the baseline cost of a conventional diesel truck as reported by the CARB ACT Cost Calculator.
Low-NO_x NG Truck	$192,719	Port Feasibility Study[5]	Cost of a MY2018 Class 8 Drayage Truck.
2018 BEV	$569,916	CARB ACT ISOR, Appendix H[2]	Cost of a MY2018 Class 8 Truck with 510kWh battery size.
2024 BEV	$384,448	CARB ACT ISOR, Appendix H[2]	Cost of a MY2024 Class 8 Truck with 510kWh battery size. Cost projection of powertrain based on ICCT Projections[6]. Cost Projection of batteries based on Bloomberg battery projections[7] for LDVs with a five-year delay.

Notes:

[1]These purchase costs are inclusive of sales tax (8%) and Federal Excise Tax (12%).

[2]CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

[3]NREL 2020 Low-NOx Diesel Cost Study. Available at: https://www.nrel.gov/docs/fy20osti/76571.pdf. Accessed: January 2021.

[4]While the NREL Low-NOx Diesel Cost Study provides incremental engine and aftertreatment costs assuming a 0.02 g/bhp-hr Federal NOx regulation, the Ramboll total cost of ownership analysis assumes a 0.05 g/bhp-hr emission rate to calculate the total lifetime emissions of a Federal Low-NOx Truck. Please see Table B-10-1 Tailpipe Assumptions for more details.

[5]2018 Feasibility Assessment for Drayage Trucks for San Pedro Bay Ports Clean Air Action Plan, 2019. Available at: https://cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/. Accessed: January 2021.

[6]2017 ICCT ZEV Report. Available at: https://theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf. Accessed: January 2021.

[7]Bloomberg 2019 Better Batteries Report. Available at: https://www.bloomberg.com/quicktake/batteries. Accessed: January 2021.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CA - California
CARB - California Air Resources Board
g/bhp-hr - gram per brakewear horsepower hour
GHG - greenhouse gas
ICCT - International Council on Clean Transportation
ISOR - Initial Statement of Reason
kWh - kilowatt-hour
L - liter
LDV - light duty vehicle
MY - model year
NOx - nitrogen oxides
NREL - National Renewable Energy Laboratory
ZEV - zero emission vehicle

Table B-2. Charging Infrastructure Cost Assumptions

Infrastructure Item	Cost	Unit	Source	Description
Infrastructure Purchase Cost	$50,000	$/Charger	CARB ACT ISOR, Appendix H[1]	Cost for a 100kW DC Fast charger.
Infrastructure Installation and Upgrade	$55,000	$/Charger	CARB ACT ISOR, Appendix H[1] CARB ICT ISOR[2]	Infrastructure installation and upgrade estimates include the cost of trenching, cables, and transformers. These costs are not inclusive of the costs for new and/or enhanced transmission infrastructure or generation.
Infrastructure Maintenance	$415	$/year	Port Feasibility Study[3]	Annualized maintenance cost over a 10-year truck lifetime. Cost estimate includes annual inspection costs and charger replacement every 10 years.

Notes:

[1]CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: November 2020.

[2]CARB ICT ISOR. Available at: https://ww3.arb.ca.gov/regact/2018/ict2018/isor.pdf. Accessed: January 2021.

[3]2018 Feasibility Assessment for Drayage Trucks for San Pedro Bay Ports Clean Air Action Plan, 2019. Available at: https://cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/. Accessed: January 2021.

Abbreviations:

ACT - Advanced Clean Truck
CARB - California Air Resources Board
DC - direct current
ICT - Innovative Clean Transit
ISOR - Initial Statement of Reason
kW - kilowatt

Table B-3. Useful Truck Life Assumptions

Useful Truck Life[1]	Unit	Source	Description
10	years	EPA CFR Title 40 Chapter 1 Subchapter C Part 86 A5[2]	Existing EPA adopted useful truck life values for heavy heavy-duty (Class 8) engines.
435,000	miles/lifetime		
15	years	EPA Cleaner Trucks Initiative Proposed Rulemaking[3]	EPA proposed useful truck life update for heavy heavy-duty (Class 8) engines.
909,900	miles/lifetime		

Notes:

[1]Ramboll Cost Analysis conducts a total cost of ownership analysis for both a 10- and 15-year useful truck life.

[2]EPA CFR Title 40 Chapter 1 Subchapter C Part 86 A. Available at: https://www.ecfr.gov/cgi-bin/text-idx?SID=0245958e1b9e7cd2a95602f83bd51858&mc=true&node=se40.21.86_1004_62&rgn=div8. Accessed: July 2020.

[3]EPA Cleaner Trucks Initiative. Available at: https://www.govinfo.gov/content/pkg/FR-2020-01-21/pdf/2020-00542.pdf. Accessed: January 2021.

Abbreviations:

CFR - Code of Federal Regulations

EPA - United States Environmental Protection Agency

Table B-4. Vehicle Maintenance Cost Assumptions

Vehicle Type	Maintenance Cost[1] ($/mile)	Source	Description
Diesel HHDT	$0.19	CARB ACT ISOR, Appendix H[2]	Ramboll Cost Analysis assumes that Low-NOx diesel and NG HHDT trucks have the same maintenace costs as a diesel HHDT.
Low NOx Diesel HHDT	$0.19	CARB ACT ISOR, Appendix H[2]	
Low NOx NG HHDT	$0.19	CARB ACT ISOR, Appendix H[2]	
HHDT BEV	$0.14	CARB ACT ISOR, Appendix H[2]	CARB ACT ISOR assumes that HHDT BEV maintenance costs are 25% lower than diesel HHDT maintenance costs.

Notes:

[1]Maintenace costs in this table are for a Regional Class 8 tractor. These values reflects the cost of labor and parts for routine maintenance, preventative maintenance, and repairing broken components.

[2]CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
NG - natural gas
NOx - nitrogen oxides

Table B-5. Midlife Overhaul Costs Assumptions

Vehicle Type	Battery Replacement Cost	Source	Description
MY 2018 BEV	**$32,432**	CARB ACT ISOR Appendix H[1]	CARB ACT ISOR assumes that a class 8 day cab will require battery replacement in year 8 of operation. CARB uses assumptions from Bloomberg's LDV battery projections with a 5-year delay to arrive at a $/kWh battery replacement cost. CARB ACT cost calculator assumes a replacement battery size of 227kWh regardless of original vehicle battery size (510kWh). Costs reported in this table are for a 227kWh battery replacement. This assumption may underestimate the overhaul cost for BEV HHDTs.
MY 2024 BEV	**$21,773**	CARB ACT Cost Calculator[2]	

Notes:

[1] CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

[2] CARB ACT Cost Calculator. Available at: https://ww2.arb.ca.gov/sites/default/files/2019-05/190508tcocalc_2.xlsx. Accessed: Accessed: January 2021.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
kWh - kilowatt-hour
LDV - light duty vehicle
MY - model year

Table B-6. Fuel Economy Assumptions

Truck Technology	EER value[1]	Fuel Economy (mi/DGE)	Source	Description
Conventional Diesel HHDT	1	7.03	CARB ACT ISOR, Appendix H[1]	Fuel Economy of a MY2024 Diesel HHDT.
Low NOx Diesel HHDT	1	7.03	CARB LCFS Regulation[2]	Diesel HHDT EER value from CARB LCFS regulation was used to calculate the fuel economy for a Low-NOx Diesel HHDT.
Low NOx NG HHDT	0.9	6.33	CARB LCFS Regulation[2]	Spark Ignition CNG EER value from CARB LCFS regulation was used to calculate a Low NOx NG HHDT fuel economy.
BEV HHDT	3.029	21.3	CARB ACT Cost Calculator[3]	Fuel Economy of a MY2024 BEV HHDT.

Notes:

[1] EER values are relative to conventional diesel

[1] CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

[2] LCFS Regulation, 2019. Table 5. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: January 2021.

[3] CARB ACT Cost Calculator. Available at: https://ww2.arb.ca.gov/sites/default/files/2019-05/190508tcocalc_2.xlsx. Accessed: January 2021.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
CNG - compressed natural gas
DGE - diesel gallon equivalent
EER - Energy Economy Ratio
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
LDV - light duty vehicle
LCFS - Low Carbon Fuel Standard
mi - miles
MY - model year
NG - Natural Gas
NO_X - nitrogen oxides

Table B-7. Vehicle Registration Fees

Annual Registration Fees[1] ($/year)	Conventional Diesel HHDT	Federal Low-NOx Diesel HHDT	CA Low-NOx Diesel HHDT	Low-NOx NG HHDT	HHDT BEV-MY2018	HHDT BEV-MY2024
Fixed Fees[2]	$247	$247	$247	$247	$95	$95
Weight Fee[3]	$2,064	$2,064	$2,064	$2,064	$358	$358
Transportation Improvement Fee[4]	$175	$175	$175	$175	$175	$175

Notes:

[1]CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

[2]Fixed registration fees are the sum of all fees that stay constant across all vehicles. These fees vary slightly from county to county; the ones shown here are specifically for Sacramento County. Low-NOx vehicles are assumed to have the same registration fees as conventional diesel trucks.

[3]Weight fees are based on the registered weight of the vehicle. This analysis assumes at all trucks are at or above 80,000 pounds. Diesel and zero-emission trucks pay different weight fees. The annual weight fee for electric vehicles greater than 10,000 pounds is $358. Low-NOx vehicles are assumed to pay the same weight fees as conventional diesel trucks.

[4]The Transportation Improvement Fee is based on vehicle purchase cost and is the same for both diesel and zero-emission vehicles. For vehicles with a price above $60,000, the fee is $175 annually. Low-NOx vehicles are assumed to pay the same Transportation Improvement Fees.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
MY - model year
NG - Natural Gas
NO_X - nitrogen oxides

Table B-8. Vehicle License Fees

Truck Age	Market Value[1,2]	Vehicle License Fees[3,4]					
		Conventional Diesel HHDT	Federal Low-NOx Diesel HHDT	CA Low-NOx Diesel HHDT	Low NOx NG HHDT	HHDT BEV-MY2018	HHDT BEV-MY2024
1	100%	$1,124	$1,161	$1,371	$1,253	$3,704	$1,811
2	90%	$1,012	$1,045	$1,234	$1,127	$3,334	$1,630
3	80%	$899	$929	$1,097	$1,002	$2,964	$1,449
4	70%	$787	$813	$959	$877	$2,593	$1,268
5	60%	$674	$697	$822	$752	$2,223	$1,086
6	50%	$562	$581	$685	$626	$1,852	$905
7	40%	$450	$464	$548	$501	$1,482	$724
8	30%	$337	$348	$411	$376	$1,111	$543
9	25%	$281	$290	$343	$313	$926	$453
10	20%	$225	$232	$274	$251	$741	$362
11	15%	$169	$174	$206	$188	$556	$272
12	15%	$169	$174	$206	$188	$556	$272
13	15%	$169	$174	$206	$188	$556	$272
14	15%	$169	$174	$206	$188	$556	$272
15	15%	$169	$174	$206	$188	$556	$272
16	15%	$169	$174	$206	$188	$556	$272
17	15%	$169	$174	$206	$188	$556	$272
18	15%	$169	$174	$206	$188	$556	$272
19	15%	$169	$174	$206	$188	$556	$272
20	15%	$169	$174	$206	$188	$556	$272

Notes:

[1]2018 Feasibility Assessment for Drayage Trucks for San Pedro Bay Ports Clean Air Action Plan, 2019. Available at: https://cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/. Accessed: January 2021.

[2]Market value is assumed to stay constant after the 11th truck year age.

[3]CARB ACT ISOR Appendix H. Available at: https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf. Accessed: January 2021.

[4]The Vehicle License fee is calculated by multiplying the market value of the vehicle by 0.65%. Vehicle Purchase costs are reported in Table B-1

[5]Insurance cost is calculated by multiplying the market value of the vehicle by 3%. Vehicle Purchase costs are reported in Table B-1.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
MY - model year
NG - Natural Gas
NO_X - nitrogen oxides

Table B-9. Vehicle Insurance Fees

Truck Age	Market Value[1,2]	Insurance Costs[1,3]					
		Conventional Diesel HHDT	Federal Low-NOx Diesel HHDT	CA Low-NOx Diesel HHDT	Low NOx NG HHDT	HHDT BEV-MY2018	HHDT BEV-MY2024
1	100%	$5,188	$5,359	$6,326	$5,782	$17,097	$8,358
2	90%	$4,669	$4,823	$5,694	$5,203	$15,388	$7,522
3	80%	$4,150	$4,287	$5,061	$4,625	$13,678	$6,686
4	70%	$3,631	$3,751	$4,428	$4,047	$11,968	$5,850
5	60%	$3,113	$3,215	$3,796	$3,469	$10,258	$5,015
6	50%	$2,594	$2,679	$3,163	$2,891	$8,549	$4,179
7	40%	$2,075	$2,143	$2,531	$2,313	$6,839	$3,343
8	30%	$1,556	$1,608	$1,898	$1,734	$5,129	$2,507
9	25%	$1,297	$1,340	$1,582	$1,445	$4,274	$2,089
10	20%	$1,038	$1,072	$1,265	$1,156	$3,419	$1,672
11	15%	$778	$804	$949	$867	$2,565	$1,254
12	15%	$778	$804	$949	$867	$2,565	$1,254
13	15%	$778	$804	$949	$867	$2,565	$1,254
14	15%	$778	$804	$949	$867	$2,565	$1,254
15	15%	$778	$804	$949	$867	$2,565	$1,254
16	15%	$778	$804	$949	$867	$2,565	$1,254
17	15%	$778	$804	$949	$867	$2,565	$1,254
18	15%	$778	$804	$949	$867	$2,565	$1,254
19	15%	$778	$804	$949	$867	$2,565	$1,254
20	15%	$778	$804	$949	$867	$2,565	$1,254

Notes:

[1] 2018 Feasibility Assessment for Drayage Trucks for San Pedro Bay Ports Clean Air Action Plan, 2019. Available at: https://cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/. Accessed: January 2021.

[2] Market value is assumed to stay constant after the 11th truck year age.

[3] Insurance cost is calculated by multiplying the market value of the vehicle by 3%. Vehicle Purchase costs are reported in Table B-1.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
MY - model year
NG - Natural Gas
NO_X - nitrogen oxides

Table B-10. Vehicle Tailpipe Emission Assumptions

Vehicle Type	Tailpipe Emission Assumptions	
	Tailpipe NO_x	Tailpipe GHG
Conventional Diesel HHDT	Default EMFAC Output	Default EMFAC Output
Federal Low-NOx Diesel HHDT	**75% NO_X** reduction from existing conventional diesel vehicle based on 0.05 g/bhp-hr NOx certification[1]	Default EMFAC Output
California Certified Low-NOx Diesel HHDT	**90% NO_X** reduction from conventional diesel vehicle based on 0.02 g/bhp-hr NOx certification[2]	Default EMFAC Output
Low-NOx Natural Gas HHDT	**90% NO_X** reduction from conventional diesel vehicle based on 0.02 g/bhp-hr NOx certification[3]	Default EMFAC Output
Battery Electric HHDT	Zero NO_x tailpipe emissions	Zero GHG tailpipe emissions

Notes:

[1]EPA is currently developing regulations to establish a Low-NOx emission standard for HHDTs through the Cleaner Trucks Initiative. As no standards have been proposed, this analysis assumes a 0.05 g/bhp-hr standard for Federal Low-NOx Diesel HHDT. Available at: https://ww3.arb.ca.gov/board/books/2020/082720/20-8-2pres.pdf. Accessed: January 2021.

[2]CARB Low NOx Omnibus has implemented a 0.05 g/bhp-hr NOx standard for MY2024-2026 Diesel HHDT. For MY2027-2030 Diesel HHDT, the regulation implements a 0.02 g/bhp-hr NOx standard. Available at: https://ww3.arb.ca.gov/regact/2020/hdomnibuslownox/isor.pdf. Accessed: January 2021.

[3]A number of NG HHDT engines are currently certified to the CARB optional 0.02 g/bhp-hr NOx standard. Available at: https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox/about. Accessed: January 2021.

Abbreviations:

CARB - California Air Resources Board
EMFAC - Emission Estimator model
EPA - United States Environmental Protection Agency
g/bhp-hr - gram per brake horsepower hour
GHG - greenhouse gas
HHDT - heavy-heavy duty truck
MY - model year
NG - natural gas
NO_X - nitrogen oxides

Table B-11. Vehicle Tailpipe Emissions Calculations

Calendar Year	Truck Age	Tailpipe Emission Factors[1,2] (g/mile)		Tailpipe Emissions (ton/year)							
				Conventional Diesel HHDT		Federal Low-NOx HHDT		CA Low-NOx Diesel HHDT		Low NOx NG HHDT	
		NO_x	CO_2e	NO_x	CO_2e	NO_x	CO_2e	NO_x	CO_2e	NO_x	CO_2e
Tailpipe Emissions for a 10-year (435,00 miles) Useful Truck life											
2024	1	1.818	1122	0.087	53.820	0.022	53.820	0.009	53.820	0.009	53.820
2025	2	1.983	1121	0.095	53.748	0.024	53.748	0.010	53.748	0.010	53.748
2026	3	2.142	1120	0.103	53.721	0.026	53.721	0.010	53.721	0.010	53.721
2027	4	2.296	1118	0.110	53.630	0.028	53.630	0.011	53.630	0.011	53.630
2028	5	2.456	1119	0.118	53.678	0.029	53.678	0.012	53.678	0.012	53.678
2029	6	2.631	1123	0.126	53.871	0.032	53.871	0.013	53.871	0.013	53.871
2030	7	2.817	1133	0.135	54.346	0.034	54.346	0.014	54.346	0.014	54.346
2031	8	2.985	1142	0.143	54.760	0.036	54.760	0.014	54.760	0.014	54.760
2032	9	3.138	1151	0.150	55.169	0.038	55.169	0.015	55.169	0.015	55.169
2033	10	3.231	1159	0.155	55.566	0.039	55.566	0.015	55.566	0.015	55.566
Tailpipe Emissions for a 15-year (909,900 miles) Useful Truck life											
2024	1	1.818	1122	0.122	75.051	0.030	75.051	0.012	75.051	0.012	75.051
2025	2	1.983	1121	0.133	74.951	0.033	74.951	0.013	74.951	0.013	74.951
2026	3	2.142	1120	0.143	74.913	0.036	74.913	0.014	74.913	0.014	74.913
2027	4	2.296	1118	0.154	74.786	0.038	74.786	0.015	74.786	0.015	74.786
2028	5	2.456	1119	0.164	74.853	0.041	74.853	0.016	74.853	0.016	74.853
2029	6	2.631	1123	0.176	75.123	0.044	75.123	0.018	75.123	0.018	75.123
2030	7	2.817	1133	0.188	75.785	0.047	75.785	0.019	75.785	0.019	75.785
2031	8	2.985	1142	0.200	76.361	0.050	76.361	0.020	76.361	0.020	76.361
2032	9	3.138	1151	0.210	76.933	0.052	76.933	0.021	76.933	0.021	76.933
2033	10	3.231	1159	0.216	77.486	0.054	77.486	0.022	77.486	0.022	77.486
2034	11	3.323	1167	0.222	78.053	0.056	78.053	0.022	78.053	0.022	78.053
2035	12	3.401	1175	0.227	78.569	0.057	78.569	0.023	78.569	0.023	78.569
2036	13	3.434	1181	0.230	78.990	0.057	78.990	0.023	78.990	0.023	78.990
2037	14	3.455	1187	0.231	79.342	0.058	79.342	0.023	79.342	0.023	79.342
2038	15	3.484	1192	0.233	79.679	0.058	79.679	0.023	79.679	0.023	79.679

Notes:

[1] Tailpipe emission factors are estimated from EMFAC2017 output and adjusted using tailpipe emission assumptiosn provided in Table B-11.

[2] Global warming potential (GWP) of 25 and 298 for CH_4 and N_2O respectively were obtained from the IPCC Fifth Assessment Report, 2014 (AR5). Available at: https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf. Accessed: January 2021.

Abbreviations:

CH_4 - methane
CO_2e - carbon dioxide equivalent
EMFAC - Emission Estimator model
HHDT - heavy-heavy duty truck
g - gram
NG - natural gas
NO_X - nitrogen oxides
N_2O - nitrous oxide

Table B-12. Upstream Emission Factors

Upstream Emission Factors by Fuel Type (g/MJ)						
Calendar Year	Diesel		CNG		Electricity	
	NO_x	CO_2e	NO_x	CO_2e	NO_x	CO_2e
2023	0.015	25.3	0.047	17.6	0.084	75.3
2024	0.015	25.2	0.047	17.4	0.080	71.7
2025	0.015	25.2	0.047	17.3	0.076	68.2
2026	0.015	25.2	0.047	17.2	0.071	64.6
2027	0.015	25.1	0.047	17.1	0.067	61.0
2028	0.015	25.1	0.047	17.0	0.063	57.4
2029	0.015	25.1	0.047	16.9	0.059	53.8
2030	0.015	25.0	0.047	16.8	0.055	50.2
2031	0.015	25.0	0.046	16.6	0.051	46.6
2032	0.015	25.0	0.046	16.6	0.047	44.2
2033	0.015	25.0	0.046	16.5	0.042	41.8
2034	0.015	25.0	0.046	16.4	0.038	39.4
2035	0.015	24.9	0.046	16.3	0.033	36.9
2036	0.015	24.9	0.046	16.3	0.029	34.5
2037	0.014	24.9	0.046	16.2	0.024	32.1
2038	0.014	24.9	0.046	16.1	0.023	30.2
2039	0.014	24.9	0.046	16.1	0.021	28.2
2040	0.014	24.8	0.046	16.0	0.020	26.3
2041	0.014	24.8	0.046	15.9	0.018	24.4
2042	0.014	24.8	0.046	15.9	0.016	22.5
2043	0.014	24.8	0.046	15.8	0.015	20.6
2044	0.014	24.8	0.046	15.8	0.013	18.6
2045	0.014	24.8	0.046	15.7	0.012	16.7
2046	0.014	24.8	0.045	15.7	0.011	15.6
2047	0.014	24.7	0.045	15.6	0.010	14.5
2048	0.014	24.7	0.045	15.6	0.009	13.4
2049	0.014	24.7	0.045	15.6	0.008	12.2
2050	0.014	24.7	0.045	15.5	0.007	11.1

Notes:
[1] Upstream emission factors for years 2023, 2031, 2037, 2045 and 2050 were derived from CA-GREET3.0 model. Emission factors for all other years were estimated by interpolating the emission factors for these years. Details regarding model inputs and assumptions are provided in Appendix A.

Abbreviations:
CA-GREET - California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
CNG - compressed natural gas
CO_2e - carbon dioxide equivalent
g - gram
MJ - megajoule
NOx - nitrogen oxides

Table B-13. Fuel Consumption

	Conventional Diesel HHDT	Low NOx Diesel HHDT	Low NOx NG HHDT	BEV HHDT
Fuel Economy (mpDGe)	7.03	7.03	6.33	21.29
10-year (435,00 miles) Useful Truck life				
Annual Mileage[1] (mi/yr)	43,500			
Fuel Usage (DGe/yr)	6,188	6,188	6,875	2,043
Energy Consumption (MJ/yr)	832,069	832,069	924,521	274,745
15-year (909,900 miles) Useful Truck life				
Annual Mileage[1] (mi/yr)	60,660			
Fuel Usage (DGe/yr)	8,629	8,629	9,587	2,849
Energy Consumption (MJ/yr)	1,160,306	1,160,306	1,289,229	383,128

Conversion Factor:

Diesel Energy Content[2] 134 MJ/gal

Notes:

[1]Annual Mileage is calculated by dividing useful truck life mileage by the useful truck life age.

[2]LCFS Regulation, Table 4. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: January 2021.

Abbreviations:

BEV - battery electric vehicle
HHDT - heavy-heavy duty truck
mi - mile
MJ - megajoule
mpDGe - miles per diesel gallon equivalent
NG - natural gas
yr - year

Table B-14. Upstream Emissions Calculations

Year	Truck Age	Upstream Emissions[1] (ton/year)							
		Conventional Diesel HHDT		Low-NOx Diesel HHDT		Low-NOx CNG HHDT		BEV HHDT	
		Diesel		Diesel		CNG		Electricity	
		NO_x	CO_2e	NO_x	CO_2e	NO_x	CO_2e	NO_x	CO_2e
Upstream Emissions for a 10-year (435,00 miles) Useful Truck life									
2024	1	0.014	23	0.014	23	0.048	18	0.024	22
2025	2	0.014	23	0.014	23	0.048	18	0.023	21
2026	3	0.014	23	0.014	23	0.048	18	0.022	20
2027	4	0.014	23	0.014	23	0.048	17	0.020	18
2028	5	0.014	23	0.014	23	0.048	17	0.019	17
2029	6	0.014	23	0.014	23	0.048	17	0.018	16
2030	7	0.013	23	0.013	23	0.047	17	0.017	15
2031	8	0.013	23	0.013	23	0.047	17	0.015	14
2032	9	0.013	23	0.013	23	0.047	17	0.014	13
2033	10	0.013	23	0.013	23	0.047	17	0.013	13
Upstream Emissions for a 15-year (909,900 miles) Useful Truck life									
2024	1	0.019	32	0.019	32	0.067	25	0.034	30
2025	2	0.019	32	0.019	32	0.067	25	0.032	29
2026	3	0.019	32	0.019	32	0.067	24	0.030	27
2027	4	0.019	32	0.019	32	0.067	24	0.028	26
2028	5	0.019	32	0.019	32	0.066	24	0.027	24
2029	6	0.019	32	0.019	32	0.066	24	0.025	23
2030	7	0.019	32	0.019	32	0.066	24	0.023	21
2031	8	0.019	32	0.019	32	0.066	24	0.022	20
2032	9	0.019	32	0.019	32	0.066	24	0.020	19
2033	10	0.019	32	0.019	32	0.066	23	0.018	18
2034	11	0.019	32	0.019	32	0.066	23	0.016	17
2035	12	0.019	32	0.019	32	0.066	23	0.014	16
2036	13	0.019	32	0.019	32	0.065	23	0.012	15
2037	14	0.019	32	0.019	32	0.065	23	0.010	14
2038	15	0.019	32	0.019	32	0.065	23	0.010	13

Notes:

[1]Upstream emissions are calculated using upstream emission factors from Table B-13 and fuel consumption values in Table B-14.

Abbreviations:

BEV - battery electric vehicle
CNG - compressed natural gas
CO_2e - carbon dioxide equivalent
HHDT - heavy-heavy duty truck
NO_X - nitrogen oxides

Table B-15. Total Cost of Ownership 10-year Analysis Summary

Description	Units[1]	Conventional Diesel HHDT	Federal Low-NO_x Diesel HHDT	CA Low-NO_x Diesel HHDT	Low-NO_x NG HHDT	BEV- 2018[2]	BEV-2024[2]
Capital Costs[3]							
Purchase Cost	dollars	$172,921	$178,623	$210,876	$192,719	$569,916	$384,448
Charging Infrastructure	dollar/charger	--	--	--	--	$105,000	$105,000
Total Capital Cost	***dollars***	***$172,921***	***$178,623***	***$210,876***	***$192,719***	***$674,916***	***$489,448***
Operational Costs[4]							
Useful Truck Life	years	10					
Annual Mileage	miles/year	43,500					
Fuel Economy	mpDGe	7.03	7.03	7.03	6.3	21.3	21.3
Lifetime Fuel Cost	dollars	$246,057	$246,057	$246,057	$140,604	$132,820	$132,820
Maintenance Cost	dollars/mile	$0.19	$0.19	$0.19	$0.19	$0.14	$0.14
Lifetime Maintenance Cost	dollars	$82,650	$82,650	$82,650	$82,650	$61,988	$61,988
Lifetime Registration Fees	dollars	$31,211	$31,420	$32,604	$31,938	$27,210	$20,399
Lifetime Insurance Fees	dollars	$29,310	$30,277	$35,744	$32,666	$96,601	$65,164
Lifetime EV Charging Infrastructure Maintenance Cost	dollars	--	--	--	--	$4,150	$4,150
8-year Battery Overhaul Cost	dollars	--	--	--	--	$32,432	$49,442
Total Lifetime Operational Costs	***dollars***	***$389,228***	***$390,404***	***$397,055***	***$287,857***	***$355,201***	***$333,962***
Total Cost							
Total Cost of Ownership	***dollars***	***$562,149***	***$569,027***	***$607,932***	***$480,576***	***$1,030,117***	***$823,411***
Incremental Cost of Ownership	***dollars***	***Baseline***	***$6,877***	***$45,782***	***-$81,573***	***$467,967***	***$261,262***
Emissions[5]							
Total Lifetime Tailpipe Emissions							
NO_x	tons	1.2	0.31	0.12	0.12	0	0
CO_2e	tons	542	542	542	542	0	0
Total Lifetime Upstream Emissions							
NO_x	tons	0.14	0.14	0.14	0.48	0.19	0.19
CO_2e	tons	230	230	230	173	169	169
Total Lifetime Emissions Well-to-Wheels[6]							
NO_x	tons	1.4	0.44	0.26	0.60	0.19	0.19
CO_2e	metric tons	701	701	701	649	154	154
Cost Effectiveness[7]							
Cost Effectiveness (Total Lifetime Tailpipe)							
NO_x	dollar/ton	Baseline	$7,501	$41,610	-$74,139	$382,791	$213,709
CO_2e	dollar/MT	Baseline	N/A	N/A	N/A	$60	$91
Cost Effectiveness (Total Lifetime Well-to-Wheels[6])							
NO_x	dollar/ton	Baseline	$7,501	$41,610	-$107,460	$399,145	$222,839
CO_2e	dollar/MT	Baseline	N/A	N/A	-$1,561	$855	$478

Notes:

[1] All Costs are in 2018 dollars.

[2] BEV-2018 refers to a MY2018 HHDT. All other HHDTs assessed are MY2024 vehicles. For more details please see Table B-1.

[3] Refer to Table B-1 and Table B-2 for details on capital cost assumptions.

[4] Refer to Tables B-4 through Table B-10 for details on operational cost assumptions.

[5] Refer to Tables B-11 through B-15 for details on emission calculations and assumptions.

[6] Well-to-Wheels emissions represent the sum of vehicle tailpipe emissions and upstream emissions.

[7] Cost effectiveness is calculated by dividing the incremental TCO of a vehicle (compared to a conventional diesel HHDT) by the total lifetime emissions reductions (compared to that of a conventional diesel HHDT). A negative cost effectiveness occurs when the cost of the vehicle is less than that of a baseline conventional diesel HHDT or when lifetime emissions of the vehicle is more than the baseline conventional diesel HHDT.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CA - California
CARB - California Air Resources Board
CO_2e - carbon dioxide equivalent
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
kWh - kilowatt hour
LCFS - Low Carbon Fuel Standard
mpDGe - miles per diesel gallon equivalent
MT - Metric Ton
MY - model year
NG - natural gas
NOx - nitrogen oxides
TCO - total cost of ownership

Table B-16. Total Cost of Ownership 15-year Analysis Summary

Description	Units[1]	Conventional Diesel HHDT	Federal Low-NO_x Diesel HHDT	CA Low-NO_x Diesel HHDT	Low-NO_x NG HHDT	BEV- 2018[2]	BEV-2024[2]
Capital Costs[3]							
Purchase Cost	dollars	$172,921	$178,623	$210,876	$192,719	$569,916	$384,448
Charging Infrastructure	dollar/Charger	--	--	--	--	$105,000	$105,000
Total Capital Cost	***dollars***	***$172,921***	***$178,623***	***$210,876***	***$192,719***	***$674,916***	***$489,448***
Operational Costs[4]							
Useful Truck Life	years	15					
Annual Mileage	miles/year	60,660					
Fuel Economy	mpDGe	7.03	7.03	7.03	6.3	21.3	21.3
Lifetime Fuel Cost	dollars	$534,549	$534,549	$534,549	$301,837	$280,943	$280,943
Maintenance Cost	dollars/mile	$0.19	$0.19	$0.19	$0.19	$0.14	$0.14
Lifetime Maintenance Cost	dollars	$172,881	$172,881	$172,881	$172,881	$129,661	$129,661
Lifetime Registration Fees	dollars	$44,484	$44,721	$46,062	$45,307	$33,129	$25,413
Lifetime Insurance Fees	dollars	$33,201	$34,296	$40,488	$37,002	$109,424	$73,814
Lifetime EV Charging Infrastructure Maintenance Cost	dollars	--	--	--	--	$6,225	$6,225
8-year Battery Overhaul Cost	dollars	--	--	--	--	$32,432	$49,442
Total Lifetime Operational Costs	***dollars***	***$785,114***	***$786,446***	***$793,980***	***$557,028***	***$591,813***	***$565,498***
Total Cost							
Total Cost of Ownership	***dollars***	***$958,035***	***$965,069***	***$1,004,857***	***$749,747***	***$1,266,729***	***$1,054,946***
Incremental Cost of Ownership	***dollars***	***Baseline***	***$7,033***	***$46,821***	***-$208,289***	***$308,694***	***$96,911***
Emissions[5]							
Total Lifetime Tailpipe Emissions							
NO_x	tons	2.8	0.71	0.28	0.28	0	0
CO_2e	tons	1151	1151	1151	1151	0	0
Total Lifetime Upstream Emissions							
NO_x	tons	0.28	0.28	0.28	0.99	0.32	0.32
CO_2e	tons	480	480	480	356	309	309
Total Lifetime Emissions Well-to-Wheels[6]							
NO_x	tons	3.1	0.99	0.57	1.28	0.32	0.32
CO_2e	metric tons	1480	1480	1480	1367	281	281
Cost Effectiveness[7]							
Cost Effectiveness (Total Lifetime Tailpipe)							
NO_x	dollar/ton	Baseline	$3,293	$18,267	-$81,264	$108,394	$34,029
CO_2e	dollar/MT	Baseline	N/A	N/A	N/A	$514	$43
Cost Effectiveness (Total Lifetime Well-to-Wheels)[6]							
NO_x	dollar/ton	Baseline	$3,293	$18,267	-$112,410	$109,901	$34,502
CO_2e	dollar/MT	Baseline	N/A	N/A	-$1,850	$257	$81

Notes:

[1] All Costs are in 2018 dollars.

[2] BEV-2018 refers to a MY2018 HHDT. All other HHDTs assessed are MY2024 vehicles. For more details please see Table B-1.

[3] Refer to Table B-1 and Table B-2 for details on capital cost assumptions.

[4] Refer to Tables B-4 through Table B-10 for details on operational cost assumptions.

[5] Refer to Tables B-11 through B-15 for details on emission calculations and assumptions.

[6] Well-to-Wheels emissions represent the sum of vehicle tailpipe emissions and upstream emissions.

[7] Cost effectiveness is calculated by dividing the incremental TCO of a vehicle (compared to a conventional diesel HHDT) by the total lifetime emissions reductions (compared to that of a conventional diesel HHDT). A negative cost effectiveness occurs when the cost of the vehicle is less than that of a baseline conventional diesel HHDT or when lifetime emissions of the vehicle is more than the baseline conventional diesel HHDT.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CA - California
CARB - California Air Resources Board
CO_2e - carbon dioxide equivalent
HHDT - heavy-heavy duty truck
ISOR - Initial Statement of Reason
kWh - kilowatt hour
LCFS - Low Carbon Fuel Standard
mpDGe - miles per diesel gallon equivalent
MT - Metric Ton
MY - model year
NG - natural gas
NOx - nitrogen oxides
TCO - total cost of ownership

Table B-17. LCFS Revenue Estimation

CARB LCFS Credit Projections[1]	Units	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Electricity	$/kWh	$0.12	$0.12	$0.12	$0.12	$0.12	$0.11	$0.11	$0.11	$0.11	$0.11	$0.11	$0.11	$0.11	$0.11	$0.11
	$/DGE	$4.65	$4.56	$4.48	$4.39	$4.31	$4.22	$4.14	$4.14	$4.14	$4.14	$4.14	$4.14	$4.14	$4.14	$4.14

Potential Truck Lifetime LCFS Revenue[2] ($/HHDT)	
BEV HHDT- 10-year Useful Life	$88,210
BEV HHDT- 15-year Useful Life	$181,986

Notes:

[1]CARB ACT Cost Calculator. Available at: https://ww2.arb.ca.gov/sites/default/files/2019-05/190508tcocalc_2.xlsx. Accessed: January 2021.

[2]Ramboll has calculated the potential LCFS revenue for BEVs across the truck lifetime using credit price projections from the ACT Cost Calculator and electricity usage assumptions detailed in Table B-13. This calculation is for illustrative purposes and assumes that the BEV HHDT owner and the BEV charging infrastructure owner are the same entity. This entity would generate credits from the LCFS program through charging of the BEV HHDT. Ramboll has not included LCFS revenue in the TCO analysis given uncertainties in future market conditions and availability of credit deficits in the LCFS program in future years.

Abbreviations:

ACT - Advanced Clean Truck
BEV - battery electric vehicle
CARB - California Air Resources Board
DGe - diesel gallon equivalent
HHDT - heavy-heavy duty truck
kWh - kilowatt hour
LCFS - Low Carbon Fuel Standard
TCO - total cost of ownership

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May 31, 2022

(Submitted via the ISOR Comment Submittal Form and by email to cleancars@arb.ca.gov)

Advanced Clean Cars
California Air Resources Board
1001 I Street,
Sacramento, CA 95814

Re: Comments on Advanced Clean Cars II Regulation Initial Statement of Reasons (ISOR) Documents

The Western States Petroleum Association (WSPA), the American Fuel & Petrochemical Manufacturers (AFPM), and the California Independent Petroleum Association (CIPA) (collectively "the Associations") appreciate the opportunity to comment on the ISOR documents released by the California Air Resources Board (CARB) for the proposed Advanced Clean Cars II (ACC II) Regulation. WSPA is a non-profit trade association that represents companies that explore for, produce, refine, transport and market petroleum, petroleum products, natural gas, and other energy supplies in California and four other western states. It has been an active participant in air quality planning issues for over 30 years. AFPM is a national trade association representing nearly all U.S. refining and petrochemical manufacturing capacity. AFPM members support more than three million quality jobs, contribute to our economic and national security, and enable the production of thousands of vital products used by families and businesses throughout the U.S. AFPM members are also leaders in producing lower carbon fuels, such as renewable diesel and sustainable aviation fuel. The California Independent Petroleum Association (CIPA) represents 300 oil and gas producers, service and supply companies, and royalty owners who operate in California. CIPA's members proudly employ thousands of highly trained and well-paid California residents who safely and responsibly operate critical energy infrastructure under the world's most stringent public health and environmental standards. CIPA's natural gas producer-members deliver the energy necessary to power our homes and businesses, fuel our transportation, power our healthcare services and create thousands of products that shape our modern lives.

Our members form the backbone of California's economy, providing jobs, fueling air, road, and marine transport, and supplying necessary energy to the manufacturing and agriculture sectors. Our industry generates more than $152 billion in total economic output, and make significant fiscal contributions to California's state and local governments, including more than $21 billion in state and local tax revenues, $11 billion in sales taxes, $7 billion in property taxes, and $1 billion in income taxes.

While the economic impact numbers are compelling, our industry's greatest asset and contribution to the state's economy are the more than 360,000 hard-working women and men with careers providing affordable, reliable energy in California. We produce 42 million gallons of gasoline and 10 million gallons a day of diesel to support the State's 35 million registered vehicles. All these contributions to the state occur while our members continue to lower the carbon intensity of their fuels consistent with the low carbon fuel standard (LCFS) program and spur investment in emission reduction technologies and renewable fuels. In fact, 82 percent of recently announced investments in renewable diesel were made by AFPM members, including several projects in California.

The Associations believe that Californians should have the freedom to choose the type of vehicle technology that best fits their personal needs based on purpose, affordability, availability, and lifestyle choices. Battery electric vehicles (BEV) currently are and will likely continue to make up a growing portion of the Light Duty Vehicle (LDV) fleet in California. However, the Associations have significant concerns regarding the ISOR and the current ACC II proposal. The Executive Order N-79-20[1] set a goal for the State that 100 percent of in-state sales of new passenger cars and trucks will be zero-emission by 2035 **to the extent consistent with State and federal law**. The current proposal is not consistent with the Executive Order (See **Comment A.3** and **A.4** in **Attachment A)**. The Executive Order also acknowledged that without coordinated action by multiple other agencies to mitigate their impacts, implementing these targets will have profound negative consequences for low-income and working-class Californians. These impacts have not been fully identified, nor have they been mitigated. The proposed sales mandate conflicts with the purpose and scope of the statutes that authorize the mobile source regulations and govern the rulemaking process.

A summary of our key comments on the ACC II proposal is provided below with additional details in **Attachment A** (Legal Comments) and **Attachment B** (Technical Comments):

1. **CARB must set a technology neutral performance-based standard rather than the Zero Emission Vehicle (ZEV) mandate that is currently proposed in the ACC II regulation. This performance standard must consider the life cycle emissions of vehicles and fuels to ensure that sufficient greenhouse gas (GHG) emissions reductions are achieved by this sector.**

Under Government Code Section 11346.2(b)(4)(A), when CARB proposes a regulation that would mandate the use of specific technologies or equipment, or prescribe specific actions or procedures, it must consider performance standards as an alternative (See **Comment A.4 in Attachment A** for further details). The Proposed ACC II Regulation is presented as a performance standard by CARB. CARB argues in the ISOR at page 180 that no specific technology is mandated, contradicting the draft regulation that proposes a ZEV sales mandate

[1] Executive Order N-79-20. Available at: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf. Accessed: May 2022.

for passenger cars and light-duty trucks beginning at 35% for 2026 model year and ramping up to 100% for the 2035 model year and beyond. This is not a performance standard; it is a technology mandate.

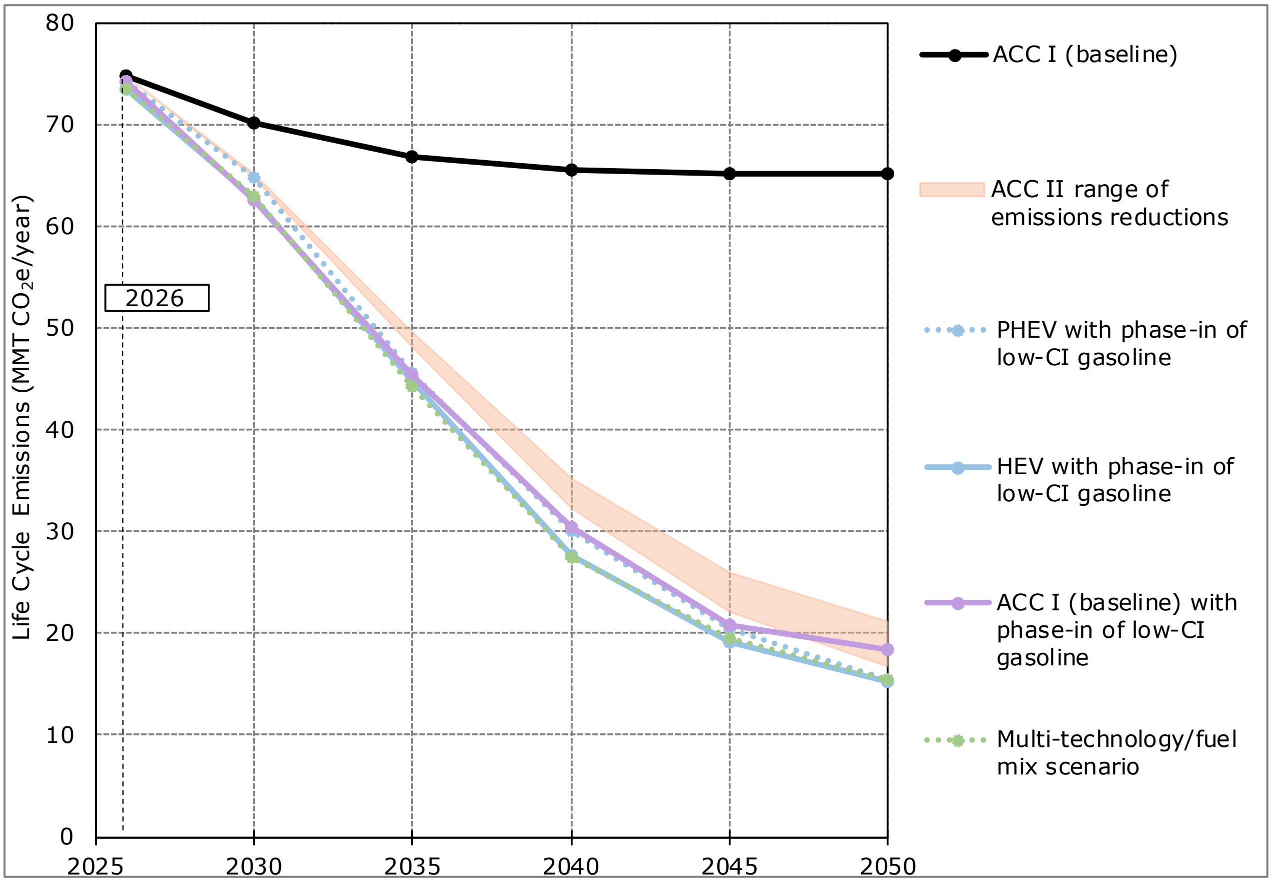
Despite multiple comments by many stakeholders, including the Associations, over the last two years, CARB has explicitly included ZEV technology mandates in its ACC II and Advanced Clean Fleets (ACF) proposals, without the necessary analyses to justify the choice of a sales mandate over a performance-based standard. CARB has even failed to analyze the full environmental effects of such a sales mandate under the proposed ACC II regulation.

To provide some of this analysis, WSPA contracted with Ramboll to produce a technology neutral study of Light Duty Automobiles (LDA) to analyze the full life cycle GHG emissions of a broad range of alternative technologies and fuels ("Ramboll LDA Study"). This study attached as **Attachment C** conclusively shows that performance standards could be an alternative to a ZEV mandate (See **Comment B.2 in Attachment B** for further details).

The Ramboll LDA Study shows that a gradual transition to low carbon intensity (CI) gasoline with current vehicle technologies (represented by the purple line in **Figure 1**) could achieve similar life cycle GHG emissions as the current ACC II proposal (represented by the pink shaded region in **Figure 1**). Importantly, GHG emissions associated with zero emission vehicles are not zero. In fact, the GHG emissions from producing battery electric vehicles (BEVs) (the "vehicle cycle") is *significantly higher* than other vehicle technology types (see **Comment 3** for additional details). The failure to analyze these real world GHG emissions is significant and distorts the claimed benefits attributed to these vehicles.

Other technologies also achieve similar or lower emissions on a life cycle basis compared to the ACC II proposal. These include hybrid electric vehicles (HEVs) coupled with low-CI fuel (represented by the blue solid line), plug-in electric hybrid vehicles (PHEVs) coupled with low-CI fuels (represented by the blue dotted line), and a combination of HEVs, PHEVs, and BEVs with low-CI fuels (represented by the green dotted line).

Figure 1: Life Cycle Emissions for Key Scenarios in the Ramboll LDA Study
California Light Duty Automobile Fleet (2026 to 2050)



CARB is therefore required to conduct these studies and consider these performance standards as an alternative to the ACC II ZEV mandate, where the alternatives better meet the other Administrative Procedures Act (APA), Office of Administrative Law (OAL) regulations and Health & Safety Code (HSC) requirements. CARB should not move forward with the ACC II ZEV mandate as it is currently proposed but instead should draft a technology-neutral performance-based standard based on the life cycle emissions of LDVs.

2. The ACC II proposal is contrary to Executive Order N-79-20 because it is not consistent with State law. The proposal continues to have severe deficiencies and omissions in the analysis that are contrary to APA and the HSC Code requirements.

There are numerous deficiencies and/or omissions in the required analyses, including but not limited to those below, that must be addressed before CARB takes action on the proposed ACC II mandates.

- Inadequate Demonstration of Achievability: CARB must perform a complete and sufficient assessment of the technological feasibility of the ACC II ZEV mandates including but not limited to the assessment of mineral resource availability, impacts to the California electric grid, application of ZEVs to long-distance use cases. CARB must also consider consumer behavior and acceptance rates for ZEV, which is critical to evaluating achievability of the

ACC II proposal. See **Comment A.2** in **Attachment A** and **Comments B.4**, **B.5**, **B.10**, **B.11**, and **B.12** in **Attachment B**.

- Incomplete Cost Assessment: CARB must perform a complete and sufficient assessment of the economic impacts of the ACC II mandates to fully assess the impact on California's economy. This assessment should account for the costs associated with upgrades to the California grid infrastructure (new and upgraded generation, transmission, and distribution) and the costs associated with the installation of public and workplace EV chargers. It should also evaluate impacts on electricity, gasoline, and diesel rates. See **Comment A.1** in **Attachment A** and **Comments B.6** and **B.7** in **Attachment B** for further details.
- Inadequate Environmental Assessment: CARB has not fully or adequately assessed the impacts of the proposed ACC II regulation on GHG emissions, the California electric grid, liquid fuels supply chain, critical mineral supply chain, vehicle manufacturing facilities, public services, utilities, and service systems. See **Comment A.6** in **Attachment A,** and **Comments B.3**, **B.4**, **B.5**, **B.8**, **B.9**, **B.13**, **B.14**, and **B.15** in **Attachment B**.
- Inadequate Alternatives Analyses: CARB has not fully or adequately evaluated or analyzed a technology neutral performance-based standard that would all low-carbon fuel and engine technologies to compete with ZEVs in their alternative analyses presented in the Environmental Assessment (EA) and the Standardized Regulatory Impact Assessment (SRIA) for the proposed ACC II. See **Comment A.6** in **Attachment A** and **Comments B.1** and **B.2** in **Attachment B** for further details.

3. CARB must incorporate life cycle emissions from ZEV in evaluating the proposed ACC II regulation.

CARB has failed to analyze the full life cycle impacts of ZEVs, which precludes a true technology-neutral comparison and overestimates ACC II GHG reductions. **Figure 2** shows the limited scope of the ACC II GHG analysis (see **Comment B.3** in **Attachment B** for further details).

CARB has not quantified vehicle cycle emissions[2] in the ACC II ISOR. They must be included due to the large differences in these emissions between ZEVs and internal combustion engine vehicles (ICEVs). As shown in **Figure 3** below, the Ramboll LDA Study found that the vehicle cycle emissions for a model year 2026 BEV could be ~167% higher than an ICEV.

2 Emissions associated with vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling.

Figure 2. CARB ACC II Emissions Assessment Scope[3]

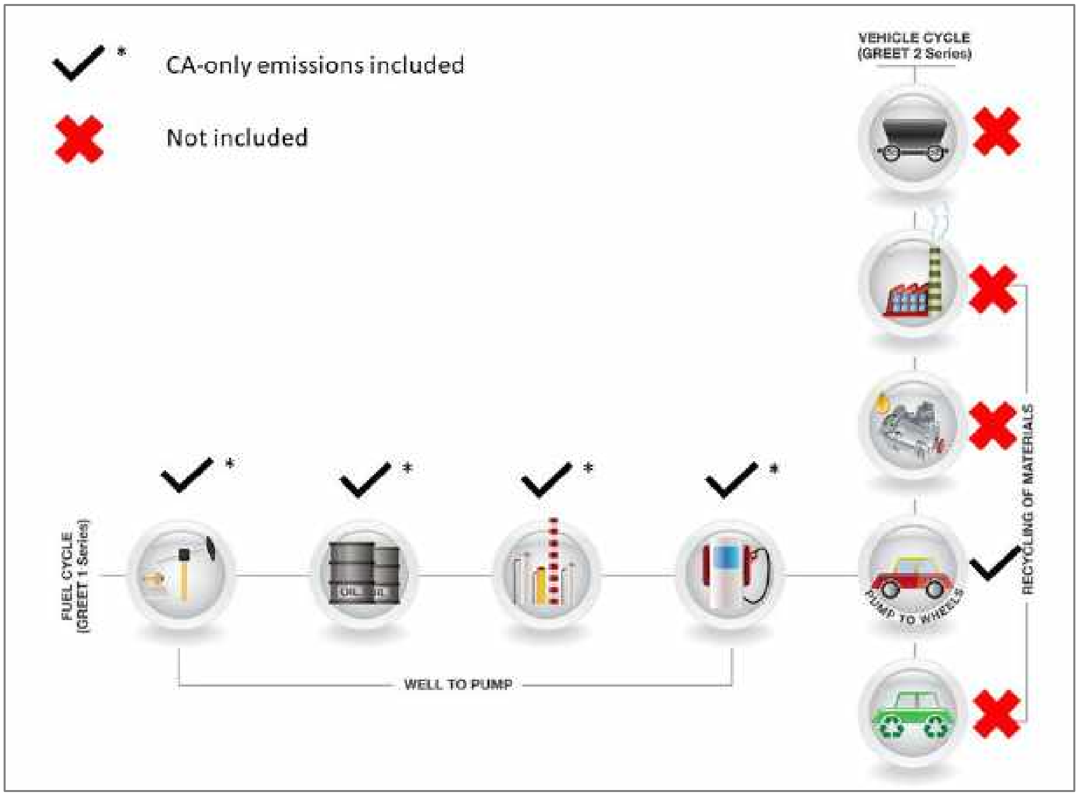
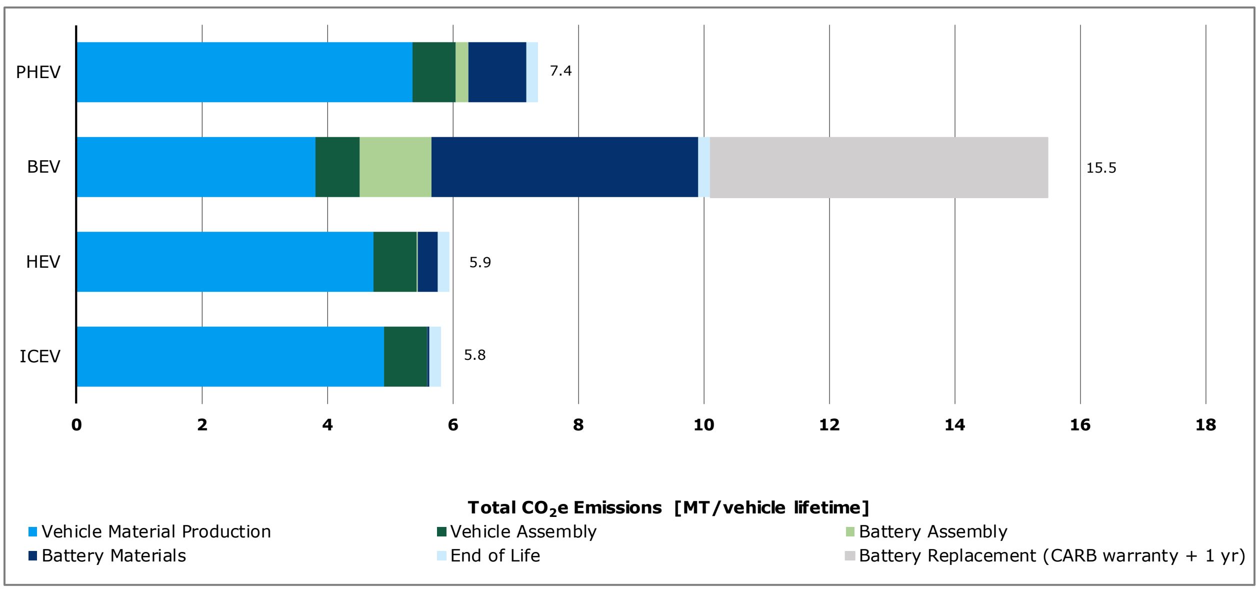


Figure 3: Vehicle Cycle GHG Emission Factors for Different Vehicle Technologies



CARB has performed no life cycle emissions analysis for ZEVs and thereby failed to adequately meet the requirements of HSC Sections 43018.5 and 57005 (see **Comment A.1.3 in**

3 GREET Model Home Page. Available at: https://greet.es.anl.gov/. Accessed: May 2022. Checkmark and X annotations by Ramboll on behalf of the Associations.

Attachment A for further details). Highly efficient low emission vehicles, which impose significantly fewer infrastructure expenses, will achieve substantial GHG emissions reductions on a faster timeline.

CARB must, therefore, update its emission analysis to include the full life cycle of the vehicle/fuel technologies included in the ACC II proposal, to understand and present the actual implications of the regulation for public review and comment, as required by law.

4. CARB must add provisions to the regulation, including periodic program reviews and program adjustments, to ensure cost containment.

CARB must also modify the ZEV mandate to include cost containment measures to protect California's economy. CARB includes cost containment measures in its other regulations, including its LCFS and GHG Cap-and-Trade programs. These measures should include:

- Annual CARB reviews and reports to the legislature of ZEV market conditions, barriers to ZEV deployment and cost to consumers, including
  - Manufacturing constraints resulting from limited critical mineral resources (see **Comment A.2 in Attachment A** and **Comment B.13 in Attachment B**)
  - Lack of affordability for purchase and use ZEVs (see **Comment A.1.2 in Attachment A** and **Comments B.9 and B.10 in Attachment B**)
  - Insufficient charging infrastructure, particularly in rural areas (see **Comment A.1.2 in Attachment A**)
  - Lower sales rates due to reluctant customer adoption (see **Comment B.12 in Attachment B**)
  - Cost of electricity (see **Comment A.1.2.** in **Attachment A**)
- Required adjustments to the program based on the review findings.

Conclusion

CARB must conduct a meaningful public notice and comment process for its complex ACC II ZEV mandate. There are significant technical, economic, and legal facts and analysis that CARB has ignored in its process, in violation of the law. CARB should address these process and analysis deficiencies by conducting technical working groups to foster stakeholder participation in scenario development and assessment. It should workshop revised ACC II language before submitting it to its Board for consideration.

Multi-technology pathways can help the state achieve faster and more certain emission reductions while expanding ways to reduce greenhouse gas emissions, to comply with the requirements of Government Code Section 11346.2(b)(4)(A). CARB should evaluate and propose performance standards as an alternative to the proposed ACC II ZEV mandate.

Thank you for the consideration of our comments. The Associations would welcome the opportunity to discuss these comments and recommendations in more detail with you. Please feel free to contact us at tderivi@wspa.org, jverburg@wspa.org, sellinghouse@wspa.org, DThoren@afpm.org, and rock@cipa.org with any questions or concerns.

Sincerely,

Tanya DeRivi	Don Thoren	Rock Zierman
Vice President	Vice President	Chief Executive Officer
Climate Policy	State & Local Outreach	
WSPA	AFPM American Fuel & Petrochemical Manufacturers	CIPA

cc: Joshua Cunningham – Branch Chief, Transportation Systems Regulations and Technology Branch – California Air Resources Board

Jim Verburg – Director, Fuels – Western States Petroleum Association

Sofie Ellinghouse – Vice President, General Counsel and Corporate Secretary – Western States Petroleum Association

Attachment A: Legal Comments

Attachment B: Technical Comments

Attachment C: List of Previous WSPA Comments on the Proposed ACC II Regulation

Attachment D: “Multi-Technology Pathways To Achieve California’s Greenhouse Gas Goals: Light-Duty Auto Case Study” by Ramboll dated May 31, 2022

Attachment E: “Impact of Advanced Clean Cars II (Internal Combustion Engine Ban) Regulation on California Businesses” by Capitol Matrix Consulting dated May 17, 2022

Attachment F: “Distributional Impacts of the Advanced Clean Cars II (Internal Combustion Engine Ban) Regulatory Proposal” by Capitol Matrix Consulting dated May 26, 2022

ATTACHMENT A
Legal Comments

Comments

CARB's ACC II ZEV mandate centers around achieving 100% zero emission vehicle (ZEV) or plug-in hybrid electric vehicle (PHEV) sales in California by model year 2035. This unprecedented mandate is not supported by a demonstration of its technological and economic feasibility. Yet, these unsupported mandates necessitate the complete electrification of the transportation sector, forcing the phase-out of oil and gas production and refinery industries. CARB lacks authority to promulgate sweeping regulations that would exchange our existing transportation system for another, with unintended and far-reaching consequences across a broad range of environmental, economic, and social issues. First and foremost, the ACC II Program is preempted by federal law and is impermissible under the California Constitution. Even if allowed, legislative delegation has its limits— if CARB wishes to push past these limits, it must return to the legislature for additional authorizations. Further, even if the legislature delegated transformative regulatory authority to CARB (which it did not), CARB has failed to meet the express statutory requirements for exercising such authority. Indeed, if CARB evaluated all the economic, technical, and environmental impacts required by statute, CARB could not reasonably finalize the ACC II Program.

A.1 CARB must perform a complete and sufficient assessment of economic impacts resulting from its ZEV targets.

CARB must perform a complete and sufficient assessment of economic impacts resulting from rapid electrification of the transportation sector. The provisions of the California Administrative Procedures Act (APA) and the California Health & Safety Code (HSC), and their implementing regulations, that govern CARB's regulatory authority require CARB to consider the economic impacts associated with any rulemaking proposal. These also require CARB to consider potential impacts to California's workers, businesses, and greater economy.[4] CARB claims these provisions as authorizing ACC II,[5] yet fails to comply with the provisions' mandates to conduct a robust economic analysis.

Specifically, the APA and HSC, and implementing regulations require CARB to assess:

- HSC §§ 43101, 43018.5 and APA § 11346.3 – Impacts to the state's economy, including specific evaluation of the following:
  - The creation of jobs within the state;
  - The creation of new businesses or the elimination of existing businesses within the state;
  - The expansion of businesses currently doing business within the state;
  - The ability of businesses in the state to compete with businesses in other states;
  - The ability of the state to maintain and attract businesses in communities with the most significant exposure to air contaminants, localized air contaminants, or both, including,

4 *See John R. Lawson Rock & Oil, Inc. v. State Air Res. Bd.*, 20 Cal. App. 5th 77, 114 (2018) (supporting a "broad reading of the required analysis").
5 *See* ISOR at 11-12, 70, 73, 77, 134, 183.

but not limited to, communities with minority populations or low-income populations, or both;

- The automobile workers and affiliated businesses in the state; and
- The benefits of the regulation to the health and welfare of California residents, worker safety, and the state's environment;

- HSC § 57005 – Less costly but equally effective alternatives to ACC II;
- APA § 11346.5(a)(7) – Adverse economic impacts on California business enterprises and individuals, including the ability of California businesses to compete with businesses in other states;
- APA § 11346.5(a)(7)(A) – The specific types of businesses that would be affected by the proposal; and
- HSC § 38562(b)(8) – The potential for leakage.

While the ISOR is a preliminary assessment, it still must take into account fact-based analyses based on information and impacts currently known to CARB.[6] Importantly, CARB's analysis cannot "ignore evidence of impacts to specific segments of businesses already doing business in California."[7] As a recent decision emphasized, "[i]f the Board's proposed regulatory amendments place[s] the state's thumb on the scale for one group of in-state businesses over another, it need[s] to consider that impact."[8] CARB notes in its ISOR that "[t]he Executive Officer has made an initial determination that the proposed regulatory action would not have a significant statewide adverse economic impact directly affecting businesses, including the ability of California businesses to compete with businesses in other state[s], or on representative private persons."[9] This conclusion is not supported by CARB's Standardized Regulatory Impact Analysis (SRIA) which overlooks key facts, including significant costs and other key impacts stemming from the forced electrification of the transportation sector.

CARB's economic analysis is deficient in several respects. First, CARB does not consider any competitive impacts to oil and gas production and refinery businesses in the state, nor to any of the numerous other businesses related to the petroleum industry (e.g., storage terminals, asphalt production, lubricants, and others). In assessing competitive advantage or disadvantage in its SRIA, CARB considers only the potential advantage to certain vehicle manufacturers as a result of already producing ZEVs.[10] This analysis completely overlooks the blatant "thumb on the scale" that ACC II will place in favor of the electricity sector as compared to oil and gas producers and refineries by forcing electrification of the transportation sector.

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6 *See California Ass'n of Med. Prods. Suppliers v. Maxwell-Jolly*, 199 Cal. App. 4th 286, 304–05 (2011); W. States Petroleum Ass'n v. Bd. of Equalization, 57 Cal. 4th 401, 428 (2013).
7 *John R. Lawson Rock & Oil, Inc. v. State Air Res. Bd.*, 20 Cal. App. 5th 77, 115 (2018).
8 *Id.*
9 ISOR at 172.
10 CARB, *Standardized Regulatory Impact Assessment (SRIA)*, at 129 (Jan. 26, 2022). Available at: https://dof.ca.gov/wp-content/uploads/Forecasting/Economics/Documents/ACCII-SRIA.pdf. Accessed: May 2022.

This analysis also overlooks potential competitive disadvantages to California businesses as compared to businesses in other states.[11]

Second, CARB fails to consider the leakage potential of its ZEV proposal, based on an accurate life cycle analysis of the greenhouse gas (GHG) emissions associated with electric vehicles and associated infrastructure, as well as residual demand for liquid fuels for internal combustion engine vehicles (ICEV) remaining in 2035 and beyond. CARB has a responsibility to minimize the "leakage" potential of any regulatory activities.[12] As part of this responsibility, CARB must analyze the potential for emissions reduction activities in the state to be offset by an equivalent or greater increase in GHG emissions outside the state. This analysis necessarily requires estimating emissions impacts outside the state, including how higher in-state power sector costs would drive greater economic investment outside of California, potentially resulting in increased emissions outside of the state, which CARB has failed to do. CARB acknowledges in its ISOR that "ICEVs will remain in use on California's roads well beyond 2035,"[13] but fails to account for the possibility that competitive disadvantages to California oil and gas production and refinery businesses will either drive these businesses out of state or force these businesses to shut down, requiring California to import petroleum or refined petroleum products to meet remaining demand.[14] Moreover, the loss of public funds by way of gas taxes is not factored into the economic analysis and should be.

Finally, despite CARB's access to ample information related to the economic impacts of electrification and existing strains on California's grid, CARB failed to address these impacts, and instead constrained its analysis to a narrow consideration of direct costs centered around vehicle manufacturing and ownership.[15] CARB's SRIA concludes that only vehicle manufacturers are directly affected by the proposed ACC II program,[16] which fails to account for extensive economic impacts stemming from the electrification of the transportation sector, discussed in detail below. This assessment is therefore insufficient to fulfill CARB's legal duty to broadly consider economic impacts.

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11 For example, businesses would face higher capital investment in vehicles, reduced fleet utilization from recharging, and higher utility rates, among other challenges. Certain businesses, particularly small businesses in rural areas, would bear disproportionate impacts, as detailed in Capitol Matrix Consulting's analysis at Appendix F.

12 HSC § 38562(b)(8).

13 ISOR at 12.

14 Importantly, refineries are long-cycle investments that require advanced planning—owners and operators will make capital decisions in the coming years about investments to serve markets 10 years from now. Under CARB's proposed program, refineries operating in California may consider this trend toward phase-out and determine that a long-term capital investment is not warranted. If the ZEV market does not materialize as anticipated, ACC II may shutter refinery operations needed to serve continued demand for liquid fuels based on incompatibility with long-term planning needs for these businesses.

15 *See* SRIA at 98.

16 *See Major Regulations Standardized Regulatory Impact Assessment Summary*, State of California Department of Finance (Jan. 21. 2022). Available at: https://dof.ca.gov/wp-content/uploads/Forecasting/Economics/Documents/Summary-ACCII-SRIA.pdf. Accessed: May 2022.

A.1.1 CARB must consider grid reliability impacts from the electrification of the transportation sector.

As part of its evaluation of potential economic impacts to the welfare of California residents and in-state businesses, CARB must assess grid reliability impacts stemming from ACC II's forced electrification of the transportation sector.[17]

California already faces unresolved grid reliability issues that will be exacerbated by ACC II's ZEV targets and the resulting increases in electricity demand. During a heatwave in August 2020, nearly half a million Californians lost power. The California Independent System Operator's (CAISO) root cause analysis of these rotating outages identified three major causal factors, including:

- "The climate change-induced extreme heat wave across the western United States resulted in demand for electricity exceeding existing electricity resource adequacy (RA) and planning targets";
- "In transitioning to a reliable, clean, and affordable resource mix, resource planning targets have not kept pace to ensure sufficient resources that can be relied upon to meet demand in the early evening hours. This made balancing demand and supply more challenging during the extreme heat wave;"
- "Some practices in the day-ahead energy market exacerbated the supply challenges under highly stressed conditions."[18]

Recent studies reflect that factors affecting grid reliability are predicted to increase in future years. For example, a recent report by the California Legislative Analyst's Office indicates that California is expected to experience higher average temperatures; more frequent, intense, and prolonged heatwaves; and a greater number of extreme heat days due to climate change.[19] As these increasingly frequent extreme weather events increase demand for electricity, existing supply shortages will also worsen.[20] According to CAISO's 2021 Summer Loads & Resources Assessment,[21] 2021 faced "potential challenges in meeting demand during extreme heat waves … [which] affect a substantial portion of the Western Interconnection and cause simultaneously high loads across the West … reduc[ing] the availability of imports into the ISO balancing authority area." As recently as July 30, 2021, Governor Gavin Newsom issued an emergency

17 These impacts also have implications for cybersecurity, as discussed at Section A.7.

18 *See* CPUC, *2020 Resource Adequacy Report* (Apr. 2022). Available at: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/resource-adequacy-homepage/2020_ra_report-revised.pdf. Accessed: May 2022.

19 Legislative Analyst's Office, *Climate Change Impacts Across California* (Apr. 5, 2022). Available at: https://lao.ca.gov/Publications/Report/4575. Accessed: May 2022.

20 Governor Newsom recently requested federal funding assistance to facilitate continued operations at the Diablo Canyon nuclear power plant in order to help meet existing supply challenges. *See* Doug Alexander, *California, Long Leery of Nuclear Power, Joins Bid to Save It*, Bloomberg Law (May 25, 2021). Available at: https://news.bloomberglaw.com/environment-and-energy/california-long-leery-of-nuclear-power-joins-bid-to-save-it?context=search&index=1. Accessed: May 2022.

21 CAISO, *2021 Summer Loads and Resources Assessment* (May 12, 2021). Available at: http://www.caiso.com/Documents/2021-Summer-Loads-and-Resources-Assessment.pdf. Accessed: May 2022.

proclamation highlighting that California currently faces an energy supply shortage of up to 3,500 megawatts during the afternoon-evening net-peak period of high-power demand on days when there are extreme weather conditions.[22,23]

ACC II and other CARB rulemakings will exacerbate supply challenges by significantly increasing demand for electricity in California. According to discussions during a Staff Workshop regarding the California Energy Commission's (CEC) 2022 Integrated Energy Policy Report Update, existing regulations are "very modest compared to what is on the near horizon and in the future"—increases in state electricity demand are already apparent, and the electrification of the transportation sector will increase demand by around 300,000 gigawatt-hours (GWh) statewide.[24] In addition, CARB's SRIA predicts a 20.23% increase in output for electric power generation, transmission, and distribution by 2040.[25]

While securing additional generation capacity will mitigate some of these supply challenges, overreliance on renewable generation may exacerbate existing shortages, particularly during early evening hours. The California Public Utility Commission's (CPUC) recently adopted Integrated Resource Plan for 2018-2020 demonstrates that substantial new resource capacity will be required to support accelerated electrification.[26] The CPUC's preferred portfolio for electricity generation heavily relies on substantial scale-up of renewable resources that already face reliability challenges.

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22 Governor Gavin Newsom, *Proclamation of a State of Emergency* (July 30, 2021), available at: https://www.gov.ca.gov/wp-content/uploads/2021/07/Energy-Emergency-Proc-7-30-21.pdf, accessed: May 2022. The order noted that "sufficient resources were not available" through CAISO's Capacity Procurement Mechanism to combat this shortfall, and that the summer of 2022 will also likely see a shortfall of up to 5,000 megawatts. To combat these shortfalls, the order called for the California Energy Commission to accelerate reviews of proposed natural gas generator projects that are 10 megawatts or larger, authorized incentive payments of up to $2 per kilowatt-hour reduced for large energy users, and eliminated permitting restrictions and air regulations on the use of existing backup fossil fuel fired generators. On August 17, 2021, the California Energy Commission approved five temporary gas-fueled generators, each with a generation capacity of 30 megawatts, to help address continued electricity shortages. Darrell Proctor, *California Will Add Gas-Fired Units to Increase Power Supply*, PowerMag (Aug. 20, 2021), available at: https://www.powermag.com/california-will-add-gas-fired-units-to-increase-power-supply/, accessed: May 2022.

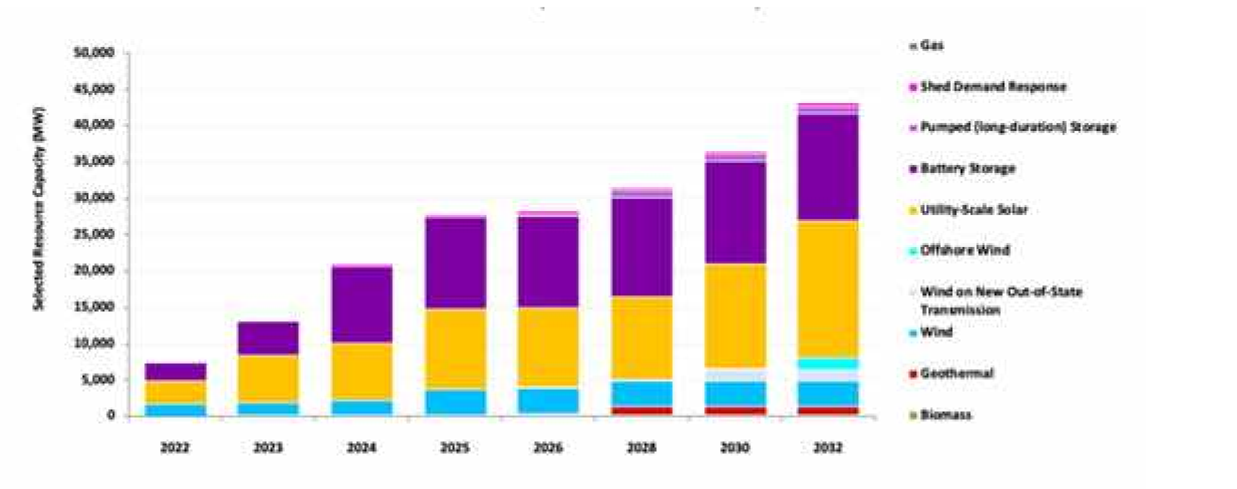
23 Further, the North American Electric Reliability Corporation's (NERC) draft 2022 Summer Reliability Assessment determined that extreme weather creates an elevated reliability risk in the western United States. NERC, *2022 Summer Reliability Assessment* (May 2022). Available at: https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2022.pdf. Accessed: May 2022.

24 CEC, *Transcript - IEPR Staff Workshop on Demand Scenarios*, Electricity Forecast, 22-IEPR-03, TN# 243031 at 64, 79 (May 12, 2022). Available at: https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=22-IEPR-03. Accessed: May 2022.

25 SRIA at 125.

26 CPUC, Order Instituting Rulemaking to Continue Electric Integrated Resource Planning and Related Procurement Processes, Decision No. 22-02-004 (Feb. 10, 2022). Available at: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M451/K412/451412947.PDF. Accessed: May 2022.

Figure A-1. New Resource Buildout Based on CPUC's Preferred Portfolio[27]



By 2026, when ACC II goes into effect, the CPUC must plan for a new resource buildout of 28,154 MW, climbing to 43,131 MW by 2032.[28] Nearly half of this capacity depends on battery storage, for which feasibility has not been demonstrated, and the majority of the remaining capacity is supplied by utility-scale solar, which also involves significant feasibility and reliability concerns.[29] Battery storage at this scale would result in significant additional demand for critical minerals, increasing consumer costs for both electricity and electric vehicles. CARB has failed to adequately assess these reliability challenges, despite its clear legal duty to do so.

A.1.2 CARB must consider economic impacts and burdens to communities, including low-income and disadvantaged communities.

CARB is required to assess any adverse economic impacts on California business enterprises and individuals resulting from its proposal.[30] Further, under Executive Order N-79-20, CARB must ensure that its ZEV regulations "serve all communities and in particular low-income and disadvantaged communities."[31] These requirements are written broadly to ensure that CARB considers a wide range of both direct and indirect impacts to individuals—this consideration must include electricity rate increases.

First, CARB must consider the impact of electricity rates. CARB acknowledges that by increasing the amount of electricity used, this will increase the amount of Utility User Tax

27 *Id.* at 87.
28 *Id*.
29 *See id*.
30 *See* APA § 11346.5(a)(7); HSC § 43018.5(c)(2)(E), (CARB must consider "[t]he ability of the state to maintain and attract businesses in communities with the most significant exposure to air contaminants, localized air contaminants, or both, including, but not limited to, communities with minority populations or low-income populations, or both.").
31 Governor Gavin Newsom, Executive Order N-79-20 (Sep. 23, 2020). Available at: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf. Accessed: May 2022.

levied.[32] However, CARB fails to address the fact that low-income and disadvantaged communities spend a disproportionate amount of their income on essential utilities, such as electricity.[33] In order to facilitate the ACC II targets, significant infrastructure buildout is necessary to support the increased electricity demand. Electrification of transportation sector will require an estimated $49 billion dollars.[34] Low-income households will bear a disproportionate share of these costs.[35]

Second, the lack of sufficient charging equipment is significant both as it relates to public and home charging. Both CARB and the CEC acknowledge that sufficient charging infrastructure is needed to accommodate the ACC II ZEV targets.[36] But CARB fails to consider that residents of low-income communities are more dependent on public charging infrastructure, which is more expensive and less convenient than home charging. A recent study indicates that home charging is often not an option for people living in multi-family housing, who are disproportionately low-income,[37] because "[p]ublic charging can be 2-4 times more expensive than home charging."[38]

While CARB does acknowledge the need to expand public charging infrastructure into ESJ communities, it does not take into consideration the interim consequences of uneven access before improvements are made. For example, CARB states that "already, in disadvantaged communities in California, used electric vehicles are purchased at higher rates than new electric vehicles."[39] As a result, the proposed solution is to increase warranty, durability and

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32 *See* SRIA at 112.

33 *See* CPUC, 2019 Annual Affordability Report at 10-11 (Apr. 2021). Available at: https://www.cpuc.ca.gov/-/media/cpuc-website/industries-and-topics/reports/2019-annual-affordability-report.pdf. Accessed: May 2022.

34 *See* CPUC, Order Instituting Rulemaking to Continue Electric Integrated Resource Planning and Related Procurement Processes, Decision No. 22-02-004 (Feb. 10, 2022), available at: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M451/K412/451412947.PDF, accessed: May 2022. Further, as discussed in additional detail in the Technical Comments at Appendix B, cumulative costs associated with electricity grid infrastructure upgrades could reach $1.55 trillion for 2026-2050. *See* Section B.6. *See also* CEC, Presentation - Transportation Energy Demand Forecast, 21-IEPR-03, TN# 240934 (Dec. 14, 2021). Available at: https://www.energy.ca.gov/event/workshop/2020-12/session-1-transportation-energy-demand-forecast-update-commissioner-workshop. Accessed: May 2022.

35 CPUC, Draft Environmental & Social Justice Action Plan Version 2.0, at 21 (Mar. 25, 2022). Available at: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M465/K846/465846599.pdf. Accessed: May 2022.

36 CEC, Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment Analyzing Charging Needs to Support ZEVs in 2030, 19-AB-2127 at ii (Jul. 14, 2021), available at: https://www.energy.ca.gov/programs-and-topics/programs/electric-vehicle-charging-infrastructure-assessment-ab-2127, accessed: May 2022 . As discussed in further detail in the Technical Comments at Appendix B, the total cost associated with purchasing and installing these chargers is estimated to be between $13 and $24 billion. *See* Section B.6.

37 *See* Scott Hardman, et al., *A perspective on equity in the transition to electric vehicle*, 2 MIT Sci. & Pol. Rev. 46, 49 (Aug. 30, 2021). Available at: https://sciencepolicyreview.org/wp-content/uploads/securepdfs/2021/08/A_perspective_on_equity_in_the_transition_to_electric_vehicles.pdf. Accessed: May 2022.

38 *Id*.

39 *See* ISOR at 21.

affordability of new ZEVs beginning in model year 2026.[40] However, CARB does not address the economic impacts to ESJ communities between now and when model year 2026 ZEVs are viable as "used."

Finally, CARB has not factored the subsidization of electric vehicles into its economic analysis. The electric vehicle market is buoyed by state and federal subsidies. From California this includes grants for the purchase of zero-emission buses, grants for the replacement or repower of heavy-duty vehicles, and various rebate programs such as the Clean Vehicle Rebate Project and the Clean Fuel Reward program,[41] and from the federal government this includes a tax credit of up to $7,500 for the purchase of a new electric vehicle.[42] Similarly, CARB must consider the impact of electric vehicle mandates on *all* motor vehicles, not just electric vehicles, as manufacturers spread unrecouped and compliance costs across their business.[43] CARB cannot claim to have reasonably considered cost impacts to consumers or accurately evaluated electric vehicle purchase prices without adjusting for these subsidies and cross-subsidization.

Without considering the aforementioned effects, CARB has failed to fully account for substantial economic impacts from forced electrification to individuals in general and to vulnerable communities in particular.

A.1.3 CARB must consider life cycle emissions from Zero Emission Vehicles in evaluating the ACC II program.

Along with impacts to the state's economy from proposed regulations, CARB is required to consider any less costly but equally effective alternatives.[44] The ISOR and associated rulemaking document do not satisfy this obligation because nowhere does CARB compare the life cycle emissions analysis of ZEVs and highly efficient low emission vehicles, which impose significantly fewer infrastructure expenses while achieving equivalent or greater GHG emissions reductions on a faster timeline.

As noted by the National Bureau of Economic Research, "…despite being treated by regulators as 'zero emission vehicles', electric vehicles are not necessarily emissions free."[45] Battery

40 *Id.* at 153.

41 *See* U.S. Dept. Energy, *California Laws and Incentives*. Available at: https://afdc.energy.gov/laws/all?state=CA#State%20Incentives. Accessed: May 2022.

42 *See* U.S. Dept. Energy, *Federal Tax Credits for New All-Electric and Plug-in Hybrid Vehicles.* Available at: https://www.fueleconomy.gov/feg/taxevb.shtml. Accessed: May 2022.

43 The Associations are concerned that ACCII will harm consumers and small businesses that depend on affordable comprable internal combustion vehicles—which cost significantly less and are more accessible— by driving up the cost of these vehicles. This cross-subsidization of electric vehicles at the expense of non-electric vehicles occurs in two ways. First, driven by the need to sell electric vehicles to meet California requirements, motor vehicle manufacturers will attempt to bolster sales by decreasing the sales price of electric vehicles and increasing the sales price of internal combustion engine vehicles. Second, manufacturers that do not meet sales mandates likely will spread the cost of buying compliance credits across all vehicle models, rather than only increasing the cost of their electric vehicles. CARB must consider the impact of ACC II on all new motor vehicles.

44 S*ee* HSC § 57005.

45 Stephen P. Holland, et al., *Environmental Benefits from Driving Electric Vehicles?*, Working Paper 21291, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w21291. Accessed: May 2022.

production, transport, and disposal or recycling present emissions and waste impacts[46] as well as national security concerns.[47] Furthermore, as the Ramboll LDA Study observes, "it is likely that the vast majority of batteries produced in the future would require virgin material given the significant increase in demand under a mass vehicle electrification scenario."[48]

Low-carbon fuels like renewable diesel, ethanol and renewable gasoline should be evaluated as an alternative because they are compatible with existing vehicle infrastructure, from light- to heavy-duty long-haul vehicles *right now*. By contrast, electric vehicles require transformation of energy production and distribution infrastructure—which will take significant time even in the most optimistic scenarios. This makes low-carbon fuels a commonsense solution to reduce transportation GHG emissions near-term, allowing battery, hydrogen, and low-carbon intensity gaseous and liquid fueled vehicles to compete to achieve the State's GHG targets in the quickest and most cost-effective manner. For example, a scenario that phases in low-carbon intensity gasoline as a drop-in fuel for ICEVs over a two-decade period could reduce GHG emissions the same or more than the proposed ZEV-only mandate, when viewed on a life cycle basis. Other scenarios involving hybrid electric vehicles and PHEVs could be equally effective in providing GHG reductions when coupled with a phase in of low-carbon intensity gasoline.

Additionally, unlike with electric vehicles, vehicle owners that use drop-in fuels such as renewable diesel achieve emission reductions but do not have to face the high up-front cost to replace their current vehicles or the costs associated with locating and installing electric vehicle charging infrastructure.[49]

Accounting for life cycle emissions and short-term emissions reductions is necessary for CARB to fulfill its legal duty to conduct a reasonable assessment of the effectiveness of alternatives and the significant impacts to the state's economy of all scenarios. From this perspective, including highly efficient low emission vehicles in the ACC II program is both less costly and equally effective in meeting CARB's regulatory goals, and CARB's failure to consider this alternative violates HSC § 57005.

A.2 CARB must perform a complete and sufficient assessment of the technological feasibility of the ACC II ZEV mandates.

Similar to economic impacts, the APA and HSC mandate that CARB consider the technological feasibility of proposed motor vehicle standards. CARB's interpretation of this requirement is overly narrow because it focuses only on whether a manufacturer has the technology to provide an electric vehicle. It fails to consider whether manufacturers have the resources (including

46 Perry Gottesfeld, *Electric cars have a dirty little recycling problem—batteries*, National Observer (Jan. 22, 2021). Available at: https://www.nationalobserver.com/2021/01/21/opinion/electric-cars-have-dirty-little-recycling-problem-their-batteries. Accessed: May 2022.

47 Eric Onstad, *China frictions steer electric automakers away from rare earth magnets*, Reuters (Jul. 19, 2021). Available at: https://www.reuters.com/business/autos-transportation/china-frictions-steer-electric-automakers-away-rare-earth-magnets-2021-07-19. Accessed: May 2022.

48 *See* Attachment D, Ramboll LDA Study, at 29.

49 *See* Attachment D, "Multi-Technology Pathways To Achieve California's Greenhouse Gas Goals: Light-Duty Auto Case Study" by Ramboll dated May 31, 2022 for further details.

critical and rare earth minerals) to shift to rapidly producing electric vehicles and whether there is a reliable supply of electricity to fuel them.[50]

Specifically, CARB is required to consider:

- HSC § 39602.5 – ambient air quality standards ("state board shall adopt these measures if they are necessary, technologically feasible, and cost effective…");
- HSC § 38562 – GHG emissions ("[T]he state board shall adopt greenhouse gas emissions limits… to achieve the maximum technologically feasible and cost-effective reductions…");
- HSC § 43013 – motor vehicle emission standards ("…which the state board has found to be necessary, cost effective, and technologically feasible, to carry out the purposes of this division");
- HSC § 43101 – new motor vehicle emission standards ("…that the state board finds to be necessary and technologically feasible to carry out the purposes of this division. Before adopting these standards, the state board shall consider the impact of these standards on the economy of the state, including, but not limited to, their effect on motor vehicle fuel efficiency.");
- HSC § 43018.5 – GHG vehicle emissions ("maximum feasible and cost-effective reduction of greenhouse gas emissions from motor vehicles");
- HSC § 43018 – NOx emissions ("the state board shall take whatever actions are necessary, cost-effective, and technologically feasible in order to achieve… a reduction in the actual emissions of reactive organic gases… [and] a reduction in emissions of oxides of nitrogen… from motor vehicles"); and
- HSC § 38560 – GHG emissions ("The state board shall adopt rules and regulations… to achieve the maximum technologically feasible and cost-effective greenhouse gas emission reductions from sources or categories of sources").

As CARB considers the technological feasibility of its proposal, it should further explore whether vehicle manufacturers are likely to possess adequate resources to adapt to these stringent requirements, especially in light of increasing global supply chain issues and commodity price increases associated with battery demand. Currently, CARB plans to set interim requirements for the percentage of electric vehicle sales starting in 2026, with this requirement increasing by 8 percentage points per year for the first 5 years, and then 6 percentage points per year for the latter 5 years. This is an unprecedented rate of vehicle technology change that the nation and vehicle manufacturers have never experienced before.

Importantly, the question here is not *only* whether a vehicle manufacturer has the technology (and, inherent in this question, the resources) to produce a single electric vehicle. Rather, examining the technological feasibility of electric vehicle mandates must include asking whether vehicle manufacturers have the technology and resources to rapidly shift to producing electric vehicles—a relatively new technology category that requires different resources than traditional vehicles—by the millions, as well as whether there is a reliable supply of electricity to fuel them.

50 Further, as noted above, the significant existing state and federal subsidies for electric vehicles call into question whether this technology is mature enough to be considered feasible.

First, both the federal government and the private sector have recognized that critical minerals are essential to the future of electric vehicles, and likewise, that unstable critical mineral supply chains could disrupt this future. According to Rystad Energy, by 2024, global demand for nickel (one of the most widely used critical minerals for EV batteries) will have increased from 2.5 million tons to 3.4 million tons, thereby surpassing supplies.[51] Likewise, the International Energy Agency has estimated that lithium demand could increase by over 40 times by 2030, and cobalt could face similar demand issues.[52,53]

The U.S. is disproportionately reliant on international supplies of critical minerals necessary for electric vehicle and electric battery production. Ninety-one percent of the lithium that the United States imports is sourced from Chile and Argentina.[54] Relatedly, China has disproportionate influence compared to other foreign nations that produce cobalt, molybdenum, and other minerals needed to produce electric vehicles. For instance, the U.S. Geological Service (USGS) reported that domestic primary aluminum production in 2021 (880,000 metric tons) was less than half of domestic production in 2013 (1,946,000 metric tons).[55] China, however, possesses over half of the entire world's aluminum smelting capacity.[56] Seventy percent of the world's supply of cobalt comes from the Democratic Republic of Congo,[57] where eight of the largest 14 mines are Chinese-owned.[58] Similarly, U.S. domestic mining production of cobalt has declined (760,000 tons in 2015 compared to 700,000 tons in 2021).[59] Secondary cobalt production has also declined between 2017 and 2021 (2,750,000 tons to 1,600,000 tons).[60] The United States imports all its graphite and manganese, having no domestic production of these minerals. China produces 82 percent of the world's graphite,[61] while Gabon, a less stable country, provides 67 percent of the United States' manganese.[62] For any one of these minerals, ACC II's 100% electrification mandate could put the United States into a situation resembling the oil embargoes of the 1970s, where foreign actors control majorities of the critical raw

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51 David Iaconangelo, *Nickel shortage spells trouble for EVs – report*, E&E News (Oct. 13, 2021). Available at: https://www.eenews.net/articles/nickel-shortage-spells-trouble-for-evs-report/. Accessed: May 2022.

52 Neil Winton, *Lithium Shortage May Stall Electric Car Revolution And Embed China's Lead: Report*, Forbes (Nov. 14, 2021). Available at: https://www.forbes.com/sites/neilwinton/2021/11/14/lithium-shortage-may-stall-electric-car-revolution-and-embed-chinas-lead-report/?sh=70d7fed046ef. Accessed: May 2022.

53 U.S. Geological Survey, *Mineral Commodity Summaries 2022,* at 100 (Jan. 31, 2022), available at: https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf, accessed: May 2022, ("2022 Mineral Commodities Summaries").

54 *Id.* In addition, 8% of imported lithium is from China and Russia. *Id.*

55 *Id.* at 22; U.S. Geological Survey, *Mineral Commodity Summaries 2018,* at 20 (Jan. 31, 2018), available at: https://minerals.usgs.gov/minerals/pubs/mcs/2018/mcs2018.pdf, accessed: May 2022, ("2018 Mineral Commodities Summaries").

56 2022 Mineral Commodieis Summaries at 23.

57 *Id.* at 53.

58 *See China Has a Secret Weapon in the Race to Dominate Electric Cars*, Bloomberg (Dec. 2, 2018). Available at: https://www.bloomberg.com/graphics/2018-china-cobalt/. Accessed: May 2022.

59 2018 Mineral Commodities Summaries at 50; 2022 Mineral Commodities Summaries at 53.

60 2022 Mineral Commodities Summary at 52.

61 *Id.* at 75.

62 *Id.* at 106.

material supplies used in the manufacture of fuels, battery, and motor components designed to provide transportation mobility services for the U.S. consumer.[63]

California's ACC II mandates risk arbitrarily exacerbating supply chain strains, and CARB does not adequately account for how the increasing adoption of electric vehicles will further affect the technological feasibility of its proposed mandates. In the Draft Environmental Assessment (EA), CARB identifies this problem but does not offer a solution: "In summary, while substantial research has been done and there is a clear commitment to increasing domestic supply of lithium, exact actions that will be taken in response to this goal of increasing domestic supply of lithium are yet to be identified with certainty."[64]

Second, as described in detail above, California already faces unresolved grid reliability issues that will be exacerbated by ACC II's ZEV targets.[65] Increases in state electricity demand are already apparent, and electrification of the transportation sector will increase demand by around 300,000 GWh statewide.[66] By 2026, when ACC II would go into effect, California will need an additional 28,154 MW, climbing to 43,131 MW by 2032.[67] Nearly half of this capacity depends on battery storage that has not been demonstrated, and the majority of the remaining capacity is supplied by utility-scale solar, which also presents significant feasibility concerns.[68] It is entirely unreasonable to determine that a vehicle is technologically feasible solely because it can be *built* when it simultaneously cannot reliably *operate* because it does not have the power to do so. Creating a rapid increase in electricity demand before more renewable energy infrastructure is built could increase emissions from traditional energy generating sources and offset GHG reductions achieved by ZEVs, an unintended consequence CARB did not consider.

By failing to account for these issues, CARB not only offers an arbitrary and capricious assessment of technological feasibility, but also violates its statutory obligations as set forth in the APA and HSC.

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63 *See* Securing America's Future Energy, *The Commanding Heights of Global Transportation*, https://secureenergy.org/wp-content/uploads/2020/09/The-Commanding-Heights-of-Global-Transportation.pdf.

64 *See* CARB, *Appendix E – Draft Environmental Analysis for the Proposed Advanced Cleans Cars II Program*, 121 (Apr. 12, 2022). Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

65 These reliability challenges are discussed in more detail in the Technical Comments at Appendix B, Section B-5.

66 CEC, *Transcript - IEPR Staff Workshop on Demand Scenarios*, Electricity Forecast, 22-IEPR-03 at 79 (May 12, 2022). Available at: https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=22-IEPR-03. Accessed: May 2022.

67 CPUC, *Order Instituting Rulemaking to Continue Electric Integrated Resource Planning and Related Procurement Processes*, Decision No. 22-02-004, at 87 (Feb. 10, 2022). Available at: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M451/K412/451412947.PDF. Accessed: May 2022.

68 *See id.*

A.3 CARB lacks the legal authority to unilaterally ban entire industries.

CARB's ACC II Program centers around achieving 100% ZEV or PHEV sales in California by model year 2035. This target necessitates the complete electrification of the transportation sector, forcing the phase-out of oil and gas production and refinery industries. CARB's attempt to unilaterally ban entire industries exceeds its delegated authority under California's Constitution.

The California Supreme Court has held that "[t]he constitutional guaranties of liberty include the privilege of every citizen to freely select those tradesmen [he desires to patronize]."[69] ACC II will intrude on this liberty interest by stripping Californians' current right to choose ICEVs when it bans new ICEV sales and effectively banning infrastructure to support these vehicles by forcing the phase-out of related industries in California. Under the California Constitution, legislation that impacts a protected liberty interest must not "be 'unreasonable, arbitrary or capricious' but... have 'a real and substantial relation to the object sought to be attained.'"[70]

ACC II's exclusive selection of ZEVs is neither reasonable nor rationally related to California's goal to limit GHG emissions from vehicles. Low-carbon fuels and highly efficient ICEVs can achieve the same GHG emissions reductions as ZEVs and on a shorter timeline. Low-carbon fuels like renewable diesel, ethanol, and renewable gasoline are compatible with existing vehicle infrastructure, from light- to heavy-duty long-haul vehicles. These fuels can *immediately* reduce transportation GHG emissions and are not dependent on an electric vehicle infrastructure. Further, when viewed from a life cycle perspective, these fuels achieve similar or greater emissions reductions and do not impair liberty interests because Californians will retain their current options to choose between ICEVs and electric vehicles. As noted above, GHG emissions from a light-duty vehicle that runs on soybean-based renewable diesel has 25% fewer life cycle GHG emissions when compared to an EV, and this percentage is even greater for a vehicle that runs on waste-oil-based renewable diesel.

Because eliminating an entire sector of industry is not rationally related to California's interest in limiting GHG emissions, ACC II impermissibly interferes with liberty interests protected under the California Constitution.

A.4 ACC II fails to comply with the APA because it effectively mandates the use of specific technologies.

APA § 11346.2(b)(4)(A) requires CARB to consider performance standards as an alternative whenever CARB proposes a regulation that would mandate the use of specific technologies or equipment, or prescribe specific actions or procedures.

ACC II will establish interim requirements for the percentage of EV sales starting in 2026— the requirement increases by 8 percentage points per year for the first 5 years, and then 6 percentage points per year for the latter 5 years, achieving 100% ZEV sales by 2035.[71] In its

69 *New Method Laundry Co. v. MacCann*, 174 Cal. 26, 32 (1916).
70 *Coleman v. Department of Personnel Administration*, 52 Cal. 3d 1102, 1125 (1991) (internal citations omitted).
71 See ISOR at 9.

ISOR, CARB indicates that its proposed ACC II program is a performance standard because "manufacturers can meet this proposed regulation requirements using BEV, PHEV or [fuel cell electric vehicle (FCEV)] technologies and with several options for securing ZEV values."[72] However, CARB also notes that, even if ACC II is considered a prescriptive standard, "[a]nything less prescriptive than ACC II in terms of emission limits and requirements for ZEVs erodes the proposal's ability to secure the emissions reductions needed for meeting California's public health and climate goals and State and federal air quality standards."[73]

CARB's conclusion that ACC II is not a prescriptive standard entirely ignores the prescriptive effect of mandating one specific avenue for compliance— ACC II requires a transition to ZEV technologies rather than setting minimum emission standards that can be achieved through a variety of technologies such as highly efficient ICEVs and low-carbon liquid fuels. Providing flexibility to choose among various ZEV technologies does not change CARB's clear selection of one compliance pathway, because this "choice" is itself prescriptive.

Similarly, CARB's cursory conclusion that ACC II "would still be preferred over other performance-based alternatives" overlooks important near-term emissions reductions achievable through low carbon fuels and other technologies.[74] CARB asserts that "[l]ess prescriptive measures would allow, by omission, additional flexibilities on technology, valuation, fleet mixing, and assurance measures that would likely not achieve the same magnitude of emissions reductions or support for the ZEV market."[75] However, CARB has not adequately analyzed the achievable emissions reductions stemming from such performance standards.

CARB completely overlooks the significant current and projected reductions in GHG emissions associated with the liquid transportation fuel pool that are occurring in response to the LCFS,[76] the federal Renewable Fuel Standard (RFS),[77] and interest from shareholders to reduce GHG emissions associated with the production of fuels. Production of fuels with lower carbon intensity has already resulted in significant reductions in GHG emissions attributable to the domestic transportation fuel pool and, due to the continued success of the LCFS and RFS, there is significant and increasing private investment in low-carbon fuel technologies that will further expand GHG reductions in the transportation economy.[78] Further, numerous companies

[72] *Id*. at 181.
[73] *Id*.
[74] *Id.*
[75] *Id*.
[76] *See* California Air Resources Board, *LCFS Workshop CARB Presentation,* at 5 (Oct. 14, 2020), available at: https://ww2.arb.ca.gov/sites/default/files/2020-10/101420presentation_carb.pdf, accessed: May 2022. ("Over 15 million metric tons of GHG reductions in 2019.")
[77] A study performed by Life Cycle Associates found that "The RFS2 has resulted in significant GHG reductions, with cumulative CO_2 savings of 980 million metric tonnes over the period of implementation to date." Stefan Unnasch and Debasish Parida, *GHG Emissions Reductions due to the RFS2 – A 2020 Update* (Feb. 11, 2021). Available at: https://ethanolrfa.org/wp-content/uploads/2021/02/LCA_-_RFS2-GHG-Update_2020.pdf. Accessed: May 2022.
[78] By prescribing specific zero-emission technologies, CARB ignores and frustrates the vast emission reductions that could be achieved via continued operation of the LCFS. Market signals benefitting electric vehicle automakers and electric generators only will drive away private investment and innovation into alternative zero emission technologies.

involved in both exploration and production of crude oil as well as production of both renewable and nonrenewable liquid fuels have begun projects to sequester, capture, or displace carbon, further reducing the GHG emissions associated with liquid fuels in the transportation sector.

Without adequately considering the emissions reductions available from a performance-based vehicle emissions standard, CARB has exceeded its regulatory authority under APA § 11346.2(b)(4)(A).

A.5 ACC II thwarts legislative priorities by undermining wildfire resilience and exacerbating impacts to low-income communities.

The California legislature has made clear that wildfire resilience is a priority for the state. Despite this clear legislative priority, CARB's proposed ACC II program will undermine wildfire resilience by forcing electrification of the transportation sector through its ZEV sales mandate, which will necessarily require significant build-out of electricity infrastructure, exacerbating existing wildfire risks and worsening wildfire impacts. These impacts will disproportionately affect low-income and disadvantaged communities.

In September 2021, Governor Newsom signed SB-456 into law, requiring the Wildfire and Forest Resilience Task Force to "develop a comprehensive implementation strategy to track and ensure the achievement of the goals and key actions identified in the state's 'Wildfire and Forest Resilience Action Plan' issued by the task force in January 2021."[79] The state has also dedicated substantial funding to Wildfire and Forest Resilience Early Action,[80] as well as fire prevention programs and projects targeted towards reducing GHG emissions caused by uncontrolled wildfires.[81]

Electric utility infrastructure poses a significant wildfire ignition risk that CARB has failed to assess, and that ACC II will exacerbate. The December 2020 *Utility Wildfire Mitigation Strategy and Roadmap* emphasized that climate change will amplify utility wildfire risks by increasing vegetation contact through invasive species and tree mortality[82] and increasing the size, scope, and frequency of wildfires, meaning that utilities will "operate in more high-risk areas going forward."[83] Utilities are already operating in areas facing extreme or elevated wildfire risk in both Northern and Southern California, and these risks "will almost certainly increase" in the future.[84]

Apart from ignition risks, overreliance on electrification, as required by ACC II, can amplify wildfire risks to electrical transmission and distribution assets throughout the state. Wildfire damages are generally very costly to repair—a 2018 CEC Report indicated that "[o]ver the 2000-2016 period, wildfire damages to the transmission and distribution system in selected

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79 Senate Bill No. 456.

80 Senate Bill No. 85 (Apr. 13, 2021) (amending the *2020-21 Budget Act* to provide $536 million in funding for various wildfire and forest resilience activities).

81 Senate Bill No. 155(5) (Sep. 23, 2021) (appropriating $200,000,000 annually from the Greenhouse Gas Reduction Fund beginning in the 2022–23 fiscal year through 2028–29 fiscal year).

82 CUPC, *Utility Wildfire Mitigation Strategy and Roadmap for the Wildfire Safety Division*, at 18 (Dec. 2020). Available at: https://energysafety.ca.gov/wp-content/uploads/docs/strategic-roadmap/final_report_wildfiremitigationstrategy_wsd.pdf. Accessed: May 2022.

83 *Id.* at 14.

84 *Id*.

areas exceeded $700 million," although "[t]otal wildfire damages to all sectors of the economy were much larger."[85] These damages can also increase generation costs and disrupt customer service.[86] Future wildfire risk is expected to significantly increase, exacerbating these existing challenges.[87] The CEC Report estimated that cost impacts of fires in a high-capacity utilization scenario would reach $92.6 million in the midcentury period.[88] Again, CARB must account for these increased costs in assessing the projected impacts of its proposed program.

CARB itself notes the increasing wildfire risks faced by the state in its ISOR: "California's annual wildfire extent has increased fivefold since the 1970s, and California's 2020 fire season alone shattered records, not only in the total amount of acres burned (at just over 4 million) but also in wildfire size, with 5 of the 6 largest wildfires in California history occurring in 2020."[89] However, CARB fails to account for any wildfire risks stemming from the electrification of the transportation sector, concluding that short-term construction-related and long-term operation related effects to wildfire would be "less than significant."[90] Instead, CARB considers only perceived *benefits* to wildfire resilience based on the unproven ability to use ZEVs "to provide grid services and decentralized backup power for California residents" to mitigate disruptions.[91] Moreover, CARB overlooks the potential hazards faced by communities with an urgent need to evacuate from fires who may be stranded if they cannot charge their electric vehicles. CARB's analysis is entirely one-sided, assessing highly attenuated benefits while ignoring demonstrable costs based on extensive analyses by other California agencies.

Low-income communities are disproportionately burdened by wildfire impacts. According to a recent study analyzing wildfire impacts from 2010 to 2020, rural communities "sustained three times more wildfire on average"-- these communities exhibited significant environmental justice indicators, including "higher rates of poverty, unemployment, and vacant housing, as well as higher proportions of low-income residents and residents without college degrees."[92]

Likewise, environmental justice communities are most impacted by de-energization events—according to the CPUC's report, "[t]hese events have had massive implications for [environmental and social justice (ESJ)] communities, particularly low-income people in rural,

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85 Larry Dale, et. al, *Assessing the Impact of Wildfires on the California Electricity Grid*, CCCA4-CEC-2018-002, at iv (Aug. 2018). Available at: https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-002_ADA.pdf. Accessed: May 2022.

86 *See id.* at 11. The CEC Report indicated that "In one Northern California subregion, over 100 wildfires occurred between 2000 and 2016, covering 15-20% of the land area. Of those, 19 fires approached within a quarter mile of Paths 25 and 66. Wildfires near transmission paths may force the California Independent System Operator (CAISO) to cut power to those paths (line outages)." *Id.*

87 In addition, increased dependency on electricity may impact emergency response, increasing vulnerability to wildfires and other natural disasters by limiting the availability of fungible fuel sources and decreasing variability of energy supply.

88 *Id.* at 28.

89 ISOR at 7 (internal citations omitted).

90 ISOR at 150.

91 ISOR at 171.

92 Shahir Masri, et al., *Disproportionate Impacts of Wildfires among Elderly and Low-Income Communities in California from 2000-2020*, at 16 (Apr. 8, 2021). Available at: https://pubmed.ncbi.nlm.nih.gov/33917945/. Accessed: May 2022.

high fire threat areas including people with access and functional needs."[93] The CPUC's 2022 *Environmental and Social Justice Action Plan* indicates that "electric utilities have used de-energization strategies more frequently to prevent ignition of wildfires by electric utility infrastructure."[94] Among the three largest utilities in California, data shows an average of 14 outages per year, impacting more than a million customers.[95] CARB must account for the impact of rapid electrification on wildfire risk *and* consider the communities that will bear them.

CARB does not have the authority to contravene express statutory mandates by omission. It must consider the potential for ACC II to increase wildfire risk and change course accordingly.

A.6 CARB does not adequately consider feasible alternatives or the full range of environmental impacts.

CARB's Draft Environmental Analysis (EA) does not meet requirements under the California Environmental Quality Act (CEQA) because it (1) fails to consider low-carbon fuel and engine technologies as feasible alternatives and (2) ignores a number of potentially significant environmental impacts.

A.6.1 The EA must consider low-carbon fuel and engine technologies as alternatives.

As mentioned, in its Draft EA, CARB has failed to consider further supporting the production of low-carbon fuel and engine technologies that can immediately reduce GHG emissions today as an alternative alongside, rather than in lieu of, mandating a certain amount of electric vehicles.[96] The Associations urge CARB to recognize the proven value of using a diversified mix of other low-carbon technologies to achieve its GHG reduction goals. At the least, CARB should present a robust and scientifically credible alternatives analysis in its Final EA that compares the costs and benefits of using all feasible technologies to the costs and benefits of mandating 100% electric vehicles.

According to the Draft EA, the "primary objectives" of the ACC II Program include goals to "[m]aintain and continue reductions in emissions of GHGs beyond 2020" and "[c]omplement existing programs and plans to ensure, to the extent feasible, that activities undertaken pursuant to the measures complement, and do not interfere with, existing planning efforts to reduce GHG emissions, criteria pollutants, petroleum-based transportation fuels, and TAC

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[93] CPUC, *DRAFT Environmental & Social Justice Action Plan Version 2.0*, at 20 (Mar. 25, 2022). Available at: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M465/K846/465846599.pdf. Accessed: May 2022.

[94] CPUC, *DRAFT Environmental & Social Justice Action Plan Version 2.0*, at 20 (Mar. 25, 2022). Available at: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M465/K846/465846599.pdf.

[95] PSE Blog, *Preventing Wildfires with Power Outages: The Growing Impacts of California's Public Safety Power Shutoffs* (Mar. 19, 2021). Available at: https://www.psehealthyenergy.org/news/blog/preventing-wildfires-with-power-outages-2/#ref. Accessed: May 2022.

[96] *See* CARB, *Appendix E – Draft Environmental Analysis for the Proposed Advanced Cleans Cars II Program*, 182-83 (Apr. 12, 2022). Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

emissions."[97] Low-carbon alternative fuel and engine technologies align with these primary objectives, and thus, CARB should consider how these technologies can achieve more immediate environmental benefits while mitigating any cost burdens the ACC II Program may impose, especially with regard to low-income communities. Indeed, not doing so would conflict and "interfere with[] existing planning efforts to reduce GHG emissions [and] criterial pollutants" under the LCFS and RFS.[98]

In the ACC II rulemaking, CARB is required to consider a reasonable range of alternatives, including "alternatives that are proposed as less burdensome and equally effective in achieving the purposes of the regulation in a manner that ensures full compliance with the authorizing statute or other law being implemented or made specific by the proposed regulation."[99] This aligns with the CEQA Guidelines, which also specify that CARB must consider a reasonable range of alternatives that "shall include those that could feasibly accomplish most of the basic objectives of the project and could avoid or substantially lessen one or more of the significant effects."[100] The CEQA Guidelines define "feasible" as "capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, legal, social, and technological factors."[101] Specifically, when considering the feasibility of alternatives, the CEQA Guidelines provide the following factors to consider: "economic viability, availability of infrastructure, general plan consistency, other plans or regulatory limitations, [and] jurisdictional boundaries."[102]

Importantly, CARB is prohibited from predetermining a particular method to narrow the alternatives it considers for achieving the agency's ultimate policy goals. When examining whether or not alternatives or particular features have been foreclosed by the agency, courts look "to the surrounding circumstances to determine whether, as a practical matter, the agency has committed itself to the project as a whole or to any particular features, so as to effectively preclude any alternatives or mitigation measures that CEQA would otherwise require to be considered."[103] By deeming ZEVs as the only acceptable technologies and hardly considering in this rulemaking how other low-carbon technologies could provide important near-term reductions in GHG emissions, CARB is effectively predetermining the outcome of this proceeding. This predetermined outcome is not only arbitrary and capricious, but is also a violation of CARB's statutory obligations.

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[97] *Id.* at 7–8. While CARB is responsible for regulating emissions from transportation fuels, CARB has provided no authority for its premise that reducing petroleum-based transportation fuels is a legitimate objective for the agency. As noted throughout these comments, carbon capture and other innovative technologies offer opportunities for petroleum-derived fuels to achieve carbon reductions equivalent to or superior to those offered by ZEVs on a lifecycle basis. It is arbitrary to seek to reduce the use of these fuels categorically without regard to their lifecycle emissions.

[98] *Id.* at 8.

[99] California Government Code § 11346.2(b)(4)(A) (emphasis).

[100] Cal. Code Regs. tit. 14, § 15126.6(c).

[101] Cal. Code Regs. Tit. 14 § 15364; *Bay Area Citizens v. Ass'n of Bay Area Governments*, 248 Cal. App. 4th 966, 1018 (2016).

[102] Cal. Code Regs. tit. 14, § 15126.6(f)(1).

[103] *Save Tara v. City of W. Hollywood*, 45 Cal. 4th 116, 139 (2008), *as modified* (Dec. 10, 2008).

While increased electric vehicle adoption will be part of the energy mix to achieve California's GHG goals, it is impossible for this strategy alone to solve the issue of transportation emissions, especially in the short-term. Electric vehicles are simply too expensive for the majority of American families, and significant portions of California's population will rely on vehicles utilizing gasoline and diesel fuel for decades to come. A recent report by the Rhodium Group projects that, nationwide, where more than half of light-duty sales are electric by 2030 and nearly 90% are electric by 2035, 34% of transportation sector GHG emissions will still remain in 2050.[104] The report concludes that "low-GHG liquid fuels are needed to fill the remaining gap and achieve net-zero emissions in the transportation sector by mid-century."[105]

Low-carbon fuels like renewable diesel, ethanol and renewable gasoline are compatible with existing vehicle infrastructure. Such fuels are a commonsense solution to *immediately* reduce transportation GHG emissions without waiting for the time and expenses it will take to build out EV infrastructure. Additionally, unlike with electric vehicles, vehicle owners that use drop-in fuels such as renewable diesel or low carbon intensity gasoline do not have to face the high up-front cost to replace their current vehicles or the costs associated with locating and installing electric vehicle charging infrastructure.[106]

A.6.2 The EA fails to consider potentially significant environmental impacts.

CEQA requires that the Draft EA and Final EA contain "[a] discussion and consideration of environmental impacts, adverse or beneficial, and feasible mitigation measures which could minimize significant adverse impacts identified," as well as "[a] discussion of cumulative and growth-inducing impacts."[107] The Draft EA for the Proposed Regulation fails to consider the following potentially significant environmental impacts:

- Regarding aesthetics, the Draft EA does not consider the unpleasing aesthetic of businesses that will close as a result of the Proposed Regulation. Because millions of businesses depend upon transportation as a factor, the ZEV mandate will likely result in the closure of not only gas stations, but many other kinds of businesses as well. This could cause many gas stations and buildings within the state to become unoccupied and fall into a state of disrepair.
- CARB does not consider how the Proposed Regulation could cause businesses to relocate to other states based on the proposal's harmful competitive impacts to California industries. The act of relocating to another state involves greenhouse gas emissions and other harmful pollutants from transportation, as well as the potential construction of new business sites. Such transportation and construction could also injure wildlife and impact overburdened communities.
- CARB does not consider how California residents will likely drive to other states to purchase more affordable, traditional vehicles, significantly increasing the number of out-of-state

104 Rhodium Group, *Closing the Transportation Emissions Gap with Clean Fuels*, at 3 (Jan. 15, 2021). Available at: https://rhg.com/wp-content/uploads/2021/01/Closing-the-Transportation-Emissions-Gap-with-Clean-Fuels-1.pdf. Accessed: May 2022.

105 *Id.* at 2.

106 *See* Attachment D, "Multi-Technology Pathways To Achieve California's Greenhouse Gas Goals: Light-Duty Auto Case Study" by Ramboll dated May 31, 2022 for further details.

107 Cal. Code Regs. tit.17, § 60004.2(a).

vehicle purchases. This will result in additional greenhouse gas emissions and other harmful pollutants, which also pose a threat to wildlife and overburdened communities.

- CARB does not consider how, because the Proposed Regulation will likely increase vehicle costs. As a result, many Californians may choose to keep their cars for longer than they otherwise would have, thereby forgoing opportunities to replace their aging vehicles with more efficient models. This would also result in additional greenhouse gas emissions and criteria pollutants, compared to existing regulatory requirements.
- CARB does not adequately consider how increased demand on the electric grid due to significantly increased ZEV use will require additional increases in electric utility construction, which will likely include gas units to make up for the intermittency of renewable resources such as wind and solar. The construction of these facilities, as well as the use of additional gas facilities to meet demand, will have environmental impacts, including impacts on biological resources and increased greenhouse gas emissions and criteria pollutants.
- CARB does not consider how the negative economic impact of this Proposed Regulation on the petroleum industry could result in the abandonment of carbon capture, utilization, and storage technology already being developed, thereby increasing greenhouse gas emissions by eliminating opportunities to mitigate these emissions.
- CARB does not consider how requiring ZEVs will necessitate accessible residential charging stations, which will drive up the costs of housing in the state and could result in housing displacement.
- CARB does not consider the cumulative effects of the factors mentioned above that could result in greenhouse gas emission and other criteria pollutant increases.

WSPA and AFPM ask that CARB fully consider and provide mitigation measures for these factors, as it must do under CEQA. Notably, supporting low-carbon fuels and engine technologies could be a potential mitigation measure, as demonstrated by the previous subsection.[108]

A.7 The ACC II program is preempted by Federal law.

A.7.1 ACC II is expressly preempted by the Energy Policy Conservation Act.

CARB lacks authority to adopt or enforce any regulation "related to" fuel-economy standards under the Energy and Policy Conservation Act (EPCA). While the Clean Air Act grants California certain leeway to address localized pollution, EPCA's broad preemption provision prevents CARB from adopting such regulations when they are "related to" fuel economy,

[108] The Draft EA demonstrates that the Proposed Regulation will have significant environmental impacts that will be important to mitigate. For example, the document notes that increased lithium mining would require expanding existing facilities or constructing new ones in the Salton Sea Area, which "is an important feeding grounds for more than 400 species of birds including waterfowl and shorebirds during annual migration[,] and several bird species also use the area for breeding (USFWS 2021)." Draft EA, at 86. The Draft EA characterizes the impacts of such mining activities to these hundreds of bird species as "potentially significant." *Id.* Additionally, CARB indicates throughout the Draft EA that making electric vehicles will require industrial-scale mining and manufacturing of batteries, which may not occur in California and will generate significant emissions. Likewise, the disposal of spent batteries will have concerning environmental impacts, and California's plan to handle significant increases in the disposal of toxic batteries is unclear.

regardless of any accompanying localized pollution benefits. This provision is self-executing, meaning that no agency action is necessary for it to be effective—the lack of a National Highway Traffic Safety Administration (NHTSA) regulation expressly preempting CARB's program does not affect EPCA's preemptive effect. This provision also contains no waiver.

ACC II is clearly related to fuel-economy standards. Courts have found that state regulations "relate to" federal matters when they have a "connection with" or contain a "reference to" these matters. CARB's SRIA specifically discusses the fuel savings that would result from this rulemaking. CARB cannot avoid EPCA's preemptive effect by characterizing this rule as an environmental regulation despite its clear implications for fuel economy.

A.7.2 ACC II conflicts with important federal statutory objectives.

A critical failing of ACC II is that in its haste to phase-out oil and gas production and refinery industries it does not consider the impact to the remainder of our energy system, including on biofuels (which will be sharply curtailed) and electricity supply (which will be overburdened). A critical failing of ACC II is that in its haste to phase-out oil and gas production and refinery industries, CARB did not consider the impact to the remainder of our energy system, as well as other essential products such as jet fuel, asphalt, petrochemicals, and lubricants. This willful blindness places ACC II on a collision course with multiple Congressionally mandated programs expressly designed to have the *opposite* impact— biofuels (increased and increasing) and electric supply (reliable). Because ACC II undermines and conflicts with the fulfillment of these Congressional objectives, it is necessarily preempted.

It is a "well-established principle that the Supremacy Clause, U.S. Const., Art. VI, cl. 2, invalidates state laws," like ACC II, "that interfere with, or are contrary to federal law."[109] Even where Congress has not completely displaced state regulation in a specific area, state law is nullified to the extent that it actually conflicts with federal law. Such conflicts arise "when compliance with both state and federal law is impossible" and "when the state law 'stands as an obstacle to the accomplishment and execution of the full purposes and objectives of Congress.'"[110] The ACC II program fails on both accounts.

First, Congress' intention to increase production, distribution, and use of biofuels is expressed in no less than three statutes, which do everything from mandating biofuel blending in liquid fuel to incentivizing its production through loans and loan guarantees. Specifically, the ACC II Program conflicts with these federal objectives and deprives federal funding programs of value by mandating complete electrification of the transportation sector. These programs set aside significant funding for the development and use of liquid fuels for transportation, with the expectation that these fuels will continue to play an important role in meeting transportation energy demand for many years.

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109 *Hillsborough Cty., Fla. v. Automated Med. Lab'ys, Inc*., 471 U.S. 707, 712–13 (1985) (citations omitted).

110 *Capital Cities Cable, Inc. v. Crisp*, 467 U.S. 691, 699 (1984) (quoting *Hines v. Davidowitz*, 312 U.S. 52, 67 (1941)); see also *Dowhal v. SmithKline Beecham Consumer Healthcare*, 32 Cal. 4th 910, 923, 929 (2004) (adopting federal construction of preemption issues and finding that "the use of a Proposition 65 warning would conflict with [federal] policy" on a theory of conflict preemption).

The Energy Policy Conservation Act (EPCA)	The Federal Power Act	The Energy Independence and Security Act of 2007 (EISA)
Includes provisions related to the integration of alternative fuels[111] in the transportation sector and requires a "reasonable distribution" of the burden of any energy-use restrictions: • 42 U.S.C. § 6374: Requires alternative fuel use by light duty Federal vehicles • 42 U.S.C. § 6391(b): Prohibition on "[u]nreasonably disproportionate share of burden" between segments of the business community and requires that, "[t]o the maximum extent practicable, any restriction under authorities to which this section applies on the use of energy shall be designed to be carried out in such manner so as to be fair and to create a reasonable distribution of the burden of such restriction on all sectors of the economy"	Provides for investment in alternative fuels through grant programs and loan guarantees: • 42 U.S.C. § 16501: Commercial byproducts from municipal solid waste and cellulosic biomass loan guarantee program – loans by private institutions for the construction of facilities for the processing and conversion of municipal solid waste and cellulosic biomass into fuel ethanol • 42 U.S.C. § 16503: Sugar ethanol loan guarantee program • 42 U.S.C. § 16071: Grant program for the acquisition of alternative fueled vehicles or fuel cell vehicles and the installation of related infrastructure	Includes specific provisions to increase energy security through increased production of biofuels: • Title 42, Chapter 152, Subchapter II: Programs for investment in biofuel research and infrastructure, centered around "increasing energy security," which is of special federal concern Requires blending of increasing volumes of biofuel and other renewable fuels: • 42 U.S.C. § 7545(o)(2)(B)(ii): Establishes requirements related to determining the applicable volume of cellulosic biofuel for the calendar years 2023 and later, based on considerations such as available infrastructure, consumer costs, and energy security

By contrast, ACC II would eliminate any role for these alternative fuels in California by requiring 100% ZEVs and PHEVs by 2035, removing a substantial portion of the demand for these fuels and depriving federal investments of significant value. This deprivation is made worse by the

[111] While EPCA recognizes electricity within its definition of alternative fuels, it is one of a multitude of alternatives in the Act that provide for a diverse energy base preserving flexibility and security. Overreliance on electricity does not reasonably distribute the burden of energy-use restrictions as required by the Act.

potential—indeed California's expectation[112]—that other states may adopt California's engine and motor vehicle emission standards under Section 177 of the Clean Air Act, 42 U.S.C. § 7507 and the potential that manufacturers are unlikely to produce two separate fleets (177 states vs. the rest of the country).[113]

Further, ACC II expressly contradicts EPCA's requirement that any burdens stemming from energy-use restrictions be reasonably distributed across all industry sectors, instead placing the entirety of the burden of these restrictions on the oil and gas production and refinery sector of California's economy.

Second, federal policy explicitly supports "the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth." 42 U.S.C. § 17381. The ACC II program conflicts with this policy by introducing material security and reliability risks to California's electricity grid.

The rapid electrification of the transportation sector will both substantially increase electricity demand in California and increase dependence on electricity services, amplifying the risk that the grid will be targeted for either physical or cyber-attacks. A 2021 Government Accountability Office Report found that "[t]he grid's distribution systems face significant cybersecurity risks—that is, threats, vulnerabilities, and impacts—and are increasingly vulnerable to cyberattacks."[114] According to the report, these risks "are compounded for distribution systems because the sheer size and dispersed nature of the systems present a large attack surface."[115] As demand increases due to accelerated electrification, grid security will pose a greater challenge due to additional resource buildout. Further, the report found that increased use of networked consumer devices that are connected to the grid's distribution systems—including electric vehicles and charging stations—also potentially introduce vulnerabilities because "distribution utilities have limited visibility and influence on the use and cybersecurity of these devices."[116] ACC II's proposed ZEV regulation will therefore introduce new vulnerabilities to the nation's distribution system by significantly increasing the use of consumer devices.

In addition, the increased demand for electricity under CARB's proposed ACC II program will worsen existing instabilities in California's grid, compromising grid reliability in direct contravention of federal policy. During a heatwave in August 2020, nearly half a million Californians lost power. As recently as July 30, 2021, Governor Gavin Newsom issued an emergency proclamation highlighting that California currently faces an energy supply shortage of up to 3,500 megawatts during the afternoon-evening net-peak period of high-power demand

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114 Gov't Accountability Office, *Electricity Grid Cybersecurity: DOE Needs to Ensure Its Plans Fully Address Risks to Distribution Systems*, GAO-21-81, at 11 (Mar. 2021). Available at: https://www.gao.gov/assets/gao-21-81.pdf. Accessed: May 2022.

114 Gov't Accountability Office, *Electricity Grid Cybersecurity: DOE Needs to Ensure Its Plans Fully Address Risks to Distribution Systems*, GAO-21-81, at 11 (Mar. 2021). Available at: https://www.gao.gov/assets/gao-21-81.pdf. Accessed: May 2022.

114 Gov't Accountability Office, *Electricity Grid Cybersecurity: DOE Needs to Ensure Its Plans Fully Address Risks to Distribution Systems*, GAO-21-81, at 11 (Mar. 2021). Available at: https://www.gao.gov/assets/gao-21-81.pdf. Accessed: May 2022.

115 *Id*.

116 *Id.* at 18.

on days when there are extreme weather conditions.[117] ACC II will increase demand despite existing shortfalls, undermining federal requirements targeting increased grid reliability.

Because CARB's proposed ACC II program conflicts with and presents an obstacle to clearly-stated federal objectives, CARB lacks the authority to promulgate these regulations—and indeed is preempted from doing so.

A.8 CARB ban on ICEVs constitutes a regulatory taking.

CARB's plan to eventually phase out the sales of all ICEVs constitutes a regulatory taking.[118] A regulatory taking occurs when a policy "substantially interferes with the ability of a property owner to make economically viable use of, derive income from, or satisfy reasonable, investment-backed profit expectations with respect to the property." *Jefferson St. Ventures, LLC v. City of Indio*, 236 Cal. App. 4th 1175, 1193–94.

The Associations' members have invested substantial amounts of money in making their oil facilities safe and productive, and therefore, have significant investment-backed expectations with respect to their properties, at least some of which may be forced to close as a result of CARB's electric vehicle mandate. California landowners also would be harmed. Landowners across the state receive royalties from renting their land to companies. Policies that shut down oil facilities would prevent companies and California landowners from realizing these investment-backed expectations. Thus, such policies would constitute a regulatory taking based on their substantial interference with these expectations, and the state would be obligated to provide just compensation for companies' and landowners' losses.

Therefore, as CARB considers the potential costs of policies that would shut down oil facilities, it should—at a minimum—account for the estimated costs of just compensation for the loss of property use and investment-backed expectations that would inevitably result

117 Governor Gavin Newsom, *Proclamation of a State of Emergency* (July 30, 2021). Available at: https://www.gov.ca.gov/wp-content/uploads/2021/07/Energy-Emergency-Proc-7-30-21.pdf. Accessed: May 2022.

118 *See* Cal. Const. art. I, § 19; U.S. Const. 5th Amend.

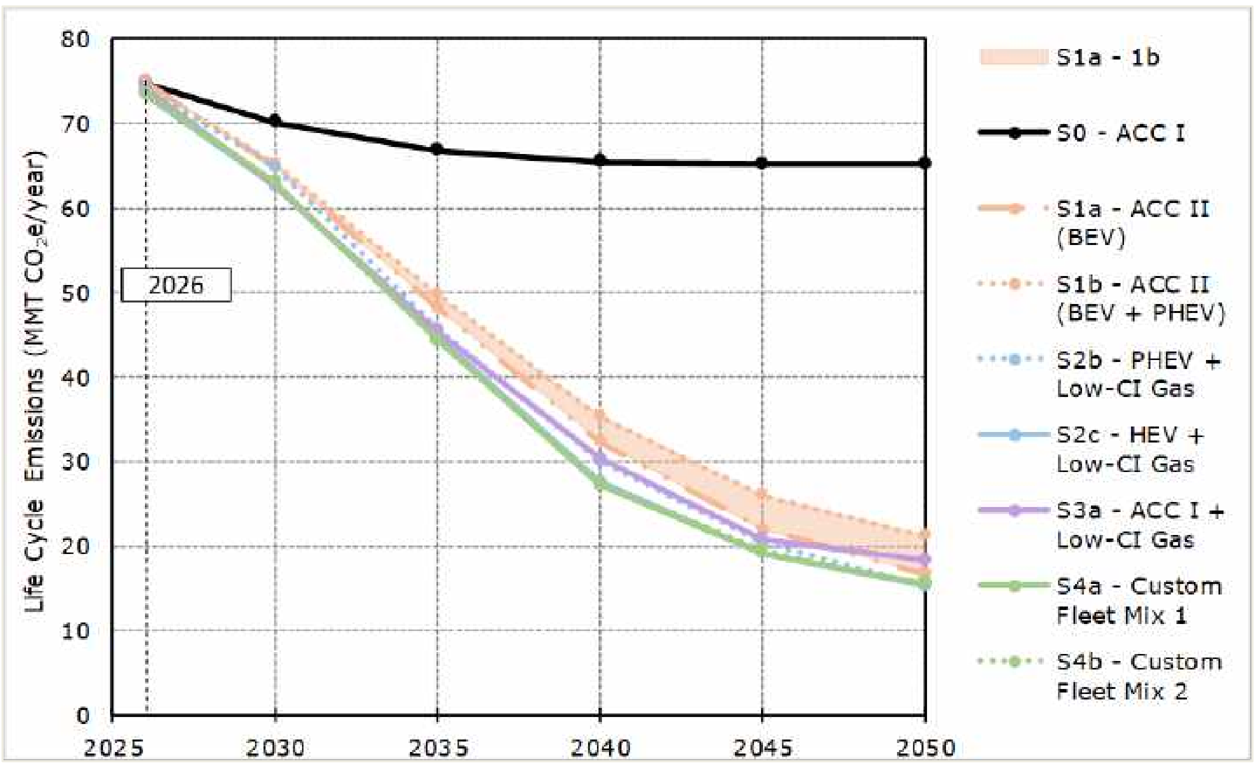
ATTACHMENT B
Technical Comments

B.1 CARB must set a technology neutral performance-based standard rather than the ZEV mandate that is currently proposed under the ACC II regulation.

Despite multiple comments by WSPA and other stakeholders over the last two years, CARB has explicitly insisted on the ZEV technology mandate in its ACC II proposal. It has failed to justify this mandate or make an argument that only the mandate can achieve the State's GHG or criteria pollutant goals. It also failed to analyze the full life cycle impacts of ZEVs, which precludes a true technology neutral comparison and overestimated ACC II GHG reductions (refer to **Comment B.3** below for further details).

WSPA contracted with Ramboll to produce the type of technology neutral study of LDVs that analyzes the full life cycle[119] GHG emissions of each technology/fuel ("Ramboll LDA Study") for the statewide light duty automobile fleet. This study (included in **Attachment D**) conclusively shows that performance standards could be an alternative to a ZEV mandate.

Figure B-1: Life Cycle Emissions for Key Scenarios



The Ramboll LDA Study shows that a gradual transition to low-CI gasoline (represented by the purple line in **Figure B-1**) with current vehicle technologies could achieve similar life cycle GHG emissions as the current ACC II proposal (represented by the pink shaded region in **Figure B-1**). The reason for this is that GHG emissions associated with zero emission vehicles are not

119 Emissions associated with vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling.

zero. The GHG emissions for the "vehicle cycle" for BEVs is significantly higher than other vehicle technology types (see **Comment B.3** for additional details).

CARB must consider alternatives such as low-CI fuels because there is not a one-size-fits-all solution to reducing transportation sector GHG emissions, and it allows for more flexibility in the transition towards lowering transportation GHG emissions in the short and long-term. Other technologies also realize similar or lower emissions on a life cycle basis compared to the ACC II proposal. These include hybrid electric vehicles (HEVs) coupled with low-CI fuel (represented by blue solid line in **Figure B-1**), plug-in electric hybrid vehicles (PHEVs) coupled with low-CI fuels (represented by the blue dotted line in **Figure B-1**), and a combination of HEVs, PHEVs, and BEVs with low-CI fuels (represented by the green solid and dotted lines). These alternative pathways would also not require the wholesale transformation of electric energy production and distribution infrastructure on an unprecedented short time scale, but they would allow battery, hydrogen, and low-carbon intensity gaseous and liquid fuelled vehicles to compete to achieve the State's GHG targets for light-duty transportation in the quickest and most cost-effective manner.

CARB could craft a regulation based on a GHG-reducing performance standard such as the LCFS instead of a ZEV sales mandate, which would be more consistent with traditional regulations that rely upon innovation within existing marketplaces. The Ramboll LDA Study shows that such an approach could dramatically reduce GHG emissions without the systemic cost and delay risks associated with the current ZEV-centric strategy that include, but are not limited to, electric generation/infrastructure development, zero emission technology readiness/feasibility, and cost.

B.2 The justification for not including an alternative analysis for "Low-Carbon Fuel Technology in lieu of ZEV Requirements" due to the inability to enforce low-carbon fueling is contradicted by the mechanisms included in the current Low Carbon Fuel Standard (LCFS).

While CARB states that they considered a low-carbon fuel technology alternative to the proposed ACC II, they rejected this alternative without analysis by claiming that this type of performance-based regulation would not be "verifiable or enforceable".[120] The conclusion appears without foundation given that CARB presently administers the LCFS program, which contains established mechanisms for verification and enforcement for such a performance-based alternative. CARB acknowledges that a low-carbon fuel technology alternative may reduce GHG emissions in the near to mid-term but fails to perform an environmental or benefit-cost analyses as required by the California Environmental Quality Act (CEQA), to assist with the process of identifying the environmentally superior alternative.

California has led the nation in the use of lower-CI fuels through its LCFS regulation, which relies on market-based mechanisms that deliver sustainable GHG emission reductions without a technology-based mandate. Further, the LCFS is poised to drive further reductions in carbon

[120] Draft Environmental Analysis (EA) for the Proposed ACC II Program. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

intensity through market incentives that will produce opportunities for carbon capture and sequestration and numerous novel low-carbon fuel pathways. CARB Executive Officer Richard W. Corey described the LCFS program as "catalyzing investments in these cleaner alternative fuels, providing consumers with more choices, and reducing emissions of toxic pollutants and greenhouse gases."[121] The assertion that there is an inability to enforce low-carbon fueling discredits all the progress that the LCFS program has made over the past 10 years and is simply incorrect. CARB has claimed leadership in this space, encouraging billions of dollars of investments in developing low-carbon fuel solutions for the California market. Before arbitrarily declaring that the program is unenforceable, CARB must give serious and robust consideration to the LCFS as an alternative approach.

By employing market-based approaches instead of instituting zero emission technology mandates, CARB would allow for innovation within existing marketplaces to dramatically reduce GHG emissions without the systemic risks associated with the ZEV-centric approach concerning electric/hydrogen infrastructure development, zero emission technology readiness, and cost.

B.3 CARB did not conduct a full life cycle greenhouse gas (GHG) emissions analysis for the vehicle/fuel system to assess GHG emission impacts of their proposal and alternatives, and thus have under-represented the full emissions impact of the regulation.

The current ACC II proposal does not consider the life cycle emissions for "zero emission" vehicles, assess GHG emissions leakage outside of the state of California that would be caused by the ACC II proposal, or include a technology-neutral analysis of alternatives that could meet the GHG reduction goals. Simply put, the ACC II proposal focuses on a complete transition to zero-emission vehicle (ZEV) without consideration of other vehicle technologies or a future role for renewable fuels.[122] In the ISOR analysis, there were several stages of the emissions assessment that were excluded. The pieces of life cycle GHG emissions that were excluded from the analysis include:

- Upstream fuel cycle GHG emissions from out-of-state fuel production and transportation activities for California reformulated gasoline (CaRFG) and hydrogen (H_2), and
- GHG emissions associated with vehicle production changes required by the proposed regulation; this could be significant particularly for minerals extraction and processing and battery production, transportation, and disposal impacts for battery electric vehicles (BEVs) that are not part of the baseline for internal combustion engine vehicles (ICEVs).

Figure B-2 below outlines the scope of the CARB ACC II emissions assessment and shows what components were included/considered and what was noticeably missing from the ISOR

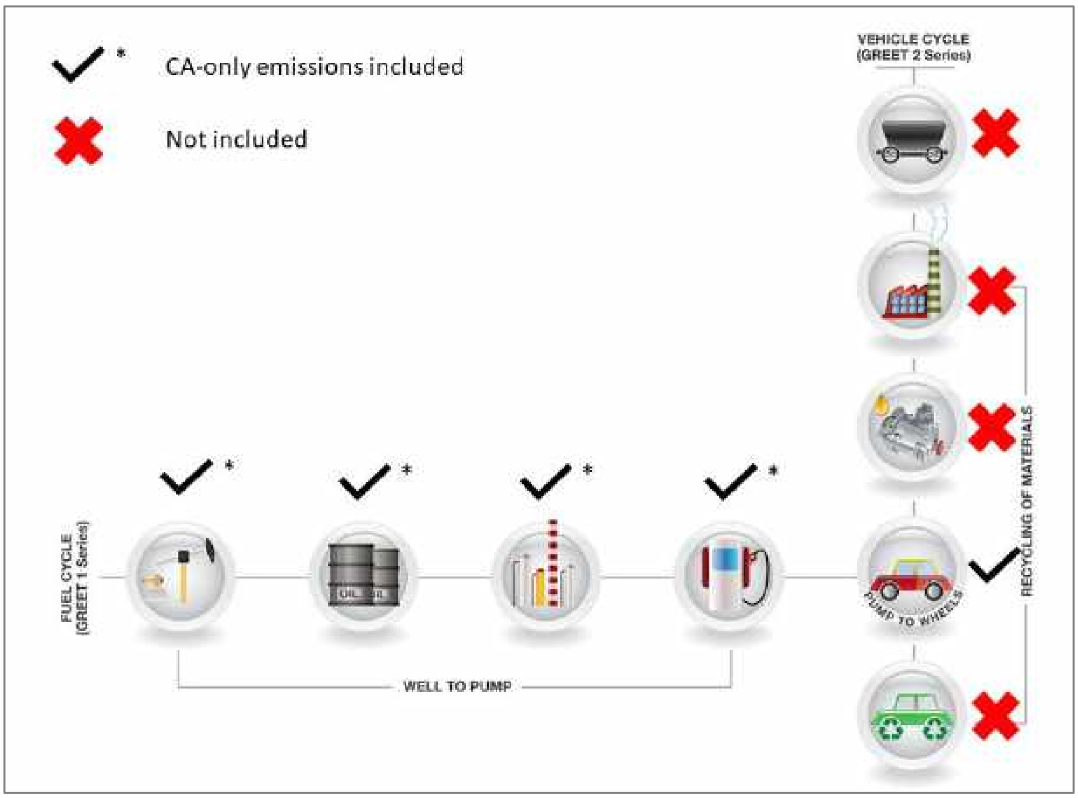
[121] Cleaner fuels have now replaced more than 3 billion gallons of diesel fuel under the LCFS. Available at: https://ww2.arb.ca.gov/news/cleaner-fuels-have-now-replaced-more-3-billion-gallons-diesel-fuel-under-low-carbon-fuel. Accessed: May 2022.

[122] Note that this is inconsistent with Federal mandates under the Renewable Fuel Standard to promote domestic production and consumption of renewable fuels in domestic transportation. 42 U.S.C. 7545.

analysis. This figure was adapted from the GREET website and shows the components that make up a comprehensive vehicle life cycle assessment.

CARB has claimed that only in-state emissions for fuels were included due to an AB 32 emission boundary at state lines. However, this boundary is a regulatory-based line that is not representative of the actual behaviour of GHG emissions. GHG emissions are global pollutants that enter the atmospheric carbon stock and cause global consequences, no matter the point of origin. CARB must assess the full life cycle emissions associated with this regulation, regardless of location of the emission. Any assessment that does not recognize these impacts misrepresents the actual environmental effects of the proposed regulation and would lead to factually incorrect conclusions that undermine any rationale for adoption of the proposed rule.

Figure B-2. CARB ACC II Emissions Assessment Scope[123]

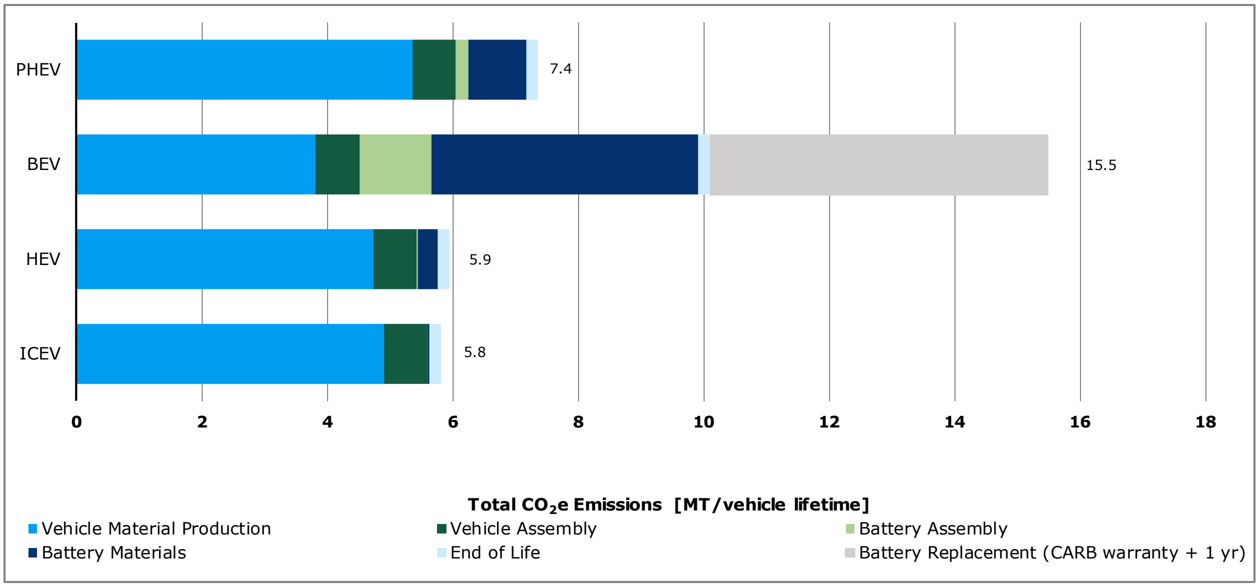


Ramboll conducted an analysis of California's light-duty auto (LDA) fleet to evaluate whether alternative vehicle technology and fuel pathways could achieve life cycle GHG emission reductions similar or greater than the ACC II proposal ("Ramboll LDA Study", included in **Attachment D**). Unlike the ISOR analysis, Ramboll has evaluated the full life cycle impacts of ZEV technologies under the ACC II proposal to more completely characterize the potential near-term and long-term GHG emissions performance and consider other pathways that would not require a replacement of the entire transportation infrastructure system.

123 GREET Model Home Page. Available at: https://greet.es.anl.gov/. Accessed: May 2022.

Vehicle cycle emissions[124] were not considered in the ISOR analysis but should be included due to the large differences in these emissions between ZEVs and ICEVs. The Ramboll LDA Study found that the vehicle cycle emissions for a model year 2026 BEVs (10.1 metric tons (MT) CO_2e per vehicle) was about 74% higher than those for a MY 2026 ICEV (5.8 MT CO_2e per vehicle) (see **Figure B-3**). If the BEV undergoes a battery replacement during its lifetime, its vehicle cycle emissions increase to 15.5 MT CO_2e per vehicle, which is ~167% higher than those of an ICEV. The significant emission increases associated with the production of a BEV, as compared to an ICEV, must be included in the ISOR emission analysis to fully understand the impacts of the proposed ACC II regulation.

Figure B-3: Vehicle Cycle GHG Emission Factors for Different Vehicle Technologies



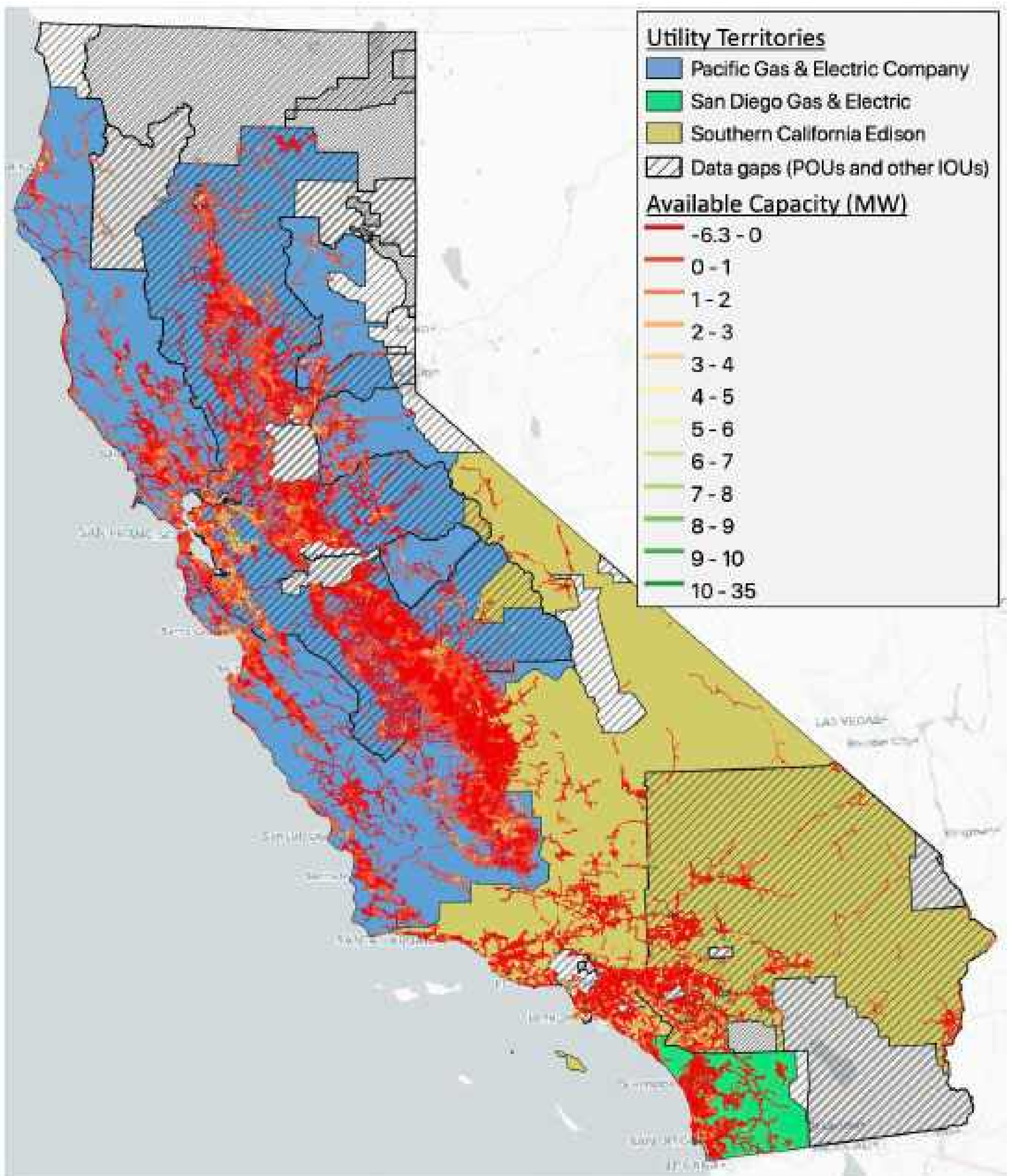
B.4 CARB does not discuss the potential impact to the California electric grid from this regulation including requirements for new and upgraded generation, transmission, and distribution.

CARB has not provided any analysis of the feasibility of the proposed regulation given the significant increase of charging infrastructure, electrical generation and transmission and distribution infrastructure that would be required to support a ZEV fleet. The Capacity Analysis from CEC's EDGE Model (**Figure B-4** below, obtained from Page 48 in the Draft EA[125]) shows the grid has no additional capacity to add electrical load for charging for most of these circuits. You can see this in numerical terms in **Figure B-5** (obtained from Virtual Medium and

124 Emissions associated with vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling.

125 Draft Environmental Analysis (EA) for the Proposed ACC II Program. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

Figure B-4: Capacity Analysis from CEC's EDGE Model[126] (dark red indicates no available additional capacity)

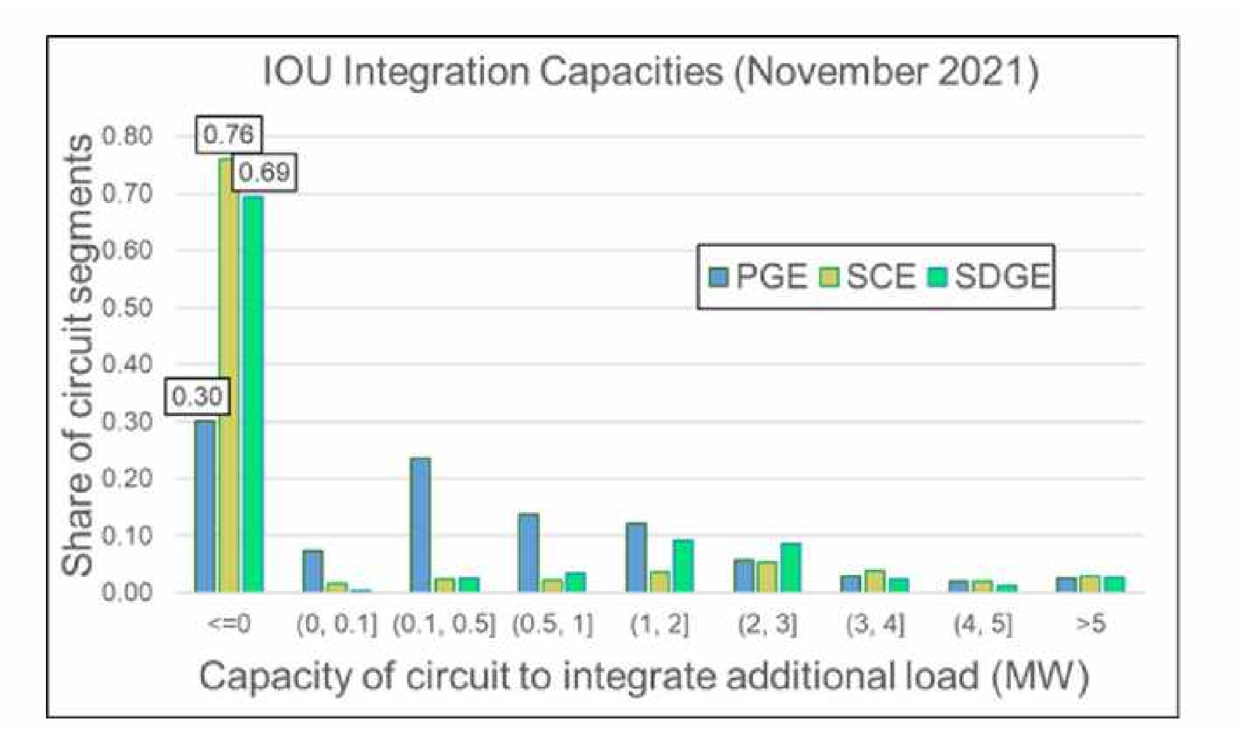


[126] Draft Environmental Analysis (EA) for the Proposed ACC II Program. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

Heavy-Duty Infrastructure Workgroup Meeting - Electricity and the Grid on January 12, 2022[127]), which details the capacity of circuits to integrate additional load. This figure illustrates that 30% to 76% of circuit segments have no capacity to integrate additional load. Thus, no appreciable charging capacity can be added to most of these circuits without the expenditure and time for additional construction of needed transmission and distribution infrastructure.

CARB has cited growth in the electric utilities sector and noted that new infrastructure will be needed to support this transition, however, they have failed to account for the costs of the infrastructure needed for this regulation in the SRIA,[128] and have instead ascribed benefits to the electric utilities sector for job growth. This is misleading, and CARB must evaluate the full economic impact to electric utilities as a result of this regulation rather than just account for the benefits while ignoring the required costs associated with this transition.

Figure B-5: Capacity of circuits to integrate additional loads[129]



127 Virtual Medium and Heavy-Duty Infrastructure Workgroup Meeting - 01/12/22. Available at: https://www.youtube.com/watch?v=_mr0TmwxGZQ. Accessed: May 2022.

128 Standardized Regulatory Impact Assessment (SRIA) for the for the Proposed ACC II Program. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

129 Virtual Medium and Heavy-Duty Infrastructure Workgroup Meeting - 01/12/22. Available at: https://www.youtube.com/watch?v=_mr0TmwxGZQ. Accessed: May 2022.

B.5 The proposed ACC II strategy will place further stress on California's strained electric infrastructure and does not address measures to ensure stability and reliability of the grid during public safety power shut-off (PSPS) events.

There have been increasing number of PSPS events in California over the last five years, due in large part to an aging electrical transmission and distribution infrastructure that utility companies in California have neglected to maintain in order to reduce their costs and increase profits.[130] In 2019, PG&E explained to the California Public Utilities Commission (CPUC) that it would take 10 years to decrease PSPS event severity significantly,[131] and this does not include all the additional upgrades that will now be needed as a result of the requirements in the proposed ACC II regulation. The proposed ZEV strategy may leave California particularly vulnerable to PSPS events, which would eliminate the ability to recharge ZEVs. CARB claims that vehicle-to-grid (V2G) technology would help solve PSPS event issues, but this is assuming that a consumer would consent to feeding their electricity back into their house without knowledge of when the power would be restored. Electrical grid upgrades are needed to prevent PSPS events and increase the stability and reliability of the electric vehicle charging infrastructure. This is an issue unique to electricity as a fuel and must be analyzed. Meanwhile, the Renewable Portfolio Standard (RPS) mandates increased reliance on renewable power sources such as solar and wind, which has already posed challenges to the reliability of the California electrical grid. CARB must consider the impacts of rolling blackouts, higher utility costs, destabilization of industrial operations, and other foreseeable consequences of shifting significant additional power demand onto the grid.

B.6 CARB has failed to account for the full costs associated with the charging infrastructure and grid infrastructure upgrades in their benefit-cost analysis of the proposed ACC II regulation.

CARB estimated a benefit-cost ratio of 1.17 for the proposed ACC II regulation in the recently released SRIA[132]. This value was calculated as a ratio of the benefits associated with the rulemaking to the total costs for vehicle ownership. The list of benefits considered for this benefit-cost ratio calculation include: cost of ownership savings (gasoline fuel costs, maintenance and repair costs, electricity cost savings from V2G integration), health benefits associated with avoided health outcomes of fine particulate matter ($PM_{2.5}$) emissions, and changes in tax/fee revenues for state and local governments. The total costs for vehicle ownership include vehicle price, charger price for single family homes, sales tax, fuel (electricity and hydrogen) cost, insurance, and registration.

While the costs considered in the calculation include charger costs for single family homes (detached, attached, duplex, triplex, and quad), CARB has not accounted for the costs

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130 Preventing Wildfires with Power Outages. Available at: https://www.psehealthyenergy.org/news/blog/preventing-wildfires-with-power-outages-2/. Accessed: May 2022.

131 Ibid.

132 ACC II Standardized Regulatory Impact Assessment (SRIA). Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

associated with multi-family residential, public, and workplace chargers which would include direct current (DC) fast charging stations. CARB claims that the "*capital cost of public charging infrastructure is assumed to be passed through to the consumer via refueling rates*".[133] Upon further review, it appears that the commercial/residential fueling (electricity) rates used in the SRIA were developed based on the fuel forecasts in the California Energy Commission's (CEC's) 2021 Integrated Energy Policy Report (IEPR).[134] While the 2021 IEPR notes that the key driver of electricity rates is the cost of investment in the grid infrastructure (including chargers) to meet state policy goals, it also states the that the demand forecasts "*do not incorporate currently nonexistent policies, such as [the proposed] Advanced Clean Cars II*". Hence, the electricity rates do not account for the costs associated with these (multi-family residential, public, and workplace) chargers. We estimated a total cost of **$13 - 24 billion** for these chargers using the charger purchase and installation costs (**Table B-1**) from South Coast Air Quality Management District's (SCAQMD's) Final Staff Report for the Warehouse Indirect Source Rule[135] and projected number of chargers (**Table B-2**) required for the implementation of the ACC II from the Draft 2022 State Strategy for the State Implementation Plan.[136] If just the costs associated with multi-family residential/public/workplace chargers were accounted for in the ACC II SRIA benefit-cost analysis, the benefit-cost ratio would fall to 1.08-1.12.

133 See Page 169 in the SRIA.

134 Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=241581. Accessed March 2022.

135 Available at: http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2021/2021-May7-027.pdf?sfvrsn=10. Accessed: May 2022.

136 Available at: https://ww2.arb.ca.gov/sites/default/files/2022-01/Draft_2022_State_SIP_Strategy.pdf. Accessed: May 2022.

Table B-1. Electric Vehicle Charger Purchase and Installation Costs

EV Charger Cost Item	EV Charger Type[1]	EV Charger Level[2] (kW)	Cost Range[2] ($/charger)	
			Low Estimate	High Estimate
Purchase	LDV DC Fast Charger	19.2-50	$10,000	$30,000
	LDV Level 1 and 2 Chargers	up to 19.2	$3,000	$5,000
Installation	LDV DC Fast Charger[3]	19.2-50	$10,000	$16,518
	LDV Level 1 and 2 Chargers	Level 2	$5,000	$10,000

Notes:

1 EV charger types based on charger levels presented in SCAQMD Warehouse ISR Staff Report.

2 Data obtained from Table 18 in Appendix B of the Final Draft Staff Report Proposed Rule 2305 – Warehouse Indirect Source Rule. Available at: http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2021/2021-May7-027.pdf?sfvrsn=10. Accessed March 2022.

Abbreviations:

$ - dollars, DC – direct current, EV – electric vehicle, LDV – light duty vehicle, SCAQMD – South Coast Air Quality Management District

Table B-2. Charger Costs Not Accounted for in the ACC II SRIA			
Charger Type	**Additional Chargers Needed (2026-2037)[1]**	**Low Estimate[2] (millions of $)**	**High Estimate[2] (millions of $)**
MUD (Level 1/2) Charger	420,073	3,361	6,301
Public Level 2 Charger	585,490	4,684	8,782
Work Level 2 Charger	470,133	3,761	7,052
Public DC Fast Charger	43,531	870	2,025
	Total Cost	12,676	24,160

Notes:

[1] Data obtained from Draft 2022 State Strategy for the State Implementation Plan, Figure 25. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-01/Draft_2022_State_SIP_Strategy.pdf. Accessed: March 2022.

[2] Charger costs estimated as a product of the additional chargers needed (shown in this table) and the sum of the purchase and installation costs for a charger (obtained from Table A-1).

Abbreviations:

MUD - Multi-unit dwellings, DC – Direct Current

Additionally, CARB has failed to account for the electricity grid infrastructure (generation, distribution, and transmission) upgrade costs that would be necessary to support the additional load demand generated from the ACC II proposal. While the SRIA acknowledges that there would be tremendous growth in the electricity grid infrastructure and estimates the benefits of job growth in this sector, it remains silent on the costs associated with this grid infrastructure upgrades and development. As noted in the 2018 E3 Deep Decarbonization in a High Renewables Future Report (2018 E3 Report), these costs could be significant. For example, the cumulative cost for electric grid infrastructure development and maintenance for a high electrification scenario that includes the deployment of 35 million ZEVs is of $1.55 trillion from 2026-2050.[137] This value is $378 billion higher than the current policy reference case that was evaluated in that 2018 E3 Report. (Refer to Table A-3 for further details on the current policy scenario and the high electrification scenario). Hence, CARB must include the costs associated with the electricity grid infrastructure updates needed for the implementation of the proposed ACC II in their benefit-cost analysis.

[137] The grid infrastructure costs accounted for in the 2018 E3 Report include: capital, operations and maintenance (O&M), administrative, and taxes.

Table B-3. 2018 E3 Report Scenario Descriptions

Scenario Parameters	E3 CEC Study[1]	
	Reference Scenario (CEC 2018 Policy)	**High Electrification Scenario**
Meets California's 2050 GHG Emission Reduction Target?	No	Yes
Meets California's 2030 LD ZEV Targets?	No, 4M LD ZEVs	Yes, 6M LD ZEVs
2050 ZEV Population (percentages as fraction of EMFAC[2] in-state fleet in 2050)	24M LD ZEVs (68%) 303k MD/HD ZEVs (4%)	35M LD ZEVs (100%) 1.3M MD/HD ZEVs (18%)
2050 Electric Grid Mix	50% Renewable (2030 through 2050)	95% Zero Carbon 70% Renewable
2050 Building Electrification	None (2030)	91% Building Energy is Electric
2050 Total Electricity Demand (TWh)	378 TWh	456 TWh
Cumulative Cost for Electric Grid Infrastructure 2026-2050 (Trillions of $)[3]	$1.17	$1.55

Notes:

1 E3 2018 Deep Decarbonization PATHWAYS Report. Available at: https://www.ethree.com/projects/deep-decarbonization-california-cec/. Accessed April 2022.
2 EMFAC2017. Available at: https://arb.ca.gov/emfac/emissions-inventory. Accessed April 2022.
3 The grid infrastructure costs accounted for in the 2018 E3 Report include: capital, operations and maintenance (O&M), administrative, and taxes.

Abbreviations:

AEO – Annual Energy Outlook, BEV – battery electric vehicle, CEC – California Energy Commission, EIA – Energy Information Agency, HD – heavy duty, LD – light duty, M – Million, NZA – Net Zero America, TWh – terawatt hour, ZEV – zero emission vehicle

B.7 The ISOR overestimates the potential benefits associated with the vehicle-to-grid (V2G) technology.

CARB has assumed there would be savings associated with V2G technology as seen in total cost of ownership calculations. These savings begin in 2027 at $2 million, increasing over time to $5.3 billion by 2040. The cumulative savings for V2G technology are nearly 40% of the total net savings as a result of the ACC II proposal and are therefore a significant driver in the benefit-cost ratio calculation. CARB has described these purported benefits, without accounting for the costs of V2G technology on the lifetime and warranties for battery electric vehicles (BEVs). If the batteries in BEVs are used as a source of power for homes, this would increase the number of vehicle battery charging cycles without adding miles which will negatively impact the battery state of health and the lifetime. Further, BEVs currently available in the market are not intended to be used in this fashion. Hence, there is potential for the battery warranty to be voided with such use. There is no mention of V2G technology in the draft regulatory language for BEVs in the proposed ACC II.[138] Hence, warranty requirements for future BEVs manufactured to meet the sales requirements of ACC II may preclude V2G technology from being used on these vehicles. Assuming benefits for V2G technology without considering the potential cost impacts to the vehicle battery lifetime and warranty results in a one-sided benefit-cost evaluation. Additionally, CARB has assumed that up to 25% of BEV owners in single-family homes will partake in this use case, without any factual basis or hard references for these assumptions. Because of this, the savings calculated as a result of these numbers must be re-evaluated and considered carefully in the benefit-cost analysis. CARB should update the SRIA to present a more complete analysis.

B.8 CARB erroneously claims that because the proposed program will divert energy from fossil fuel-powered systems to an increasingly renewable electrical system, the regulation will not result in a significant cumulative impact related to energy, grossly oversimplifies the efforts that will be required to achieve this transition.

CARB appears to be arguing that a unit of energy is fungible regardless of its source (i.e., from the electrical grid or from liquid fuels) and that because the net consumption of energy for fueling will decrease as a result of this transition, the overall impacts to the energy sector will be less than significant. This assumption is fundamentally flawed because these two energy systems (the electrical grid and liquid fuels) are wholly independent.

The challenges associated with increasing the supply in the electrical grid will include complications of mismatched renewable energy supply and demand (i.e., duck curve), upgrading the grid infrastructure (generation, storage, transmission, and distribution) to accommodate increased electric vehicle charging.

The renewable energy supply versus demand curve (i.e., duck curve) is one example of a barrier that is unique to renewable energy that will need to be considered during the transition to electric vehicles alongside the transition to 100% renewable grid electricity. California has abundant solar energy generated during the day when demand is low and lower supply of renewable energy at night paired with higher demand when residents will want to charge their electric vehicles and power other appliances once they get home from work. This imbalance calls for advanced efforts to plan EV charging events and make improvements to the grid infrastructure to accommodate the increased demand at off-peak hours. Based on the ACC II

[138] Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa9.pdf. Accessed: May 2022.

SRIA, residential charging is projected to be the second cheapest form of charging an electric vehicle battery for the foreseeable future.[139] Electric utilities will have to work with EV users to implement smart charging measures that do not exacerbate the duck curve. This planning may include increasing investment in energy storage devices that can be used to supply power at off-peak periods (I.e., night-time) when BEV users will charge their cars.

This proposed regulation will require an increase in electrical consumption on the scale of terawatt-hours (TWh's) on an annual basis. The impacts of this increased demand to the State's electrical generation, distribution, and transmission systems must be analyzed. CARB cannot assert without evidence that renewable energy would be available for the increased demand for electrical generation without impacts to the existing grid infrastructure.

The ISOR assumption that the regulation will not have a significant cumulative impact related to energy does not consider the factors described above that will generate additional stress on the electric grid. The challenges that renewable electricity presents must be analyzed, and there is no credible basis to assume that there will be no cumulative impact to energy as a result of this transition to ZEVs.

Additionally, CARB has not considered any alternatives that minimize the number of stranded liquid fuel infrastructure assets or addressed the economic impact of these stranded assets that will result by the adoption of the ACC II proposal. If this regulation were to consider a technology-neutral approach, there could be potential for existing liquid fuels infrastructure to be converted from carrying fossil fuels to renewable fuels. This has already been demonstrated by the conversion of some refineries to renewable fuel facilities.[140] There are over 14 refineries currently located in California and the total input capacity is more than 1.7 million barrels per day.[141] The liquid fuel network in California is already extensive and fully built out to scale. Hence using this existing network for the production and distribution of renewable fuels presents a lower risk scenario compared to an unprecedented rate of electrical grid infrastructure development on which the implementation of the current ACC II proposal would require.

B.9 CARB has not fully assessed the economic impact the proposed regulation would have on the liquid fuels supply chain.

CARB assumes that gasoline prices will follow the current CEC IEPR fuel price projection but has not assessed the impacts a technology mandate could have on these prices and how this will affect the domestic and foreign supply-chains. As discussed in the Stillwater Study[142] if the proposed regulation goes into effect as currently written, there will be a 66% decrease in gasoline sales by 2035 and a 90% decrease by 2050. Gasoline and petroleum-based diesel

139 ACC II Standardized Regulatory Impact Assessment (SRIA). Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

140 Possible Market Implications of California's Efforts to Ban Internal Combustion Engines. Available at: https://stillwaterassociates.com/possible-market-implications-of-californias-efforts-to-ban-internal-combustion-engines/. Accessed: May 2022.

141 Ibid.

142 Ibid.

demand will be reduced to 1 billion gallons per year, which is less than half of what is produced by a moderate California facility today. As a result of this, it is likely California will consolidate or eliminate the entire petroleum refining industry in the State and shift to imported finished product (See the Stillwater Study[143] and **Attachment E**). This will lengthen the supply chain and threaten the security of supply. Capitol Matrix Consulting predicts that per-gallon petroleum prices will increase as a result of this increased importation of finished product as the supply-chain is lengthened and the fixed costs for distribution and sale of gasoline are spread over a decreasing number of customers (**Attachment E**). CARB has addressed the job and income-related impacts of declining oil and gasoline production, refining and distribution in California, but has not addressed the long-term impacts to the gasoline and diesel prices in the state and the impact this would have on consumers and the economy.

B.10 The ISOR assessment of the prices of ZEVs is unfounded and leads to a skewed cost assessment that does not fully capture the cost of ZEVs to consumers.

The ISOR estimates of the future ZEV price declines do not consider the supply-chain constraints that could have an impact on the cost of the ZEVs. Capitol Matrix Consulting (CMC) completed a review of the impact of ACC II on California Businesses (**Attachment E**) and notes that CARB has assumed a continued decrease in battery costs of ~7% per year from 2020-2030 and ~5% annually from 2030-2035. CMC found that this does not take into account key factors that drive battery prices up such as supply constraints and worldwide demand for battery-powered vehicles. CMC cites that battery prices are rising in 2022 due to increases in prices of battery-related metals. These prices could potentially continue to increase as there is a continued growing uptake of battery-powered vehicles, and this would be further exacerbated by the additional demand generated by the implementation of the ACC II proposal.

CMC estimated the resulting incremental purchase price of a EV pickup would be $16,000 in 2026 and nearly $10,000 in 2035, if the recent uptick in battery prices was taken into account and the future price decline assumptions in the SRIA were cut in half. CARB should re-evaluate they assumptions for BEV vehicles update their cost-effectiveness and benefit-cost ratio analysis to reflect the recent market trends noted in CMC's analysis (**Attachment E**).

The ISOR analysis does not address distributional impacts of the Proposed ACC II regulation. CMC also conducted a review of the distributional impacts of the ACC II proposal (**Attachment F**) and found that the incremental cost for a BEV compared to an ICE vehicle with similar features, capabilities, and range is $12,000 or more for small passenger vehicles, and well over $20,000 for high-end sedans, SUVs, and pickup trucks. The increased expenditures required to purchase and maintain a ZEV will be disproportionally felt by lower- and middle-income households. CARB must consider these cost implications when evaluating the proposed rule.

143 Ibid.

B.11 CARB has not demonstrated that ZEVs will meet the long-distance use cases of customers, and therefore has not demonstrated that this regulation will achieve the claimed GHG emission reductions.

The ISOR analysis has not definitively shown that BEVs will be used as a one-to-one replacement for ICEVs, which may lead to a use case that has not been addressed in the environmental assessment as currently written. The Stillwater Study[144] on Possible Market Implications of California's Efforts to Ban ICEs states that ZEVs are expected to provide only 65-95 percent of the vehicle miles travelled by their gasoline counterpart. The Study also notes that ICEVs would be typically used for infrequent long-distance trips which contribute to a majority of the GHG emissions, because today's long-range ZEVs with supercharger recharging add significantly more travel time on long trips.

While BEV ranges have continued to improve, the charging times have still lagged, and consumers may continue to use ICEVs for long-range range trips even past 2035 while they still own these vehicles if battery and charging technology do not improve significantly. CARB must consider a technology-neutral alternative, which could allow liquid fuel alternatives that would meet a performance-based standard. This could allow a phase-in of low-carbon drop-in replacement fuels that could be used in an ICEV, PHEV or HEV, thus generating near- and long-term GHG reductions for long-range applications.

B.12 CARB has not proven that consumers will be able to buy ZEVs on the schedule outlined in the rule.

While the ISOR analyses indicates that the total cost of ownership of ZEVs are less than their ICEVs counterparts, they have not evaluated if consumers will have the capital necessary to invest in ZEVs which have a higher purchase price than ICEVs. Capitol Matrix Consulting (CMC) completed a review of the impact of ACC II on California Businesses (**Attachment E**) and found that the ACC II regulation could lead to a "loss of customer discretionary income tied to higher ZEV purchase prices". As a result, customers who do not want to give up their extra discretionary income may postpone the purchase of a ZEV, resulting in lower ZEV sales rates than those assumed under the current ACC II proposal.

While CARB claims that the purchase price of ZEVs will drop rapidly in the future (~7% annually from 2026-2030 and ~5% annually from 2030-2035), current market trends indicate otherwise (refer to **Comment B.10** for further details). Affordability of ZEVs has not been guaranteed by the proposed ACC II regulation, leaving consumers with very few choices for affordable ZEVs. CARB must consider customer-related impacts of the proposed ACC II as described in the CMC analysis (**Attachment E**) while evaluating the feasibility and cost-effectiveness of their proposal.

[144] Ibid.

B.13 CARB has provided no foundation for the conclusion that the Proposed Program "would not result in a cumulatively considerable contribution to a significant cumulant impact related to mineral resources."

CARB has not assessed the amount of mineral resources that would be required for this regulation, and therefore has no factual basis to conclude that the impact "would be generally small when viewed in the context of global lithium markets."[145] Nor has CARB developed the factual record needed to conclude that other mineral resources needed to meet ACC II are adequate.

The findings of the 2021 International Energy Agency's report titled *The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions*,[146] indicate that a typical electric car would require six times the amount of mineral inputs compared to a conventional vehicle. This report also stated that the rapid deployment of clean energy technologies (including EVs) would result in a significant impact on mineral resources, and that there are currently not enough of these resources available to meet this demand.

CARB must provide a basis for their significance argument, including but not limited to an estimate of the minerals required to manufacture the ZEVs mandated by this proposed regulation, the potential strain on global mineral resources, and impacts to the global supply chains for lithium, cobalt, nickel, and other critical minerals. The assessment should include sensitivity analysis to determine how costs and availability may be affected by mineral scarcity and global supply chain disruptions.

While CARB did not provide mineral resource estimates for the proposed regulation, CARB does provide an estimate for the projected annual increase in battery production in Table 4 of the Draft EA.[147] These projections show an annual increase in battery production, ranging from 43.2 gigawatt-hours (GWh) in 2026 to 150.8 GWh in 2035. The recently released Assembly Bill (AB) 2832 Lithium-ion Car Battery Recycling Advisory Group Final Report cites that over 60 GWh of Li-ion battery capacity has been deployed in the US EV market from 2010-2020.[148] In the current proposal, CARB expects that two-thirds of this capacity that was deployed over the last decade, would be made available during the first year of the rule implementation. CARB also projects that the annual battery production capacity would continue to increase into the future reaching levels that are two and a half times the production capacity deployed in the last decade. This unprecedented ramp-up in battery production capacity which in turn would lead to

145 CARB. Draft Environmental Assessment. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

146 International Energy Agency (IEA). 2021. The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions. Available at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions. Accessed: May 2022.

147 CARB. Draft Environmental Assessment. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

148 Available at: https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf. Accessed: May 2022.

a similar ramp up of mineral extraction cannot be ignored. CARB must first analyze and evaluate these impacts before rushing to conclude that they are “not significant”.

B.14 The ISOR assertion that no new facilities will be required to manufacture ZEVs is likely not representative of reality. The manufacturing process of ZEVs greatly differs from that of ICEVs and will require dedicated facilities outside of the existing ICEV manufacturing facilities.

CARB has failed to fully address the additional resources and facilities that will be needed to ramp up electric vehicle production to meet the proposed state zero-emission vehicle mandate. CARB has stated that they assume that existing vehicle manufacturing facilities will be able to meet the growing demand for ZEVs, but this assumption fails to account for the differences in the manufacturing processes between ICEVs and ZEVs.

As CARB describes in the Draft EA, Lithium-ion (Li-ion) batteries can pose a potential risk if damaged, exposed to a fire or a heat source, or poorly packaged.[149] This risk will need to be mitigated through additional measures, which could include additional training of facility operators, emergency responders, and manufacturing personnel and additional design measures added to vehicle manufacturing facilities. The assumptions that no new facilities will be required assumes that all these upgrades can take place at existing ICEV manufacturing facilities. This assumption is made without any factual basis. CARB must consult with existing ICEV and ZEV manufacturers to understand the differences in the manufacturing processes and use this information to assess and evaluate the environmental and economic impacts associated with the conversion of ICEV manufacturing facilities to ZEV manufacturing facilities.

B.15 The ISOR misrepresents potential impacts to public services, utilities, and service systems.

CARB must comprehensively address the full potential of impacts to public services, utilities, and service systems to understand the potential environmental and economic impacts this regulation will have, including the potential impact on the State’s GHG reduction goals as well as its criteria pollutant emissions goals. Increased use of high-capacity battery storage and high-voltage upgrades to the grid’s electrical distribution and transmission infrastructure may lead to increased risk of wildfires, which would have an impact on fire response and other emergency services. CARB recognized that the increased reliance on the electrical grid and increase in infrastructure needed could lead to increased risk of wildfire ignition, but they have failed to fully account for the environmental effects of this impact and impacts on public services such as CAL FIRE. According to a letter by the California State Auditor, 19% of CAL FIRE-reported acres burned from 2019-2020 were caused by electrical power. [150] A scale-up of the grid in response to the ZEV mandate could have detrimental effects on public services that support fire-suppression and wildfire response. These impacts may be significant. A January

149 Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

150 California State Auditor. Electrical System Safety: California’s Oversight of the Efforts by Investor-Owned Utilities to Mitigate the Risk of Wildfires Needs Improvement. Available at: https://www.bsa.ca.gov/reports/2021-117/. Accessed: May 2022.

2021 study by Stanford researchers modelling the effects of wildfires on ambient air quality indicated that the contribution of wildfire smoke to $PM_{2.5}$ concentrations currently accounts for up to half of the overall $PM_{2.5}$ exposures in western regions of the United States.[151] CARB must perform a full economic and emissions analysis of the potential impacts of increased wildfire risk as a result of the proposed ACC II regulation.

B.16 CARB must provide justification as to why rescinding the SAFE rule would result in an increase in BEVs in the State's baseline fleet from ~11% to ~19% in 2026.

The Emissions Inventory Methods for the ACC II analysis (ISOR Appendix D) appear to update the baseline BEV and PHEV sales following the rescinding of the Safer Affordable Fuel-Efficient Vehicles (SAFE) rule. However, in the newest version of EMFAC released (v1.0.2), the light-duty auto (LDA) population in 2026-2050 does not appear to change relative to the population from the previous version of EMFAC (v1.0.1), which included the SAFE rule. It is not clear how CARB has derived these new ZEV vehicle baseline population values presented in the ISOR Appendix D, and their basis for increasing the BEV population baseline based on the rescinding of the SAFE rule is similarly unclear. The SAFE rule sets a standard for GHG emission reductions, not a mandate of increased BEV and PHEV sales. CARB must provide justification as to why this would result in an increase in BEVs in the State's fleet from ~11% to ~19% in 2026 given the SAFE rule does not require the sale of ZEVs and provide EMFAC runs to show where how this new population baseline was derived to ensure transparency in their emissions inventory development through this rulemaking process.

[151] Available at: https://www.pnas.org/doi/10.1073/pnas.2011048118. Accessed: May 2022.

ATTACHMENT C
List of Previous WSPA Comments on the Proposed ACC II Regulation

October 27, 2021 Comments[152]

1. CARB's credit pooling concept requires further discussion.
2. CARB must include lower-carbon alternative fuel and engine technologies.

September 1, 2021 Comments[153]

1. CARB must evaluate lower-CI vehicle/fuel systems, similar to the evaluation for the BEV/electrical grid system. Such an evaluation would show that there are additional cost-effective options, which build on the Low Carbon Fuel Standard (LCFS) and other successful programs, for reducing GHG emissions.
2. CARB must determine if additional ZEV requirements could increase consumer costs and potentially delay ZEV deployment, assess if new PHEV and LEV standards are appropriate, and evaluate how these factors may impact the emission benefits sought in ACC II.
3. It is CARB's responsibility to provide analyses on alternatives to the draft regulatory proposal that include emissions and cost benefits analyses, whether or not stakeholders provide analyzed alternatives.
4. CARB must clarify and expand the scope of the Environmental Analysis (EA) to ensure that all indirect and unintentional impacts from this rule are being considered, as required under CEQA.
    a. Note: CARB claims that the upstream emissions of electricity generation will be accounted for in the analysis, but has not yet published the analysis
5. CARB's assumptions in the ZEV Cost Modeling workbook released prior to the May 6th ACC II workshop are optimistic and do not reflect the true cost increase that consumers would likely experience while purchasing a ZEV.
    a. Note: CARB has updated some of these parameters but has not released an updated cost analysis workbook.
6. We respectfully request that CARB respond to our prior June 11th comment letter (Attachment A) and this letter.

June 11, 2021 Comments[154]

1. Evaluate multiple vehicle/fuel technology scenarios instead of focusing on an electric vehicle (EV) centric approach to reducing NOx and Greenhouse Gas (GHG) emissions from light-duty and medium-duty vehicles (LD/MDVs)

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152 WSPA Comments on the October 13, 2021, Public Workshop on the ACC II Regulation. Available at: https://www.arb.ca.gov/lists/com-attach/27-accii-comments-w3-ws-UwxTMwFpAz5XMAhk.pdf. Accessed: April 2022.

153 WSPA Comments on the August 11, 2021 Public Workshop on the ACC II Regulation. Available at: https://www.arb.ca.gov/lists/com-attach/19-accii-comments-w3-ws-BXJVIF0sBDZWDwVm.pdf. Accessed: April 2022.

154 WSPA Comments on the May 6, 2021 Public Workshop on the ACC II Regulation. These comments are not posted online.

2. Justify that a bifurcated criteria air pollutant emission standard for ZEVs and non-ZEVs will be a cost-effective pathway to achieve emission reductions
3. Evaluate the impact of the proposed ZEV penetration on the state-wide particulate matter (PM) inventory (notably, due to heavier battery electric vehicles (BEVs)), especially in PM2.5 nonattainment areas
4. Consider the costs of additional road maintenance and loss of revenue from fuel sales into a techno-economic feasibility and cost-effectiveness assessment
5. Assess how future electric grid reliability and infrastructure needs will affect the feasibility of CARB's proposed ZEV purchase mandate
6. Evaluate potential electric vehicle battery supply chain requirements, especially demand for critical mineral resources which would be necessary to support the proposed ZEV sales mandate
7. Evaluate the feasibility of achieving CARB's anticipated near-term ZEV sales targets given current low adoption rates and consumer concerns
8. Address shortfalls in BEV performance that fail to satisfy end-uses currently met by internal combustion engines (ICEs)
9. Incorporate the cost implications of the proposed Durability and Minimum Warranty Requirements on the future sales prices of ZEVs
10. Account for increased financial burden on non-dealer Independent Repair Shops resulting from ZEV transition
11. Provide data regarding the expected emission impacts of medium duty vehicle travel that is in towing mode
    a. Note: CARB presented some verbal comments about the emissions impact of this regulation but has not provided emission calculations

WSPA | AFPM American Fuel & Petrochemical Manufacturers | CIPA California Independent Petroleum Association

ATTACHMENT D

"Multi-Technology Pathways To Achieve California's Greenhouse Gas Goals: Light-Duty Auto Case Study" by Ramboll dated May 31, 2022

Prepared for
Western States Petroleum Association
Sacramento, California

Prepared by
Ramboll US Consulting, Inc.
Irvine, California

Project Number
1690024977

Date
May, 2022

MULTI-TECHNOLOGY PATHWAYS TO ACHIEVE CALIFORNIA'S GREENHOUSE GAS GOALS:

LIGHT-DUTY AUTO CASE STUDY

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RAMBOLL

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ACRONYMS AND ABBREVIATIONS

AB:	Assembly Bill
ACC:	Advanced Clean Cars
ANL:	Argonne National Laboratory
BEV:	battery electric vehicle
CA-GREET:	California's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
CAP:	criteria air pollutant
CARB:	California Air Resources Board
CARBOB:	California reformulated gasoline blendstock for oxygenate blending
CaRFG:	California reformulated gasoline
CEC:	California Energy Commission
CEQA:	California Environmental Quality Act
CH_4	methane
CI:	carbon intensity
CO_2:	carbon dioxide
CO_2e:	carbon dioxide equivalent
cVMT:	combustion vehicle mile traveled
CY:	calendar year
DSL:	diesel
E3:	Energy + Environmental Economics
EA:	environmental assessment
EER:	energy economy ratio
eGRID:	Emissions & Generation Resource Integrated Database
EMFAC:	EMission FACtors Model
EPA:	Environmental Protection Agency
EV:	electric vehicle
eVMT:	electric vehicle mile traveled
FCEV:	fuel cell electric vehicle
g:	gram
GHG:	greenhouse gas
GREET:	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
GWP:	global warming potential

H_2:	hydrogen
HEV:	hybrid electric vehicle
ICE:	internal combustion engine
ICEV:	internal combustion engine vehicle
IPCC:	International Panel on Climate Change
ISOR:	Initial Statement of Reasons
kWh:	kilowatt-hour
LCFS:	Low Carbon Fuel Standard
LDA:	light-duty auto
LDT1:	light-duty truck 1
LDT2:	light-duty truck 2
LDV:	light-duty vehicle
Li-ion:	lithium ion
mi:	mile
MJ:	megajoule
MMT:	million metric tons
MPG:	miles per gallon
MPGe:	miles per gallon equivalent
MT:	metric ton
MSS	Mobile Source Strategy
MY:	model year
N_2O	nitrous oxide
NG:	natural gas
NMC:	nickel manganese cobalt
PHEV:	plug-in hybrid electric vehicle
SMR:	steam methane reforming
SOC:	state of charge
SRIA:	Standardized Regulatory Impact Assessment
US:	United States
VMT:	vehicle mile traveled
ZEV:	zero emission vehicle

EXECUTIVE SUMMARY

The California Air Resources Board (CARB or Board) Advanced Clean Cars program aims to reduce criteria air pollutants (CAP) and greenhouse gas (GHG) emissions throughout the state by setting regulations and standards aimed at light-duty vehicles (LDVs). The newest generation of rulemaking that has been drafted is the Advanced Clean Cars II (ACC II) proposal and is expected to be presented to the Board in summer 2022. This proposal introduced by CARB includes setting zero emission vehicle (ZEV) sales mandates for model year 2026 and later passenger cars and light-duty trucks (i.e., light-duty vehicles, LDVs). This proposed sales mandate would begin at 35% in 2026 and ramp up to 100% for the 2035 model year and beyond.[1] The stated aim of the ACC II proposal is to reduce CAP and GHG emissions through a ZEV sales mandate. This technology mandate is different from traditional CARB motor vehicle regulations that set engine emission standards or emission-based performance standards that allowed multiple lower-emitting technologies to compete. Although a stated goal is to reduce GHG emissions, the current ACC II proposal does not consider or analyze the full life cycle emissions for "zero emission" vehicles, account for greenhouse gas emissions leakage that would be caused outside of the state of California by the ACC II proposal, or include a technology-neutral analysis of alternatives that could help meet the greenhouse gas reduction goals. Simply put, CARB's ACC II proposal focuses on a complete transition to ZEVs without a full accounting of GHG emissions impacts, and without consideration of other vehicle technologies or a future role for renewable and other low carbon fuels.

Ramboll has conducted an analysis of California's light-duty auto (LDA) fleet to evaluate whether alternative vehicle technology and fuel pathways could achieve life cycle GHG emission reductions similar or greater than the ACC II proposal. Unlike CARB's analysis, Ramboll has evaluated the full life cycle impacts of ZEV technologies under the ACC II proposal to more completely characterize the potential near-term and long-term GHG emissions performance and considers other pathways that would not require a replacement of the entire transportation infrastructure system. These alternative pathways would also not require the wholesale transformation of electric energy production and distribution infrastructure on an unprecedented short time scale, but they would allow battery, hydrogen, and low-carbon intensity gaseous and liquid fueled vehicles to compete to achieve the State's GHG targets for light-duty transportation in the quickest and most cost-effective manner.

> Ramboll's **multi-technology pathways analysis** demonstrates that there are multiple light duty vehicle technology and fuel pathways that can meet California's GHG emission reduction targets.

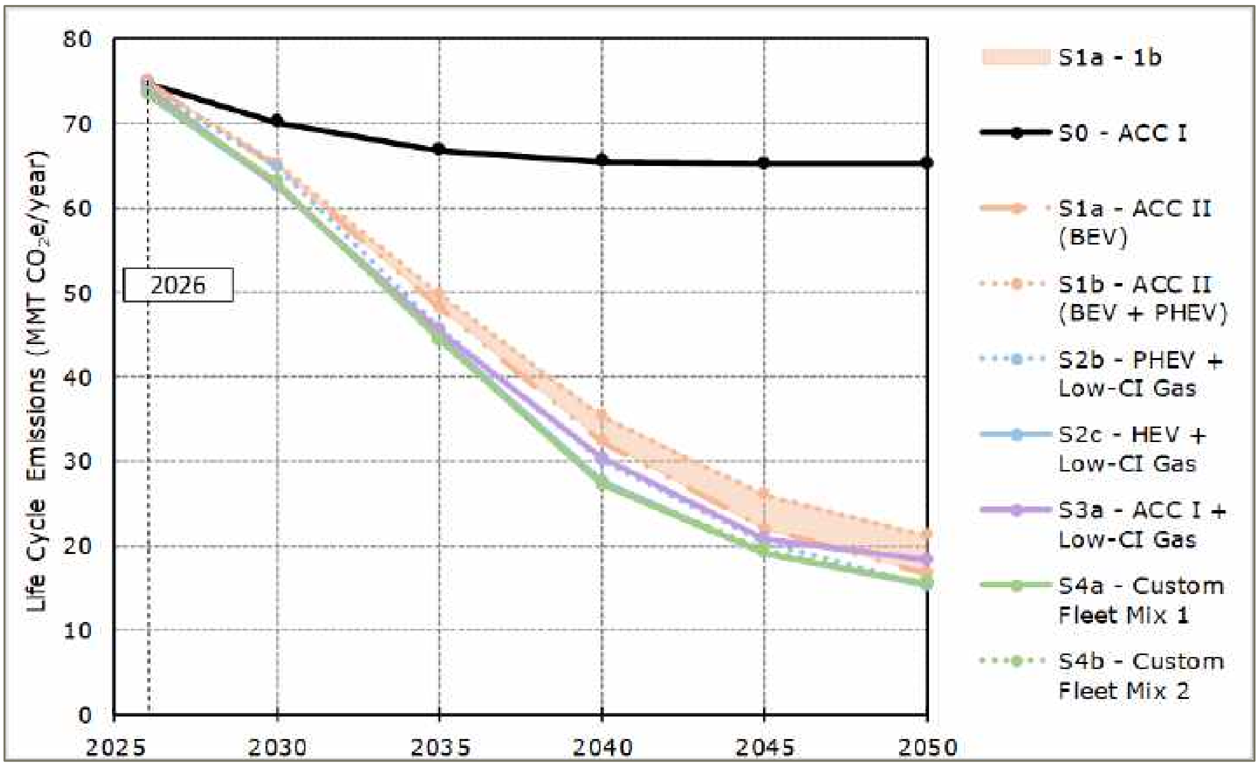
The main conclusions of our analysis are:

- Zero emission vehicle technology is only one of many different technology/fuel scenarios that could be utilized to meet California's GHG emission reduction targets;
- A full life cycle emission assessment is necessary if GHG reductions are a goal of the regulation, in order to understand the cradle-to-grave effects of a given vehicle/fuel technology pathway;

[1] California Air Resources Board (CARB). 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

- BEV technology of the scope and schedule proposed under ACC II would require technology and electrical generation/infrastructure developments that CARB has not analyzed and cannot mandate, control, or incentivize;
- There is a growing potential for renewable and low carbon fuels, including some with negative carbon intensity (CI), to meet long-term GHG reduction targets for light-duty transportation;
- Low-CI gasoline (included in scenarios represented by the blue, purple, and green lines in **Figure ES-1**) could decarbonize the transportation sector at a rate comparable to a ZEV-only regulation (represented by the pink shaded region in **Figure ES-1**); and
- Allowing the market flexibility to meet emission reduction targets could lead to a more diverse deployment of fuel and vehicle technologies to meet State targets.

Figure ES-1: Life Cycle Emissions for Key Scenarios



These conclusions show that GHG reductions attributed by CARB to the proposed ACC II regulation are incomplete and emphasize the need for CARB to conduct a full life cycle GHG emission assessment to quantify the cradle-to-grave effects of the draft ACC II proposal. As demonstrated in this study, a full life cycle analysis demonstrates that there are multiple GHG-reducing vehicle/fuel technologies that, individually or in combination, have equivalent GHG reductions as ZEV-mandated ACC II proposal. CARB should revise the environmental analysis to consider all feasible vehicle/fuel pathways that could achieve the State's emission reduction goals. This must be done in the alternative analyses presented in the Standardized Regulatory Impact Assessment (SRIA)[2] and the Environmental Assessment (EA)[3] for the proposed ACC II, including evaluations of the environmental, cost, and socioeconomic impacts of the different technology pathways. Consistent with rule development precedent, the results of this broader alternative analyses should inform the appropriate revisions to the draft ACC II rule language.

[2] CARB. 2022. Appendix C-1: Standardized Regulatory Impact Assessment (SRIA). April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

[3] CARB. 2022. Appendix E-1: Draft Environmental Analysis for the Proposed Advanced Clean Cars II Program. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

1. INTRODUCTION

1.1 Proposed ACC II Regulation Summary

The California Air Resources Board (CARB) Advanced Clean Cars program aims to reduce criteria air pollutants (CAP) and greenhouse gas (GHG) emissions throughout the state by setting regulations and standards aimed at LDVs. The newest generation of rulemaking that has been drafted is the Advanced Clean Cars II (ACC II) proposal and is expected to be presented to the Board in summer 2022. This proposal introduced by CARB includes setting zero emission vehicle (ZEV) sales mandates for model year 2026 and later passenger cars and light-duty trucks (i.e., light-duty vehicles, LDVs). This proposed sales mandate begins at 35% in 2026 and would ramp up to 100% for the 2035 model year and beyond.[4] The stated aim of the ACC II regulation is to reduce CAP and GHG emissions through a ZEV sales mandate. This technology mandate is different from traditional CARB motor vehicle regulations that set engine emission standards or emission-based performance standards that allowed multiple lower-emitting technologies to compete. Although a stated goal is to reduce GHG emissions, the current ACC II proposal does not consider or analyze the full life cycle emissions for "zero emission" vehicles, account for greenhouse gas emissions leakage that would be caused outside of the state of California by the ACC II proposal, or include a technology-neutral analysis of alternatives that could help meet the greenhouse gas reduction goals. Simply put, CARB's ACC II proposal focuses on a complete transition to ZEVs without a full accounting of GHG emissions impacts, and without consideration of other vehicle technologies or a future role for renewable and other low carbon fuels.

The current ACC II proposal takes a narrow approach to achieving the State's GHG emission goals by setting a ZEV mandate, rather than setting performance-based emission targets. The alternatives analyzed in the Standardized Regulatory Impact Assessment (SRIA)[5] and the Environmental Assessment (EA)[6] for the proposed ACC II represent varying penetration rates for ZEV sales mandates for the 2026 through 2035 model years, and do not include a performance-based analysis of technology/fuel alternatives.

Additionally, CARB has not conducted a full life cycle GHG analysis for the vehicle/fuel system to assess GHG emission impacts of their proposal and alternatives. CARB did not consider the upstream fuel cycle GHG emissions from out-of-state fuel production and transportation activities for California reformulated gasoline (CaRFG) and hydrogen (H_2), and vehicle cycle GHG emissions associated with the vehicle production. These life cycle emissions are significant, particularly for battery electric vehicles (BEVs) as compared to internal combustion engine vehicles (ICEVs), due to the energy-intensive nature of producing a BEV battery. Failure to consider these GHG emissions has the effect of overstating the emissions benefits of the proposed ACC II regulation.

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4 California Air Resources Board (CARB). 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

5 CARB. 2022. Appendix C-1: Standardized Regulatory Impact Assessment (SRIA). April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

6 CARB. 2022. Appendix E-1: Draft Environmental Analysis for the Proposed Advanced Clean Cars II Program. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: May 2022.

1.2 Purpose of this Study

The proposed ACC II regulation would prescribe a ZEV-centric pathway to achieve the State's long-term climate goals through sales mandates. Ramboll conducted an analysis of California's light-duty auto (LDA) fleet to evaluate alternative vehicle technology and fuel pathways that could achieve life cycle GHG emission reductions similar or greater than the ACC II proposal. Ramboll's analysis approaches the State's climate goals from an emission reduction or environmental performance perspective, rather than a technology mandate and a potential means to allow increased market flexibility. This analysis evaluates the life cycle impacts of ACC II to more fully characterize the potential near-term and long-term GHG emissions reductions of that proposal and considers alternative technology/fuel pathways that would not require an overhaul of the entire transportation infrastructure system. These alternative pathways would not require the wholesale transformation of energy production and distribution infrastructure on an unprecedented short time scale, but they would allow battery, hydrogen, and low carbon intensity gaseous and liquid fueled vehicles to potentially co-exist in a market to achieve the State's GHG targets in the quickest and most cost-effective manner.

This white paper provides a summary of the methodology, results, and conclusions of Ramboll's analysis.

2. MULTI-TECHNOLOGY SCENARIOS: LIGHT-DUTY VEHICLE FLEET EXAMPLE

The CARB ACC II proposal would prescribe a sales mandate for ZEVs in the LDV fleet in order to meet California's long-term climate goals. **Table 2-1** below presents the proposed ZEV sales requirements for the statewide LDV fleet as contained in the draft ACC II regulation released on April 12, 2022. As shown in the table, the draft ACC II regulation requires manufacturers that produce and deliver LDVs for sale in California to meet increasing ZEV sales fractions from 35% in the 2026 model year, 68% in 2030, and 100% by the 2035 model year and beyond. In the proposed ACC II regulation, CARB does not consider or assess other scenarios that could use a mix of alternative vehicle and fuel technologies to achieve the California's long-term climate goals.

Table 2-1. ZEV Sales Requirements in the Proposed ACC II Regulation[7]

Model Year	Percentage Requirement
2026	35%
2027	43%
2028	51%
2029	59%
2030	68%
2031	76%
2032	82%
2033	88%
2034	94%
2035 and subsequent	100%

Ramboll's analysis presented in this report evaluates the potential GHG emission benefits for a series of technology and fuel scenarios for a subset of the statewide LDV fleet consisting of light-duty autos (LDAs)[8] from calendar year 2026 through 2050. Specifically, Ramboll's scenario analysis considers gasoline-fueled ICEVs, BEVs, plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and fuel cell electric vehicles (FCEVs).[9] Additional information on each of the vehicle technologies considered in this analysis is presented in **Section 3.1**. The purpose of this analysis is to evaluate if there are alternative vehicle/fuel

[7] CARB. 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

[8] LDVs subject to ACC II ZEV sales requirements include the LDA, LDT1, and LDT2 vehicle classes in EMFAC2021. Only the LDA vehicle class is considered in Ramboll's analysis.

[9] Natural gas vehicles are excluded as they are not included in the default EMFAC2021 LDA fleet. Diesel vehicles are not included in this analysis because they comprise less than 0.3% of the total LDA population in EMFAC2021.

technology pathways besides CARB's ACC II proposal that could achieve life cycle GHG emission reductions similar or greater than the ACC II proposal and meet the State's long-term climate goals. Because CARB does not provide a breakdown between the classes of LDVs included in the ACC II proposal, Ramboll's analysis of the proposed ACC II scenarios assumes the sales mandates and other requirements (e.g., range requirements, battery warranty, etc.) for LDVs in the ACC II proposal apply to LDAs. Additionally, because the ZEV sales mandates in the ACC II proposal can be met with a combination of PHEVs, BEVs and FCEVs, Ramboll's analysis considers several scenarios to outline the range of potential fleet mixes allowable under the proposed ACC II regulation.

A brief description of the analyzed scenarios is presented below. **Figure 2-1** and **Figure 2-2** present new vehicle sales fractions by model year while **Figure 2-3** and **Figure 2-4** show the resulting fleet mix. **Figure 2-5** through **Figure 2-7** presents the resulting fuel usage for these scenarios. A detailed matrix of all scenarios can be found in **Appendix A**.

- **S0 – ACC I**: This scenario serves as the baseline and is based on EMFAC2021 fleet mix defaults, which represents ACC I PHEV and BEV sales requirements. As shown in **Figure 2-2**, the fleet is comprised primarily of ICEVs, with a small but increasing percentage of PHEVs and BEVs. PHEVs and BEVs represent approximately 4% and 12% of new vehicle sales, respectively, for model years 2026-2050 (**Figure 2-1**). Note, in all scenarios, the existing sales fraction and population of PHEVs and BEVs in EMFAC2021 defaults served as the minimum penetration of these vehicle technologies. Thus, while additional BEVs and/or PHEVs were added in some scenarios, only ICEVs in the EMFAC2021 default fleet were replaced with other vehicle types as applicable in each scenario.
- **S1 – Baseline ACC II Scenarios**: In this set of scenarios, Ramboll evaluated multiple possible outcomes allowable under the proposed ACC II regulation to understand the range of potential emission reductions.
  - **S1a – ACC II (BEV)**: This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with BEVs.
  - **S1b – ACC II (BEV + PHEV)**: This scenario assumes that the ZEV sales needed to meet the ZEV sales requirements in the draft ACC II proposal are met with the maximum allowable fraction of PHEVs (20% of ZEV sales requirement) and BEVs (80% of ZEV sales requirement).
  - **S1c – ACC II (CARB SRIA)**: This scenario assumes that the ZEV sales needed to meet the draft ACC II proposal are met with combination of PHEVs, BEVs, and FCEVs as noted in the CARB's SRIA for the ACC II proposal.
  - **S1d – ACC II (FCEV)**: This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with FCEVs. The carbon intensity (CI) of hydrogen fuel used to power FCEVs in this scenario was developed based on the feedstock projections in CARB's SRIA for the ACC II proposal. Refer to **Section 3.2.4** for further discussion of hydrogen pathways.
    - **S1d-1 – ACC II (FCEV) + AB32 H_2**: This sensitivity scenario is identical to scenario S1d – ACC II (FCEV) with the following exception: the CI for hydrogen

fuel used to power FCEVs was developed based on the assumptions in the Assembly Bill (AB) 32 Source Emissions Initial Modeling Results[10] ("AB 32 Initial Modeling") for the draft 2022 Scoping Plan Update.

- **S2 – Alternative Scenarios Part 1**: In this set of scenarios, Ramboll evaluated alternatives to the draft ACC II proposal where the ZEV sales requirements are met with PHEVs or HEVs instead of BEVs and FCEVs. Some of these scenarios also include the phase-in of a lower CI renewable drop-in fuel ("low-CI gasoline") used as a replacement for CaRFG that is used to fuel internal combustion engines (ICEs) in ICEVs, PHEVs, and HEVs. The carbon intensity of low-CI gasoline analyzed in these scenarios is 19g CO_2e/MJ (see **Section 3.2.2** for further discussion of low-CI gasoline).
  - **S2a – PHEV**: This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with PHEVs.
  - **S2b – PHEV + Low-CI Gas**: This vehicle fleet mix for this scenario is identical to scenario S2a – PHEV. However, it also includes the gradual phase-in of low-CI gasoline (see orange area in **Figure 2-6**) beginning as a replacement of 1% of CaRFG in 2026 and increasing to a replacement of 30% and 100% of CaRFG by 2035 and 2050 respectively.
  - **S2c – HEV + Low-CI Gas**: This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with all HEVs. It also includes a phase-in of low-CI gasoline (see orange area in **Figure 2-6**) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 35% and 100% of CaRFG by 2035 and 2050 respectively.
- **S3 – Alternative Scenarios Part 2**: In this set of scenarios, Ramboll utilized the same vehicle fleet mix as scenario S0 – ACC I along with a phase-in of low-CI gasoline as a replacement for CaRFG that is used to power internal combustion engines in the analyzed LDAs. The scenarios considered under S3 evaluate a range carbon intensities and phase in timetables for low-CI gasoline.
  - **S3a – Low-CI Gas**: This scenario analyzes the same vehicle fleet mix as S0 – ACC I with a gradual phase-in of low-CI gasoline (see orange area in **Figure 2-6**) beginning as a replacement of 1% of CaRFG in 2026 and increasing to a replacement of 45% and 100% of CaRFG by 2035 and 2050 respectively. The CI of the low-CI gasoline used in this scenario is 19 g CO_2e/MJ (see **Section 3.2.2** for further discussion of low-CI gasoline).
    - **S3a-1 – Low-CI Gas (Upper Range)**: This sensitivity scenario is identical to scenario S3a – Low CI Gas with the following exception: the carbon intensity of the low-CI gasoline is increased by 10 g CO_2e/MJ to 29 g CO_2e/MJ.

[10] Energy + Environmental Economics (E3). 2022. AB 32 Initial Model Results. March 15. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-03/SP22-Model-Results-E3-ppt.pdf. Accessed: May 2022.

    - **S3a-2 – Low-CI Gas (Lower Range)**: This sensitivity scenario is identical to scenario S3a – Low-CI Gas with the following exception: the carbon intensity of the low-CI gasoline is reduced by 10 g CO_2e/MJ to 9 g CO_2e/MJ.
  - **S3b – Low-CI Gas (Delayed)**: This scenario is identical to scenario 3a with the following exception: the phase in of low-CI gasoline is delayed and occurs more slowly from 2026-2035 (replacement of 1% to 20% of CaRFG from 2026-2035) but increases rapidly from 2035-2040 (replacement of 97% and 100% of CaRFG by 2045 and 2050 respectively), as compared with scenario 3a (see orange area in **Figure 2-6**).
- **S4 – Alternative Scenarios Part 3**: In this set of scenarios, Ramboll evaluated various vehicle fleet mixes that utilize a combination of HEVs, PHEVs, BEVs, and/or FCEVs along with a gradual phase-in of low-CI gasoline as a replacement for CaRFG that is used to power ICEs in the analyzed LDA fleet.
  - **S4a – Custom Fleet Mix 1**: This scenario evaluates a custom fleet mix (see **Figure 2-4**) that assumes early implementation of HEVs from 2026-2035, with HEV sales declining after 2035 (see green area in **Figure 2-2**). PHEV sales increase by 1% per year from 2026-2040 and 2% per year thereafter (see gold area in **Figure 2-2**). BEV sales increase by 1% per year from 2030-2044 and 2% per year thereafter (see blue area in **Figure 2-2**). This scenario also includes a phase-in of low-CI gasoline (CI of 19 g CO_2e/MJ) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 100% of CaRFG by 2050 (see orange area in **Figure 2-6**).
  - **S4b – Custom Fleet Mix 2**: This scenario evaluates a custom fleet mix (see **Figure 2-4**) similar to S4a – Custom Fleet Mix 1, but with aggressive early implementation of HEVs from 2026-2035 and HEV sales declining after 2035 (see green area in **Figure 2-2**). PHEV sales increase by 1% per year from 2028-2031, stay constant from 2031-2035, increase by 2% per year from 2036-2039, increase by 4% per year in 2040 and 2041, and then stay constant at 39% from 2042 and thereafter (see gold area in **Figure 2-2**). Phase-in of additional BEVs is delayed until 2036, beginning at 7% in 2036 and increasing by 1% per year from 2036-2041. Additional BEV sales then increase by 3.5% per year until 2046 and remain constant thereafter at 42% (see blue area in **Figure 2-2**). This scenario also includes a phase-in of low-CI gasoline (CI of 19 g CO_2e/MJ) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 100% of CaRFG by 2050 (see orange area in **Figure 2-7**).
  - **S4c – Custom Fleet Mix 3**: This scenario evaluates a custom fleet mix (see **Figure 2-4**) similar to scenario S4a - Custom Fleet Mix 1, but with more FCEVs and less BEVs. Specifically, HEV and PHEV implementation is the same as scenario 4a (see green and gold areas in **Figure 2-2**), while BEV sales increase by only 0.5% per year from 2031-2044 and 1.5% per year thereafter (see blue area in **Figure 2-2**). FCEV sales start at 1% in 2030 and increase by 0.5% per year thereafter (see purple area in **Figure 2-2**). This scenario also includes a phase-in of low-CI gasoline (CI of 19 g CO_2e/MJ) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 100% of CaRFG by 2050 (see orange area in **Figure 2-7**). Similar to scenario S1d – ACC II (FCEV), the carbon intensity (CI) of hydrogen fuel used to

power FCEVs in this scenario was developed based on the feedstock projections in CARB’s SRIA for the ACC II proposal. Refer to **Section 3.2.4** for further discussion of hydrogen pathways.

Figure 2-1. LDA New Vehicle Sales Fractions for Scenarios 0, 1a, 1b, 1c, 1d, and 2a

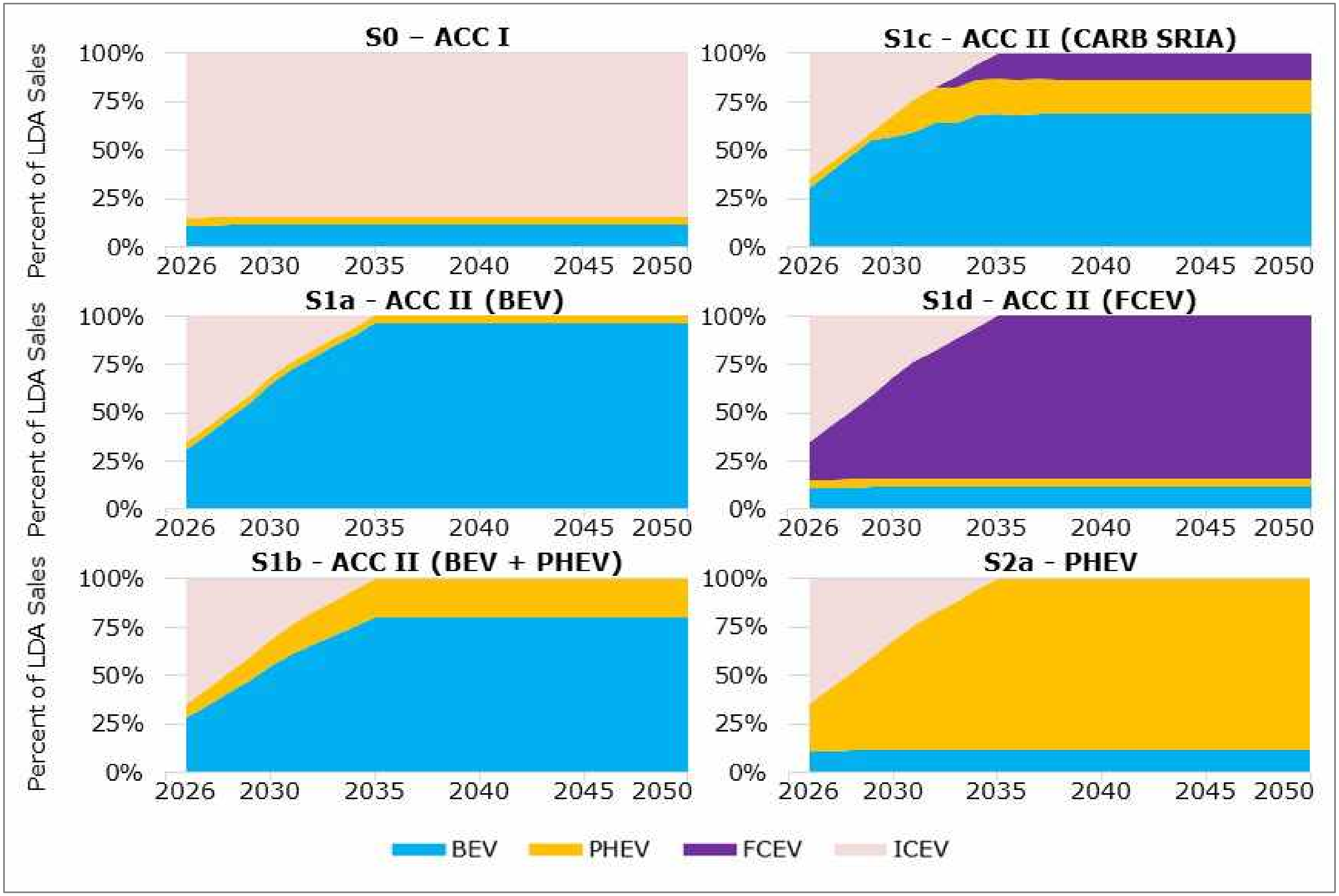


Figure 2-2. LDA New Vehicle Sales Fractions for Scenarios 2b, 2c, 3a, 4a, 4b, and 4c

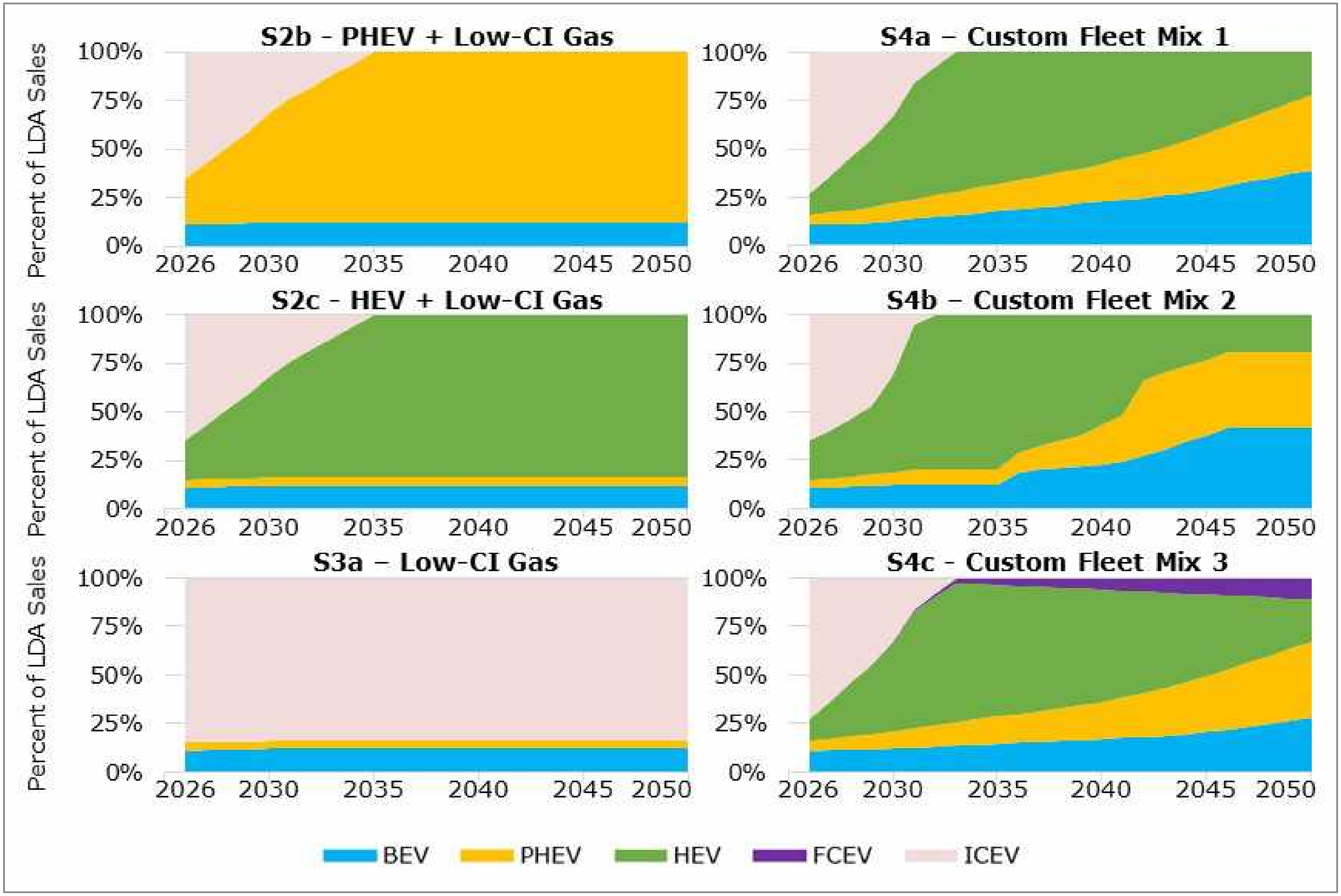


Figure 2-3. LDA Fleet Mixes for Scenarios 0, 1a, 1b, 1c, 1d, and 2a

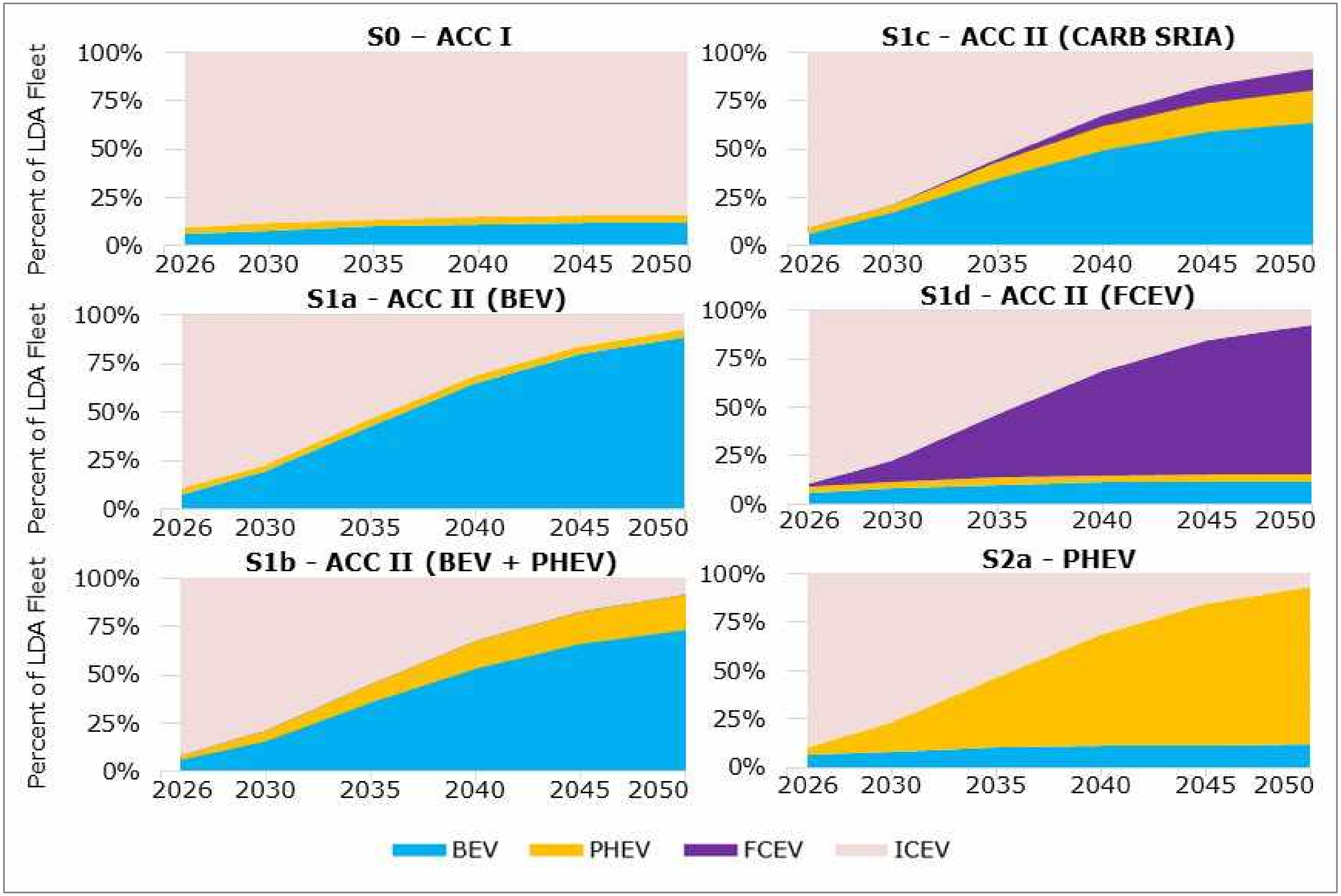


Figure 2-4. LDA Fleet Mixes for Scenarios 2b, 2c, 3a, 3b, 4a, 4b, and 4c

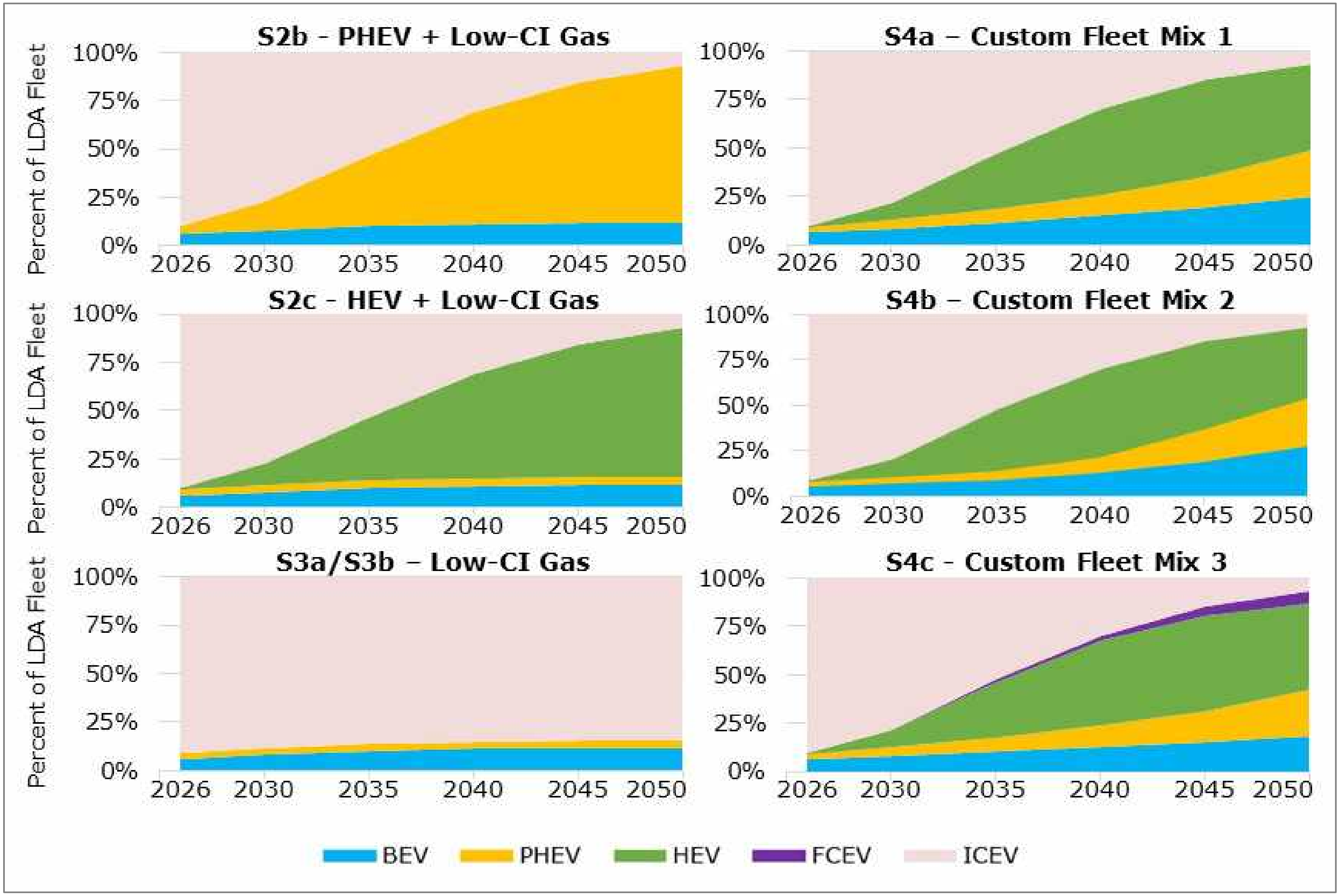


Figure 2-5. Fuel Usage Fractions for Scenarios 0, 1a, 1b, 1c, 1d, and 1d-1

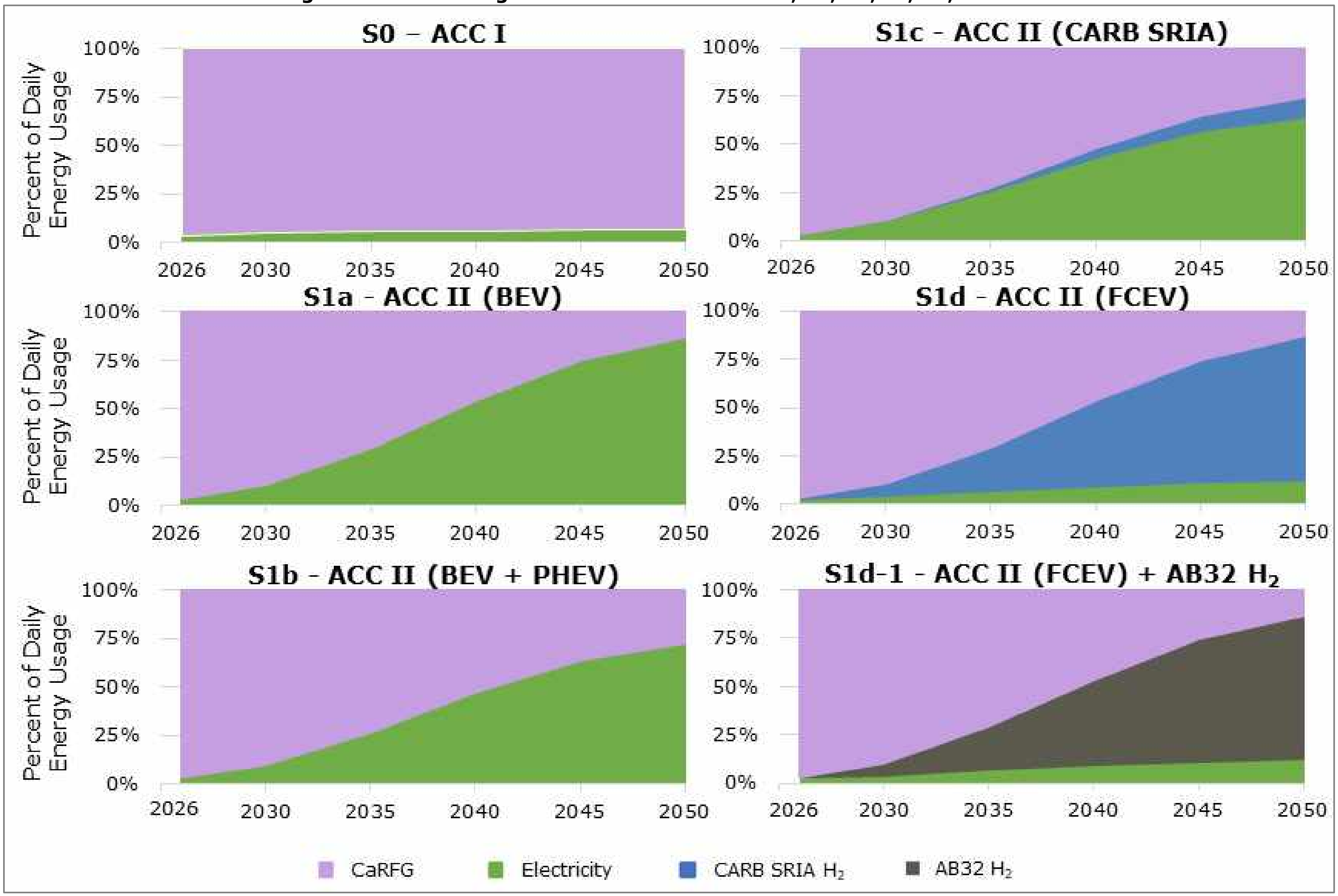


Figure 2-6. Fuel Usage Fractions for Scenarios 2a, 2b, 2c, 3a, 3b, and 4a

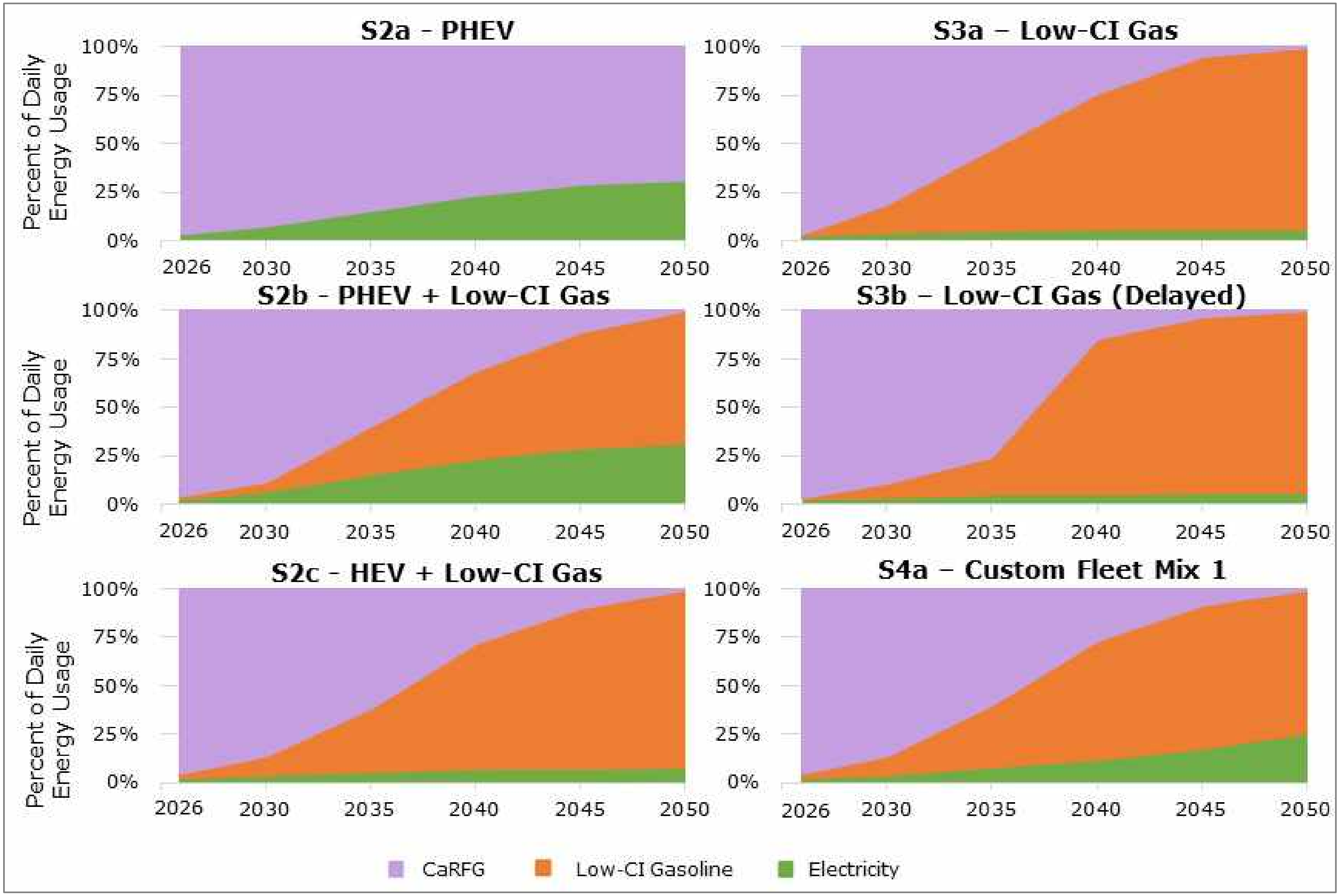
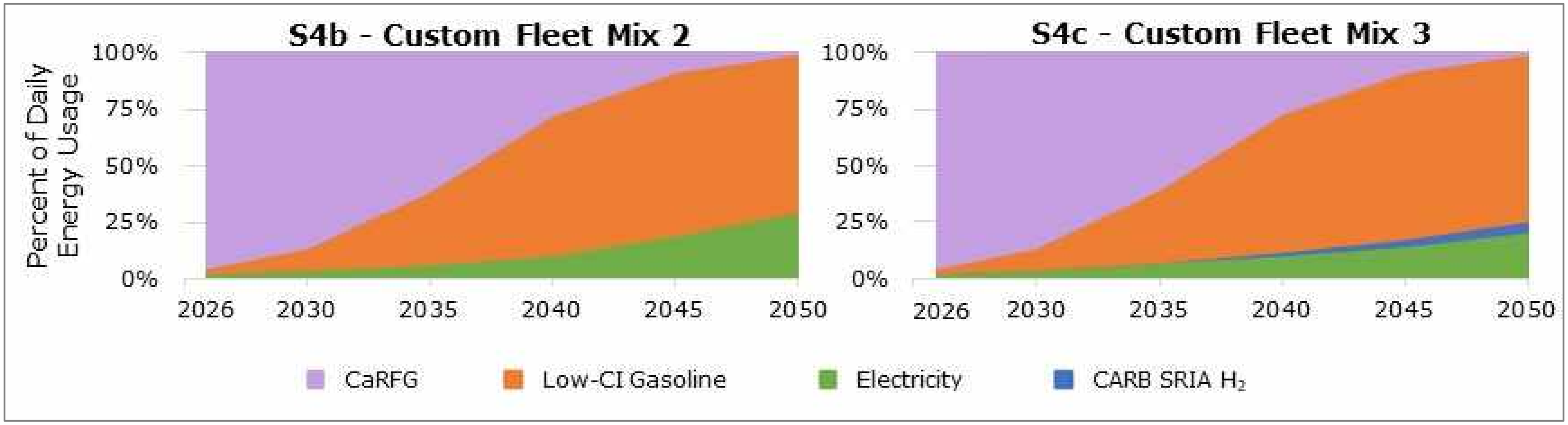


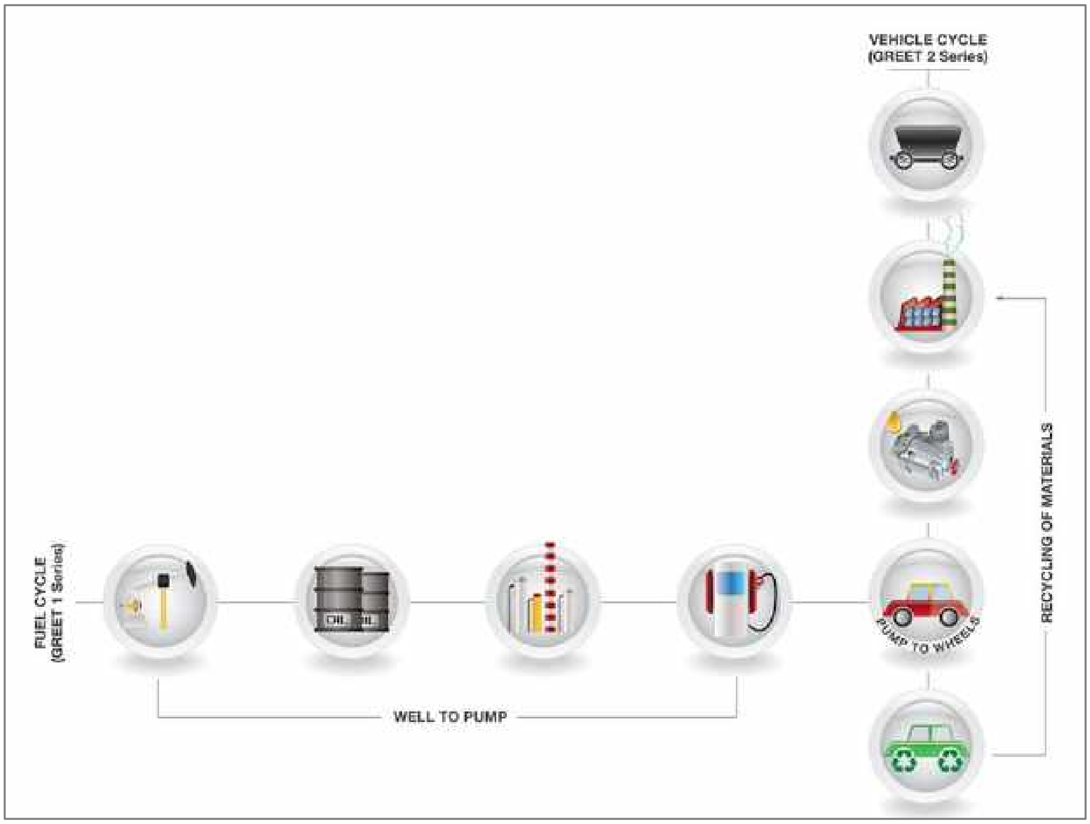
Figure 2-7. Fuel Usage Fractions for Scenarios 4b and 4c



3. SCENARIO ANALYSIS METHODOLOGY

An accurate assessment of future vehicle/fuel technology pathways requires full life cycle emissions analysis, including fuel cycle emissions and vehicle cycle emissions. The vehicle cycle analysis includes emissions associated with vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal and recycling, while the fuel cycle analysis considers energy use and emissions associated with fuel production and distribution activities as well as energy use and emissions associated with vehicle operation.[11,12] The various processes included in the fuel cycle and vehicle cycle are represented in **Figure 3-1** below.

Figure 3-1. Fuel Cycle and Vehicle Cycle Emissions Representation in the GREET Model[13]



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[11] P. Moon, A. Burnham, M. Wang. 2006. "Vehicle-Cycle Energy and Emission Effects of Conventional and Advanced Vehicles (abstract)". April 3. Available here: https://greet.es.anl.gov/publication-hkjun004. Accessed: May 2022.

[12] USEPA. Lifecycle Analysis of Greenhouse Gas Emissions under the Renewable Fuel Standard. Available at: https://www.epa.gov/renewable-fuel-standard-program/lifecycle-analysis-greenhouse-gas-emissions-under-renewable-fuel. Accessed: May 2022.

[13] ANL. 2021. Greenhouse gases, Regulated Emissions, and Energy use in Technologies model. Available at: https://greet.es.anl.gov/. Accessed: May 2022.

The following sections provide a high-level description of the methodology used for Ramboll's scenario analysis. Detailed modeling inputs, outputs, and methodology are provided in **Appendix A**.

3.1 Vehicle Technologies

Several LDA vehicle technologies are considered in Ramboll's analysis, as described in the following sections. Of these vehicle technologies, ICEVs, PHEVs, and BEVs are present in the EMFAC2021 default fleet mix for LDAs while FCEVs and HEVs are not. As described previously, LDAs fueled by diesel and natural gas are not included in this analysis.[14]

3.1.1 Internal Combustion Engine Vehicles

ICEVs are vehicles that use only an internal combustion engine to attain propulsion power. As described previously, only gasoline-fueled ICEVs are considered in this analysis. ICEVs comprise the majority of the LDA fleet in the EMFAC2021 default fleet mix and are replaced to varying degrees with other vehicle technologies in the scenarios described in **Section 2**. Key data for ICEVs used to perform the analysis were derived from EMFAC2021.[15] Specifically, Ramboll used EMFAC2021 data to derive fuel economy, daily vehicle miles travelled (VMT) per vehicle, and tailpipe emission factors for ICEVs by model year for each calendar year. Fuel economy for ICEVs was determined using fuel consumption and VMT data from EMFAC2021 and vary by model year and calendar year, ranging from about 18 miles per gallon (MPG) for the oldest vehicles to 35 MPG for the newest vehicles. Similarly, daily VMT per vehicle was calculated using VMT and population data from EMFAC2021 and ranges from 5 miles per vehicle per day for the oldest vehicles to 55 miles per vehicle per day for the newest vehicles. The methodology used to calculate tailpipe emissions is discussed in **Section 3.3**. See **Appendix A** (**Tables A-8** through **A-25**) for ICEV fuel economy, tailpipe emission factors, and daily VMT per vehicle by model year for each calendar year considered in this analysis.

Daily VMT per vehicle for ICEVs serves as the basis for calculating VMT for other vehicle technologies as ICEVs are replaced with PHEVs, BEVs, HEVs, or FCEVs in each scenario. Specifically, this analysis assumes that any vehicle technology replacing an ICEV travels the same number of miles per vehicle per day as the ICEV it is replacing, as determined from EMFAC2021. Thus, in each scenario, as ICEVs are replaced with other vehicle technologies, the population and corresponding VMT of ICEVs is reduced and allocated to the replacement vehicles in a one-to-one ratio.[16] Similarly, Ramboll's analysis assumes that the vehicle lifetime (i.e., retirement rate) for ICEVs obtained from EMFAC2021 remains the same for any replacement vehicle technology. Therefore, Ramboll's analysis does not alter the total vehicle

[14] Natural gas vehicles are excluded as they are not included in the default EMFAC2021 LDA fleet. Diesel vehicles are not included in this analysis because they comprise less than 0.3% of the total LDA population in EMFAC2021.

[15] This analysis uses EMFAC2021 v1.0.1. A newer version of EMFAC2021 v1.0.2 was released on May 2, 2022 (after completion of this analysis) that reflects the revocation of the Safe Affordable Fuel-Efficient or SAFE vehicles rule. While this update increases the fuel economy, methane (CH_4), and nitrous oxide (N_2O) tailpipe emission factors by <5% and <0.5% for 2025+ model year ICEVs and PHEVs, respectively, it does not change the overall conclusions of the analysis.

[16] For PHEVs replacing ICEVs, total VMT from the ICEV is allocated to eVMT and cVMT for the replacement PHEV according to the EMFAC2021 default split between eVMT and cVMT for the replacement vehicle. Additional details are provided in **Section 3.1.3** and **Appendix A.**

population and VMT projections in EMFAC2021, even as vehicle technologies change in each scenario.

3.1.2 Battery Electric Vehicles

BEVs are vehicles that use energy from batteries to attain propulsion power. BEVs have larger batteries than PHEVs and HEVs and are plugged in and charged using electricity from the grid. BEVs have no ICE, do not use gasoline fuel, and have zero tailpipe emissions. BEVs comprise a small but increasing percentage of the EMFAC2021 default fleet mix and are the primary vehicle technology assumed to replace ICEVs under the proposed ACC II regulation. Fuel economy for BEVs was calculated using energy consumption and VMT data from EMFAC2021. Unlike fuel economy for ICEVs, which varies by model year and calendar year, fuel economy for all model year BEVs in EMFAC2021 is fixed at 0.386 kilowatt-hour per mile (kWh/mi) (~86 miles per gallon equivalent (MPGe))[17] irrespective of the calendar year in which they operate. Although VMT per vehicle for BEVs is not used in this analysis because any BEV replacing a ICEV is assumed to travel the same number of miles as the ICEV it is replacing, EMFAC2021 assumes that BEVs generally travel a similar number of miles per vehicle per day as ICEVs.

3.1.3 Plug-In Hybrid Electric Vehicles

PHEVs are vehicles that use energy from a battery, an ICE fueled by gasoline, or a combination of the two to attain propulsion power. PHEVs have smaller batteries than BEVs but can operate solely on energy from the battery and can be plugged in and charged using electricity from the grid. PHEVs comprise a small but increasing percentage of the EMFAC2021 default fleet mix and are the only vehicle technology considered in this analysis that is capable of both electric-only trips and trips using an ICE.

In order to account for the two potential operational modes of a PHEV (i.e., propulsion using only energy from the battery or propulsion with use of the ICE), total VMT in EMFAC2021 is resolved by combustion VMT (cVMT), for miles traveled by vehicles powered by an ICE, and electric VMT (eVMT), for miles traveled by vehicles powered by energy from a battery.[18] Similarly, EMFAC2021 accounts for electric energy consumption separate from gasoline fuel consumption. In EMFAC2021, eVMT is defined as miles traveled during a pure electricity powered trip, and energy consumption is determined based on only pure electric trips during which an ICE does not turn on.[19] Thus, only PHEVs have both cVMT and eVMT and both energy consumption and fuel consumption in EMFAC2021. The remaining vehicle technologies in EMFAC2021 have either cVMT and fuel consumption (e.g., ICEVs), or eVMT and energy consumption (e.g., BEVs). Throughout this analysis, we utilize the term "fuel

[17] Non-liquid fuels, like electricity and hydrogen, are not measured in gallons, so using conversion factors allows them to be displayed on an energy-equivalent basis using the familiar MPG measurement. MPGe, or miles per gallon of gasoline equivalent, is calculated based on the energy content of gasoline, 119.53 MJ/gal for CARBOB, which is then converted to kWh to derive a conversion factor of 33.203 kilowatt-hours/gallon of gasoline equivalent. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/quarterlysummary_043022.xlsx. Accessed: May 2022.

[18] CARB. 2021. EMFAC2021 Volume I – User's Guide. January 15. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-01/EMFAC202x_Users_Guide_01112021_final.pdf. Accessed: May 2022.

[19] CARB. 2021. EMFAC2021 Volume III Technical Document - Version 1.0.0. March 31. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-03/emfac2021_volume_3_technical_document.pdf. Accessed: May 2022.

economy" as a fuel-neutral description of miles traveled per unit of fuel or energy consumed, whether the fuel is gasoline, hydrogen, or electricity. For example, fuel economies for all vehicles considered in this analysis are shown in **Appendix A, Tables A-8, A-11, A-14, A-17, A-20, and A-23.**

Based on these distinctions, Ramboll used EMFAC2021 data to derive electric and gasoline fuel economy, and the split between eVMT and cVMT for PHEVs. Gasoline fuel economy was determined based on fuel consumption and cVMT while electric fuel economy was determined based on energy consumption and eVMT. Gasoline fuel economy values for PHEVs in EMFAC2021 vary by model year and calendar year, ranging from 23 MPG to 29 MPG. In contrast, electric fuel economy values for PHEVs are constant in EMFAC2021 at 0.302 kWh/mi (~110 MPGe) for all model years in all calendar years. For PHEVs, the split between eVMT and cVMT varies by model year and calendar year. The eVMT fraction of total VMT increases from 46% in the earlier model years to 59% in the later model years, while the cVMT fraction decreases from 54% to 41%. These percentages are used to allocate total VMT to eVMT and cVMT when a PHEV replaces a ICEV in the scenario analysis. Although total VMT per vehicle for PHEVs is not used in this analysis because any PHEV replacing a ICEV is assumed to travel the same number of miles as the ICEV it is replacing, EMFAC2021 data shows that PHEVs generally travel a similar number of miles per vehicle per day as ICEVs. The methodology used to estimate tailpipe emissions for PHEVs is discussed in **Section 3.3**. See **Tables A-8** through **A-25** in **Appendix A** for PHEV fuel economy, tailpipe emission factors, and eVMT and cVMT percentages.

3.1.4 Hybrid Electric Vehicles (HEVs)

HEVs operate similar to ICEVs and obtain propulsion power primarily from an ICE, but incorporate a small battery and electric motor to improve overall fuel economy. Unlike BEVs and PHEVs, HEVs are not able to be plugged in and charged using electricity from the grid, nor are they capable of electric-only trips. Because of these operational characteristics, HEVs were analyzed similar to ICEVs in this analysis. HEVs are not included in the EMFAC2021 default fleet mix but were considered as replacements for ICEVs in some of the scenarios described in **Section 2**.

Fuel economy for HEVs was calculated based on the fuel economy of ICEVs obtained from EMFAC2021 and the relative fuel economies of the average model year 2020 HEV and ICEV as obtained from the United States Environmental Protection Agency's (USEPA's) 2020 EPA Automotive Trends Report ("EPA Report").[20] The EPA Report shows that, as a production-weighted average, hybrid cars had a fuel economy about 41% higher than the average non-hybrid car in model year (MY) 2020. This factor was assumed to remain constant in future years and was used to estimate fuel economies for MY 2026 to 2050 HEVs. Using this factor, HEVs are estimated to have gasoline fuel economies ranging from about 43 MPG to 50 MPG. The methodology used to calculate tailpipe emissions for HEVs is discussed in **Section 3.3** and HEV fuel economies are shown in **Appendix A**.

[20] United States Environmental Protection Agency (USEPA). 2021. The 2020 EPA Automotive Trends Report. EPA-420-R-21-003. January. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf. Accessed: May 2022.

3.1.5 Fuel Cell Electric Vehicles

FCEVs use an electric propulsion system similar to that of BEVs but use an on-board fuel cell to convert energy stored as hydrogen to electricity rather than utilizing energy only from a battery. Thus, FCEVs are fueled with hydrogen stored in a tank on the vehicle. Similar to BEVs, FCEVs produce zero tailpipe emissions. FCEVs are not included in the EMFAC2021 default fleet mix but were considered as replacements for ICEVs in some of the scenarios described in **Section 2**. Fuel economy for FCEVs was calculated based on the fuel economy of ICEVs and the Energy Economy Ratio (EER) of a FCEV relative to an ICEV. EERs are dimensionless values that represent the efficiency of a fuel as used in a powertrain as compared to a reference fuel used in the same powertrain. Ramboll used an EER of 2.5 based on the value for a FCEV used as a replacement for a gasoline-fueled ICEV in light/medium-duty applications as reported in CARB's LCFS Regulation.[21] This EER was applied to ICEV fuel economies as described in **Section 3.1.1** to determine FCEV fuel economies by model year and calendar year for MY 2026-2050 FCEVs. Using this methodology, FCEV energy economies range from about 0.366 to 0.374 kWh/mi (89 to 91 MPGe) as shown in **Appendix A**.

3.2 Fuel Cycle Emissions

An accurate assessment of future vehicle/fuel technology pathways requires a complete fuel-cycle analysis, commonly called a well-to-wheels analysis. A well-to-wheels analysis considers energy use and emissions associated with fuel production and distribution activities ("well-to-tank" or "upstream") as well as energy use and emissions associated with vehicle operation ("tank-to-wheels" or "tailpipe") activities.[22] The following sub-sections describes the methodology used to estimate upstream and tailpipe emissions for the vehicle/fuel technologies that are considered in this analysis.

3.2.1 Upstream (Well-to-Tank) Emissions

Upstream emissions are generated from feedstock-related processes (recovery, processing, storage, and transportation of feedstocks) and fuel-related processes (production, transportation, storage, and distribution of fuels).[23]

Ramboll estimated well-to-tank GHG emission factors for each analyzed fuel type (CaRFG, low-CI gasoline, electricity, and hydrogen) using carbon intensities obtained from the CA-GREET3.0 model,[24] LCFS Lookup Pathways Tables,[25] LCFS Quarterly Summary data,[26]

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[21] CARB. 2020. Unofficial Electronic Version of the Low Carbon Fuel Standard. May 27. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

[22] Brinkman, Norman, Michael Wang, Trudy Weber, and Thomas Darlington. 2005. Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems – A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions. May. Available at: https://greet.es.anl.gov/files/4mz3q5dw. Accessed: May 2022.

[23] Ibid.

[24] CA-GREET 3.0 Model. Available at: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm. Accessed: January 2021.

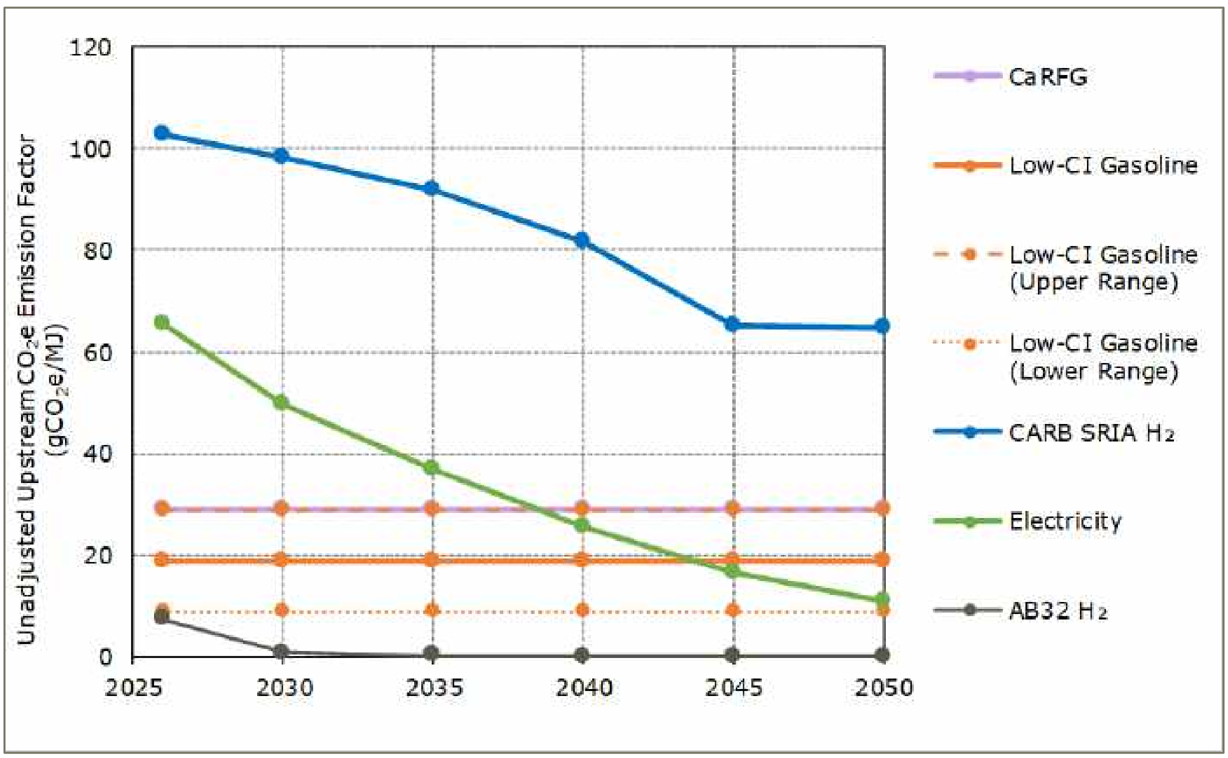
[25] CARB. 2018. CA-GREET3.0 Lookup Table Pathways Technical Support Documentation. August 13. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: May 2022.

[26] CARB. LCFS Quarterly Summaries. Available at: https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries. Accessed: May 2022.

and assumptions used in CARB's ACC II SRIA,[27] and AB 32 Initial Modeling.[28] Upstream GHG emission factors are typically represented as carbon intensities, i.e., the mass of GHG emissions in carbon dioxide equivalent (CO_2e) per unit of energy consumed in mega joules (MJ) for each fuel type. Carbon intensities for all fuel pathways considered in this analysis with and without EER adjustment are shown in **Figure 3-2** and **Figure 3-3** respectively. Additional details on the methodology used to estimate upstream GHG emission factors or CIs are provided in **Sections 3.2.1.1** through **3.2.1.4**.

Ramboll estimated the total upstream GHG emissions for each analysis year in each modeled scenario as a sum-product the upstream CI for each fuel type (**Figure 3-2**) and the total amount of each fuel consumed for each fuel type across all vehicle technologies (**Tables A-26** through **A-91** in **Appendix A**). The total amount of each fuel consumed was calculated using the VMT and fuel economy of the vehicle technologies included in each scenario. Fuel economies and VMT are determined as described in **Section 3.1**. This methodology accounts for the differences in EER between vehicle technologies because the conventional gasoline fuel energy derived from EMFAC2021 for the proportion of ICEVs replaced by other vehicle technologies was adjusted by the relative fuel economy of the replacement vehicles.

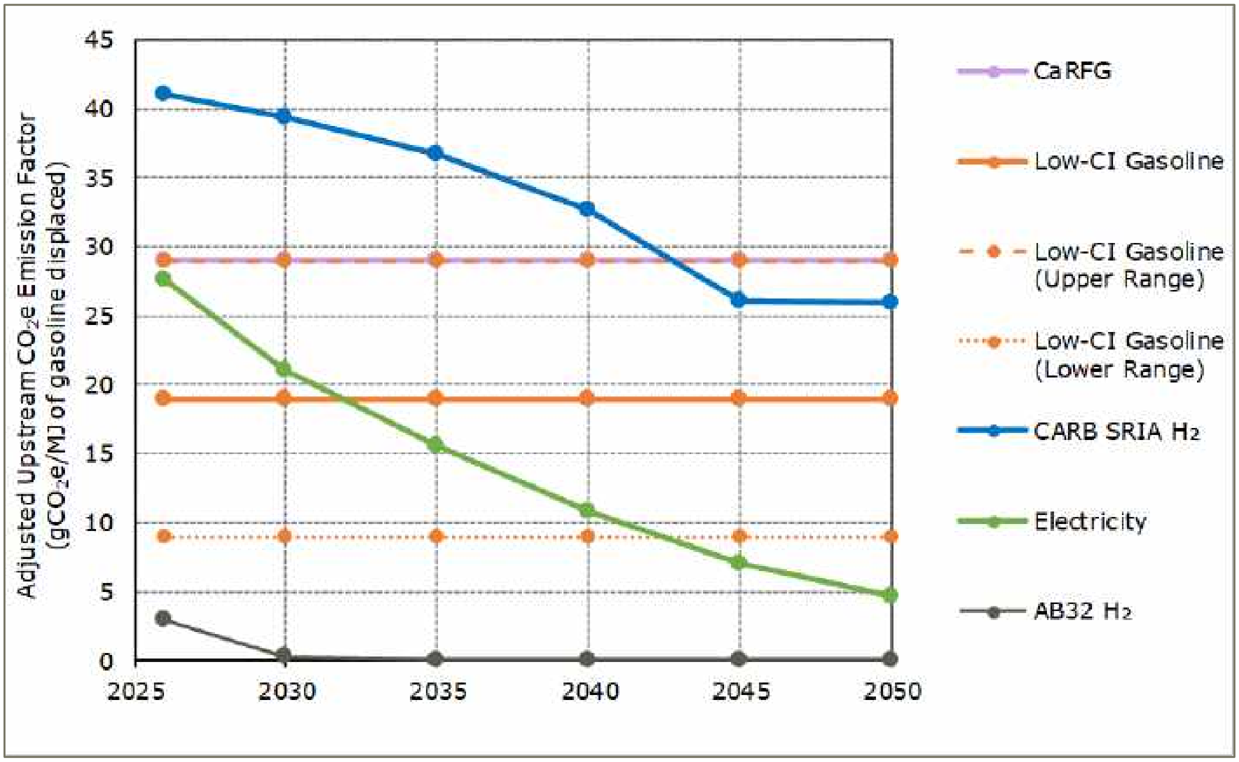
Figure 3-2. Upstream (EER-unadjusted) GHG Emission Factors by Fuel Type



[27] CARB. 2022. Appendix C-1: Standardized Regulatory Impact Assessment (SRIA). April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

[28] E3. 2022. AB 32 Initial Model Results. March 15. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-03/SP22-Model-Results-E3-ppt.pdf. Accessed: May 2022.

Figure 3-3. Upstream (EER-adjusted) GHG Emission Factors by Fuel Type



3.2.1.1 California Reformulated Gasoline

Ramboll estimated the upstream CI of CaRFG as an energy-weighted average value of the upstream CIs of the two components that make up CaRFG: California reformulated gasoline blendstock for oxygenate blending (CARBOB), and ethanol.

The upstream CI values used in this calculation include:

- 26.9 g CO_2e/MJ for CARBOB obtained from the CA-GREET3.0 Lookup Table Pathways,[29] and
- 59.8 g CO_2e/MJ for ethanol calculated as an average of the ethanol CIs available in the LCFS Quarterly Reports[30] for the most recent period (2020 Q1 to 2021 Q3) at the time of this analysis.

The blend ratio applied to these CI values to obtain a CI of 29.1 g CO_2e/MJ for CaRFG is 6.61% ethanol and 93.39% CARBOB on an energy basis, which is consistent with the 9.5% ethanol blend by volume assumed in the GREET model.[31]

[29] CARB. 2018. CA-GREET3.0 Lookup Table Pathways Technical Support Documentation. August 13. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: May 2022.

[30] CARB. LCFS Quarterly Summaries. Available at: https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries. Accessed: May 2022.

[31] CA-GREET3.0 Model. Available here: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm?_ga=2.255823756.582239942.1645477627-990540269.1603987774. Accessed: May 2022. Available under the tab 'Petroleum' under 'Energy % Ethanol in CaRFG'.

Finally, Ramboll estimated the upstream GHG emissions for CaRFG consumed by LDVs in each scenario using this CI value and the total consumption of CaRFG across all vehicle technologies in each analysis year.

3.2.1.2 Low-CI Gasoline

To estimate a carbon intensity for the low-CI gasoline considered in this analysis, a review of currently available and documented carbon intensities for low-CI renewable gasoline drop-in fuels was performed, as documented in **Table 3-1**. Sources for low-CI drop-in renewable gasoline fuels included the USEPA lifecycle GHG results, LCFS fuel pathways, Argonne National Laboratory (ANL) state-of-technology research, CARB-driven research, and a research paper published by the University of Chicago ANL. While the research yielded multiple pathways that spanned both renewable gasoline (e.g., bio-based feedstocks) as well as lower-CI gasoline alternatives, we chose to represent them as a single category due to their similar function as a drop-in replacement fuel. The average of these values was taken in order to find a representative carbon intensity for the low-CI gasoline fuel considered in this analysis, resulting in a CI of 19.0 g CO_2e/MJ, which is about 35% lower than the upstream CI for CaRFG.

Upstream GHG emissions associated with the use of low-CI gasoline in LDAs with ICEs for Scenarios S2b - PHEV + Low -CI Gas, S2c – HEV + Low-CI Gas, S3a – Low-CI Gas, S3b – Low-CI Gas (Delayed) and Custom Fleet Mix scenarios (S4a, S4b, and S4c) were calculated using this CI value of 19 g CO_2e/MJ and the total consumption of low-CI gasoline across all vehicle technologies in each analysis year.

In order to understand the impact of this carbon intensity on upstream and life cycle emissions, we also considered two sensitivity scenarios:

- Scenario 3a-1 – Low-CI Gas (Upper Range): For this scenario the low-CI gasoline CI was increased by 10 g CO_2e/MJ to 29 g CO_2e/MJ. This value is similar to the upstream CI for CaRFG.
- Scenario 3a-2 – Low CI-Gas (Lower Range): For this scenario the low-CI gasoline CI was reduced by 10 g CO_2e/MJ to 9 g CO_2e/MJ. This value is about 69% lower than the upstream CI for CaRFG.

Table 3-1. Low-CI Fuel Carbon Intensity Summary

Reference	Process	Feedstock	Upstream CI ($g\ CO_2e/MJ$)
USEPA Lifecycle GHG Results[1]	Direct biochemical fermentation	Cellulose from corn stover	-29.0
USEPA Lifecycle GHG Results[1]	Catalytic pyrolysis and upgrading	Cellulose from corn stover	28.7
USEPA Lifecycle GHG Results[1]	Biochemical fermentation and upgrading	Cellulose from corn stover	30.6
LCFS Fuel Pathways[2]	Pyrolysis	Forest residue [transport by rail]	21.2
LCFS Fuel Pathways[2]	Pyrolysis	Forest residue [transport by truck]	26.1
ANL state-of-technology research[3]	Ex Situ Catalytic Fast Pyrolysis	Woody biomass	20.7
Biofuel Supply Module[4]	Pyrolysis	Cellulosic	8.1
Biofuel Supply Module[4]	Pyrolysis	Wood	24.7
University of Chicago ANL Research Paper[5]	Fischer-Tropsch Fuel Synthesis	Solar/Nuclear/Wind Energy for Hydrogen and Corn Ethanol Production for CO_2	37.1
		Average Carbon Intensity	**19.0**

References:

1 EPA. 2016. Lifecycle Greenhouse Gas Results. Available here: https://www.epa.gov/fuels-registration-reporting-and-compliance-help/lifecycle-greenhouse-gas-results. Accessed: May 2022.

2 CARB. 2022. LCFS Current Pathways. Available here: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/currentpathways_all.xlsx. Accessed: May 2022.

3 Argonne National Laboratory. 2021. Supply chain sustainability analysis of renewable hydrocarbon fuels- update of the 2020 state-of-technology cases. Available here: https://greet.es.anl.gov/publication-2020_update_renewable_hc_fuel. Accessed: May 2022.

4 CARB. 2016. Biofuels Supply Module. Available here: https://www.arb.ca.gov/cc/scopingplan/meetings/090716/bfsmv83b.zip. Accessed: May 2022.

5 University of Chicago. 2021. Life Cycle Analysis of Electrofuels: Fischer–Tropsch Fuel Production from Hydrogen and Corn Ethanol Byproduct CO_2. Available here: https://pubs.acs.org/doi/10.1021/acs.est.0c05893. Accessed: May 2022.

3.2.1.3 Electricity

Ramboll estimated upstream GHG emissions associated with the production and distribution of electricity consumed by PHEVs and BEVs in each modeled scenario using emission factors obtained from the CA-GREET 3.0 model.[32] Developed from Argonne National Laboratory's GREET 2016 model,[33] the CA-GREET 3.0 model is used by CARB to calculate well-to-wheel emissions from transportation fuels under the California LCFS Program. Hence, use of this model to estimate upstream emissions is consistent with the CARB methodologies.

For purposes of this analysis, Ramboll adjusted the electricity grid mix inputs to the CA-GREET 3.0 model based on California Energy Commission (CEC) projections for each of the modeled calendar years 2026, 2030, 2035, 2040, 2045, and 2050.[34] Further details regarding CA-GREET 3.0 model inputs and outputs can be found in **Appendix A**.

As shown in **Figure 3-2**, the electricity CI values estimated using CA-GREET 3.0 decrease from 65.3 g CO_2e/MJ in 2026 to 11.1 g CO_2e/MJ in 2050. Once adjusted for the differences in the efficiency of electricity in BEVs as compared to gasoline-fueled ICEVs, the electricity CI values range from 27.6 g CO_2e/MJ of gasoline displaced (5.1% lower than that for CaRFG) in 2026 to 4.7 g CO_2e/MJ of gasoline displaced (83.9% lower than that for CaRFG) in 2050 (**Figure 3-3**).

3.2.1.4 Hydrogen

The methodology used to derive the carbon intensity for the hydrogen fuel pathways modeled in this analysis are described in the following sub-sections.

CARB SRIA Hydrogen

Ramboll assumed that 40% of the hydrogen for the CARB SRIA H_2 fuel pathway would come from renewable feedstocks and the remaining 60% from fossil feedstocks based on the methodology used in the SRIA for the proposed ACC II[35] and discussions with CARB ACC II staff.[36] The fossil feedstock for hydrogen is assumed to be fossil natural gas which is processed via a steam methane reformation (SMR) process to produce Fossil Hydrogen per

[32] CARB. 2019. CA-GREET3.0 Model - Current Version: Effective January 4, 2019 (released August 13, 2018). Available at: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm?_ga=2.203396115.367263062.1651770761-1504446328.1547148412. Accessed: May 2022.

[33] Available at: https://greet.es.anl.gov/publication-greet-model. Accessed: January 2021.

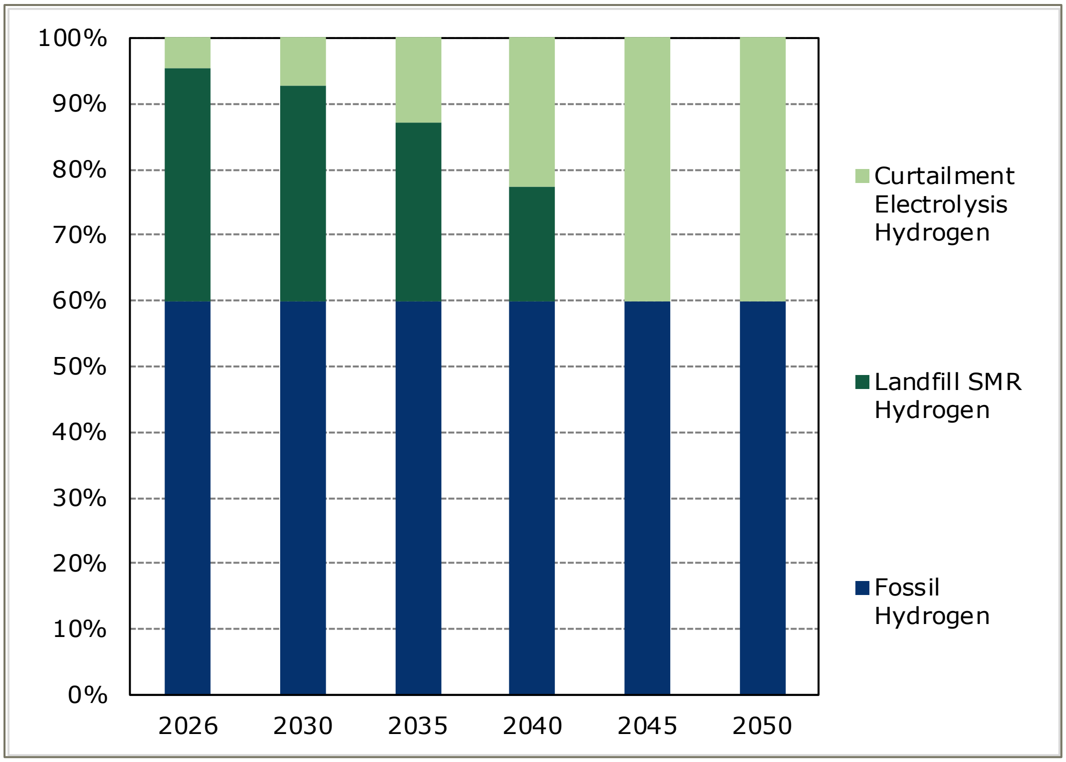
[34] CEC 2018. Deep Decarbonization in a High Renewables Future - Implications for Renewable Integration and Electric System Flexibility, Docket 18-IEPR-06 - 223869, Slide 10. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=223869&DocumentContentId=54081. Accessed: January 2021.

[35] CARB. 2022. Appendix C-1: Standardized Regulatory Impact Assessment (SRIA). April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

[36] Based on e-mail communication between S. Moca, Ramboll US Consulting and CARB ACC II Staff on February 15, 2022. CARB staff indicated in their email that hydrogen fuel in the SRIA for the proposed ACC II consisted of 3 major blends of fuel types: fossil natural gas (NG) hydrogen, renewable hydrogen from renewable NG, renewable hydrogen from curtailments. CARB assumed that renewable hydrogen levels off at 40% of the total hydrogen used, and that renewable hydrogen gradually transitions from renewable NG hydrogen to renewable hydrogen from curtailments. CARB shared that this transition was modeled with a log function assuming a market share (%) of renewable hydrogen at specific time points which are 6% at 2020, 10% at 2025, and 100% at 2045. Additionally, they shared that the renewable natural gas feedstock was assumed to be 100% from landfill biogas. Lastly, for renewable hydrogen from curtailments, CARB staff assumed zero GHG emissions given transmission/distribution and refilling phases using renewable energy.

the 2020 Mobile Source Strategy[37] and as cited in the SRIA. The renewable feedstock is assumed to be Landfill Biogas with hydrogen production via SMR (Landfill SMR Hydrogen) and electrolysis using curtailment electricity (Curtailment Electrolysis Hydrogen). [38] Based on correspondence with CARB ACC II staff, the transition of hydrogen production from landfill biogas to curtailment electricity was modeled with a log function assuming specific feedstock shares at three points in time: 6% at 2020, 10% at 2025, and 100% at 2045.[39] The feedstock breakdown shown in **Figure 3-4** below illustrates this transition.

Figure 3-4: Feedstock Breakdown for CARB SRIA H_2[40]



The upstream carbon intensity values for each feedstock were estimated as follows:

- Fossil Hydrogen: A CI of 117.67 g CO_2e/MJ for Fossil Hydrogen was obtained from the LCFS certified pathway for hydrogen production from SMR using fossil natural gas.[41]

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[37] CARB. 2021. 2020 Mobile Source Strategy. October 28. Available here: https://ww2.arb.ca.gov/sites/default/files/2021-12/2020_Mobile_Source_Strategy.pdf. Accessed: May 2022.

[38] Curtailment is the reduction of output of a renewable resource below what it could have otherwise produced due to oversupply or other factors. Thus, the energy source for curtailment electrolysis hydrogen is envisioned to be electricity produced by an oversupply of a renewable resource. Reference: CAISO. 2017. Impacts of renewable energy on grid operations. Available here: https://www.caiso.com/documents/curtailmentfastfacts.pdf. Accessed: May 2022.

[39] Based on e-mail communications between S. Moca, Ramboll US Consulting and CARB ACC II Staff on February 15, 2022.

[40] Ibid.

[41] CARB. 2018. CA-GREET3.0 Lookup Table Pathways Technical Support Documentation. August 13. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: May 2022.

Since the gaseous hydrogen compression and precooling processes in this pathway use California grid electricity, the CIs for Fossil Hydrogen SMR were adjusted over time to account for the increased renewables in the grid. Refer to **Table A-6** in **Appendix A** for further details.

- Landfill SMR Hydrogen: A CI of 99.48 g CO_2e/MJ for Landfill SMR Hydrogen was obtained from the LCFS certified pathway for hydrogen production from SMR using landfill biogas.[42] Since the gaseous hydrogen compression and precooling processes in this pathway use California grid electricity, the CIs for Landfill SMR were adjusted over time to account for the increased renewables in the grid. Refer to **Table A-6** in **Appendix A** for further details.
- Curtailment Electrolysis Hydrogen: It was assumed that Curtailment Electrolysis Hydrogen would have a CI of zero, as the hydrogen is produced by electrolysis using curtailment electricity.[43]

The resulting CIs for the CARB SRIA Hydrogen are estimated as a feedstock weighted average of the CIs for the individual feedstocks (Fossil Hydrogen, Landfill SMR, and Curtailment Electrolysis) based on the feedstock breakdown shown in **Figure 3-4** for each analysis year. As shown in **Figure 3-2**, these CIs reduce from 102.6 g CO_2e/MJ in 2026 to 64.8 g CO_2e/MJ in 2050. Once adjusted for the for differences in the efficiency of electricity in FCEVs as compared to gasoline-fueled ICEVs, the CARB SRIA Hydrogen CI values range from 41.0 g CO_2e/MJ of gasoline displaced (41% greater than that for CaRFG) in 2026 to 25.9 g CO_2e/MJ of gasoline displaced (11% lower than that for CaRFG) in 2050 (**Figure 3-3**).

AB32 Hydrogen

The AB 32 Initial Modeling[44] for the draft 2022 Scoping Plan Update assumes that 100% of hydrogen production in the future would come from renewable sources, with the primary hydrogen production pathway being electrolysis using electricity generated by solar photovoltaic systems (Solar Electrolysis Hydrogen). To evaluate how hydrogen from a 100% renewable feedstock (AB32 Hydrogen) would impact the GHG inventory for the draft ACC II proposal, Ramboll modeled sensitivity scenario S1d-1 – ACC II (FCEV) + AB32 H_2 with this lower CI hydrogen. The following assumptions were used to develop the CI for AB32 Hydrogen:

- We assumed that AB32 Hydrogen would be a combination of hydrogen produced using the following pathways: Landfill SMR Hydrogen and Solar Electrolysis Hydrogen.
- The methodology used to estimate the CI for Landfill SMR Hydrogen is described in **Section 3.2.4.1**. As noted in that section, this CI reduces over time to account for the increased renewables in the California grid electricity that is used in the hydrogen compression and precooling processes. Refer to **Tables A-6** and **A-7** for further details.

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[42] Ibid.

[43] Based on e-mail communications between S. Moca, Ramboll US Consulting and CARB ACC II Staff on February 15, 2022

[44] E3. 2022. CARB Draft Scoping Plan: AB32 Source Emissions Initial Modeling Results. March 15. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-03/SP22-Model-Results-E3-ppt.pdf. Accessed: May 2022.

- The upstream CI for Solar Electrolysis Hydrogen was assumed to be zero, as hydrogen is produced using electrolysis with zero CI electricity that is generated by solar photovoltaic systems.
- The volumes of Landfill SMR Hydrogen for the analysis years was assumed to not exceed the total renewable hydrogen volume (2,700,000 kg/year or 324,000,000 MJ/year) produced in 2021 per Annual Hydrogen Evaluation.[45] The remaining hydrogen demand in each analysis year was assumed to be met by Solar Electrolysis Hydrogen. Refer to **Table A-7** for further details.

The resulting CIs for the AB32 Hydrogen were estimated as a feedstock weighted average of the CIs for the individual feedstocks (Landfill SMR and Solar Electrolysis) are shown in **Figure 3-2** for each analysis year. These CIs reduce from 7.45 g CO_2e/MJ in 2026 to less than 1 g CO_2e/MJ in 2030 and beyond. Once adjusted for the for differences in the efficiency of electricity in FCEVs as compared to gasoline-fueled ICEVs, the AB32 Hydrogen CIs values are even lower, ranging from 2.98 g CO_2e/MJ of gasoline displaced in 2026 to less than 0.5 g CO_2e/MJ of gasoline displaced in 2030 and beyond (**Figure 3-3**).

3.2.2 Tailpipe (Tank-to-Wheel) Emissions

Tailpipe emissions (tank-to-wheel) are generated from fuel consumption during vehicle operation.[46] **Table 3-2** summarizes the assumptions used to estimate the tailpipe GHG emissions from various vehicle/fuel technologies that are included in this analysis.

Table 3-2. Tailpipe Emission Assumptions

Vehicle/Fuel Technology	Tailpipe GHG
ICEVs fueled by CaRFG	Default EMFAC emission factors adjusted for the ethanol content of CaRFG
ICEVs fueled by Low-CI Gasoline	Zero tailpipe CO_2 emissions, default EMFAC emission factors for CH_4 and N_2O emissions
PHEVs fueled by CaRFG and Electricity	cVMT: Default EMFAC emission factors adjusted for the ethanol content of CaRFG eVMT: Zero GHG tailpipe emissions
PHEVs fueled by Low-CI Gasoline and Electricity	cVMT: Zero tailpipe CO_2 emissions, default EMFAC emission factors for CH_4 and N_2O emissions eVMT: Zero GHG tailpipe emissions
HEVs fueled by CaRFG	Default EMFAC emission factors for ICEVs adjusted for the fuel economy of HEVs and the ethanol content of CaRFG
HEVs fueled by Low-CI Gasoline	Zero tailpipe CO_2 emissions, default EMFAC emission factors for CH_4 and N_2O emissions

[45] CARB. 2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. September. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf. Accessed: May 2022.

[46] Brinkman, Norman, Michael Wang, Trudy Weber, and Thomas Darlington. 2005. Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems – A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions. May. Available at: https://greet.es.anl.gov/files/4mz3q5dw. Accessed: May 2022.

Table 3-2. Tailpipe Emission Assumptions	
Vehicle/Fuel Technology	**Tailpipe GHG**
BEVs fueled by Electricity	Zero GHG tailpipe emissions
FCEVs fueled by Hydrogen	Zero GHG tailpipe emissions

Combustion of gasoline (CaRFG and Low-CI gasoline) in ICEs in ICEVs, PHEVs, and HEVs generate the following greenhouse gas emissions: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Ramboll estimated tailpipe GHG emissions from gasoline fueled vehicle operation for each Scenario using data from EMFAC2021, as follows:

- EMFAC2021[47,48] was queried at the statewide level for analysis years 2026, 2030, 2035, 2040, 2045 and 2050 to obtain daily total GHG exhaust emissions and gasoline fuel consumption data for ICEV and PHEV LDAs by model year.
- Tailpipe emission factors for CO_2, CH_4, and N_2O in mass of emissions per unit of gasoline fuel consumed (e.g., tons/gal and tons/MJ) were calculated for ICEVs and PHEVs as a ratio of the total exhaust emissions to gasoline fuel consumption obtained from EMFAC2021[49] for each model year vehicle in each analysis year. Refer to **Tables A-10**, **A-13**, **A-16**, **A-19**, **A-22**, and **A-25** in **Appendix A** for further details.
- Tailpipe GHG emission factors in mass of emissions per unit of gasoline fuel consumed (e.g., tons/gal and tons/MJ) for HEVs are assumed to be the same as ICEVs because of their operating characteristics, as described in **Section 3.1.4**.
- Tailpipe GHG emissions for ICEVs, PHEVs, and HEVs were then estimated using tailpipe GHG emission factors and the cVMT and gasoline fuel economies for these vehicle technologies in each Scenario (determined as described in **Section 3.1**). Specifically, gasoline fuel economies were used to calculate the average daily gasoline consumption for each vehicle type based on daily cVMT, and then the tailpipe emission factors for each vehicle type, were applied to the gasoline fuel consumption to estimate average daily tailpipe emissions of CO_2, CH_4, and N_2O for ICEVs, PHEVs, and HEVs.
- Total average daily tailpipe GHG emissions reported in units of carbon dioxide equivalent (CO_2e) were calculated by applying the global warming potentials (GWPs) from the International Panel on Climate Change (IPCC) Fourth Assessment Report[50] to the average daily emissions of CO_2, CH_4, and N_2O.

[47] CARB. 2021. EMFAC2021 Database v1.0.1. Available at: https://arb.ca.gov/emfac/emissions-inventory. Accessed: January 2022.

[48] This analysis uses EMFAC2021 v1.0.1. A newer version of EMFAC2021 v1.0.2 was released on May 2, 2022 (after completion of this analysis) that reflects the revocation of the Safe Affordable Fuel-Efficient or SAFE vehicles rule. While this update increases the fuel economy, methane (CH_4), and nitrous oxide (N_2O) tailpipe emission factors by <5% and <0.5% for 2025+ model year ICEVs and PHEVs, respectively, it does not change the overall conclusions of the analysis.

[49] Note, tailpipe emission factors for PHEVs are based only on *fuel* consumption, as *energy* consumption associated with pure electric trips has zero tailpipe emissions.

[50] Greenhouse Gas Protocol. Available at: https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf. Accessed January 2021.

- These average daily GHG emissions are scaled up to annual GHG emissions based on 347 days of operation per year for LDAs reported in EMFAC technical documentation.[51]
- Finally, since the CO_2 emissions generated by the combustion of the renewable ethanol content in CaRFG and Low-CI gasoline are considered biogenic, they are excluded from this analysis,[52] using the following adjustments.
  - Adjustments for Tailpipe GHG Emissions Associated with CaRFG: EMFAC2021 calculates tailpipe emissions assuming gasoline vehicles are fueled by CaRFG. However, while tailpipe CO_2 emissions in EMFAC2021 account for the reduction in carbon content of CaRFG relative to CARBOB due to the 9.5 percent blend of ethanol by volume, CO_2 emissions from the renewable ethanol fraction in CaRFG are still included in EMFAC2021 default outputs. Thus, in order to account for the elimination of CO_2 emissions from the renewable ethanol content of CaRFG, Ramboll applied an emission reduction factor of 6.3 percent to all tailpipe CO_2 emissions resulting from the use of CaRFG. The emission reduction factor was derived based the 9.5 percent volume fraction of ethanol in CaRFG and the carbon content of ethanol, CARBOB, and CaRFG, assuming renewable ethanol has zero CO_2 tailpipe emissions. No adjustments were made to the tailpipe CH_4 and N_2O.
  - Adjustments for Tailpipe GHG Emissions Associated with Low-CI Gasoline: The low-CI gasoline included in this analysis is produced from renewable feedstocks (See **Section 3.2.1.2)** and tailpipe CO_2 emissions associated with the combustion of this fuel are biogenic and set to zero. No adjustments were made to tailpipe CH_4 and N_2O emissions for Low-CI Gasoline use.

Electricity consumption from batteries in PHEVs and BEVs does not produce tailpipe emissions. Hence, tailpipe GHG emissions for eVMT associated with PHEVs and BEVs was assumed to be zero. Similarly, hydrogen consumption in FCEVs does not generate GHG emissions, so tailpipe GHG emissions for FCEVs are assumed to be zero. Further details regarding tailpipe emission estimation methodology, including EMFAC2021 inputs and outputs, can be found in **Appendix A**.

3.3 Vehicle Cycle Emissions

Ramboll estimated vehicle cycle emissions using the Argonne National Laboratory (ANL) 2021 Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) Model.[53] GREET is a life cycle model developed by Argonne National Laboratory that evaluates the energy and environmental impacts of a range of vehicle technologies and transportation fuels, allowing users to model the effects of various vehicle-fuel type

[51] CARB. 2018. EMFAC 2017 Volume III – Technical Documentation. July 20. Available at: https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf. Accessed: May 2022.

[52] This aligns CARB's methodology for estimating the statewide GHG emission inventory, as noted in the 2021 CARB Report on the *California Greenhouse Gas Emissions for 2000 to 2019*, which states that "carbon dioxide (CO_2) emissions from biofuels (the biofuel components of fuel blends) are classified as "biogenic CO_2". They are tracked separately from the rest of the emissions in the inventory and are not included in the total emissions when comparing to California's 2020 and 2030 GHG Limits." Available at: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2019/ghg_inventory_trends_00-19.pdf?msclkid=9f56cab9d01611ec878dcdb49cca2c91. Accessed: May 2022.

[53] ANL. 2021. Greenhouse gases, Regulated Emissions, and Energy use in Technologies model. Available at: https://greet.es.anl.gov/. Accessed: May 2022.

combinations. GREET 1 focuses on fuel life cycle impacts and estimates the energy consumption and emissions associated with fuel production ("well-to-tank") and vehicle operation ("tank-to-wheel"). GREET 2 is the vehicle life cycle model and evaluates the energy and emission impacts associated with vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling.[54]

3.3.1 Vehicle Cycle Emission Factors

For this analysis, Ramboll used GREET 2 (and GREET 1 inputs as needed) to estimate vehicle life cycle emission factors for ICEV, HEV, BEV, and PHEV technologies. FCEVs were not included in the scope of Ramboll's vehicle cycle emissions analysis.[55] The vehicles are evaluated as model year 2026 passenger vehicles; while vehicle cycle emissions may decrease over time with the increase in the renewable content of the electricity used for vehicle production, we do not expect the reduction to significantly alter the results or conclusions of the study.

Battery recycling for BEVs and PHEVs is not included in this assessment. This assumption is informed by current end-of-life recycling rate of <1% globally for lithium and rare earth minerals noted in the 2021 International Energy Association (IEA) Study on the *Role of Critical Minerals in Clean Energy Transition.*[56] Furthermore, it is likely that the vast majority of batteries produced in the future would require virgin material given the significant increase in demand under a mass vehicle electrification scenario.

The vehicle emission and electric grid mix data input to the model is based on the most current information available at the time of this study as the scope of this analysis does not include forecasting or projecting future energy demands from vehicle and battery manufacturing.

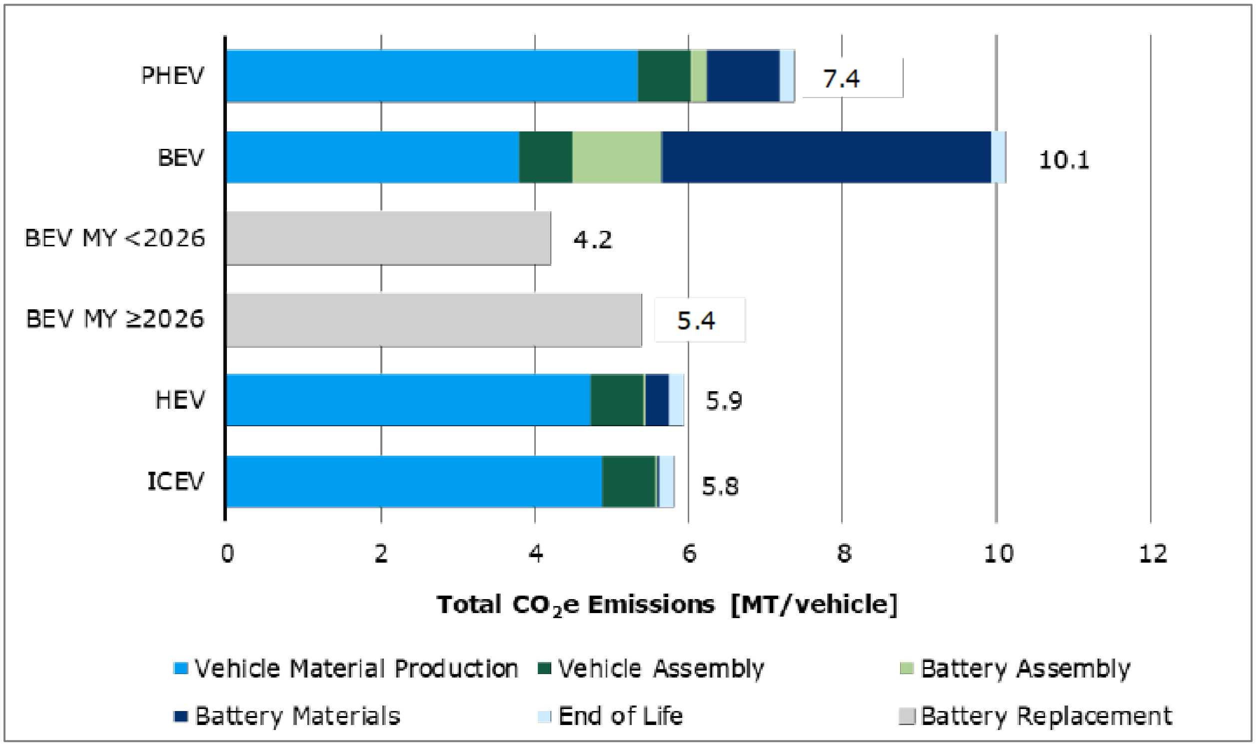
The resulting vehicle cycle emission factors in metric tons of CO_2e per vehicle for PHEVs, BEVs, HEVs, and ICEVs are shown in **Figure 3-5**. Additional details on the GREET model inputs used to estimate these emissions are described in the following sub-sections.

[54] ANL. 2021. GREET Model Platforms. Available at: https://greet.es.anl.gov/greet.models. Accessed: May 2022.

[55] FCEVs represented only a small fraction (<0.8%) of total 2020 ZEV sales and an even smaller fraction (<0.06%) of the total 2020 LDV sales in California. The vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling processes are still in the developmental stage, and it would be too speculative to estimate vehicle cycle emissions until the market for these vehicles mature. Sales data obtained from CEC data dashboard 'New ZEV Sales in California'. Available here: https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/new-zev-sales. Accessed: May 2022.

[56] International Energy Agency (IEA). 2021. The Role of Critical Minerals in Clean Energy Transitions. May. Available at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions?msclkid=fa519918d01f11ecbcf188dc9fbbf9f2. Accessed: May 2022.

Figure 3-5: Vehicle Cycle and Battery Replacement GHG Emission Factors



3.3.1.1 GREET Inputs for ICEVs and HEVs

To model ICEVs and HEVs, Ramboll used default values in the GREET model for all vehicle production and assembly parameters except for the electricity mix used for material and fuel production. The US electric mix for stationary use in GREET 1 was updated with the 2020 national electricity mix published by the EPA's Emissions & Generation Resource Integrated Database (eGRID).[57] Ramboll also updated the GREET 1 electric grid mixes for fuel production for non-US countries where vehicle and battery components are produced or assembled. These grid mixes were updated using most recent available data from the IEA.[58] A full matrix of all non-default GREET inputs can be found in **Appendix A**.

3.3.1.2 GREET Inputs for BEVs and PHEVs

For BEVs, Ramboll modeled a lithium-ion (Li-ion) battery with a nickel manganese cobalt (NMC 622) cathode material, which per a 2021 study from the International Council on Clean Transportation (ICCT) is the most common cathode material used in BEVs globally.[59] The Li-ion peak battery energy for BEVs is modeled as 81 kWh. This value was calculated as a product of BEV fuel economy, range, and charge utilization. The fuel economy is 2.59-mi/kWh based on EMFAC2021 data (described in **Section 3.1.2**), the range is

[57] EPA. 2022. eGRID Summary Tables 2020. January 27. Available here: https://www.epa.gov/egrid/summary-data. Accessed: May 2022.

[58] IEA. 2022. Countries and regions. Available at: https://www.iea.org/countries. Accessed: May 2022.

[59] ICCT. 2021. A Global Comparison of The Life-Cycle Greenhouse Gas Emissions Of Combustion Engine And Electric Passenger Cars. Available here: https://theicct.org/publication/a-global-comparison-of-the-life-cycle-greenhouse-gas-emissions-of-combustion-engine-and-electric-passenger-cars/. Accessed: May 2022.

200 miles based on the minimum certified all-electric range in the draft ACC II regulation,[60] and the state of charge (SOC) utilization is 95% based on CARB's ZEV cost modeling worksheets.[61,62] Battery production and assembly share by country is derived from the number of battery cells supplied to the US BEV market by production location, reported in an Argonne National Laboratory publication on the 2010-2020 Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States.[63] Production shares for 2020 were used in order to reflect the most current information available.

To model PHEVs, Ramboll assumed the NMC 111 cathode material (which is the GREET default) since NMC 622 is not an option provided in GREET 2 for PHEVs. The Li-ion peak battery energy for PHEVs is modeled as 14 kWh. This value was calculated as a product of PHEV fuel economy, range, and charge utilization. The fuel economy is 3.31 mi/kWh based on EMFAC2021 data (described in **Section 3.1.3**), the range is 40 miles based on the US-06 minimum certified all-electric range in the draft ACC II regulation,[64] and the SOC utilization is 85% based on CARB's ZEV cost modeling worksheets.[65,66] Battery production and assembly shares by country are assumed to be equivalent to those used in the BEV model.

All other vehicle and battery parameters for BEVs and PHEVs were left unchanged from GREET default values, and a full matrix of all non-default inputs for these vehicles can be found in **Appendix A**.

3.3.2 Vehicle Cycle GHG Emissions in Scenario Analysis

Ramboll incorporated vehicle cycle GHG emissions for all ICEVs, PHEVs, BEVs, and HEVs in the scenario analysis by calculating GHG emissions for all vehicles of a given model year, and attributing those emissions to the corresponding calendar year (assumed to be the same as the model year) in which they were produced. The following steps were used to develop the vehicle cycle emissions and incorporate it into the scenario analysis:

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60 CARB. 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

61 CARB. 2021. ZEV Cost Modeling Workbook October 2021. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-11/ZEV_Cost_Modeling_Workbook_Update_October2021.xlsx. Accessed: January 2022.

62 The October 2021 version of CARB's ZEV Cost Modeling Workbook was referenced for this analysis. A newer version of this workbook was released in late April 2022 (after completion of this analysis), which assumed a lower SOC utilization for BEV batteries of 92.5%. However, this does not change the overall conclusions of the analysis.

63 ANL. 2021. Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010-2020. March. Available at: https://publications.anl.gov/anlpubs/2021/04/167369.pdf. Accessed: May 2022.

64 CARB. 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

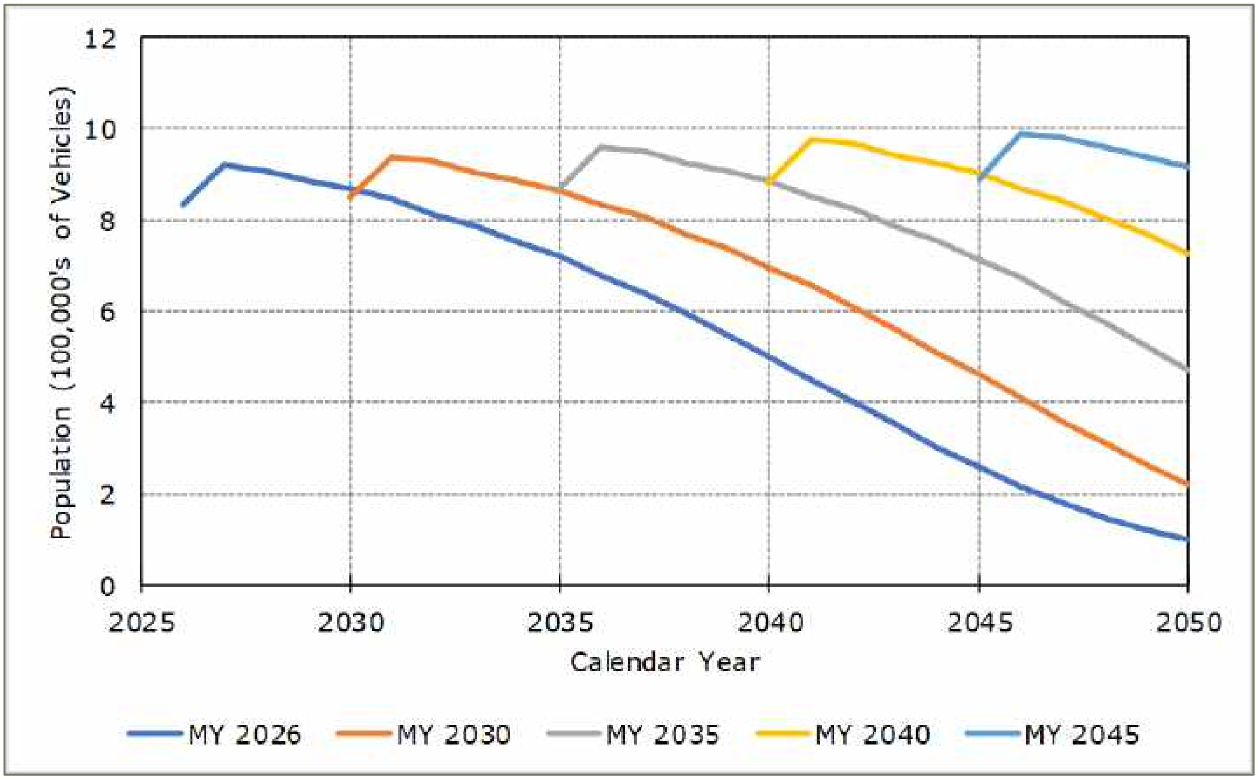
65 CARB. 2021. ZEV Cost Modeling Workbook October 2021. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-11/ZEV_Cost_Modeling_Workbook_Update_October2021.xlsx. Accessed: January 2022.

66 The October 2021 version of CARB's ZEV Cost Modeling Workbook was referenced for this analysis. A newer version of this workbook was released in late April 2022 (after completion of this analysis), which assumed a lower SOC utilization for PHEV batteries of 80%. However, this does not change the overall conclusions of the analysis.

- Ramboll assumed that the total number of vehicles produced for a given model year is equal to the peak population of that model year in EMFAC2021. **Figure 3-6** shows that the peak vehicle population for any given model year in EMFAC2021 occurs one year after the corresponding calendar year (CY) in which they were first introduced to the fleet.[67]
- GHG emissions from production of vehicles of a certain MY are assumed to occur in the calendar year the vehicles are produced (for example, MY 2026 vehicle population peaks in CY 2027, but vehicle cycle emission from vehicle production occur in CY 2026).
- Since EMFAC2021 does not output fleet data for CY 2051, Ramboll estimated the peak population of MY 2050 vehicles (which would occur in CY 2051) by applying the percentage increase in MY 2049 vehicles from CY 2049 to CY 2050 to the MY 2050 vehicle population in CY 2050.
- It is assumed that production patterns for different vehicle technologies would be similar to the pattern modeled in EMFAC2021. Therefore, the total number of vehicles produced for each vehicle technology in each model year is calculated based on the fleet mix percentage for that vehicle technology and the total peak population in the following calendar year. Fleet mixes for each scenario are shown in **Figure 2-3** and **Figure 2-4** and detailed tables showing fleet mix percentages and population data for each vehicle technology by model year in each calendar year are included in **Appendix A**.
- Finally, the total annual life cycle GHG emissions for each modeled scenario in the analysis years (2026, 2030, 2035, 2045, and 2050) were estimated as follows: The total number of vehicles produced for each vehicle technology in an analysis year was multiplied by the corresponding GREET vehicle life cycle emission factor (on a per-vehicle basis, see **Figure 3-5** for vehicle cycle emission factors) in order to generate vehicle life cycle GHG emissions. These emissions were then added to the upstream and tailpipe emissions for each analysis year in order to estimate total annual life cycle GHG emissions.

[67] Total LDA vehicle population reported in **Figure 3-6** is based on the EMFAC2021 queries performed for this analysis, as described in detail in Appendix A. Diesel vehicles are not included.

Figure 3-6: LDA Vehicle Population in EMFAC2021



3.3.3 GHG Emissions from Lithium Battery Replacement

In addition to GHG emissions from vehicle and battery production, Ramboll analyzed the GHG emissions associated with battery replacement for BEVs. Battery replacement for BEVs lithium-ion batteries is assumed to occur in the ninth year of use based on the 8-year warranty requirement proposed in the CARB ACC II Initial Statement of Reasons (ISOR) Staff Report.[68] Ramboll's scenario analysis assumes that one battery replacement occurs over the vehicle lifetime for all BEVs remaining in the vehicle fleet in the ninth year of operation (e.g., battery replacement emissions in CY 2026 are calculated based on the population of MY 2017 BEVs in CY 2026). This methodology accounts for the default retirement rate of vehicles in EMFAC2021, as illustrated in **Figure 3-6** above.

The emissions per vehicle associated with this battery replacement were estimated from the results of the GREET modelling described in **Section 3.4.1**. In particular, the emissions for battery production and assembly were combined to estimate battery replacement emissions on a per vehicle basis. For MY 2026-2050 BEVs, BEV battery replacement is assumed to occur for an 81-kWh battery as described in **Section 3.4.1**. However, for pre-2026 BEVs, a peak battery energy of 62.5 kWh was assumed a weighted average of the battery sizes and cumulative sales of various BEV models from 2010-2020 in the United States.[69] Thus,

[68] CARB. 2022. Staff Report: Initial Statement of Reasons. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/isor.pdf. Accessed: May 2021.

[69] Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010-2020. March. Available at: https://publications.anl.gov/anlpubs/2021/04/167369.pdf. Accessed: May 2022.

battery replacement emission factors for BEVs MY <2026 and BEVs MY ≥2026 were estimated separately, as represented by the gray bars in **Figure 3-5**.

Battery replacement emissions were calculated by multiplying the remaining population of BEVs in the vehicle fleet in the ninth year of operation by the emission factors per vehicle shown in **Figure 3-5**. The resulting emissions associated with BEV mid-life battery replacements were incorporated into the multi-technology scenario analysis by adding battery replacement emissions to life cycle emissions.

While batteries in PHEVs and HEVs deteriorate over time, for purposes of this analysis Ramboll has assumed that vehicle owners/operators would not replace the battery in these vehicle technologies. Instead, they would continue to operate these vehicles using the ICE and the underperforming battery till the end of the vehicle lifetime.

4. SCENARIO ANALYSIS EMISSIONS RESULTS

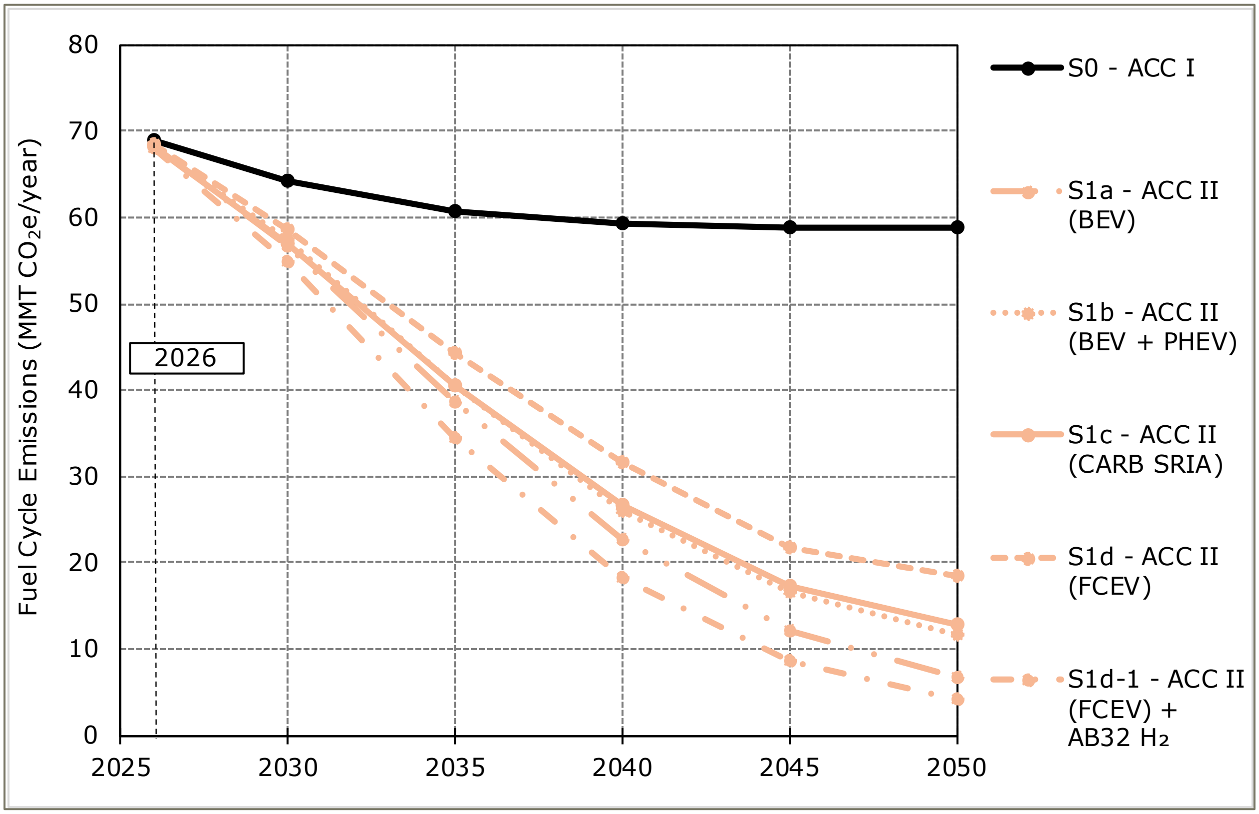
4.1 Fuel Cycle (Well-to-Wheel) Emissions

Fuel cycle emissions, also known as "well-to-wheel" emissions, include both upstream (well-to-tank) emissions and tailpipe (tank-to-wheel) emissions and represent overall emissions impacts of the fuel, including extraction of the raw materials for the fuel, fuel production and distribution, and use of the finished fuel during operation of the vehicle.[70] **Figure 4-1** through **Figure 4-4** below present the estimated total GHG fuel cycle emissions for calendar years 2026 to 2050 for each modeled scenario: S0 – ACC I (represented by black line), S1 – Baseline ACC II Scenarios (represented by the pink lines and shaded pink region), S2 – Alternative Scenarios Part 1 (represented by blue lines), S3 – Alternative Scenarios Part 2 (represented by purple lines), S4 – Alternative Scenarios Part 3 (represented by green lines).

The results presented in **Figure 4-1** show that scenario S1d – ACC II (FCEV) achieves the fewest GHG emissions reductions of the S1 - Baseline ACC II Scenarios as compared to the S0 – ACC I Scenario. This result is driven by the relatively high CI of the CARB SRIA Hydrogen as compared to electricity and the AB32 Hydrogen that displace CaRFG used in scenario S0 – ACC I. On the other hand, scenario S1d-1 – ACC II (FCEV) + AB32 H_2 provides the greatest potential GHG emission reductions of the S1 - Baseline ACC II Scenarios, due to the significant reduction in upstream emissions for AB32 Hydrogen as compared to CaRFG.

[70] https://www.epa.gov/renewable-fuel-standard-program/lifecycle-analysis-greenhouse-gas-emissions-under-renewable-fuel

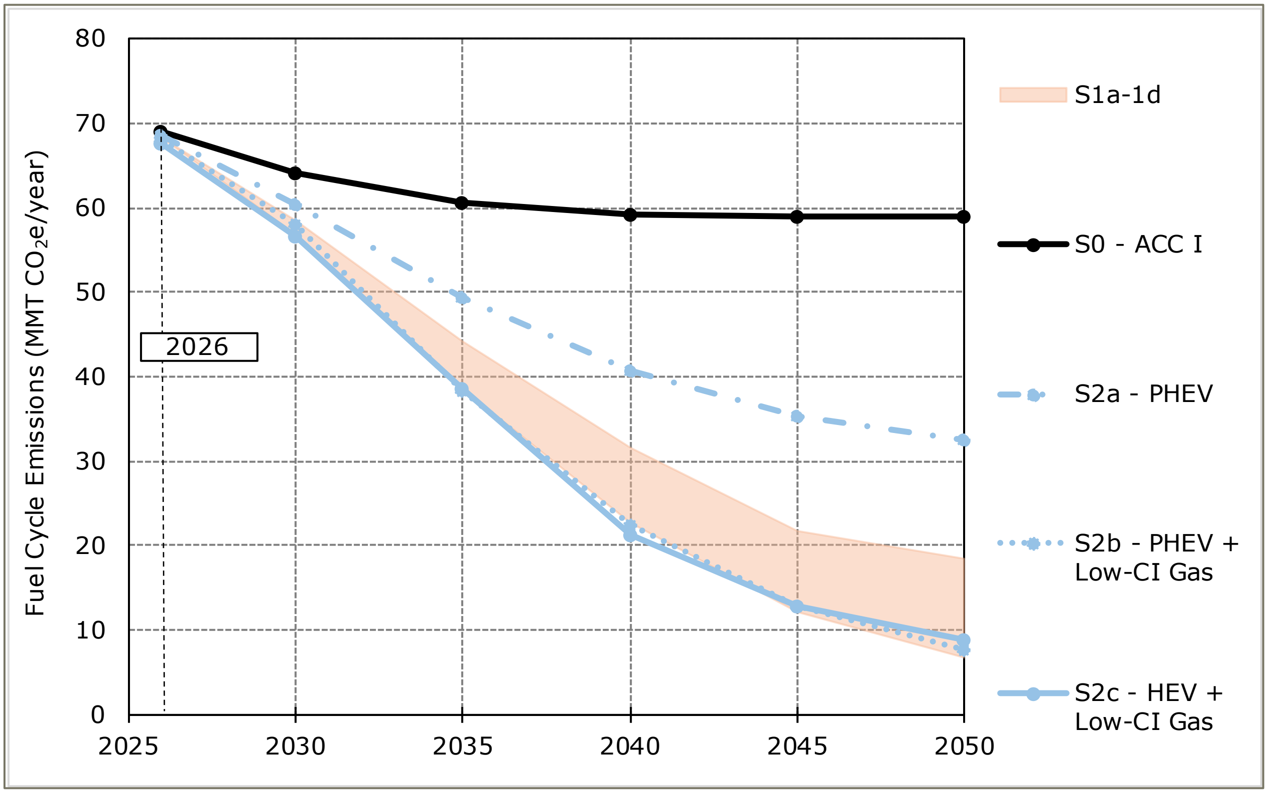
Figure 4-1: Fuel Cycle Emissions for Baseline Scenarios



As shown in **Figure 3-3**, AB32 Hydrogen pathway provides the lowest CI of all fuels considered, resulting in nearly carbon-free hydrogen with an upstream EER-adjusted CI less than 0.5 g CO_2e/MJ of gasoline displaced from 2030-2050. Aside from sensitivity scenario S1d-1 – ACC II (FCEV) + AB32 H_2, scenario S1a – ACC II (BEV), which assumes any additional ZEVs sales beyond those in the S0 – ACC I Scenario that are needed to meet the proposed ACC II ZEV sales requirements are met with BEVs, represents the lower bound of achievable GHG emissions under the draft ACC II proposal. Assuming the proposed ACC II sales requirements are met with the maximum allowable fraction of PHEVs in scenario S-1b – ACC II (BEV + PHEV) provides fewer fuel cycle GHG emission reductions than scenario S-1a – ACC II (BEV) in comparison to scenario S0 – ACC I. Results for S1c – ACC II (CARB SRIA) are similar to scenario S1b – ACC II (BEV + PHEV), although scenario S1c – ACC II (CARB SRIA) provides slightly lower fuel cycle GHG emission reductions in comparison to scenario S0 – ACC I in CY 2040-2050 due to the inclusion of FCEVs fueled by the CARB SRIA Hydrogen.

Figure 4-2 shows results for S2 - Alternative Scenarios Part 1, which estimate GHG emission reductions achievable from increased penetration of PHEVs or HEVs. Some of these scenarios include a phase-in of low-CI gasoline as a replacement for CaRFG that is used for ICEs in ICEVs, PHEVs, and HEVs.

Figure 4-2: Fuel Cycle Emissions for Alternative Scenarios Part 1



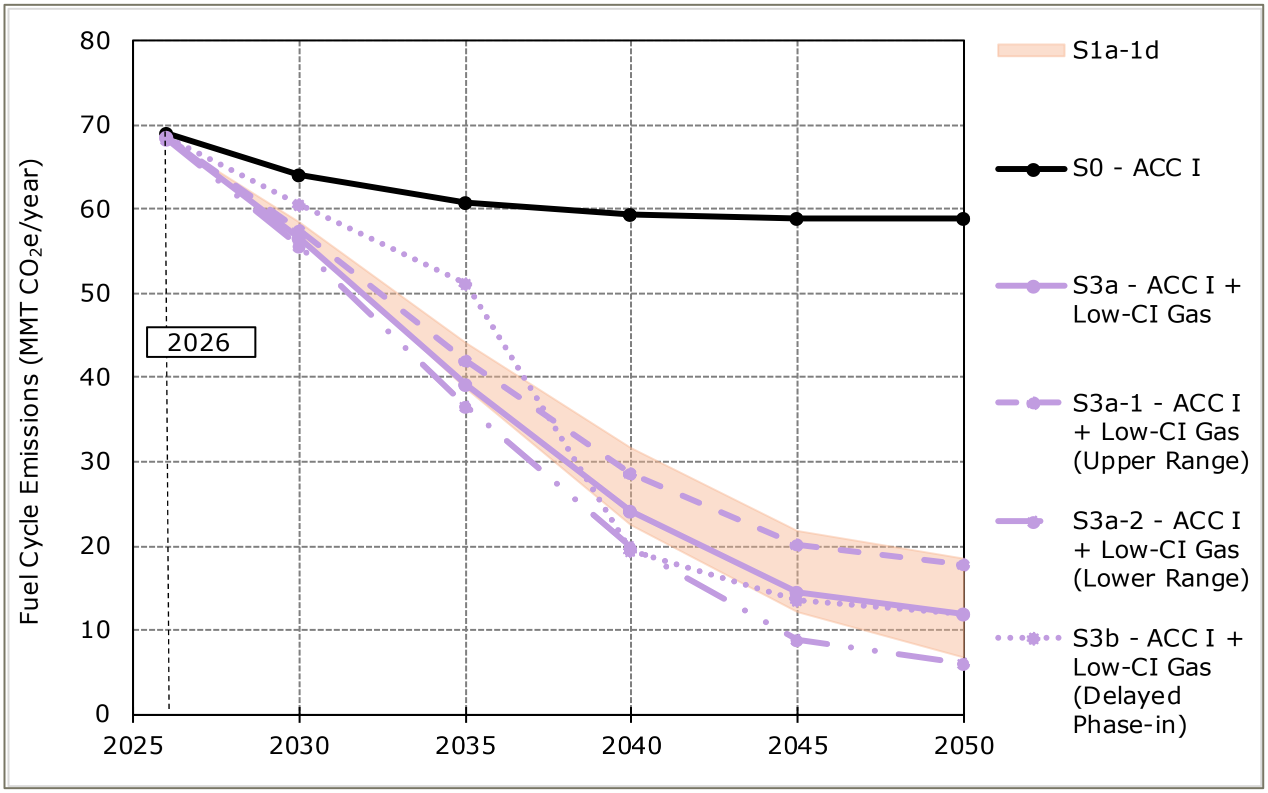
These results (**Figure 4-2**) show that we can achieve >50% of the estimated GHG reductions from the draft ACC-II proposal (scenarios S1a-1d, represented by the shaded pink region) as compared to S0 – ACC I (represented by the black solid line), by using PHEVs sales[71] to meet the ACC II ZEV sales requirements (S2a – PHEV, represented by the blue dash-dot-dash line). Phasing in Low-CI gasoline (S2b – PHEV + Low-CI Gas, represented by the blue dotted line) with these PHEVs sales could increase the GHG reductions so they are comparable to the reductions achieved with draft ACC-II proposal (scenarios S1a through S1d, represented by the shaded pink region). Similarly, a combination of HEVs sales[72] to meet the ACC II ZEV sales requirement and a phase-in of Low-CI gasoline to fuel ICEs in ICEVs, HEVs, and PHEVs (S2c – PHEV + Low-CI Gas, represented by the solid blue line) can also achieve GHG reductions that are comparable to the those from the draft ACC II proposal (scenarios S1a through S1d, represented by the shaded pink region) relative to Scenario S0 - ACC I.

Results for S3 - Alternative Scenarios Part 2, which explore the use of low-CI gasoline to generate GHG emission reductions needed to meet the State's long-term climate goals with no change in fleet mix, are shown in **Figure 4-3**.

[71] Any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0 - ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with PHEVs.

[72] Any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0 - ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with HEVs.

Figure 4-3: Fuel Cycle Emissions for Alternative Scenarios Part 2

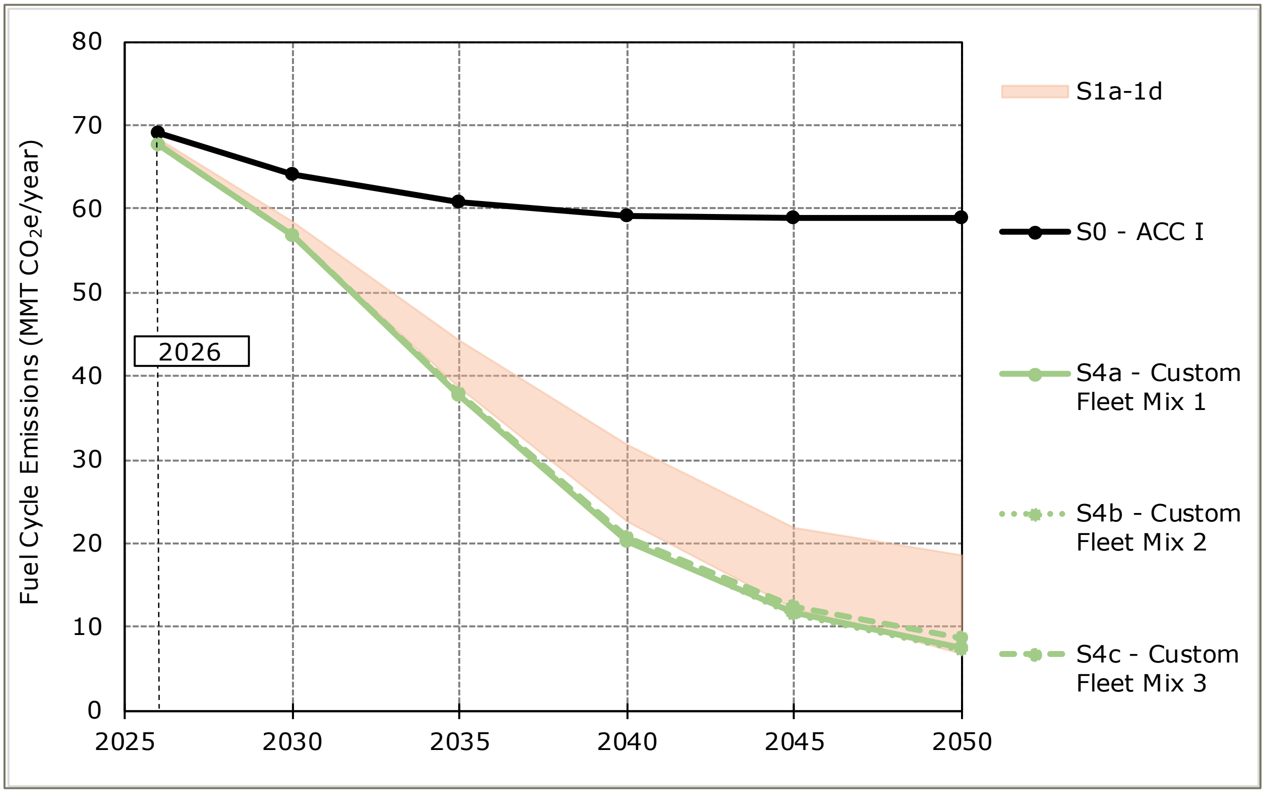


These results (**Figure 4-3**) show that a phase in of low-CI gasoline alone (represented by the purple lines) with no additional ZEV sales beyond those included in scenario S0 – ACC I (represented by the solid black line) can achieve fuel cycle GHG reductions similar to those achieved in the baseline ACC II scenarios (S1a through S1d, represented by the pink area) as compared to scenario S0 - ACC I. Results for scenario S3a-1 – Low-CI Gas indicate that phase in of low-CI gasoline (with a carbon intensity of 19 g CO_2e/MJ) could achieve similar or greater emission reductions than the lowest emission baseline ACC II scenario S1a - ACC II (BEV) through 2035, although emission reductions fall short of those estimated for Scenario S1a in 2040-2050. Reducing the carbon intensity of low-CI gasoline (S3a-2 – Low-CI Gas (Lower Range)) to 9 g CO_2e/MJ could generate further GHG emission reductions that exceed those estimated for the baseline ACC II scenarios relative to scenario S0 - ACC I. Even if the carbon intensity of low-CI gasoline was increased to 29 g CO_2e/MJ (S3a-1 – Low-CI Gas (Upper Range)), we can achieve GHG emission reductions (relative to S0 – ACC I) that are similar to the draft ACC II proposal (scenarios S1a through S1d).

The delayed phase in of low-CI gasoline considered in scenario S3b – Low-CI Gas (Delayed) decreases the emissions reductions (relative to S0 – ACC I) achieved through 2035 but achieves greater emission reductions from 2040-2050. Results for Alternative Scenarios Part 2 and Alternative Scenarios Part 3 show that low-CI gasoline could potentially achieve the State's long-term climate goals and decarbonize the transportation sector at a rate comparable to a ZEV-only regulation like the draft ACC II proposal.

Figure 4-4 shows results for Alternative Scenarios Part 3, which explore the potential emission reductions achievable from a diverse deployment of vehicle technologies. These scenarios (S-4a through S-4c, represented by the green lines) all provide fuel cycle GHG emission reductions (relative to S0 – ACC I) that exceed those achieved in the baseline ACC II scenarios (S1a through S1d, represented by the pink area) for all calendar years except 2050. These results show that increased ZEV sales mandates are not the only way to achieve the State's climate goals and a combination of different vehicle technologies and fuel pathways could be utilized to meet California's GHG emission reduction targets.

Figure 4-4: Fuel Cycle Emissions for Alternative Scenarios Part 3



4.2 Life Cycle Emissions

Life cycle emissions include fuel cycle emissions and vehicle cycle emissions and provide a comprehensive life cycle-based assessment of the potential GHG emissions from all vehicle technologies. **Figure 4-5** through **Figure 4-8** below present the estimated total GHG life cycle emissions for calendar years 2026 to 2050 for each modeled scenario that does not include FCEVs,[73] using the same color scheme for each scenario described previously in **Section 4.1**.

The addition of vehicle cycle emissions to fuel cycle emissions increases the total GHG emissions in all calendar years in all scenarios relative to those shown in **Figure 4-1** through **Figure 4-4**. Additionally, because BEVs have the highest vehicle cycle GHG emissions (see **Figure 3-5** for vehicle cycle emissions for each vehicle type), scenarios with significant BEV penetration show the largest increase in life cycle GHG emissions relative to fuel cycle emissions. As a result, scenarios that focus on implementation of low-CI gasoline rather than

[73] As described in **Section 3.4**, life cycle emission results are not available for scenarios with FCEVs, so scenarios that include FCEVs are not shown in **Figure 4-5** through **Figure 4-8**.

increased penetration of BEVs generally achieve greater life cycle GHG emission reductions relative to scenario S0 – ACC I.

The results presented in **Figure 4-5** show that scenario S1a – ACC II (BEV) continues to provide greater GHG emission reductions (relative to S0 – ACC I) than scenario S1b – ACC II (BEV + PHEV), despite greater vehicle cycle emissions from more BEVs in scenario S1a – ACC II (BEV) than scenario S1b – ACC II (BEV + PHEV). Note that in **Figure 4-5** through **Figure 4-8**, life cycle emissions for Baseline ACC II Scenarios (pink shaded region) are bounded by scenarios S1a and S1b because scenarios with FCEVs (S1c, S1d, and S1d-1) are not included in the life cycle analysis.

Results for S3 - Alternative Scenarios Part 1 in **Figure 4-6** show that increased penetration of only PHEVs or HEVs combined with phase in of low-CI gasoline can provide greater life cycle GHG emission reductions than the draft ACC II proposal (scenarios S1a and S1b, represented by the shaded pink region). Similarly, GHG emission reductions from the phase in of low-CI gasoline (Alternative Scenarios Part 2, represented by purple lines in **Figure-4-7**) without any fleet mix changes from S0 – ACC I could exceed life cycle GHG emission reductions in the draft ACC II proposal (scenarios S1a and S1b, represented by the shaded pink region) in all years except 2050. Finally, **Figure 4-8** shows that a diverse mix of fuel and vehicle technologies (Alternative Scenarios Part 3, represented by green lines) can achieve greater life cycle GHG emission reductions relative to S0 – ACC I in all calendar years than the ZEV-centric approach in the draft ACC II proposal (scenarios S1a and S1b, represented by the shaded pink region).

Figure 4-5: Life Cycle Emissions for Baseline Scenarios

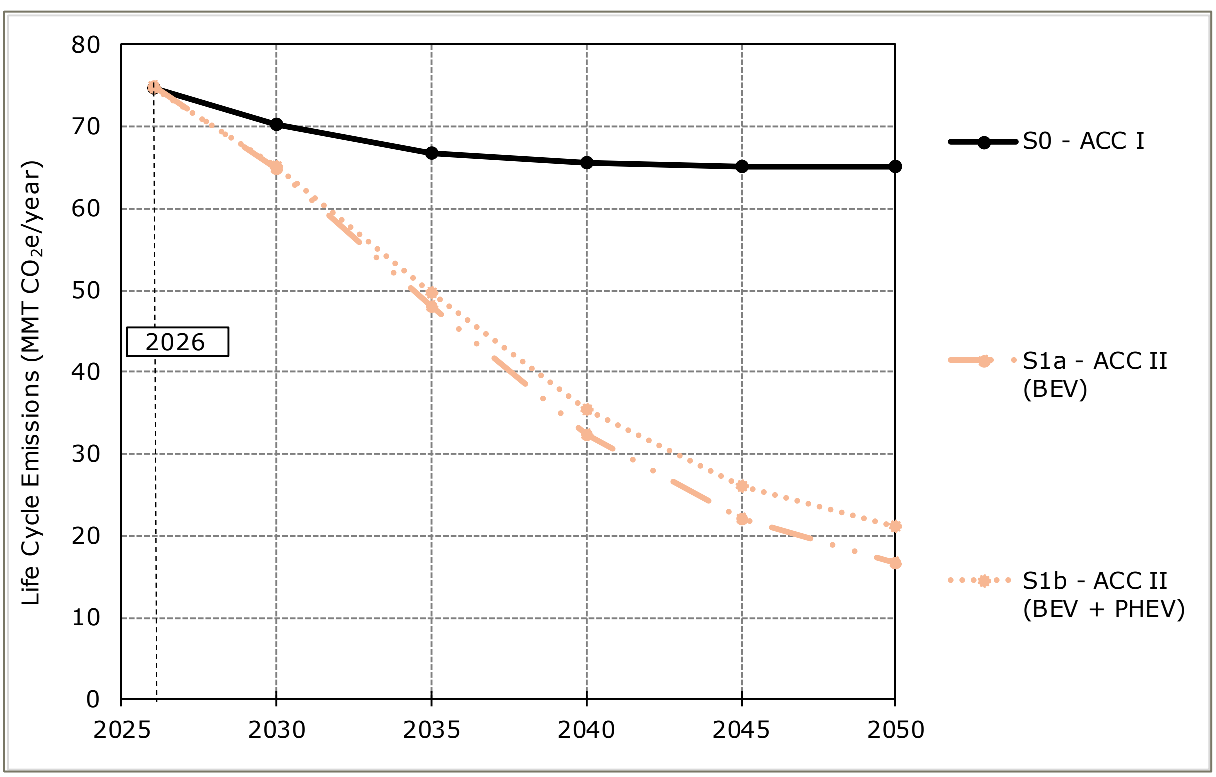


Figure 4-6: Life Cycle Emissions for Alternative Scenarios Part 1

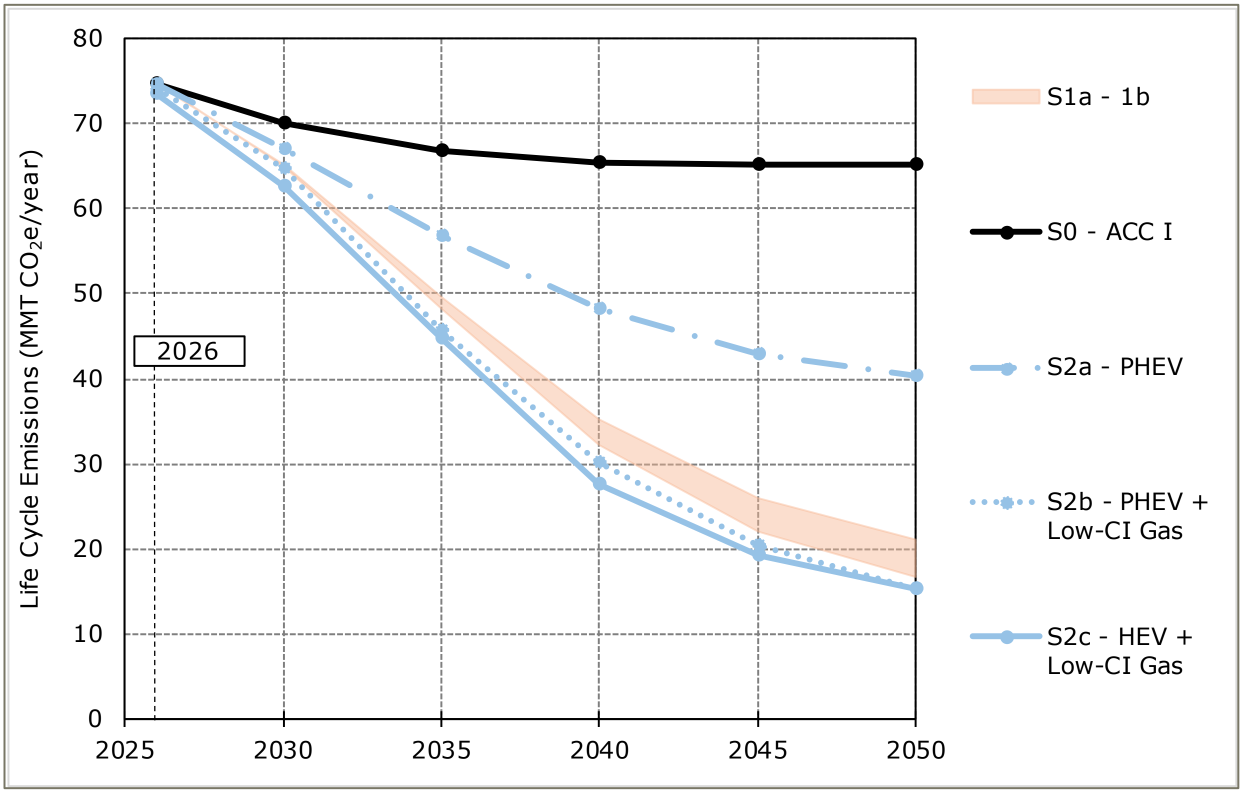


Figure 4-7: Life Cycle Emissions for Alternative Scenarios Part 2

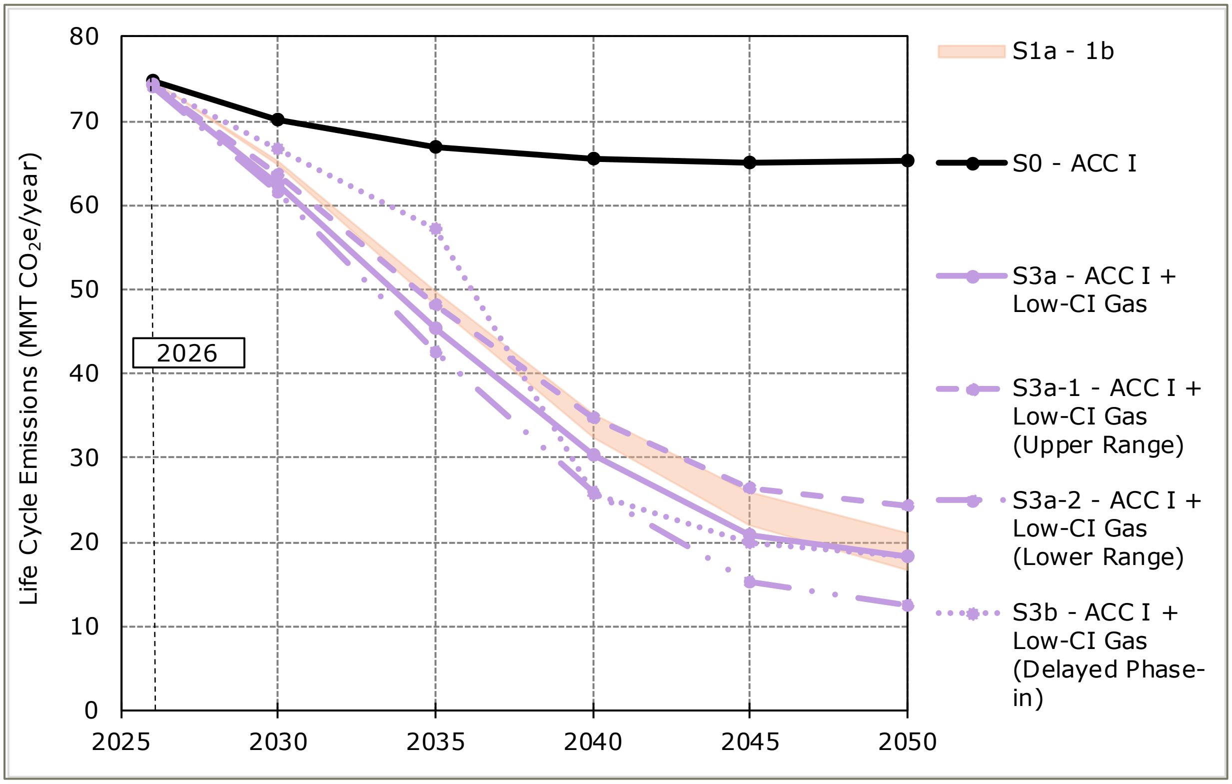
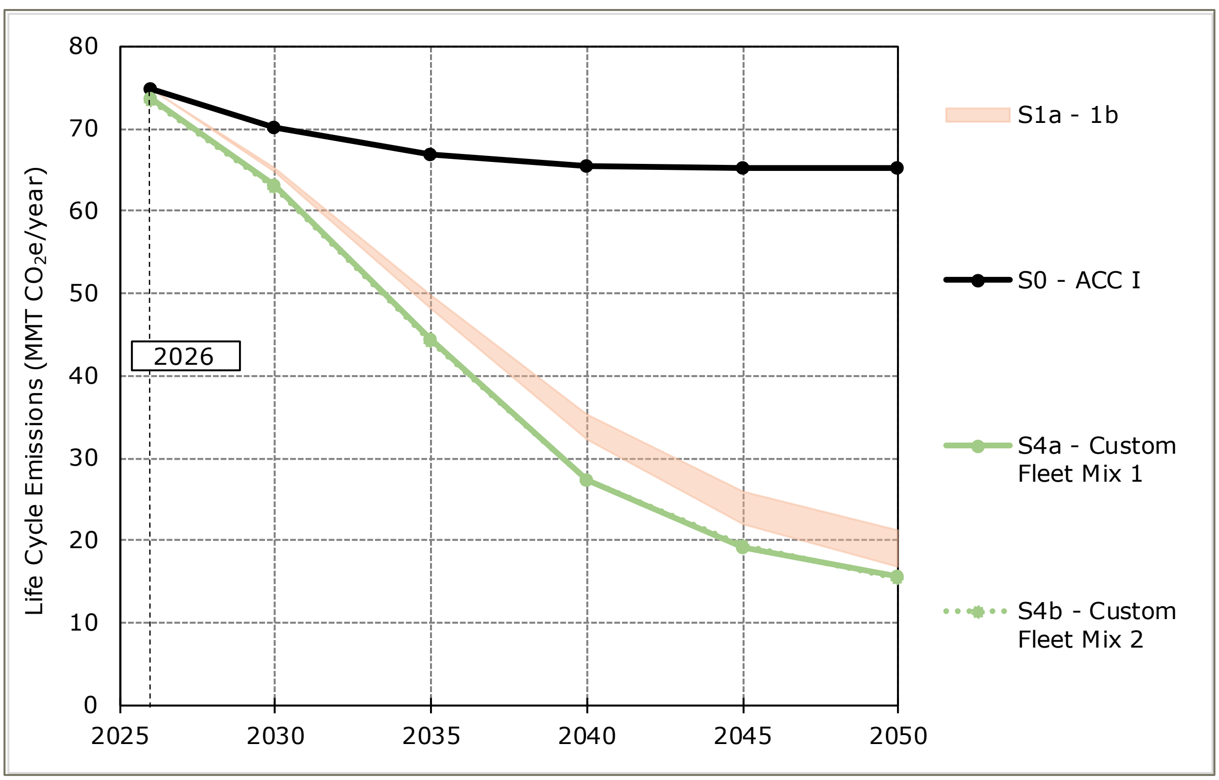


Figure 4-8: Life Cycle Emissions for Alternative Scenarios Part 3



4.3 Life Cycle Emissions with BEV Battery Replacement

Figure 4-9 through **Figure 4-12** show life cycle GHG emissions, including life cycle emissions associated with BEV battery replacement, for all scenarios without FCEVs[74] using the same color scheme for each scenario described previously. The inclusion of GHG emissions from BEV battery replacement increases the total GHG emissions in all calendar years for all scenarios with BEVs relative to the life cycle emission totals discussed in **Section 4.2**. As a result, scenarios that focus on implementation of low-CI gasoline rather than increased penetration of BEVs generally achieve greater GHG emission reductions relative to scenario S0 – ACC I.

Figure 4-9 shows that scenario S1a – ACC II (BEV) continues to provide greater GHG emission reductions (relative to S0 – ACC I) than scenario S1b – ACC II (BEV + PHEV), despite greater life cycle emissions from more BEV battery replacements in scenario S1a – ACC II (BEV) than scenario S1b – ACC II (BEV + PHEV). In **Figures 4-10** through **4-12**, the pink shaded region represents the range of life cycle emissions with BEV replacement for Baseline ACC II Scenarios S1a and S1b only, as other ACC II scenarios with FCEVs S1c, S1d, and S1d-a are not included in the life cycle analysis.

Results for S3 - Alternative Scenarios Part 1 in **Figure 4-10** show that increased penetration of only PHEVs or HEVs combined with phase in of low-CI gasoline provide even greater life cycle GHG emission reductions than the draft ACC II proposal (scenarios S1a and S1b, represented by the shaded pink region), when BEV replacement is included (compare with **Figure 4-6**, which does not include life cycle emissions for battery replacement). Similarly, phase in of low-CI gasoline alone (Alternative Scenarios Part 2, represented by purple lines in **Figure 4-11**), becomes a more attractive option to achieve similar to or greater GHG emission reductions (relative to S0 – ACC I) than those achieved by the draft ACC II proposal (S1a and S1b), when BEV battery replacement emissions are included. Finally, the mix of fuel and vehicle technologies in Alternative Scenarios Part 3 (represented by the green lines in **Figure 4-12**) provides even greater life cycle GHG emission reductions than the baseline ACC II scenarios when BEV battery replacement emissions are included (compare with **Figure 4-8**). Overall, inclusion of GHG emissions associated with the entire life cycle of the fuel and vehicle technologies including BEV battery replacement illustrates the importance of considering multiple vehicle technology and fuel pathways to achieve GHG emissions reductions rather than focusing on ZEV sales mandates as required in the draft ACC II proposal.

[74] As described in **Section 3.4**, life cycle emission results are not available for scenarios with FCEVs, so scenarios that include FCEVs are not shown in **Figure 4-9** through **Figure 4-12**.

Figure 4-9: Life Cycle Emissions with BEV Battery Replacement for Baseline Scenarios

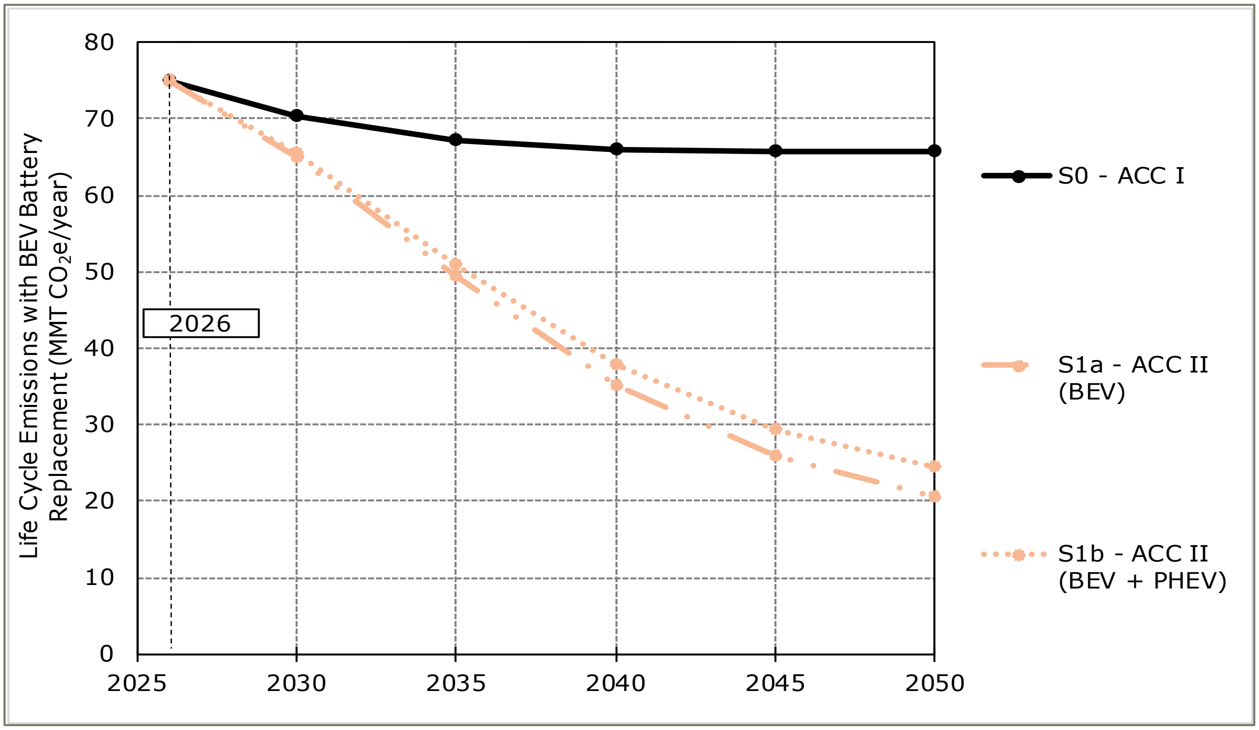


Figure 4-10: Life Cycle Emissions with BEV Battery Replacement for Alternative Scenarios Part 1

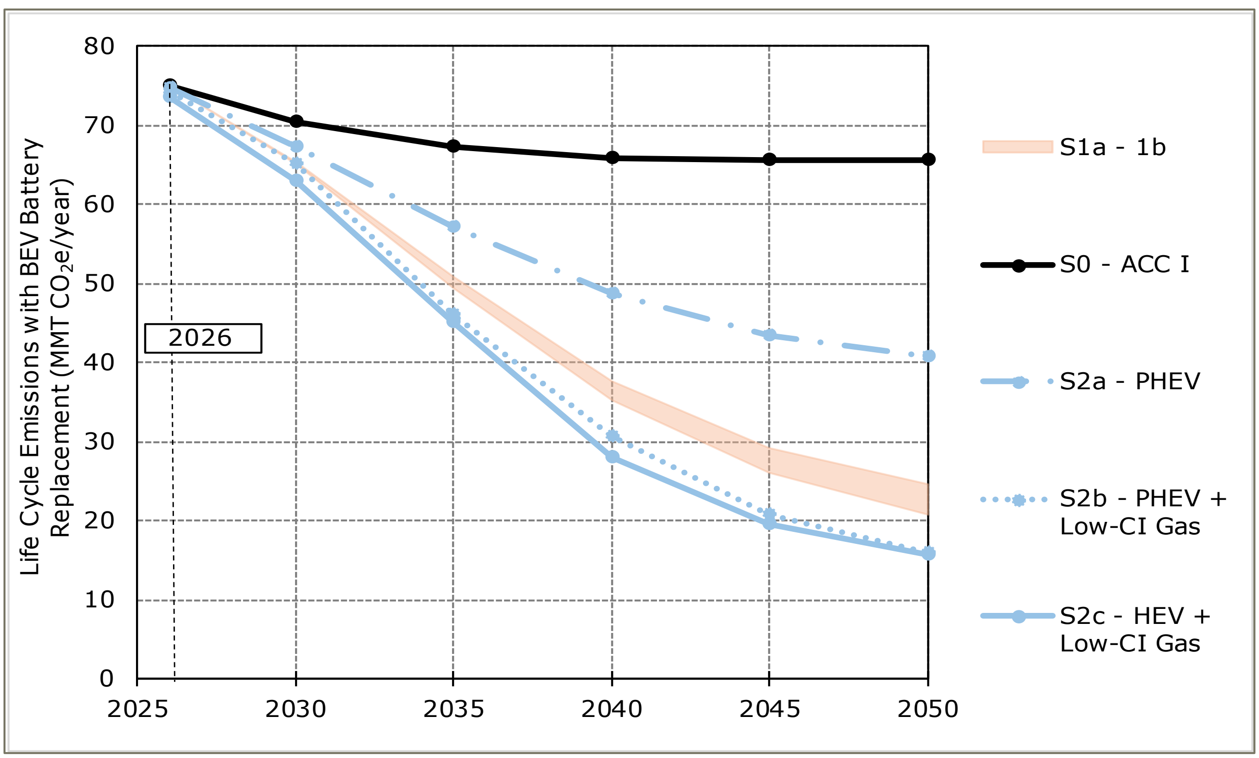


Figure 4-11: Life Cycle Emissions with BEV Battery Replacement for Alternative Scenarios Part 2

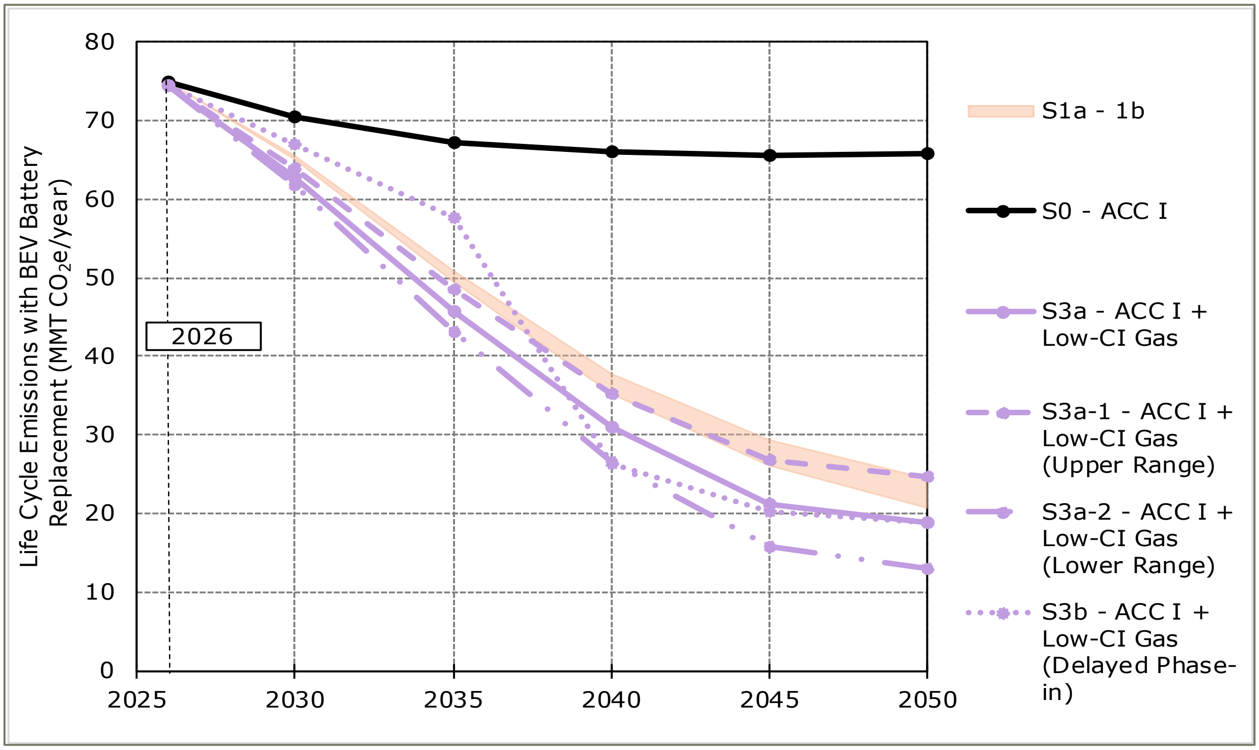
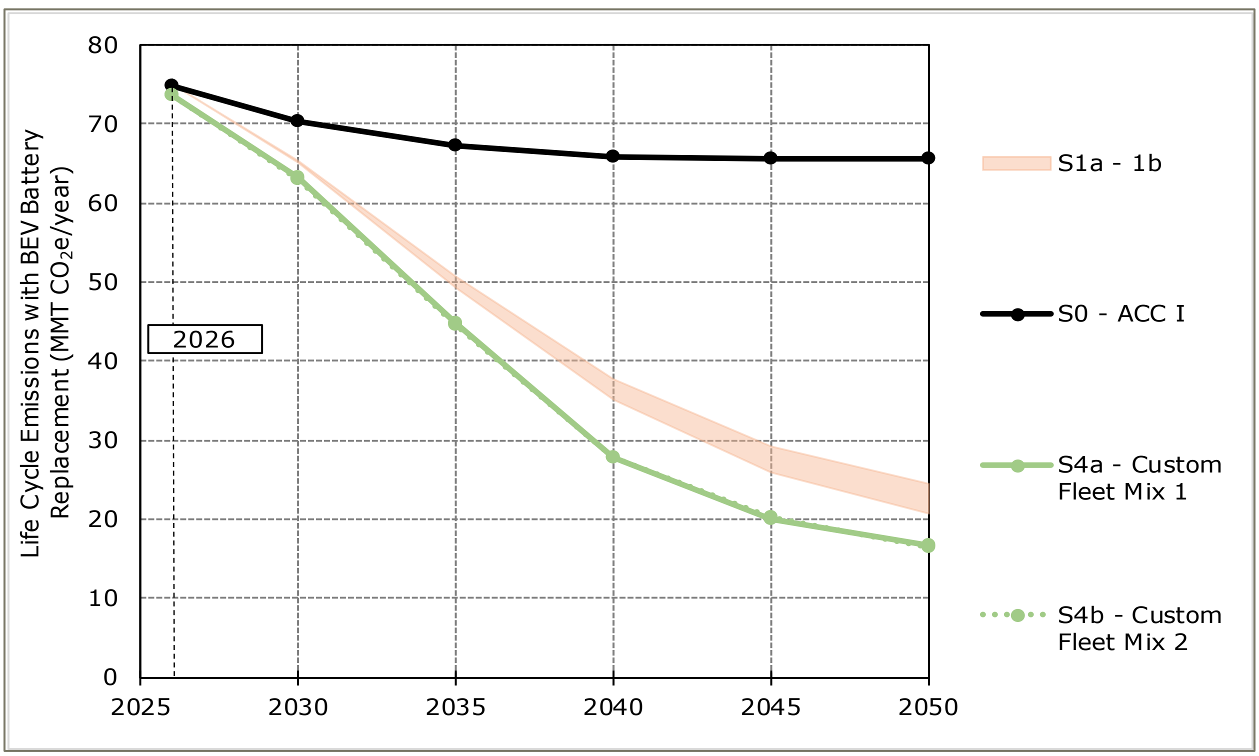


Figure 4-12: Life Cycle Emissions with BEV Battery Replacement for Alternative Scenarios Part 3



5. CONCLUSIONS

5.1 Summary of Analysis Conclusions

Ramboll's analysis demonstrates that there are a number of vehicle technology and fuel pathways that could achieve equal or greater GHG reductions as the proposed ACC II rulemaking. These alternative pathways would not require transformation of energy production and distribution infrastructure on an unprecedented short time scale, but they would allow battery, hydrogen, and low-CI gaseous and liquid fueled vehicles to compete to achieve the State's GHG targets in the quickest and most cost-effective manner. For example, a scenario that phases in low-CI gasoline as a drop-in fuel for ICEVs over a two-decade period could reduce GHG emission the same or more than the proposed ZEV-only mandate, when viewed on a life cycle basis. Other scenarios involving HEVs and PHEVs could be equally effective in providing GHG reductions when coupled with a phase in of low-CI gasoline. CARB could craft a regulation based on a GHG-reducing performance standard instead of instituting zero emission technology mandates, which is more consistent with traditional technology-forcing regulations that rely upon innovation within existing marketplaces. This study shows that such an approach could dramatically reduce GHG emissions without the systemic cost and delay risks associated with the current ZEV-centric strategy that include, but are not limited to, electric generation/infrastructure development, zero emission technology readiness, and cost.

The main conclusions of our analysis:

- Zero emission vehicle technology is only one of many different technology/fuel scenarios that could be utilized to meet California's GHG emission reduction targets;
- A full life cycle emission assessment is necessary if GHG reductions are a goal of the regulation, in order to understand the cradle-to-grave effects of a given vehicle/fuel technology pathway;
- BEV technology of the scope and schedule in ACC II would require technology and electrical generation/infrastructure developments that CARB has not analyzed and cannot mandate, control, or incentivize;
- There is a growing potential for renewable and low carbon fuels, including some with negative carbon intensity, to meet long-term GHG reductions;
- Low-CI gasoline could decarbonize the transportation sector at a rate comparable to a ZEV-only regulation; and
- Allowing the market flexibility to meet emission reduction targets could lead to a more diverse deployment of fuel and vehicle technologies to meet State targets.

These conclusions emphasize the need for CARB to conduct a similar analysis for the light and medium duty vehicle sector targeted in the draft ACC II proposal, to identify vehicle/fuel technology pathways that meet the emission reduction goals earlier and more cost effectively than the proposed ZEV-centric approach.

5.2 Next Steps – Technical

By focusing on a strategy that relies on ZEV sales mandates and not assessing the full life cycle GHG impacts of that strategy, CARB has overstated the potential emission benefits from PHEVs and BEVs while ignoring different vehicle/fuel pathways that could meet

California's GHG emission reduction targets. Finally, CARB has not demonstrated they have minimized leakage as required under AB32.

CARB should conduct a full life cycle GHG emission assessment to quantify the cradle-to-grave effects of the draft ACC II proposal and consider alternative GHG-reducing vehicle/fuel technologies in a technology-forcing (not technology mandating) rulemaking for California's LDV fleet that meets the State's emission goals. Such an analysis should build out and evaluate multiple scenarios beyond the singular ZEV-centric pathway proposed in the current ACC II regulation. These scenarios should be evaluated in the ACC II alternatives analyses presented in the SRIA and EA for technical feasibility, environmental impacts, and cost-effectiveness. These broader alternative analyses should include an assessment of the future availability of fueling (electric, hydrogen, and renewable and low carbon fuels) and related infrastructure to support this transition and help inform the final ACC II regulation.

APPENDIX A
SCENARIO ANALYSIS ASSUMPTIONS AND DETAILED METHODOLOGY

This Appendix describes the methodology used to calculate upstream, tailpipe, and vehicle cycle emissions for the Ramboll scenario analysis. A list of all tables accompanying this appendix is located after this analysis description. **Table A-1** provides a list of the analyzed scenarios. Refer to **Section 2** of the main document for further details on the scenarios.

Upstream Well-to-Tank Emissions

Ramboll estimated well-to-tank greenhouse gas (GHG) emission factors for each analyzed fuel type (California Reformulated Gasoline (CaRFG), low carbon intensity (CI) gasoline, electricity, and hydrogen) using carbon intensities obtained from the CA-GREET3.0 model,[1] Low Carbon Fuel Standard (LCFS) Lookup Pathways Tables,[2] LCFS Quarterly Summary data,[3] and assumptions used in California Air Resources Board's (CARB's) Standardized Regulatory Impact Assessment (SRIA)[4] for the Advanced Clean Cars II (ACC II) proposal and Assembly Bill (AB) 32 Initial Modeling.[5] Upstream GHG emission factors are typically represented as carbon intensities, i.e., the mass of GHG emissions in carbon dioxide equivalent (CO_2e) per unit of energy consumed in mega joules (MJ) for each fuel type. Upstream GHG emission factors for all fuel pathways considered in this analysis without and with EER adjustment are shown in **Table A-2** and **Table A-3** respectively.

<u>California Reformulated Gasoline</u>

Ramboll estimated the upstream CI of CaRFG as an energy-weighted average value of the upstream CIs of the two components that make up CaRFG: California reformulated gasoline blendstock for oxygenate blending (CARBOB), and ethanol. A summary of these emission factors and the ethanol content of CaRFG that is used to estimate the upstream GHG emission factor for CaRFG is provided in **Table A-4**.

<u>Low-CI Gasoline</u>

To estimate a carbon intensity for the low-CI gasoline considered in this analysis, a review of currently available and documented carbon intensities for low-CI renewable gasoline drop-in fuels was performed, as documented in **Table 3-1** of the main document. Sources for low-CI drop-in renewable gasoline fuels included the USEPA lifecycle GHG results, LCFS fuel pathways, Argonne National Laboratory (ANL) state-of-technology research, CARB-driven research, and a research paper published by the University of Chicago ANL. While the research yielded multiple pathways that spanned both renewable gasoline (e.g., bio-based feedstocks) as well as lower-CI gasoline alternatives, we chose to represent them as a single category due to their similar function as a drop-in replacement fuel. The average of these values was taken in order to find a representative carbon intensity for the low-CI gasoline fuel considered in this analysis, resulting in a CI of 19.0 g CO_2e/MJ, which is about 35% lower than the upstream CI for CaRFG.

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[1] CA-GREET 3.0 Model. Available at: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm. Accessed: January 2021.

[2] CARB. 2018. CA-GREET3.0 Lookup Table Pathways Technical Support Documentation. August 13. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: May 2022.

[3] CARB. LCFS Quarterly Summaries. Available at: https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries. Accessed: May 2022.

[4] CARB. 2022. Appendix C-1: Standardized Regulatory Impact Assessment (SRIA). April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

[5] E3. 2022. AB 32 Initial Model Results. March 15. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-03/SP22-Model-Results-E3-ppt.pdf. Accessed: May 2022.

In order to understand the impact of this carbon intensity on upstream and life cycle emissions, we also considered two sensitivity scenarios:

- Scenario 3a-1 – Low-CI Gas (Upper Range): For this scenario the low-CI gasoline CI was increased by 10 g CO2e/MJ to 29 g CO2e/MJ. This value is similar to the upstream CI for CaRFG.
- Scenario 3a-2 – Low CI-Gas (Lower Range): For this scenario the low-CI gasoline CI was reduced by 10 g CO_2e/MJ to 9 g CO_2e/MJ. This value is about 69% lower than the upstream CI for CaRFG.

Upstream GHG emission factors for low-CI gasoline compared to other fuels considered in this analysis without and with EER adjustment are shown in **Table A-2** and **Table A-3** respectively.

Electricity

Ramboll estimated upstream GHG emissions associated with the production and distribution of electricity consumed by PHEVs and BEVs in each modeled scenario using emission factors obtained from the CA-GREET 3.0 model.[6] Developed from ANL's GREET 2016 model,[7] the CA-GREET 3.0 model is used by CARB to calculate well-to-wheel emissions from transportation fuels under the California LCFS Program. Hence, use of this model to estimate upstream emissions is consistent with the CARB methodologies.

For purposes of this analysis, Ramboll adjusted the electricity grid mix inputs to the CA-GREET 3.0 model based on California Energy Commission (CEC) projections for each of the modeled calendar years 2026, 2030, 2035, 2040, 2045, and 2050.[8] The CA-GREET 3.0 California grid mix inputs for estimating upstream electricity GHG emission factors can be found in **Table A-5**.

Hydrogen

CARB SRIA Hydrogen

Ramboll assumed that 40% of the hydrogen for the CARB SRIA H_2 fuel pathway would come from renewable feedstocks and the remaining 60% from fossil feedstocks based on the methodology used in the SRIA for the proposed ACC II[9] and discussions with CARB ACC II staff.[10] The fossil feedstock for hydrogen is assumed to be fossil natural gas which is processed via a steam methane reformation

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6 CARB. 2019. CA-GREET3.0 Model - Current Version: Effective January 4, 2019 (released August 13, 2018). Available at: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm?_ga=2.203396115.367263062.1651770761-1504446328.1547148412. Accessed: May 2022.

7 Available at: https://greet.es.anl.gov/publication-greet-model. Accessed: January 2021.

8 CEC 2018. Deep Decarbonization in a High Renewables Future - Implications for Renewable Integration and Electric System Flexibility, Docket 18-IEPR-06 - 223869, Slide 10. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=223869&DocumentContentId=54081. Accessed: January 2021.

9 CARB. 2022. Appendix C-1: Standardized Regulatory Impact Assessment (SRIA). April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

10 Based on e-mail communication between S. Moca, Ramboll US Consulting and CARB ACC II Staff on February 15, 2022. CARB staff indicated in their email that hydrogen fuel in the SRIA for the proposed ACC II consisted of 3 major blends of fuel types: fossil natural gas (NG) hydrogen, renewable hydrogen from renewable NG, renewable hydrogen from curtailments. CARB assumed that renewable hydrogen levels off at 40% of the total hydrogen used, and that renewable hydrogen gradually transitions from renewable NG hydrogen to renewable hydrogen from curtailments. CARB shared that this transition was modelled with a log function assuming a market share (%) of renewable hydrogen at specific time points which are 6% at 2020, 10% at 2025, and 100% at 2045. Additionally, they shared that the renewable natural gas feedstock was assumed to be 100% from landfill biogas. Lastly, for renewable hydrogen from curtailments, CARB staff assumed zero GHG emissions given transmission/distribution and refilling phases using renewable energy.

(SMR) process to produce Fossil Hydrogen per the 2020 Mobile Source Strategy[11] and as cited in the SRIA. The renewable feedstock is assumed to be Landfill Biogas with hydrogen production via SMR (Landfill SMR Hydrogen) and electrolysis using curtailment electricity (Curtailment Electrolysis Hydrogen). Based on correspondence with CARB ACC II staff, the transition of hydrogen production from landfill biogas to curtailment electricity was modeled with a log function assuming specific feedstock shares at three points in time: 6% at 2020, 10% at 2025, and 100% at 2045.[12] A summary of these upstream GHG emission factors and fractions of the feedstocks used to estimate the upstream GHG emission factor for CARB SRIA hydrogen is provided in **Table A-6**.

CARB AB32 Hydrogen

The AB 32 Initial Modeling[13] for the draft 2022 Scoping Plan Update assumes that 100% of hydrogen production in the future would come from renewable sources, with the primary hydrogen production pathway being electrolysis using electricity generated by solar photovoltaic systems (Solar Electrolysis Hydrogen). We assumed that AB32 Hydrogen would be a combination of hydrogen produced using the following pathways: Landfill SMR Hydrogen and Solar Electrolysis Hydrogen. The volumes of Landfill SMR Hydrogen for the analysis years was assumed to not exceed the total renewable hydrogen volume (2,700,000 kg/year or 324,000,000 MJ/year) produced in 2021 per Annual Hydrogen Evaluation.[14] The remaining hydrogen demand in each analysis year was assumed to be met by Solar Electrolysis Hydrogen. The resulting CIs for the AB32 Hydrogen were estimated as a feedstock weighted average of the CIs for the individual feedstocks (Landfill SMR and Solar Electrolysis). A summary of these emission factors and fuel consumption for each feedstock for modelled sensitivity scenario S1d-1 – ACC II (FCEV) + AB32 H_2 is provided in **Table A-7**.

Tailpipe (Tank-to-Wheel) Emissions

CARB's EMFAC2021 model[15] was used to estimate tailpipe emissions for greenhouse gases (GHGs) for all light-duty vehicle (LDV) types included in this analysis. Specifically, Ramboll's analysis considers a sub-set of the statewide LDV fleet consisting of light-duty autos (LDAs), excluding those fueled by natural gas (NG) and diesel (DSL).[16] **Table 3-2** of the main document summarizes the assumptions used to estimate the tailpipe GHG emissions from various vehicle/fuel technologies that are included in this analysis. For this analysis, EMFAC2021[17] was queried at the statewide level for analysis years 2026, 2030, 2035, 2040, 2045 and 2050 to obtain daily total exhaust emissions, vehicle population, vehicle miles travelled (VMT), energy consumption, and fuel consumption data by model year for the

[11] CARB. 2021. 2020 Mobile Source Strategy. October 28. Available here: https://ww2.arb.ca.gov/sites/default/files/2021-12/2020_Mobile_Source_Strategy.pdf. Accessed: May 2022.

[12] Based on e-mail communications between S. Moca, Ramboll US Consulting and CARB ACC II Staff on February 15, 2022.

[13] E3. 2022. CARB Draft Scoping Plan: AB32 Source Emissions Initial Modeling Results. March 15. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-03/SP22-Model-Results-E3-ppt.pdf. Accessed: May 2022.

[14] CARB. 2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. September. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf. Accessed: May 2022.

[15] EMFAC2021 Database v1.0.1. Available at: https://arb.ca.gov/emfac/emissions-inventory. Accessed January 2022.

[16] Natural gas vehicles are excluded as they are not included in the default EMFAC2021 LDA fleet. Diesel vehicles are not included in this analysis because they comprise less than 0.3% of the total LDA population in EMFAC2021.

[17] EMFAC2021 Database v1.0.1. Available at: https://arb.ca.gov/emfac/emissions-inventory. Accessed January 2022.

following types of LDAs: gasoline-fueled internal combustion engine vehicles (ICEVs), battery electric vehicles (BEVs), and plug-in hybrid vehicles (PHEVs).

As described in **Section 3.1.3** of the main document, total VMT in EMFAC2021 is resolved by combustion VMT (cVMT), for miles traveled by vehicles powered by an internal combustion engine (ICE), and electric VMT (eVMT), for miles traveled by vehicles powered by energy from a battery.[18] Similarly, EMFAC2021 accounts for electric energy consumption separate from gasoline fuel consumption. In EMFAC2021, eVMT is defined as miles traveled during a pure electricity powered trip, and energy consumption is determined based on only pure electric trips during which an ICE does not turn on.[19] Thus, only PHEVs have both cVMT and eVMT and both energy consumption and fuel consumption in EMFAC2021. The remaining vehicle technologies in EMFAC2021 have either cVMT and fuel consumption (e.g., ICEVs), or eVMT and energy consumption (e.g., BEVs). Throughout this analysis, we utilize the term "fuel economy" as a fuel-neutral description of miles traveled per unit of fuel or energy consumed, whether the fuel is gasoline, hydrogen, or electricity.

Specific inputs used in the EMFAC2021 query are as follows:

- Run Mode: Emissions
- Region Type: Statewide
- Region: California
- Calendar Year: 2026, 2030, 2035, 2040, 2045 and 2050
- Season: Annual
- Vehicle Category: LDA[20]
- Model Year: All Model Years
- Speed: Aggregated
- Fuel Type: Gasoline, Electricity, and Plug-in Hybrid

EMFAC2021 was queried separately for each calendar year using the inputs above. Note, EMFAC2021 outputs are provided on a per day basis. Daily emissions calculated based on EMFAC2021 data are scaled to annual emissions based on 347 days of operation per year for LDAs reported in EMFAC technical documentation.[21]

The methodology used to calculate tailpipe emissions is summarized in **Section 3.2.2** of the main document and **Table A-8** through **Table A-91** in this Appendix. Tailpipe emissions in scenario S0 were obtained directly from EMFAC2021 and adjusted for the ethanol content of CaRFG. Tailpipe emissions in all other scenarios were estimated based on fleet mix composition and the VMT, fuel

[18] CARB. 2021. EMFAC2021 Volume I – User's Guide. January 15. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-01/EMFAC202x_Users_Guide_01112021_final.pdf. Accessed: May 2022.

[19] CARB. 2021. EMFAC2021 Volume III Technical Document - Version 1.0.0. March 31. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-03/emfac2021_volume_3_technical_document.pdf. Accessed: May 2022.

[20] The LDA vehicle category is the same in EMFAC2007, EMFAC2011, and EMFAC202x vehicle categories.

[21] CARB. 2018. EMFAC 2017 Volume III – Technical Documentation. July 20. Available at: https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf. Accessed: May 2022.

economy, and emission factors for ICEVs, PHEVs, and HEVs. The following describes the procedure used to calculate tailpipe emissions in all scenarios other than S0:

1. **Fleet Mix:** The fleet mix composition for each model year in each calendar year was determined based on the specific vehicle technology penetration assumptions for each scenario, as described in **Section 2** of the main document and shown in **Table A-1**.
    a. Specifically, ICEVs in the EMFAC2021 default fleet were replaced with other vehicle technologies (e.g., BEVs, PHEVs, HEV, and/or FCEVs) based on the sales percentage of each vehicle technology for each model year in each scenario. Note, in all scenarios, the existing sales fraction and population of PHEVs and BEVs in EMFAC2021 defaults served as the minimum penetration of these vehicle technologies. Thus, while additional BEVs and/or PHEVs were added in some scenarios, only ICEVs in the EMFAC2021 default fleet were replaced with other vehicle types as applicable in each scenario.
    b. This step determines the vehicle population for each vehicle technology for each model year in each calendar year. The resulting fleet mix population data for each scenario, aggregated by model year, is presented in **Figure 2-3** and **Figure 2-4** of the main document. Detailed population breakdown by vehicle technology and model year for each calendar year is presented in **Table A-26 through Table A-91.**
2. **VMT:** The daily VMT for each vehicle technology was calculated based on the vehicle population data determined in step 1 and the miles per vehicle per day for ICEVs.
    a. Specifically, Ramboll's scenario analysis assumes that any vehicle technology replacing an ICEV travels the same number of miles per vehicle as the ICEV it is replacing, as determined from EMFAC2021 data on a per model year basis for each calendar year. Thus, in each scenario, as ICEVs are replaced with other vehicle technologies, the population and corresponding VMT of ICEVs is reduced and allocated to the replacement vehicles in a one-to-one ratio.
    b. For PHEVs replacing ICEVs, total VMT from the ICEV is allocated to eVMT and cVMT for the replacement PHEV according to the EMFAC2021 default split between eVMT and cVMT for the replacement vehicle. The split between eVMT and cVMT for PHEVs varies by model year and calendar year, as described **Section 3.1.3** of the main document and shown in **Tables A-9, A-12, A-15, A-18, A-21**, and **A-24**.
3. **Fuel Consumption:** Fuel consumption for each vehicle technology was calculated based on the VMT determined in step 2 and the fuel economy for each vehicle.
    a. Fuel economy for each vehicle technology was determined based on EMFAC2021 data as described in **Section 3.1** of the main document and shown in **Tables A-8, A-11, A-14, A-17, A-20**, and **A-23**. Fuel consumption for each vehicle technology was first determined on a per model year basis to account for the variability in VMT and fuel economy by model year.
    b. Additionally, in order to account for upstream emissions and renewable fuel adjustments to tailpipe emissions, total fuel consumption for each fuel type across all vehicle technologies was calculated in each calendar year. Specifically, total gasoline fuel consumption was calculated as the sum of gasoline fuel usage from ICEVs, HEVs, and cVMT from PHEVs, while total electricity fuel consumption was calculated as the sum of electricity usage from BEVs and eVMT from PHEVs. Total hydrogen fuel consumption is equal to the total hydrogen usage from FCEVs are these are the only vehicles in this analysis fueled by hydrogen.

c. Total fuel consumption for gasoline was then allocated to CaRFG and Low-CI Gasoline according to the phase-in of Low-CI Gasoline in each scenario, as described in **Section 2** of the main document. Fuel consumption for all vehicle technologies and fuel types is reported in megajoules per day (MJ/day).

4. **Unadjusted Tailpipe Emissions:** Tailpipe emissions for ICEVs, PHEVs, and HEVs were estimated using the fuel consumption values determined in step 3 and the emission factors for these vehicle technologies derived from EMFAC2021 as described in **Section 3.3** of the main document and shown in **Tables A-10, A-13, A-16, A-19, A-22** and **A-25**. Tailpipe emissions for FCEVs and BEVs are zero.

   a. Tailpipe emissions for each calendar year were determined first on a per model year basis to account for the variation in fuel economy, emission factors, VMT, and population of each vehicle technology in each model year. Total tailpipe emissions in each calendar year were calculated as the sum of tailpipe emissions across all vehicle types and all model years in that calendar year.

   b. Tailpipe emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are calculated separately. Additionally, in order to account for renewable fuel adjustments to tailpipe emissions (step 5), tailpipe CO_2 emissions for each gasoline fuel type in each calendar year were calculated based on the penetration of each fuel type and the total tailpipe CO_2 emissions in that calendar year.

5. **Renewable Fuel Adjustments:** Tailpipe emissions are also adjusted based on the use of renewable fuels. Ramboll's analysis includes two gasoline fuel types: CaRFG, the default fuel assumed in EMFAC2021, and Low-CI Gasoline, a lower CI renewable drop-in fuel used as a replacement for CaRFG that is used to fuel internal combustion engines (ICEs) in ICEVs, PHEVs, and HEVs. As described in **Section 3.2.2** of the main document, since the CO_2 emissions generated by the combustion of the renewable ethanol content in CaRFG and Low-CI gasoline are considered biogenic, they are excluded from this analysis.[22] Adjustment factors for CO_2 emissions for each fuel type are applied to the portion of the tailpipe CO_2 emissions from that fuel type as determined in step 4b. No adjustments were made to the tailpipe CH_4 and N_2O emissions.

   a. As described in **Section 3.2.2** of the main document, Ramboll adjusted tailpipe emissions from CaRFG to account for the elimination of CO_2 emissions from the renewable ethanol content of CaRFG. Specifically, assuming the 9.5 percent volume fraction of ethanol is renewable and therefore has zero CO_2 emissions. Ramboll applied a 6.3 percent reduction factor to all tailpipe CO_2 emissions resulting from the use of CaRFG to account for the elimination of CO_2 emissions from the renewable ethanol content.

      - This 6.3 percent reduction factor is estimated as the ratio of the CaRFG tailpipe CO2 emission factor to the gasoline tailpipe CO2 emission factor.

[22] This aligns CARB's methodology for estimating the statewide GHG emission inventory, as noted in the 2021 CARB Report on the *California Greenhouse Gas Emissions for 2000 to 2019*, which states that "carbon dioxide (CO_2) emissions from biofuels (the biofuel components of fuel blends) are classified as "biogenic CO_2". They are tracked separately from the rest of the emissions in the inventory and are not included in the total emissions when comparing to California's 2020 and 2030 GHG Limits." Available at: https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2019/ghg_inventory_trends_00-19.pdf?msclkid=9f56cab9d01611ec878dcdb49cca2c91. Accessed: May 2022.

- The CaRFG tailpipe CO_2 emission factor is calculated as a weighted sum of the tailpipe CO_2 emission factors for ethanol and gasoline, assuming a volume fraction of 9.5% for ethanol.
  - The tailpipe CO_2 emission factor for ethanol is derived from CARB's Mandatory Reporting of Greenhouse Gases data.[23]
  - The tailpipe CO_2 emission factor for gasoline is derived from EMFAC fuel combustion data.[24]

b. The low-CI gasoline included in this analysis is produced from renewable feedstocks (See **Section 3.2.1.2** of the main document) and tailpipe CO_2 emissions associated with the combustion of this fuel are biogenic and set to zero.

6. **Final Tailpipe Emissions:** Total tailpipe GHG emissions are reported in units of carbon dioxide equivalent (CO_2e). CO_2e is calculated based on final CO_2, CH_4, and N_2O emissions, after accounting for renewable fuel adjustments, using global warming potentials (GWPs) from the International Panel on Climate Change (IPCC) Fourth Assessment Report (AR4).[25] The GWPs used for CO_2, CH_4, and N_2O are 1, 25, and 298, respectively.

Vehicle Cycle Emissions

For this analysis, Ramboll used GREET 2 (and GREET 1 inputs as needed) to estimate vehicle life cycle emission factors for ICEV, HEV, BEV, and PHEV technologies. FCEVs were not included in the scope of Ramboll's vehicle cycle emissions analysis.[26] The vehicles are evaluated as model year 2026 passenger vehicles; while vehicle cycle emissions may decrease over time with the increase in the renewable content of the electricity used for vehicle production, we do not expect the reduction to significantly alter the results or conclusions of the study.

Battery recycling for BEVs and PHEVs is not included in this assessment. This assumption is informed by current end-of-life recycling rate of <1% globally for lithium and rare earth minerals noted in the 2021 International Energy Association (IEA) Study on the *Role of Critical Minerals in Clean Energy Transition.*[27] Furthermore, it is likely that the vast majority of batteries produced in the future would require virgin material given the significant increase in demand under a mass vehicle electrification scenario.

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[23] Available at: https://www.arb.ca.gov/cc/reporting/ghg-rep/regulation/subpart_c_rule_part98.pdf. Accessed: May 2022.

[24] Available at: https://ww2.arb.ca.gov/sites/default/files/ghg-inventory-doc/doc/docs1/1a3bii_onroad_light-dutyvehicles_light-dutytrucks_fuelcombustion_gasoline_co2_2018.htm. Accessed: May 2022.

[25] Greenhouse Gas Protocol. Available at: https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf. Accessed January 2021.

[26] FCEVs represented only a small fraction (<0.8%) of total 2020 ZEV sales and an even smaller fraction (<0.06%) of the total 2020 LDV sales in California. The vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling processes are still in the developmental stage, and it would be too speculative to estimate vehicle cycle emissions until the market for these vehicles mature. Sales data obtained from CEC data dashboard 'New ZEV Sales in California'. Available here: https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/new-zev-sales. Accessed: May 2022.

[27] International Energy Agency (IEA). 2021. The Role of Critical Minerals in Clean Energy Transitions. May. Available at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions?msclkid=fa519918d01f11ecbcf188dc9fbbf9f2. Accessed: May 2022.

The vehicle emission and electric grid mix data input to the model is based on the most current information available at the time of this study as the scope of this analysis does not include forecasting or projecting future energy demands from vehicle and battery manufacturing.

GREET Inputs for ICEVs and HEVs

To model ICEVs and HEVs, Ramboll used default values in the GREET model for all vehicle production and assembly parameters except for the electricity mix used for material and fuel production. The US electric mix for stationary use in GREET 1 was updated with the 2020 national electricity mix published by the EPA's Emissions & Generation Resource Integrated Database (eGRID).[28] The non-default GREET inputs for U.S. stationary grid mix can be found in **Table A-92**. Ramboll also updated the GREET 1 electric grid mixes for fuel production for non-US countries where vehicle and battery components are produced or assembled. These grid mixes were updated using most recent available data from the IEA.[29] The non-default GREET inputs for international grid mixes can be found in **Table A-93**. A full matrix of all non-default GREET inputs can be found in **Table A-94.** The total life cycle emissions for each vehicle technology estimated from the GREET model can be found in **Table A-95**.

GREET Inputs for BEVs and PHEVs

For BEVs, Ramboll modeled a lithium-ion (Li-ion) battery with a nickel manganese cobalt (NMC 622) cathode material, which per a 2021 study from the International Council on Clean Transportation (ICCT) is the most common cathode material used in BEVs globally.[30] The Li-ion peak battery energy for BEVs is modeled as 81 kWh. This value was calculated as a product of BEV fuel economy, range, and charge utilization. The fuel economy is 2.59-mi/kWh based on EMFAC2021 data (described in **Section 3.1.2** of the main document), the range is 200 miles based on the minimum certified all-electric range in the draft ACC II regulation,[31] and the state of charge (SOC) utilization is 95% based on CARB's ZEV cost modeling worksheets.[32,33] Battery production and assembly share by country is derived from the number of battery cells supplied to the US BEV market by production location, reported in an Argonne National Laboratory publication on the 2010-2020 Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States.[34] Production shares for 2020 were used in order to

[28] EPA. 2022. eGRID Summary Tables 2020. January 27. Available here: https://www.epa.gov/egrid/summary-data. Accessed: May 2022.

[29] IEA. 2022. Countries and regions. Available at: https://www.iea.org/countries. Accessed: May 2022.

[30] ICCT. 2021. A Global Comparison of The Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars. Available here: https://theicct.org/publication/a-global-comparison-of-the-life-cycle-greenhouse-gas-emissions-of-combustion-engine-and-electric-passenger-cars/. Accessed: May 2022.

[31] CARB. 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

[32] CARB. 2021. ZEV Cost Modeling Workbook October 2021. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-11/ZEV_Cost_Modeling_Workbook_Update_October2021.xlsx. Accessed: January 2022.

[33] The October 2021 version of CARB's ZEV Cost Modeling Workbook was referenced for this analysis. A newer version of this workbook was released in late April 2022 (after completion of this analysis), which assumed a lower SOC utilization for BEV batteries of 92.5%. However, this does not change the overall conclusions of the analysis.

[34] ANL. 2021. Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010-2020. March. Available at: https://publications.anl.gov/anlpubs/2021/04/167369.pdf. Accessed: May 2022.

reflect the most current information available. A full matrix of all non-default GREET inputs can be found in **Table A-94.**

To model PHEVs, Ramboll assumed the NMC 111 cathode material (which is the GREET default) since NMC 622 is not an option provided in GREET 2 for PHEVs. The Li-ion peak battery energy for PHEVs is modeled as 14 kWh. This value was calculated as a product of PHEV fuel economy, range, and charge utilization. The fuel economy is 3.31 mi/kWh based on EMFAC2021 data (described in **Section 3.1.3** of the main document), the range is 40 miles based on the US-06 minimum certified all-electric range in the draft ACC II regulation,[35] and the SOC utilization is 85% based on CARB's ZEV cost modeling worksheets.[36,37] Battery production and assembly shares by country are assumed to be equivalent to those used in the BEV model. A full matrix of all non-default GREET inputs can be found in **Table A-94.**

All other vehicle and battery parameters for BEVs and PHEVs were left unchanged from GREET default values, and a full matrix of all non-default GREET inputs can be found in **Table A-94.** The total life cycle emissions for each vehicle technology estimated from the GREET model can be found in **Table A-95**.

<u>Vehicle Cycle GHG Emissions in Scenario Analysis</u>

Ramboll incorporated vehicle cycle GHG emissions for all ICEVs, PHEVs, BEVs, and HEVs in the scenario analysis by calculating GHG emissions for all vehicles of a given model year and attributing those emissions to the corresponding calendar year (assumed to be the same as the model year) in which they were produced as described in **Section 3.3.2** of the main document.

Ramboll assumed that the total number of vehicles produced for a given model year is equal to the peak population of that model year in EMFAC2021. **Figure 3-6** of the main document shows that the peak vehicle population for any given model year in EMFAC2021 occurs one year after the corresponding calendar year (CY) in which they were first introduced to the fleet. These values are summarized in **Table A-96**. Specific inputs used in the EMFAC2021 query used to generate the peak vehicle population for the analysis years are as follows:

- <u>Run Mode</u>: Emissions
- <u>Region Type</u>: Statewide
- <u>Region</u>: California
- <u>Calendar Year</u>: 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050
- <u>Season</u>: Annual

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[35] CARB. 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

[36] CARB. 2021. ZEV Cost Modeling Workbook October 2021. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-11/ZEV_Cost_Modeling_Workbook_Update_October2021.xlsx. Accessed: January 2022.

[37] The October 2021 version of CARB's ZEV Cost Modeling Workbook was referenced for this analysis. A newer version of this workbook was released in late April 2022 (after completion of this analysis), which assumed a lower SOC utilization for PHEV batteries of 80%. However, this does not change the overall conclusions of the analysis.

- Vehicle Category: LDA[38]
- Model Year: 2026, 2030, 2035, 2040, 2045, 2050
- Speed: Aggregated
- Fuel Type: Gasoline, Electricity, and Plug-in Hybrid

As noted in the **Table A-96**, number of vehicles produced for each vehicle technology in a calendar year is calculated based on the fleet mix for the model year vehicle and the total peak vehicle population for that model year. For example, the vehicle population produced in calendar year 2026, is based on the fleet mix of the 2026 model year vehicles and the peak population of model year 2026 vehicles. The vehicle cycle emissions for each calendar year are calculated using the vehicle cycle emission factors from **Table A-95** and the vehicle population for each vehicle technology in **Table A-96**. The total vehicle cycle emissions for each scenario in the analyzed calendar years are summarized in **Table A-96**.

GHG Emissions from Lithium Battery Replacement

In addition to GHG emissions from vehicle and battery production, Ramboll analyzed the GHG emissions associated with battery replacement for BEVs. Battery replacement for BEVs lithium-ion batteries is assumed to occur in the ninth year of use based on the 8-year warranty requirement proposed in the CARB ACC II Initial Statement of Reasons (ISOR) Staff Report.[39] Ramboll's scenario analysis assumes that one battery replacement occurs over the vehicle lifetime for all BEVs remaining in the vehicle fleet in the ninth year of operation (e.g., battery replacement emissions in CY 2026 are calculated based on the population of MY 2017 BEVs in CY 2026). This methodology accounts for the default retirement rate of vehicles in EMFAC2021, as illustrated in **Figure 3-6** in the main document.

The emissions per vehicle associated with this battery replacement were estimated from the results of the GREET modelling described in **Section 3.4.1** of the main document and in **Tables A-97 and A-98.** In particular, the emissions for battery production and assembly were combined to estimate battery replacement emissions on a per vehicle basis. For MY 2026-2050 BEVs, BEV battery replacement is assumed to occur for an 81-kWh battery as described in **Section 3.4.1** of the main report and in **Table A-97**. However, for pre-2026 BEVs, a peak battery energy of 62.5 kWh was assumed a weighted average of the battery sizes and cumulative sales of various BEV models from 2010-2020 in the United States.[40] Thus, battery replacement emission factors for BEVs MY <2026 and BEVs MY ≥2026 were estimated separately, as represented by the gray bars in **Figure 3-5** in the main document and **Table A-97**. Total emissions from the vehicle battery replacement in each scenario can be found in **Table A-98**.

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[38] The LDA vehicle category is the same in EMFAC2007, EMFAC2011, and EMFAC202x vehicle categories.

[39] CARB. 2022. Staff Report: Initial Statement of Reasons. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/isor.pdf. Accessed: May 2021.

[40] Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010-2020. March. Available at: https://publications.anl.gov/anlpubs/2021/04/167369.pdf. Accessed: May 2022.

APPENDIX A TABLES
SCENARIO ANALYSIS ASSUMPTIONS AND DETAILED METHODOLOGY

APPENDIX A TABLES

Table A-1. Scenario Matrix

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Scenario #	Scenario Name	Parameter	Battery Electric Vehicle	Plug-in Hybrid Electric Vehicle	Fuel Cell Electric Vehicle	Hybrid Electric Vehicle	Internal Combustion Engine Vehicle	Scenario Description
S0	ACC I	**Fleet Mix**[1]	EMFAC2021 default[3]					This scenario serves as the baseline and is based on EMFAC2021 fleet mix defaults, which represents ACC I PHEV and BEV sales requirements.
		Fuel Type[2]						
S1a	ACC II (BEV)	**Fleet Mix**[1]	EMFAC2021 default for pre-2026 MYs, meets ACC II ZEV sales requirement with PHEVs for MY 2026+	EMFAC2021 default[3]	N/A	N/A	Remaining fleet mix	This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with BEVs.
		Fuel Type[2]	Electricity	Electricity for eVMT and CaRFG for cVMT	N/A	N/A	CaRFG	
S1b	ACC II (BEV + PHEV)	**Fleet Mix**[1]	EMFAC2021 default for pre-2026 MYs, meets 80% of ACC II ZEV sales requirement for MY 2026+	EMFAC2021 default for pre-2026 MYs, meets 20% of ACC II ZEV sales requirement for MY 2026+	N/A	N/A	Remaining fleet mix	This scenario assumes that the ZEV sales needed to meet the ZEV sales requirements in the draft ACC II proposal are met with the maximum allowable fraction of PHEVs (20% of ZEV sales requirement) and BEVs (80% of ZEV sales requirement).
		Fuel Type[2]	Electricity	Electricity for eVMT and CaRFG for cVMT	N/A	N/A	CaRFG	
S1c	ACC II (CARB SRIA)	**Fleet Mix**[1]	EMFAC2021 default for pre-2026 MYs, fleet mix assumptions in CARB SRIA were applied to meet the ACC II sales requirements[4] for MY 2026+			N/A	Remaining fleet mix	This scenario assumes that the ZEV sales needed to meet the draft ACC II proposal are met with combination of PHEVs, BEVs, and FCEVs as noted in the CARB's SRIA for the ACC II proposal.
		Fuel Type[2]	Electricity	Electricity for eVMT and CaRFG for cVMT	CARB SRIA H_2	N/A	CaRFG	
S1d	ACC II (FCEV)	**Fleet Mix**[1]	EMFAC2021 default[3]	EMFAC2021 default[3]	EMFAC2021 default for pre-2026 MYs, meets ACC II ZEV sales requirement with BEVs and PHEVs for MY 2026+	N/A	Remaining fleet mix	This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with FCEVs. The carbon intensity (CI) of hydrogen fuel used to power FCEVs in this scenario was developed based on the feedstock projections in CARB's SRIA for the ACC II proposal. Refer to Section 3.2.4 for further discussion of hydrogen pathways.
		Fuel Type[2]	Electricity	Electricity for eVMT and CaRFG for cVMT	CARB SRIA H_2	N/A	CaRFG	
S1d-1	ACC II (FCEV) + AB32 H_2	**Fleet Mix**[1]	Same as Scenario S1d					This sensitivity scenario is identical to scenario S1d – ACC II (FCEV) with the following exception: the CI for hydrogen fuel used to power FCEVs was developed based on the assumptions in the AB 32 Source Emissions Initial Modeling Results for the draft 2022 Scoping Plan Update.
		Fuel Type[2]	Same as Scenario S1d		CARB AB32 H_2	N/A	Same as Scenario S1d	
S2a	PHEV	**Fleet Mix**[1]	EMFAC2021 default[3]	EMFAC2021 default for pre-2026 MYs, meets ACC II ZEV sales requirement with BEVs for MY 2026+	N/A	N/A	Remaining fleet mix	This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with PHEVs.
		Fuel Type[2]	Electricity	Electricity for eVMT and CaRFG for cVMT	N/A	N/A	CaRFG	
S2b	PHEV + Low-CI Gas	**Fleet Mix**[1]	EMFAC2021 default[3]	EMFAC2021 default for pre-2026 MYs, meets ACC II ZEV sales requirement with BEVs for MY 2026+	N/A	N/A	Remaining fleet mix	This vehicle fleet mix for this scenario is identical to scenario S2a – PHEV. However, it also includes the gradual phase-in of low-CI gasoline (see orange area in Figure 2-6) beginning as a replacement of 1% of CaRFG in 2026 and increasing to a replacement of 30% and 100% of CaRFG by 2035 and 2050 respectively.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline for cVMT	N/A	N/A	A combination of CaRFG and Low-CI Gasoline	
S2c	HEV + Low-CI Gas	**Fleet Mix**[1]	EMFAC2021 default[3]	EMFAC2021 default[2]	N/A	EMFAC2021 default for pre-2026 MYs, meets ACC II ZEV sales requirement with BEVs and PHEVs for MY 2026+	Remaining fleet mix	This scenario assumes that any additional ZEVs sales beyond those (BEVs and PHEVs) in the S0-ACC I Scenario that are needed to meet the ZEV sales requirements in the draft ACC II proposal are met with all HEVs. It also includes a phase-in of low-CI gasoline (see orange area in Figure 2-6) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 35% and 100% of CaRFG by 2035 and 2050 respectively.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline for cVMT	N/A	A combination of CaRFG and Low-CI Gas	A combination of CaRFG and Low-CI Gasoline	
S3a	Low-CI Gas	**Fleet Mix**[1]	EMFAC2021 default[3]					This scenario analyzes the same vehicle fleet mix as S0 – ACC I with a gradual phase-in of low-CI gasoline beginning as a replacement of 1% of CaRFG in 2026 and increasing to a replacement of 45% and 100% of CaRFG by 2035 and 2050 respectively. The CI of the low-CI gasoline used in this scenario is 19 g CO_2e/MJ.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline for cVMT	EMFAC2021 default[3]		A combination of CaRFG and Low-CI Gasoline	
3a-1	Low-CI Gas (Upper Range)	**Fleet Mix**[1]	EMFAC2021 default[3]					This sensitivity scenario is identical to scenario S3a – Low CI Gas with the following exception: the carbon intensity of the low-CI gasoline is increased by 10 g CO_2e/MJ to 29 g CO_2e/MJ.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline (upper range) for cVMT	EMFAC2021 default[3]		A combination of CaRFG and Low-CI Gasoline (upper range)	

Table A-1. Scenario Matrix

Scenario #	Scenario Name	Parameter	Battery Electric Vehicle	Plug-in Hybrid Electric Vehicle	Fuel Cell Electric Vehicle	Hybrid Electric Vehicle	Internal Combustion Engine Vehicle	Scenario Description
S3a-2	Low-CI Gas (Lower Range)	**Fleet Mix**[1]	EMFAC2021 default[3]					This sensitivity scenario is identical to scenario S3a – Low-CI Gas with the following exception: the carbon intensity of the low-CI gasoline is reduced by 10 g CO_2e/MJ to 9 g CO_2e/MJ.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline (lower range) for cVMT	EMFAC2021 default[3]		A combination of CaRFG and Low-CI Gasoline (upper range)	
S3b	Low-CI Gas (Delayed)	**Fleet Mix**[1]	EMFAC2021 default[3]					This scenario is identical to scenario 3a with the following exception: the phase in of low-CI gasoline is delayed and occurs more slowly from 2026-2035 (replacement of 1% to 20% of CaRFG from 2026-2035) but increases rapidly from 2035-2040 (replacement of 97% and 100% of CaRFG by 2045 and 2050 respectively), as compared with scenario 3a.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline for cVMT	EMFAC2021 default[3]		A combination of CaRFG and Low-CI Gasoline	
S4a	Custom Fleet Mix 1	**Fleet Mix**[1]	EMFAC2021 default for pre-2030 MYs, fleet fraction increases by 1% annually for MY 2030 to MY 2044 and 2% annually for subsequent MYs	EMFAC2021 default for pre-2026 MYs, fleet fraction increases by 1% annually for MY 2026 to MY 2040 and 2% annually for subsequent MYs	N/A	EMFAC2021 default for pre-2026 MYs, fleet fraction increases from 11% in MY 2026 to 72% in MY 2033 and then begins dropping with increases in BEVs and PHEVs	Remaining fleet mix up to MY 2032, no additional ICEVs in subsequent MYs	This scenario evaluates a custom fleet mix with a combination of HEVs, PHEVs, BEVs, and ICEVs. It also includes a phase-in of low-CI gasoline (CI of 19 g CO_2e/MJ) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 100% of CaRFG by 2050.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline for cVMT	N/A	A combination of CaRFG and Low-CI Gasoline	A combination of CaRFG and Low-CI Gasoline	
S4b	Custom Fleet Mix 2	**Fleet Mix**[1]	EMFAC2021 default for pre-2036 MYs, fleet fraction of 19% in MY 2036, increases by 1% annually from MY 2037 to MY 2040, increases by 3.5% MY 2041 to MY 2045 and remains at 42% for subsequent MYs	EMFAC2021 default for pre-2028 MYs, increases 1% annually from MY 2028 to MY 2031, remains at 8% fleet fraction from MY 2031 to MY 2035, increases by 2% annually from MY 2036 to MY 2039, increases by 4% annually in MY 2040 and MY 2041, and remains at 39% for subsequent MYs	N/A	EMFAC2021 default for pre-2026 MYs, fleet fraction increases from 20% in MY 2026 to 80% for MY 2032 to MY 2035 and begins dropping with increases in BEVs and PHEVs.	Remaining fleet mix up to MY 2031, no additional ICEVs in subsequent MYs	This scenario evaluates a custom fleet mix with a combination of HEVs, PHEVs, BEVs, and ICEVs. It also includes a phase-in of low-CI gasoline (CI of 19 g CO_2e/MJ) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 100% of CaRFG by 2050.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline for cVMT	N/A	A combination of CaRFG and Low-CI Gasoline	A combination of CaRFG and Low-CI Gasoline	
S4c	Custom Fleet Mix 3	**Fleet Mix**[1]	EMFAC2021 default for pre-2030 MYs, fleet fraction increases by 0.5% annually for MY 2030 to MY 2044 and 1.5% annually for subsequent MYs	EMFAC2021 default for pre-2026 MYs, fleet fraction increases by 1% annually for MY 2026 to MY 2040 and 2% annually for subsequent MYs	No FCEVs in pre-2030 MY, fleet fraction of 1% in MY 2030, increases by 0.5% annually for subsequent MYs	EMFAC2021 default for pre-2026 MYs, fleet fraction increases from 11% in MY 2026 to 72% in MY 2033 and then begins dropping with increases in BEVs, PHEVs, and FCEVs	Remaining fleet mix	This scenario evaluates a custom fleet mix with a combination of HEVs, PHEVs, BEVs, FCVEs, and ICEVs. This scenario also includes a phase-in of low-CI gasoline (CI of 19 g CO_2e/MJ) beginning as a replacement of 2% of CaRFG in 2026 and increasing to a replacement of 100% of CaRFG by 2050.
		Fuel Type[2]	Electricity	Electricity for eVMT and a combination of CaRFG and Low-CI Gasoline for cVMT	CARB SRIA H_2	A combination of CaRFG and Low-CI Gasoline	A combination of CaRFG and Low-CI Gasoline	

Notes:

[1] Fleet mix for each scenario is presented in Figures 2-3 and 2-4, and described in Section 2 of the report. Detailed fleet mix data is presented in Tables A-26 through A-91.

[2] Fuel mix for each scenario is presented in Figures 2-5 through 2-7, and described in Section 2 of the report. Additional details on the types of fuels is presented in Section 3.2.1.

[3] In all scenarios, the existing sales fraction and population of PHEVs and BEVs in EMFAC2021 defaults served as the minimum penetration of these vehicle technologies. Thus, while additional BEVs and/or PHEVs were added in some scenarios, only ICEVs in the EMFAC2021 default fleet were replaced with other vehicle types as applicable in each scenario. Note, EMFAC2021 default fleet mix does FCEVs. The EMFAC2021 v1.0.1 model is available at: https://arb.ca.gov/emfac/emissions-inventory/ (Accessed: January 2022).

[4] Fleet mix assumptions taken from the Standardized Regulatory Impact Assessment (SRIA) for the proposed ACC II. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf. Accessed: May 2022.

Abbreviations:

AB - Assembly Bill
ACC - Advanced Clean Cars
BEV - battery electric vehicle
CA - California
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CI - carbon intensity
CO_2e - carbon dioxide equivalent
cVMT - combustion vehicle miles traveled
CY - calendar year
EMFAC - EMission FACtor Model
eVMT - electric vehicle miles traveled
FCEV - fuel cell electric vehicle
g - gram
GHG - greenhouse gas
H_2 - hydrogen
HEV - hybrid electric vehicle
ICEV - internal combustion electric vehicle
MJ - megajoule
PHEV - plug-in hybrid electric vehicle
SRIA - Standardized Regulatory Impact Assessment
ZEV- zero emission vehicle
N/A - not applicable

Table A-2. Upstream (EER-Unadjusted) GHG Emission Factors by Fuel Type

Calendar Year	Upstream (EER-Unadjusted) GHG Emission Factors ($g\ CO_2e$ / MJ fuel)						
	CaRFG[1]	Low-CI Gasoline[2]	Low-CI Gasoline (Upper Range)[3]	Low-CI Gasoline (Lower Range)[3]	Electricity[4]	CARB SRIA Hydrogen[5]	AB32 Hydrogen[6]
2026	29.1	19.0	29.0	9.0	65.3	102.6	7.4
2030	29.1	19.0	29.0	9.0	49.9	98.4	0.81
2035	29.1	19.0	29.0	9.0	36.8	91.8	0.28
2040	29.1	19.0	29.0	9.0	25.7	81.7	0.18
2045	29.1	19.0	29.0	9.0	16.7	65.2	0.14
2050	29.1	19.0	29.0	9.0	11.1	64.8	0.13

Notes:

[1] Upstream emission factors for CaRFG are estimated as shown in Table A-4 and described in Section 3.2.1.1 of the report.

[2] Upstream emission factors for Low-CI gasoline are estimated as shown in Table 3-1 and described in Section 3.2.1.2 of the report.

[3] Upper and lower ranges of the upstream emission factors for Low-CI gasoline used in sensitivity scenarios S3a-1 - Low-CI Gas (Upper Range) and S3a-2 - Low-CI Gas (Lower Range), are estimated as described in Section 3.2.1.2 of the report.

[4] Upstream emission factors for electricity used to fuel BEVs and PHEVs are estimated as described in Section 3.2.1.3 of the report.

[5] Upstream emission factors for CARB SRIA Hydrogen are estimated as shown in Table A-6 and described in Section 3.2.1.4 of the report.

[6] Upstream emission factors for AB32 Hydrogen are estimated as shown in Table A-7 and described in Section 3.2.1.4 of the report. This carbon intensity is specific to the hydrogen usage in scenario S1d-1 - ACC II (FCEV) + AB32 H_2.

Abbreviations:

AB - Assembly Bill
ACC - Advanced Clean Cars
BEV - battery electric vehicle
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CI - carbon intensity
CO_2e - carbon dioxide equivalent
EER - energy economy ratio
EMFAC - EMission FACtor Model
FCEV - fuel cell electric vehicle
g - gram
GHG - greenhouse gas
H_2 - hydrogen
MJ - megajoule
PHEV - plug-in hybrid electric vehicle
SRIA - Standardized Regulatory Impact Assessment

Table A-3. Upstream (EER-Adjusted) GHG Emission Factors by Fuel Type
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Calendar Year	Upstream (EER-Adjusted) GHG Emission Factors ($g CO_2e$ / MJ of gasoline displaced)						
	CaRFG[1]	Low-CI Gasoline[1]	Low-CI Gasoline (Upper Range)[1]	Low-CI Gasoline (Lower Range)[1]	Electricity[2]	CARB SRIA Hydrogen[2]	AB32 Hydrogen[2]
2026	29.1	19.0	29.0	9.0	27.6	41.0	3.0
2030	29.1	19.0	29.0	9.0	21.0	39.3	0.32
2035	29.1	19.0	29.0	9.0	15.5	36.7	0.11
2040	29.1	19.0	29.0	9.0	10.8	32.7	0.07
2045	29.1	19.0	29.0	9.0	7.0	26.1	0.06
2050	29.1	19.0	29.0	9.0	4.7	25.9	0.05

Notes:

[1] Obtained from Table A-2.

[2] Upstream (EER-Adjusted) GHG emission factors for electricity and hydrogen are calculated based on EER-Unadjusted GHG emission factors shown in Table A-2 and the EER adjustment ratios for BEVs and FCEVs shown below.

[3] The EERs for BEVS were calculated from EMFAC2021 data. Available here: https://arb.ca.gov/emfac/. Accessed: January 2022.

[4] The EERs for FCEVs was obtained from the *LCFS Final Regulation Order* , Table 5. Available here: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Energy Economy Ratios:

BEV[3]	CY 2026	2.3705
BEV[3]	CY 2030	2.3716
BEV[3]	CY 2035	2.3720
BEV[3]	CY 2040	2.3723
BEV[3]	CY 2045	2.3718
BEV[3]	CY 2050	2.3720
FCEV[4]	CY 2026 - 2050	2.5

Abbreviations:

AB - Assembly Bill
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CI - carbon intensity
CY - calendar year
CO_2e - carbon dioxide equivalent
EER - energy economy ratio
EMFAC - EMission FACtor Model
g - gram
GHG - greenhouse gas
MJ - megajoule
SRIA - Standardized Regulatory Impact Assessment

Table A-4. Estimating Upstream GHG Emission Factors for CaRFG

Upstream GHG Emission Factor for CARBOB[1] (g CO_2e/MJ)	Upstream GHG Emission Factor for Ethanol[2] (g CO_2e/MJ)	Ethanol Energy Content in CaRFG[3] (MJ Ethanol/MJ CaRFG)	Upstream GHG Emission Factor for CaRFG[4] (g CO_2e/MJ)
26.88	59.8	6.61%	29.1

Notes:

[1]Obtained from Table A.1 in *CA-GREET3.0 Lookup Table Pathways Technical Support Documentation* dated August 13, 2018. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: May 2022.

[2]Estimated as an average of the ethanol carbon intensities available in the most recent LCFS Quarterly Reports at the time of this analysis (2020 Q1 to 2021 Q3). Available at: https://ww2.arb.ca.gov/sites/default/files/2022-01/quarterlysummary_013122_0.xlsx. Accessed: May 2022.

[3] The Ethanol energy content of CaRFG was obtained from the *CA-GREET3.0 Model - Current Version: Effective January 4, 2019 (released August 13, 2018)* . Available at: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm?_ga=2.35180577.1071504132.1642096595-990540269.1603987774. Accessed: May 2022.

[4] Estimated as an energy weighted average of the upstream GHG emission factors of CARBOB and ethanol.

Abbreviations:

CA - California

CARBOB - California Reformulated Gasoline Blendstock for Oxygenate Blending

CaRFG - California Reformulated Gasoline

CI - carbon intensity

CO_2e - carbon dioxide equivalents

EtOH - ethanol

g - gram

GHG - greenhouse gas

GREET - Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model

LCFS - Low Carbon Fuel Standard

MJ - megajoule

Table A-5. CA-GREET 3.0 California Electricity Grid Mix Inputs for Estimating Upstream GHG Emission Factors

Year[1]	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydro-electric	Geo-thermal	Wind	Solar
2026	0.00%	40.64%	0.00%	0.10%	2.87%	9.68%	7.76%	10.34%	28.61%
2030	0.00%	30.29%	0.00%	0.38%	2.56%	9.25%	9.93%	10.76%	36.83%
2035	0.00%	22.25%	0.00%	0.18%	0.30%	8.09%	9.00%	18.74%	41.43%
2040	0.00%	15.13%	0.00%	0.00%	0.00%	6.85%	8.80%	25.11%	44.11%
2045	0.00%	9.66%	0.00%	0.00%	0.00%	6.44%	6.71%	29.65%	47.54%
2050	0.00%	6.05%	0.00%	0.00%	0.00%	5.23%	6.64%	33.98%	48.11%

Notes:

[1] Electricity grid projections out to 2050 were sourced from Energy and Environmental Economics (E3) 2018 Deep Decarbonization report commissioned by the CEC. Available at: https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf. Accessed: May 2022.

Abbreviations:

CEC - California Energy Commission

Table A-6. Estimating Upstream GHG Emission Factors for CARB SRIA Hydrogen

Calendar Year	Composition of CARB SRIA Hydrogen[1]			Upstream GHG Emission Factors for the Components of CARB SRIA Hydrogen ($g\ CO_2e/MJ$)			Upstream GHG Emission Factor for CARB SRIA Hydrogen[4] ($g\ CO_2e/MJ$)
	Fossil Hydrogen	Landfill SMR Hydrogen	Curtailment Electrolysis Hydrogen	Fossil Hydrogen[2]	Landfill SMR Hydrogen[2]	Curtailment Electrolysis Hydrogen[3]	
2026	60%	35%	5%	114	96.1	0	103
2030	60%	33%	7%	113	94.3	0	98.4
2035	60%	27%	13%	111	92.8	0	91.8
2040	60%	17%	23%	110	91.5	0	81.7
2045	60%	0%	40%	109	90.4	0	65.2
2050	60%	0%	40%	108	89.7	0	64.8

Notes:

[1] Developed based on the methodology used in the Standardized Regulatory Impact Assessment for the proposed ACC II (available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appc1.pdf, accessed: May 2022) and discussions with CARB ACC II staff. Refer to Section 3.2.1.4 of the report for further details.

[2] The fuel pathway codes HYF and HYB from the *CA-GREET 3.0 Lookup Table Pathways Technical Support Documentation* (available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf, accessed: May 2022) were used to represent Fossil Hydrogen and Landfill SMR Hydrogen respectively. The total carbon intensity CIs for these pathways (noted below) were adjusted for improvements in the CI of California average grid electricity used in the gaseous H_2 compression and precooling stage of the pathway process to estimate the upstream GHG emissions for each calendar year. For each calendar year, the adjustment was performed by replacing the portion of the total CI associated with the gaseous H_2 compression and precooling stage of the process with the product of the electricity used for this stage (shown below) and the upstream GHG emission factor for electricity obtained from Table A-2.

[3] It was assumed that Curtailment Electrolysis Hydrogen would have a CI of zero, as the hydrogen is produced by electrolysis using curtailment electricity.

[4] Estimated as a composition weighted average of the GHG emission factors for Fossil Hydrogen, Landfill SMR Hydrogen and Curtailment Electrolysis Hydrogen.

[5] Obtained from Table F.3 in *CA-GREET 3.0 Lookup Table Pathways Technical Support Documentation*. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf. Accessed: May 2022.

[6] Estimated as the ratio of the CI for the gaseous H_2 compression and precooling stage to the total CI for California average grid electricity (93.75 g CO_2e/MJ) in the *CA-GREET3.0 Lookup Table Pathways Technical Support Documentation* (available at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf, accessed: May 2022).

Carbon Intensity Data for Hydrogen Pathways:

Fuel Pathway Code	Process Description	Total CI for the Process[5] ($g\ CO_2e/MJ\ H_2$)	CI for the Gaseous H_2 Compression and Precooling Stage of the Process[5] ($g\ CO_2e/MJ\ H_2$)	California Grid Electricity Used for the Gaseous H_2 Compression and Precooling Stage of the Process[6] ($MJ\ Electricity/MJ\ H_2$)
HYF	NG to Gaseous H_2 from SMR	117.67	11.04	0.118
HYB	Biomethane to Gaseous H_2 from SMR	99.48	11.04	0.118

Abbreviations:

CARB - California Air Resources Board
CI - carbon intensity
CO_2e - carbon dioxide equivalents
g - gram
H_2 - hydrogen
GREET - Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model

Table A-7. Estimating Upstream GHG Emission Factors for AB32 Hydrogen

Calendar Year	Fuel Consumption in Scenario S1d-1 – ACC II (FCEV) + AB32 H_2 (MJ of hydrogen/day)			Upstream GHG Emission Factors for the Components of AB32 Hydrogen (g CO_2e/MJ)		Upstream GHG Emission Factors for AB32 Hydrogen[6] (g CO_2e/MJ)
	Total Hydrogen[1]	Landfill SMR Hydrogen[2]	Solar Electrolysis Hydrogen[3]	Landfill SMR Hydrogen[4]	Solar Electrolysis Hydrogen[5]	
2026	12,056,007	933,718	11,122,289	96.1	0	7.4
2030	109,330,786	933,718	108,397,068	94.3	0	0.81
2035	305,039,242	933,718	304,105,524	92.8	0	0.28
2040	478,787,295	933,718	477,853,578	91.5	0	0.18
2045	583,944,601	933,718	583,010,883	90.4	0	0.14
2050	635,526,470	933,718	634,592,752	89.7	0	0.13

Notes:

[1] Obtained from Tables A-51 through A-55.

[2] The amount of Landfill SMR Hydrogen consumed in future years is capped at the amount of renewable hydrogen produced in 2021. The annual production of renewable hydrogen in 2021 was obtained from Figure ES 8 in the *2021 Annual Hydrogen Evaluation* (available at: https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf, accessed: May 2021). This annual value was converted to a daily consumption value using 347 light duty auto operational days per year obtained from the *EMFAC2017 Volume III - Technical Documentation* (available at: https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf, accessed: May 2022).

[3] Estimated as the difference of the total hydrogen consumed and Landfill SMR Hydrogen consumed.

[4] Obtained from Table A-6.

[5] The upstream GHG emission factor for Solar Electrolysis Hydrogen was assumed to be zero, as hydrogen is produced using electrolysis with zero CI electricity that is generated by solar photovoltaic systems.

[6] Estimated as an consumption weighted average of GHG emission factors for Landfill SMR Hydrogen and Solar Electrolysis Hydrogen.

Abbreviations:

CI - carbon intensity
CO_2e - carbon dioxide equivalents
EMFAC - EMission FACtors Model
g - gram
H_2 - Hydrogen
HYB - Gaseous Hydrogen from Fossil Natural Gas and Steam Reformation of Methane
HYF - Gaseous Hydrogen from Landfill Biomethane and Steam Reformation of Methane
GREET - Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model
kg - kilogram
LCFS - Low Carbon Fuel Standard
LDA - light duty auto
MJ - megajoule
NG - natural gas
yr - year

Table A-8. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2026

	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
Model Year[1]	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
1982	0.056	6.48	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1983	0.055	6.41	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1984	0.054	6.27	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1985	0.053	6.17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1986	0.050	5.82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1987	0.050	5.79	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1988	0.050	5.76	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1989	0.049	5.72	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1990	0.049	5.69	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1991	0.049	5.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1992	0.049	5.64	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1993	0.046	5.27	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1994	0.045	5.24	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1995	0.045	5.21	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1996	0.045	5.22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1997	0.044	5.11	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1998	0.043	4.97	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1999	0.042	4.85	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2000	0.042	4.86	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2001	0.042	4.85	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2002	0.042	4.84	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	0.042	4.85	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2004	0.044	5.04	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2005	0.043	4.96	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table A-8. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2026

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2006	0.043	4.97	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2007	0.042	4.85	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2008	0.042	4.88	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2009	0.040	4.62	0.386	1.39	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2010	0.036	4.21	0.386	1.39	0.035	4.11	0.302	1.09	N/A	N/A	N/A
2011	0.038	4.38	0.386	1.39	0.035	4.11	0.302	1.09	N/A	N/A	N/A
2012	0.036	4.18	0.386	1.39	0.035	4.08	0.302	1.09	N/A	N/A	N/A
2013	0.035	4.06	0.386	1.39	0.035	4.07	0.302	1.09	N/A	N/A	N/A
2014	0.035	4.07	0.386	1.39	0.035	4.06	0.302	1.09	N/A	N/A	N/A
2015	0.034	3.99	0.386	1.39	0.035	4.05	0.302	1.09	N/A	N/A	N/A
2016	0.034	3.90	0.386	1.39	0.035	4.04	0.302	1.09	N/A	N/A	N/A
2017	0.034	3.94	0.386	1.39	0.035	4.04	0.302	1.09	N/A	N/A	N/A
2018	0.034	3.93	0.386	1.39	0.035	4.03	0.302	1.09	N/A	N/A	N/A
2019	0.033	3.88	0.386	1.39	0.035	4.02	0.302	1.09	N/A	N/A	N/A
2020	0.033	3.77	0.386	1.39	0.035	4.01	0.302	1.09	N/A	N/A	N/A
2021	0.032	3.68	0.386	1.39	0.035	4.00	0.302	1.09	N/A	N/A	N/A
2022	0.031	3.60	0.386	1.39	0.035	4.01	0.302	1.09	N/A	N/A	N/A
2023	0.030	3.52	0.386	1.39	0.035	4.01	0.302	1.09	N/A	N/A	N/A
2024	0.030	3.44	0.386	1.39	0.035	4.01	0.302	1.09	N/A	N/A	N/A
2025	0.029	3.37	0.386	1.39	0.035	4.01	0.302	1.09	N/A	N/A	N/A

Table A-8. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2026	0.028	3.29	0.386	1.39	0.035	4.02	0.302	1.09	1.32	0.020	2.34

Notes:

[1] Estimated using fuel consumption, energy consumption, and VMT outputs for LDA from EMFAC2021.

[2] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 1985-1986, 1988, 1990-1992, and 1996 BEVs.

[3] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[4] Fuel economies for MY 2026+ FCEVs were estimated by applying an EER of 2.5 to the gasoline ICEV fuel economy. This EER value was obtained from: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

[5] For the purposes of this analysis, we assumed FCEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[6] Fuel economies for MY 2026+ HEVs were estimated by applying an EER of 1.41 to the gasoline ICEV fuel economy. This EER value was derived from the relative fuel economies of the average MY 2020 HEV and ICEV as obtained from The 2020 EPA Automotive Trends Report. This factor was assumed to remain constant in future years and was used to estimate fuel economies for MY 2026 to 2050 HEVs. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf. Accessed: May 2022.

[7] For the purposes of this analysis, we assumed HEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[8] California Reformulated Gasoline (CaRFG) energy density and the conversion factor from kWh to MJ were obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Constants and Conversion Factors:

CaRFG Energy Density[8]	115.83	MJ/gal
Conversion Factor[8]	3.6	MJ/kWh
FCEV EER[4]	2.5	
HEV EER[6]	1.41	

Abbreviations:

BEV - battery electric vehicle
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
EER - energy economy ratio
EPA - Environmental Protection Agency
EMFAC - EMission FACtor Model
FCEV - fuel cell electric vehicle
gal - gallon
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
kWh - kilowatt hour
LDA - light duty auto
LCFS - Low Carbon Fuel Standard
mi - mile
MJ - megajoule
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle mile traveled

Table A-9. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2026

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
1982	4,657	26,874	5.77	0	0	0	N/A	N/A
1983	5,273	32,227	6.11	0	0	0	N/A	N/A
1984	7,858	52,558	6.69	0	0	0	N/A	N/A
1985	10,024	70,578	7.04	0	0	0	N/A	N/A
1986	10,647	79,719	7.49	0	0	0	N/A	N/A
1987	12,832	101,240	7.89	0	0	0	N/A	N/A
1988	12,139	102,970	8.48	0	0	0	N/A	N/A
1989	14,970	135,380	9.04	0	0	0	N/A	N/A
1990	18,044	174,283	9.66	0	0	0	N/A	N/A
1991	21,281	217,683	10.2	0	0	0	N/A	N/A
1992	18,332	199,758	10.9	0	0	0	N/A	N/A
1993	20,138	233,503	11.6	0	0	0	N/A	N/A
1994	22,840	281,137	12.3	0	0	0	N/A	N/A
1995	29,675	387,901	13.1	0	0	0	N/A	N/A
1996	29,436	407,796	13.9	0	0	0	N/A	N/A
1997	39,761	583,473	14.7	0	0	0	N/A	N/A
1998	48,817	759,429	15.6	0	0	0	N/A	N/A
1999	56,921	938,152	16.5	0	0	0	N/A	N/A
2000	76,964	1,342,284	17.4	0	0	0	N/A	N/A
2001	87,221	1,606,469	18.4	0	0	0	N/A	N/A
2002	102,135	1,992,256	19.5	0	0	0	N/A	N/A
2003	127,287	2,622,480	20.6	0	0	0	N/A	N/A
2004	143,690	3,119,968	21.7	0	0	0	N/A	N/A
2005	191,623	4,384,633	22.9	0	0	0	N/A	N/A
2006	225,488	5,424,766	24.1	0	0	0	N/A	N/A
2007	275,180	6,939,253	25.2	0	0	0	N/A	N/A
2008	258,265	6,829,991	26.4	0	0	0	N/A	N/A

Table A-9. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2026

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2009	229,086	6,347,878	27.7	0	0	0	N/A	N/A
2010	292,924	8,485,008	29.0	141	167	308	46%	54%
2011	307,002	9,314,386	30.3	7,615	9,007	16,623	46%	54%
2012	465,759	14,799,666	31.8	81,301	96,163	177,464	46%	54%
2013	592,447	19,649,699	33.2	170,161	201,266	371,427	46%	54%
2014	599,553	20,804,616	34.7	261,690	309,525	571,215	46%	54%
2015	738,821	26,786,257	36.3	209,303	247,562	456,865	46%	54%
2016	754,102	28,526,656	37.8	238,915	282,587	521,502	46%	54%
2017	794,462	31,216,468	39.3	650,114	768,951	1,419,065	46%	54%
2018	705,513	28,851,497	40.9	625,674	740,043	1,365,716	46%	54%
2019	622,322	26,519,738	42.6	490,993	544,904	1,035,897	47%	53%
2020	508,892	22,556,130	44.3	525,700	564,979	1,090,679	48%	52%
2021	619,444	28,547,651	46.1	746,145	756,758	1,502,904	50%	50%
2022	724,703	34,701,680	47.9	1,045,860	869,457	1,915,316	55%	45%
2023	731,635	36,367,737	49.7	1,132,848	883,942	2,016,790	56%	44%
2024	747,543	38,509,686	51.5	1,225,174	897,466	2,122,640	58%	42%
2025	758,530	40,393,349	53.3	1,323,268	906,781	2,230,049	59%	41%
2026	706,862	38,782,248	54.9	1,122,062	768,903	1,890,965	59%	41%

Notes:

[1] Values in shaded cells are zero or not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Obtained from EMFAC2021 data.

Abbreviations:

cVMT - combustion vehicle mile traveled
EMFAC - EMission FACtor Model
eVMT - electric vehicle mile traveled
ICEV - internal combustion engine vehicle
LDA - light duty auto
mi - mile
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle miles traveled

Table A-10. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2026

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
1982	9.48E-03	8.19E-05	5.07E-06	4.38E-08	2.05E-06	1.77E-08	N/A	N/A	N/A	N/A	N/A	N/A
1983	9.48E-03	8.19E-05	4.83E-06	4.17E-08	1.87E-06	1.61E-08	N/A	N/A	N/A	N/A	N/A	N/A
1984	9.48E-03	8.19E-05	4.20E-06	3.62E-08	1.86E-06	1.61E-08	N/A	N/A	N/A	N/A	N/A	N/A
1985	9.48E-03	8.19E-05	4.65E-06	4.02E-08	1.68E-06	1.45E-08	N/A	N/A	N/A	N/A	N/A	N/A
1986	9.48E-03	8.19E-05	4.82E-06	4.16E-08	1.76E-06	1.52E-08	N/A	N/A	N/A	N/A	N/A	N/A
1987	9.48E-03	8.19E-05	4.74E-06	4.10E-08	1.75E-06	1.51E-08	N/A	N/A	N/A	N/A	N/A	N/A
1988	9.48E-03	8.19E-05	4.63E-06	4.00E-08	1.74E-06	1.50E-08	N/A	N/A	N/A	N/A	N/A	N/A
1989	9.48E-03	8.19E-05	4.54E-06	3.92E-08	1.72E-06	1.48E-08	N/A	N/A	N/A	N/A	N/A	N/A
1990	9.48E-03	8.19E-05	4.44E-06	3.83E-08	1.71E-06	1.48E-08	N/A	N/A	N/A	N/A	N/A	N/A
1991	9.48E-03	8.19E-05	4.36E-06	3.76E-08	1.71E-06	1.47E-08	N/A	N/A	N/A	N/A	N/A	N/A
1992	9.48E-03	8.19E-05	4.27E-06	3.68E-08	1.70E-06	1.47E-08	N/A	N/A	N/A	N/A	N/A	N/A
1993	9.48E-03	8.19E-05	4.47E-06	3.86E-08	1.81E-06	1.56E-08	N/A	N/A	N/A	N/A	N/A	N/A
1994	9.48E-03	8.19E-05	4.44E-06	3.84E-08	1.80E-06	1.55E-08	N/A	N/A	N/A	N/A	N/A	N/A
1995	9.48E-03	8.19E-05	4.39E-06	3.79E-08	1.79E-06	1.54E-08	N/A	N/A	N/A	N/A	N/A	N/A
1996	9.48E-03	8.19E-05	5.07E-06	4.37E-08	1.98E-06	1.71E-08	N/A	N/A	N/A	N/A	N/A	N/A
1997	9.48E-03	8.19E-05	4.17E-06	3.60E-08	1.80E-06	1.55E-08	N/A	N/A	N/A	N/A	N/A	N/A
1998	9.48E-03	8.19E-05	3.30E-06	2.85E-08	1.61E-06	1.39E-08	N/A	N/A	N/A	N/A	N/A	N/A
1999	9.48E-03	8.19E-05	2.41E-06	2.08E-08	1.41E-06	1.22E-08	N/A	N/A	N/A	N/A	N/A	N/A
2000	9.48E-03	8.19E-05	1.48E-06	1.28E-08	1.18E-06	1.02E-08	N/A	N/A	N/A	N/A	N/A	N/A
2001	9.48E-03	8.19E-05	1.38E-06	1.19E-08	1.11E-06	9.61E-09	N/A	N/A	N/A	N/A	N/A	N/A
2002	9.48E-03	8.19E-05	1.31E-06	1.13E-08	1.07E-06	9.25E-09	N/A	N/A	N/A	N/A	N/A	N/A
2003	9.48E-03	8.19E-05	1.17E-06	1.01E-08	9.82E-07	8.48E-09	N/A	N/A	N/A	N/A	N/A	N/A
2004	9.48E-03	8.19E-05	4.91E-07	4.24E-09	2.79E-07	2.41E-09	N/A	N/A	N/A	N/A	N/A	N/A
2005	9.48E-03	8.19E-05	4.43E-07	3.82E-09	2.73E-07	2.35E-09	N/A	N/A	N/A	N/A	N/A	N/A
2006	9.48E-03	8.19E-05	3.77E-07	3.25E-09	2.53E-07	2.18E-09	N/A	N/A	N/A	N/A	N/A	N/A
2007	9.48E-03	8.19E-05	3.82E-07	3.30E-09	2.70E-07	2.33E-09	N/A	N/A	N/A	N/A	N/A	N/A
2008	9.48E-03	8.19E-05	3.57E-07	3.08E-09	2.61E-07	2.26E-09	N/A	N/A	N/A	N/A	N/A	N/A
2009	9.48E-03	8.19E-05	3.42E-07	2.96E-09	2.68E-07	2.31E-09	N/A	N/A	N/A	N/A	N/A	N/A
2010	9.48E-03	8.19E-05	3.53E-07	3.05E-09	2.87E-07	2.48E-09	9.48E-03	8.19E-05	3.53E-07	3.05E-09	1.89E-07	1.63E-09
2011	9.48E-03	8.19E-05	3.40E-07	2.94E-09	2.71E-07	2.34E-09	9.48E-03	8.19E-05	3.40E-07	2.94E-09	1.84E-07	1.59E-09
2012	9.48E-03	8.19E-05	3.27E-07	2.82E-09	2.74E-07	2.37E-09	9.48E-03	8.19E-05	3.30E-07	2.85E-09	1.80E-07	1.56E-09
2013	9.48E-03	8.19E-05	3.14E-07	2.71E-09	2.74E-07	2.36E-09	9.48E-03	8.19E-05	3.20E-07	2.76E-09	1.77E-07	1.53E-09
2014	9.48E-03	8.19E-05	3.07E-07	2.65E-09	2.66E-07	2.30E-09	9.48E-03	8.19E-05	3.10E-07	2.67E-09	1.73E-07	1.49E-09
2015	9.48E-03	8.19E-05	2.99E-07	2.59E-09	2.63E-07	2.27E-09	9.48E-03	8.19E-05	3.00E-07	2.59E-09	1.69E-07	1.46E-09

Table A-10. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2016	9.48E-03	8.19E-05	3.27E-07	2.82E-09	2.68E-07	2.31E-09	9.48E-03	8.19E-05	2.91E-07	2.51E-09	1.66E-07	1.43E-09
2017	9.48E-03	8.19E-05	2.97E-07	2.57E-09	2.54E-07	2.19E-09	9.48E-03	8.19E-05	2.83E-07	2.44E-09	1.62E-07	1.40E-09
2018	9.48E-03	8.19E-05	2.78E-07	2.40E-09	2.45E-07	2.12E-09	9.48E-03	8.19E-05	2.75E-07	2.37E-09	1.59E-07	1.38E-09
2019	9.48E-03	8.19E-05	2.58E-07	2.23E-09	2.37E-07	2.04E-09	9.48E-03	8.19E-05	2.73E-07	2.36E-09	1.59E-07	1.37E-09
2020	9.48E-03	8.19E-05	2.47E-07	2.13E-09	2.33E-07	2.01E-09	9.48E-03	8.19E-05	2.69E-07	2.32E-09	1.57E-07	1.36E-09
2021	9.48E-03	8.19E-05	2.28E-07	1.97E-09	2.25E-07	1.94E-09	9.48E-03	8.19E-05	2.67E-07	2.31E-09	1.57E-07	1.35E-09
2022	9.48E-03	8.19E-05	2.06E-07	1.77E-09	2.14E-07	1.85E-09	9.48E-03	8.19E-05	2.80E-07	2.42E-09	1.62E-07	1.40E-09
2023	9.48E-03	8.19E-05	1.85E-07	1.60E-09	2.02E-07	1.74E-09	9.48E-03	8.19E-05	2.80E-07	2.42E-09	1.62E-07	1.40E-09
2024	9.48E-03	8.19E-05	1.64E-07	1.42E-09	1.88E-07	1.62E-09	9.48E-03	8.19E-05	2.80E-07	2.41E-09	1.62E-07	1.39E-09
2025	9.48E-03	8.19E-05	1.32E-07	1.14E-09	1.68E-07	1.45E-09	9.48E-03	8.19E-05	2.80E-07	2.42E-09	1.62E-07	1.40E-09
2026	9.48E-03	8.19E-05	1.26E-07	1.09E-09	1.58E-07	1.36E-09	9.48E-03	8.19E-05	2.74E-07	2.36E-09	1.59E-07	1.37E-09

Notes:

[1] Values in shaded cells are not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Tailpipe greenhouse gas emission factors were estimated as a ratio of the greenhouse gas emissions (CO_2, CH_4, N_2O) to the gasoline fuel consumption outputs for each model year from EMFAC2021 data.

[3] California Reformulated Gasoline (CaRFG) energy density for the conversion factor from gal to MJ was obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Conversion Factor

CaRFG Energy Density[3]	115.83	MJ/gal

Abbreviations:

CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
gal - gallon
ICEV - internal combustion engine vehicle
LCFS - Low Carbon Fuel Standard
MJ - megajoule
MY - model year
N_2O - Nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-11. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
1986	0.051	5.95	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1987	0.051	5.93	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1988	0.051	5.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1989	0.051	5.85	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1990	0.050	5.81	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1991	0.050	5.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1992	0.050	5.75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1993	0.046	5.38	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1994	0.046	5.34	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1995	0.046	5.31	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1996	0.046	5.31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1997	0.045	5.18	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1998	0.044	5.04	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1999	0.042	4.90	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2000	0.042	4.92	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2001	0.042	4.90	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2002	0.042	4.89	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	0.042	4.89	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2004	0.044	5.08	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2005	0.043	5.00	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2006	0.043	5.01	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2007	0.042	4.88	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table A-11. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2030

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2008	0.042	4.91	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2009	0.040	4.65	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2010	0.036	4.23	0.386	1.390	0.036	4.16	0.302	1.087	N/A	N/A	N/A
2011	0.038	4.40	0.386	1.390	0.036	4.16	0.302	1.087	N/A	N/A	N/A
2012	0.036	4.20	0.386	1.390	0.036	4.13	0.302	1.087	N/A	N/A	N/A
2013	0.035	4.07	0.386	1.390	0.035	4.11	0.302	1.087	N/A	N/A	N/A
2014	0.035	4.08	0.386	1.390	0.035	4.10	0.302	1.087	N/A	N/A	N/A
2015	0.035	4.00	0.386	1.390	0.035	4.09	0.302	1.087	N/A	N/A	N/A
2016	0.034	3.92	0.386	1.390	0.035	4.07	0.302	1.087	N/A	N/A	N/A
2017	0.034	3.95	0.386	1.390	0.035	4.07	0.302	1.087	N/A	N/A	N/A
2018	0.034	3.94	0.386	1.390	0.035	4.06	0.302	1.087	N/A	N/A	N/A
2019	0.034	3.89	0.386	1.390	0.035	4.05	0.302	1.087	N/A	N/A	N/A
2020	0.033	3.78	0.386	1.390	0.035	4.04	0.302	1.087	N/A	N/A	N/A
2021	0.032	3.69	0.386	1.390	0.035	4.03	0.302	1.087	N/A	N/A	N/A
2022	0.031	3.60	0.386	1.390	0.035	4.04	0.302	1.087	N/A	N/A	N/A
2023	0.030	3.52	0.386	1.390	0.035	4.03	0.302	1.087	N/A	N/A	N/A
2024	0.030	3.44	0.386	1.390	0.035	4.03	0.302	1.087	N/A	N/A	N/A
2025	0.029	3.37	0.386	1.390	0.035	4.03	0.302	1.087	N/A	N/A	N/A
2026	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337
2027	0.028	3.29	0.386	1.390	0.035	4.01	0.302	1.087	1.32	0.020	2.336
2028	0.028	3.29	0.386	1.390	0.035	4.01	0.302	1.087	1.32	0.020	2.337
2029	0.028	3.30	0.386	1.390	0.035	4.01	0.302	1.087	1.32	0.020	2.337

Table A-11. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2030

	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
Model Year[1]	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2030	0.028	3.30	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.338

Notes:

[1] Estimated using fuel consumption, energy consumption, and VMT outputs for LDA from EMFAC2021.

[2] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 1986, 1988, 1990-1992, and 1996 BEVs.

[3] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[4] Fuel economies for MY 2026+ FCEVs were estimated by applying an EER of 2.5 to the gasoline ICEV fuel economy. This EER value was obtained from: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

[5] For the purposes of this analysis, we assumed FCEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[6] Fuel economies for MY 2026+ HEVs were estimated by applying an EER of 1.41 to the gasoline ICEV fuel economy. This EER value was derived from the relative fuel economies of the average MY 2020 HEV and ICEV as obtained from The 2020 EPA Automotive Trends Report. This factor was assumed to remain constant in future years and was used to estimate fuel economies for MY 2026 to 2050 HEVs. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf. Accessed: May 2022.

[7] For the purposes of this analysis, we assumed HEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[8] California Reformulated Gasoline (CaRFG) energy density and the conversion factor from kWh to MJ were obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Constants and Conversion Factors:

CaRFG Energy Density[8]	115.83	MJ/gal
Conversion Factor[8]	3.6	MJ/kWh
FCEV EER[4]	2.5	
HEV EER[6]	1.41	

Abbreviations:

BEV - battery electric vehicle
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
EER - energy economy ratio
EPA - Environmental Protection Agency
EMFAC - EMission FACtor Model
FCEV - fuel cell electric vehicle
gal - gallon
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
kWh - kilowatt hour
LDA - light duty auto
LCFS - Low Carbon Fuel Standard
mi - mile
MJ - megajoule
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle mile traveled

Table A-12. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2030

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
1986	9,277	53,700	5.8	0	0	0	N/A	N/A
1987	11,036	66,623	6.0	0	0	0	N/A	N/A
1988	10,287	66,938	6.5	0	0	0	N/A	N/A
1989	12,682	87,678	6.9	0	0	0	N/A	N/A
1990	15,335	113,727	7.4	0	0	0	N/A	N/A
1991	17,755	139,333	7.8	0	0	0	N/A	N/A
1992	14,968	125,543	8.4	0	0	0	N/A	N/A
1993	15,722	140,921	9.0	0	0	0	N/A	N/A
1994	16,938	161,630	10	0	0	0	N/A	N/A
1995	21,266	216,234	10	0	0	0	N/A	N/A
1996	20,041	216,378	11	0	0	0	N/A	N/A
1997	25,571	293,230	11	0	0	0	N/A	N/A
1998	29,544	360,282	12	0	0	0	N/A	N/A
1999	32,392	420,297	13	0	0	0	N/A	N/A
2000	41,346	570,135	14	0	0	0	N/A	N/A
2001	44,766	655,169	15	0	0	0	N/A	N/A
2002	49,911	776,791	16	0	0	0	N/A	N/A
2003	59,781	987,738	17	0	0	0	N/A	N/A
2004	65,751	1,150,109	17	0	0	0	N/A	N/A
2005	86,903	1,608,897	19	0	0	0	N/A	N/A
2006	103,055	2,015,934	20	0	0	0	N/A	N/A
2007	128,610	2,648,443	21	0	0	0	N/A	N/A
2008	125,543	2,723,177	22	0	0	0	N/A	N/A
2009	116,809	2,665,820	23	0	0	0	N/A	N/A
2010	158,274	3,790,216	24	63	75	138	46%	54%
2011	175,648	4,423,155	25	3,616	4,277	7,894	46%	54%
2012	282,481	7,476,616	26	41,072	48,580	89,652	46%	54%
2013	378,095	10,478,988	28	90,738	107,324	198,062	46%	54%
2014	402,992	11,724,588	29	147,458	174,412	321,870	46%	54%
2015	518,113	15,796,707	30	123,416	145,976	269,392	46%	54%

Table A-12. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2030

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2016	553,278	17,650,767	32	147,786	174,800	322,586	46%	54%
2017	604,853	20,084,898	33	418,135	494,567	912,702	46%	54%
2018	555,971	19,259,219	35	417,450	493,757	911,207	46%	54%
2019	505,059	18,279,445	36	338,461	375,624	714,084	47%	53%
2020	424,894	16,029,340	38	373,698	401,619	775,317	48%	52%
2021	528,088	20,762,889	39	542,857	550,578	1,093,435	50%	50%
2022	629,123	25,762,005	41	776,697	645,693	1,422,390	55%	45%
2023	652,013	27,788,406	43	865,876	675,628	1,541,504	56%	44%
2024	670,253	29,718,527	44	945,654	692,712	1,638,366	58%	42%
2025	697,118	32,142,427	46	1,052,876	721,492	1,774,368	59%	41%
2026	735,995	35,239,627	48	1,019,135	698,371	1,717,506	59%	41%
2027	753,379	37,425,433	50	1,081,272	740,951	1,822,223	59%	41%
2028	774,987	39,867,277	51	1,144,715	784,426	1,929,141	59%	41%
2029	786,767	41,769,541	53	1,188,690	814,560	2,003,250	59%	41%
2030	712,577	38,930,072	55	1,099,919	753,729	1,853,648	59%	41%

Notes:

[1] Values in shaded cells are zero or not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Obtained from EMFAC2021 data.

Abbreviations:

cVMT - combustion vehicle mile traveled
EMFAC - EMission FACtor Model
eVMT - electric vehicle mile traveled
ICEV - internal combustion engine vehicle
LDA - light duty auto
mi - mile
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle miles traveled

Table A-13. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2030

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
1986	9.48E-03	8.19E-05	5.23E-06	4.51E-08	1.78E-06	1.54E-08	N/A	N/A	N/A	N/A	N/A	N/A
1987	9.48E-03	8.19E-05	5.18E-06	4.47E-08	1.77E-06	1.53E-08	N/A	N/A	N/A	N/A	N/A	N/A
1988	9.48E-03	8.19E-05	5.06E-06	4.37E-08	1.76E-06	1.52E-08	N/A	N/A	N/A	N/A	N/A	N/A
1989	9.48E-03	8.19E-05	4.96E-06	4.28E-08	1.74E-06	1.50E-08	N/A	N/A	N/A	N/A	N/A	N/A
1990	9.48E-03	8.19E-05	4.85E-06	4.19E-08	1.73E-06	1.49E-08	N/A	N/A	N/A	N/A	N/A	N/A
1991	9.48E-03	8.19E-05	4.77E-06	4.11E-08	1.73E-06	1.49E-08	N/A	N/A	N/A	N/A	N/A	N/A
1992	9.48E-03	8.19E-05	4.66E-06	4.02E-08	1.72E-06	1.49E-08	N/A	N/A	N/A	N/A	N/A	N/A
1993	9.48E-03	8.19E-05	4.87E-06	4.20E-08	1.83E-06	1.58E-08	N/A	N/A	N/A	N/A	N/A	N/A
1994	9.48E-03	8.19E-05	4.83E-06	4.17E-08	1.82E-06	1.57E-08	N/A	N/A	N/A	N/A	N/A	N/A
1995	9.48E-03	8.19E-05	4.76E-06	4.11E-08	1.81E-06	1.56E-08	N/A	N/A	N/A	N/A	N/A	N/A
1996	9.48E-03	8.19E-05	5.50E-06	4.75E-08	2.01E-06	1.73E-08	N/A	N/A	N/A	N/A	N/A	N/A
1997	9.48E-03	8.19E-05	4.54E-06	3.92E-08	1.83E-06	1.58E-08	N/A	N/A	N/A	N/A	N/A	N/A
1998	9.48E-03	8.19E-05	3.60E-06	3.11E-08	1.64E-06	1.42E-08	N/A	N/A	N/A	N/A	N/A	N/A
1999	9.48E-03	8.19E-05	2.64E-06	2.28E-08	1.45E-06	1.26E-08	N/A	N/A	N/A	N/A	N/A	N/A
2000	9.48E-03	8.19E-05	1.65E-06	1.42E-08	1.22E-06	1.05E-08	N/A	N/A	N/A	N/A	N/A	N/A
2001	9.48E-03	8.19E-05	1.54E-06	1.33E-08	1.16E-06	9.99E-09	N/A	N/A	N/A	N/A	N/A	N/A
2002	9.48E-03	8.19E-05	1.46E-06	1.26E-08	1.12E-06	9.63E-09	N/A	N/A	N/A	N/A	N/A	N/A
2003	9.48E-03	8.19E-05	1.30E-06	1.12E-08	1.03E-06	8.87E-09	N/A	N/A	N/A	N/A	N/A	N/A
2004	9.48E-03	8.19E-05	5.56E-07	4.80E-09	2.96E-07	2.56E-09	N/A	N/A	N/A	N/A	N/A	N/A
2005	9.48E-03	8.19E-05	5.01E-07	4.33E-09	2.90E-07	2.51E-09	N/A	N/A	N/A	N/A	N/A	N/A
2006	9.48E-03	8.19E-05	4.26E-07	3.68E-09	2.71E-07	2.34E-09	N/A	N/A	N/A	N/A	N/A	N/A
2007	9.48E-03	8.19E-05	4.32E-07	3.73E-09	2.90E-07	2.51E-09	N/A	N/A	N/A	N/A	N/A	N/A
2008	9.48E-03	8.19E-05	4.04E-07	3.49E-09	2.82E-07	2.43E-09	N/A	N/A	N/A	N/A	N/A	N/A
2009	9.48E-03	8.19E-05	3.88E-07	3.35E-09	2.90E-07	2.51E-09	N/A	N/A	N/A	N/A	N/A	N/A
2010	9.48E-03	8.19E-05	4.00E-07	3.45E-09	3.12E-07	2.69E-09	9.48E-03	8.19E-05	4.06E-07	3.50E-09	2.08E-07	1.80E-09
2011	9.48E-03	8.19E-05	3.86E-07	3.33E-09	2.95E-07	2.55E-09	9.48E-03	8.19E-05	3.90E-07	3.37E-09	2.02E-07	1.75E-09
2012	9.48E-03	8.19E-05	3.70E-07	3.20E-09	3.00E-07	2.59E-09	9.48E-03	8.19E-05	3.78E-07	3.26E-09	1.98E-07	1.71E-09
2013	9.48E-03	8.19E-05	3.57E-07	3.08E-09	3.01E-07	2.60E-09	9.48E-03	8.19E-05	3.66E-07	3.16E-09	1.94E-07	1.67E-09
2014	9.48E-03	8.19E-05	3.50E-07	3.02E-09	2.94E-07	2.53E-09	9.48E-03	8.19E-05	3.53E-07	3.04E-09	1.89E-07	1.63E-09
2015	9.48E-03	8.19E-05	3.41E-07	2.95E-09	2.92E-07	2.52E-09	9.48E-03	8.19E-05	3.41E-07	2.94E-09	1.85E-07	1.59E-09

Table A-13. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2016	9.48E-03	8.19E-05	3.73E-07	3.22E-09	2.98E-07	2.57E-09	9.48E-03	8.19E-05	3.30E-07	2.85E-09	1.81E-07	1.56E-09
2017	9.48E-03	8.19E-05	3.40E-07	2.94E-09	2.85E-07	2.46E-09	9.48E-03	8.19E-05	3.20E-07	2.76E-09	1.77E-07	1.53E-09
2018	9.48E-03	8.19E-05	3.20E-07	2.76E-09	2.77E-07	2.39E-09	9.48E-03	8.19E-05	3.10E-07	2.68E-09	1.73E-07	1.49E-09
2019	9.48E-03	8.19E-05	2.98E-07	2.57E-09	2.70E-07	2.33E-09	9.48E-03	8.19E-05	3.07E-07	2.65E-09	1.72E-07	1.49E-09
2020	9.48E-03	8.19E-05	2.86E-07	2.47E-09	2.69E-07	2.32E-09	9.48E-03	8.19E-05	3.03E-07	2.61E-09	1.70E-07	1.47E-09
2021	9.48E-03	8.19E-05	2.66E-07	2.29E-09	2.63E-07	2.27E-09	9.48E-03	8.19E-05	3.00E-07	2.59E-09	1.69E-07	1.46E-09
2022	9.48E-03	8.19E-05	2.41E-07	2.08E-09	2.55E-07	2.20E-09	9.48E-03	8.19E-05	3.14E-07	2.72E-09	1.75E-07	1.51E-09
2023	9.48E-03	8.19E-05	2.19E-07	1.89E-09	2.45E-07	2.11E-09	9.48E-03	8.19E-05	3.14E-07	2.71E-09	1.75E-07	1.51E-09
2024	9.48E-03	8.19E-05	1.96E-07	1.69E-09	2.33E-07	2.01E-09	9.48E-03	8.19E-05	3.13E-07	2.70E-09	1.75E-07	1.51E-09
2025	9.48E-03	8.19E-05	1.60E-07	1.38E-09	2.14E-07	1.85E-09	9.48E-03	8.19E-05	3.13E-07	2.70E-09	1.75E-07	1.51E-09
2026	9.48E-03	8.19E-05	1.53E-07	1.32E-09	2.06E-07	1.78E-09	9.48E-03	8.19E-05	3.05E-07	2.63E-09	1.71E-07	1.48E-09
2027	9.48E-03	8.19E-05	1.45E-07	1.25E-09	1.94E-07	1.68E-09	9.48E-03	8.19E-05	2.96E-07	2.56E-09	1.68E-07	1.45E-09
2028	9.48E-03	8.19E-05	1.38E-07	1.19E-09	1.82E-07	1.57E-09	9.48E-03	8.19E-05	2.88E-07	2.49E-09	1.65E-07	1.42E-09
2029	9.48E-03	8.19E-05	1.32E-07	1.14E-09	1.70E-07	1.47E-09	9.48E-03	8.19E-05	2.81E-07	2.43E-09	1.62E-07	1.40E-09
2030	9.48E-03	8.19E-05	1.25E-07	1.08E-09	1.57E-07	1.36E-09	9.48E-03	8.19E-05	2.74E-07	2.37E-09	1.60E-07	1.38E-09

Notes:

[1] Values in shaded cells are not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Tailpipe greenhouse gas emission factors were estimated as a ratio of the greenhouse gas emissions (CO_2, CH_4, N_2O) to the gasoline fuel consumption outputs for each model year from EMFAC2021 data.

[3] California Reformulated Gasoline (CaRFG) energy density for the conversion factor from gal to MJ was obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Conversion Factor

CaRFG Energy Density[3]	115.83	MJ/gal

Abbreviations:

CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
gal - gallon
ICEV - internal combustion engine vehicle
LCFS - Low Carbon Fuel Standard
MJ - megajoule
MY - model year
N_2O - Nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-14. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
1991	0.051	5.97	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1992	0.051	5.93	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1993	0.048	5.54	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1994	0.047	5.49	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1995	0.047	5.45	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1996	0.047	5.45	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1997	0.046	5.31	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1998	0.044	5.15	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1999	0.043	5.00	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2000	0.043	5.00	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2001	0.043	4.98	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2002	0.043	4.96	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	0.043	4.96	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2004	0.044	5.14	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2005	0.044	5.05	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2006	0.044	5.06	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2007	0.043	4.93	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2008	0.043	4.95	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2009	0.040	4.69	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2010	0.037	4.26	0.386	1.390	0.037	4.26	0.302	1.087	N/A	N/A	N/A
2011	0.038	4.44	0.386	1.390	0.037	4.25	0.302	1.087	N/A	N/A	N/A
2012	0.036	4.23	0.386	1.390	0.036	4.21	0.302	1.087	N/A	N/A	N/A

Table A-14. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2013	0.035	4.10	0.386	1.390	0.036	4.19	0.302	1.087	N/A	N/A	N/A
2014	0.035	4.11	0.386	1.390	0.036	4.17	0.302	1.087	N/A	N/A	N/A
2015	0.035	4.03	0.386	1.390	0.036	4.15	0.302	1.087	N/A	N/A	N/A
2016	0.034	3.94	0.386	1.390	0.036	4.13	0.302	1.087	N/A	N/A	N/A
2017	0.034	3.97	0.386	1.390	0.036	4.13	0.302	1.087	N/A	N/A	N/A
2018	0.034	3.96	0.386	1.390	0.036	4.11	0.302	1.087	N/A	N/A	N/A
2019	0.034	3.91	0.386	1.390	0.035	4.10	0.302	1.087	N/A	N/A	N/A
2020	0.033	3.80	0.386	1.390	0.035	4.09	0.302	1.087	N/A	N/A	N/A
2021	0.032	3.70	0.386	1.390	0.035	4.08	0.302	1.087	N/A	N/A	N/A
2022	0.031	3.62	0.386	1.390	0.035	4.09	0.302	1.087	N/A	N/A	N/A
2023	0.031	3.54	0.386	1.390	0.035	4.08	0.302	1.087	N/A	N/A	N/A
2024	0.030	3.46	0.386	1.390	0.035	4.08	0.302	1.087	N/A	N/A	N/A
2025	0.029	3.38	0.386	1.390	0.035	4.07	0.302	1.087	N/A	N/A	N/A
2026	0.029	3.30	0.386	1.390	0.035	4.06	0.302	1.087	1.32	0.020	2.343
2027	0.028	3.30	0.386	1.390	0.035	4.05	0.302	1.087	1.32	0.020	2.341
2028	0.028	3.30	0.386	1.390	0.035	4.04	0.302	1.087	1.32	0.020	2.340
2029	0.028	3.30	0.386	1.390	0.035	4.04	0.302	1.087	1.32	0.020	2.339
2030	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.338
2031	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337
2032	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337
2033	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337
2034	0.028	3.30	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337

Table A-14. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2035

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2035	0.028	3.30	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.338

Notes:

[1] Estimated using fuel consumption, energy consumption, and VMT outputs for LDA from EMFAC2021.

[2] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 1991-1992, and 1996 BEVs.

[3] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[4] Fuel economies for MY 2026+ FCEVs were estimated by applying an EER of 2.5 to the gasoline ICEV fuel economy. This EER value was obtained from: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

[5] For the purposes of this analysis, we assumed FCEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[6] Fuel economies for MY 2026+ HEVs were estimated by applying an EER of 1.41 to the gasoline ICEV fuel economy. This EER value was derived from the relative fuel economies of the average MY 2020 HEV and ICEV as obtained from The 2020 EPA Automotive Trends Report. This factor was assumed to remain constant in future years and was used to estimate fuel economies for MY 2026 to 2050 HEVs. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf. Accessed: May 2022.

[7] For the purposes of this analysis, we assumed HEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[8] California Reformulated Gasoline (CaRFG) energy density and the conversion factor from kWh to MJ were obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Constants and Conversion Factors:

CaRFG Energy Density[8]	115.83	MJ/gal
Conversion Factor[8]	3.6	MJ/kWh
FCEV EER[4]	2.5	
HEV EER[6]	1.41	

Abbreviations:

BEV - battery electric vehicle
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
EER - energy economy ratio
EPA - Environmental Protection Agency
EMFAC - EMission FACtor Model
FCEV - fuel cell electric vehicle
gal - gallon
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
kWh - kilowatt hour
LDA - light duty auto
LCFS - Low Carbon Fuel Standard
mi - mile
MJ - megajoule
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle mile traveled

Table A-15. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2035

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
1991	14,887	83,238	5.6	0	0	0	N/A	N/A
1992	12,386	73,866	6.0	0	0	0	N/A	N/A
1993	12,876	82,099	6.4	0	0	0	N/A	N/A
1994	13,908	94,494	6.8	0	0	0	N/A	N/A
1995	17,011	123,543	7.3	0	0	0	N/A	N/A
1996	15,726	121,539	7.7	0	0	0	N/A	N/A
1997	19,249	158,576	8.2	0	0	0	N/A	N/A
1998	21,231	187,010	8.8	0	0	0	N/A	N/A
1999	21,841	205,304	9.4	0	0	0	N/A	N/A
2000	26,428	265,384	10	0	0	0	N/A	N/A
2001	26,524	283,726	11	0	0	0	N/A	N/A
2002	27,790	317,518	11	0	0	0	N/A	N/A
2003	30,887	376,225	12	0	0	0	N/A	N/A
2004	31,459	408,283	13	0	0	0	N/A	N/A
2005	38,743	535,327	14	0	0	0	N/A	N/A
2006	43,503	638,613	15	0	0	0	N/A	N/A
2007	51,445	799,312	16	0	0	0	N/A	N/A
2008	48,196	793,719	16	0	0	0	N/A	N/A
2009	43,832	763,803	17	0	0	0	N/A	N/A
2010	59,373	1,091,266	18	18	21	40	46%	54%
2011	67,186	1,306,293	19	1,068	1,263	2,331	46%	54%
2012	112,410	2,309,971	21	12,690	15,010	27,700	46%	54%
2013	158,581	3,430,157	22	29,703	35,132	64,835	46%	54%
2014	180,829	4,127,429	23	51,909	61,397	113,306	46%	54%
2015	248,911	5,985,259	24	46,760	55,307	102,067	46%	54%
2016	285,862	7,224,095	25	60,473	71,527	131,999	46%	54%

Table A-15. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2035

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2017	332,615	8,781,906	26	182,759	216,166	398,925	46%	54%
2018	327,985	9,068,940	28	196,448	232,358	428,806	46%	54%
2019	314,542	9,122,584	29	168,863	187,404	356,267	47%	53%
2020	281,575	8,538,414	30	199,152	214,033	413,185	48%	52%
2021	366,087	11,609,825	32	303,685	308,004	611,689	50%	50%
2022	459,912	15,239,652	33	459,675	382,142	841,817	55%	45%
2023	491,823	17,014,444	35	530,420	413,878	944,297	56%	44%
2024	528,134	19,062,159	36	606,875	444,549	1,051,424	58%	42%
2025	560,849	21,113,845	38	691,977	474,183	1,166,161	59%	41%
2026	611,788	23,987,125	39	694,031	475,591	1,169,622	59%	41%
2027	641,056	26,164,902	41	756,264	518,236	1,274,500	59%	41%
2028	673,388	28,593,522	42	821,257	562,774	1,384,031	59%	41%
2029	697,604	30,804,673	44	876,678	600,751	1,477,429	59%	41%
2030	724,988	33,263,210	46	939,492	643,795	1,583,287	59%	41%
2031	747,432	35,611,885	48	1,005,719	689,178	1,694,896	59%	41%
2032	766,329	37,880,091	49	1,069,693	733,017	1,802,710	59%	41%
2033	789,556	40,405,518	51	1,141,034	781,903	1,922,937	59%	41%
2034	801,955	42,330,283	53	1,195,570	819,275	2,014,845	59%	41%
2035	727,792	39,498,292	54	1,115,874	764,662	1,880,536	59%	41%

Notes:

[1] Values in shaded cells are zero or not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Obtained from EMFAC2021 data.

Abbreviations:

cVMT - combustion vehicle mile traveled
EMFAC - EMission FACtor Model
eVMT - electric vehicle mile traveled
ICEV - internal combustion engine vehicle
LDA - light duty auto
mi - mile
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle miles traveled

Table A-16. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2035

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
1991	9.48E-03	8.19E-05	5.32E-06	4.59E-08	1.75E-06	1.51E-08	N/A	N/A	N/A	N/A	N/A	N/A
1992	9.48E-03	8.19E-05	5.22E-06	4.51E-08	1.75E-06	1.51E-08	N/A	N/A	N/A	N/A	N/A	N/A
1993	9.48E-03	8.19E-05	5.46E-06	4.71E-08	1.86E-06	1.60E-08	N/A	N/A	N/A	N/A	N/A	N/A
1994	9.48E-03	8.19E-05	5.41E-06	4.67E-08	1.85E-06	1.59E-08	N/A	N/A	N/A	N/A	N/A	N/A
1995	9.48E-03	8.19E-05	5.33E-06	4.60E-08	1.84E-06	1.59E-08	N/A	N/A	N/A	N/A	N/A	N/A
1996	9.48E-03	8.19E-05	6.18E-06	5.33E-08	2.05E-06	1.77E-08	N/A	N/A	N/A	N/A	N/A	N/A
1997	9.48E-03	8.19E-05	5.11E-06	4.41E-08	1.88E-06	1.63E-08	N/A	N/A	N/A	N/A	N/A	N/A
1998	9.48E-03	8.19E-05	4.07E-06	3.51E-08	1.70E-06	1.47E-08	N/A	N/A	N/A	N/A	N/A	N/A
1999	9.48E-03	8.19E-05	3.01E-06	2.59E-08	1.52E-06	1.31E-08	N/A	N/A	N/A	N/A	N/A	N/A
2000	9.48E-03	8.19E-05	1.90E-06	1.64E-08	1.29E-06	1.11E-08	N/A	N/A	N/A	N/A	N/A	N/A
2001	9.48E-03	8.19E-05	1.78E-06	1.53E-08	1.22E-06	1.05E-08	N/A	N/A	N/A	N/A	N/A	N/A
2002	9.48E-03	8.19E-05	1.68E-06	1.45E-08	1.17E-06	1.01E-08	N/A	N/A	N/A	N/A	N/A	N/A
2003	9.48E-03	8.19E-05	1.49E-06	1.29E-08	1.08E-06	9.32E-09	N/A	N/A	N/A	N/A	N/A	N/A
2004	9.48E-03	8.19E-05	6.51E-07	5.62E-09	3.20E-07	2.76E-09	N/A	N/A	N/A	N/A	N/A	N/A
2005	9.48E-03	8.19E-05	5.86E-07	5.06E-09	3.14E-07	2.71E-09	N/A	N/A	N/A	N/A	N/A	N/A
2006	9.48E-03	8.19E-05	4.98E-07	4.30E-09	2.94E-07	2.54E-09	N/A	N/A	N/A	N/A	N/A	N/A
2007	9.48E-03	8.19E-05	5.05E-07	4.36E-09	3.16E-07	2.72E-09	N/A	N/A	N/A	N/A	N/A	N/A
2008	9.48E-03	8.19E-05	4.72E-07	4.07E-09	3.07E-07	2.65E-09	N/A	N/A	N/A	N/A	N/A	N/A
2009	9.48E-03	8.19E-05	4.52E-07	3.90E-09	3.18E-07	2.74E-09	N/A	N/A	N/A	N/A	N/A	N/A
2010	9.48E-03	8.19E-05	4.67E-07	4.03E-09	3.42E-07	2.96E-09	9.48E-03	8.19E-05	4.92E-07	4.25E-09	2.39E-07	2.06E-09
2011	9.48E-03	8.19E-05	4.50E-07	3.88E-09	3.25E-07	2.80E-09	9.48E-03	8.19E-05	4.70E-07	4.06E-09	2.31E-07	1.99E-09
2012	9.48E-03	8.19E-05	4.32E-07	3.73E-09	3.31E-07	2.86E-09	9.48E-03	8.19E-05	4.54E-07	3.92E-09	2.26E-07	1.95E-09
2013	9.48E-03	8.19E-05	4.17E-07	3.60E-09	3.34E-07	2.88E-09	9.48E-03	8.19E-05	4.38E-07	3.78E-09	2.20E-07	1.90E-09
2014	9.48E-03	8.19E-05	4.09E-07	3.53E-09	3.26E-07	2.82E-09	9.48E-03	8.19E-05	4.21E-07	3.64E-09	2.14E-07	1.85E-09
2015	9.48E-03	8.19E-05	3.99E-07	3.45E-09	3.26E-07	2.82E-09	9.48E-03	8.19E-05	4.06E-07	3.50E-09	2.08E-07	1.80E-09
2016	9.48E-03	8.19E-05	4.37E-07	3.77E-09	3.32E-07	2.87E-09	9.48E-03	8.19E-05	3.91E-07	3.38E-09	2.03E-07	1.76E-09
2017	9.48E-03	8.19E-05	4.00E-07	3.45E-09	3.20E-07	2.76E-09	9.48E-03	8.19E-05	3.78E-07	3.27E-09	1.98E-07	1.71E-09
2018	9.48E-03	8.19E-05	3.76E-07	3.25E-09	3.13E-07	2.71E-09	9.48E-03	8.19E-05	3.66E-07	3.16E-09	1.94E-07	1.67E-09
2019	9.48E-03	8.19E-05	3.51E-07	3.03E-09	3.09E-07	2.67E-09	9.48E-03	8.19E-05	3.61E-07	3.12E-09	1.92E-07	1.66E-09

Table A-16. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2035

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2020	9.48E-03	8.19E-05	3.38E-07	2.92E-09	3.10E-07	2.68E-09	9.48E-03	8.19E-05	3.55E-07	3.07E-09	1.90E-07	1.64E-09
2021	9.48E-03	8.19E-05	3.15E-07	2.72E-09	3.07E-07	2.65E-09	9.48E-03	8.19E-05	3.51E-07	3.03E-09	1.89E-07	1.63E-09
2022	9.48E-03	8.19E-05	2.88E-07	2.49E-09	3.01E-07	2.60E-09	9.48E-03	8.19E-05	3.67E-07	3.17E-09	1.95E-07	1.68E-09
2023	9.48E-03	8.19E-05	2.63E-07	2.27E-09	2.93E-07	2.53E-09	9.48E-03	8.19E-05	3.66E-07	3.16E-09	1.94E-07	1.68E-09
2024	9.48E-03	8.19E-05	2.37E-07	2.05E-09	2.84E-07	2.45E-09	9.48E-03	8.19E-05	3.64E-07	3.15E-09	1.94E-07	1.67E-09
2025	9.48E-03	8.19E-05	1.96E-07	1.69E-09	2.64E-07	2.28E-09	9.48E-03	8.19E-05	3.64E-07	3.14E-09	1.94E-07	1.67E-09
2026	9.48E-03	8.19E-05	1.89E-07	1.63E-09	2.59E-07	2.24E-09	9.48E-03	8.19E-05	3.53E-07	3.05E-09	1.90E-07	1.64E-09
2027	9.48E-03	8.19E-05	1.80E-07	1.56E-09	2.48E-07	2.15E-09	9.48E-03	8.19E-05	3.43E-07	2.96E-09	1.86E-07	1.60E-09
2028	9.48E-03	8.19E-05	1.73E-07	1.50E-09	2.38E-07	2.06E-09	9.48E-03	8.19E-05	3.33E-07	2.87E-09	1.82E-07	1.57E-09
2029	9.48E-03	8.19E-05	1.66E-07	1.44E-09	2.28E-07	1.97E-09	9.48E-03	8.19E-05	3.23E-07	2.79E-09	1.78E-07	1.54E-09
2030	9.48E-03	8.19E-05	1.59E-07	1.37E-09	2.17E-07	1.87E-09	9.48E-03	8.19E-05	3.14E-07	2.71E-09	1.75E-07	1.51E-09
2031	9.48E-03	8.19E-05	1.52E-07	1.32E-09	2.06E-07	1.78E-09	9.48E-03	8.19E-05	3.06E-07	2.64E-09	1.72E-07	1.48E-09
2032	9.48E-03	8.19E-05	1.45E-07	1.26E-09	1.94E-07	1.68E-09	9.48E-03	8.19E-05	2.97E-07	2.57E-09	1.68E-07	1.45E-09
2033	9.48E-03	8.19E-05	1.39E-07	1.20E-09	1.82E-07	1.57E-09	9.48E-03	8.19E-05	2.89E-07	2.50E-09	1.65E-07	1.43E-09
2034	9.48E-03	8.19E-05	1.32E-07	1.14E-09	1.70E-07	1.47E-09	9.48E-03	8.19E-05	2.82E-07	2.43E-09	1.62E-07	1.40E-09
2035	9.48E-03	8.19E-05	1.26E-07	1.08E-09	1.57E-07	1.36E-09	9.48E-03	8.19E-05	2.76E-07	2.38E-09	1.60E-07	1.38E-09

Notes:

[1] Values in shaded cells are not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Tailpipe greenhouse gas emission factors were estimated as a ratio of the greenhouse gas emissions (CO_2, CH_4, N_2O) to the gasoline fuel consumption outputs for each model year from EMFAC2021 data.

[3] California Reformulated Gasoline (CaRFG) energy density for the conversion factor from gal to MJ was obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Conversion Factor

CaRFG Energy Density[3]	115.83	MJ/gal

Abbreviations:

CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
gal - gallon
ICEV - internal combustion engine vehicle
LCFS - Low Carbon Fuel Standard
MJ - megajoule
MY - model year
N_2O - Nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-17. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
1996	0.049	5.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1997	0.047	5.47	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1998	0.046	5.29	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1999	0.044	5.12	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2000	0.044	5.11	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2001	0.044	5.08	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2002	0.044	5.06	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	0.044	5.05	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2004	0.045	5.23	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2005	0.044	5.13	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2006	0.044	5.13	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2007	0.043	5.00	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2008	0.043	5.02	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2009	0.041	4.75	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2010	0.037	4.31	0.386	1.390	0.038	4.41	0.302	1.087	N/A	N/A	N/A
2011	0.039	4.49	0.386	1.390	0.038	4.39	0.302	1.087	N/A	N/A	N/A
2012	0.037	4.27	0.386	1.390	0.037	4.34	0.302	1.087	N/A	N/A	N/A
2013	0.036	4.14	0.386	1.390	0.037	4.30	0.302	1.087	N/A	N/A	N/A
2014	0.036	4.15	0.386	1.390	0.037	4.27	0.302	1.087	N/A	N/A	N/A
2015	0.035	4.06	0.386	1.390	0.037	4.25	0.302	1.087	N/A	N/A	N/A
2016	0.034	3.97	0.386	1.390	0.036	4.22	0.302	1.087	N/A	N/A	N/A
2017	0.035	4.00	0.386	1.390	0.036	4.21	0.302	1.087	N/A	N/A	N/A
2018	0.034	3.99	0.386	1.390	0.036	4.19	0.302	1.087	N/A	N/A	N/A
2019	0.034	3.94	0.386	1.390	0.036	4.17	0.302	1.087	N/A	N/A	N/A

Table A-17. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1] (gal of gasoline/ mi)	Internal Combustion Engine Vehicle[1] (MJ of gasoline/ mi)	Battery Electric Vehicle[1,2] (kWh of electricity/ mi)	Battery Electric Vehicle[1,2] (MJ of electricity/ mi)	Plug-in Hybrid Electric Vehicle[1,3] (gal of gasoline/ mi)	Plug-in Hybrid Electric Vehicle[1,3] (MJ of gasoline/ mi)	Plug-in Hybrid Electric Vehicle[1,3] (kWh of electricity/ mi)	Plug-in Hybrid Electric Vehicle[1,3] (MJ of electricity/ mi)	Fuel Cell Electric Vehicle[4,5] (MJ of hydrogen/ mi)	Hybrid Electric Vehicle[6,7] (gal of gasoline/ mi)	Hybrid Electric Vehicle[6,7] (MJ of gasoline /mi)
2020	0.033	3.82	0.386	1.390	0.036	4.15	0.302	1.087	N/A	N/A	N/A
2021	0.032	3.72	0.386	1.390	0.036	4.14	0.302	1.087	N/A	N/A	N/A
2022	0.031	3.64	0.386	1.390	0.036	4.15	0.302	1.087	N/A	N/A	N/A
2023	0.031	3.55	0.386	1.390	0.036	4.14	0.302	1.087	N/A	N/A	N/A
2024	0.030	3.47	0.386	1.390	0.036	4.13	0.302	1.087	N/A	N/A	N/A
2025	0.029	3.39	0.386	1.390	0.036	4.13	0.302	1.087	N/A	N/A	N/A
2026	0.029	3.32	0.386	1.390	0.035	4.11	0.302	1.087	1.33	0.020	2.353
2027	0.029	3.31	0.386	1.390	0.035	4.10	0.302	1.087	1.33	0.020	2.351
2028	0.029	3.31	0.386	1.390	0.035	4.09	0.302	1.087	1.32	0.020	2.349
2029	0.029	3.31	0.386	1.390	0.035	4.08	0.302	1.087	1.32	0.020	2.347
2030	0.029	3.31	0.386	1.390	0.035	4.07	0.302	1.087	1.32	0.020	2.345
2031	0.029	3.30	0.386	1.390	0.035	4.06	0.302	1.087	1.32	0.020	2.343
2032	0.028	3.30	0.386	1.390	0.035	4.06	0.302	1.087	1.32	0.020	2.341
2033	0.028	3.30	0.386	1.390	0.035	4.05	0.302	1.087	1.32	0.020	2.340
2034	0.028	3.30	0.386	1.390	0.035	4.04	0.302	1.087	1.32	0.020	2.339
2035	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.338
2036	0.028	3.29	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.337
2037	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337
2038	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337
2039	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.338

Table A-17. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2040	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.339

Notes:

[1] Estimated using fuel consumption, energy consumption, and VMT outputs for LDA from EMFAC2021.

[2] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 1996 BEVs.

[3] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[4] Fuel economies for MY 2026+ FCEVs were estimated by applying an EER of 2.5 to the gasoline ICEV fuel economy. This EER value was obtained from: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

[5] For the purposes of this analysis, we assumed FCEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[6] Fuel economies for MY 2026+ HEVs were estimated by applying an EER of 1.41 to the gasoline ICEV fuel economy. This EER value was derived from the relative fuel economies of the average MY 2020 HEV and ICEV as obtained from The 2020 EPA Automotive Trends Report. This factor was assumed to remain constant in future years and was used to estimate fuel economies for MY 2026 to 2050 HEVs. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf. Accessed: May 2022.

[7] For the purposes of this analysis, we assumed HEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[8] California Reformulated Gasoline (CaRFG) energy density and the conversion factor from kWh to MJ were obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Constants and Conversion Factors:

CaRFG Energy Density[8]	115.83	MJ/gal
Conversion Factor[8]	3.6	MJ/kWh
FCEV EER[4]	2.5	
HEV EER[6]	1.41	

Abbreviations:

BEV - battery electric vehicle
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
EER - energy economy ratio
EPA - Environmental Protection Agency
EMFAC - EMission FACtor Model
FCEV - fuel cell electric vehicle
gal - gallon
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
kWh - kilowatt hour
LDA - light duty auto
LCFS - Low Carbon Fuel Standard
mi - mile
MJ - megajoule
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle mile traveled

Table A-18. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2040

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
1996	13,224	72,312	5.5	0	0	0	N/A	N/A
1997	15,957	92,752	5.8	0	0	0	N/A	N/A
1998	17,428	108,316	6.2	0	0	0	N/A	N/A
1999	17,981	119,531	6.6	0	0	0	N/A	N/A
2000	21,212	151,161	7.1	0	0	0	N/A	N/A
2001	20,869	159,156	7.6	0	0	0	N/A	N/A
2002	20,957	171,479	8.2	0	0	0	N/A	N/A
2003	22,226	195,022	8.8	0	0	0	N/A	N/A
2004	21,228	199,248	9.4	0	0	0	N/A	N/A
2005	24,808	249,161	10	0	0	0	N/A	N/A
2006	25,795	276,191	11	0	0	0	N/A	N/A
2007	28,657	326,097	11	0	0	0	N/A	N/A
2008	24,894	301,500	12	0	0	0	N/A	N/A
2009	20,958	270,212	13	0	0	0	N/A	N/A
2010	26,447	361,660	14	6.0	7.1	13	46%	54%
2011	28,341	412,245	15	337	399	736	46%	54%
2012	44,963	695,148	15	3,820	4,518	8,337	46%	54%
2013	60,869	996,499	16	8,631	10,209	18,841	46%	54%
2014	67,874	1,179,323	17	14,836	17,547	32,383	46%	54%
2015	93,376	1,719,251	18	13,435	15,891	29,326	46%	54%
2016	109,366	2,128,788	19	17,821	21,079	38,900	46%	54%
2017	132,055	2,699,673	20	56,183	66,452	122,635	46%	54%
2018	137,285	2,954,566	22	64,013	75,714	139,728	46%	54%
2019	141,083	3,200,331	23	59,257	65,763	125,020	47%	53%
2020	135,652	3,231,000	24	75,437	81,073	156,509	48%	52%
2021	189,590	4,743,853	25	124,202	125,969	250,170	50%	50%
2022	253,809	6,663,799	26	201,169	167,239	368,408	55%	45%
2023	291,017	8,008,938	28	249,865	194,966	444,831	56%	44%
2024	329,600	9,500,130	29	302,663	221,707	524,369	58%	42%
2025	371,783	11,216,709	30	367,851	252,073	619,924	59%	41%

Table A-18. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2040

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2026	424,233	13,376,857	32	387,238	265,358	652,596	59%	41%
2027	468,739	15,435,541	33	446,370	305,879	752,249	59%	41%
2028	508,037	17,458,838	34	501,706	343,798	845,504	59%	41%
2029	549,764	19,702,986	36	561,028	384,449	945,477	59%	41%
2030	583,369	21,789,367	37	615,754	421,951	1,037,705	59%	41%
2031	621,402	24,173,776	39	683,067	468,078	1,151,145	59%	41%
2032	652,332	26,418,301	40	746,398	511,476	1,257,874	59%	41%
2033	686,690	28,932,714	42	817,336	560,087	1,377,423	59%	41%
2034	712,396	31,215,626	44	881,714	604,202	1,485,917	59%	41%
2035	742,681	33,813,271	46	954,983	654,410	1,609,393	59%	41%
2036	764,974	36,168,195	47	1,021,378	699,908	1,721,285	59%	41%
2037	783,440	38,427,887	49	1,085,103	743,576	1,828,679	59%	41%
2038	805,975	40,923,252	51	1,155,587	791,876	1,947,462	59%	41%
2039	817,118	42,781,561	52	1,208,239	827,956	2,036,195	59%	41%
2040	739,955	39,816,664	54	1,124,791	770,773	1,895,564	59%	41%

Notes:

[1] Values in shaded cells are zero or not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Obtained from EMFAC2021 data.

Abbreviations:

cVMT - combustion vehicle mile traveled
EMFAC - EMission FACtor Model
eVMT - electric vehicle mile traveled
ICEV - internal combustion engine vehicle
LDA - light duty auto
mi - mile
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle miles traveled

Table A-19. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2040

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
1996	9.48E-03	8.19E-05	6.93E-06	5.98E-08	2.10E-06	1.81E-08	N/A	N/A	N/A	N/A	N/A	N/A
1997	9.48E-03	8.19E-05	5.78E-06	4.99E-08	1.94E-06	1.68E-08	N/A	N/A	N/A	N/A	N/A	N/A
1998	9.48E-03	8.19E-05	4.63E-06	4.00E-08	1.77E-06	1.53E-08	N/A	N/A	N/A	N/A	N/A	N/A
1999	9.48E-03	8.19E-05	3.46E-06	2.99E-08	1.60E-06	1.38E-08	N/A	N/A	N/A	N/A	N/A	N/A
2000	9.48E-03	8.19E-05	2.23E-06	1.92E-08	1.37E-06	1.18E-08	N/A	N/A	N/A	N/A	N/A	N/A
2001	9.48E-03	8.19E-05	2.08E-06	1.79E-08	1.30E-06	1.12E-08	N/A	N/A	N/A	N/A	N/A	N/A
2002	9.48E-03	8.19E-05	1.96E-06	1.70E-08	1.25E-06	1.08E-08	N/A	N/A	N/A	N/A	N/A	N/A
2003	9.48E-03	8.19E-05	1.74E-06	1.50E-08	1.15E-06	9.89E-09	N/A	N/A	N/A	N/A	N/A	N/A
2004	9.48E-03	8.19E-05	7.73E-07	6.67E-09	3.49E-07	3.01E-09	N/A	N/A	N/A	N/A	N/A	N/A
2005	9.48E-03	8.19E-05	6.93E-07	5.98E-09	3.42E-07	2.95E-09	N/A	N/A	N/A	N/A	N/A	N/A
2006	9.48E-03	8.19E-05	5.88E-07	5.08E-09	3.22E-07	2.78E-09	N/A	N/A	N/A	N/A	N/A	N/A
2007	9.48E-03	8.19E-05	5.95E-07	5.13E-09	3.45E-07	2.98E-09	N/A	N/A	N/A	N/A	N/A	N/A
2008	9.48E-03	8.19E-05	5.55E-07	4.79E-09	3.35E-07	2.89E-09	N/A	N/A	N/A	N/A	N/A	N/A
2009	9.48E-03	8.19E-05	5.30E-07	4.57E-09	3.47E-07	2.99E-09	N/A	N/A	N/A	N/A	N/A	N/A
2010	9.48E-03	8.19E-05	5.46E-07	4.71E-09	3.74E-07	3.23E-09	9.48E-03	8.19E-05	6.07E-07	5.24E-09	2.77E-07	2.39E-09
2011	9.48E-03	8.19E-05	5.26E-07	4.54E-09	3.54E-07	3.06E-09	9.48E-03	8.19E-05	5.78E-07	4.99E-09	2.67E-07	2.31E-09
2012	9.48E-03	8.19E-05	5.05E-07	4.36E-09	3.62E-07	3.13E-09	9.48E-03	8.19E-05	5.57E-07	4.81E-09	2.61E-07	2.25E-09
2013	9.48E-03	8.19E-05	4.86E-07	4.20E-09	3.66E-07	3.16E-09	9.48E-03	8.19E-05	5.36E-07	4.63E-09	2.54E-07	2.19E-09
2014	9.48E-03	8.19E-05	4.77E-07	4.12E-09	3.58E-07	3.09E-09	9.48E-03	8.19E-05	5.13E-07	4.43E-09	2.46E-07	2.13E-09
2015	9.48E-03	8.19E-05	4.66E-07	4.02E-09	3.59E-07	3.10E-09	9.48E-03	8.19E-05	4.93E-07	4.25E-09	2.39E-07	2.06E-09
2016	9.48E-03	8.19E-05	5.11E-07	4.41E-09	3.66E-07	3.16E-09	9.48E-03	8.19E-05	4.74E-07	4.09E-09	2.33E-07	2.01E-09
2017	9.48E-03	8.19E-05	4.67E-07	4.03E-09	3.54E-07	3.05E-09	9.48E-03	8.19E-05	4.56E-07	3.94E-09	2.26E-07	1.95E-09
2018	9.48E-03	8.19E-05	4.40E-07	3.80E-09	3.48E-07	3.00E-09	9.48E-03	8.19E-05	4.39E-07	3.79E-09	2.21E-07	1.90E-09
2019	9.48E-03	8.19E-05	4.11E-07	3.54E-09	3.46E-07	2.98E-09	9.48E-03	8.19E-05	4.33E-07	3.74E-09	2.18E-07	1.88E-09
2020	9.48E-03	8.19E-05	3.96E-07	3.42E-09	3.49E-07	3.01E-09	9.48E-03	8.19E-05	4.24E-07	3.66E-09	2.15E-07	1.86E-09
2021	9.48E-03	8.19E-05	3.70E-07	3.19E-09	3.48E-07	3.00E-09	9.48E-03	8.19E-05	4.18E-07	3.61E-09	2.13E-07	1.84E-09
2022	9.48E-03	8.19E-05	3.38E-07	2.92E-09	3.44E-07	2.97E-09	9.48E-03	8.19E-05	4.36E-07	3.77E-09	2.20E-07	1.90E-09
2023	9.48E-03	8.19E-05	3.10E-07	2.68E-09	3.37E-07	2.91E-09	9.48E-03	8.19E-05	4.33E-07	3.74E-09	2.19E-07	1.89E-09
2024	9.48E-03	8.19E-05	2.80E-07	2.42E-09	3.29E-07	2.84E-09	9.48E-03	8.19E-05	4.30E-07	3.72E-09	2.18E-07	1.88E-09
2025	9.48E-03	8.19E-05	2.32E-07	2.01E-09	3.09E-07	2.67E-09	9.48E-03	8.19E-05	4.29E-07	3.70E-09	2.17E-07	1.88E-09

Table A-19. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2040

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2026	9.48E-03	8.19E-05	2.26E-07	1.95E-09	3.06E-07	2.64E-09	9.48E-03	8.19E-05	4.15E-07	3.59E-09	2.13E-07	1.84E-09
2027	9.48E-03	8.19E-05	2.16E-07	1.87E-09	2.96E-07	2.56E-09	9.48E-03	8.19E-05	4.02E-07	3.47E-09	2.08E-07	1.79E-09
2028	9.48E-03	8.19E-05	2.09E-07	1.81E-09	2.87E-07	2.48E-09	9.48E-03	8.19E-05	3.90E-07	3.36E-09	2.03E-07	1.75E-09
2029	9.48E-03	8.19E-05	2.02E-07	1.75E-09	2.78E-07	2.40E-09	9.48E-03	8.19E-05	3.77E-07	3.26E-09	1.99E-07	1.72E-09
2030	9.48E-03	8.19E-05	1.95E-07	1.68E-09	2.68E-07	2.32E-09	9.48E-03	8.19E-05	3.66E-07	3.16E-09	1.94E-07	1.68E-09
2031	9.48E-03	8.19E-05	1.88E-07	1.62E-09	2.59E-07	2.23E-09	9.48E-03	8.19E-05	3.55E-07	3.06E-09	1.90E-07	1.64E-09
2032	9.48E-03	8.19E-05	1.81E-07	1.56E-09	2.49E-07	2.15E-09	9.48E-03	8.19E-05	3.45E-07	2.97E-09	1.86E-07	1.61E-09
2033	9.48E-03	8.19E-05	1.74E-07	1.50E-09	2.39E-07	2.06E-09	9.48E-03	8.19E-05	3.35E-07	2.89E-09	1.83E-07	1.58E-09
2034	9.48E-03	8.19E-05	1.67E-07	1.44E-09	2.28E-07	1.97E-09	9.48E-03	8.19E-05	3.25E-07	2.81E-09	1.79E-07	1.55E-09
2035	9.48E-03	8.19E-05	1.60E-07	1.38E-09	2.17E-07	1.88E-09	9.48E-03	8.19E-05	3.16E-07	2.73E-09	1.76E-07	1.52E-09
2036	9.48E-03	8.19E-05	1.53E-07	1.32E-09	2.06E-07	1.78E-09	9.48E-03	8.19E-05	3.07E-07	2.65E-09	1.72E-07	1.49E-09
2037	9.48E-03	8.19E-05	1.46E-07	1.26E-09	1.95E-07	1.68E-09	9.48E-03	8.19E-05	2.99E-07	2.58E-09	1.69E-07	1.46E-09
2038	9.48E-03	8.19E-05	1.39E-07	1.20E-09	1.83E-07	1.58E-09	9.48E-03	8.19E-05	2.91E-07	2.51E-09	1.66E-07	1.43E-09
2039	9.48E-03	8.19E-05	1.33E-07	1.15E-09	1.70E-07	1.47E-09	9.48E-03	8.19E-05	2.83E-07	2.45E-09	1.63E-07	1.41E-09
2040	9.48E-03	8.19E-05	1.26E-07	1.09E-09	1.58E-07	1.36E-09	9.48E-03	8.19E-05	2.77E-07	2.39E-09	1.60E-07	1.38E-09

Notes:

[1] Values in shaded cells are not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Tailpipe greenhouse gas emission factors were estimated as a ratio of the greenhouse gas emissions (CO_2, CH_4, N_2O) to the gasoline fuel consumption outputs for each model year from EMFAC2021 data.

[3] California Reformulated Gasoline (CaRFG) energy density for the conversion factor from gal to MJ was obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Conversion Factor

CaRFG Energy Density[3]	115.83	MJ/gal

Abbreviations:

CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
gal - gallon
ICEV - internal combustion engine vehicle
LCFS - Low Carbon Fuel Standard
MJ - megajoule
MY - model year
N_2O - Nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-20. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2002	0.045	5.18	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	0.045	5.17	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2004	0.046	5.34	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2005	0.045	5.23	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2006	0.045	5.23	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2007	0.044	5.09	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2008	0.044	5.10	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2009	0.042	4.82	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2010	0.038	4.38	0.386	1.390	0.040	4.61	0.302	1.087	N/A	N/A	N/A
2011	0.039	4.55	0.386	1.390	0.040	4.59	0.302	1.087	N/A	N/A	N/A
2012	0.037	4.33	0.386	1.390	0.039	4.51	0.302	1.087	N/A	N/A	N/A
2013	0.036	4.19	0.386	1.390	0.038	4.46	0.302	1.087	N/A	N/A	N/A
2014	0.036	4.20	0.386	1.390	0.038	4.42	0.302	1.087	N/A	N/A	N/A
2015	0.035	4.11	0.386	1.390	0.038	4.37	0.302	1.087	N/A	N/A	N/A
2016	0.035	4.01	0.386	1.390	0.037	4.33	0.302	1.087	N/A	N/A	N/A
2017	0.035	4.04	0.386	1.390	0.037	4.32	0.302	1.087	N/A	N/A	N/A
2018	0.035	4.03	0.386	1.390	0.037	4.29	0.302	1.087	N/A	N/A	N/A
2019	0.034	3.97	0.386	1.390	0.037	4.27	0.302	1.087	N/A	N/A	N/A
2020	0.033	3.85	0.386	1.390	0.037	4.24	0.302	1.087	N/A	N/A	N/A
2021	0.032	3.75	0.386	1.390	0.036	4.22	0.302	1.087	N/A	N/A	N/A
2022	0.032	3.66	0.386	1.390	0.037	4.23	0.302	1.087	N/A	N/A	N/A
2023	0.031	3.58	0.386	1.390	0.036	4.22	0.302	1.087	N/A	N/A	N/A
2024	0.030	3.50	0.386	1.390	0.036	4.20	0.302	1.087	N/A	N/A	N/A
2025	0.029	3.41	0.386	1.390	0.036	4.19	0.302	1.087	N/A	N/A	N/A

Table A-20. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2026	0.029	3.34	0.386	1.390	0.036	4.17	0.302	1.087	1.33	0.020	2.366
2027	0.029	3.33	0.386	1.390	0.036	4.16	0.302	1.087	1.33	0.020	2.363
2028	0.029	3.33	0.386	1.390	0.036	4.14	0.302	1.087	1.33	0.020	2.360
2029	0.029	3.32	0.386	1.390	0.036	4.13	0.302	1.087	1.33	0.020	2.358
2030	0.029	3.32	0.386	1.390	0.036	4.12	0.302	1.087	1.33	0.020	2.355
2031	0.029	3.32	0.386	1.390	0.035	4.11	0.302	1.087	1.33	0.020	2.353
2032	0.029	3.31	0.386	1.390	0.035	4.10	0.302	1.087	1.33	0.020	2.351
2033	0.029	3.31	0.386	1.390	0.035	4.09	0.302	1.087	1.32	0.020	2.348
2034	0.029	3.31	0.386	1.390	0.035	4.08	0.302	1.087	1.32	0.020	2.346
2035	0.029	3.31	0.386	1.390	0.035	4.07	0.302	1.087	1.32	0.020	2.344
2036	0.029	3.30	0.386	1.390	0.035	4.06	0.302	1.087	1.32	0.020	2.342
2037	0.028	3.30	0.386	1.390	0.035	4.05	0.302	1.087	1.32	0.020	2.340
2038	0.028	3.30	0.386	1.390	0.035	4.05	0.302	1.087	1.32	0.020	2.339
2039	0.028	3.30	0.386	1.390	0.035	4.04	0.302	1.087	1.32	0.020	2.338
2040	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.337
2041	0.028	3.29	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.337
2042	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.336
2043	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.336
2044	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337

Table A-20. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2045

	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
Model Year[1]	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2045	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.338

Notes:

[1] Estimated using fuel consumption, energy consumption, and VMT outputs for LDA from EMFAC2021.

[2] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[3] Fuel economies for MY 2026+ FCEVs were estimated by applying an EER of 2.5 to the gasoline ICEV fuel economy. This EER value was obtained from: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

[4] For the purposes of this analysis, we assumed FCEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[5] Fuel economies for MY 2026+ HEVs were estimated by applying an EER of 1.41 to the gasoline ICEV fuel economy. This EER value was derived from the relative fuel economies of the average MY 2020 HEV and ICEV as obtained from The 2020 EPA Automotive Trends Report. This factor was assumed to remain constant in future years and was used to estimate fuel economies for MY 2026 to 2050 HEVs. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf. Accessed: May 2022.

[6] For the purposes of this analysis, we assumed HEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[7] California Reformulated Gasoline (CaRFG) energy density and the conversion factor from kWh to MJ were obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Constants and Conversion Factors:

CaRFG Energy Density[8]	115.83	MJ/gal
Conversion Factor[8]	3.6	MJ/kWh
FCEV EER[4]	2.5	
HEV EER[6]	1.41	

Abbreviations:

BEV - battery electric vehicle
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
EER - energy economy ratio
EPA - Environmental Protection Agency
EMFAC - EMission FACtor Model
FCEV - fuel cell electric vehicle
gal - gallon
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
kWh - kilowatt hour
LDA - light duty auto
LCFS - Low Carbon Fuel Standard
mi - mile
MJ - megajoule
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle mile traveled

Table A-21. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2045

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2001	17,581	94,583	5.4	0	0	0	N/A	N/A
2002	17,396	100,344	5.8	0	0	0	N/A	N/A
2003	18,261	112,979	6.2	0	0	0	N/A	N/A
2004	17,485	116,203	6.6	0	0	0	N/A	N/A
2005	19,931	142,143	7.1	0	0	0	N/A	N/A
2006	20,294	155,022	7.6	0	0	0	N/A	N/A
2007	21,610	176,019	8.1	0	0	0	N/A	N/A
2008	17,913	156,259	8.7	0	0	0	N/A	N/A
2009	14,142	131,698	9.3	0	0	0	N/A	N/A
2010	16,923	167,962	10	2.8	3.3	6.1	46%	54%
2011	16,799	177,929	11	146	172	318	46%	54%
2012	25,037	283,138	11	1,556	1,841	3,397	46%	54%
2013	31,446	377,741	12	3,274	3,873	7,147	46%	54%
2014	32,442	416,070	13	5,238	6,195	11,432	46%	54%
2015	41,547	568,350	14	4,445	5,257	9,702	46%	54%
2016	46,072	670,045	15	5,614	6,641	12,255	46%	54%
2017	52,700	809,463	15	16,866	19,949	36,816	46%	54%
2018	52,549	854,813	16	18,555	21,947	40,502	46%	54%
2019	52,919	912,275	17	16,914	18,772	35,686	47%	53%
2020	51,080	928,787	18	21,737	23,361	45,098	48%	52%
2021	72,808	1,399,143	19	36,713	37,235	73,949	50%	50%
2022	101,322	2,054,388	20	62,144	51,662	113,806	55%	45%
2023	122,476	2,616,978	21	81,791	63,820	145,610	56%	44%
2024	148,333	3,336,228	22	106,456	77,981	184,437	58%	42%
2025	179,162	4,238,753	24	139,197	95,386	234,583	59%	41%
2026	219,761	5,458,500	25	158,172	108,389	266,560	59%	41%
2027	258,741	6,740,091	26	195,082	133,681	328,763	59%	41%
2028	300,679	8,206,602	27	236,011	161,729	397,740	59%	41%

Table A-21. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2045

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2029	343,168	9,805,520	29	279,399	191,461	470,860	59%	41%
2030	386,794	11,559,183	30	326,869	223,990	550,859	59%	41%
2031	431,003	13,462,108	31	380,619	260,822	641,441	59%	41%
2032	477,078	15,562,560	33	439,942	301,474	741,415	59%	41%
2033	518,165	17,640,250	34	498,612	341,678	840,290	59%	41%
2034	561,504	19,936,064	36	563,435	386,099	949,533	59%	41%
2035	597,713	22,117,686	37	625,020	428,301	1,053,321	59%	41%
2036	636,105	24,516,409	39	692,733	474,702	1,167,435	59%	41%
2037	667,180	26,769,914	40	756,313	518,270	1,274,583	59%	41%
2038	701,654	29,290,747	42	827,427	567,001	1,394,428	59%	41%
2039	727,252	31,573,998	43	891,808	611,119	1,502,927	59%	41%
2040	757,391	34,167,150	45	964,943	661,235	1,626,178	59%	41%
2041	779,333	36,510,552	47	1,031,005	706,505	1,737,509	59%	41%
2042	797,208	38,746,345	49	1,094,047	749,705	1,843,752	59%	41%
2043	818,902	41,198,116	50	1,163,291	797,155	1,960,447	59%	41%
2044	828,649	42,981,664	52	1,213,825	831,784	2,045,609	59%	41%
2045	748,769	39,907,881	53	1,127,300	772,492	1,899,793	59%	41%

Notes:

[1] Values in shaded cells are zero or not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Obtained from EMFAC2021 data.

Abbreviations:

cVMT - combustion vehicle mile traveled
EMFAC - EMission FACtor Model
eVMT - electric vehicle mile traveled
ICEV - internal combustion engine vehicle
LDA - light duty auto
mi - mile
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle miles traveled

Table A-22. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2045

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2001	9.48E-03	8.19E-05	2.42E-06	2.09E-08	1.38E-06	1.19E-08	N/A	N/A	N/A	N/A	N/A	N/A
2002	9.48E-03	8.19E-05	2.30E-06	1.98E-08	1.33E-06	1.15E-08	N/A	N/A	N/A	N/A	N/A	N/A
2003	9.48E-03	8.19E-05	2.04E-06	1.76E-08	1.22E-06	1.06E-08	N/A	N/A	N/A	N/A	N/A	N/A
2004	9.48E-03	8.19E-05	9.22E-07	7.96E-09	3.84E-07	3.31E-09	N/A	N/A	N/A	N/A	N/A	N/A
2005	9.48E-03	8.19E-05	8.27E-07	7.14E-09	3.77E-07	3.25E-09	N/A	N/A	N/A	N/A	N/A	N/A
2006	9.48E-03	8.19E-05	7.01E-07	6.05E-09	3.55E-07	3.07E-09	N/A	N/A	N/A	N/A	N/A	N/A
2007	9.48E-03	8.19E-05	7.08E-07	6.12E-09	3.81E-07	3.29E-09	N/A	N/A	N/A	N/A	N/A	N/A
2008	9.48E-03	8.19E-05	6.59E-07	5.69E-09	3.69E-07	3.19E-09	N/A	N/A	N/A	N/A	N/A	N/A
2009	9.48E-03	8.19E-05	6.28E-07	5.43E-09	3.83E-07	3.30E-09	N/A	N/A	N/A	N/A	N/A	N/A
2010	9.48E-03	8.19E-05	6.45E-07	5.57E-09	4.12E-07	3.56E-09	9.48E-03	8.19E-05	7.57E-07	6.54E-09	3.25E-07	2.80E-09
2011	9.48E-03	8.19E-05	6.21E-07	5.36E-09	3.90E-07	3.37E-09	9.48E-03	8.19E-05	7.19E-07	6.21E-09	3.13E-07	2.70E-09
2012	9.48E-03	8.19E-05	5.95E-07	5.14E-09	3.98E-07	3.43E-09	9.48E-03	8.19E-05	6.94E-07	5.99E-09	3.05E-07	2.63E-09
2013	9.48E-03	8.19E-05	5.72E-07	4.94E-09	4.01E-07	3.46E-09	9.48E-03	8.19E-05	6.68E-07	5.76E-09	2.97E-07	2.57E-09
2014	9.48E-03	8.19E-05	5.59E-07	4.83E-09	3.92E-07	3.39E-09	9.48E-03	8.19E-05	6.38E-07	5.51E-09	2.88E-07	2.48E-09
2015	9.48E-03	8.19E-05	5.45E-07	4.71E-09	3.93E-07	3.39E-09	9.48E-03	8.19E-05	6.10E-07	5.27E-09	2.79E-07	2.41E-09
2016	9.48E-03	8.19E-05	5.97E-07	5.16E-09	4.00E-07	3.45E-09	9.48E-03	8.19E-05	5.85E-07	5.05E-09	2.71E-07	2.34E-09
2017	9.48E-03	8.19E-05	5.45E-07	4.71E-09	3.87E-07	3.34E-09	9.48E-03	8.19E-05	5.61E-07	4.85E-09	2.63E-07	2.27E-09
2018	9.48E-03	8.19E-05	5.13E-07	4.43E-09	3.82E-07	3.30E-09	9.48E-03	8.19E-05	5.38E-07	4.65E-09	2.55E-07	2.20E-09
2019	9.48E-03	8.19E-05	4.79E-07	4.14E-09	3.81E-07	3.29E-09	9.48E-03	8.19E-05	5.29E-07	4.57E-09	2.52E-07	2.17E-09
2020	9.48E-03	8.19E-05	4.63E-07	4.00E-09	3.86E-07	3.33E-09	9.48E-03	8.19E-05	5.17E-07	4.46E-09	2.48E-07	2.14E-09
2021	9.48E-03	8.19E-05	4.32E-07	3.73E-09	3.86E-07	3.34E-09	9.48E-03	8.19E-05	5.08E-07	4.39E-09	2.45E-07	2.11E-09
2022	9.48E-03	8.19E-05	3.95E-07	3.41E-09	3.84E-07	3.31E-09	9.48E-03	8.19E-05	5.28E-07	4.56E-09	2.52E-07	2.18E-09
2023	9.48E-03	8.19E-05	3.62E-07	3.13E-09	3.79E-07	3.27E-09	9.48E-03	8.19E-05	5.23E-07	4.51E-09	2.50E-07	2.16E-09
2024	9.48E-03	8.19E-05	3.28E-07	2.83E-09	3.71E-07	3.20E-09	9.48E-03	8.19E-05	5.18E-07	4.47E-09	2.49E-07	2.15E-09
2025	9.48E-03	8.19E-05	2.72E-07	2.35E-09	3.51E-07	3.03E-09	9.48E-03	8.19E-05	5.14E-07	4.44E-09	2.48E-07	2.14E-09
2026	9.48E-03	8.19E-05	2.65E-07	2.28E-09	3.48E-07	3.01E-09	9.48E-03	8.19E-05	4.97E-07	4.29E-09	2.42E-07	2.09E-09
2027	9.48E-03	8.19E-05	2.55E-07	2.20E-09	3.39E-07	2.93E-09	9.48E-03	8.19E-05	4.79E-07	4.14E-09	2.36E-07	2.03E-09
2028	9.48E-03	8.19E-05	2.47E-07	2.13E-09	3.31E-07	2.86E-09	9.48E-03	8.19E-05	4.63E-07	4.00E-09	2.30E-07	1.98E-09

Table A-22. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2045

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2029	9.48E-03	8.19E-05	2.39E-07	2.07E-09	3.23E-07	2.79E-09	9.48E-03	8.19E-05	4.48E-07	3.86E-09	2.24E-07	1.94E-09
2030	9.48E-03	8.19E-05	2.32E-07	2.00E-09	3.14E-07	2.71E-09	9.48E-03	8.19E-05	4.33E-07	3.74E-09	2.19E-07	1.89E-09
2031	9.48E-03	8.19E-05	2.25E-07	1.94E-09	3.06E-07	2.64E-09	9.48E-03	8.19E-05	4.19E-07	3.62E-09	2.14E-07	1.85E-09
2032	9.48E-03	8.19E-05	2.17E-07	1.88E-09	2.97E-07	2.56E-09	9.48E-03	8.19E-05	4.05E-07	3.50E-09	2.09E-07	1.80E-09
2033	9.48E-03	8.19E-05	2.10E-07	1.82E-09	2.88E-07	2.49E-09	9.48E-03	8.19E-05	3.93E-07	3.39E-09	2.04E-07	1.76E-09
2034	9.48E-03	8.19E-05	2.03E-07	1.75E-09	2.79E-07	2.41E-09	9.48E-03	8.19E-05	3.80E-07	3.28E-09	2.00E-07	1.73E-09
2035	9.48E-03	8.19E-05	1.96E-07	1.69E-09	2.69E-07	2.32E-09	9.48E-03	8.19E-05	3.69E-07	3.18E-09	1.96E-07	1.69E-09
2036	9.48E-03	8.19E-05	1.89E-07	1.63E-09	2.60E-07	2.24E-09	9.48E-03	8.19E-05	3.58E-07	3.09E-09	1.91E-07	1.65E-09
2037	9.48E-03	8.19E-05	1.82E-07	1.57E-09	2.50E-07	2.16E-09	9.48E-03	8.19E-05	3.47E-07	3.00E-09	1.87E-07	1.62E-09
2038	9.48E-03	8.19E-05	1.75E-07	1.51E-09	2.39E-07	2.07E-09	9.48E-03	8.19E-05	3.37E-07	2.91E-09	1.84E-07	1.59E-09
2039	9.48E-03	8.19E-05	1.68E-07	1.45E-09	2.29E-07	1.98E-09	9.48E-03	8.19E-05	3.27E-07	2.83E-09	1.80E-07	1.55E-09
2040	9.48E-03	8.19E-05	1.61E-07	1.39E-09	2.18E-07	1.88E-09	9.48E-03	8.19E-05	3.18E-07	2.75E-09	1.77E-07	1.52E-09
2041	9.48E-03	8.19E-05	1.54E-07	1.33E-09	2.07E-07	1.78E-09	9.48E-03	8.19E-05	3.09E-07	2.67E-09	1.73E-07	1.49E-09
2042	9.48E-03	8.19E-05	1.47E-07	1.27E-09	1.95E-07	1.68E-09	9.48E-03	8.19E-05	3.01E-07	2.60E-09	1.70E-07	1.47E-09
2043	9.48E-03	8.19E-05	1.40E-07	1.21E-09	1.83E-07	1.58E-09	9.48E-03	8.19E-05	2.93E-07	2.53E-09	1.67E-07	1.44E-09
2044	9.48E-03	8.19E-05	1.34E-07	1.15E-09	1.71E-07	1.48E-09	9.48E-03	8.19E-05	2.86E-07	2.47E-09	1.64E-07	1.41E-09
2045	9.48E-03	8.19E-05	1.27E-07	1.10E-09	1.58E-07	1.36E-09	9.48E-03	8.19E-05	2.79E-07	2.41E-09	1.61E-07	1.39E-09

Notes:

[1] Values in shaded cells are not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Tailpipe greenhouse gas emission factors were estimated as a ratio of the greenhouse gas emissions (CO_2, CH_4, N_2O) to the gasoline fuel consumption outputs for each model year from EMFAC2021 data.

[3] California Reformulated Gasoline (CaRFG) energy density for the conversion factor from gal to MJ was obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Conversion Factor

CaRFG Energy Density[3] 115.83 MJ/gal

Abbreviations:

CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
gal - gallon
ICEV - internal combustion engine vehicle
LCFS - Low Carbon Fuel Standard
MJ - megajoule
MY - model year
N_2O - Nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-23. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2050

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2006	0.046	5.35	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2007	0.045	5.20	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2008	0.045	5.21	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2009	0.043	4.92	0.386	1.390	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2010	0.039	4.46	0.386	1.390	0.042	4.91	0.302	1.087	N/A	N/A	N/A
2011	0.040	4.64	0.386	1.390	0.042	4.88	0.302	1.087	N/A	N/A	N/A
2012	0.038	4.41	0.386	1.390	0.041	4.76	0.302	1.087	N/A	N/A	N/A
2013	0.037	4.27	0.386	1.390	0.040	4.68	0.302	1.087	N/A	N/A	N/A
2014	0.037	4.26	0.386	1.390	0.040	4.63	0.302	1.087	N/A	N/A	N/A
2015	0.036	4.17	0.386	1.390	0.039	4.57	0.302	1.087	N/A	N/A	N/A
2016	0.035	4.07	0.386	1.390	0.039	4.51	0.302	1.087	N/A	N/A	N/A
2017	0.035	4.10	0.386	1.390	0.039	4.48	0.302	1.087	N/A	N/A	N/A
2018	0.035	4.08	0.386	1.390	0.038	4.44	0.302	1.087	N/A	N/A	N/A
2019	0.035	4.02	0.386	1.390	0.038	4.41	0.302	1.087	N/A	N/A	N/A
2020	0.034	3.90	0.386	1.390	0.038	4.37	0.302	1.087	N/A	0.024	2.765
2021	0.033	3.79	0.386	1.390	0.037	4.34	0.302	1.087	N/A	0.023	2.690
2022	0.032	3.70	0.386	1.390	0.038	4.35	0.302	1.087	N/A	0.023	2.626
2023	0.031	3.61	0.386	1.390	0.037	4.33	0.302	1.087	N/A	0.022	2.563
2024	0.030	3.53	0.386	1.390	0.037	4.31	0.302	1.087	N/A	0.022	2.502
2025	0.030	3.44	0.386	1.390	0.037	4.29	0.302	1.087	N/A	0.021	2.442
2026	0.029	3.36	0.386	1.390	0.037	4.26	0.302	1.087	1.34	0.021	2.385

Table A-23. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2050

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2027	0.029	3.36	0.386	1.390	0.037	4.24	0.302	1.087	1.34	0.021	2.381
2028	0.029	3.35	0.386	1.390	0.036	4.22	0.302	1.087	1.34	0.021	2.377
2029	0.029	3.35	0.386	1.390	0.036	4.20	0.302	1.087	1.34	0.020	2.373
2030	0.029	3.34	0.386	1.390	0.036	4.19	0.302	1.087	1.34	0.020	2.370
2031	0.029	3.34	0.386	1.390	0.036	4.17	0.302	1.087	1.33	0.020	2.367
2032	0.029	3.33	0.386	1.390	0.036	4.16	0.302	1.087	1.33	0.020	2.364
2033	0.029	3.33	0.386	1.390	0.036	4.14	0.302	1.087	1.33	0.020	2.361
2034	0.029	3.32	0.386	1.390	0.036	4.13	0.302	1.087	1.33	0.020	2.358
2035	0.029	3.32	0.386	1.390	0.036	4.12	0.302	1.087	1.33	0.020	2.356
2036	0.029	3.32	0.386	1.390	0.035	4.11	0.302	1.087	1.33	0.020	2.353
2037	0.029	3.31	0.386	1.390	0.035	4.10	0.302	1.087	1.33	0.020	2.351
2038	0.029	3.31	0.386	1.390	0.035	4.09	0.302	1.087	1.32	0.020	2.349
2039	0.029	3.31	0.386	1.390	0.035	4.08	0.302	1.087	1.32	0.020	2.347
2040	0.029	3.31	0.386	1.390	0.035	4.07	0.302	1.087	1.32	0.020	2.345
2041	0.029	3.30	0.386	1.390	0.035	4.06	0.302	1.087	1.32	0.020	2.343
2042	0.028	3.30	0.386	1.390	0.035	4.05	0.302	1.087	1.32	0.020	2.341
2043	0.028	3.30	0.386	1.390	0.035	4.05	0.302	1.087	1.32	0.020	2.340
2044	0.028	3.30	0.386	1.390	0.035	4.04	0.302	1.087	1.32	0.020	2.339
2045	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.338
2046	0.028	3.29	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.337
2047	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.336
2048	0.028	3.29	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337
2049	0.028	3.30	0.386	1.390	0.035	4.02	0.302	1.087	1.32	0.020	2.337

Table A-23. Fuel Economies for Light Duty Auto Vehicles in Calendar Year 2050

Model Year[1]	Internal Combustion Engine Vehicle[1]		Battery Electric Vehicle[1,2]		Plug-in Hybrid Electric Vehicle[1,3]				Fuel Cell Electric Vehicle[4,5]	Hybrid Electric Vehicle[6,7]	
	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(gal of gasoline/ mi)	(MJ of gasoline/ mi)	(kWh of electricity/ mi)	(MJ of electricity/ mi)	(MJ of hydrogen/ mi)	(gal of gasoline/ mi)	(MJ of gasoline /mi)
2050	0.028	3.30	0.386	1.390	0.035	4.03	0.302	1.087	1.32	0.020	2.338

Notes:

[1] Estimated using fuel consumption, energy consumption, and VMT outputs for LDA from EMFAC2021.

[2] Values in shaded cells are not applicable as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[3] Fuel economies for MY 2026+ FCEVs were estimated by applying an EER of 2.5 to the gasoline ICEV fuel economy. This EER value was obtained from: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

[4] For the purposes of this analysis, we assumed FCEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[5] Fuel economies for MY 2026+ HEVs were estimated by applying an EER of 1.41 to the gasoline ICEV fuel economy. This EER value was derived from the relative fuel economies of the average MY 2020 HEV and ICEV as obtained from The 2020 EPA Automotive Trends Report. This factor was assumed to remain constant in future years and was used to estimate fuel economies for MY 2026 to 2050 HEVs. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010U68.pdf. Accessed: May 2022.

[6] For the purposes of this analysis, we assumed HEVs do not exist prior to MY2026, so the values in shaded cells are not applicable.

[7] California Reformulated Gasoline (CaRFG) energy density and the conversion factor from kWh to MJ were obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Constants

CaRFG Energy Density[8]	115.83	MJ/gal
Conversion Factor[8]	3.6	MJ/kWh
FCEV EER[4]	2.5	
HEV EER[6]	1.41	

Abbreviations:

BEV - battery electric vehicle
CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
EER - energy economy ratio
EPA - Environmental Protection Agency
EMFAC - EMission FACtor Model
FCEV - fuel cell electric vehicle
gal - gallon
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
kWh - kilowatt hour
LDA - light duty auto
LCFS - Low Carbon Fuel Standard
mi - mile
MJ - megajoule
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle mile traveled

Table A-24. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2006	17,095	92,566	5.4	0	0	0	N/A	N/A
2007	17,938	103,245	5.8	0	0	0	N/A	N/A
2008	14,711	90,788	6.2	0	0	0	N/A	N/A
2009	11,643	76,845	6.6	0	0	0	N/A	N/A
2010	13,584	95,789	7.1	1.6	1.9	3.5	46%	54%
2011	13,206	99,842	7.6	82	97	178	46%	54%
2012	18,883	153,117	8.1	842	996	1,838	46%	54%
2013	22,656	196,080	8.7	1,701	2,012	3,714	46%	54%
2014	21,908	203,097	9.3	2,559	3,027	5,586	46%	54%
2015	26,586	264,281	10	2,069	2,447	4,516	46%	54%
2016	27,295	289,355	11	2,428	2,872	5,300	46%	54%
2017	29,325	329,581	11	6,881	8,139	15,020	46%	54%
2018	27,113	323,766	12	7,059	8,349	15,408	46%	54%
2019	25,304	322,113	13	5,993	6,651	12,643	47%	53%
2020	22,760	307,409	14	7,225	7,765	14,991	48%	52%
2021	30,740	441,231	14	11,627	11,792	23,418	50%	50%
2022	40,577	617,884	15	18,766	15,601	34,367	55%	45%
2023	47,100	760,380	16	23,853	18,612	42,465	56%	44%
2024	55,817	953,752	17	30,538	22,370	52,908	58%	42%
2025	67,473	1,219,241	18	40,165	27,524	67,689	59%	41%
2026	84,407	1,610,993	19	46,792	32,065	78,857	59%	41%
2027	103,307	2,079,306	20	60,306	41,325	101,631	59%	41%
2028	126,564	2,683,403	21	77,308	52,976	130,285	59%	41%
2029	154,469	3,445,797	22	98,336	67,385	165,721	59%	41%
2030	186,433	4,371,092	23	123,768	84,813	208,582	59%	41%
2031	223,318	5,496,882	25	155,589	106,619	262,208	59%	41%
2032	263,400	6,799,816	26	192,410	131,851	324,261	59%	41%
2033	306,740	8,297,021	27	234,716	160,841	395,557	59%	41%
2034	350,568	9,927,424	28	280,777	192,405	473,181	59%	41%

Table A-24. Estimating Average Daily Mileage for LDA ICEVs and Fraction of Daily Electric Miles Traveled by LDA PHEVs in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle[1]				
	Population[2] (vehicles)	Daily VMT[2] (miles/day)	Average Daily Mileage per Vehicle (mi/vehicle/day)	Average Daily eVMT[2] (miles/day)	Average Daily cVMT[2] (miles/day)	Average Daily VMT[2] (miles/day)	eVMT (% of Average Daily VMT)	cVMT (% of Average Daily VMT)
2035	396,387	11,740,282	30	331,991	227,499	559,490	59%	41%
2036	441,302	13,661,164	31	386,246	264,678	650,924	59%	41%
2037	488,028	15,778,407	32	446,041	305,654	751,695	59%	41%
2038	529,547	17,868,081	34	505,048	346,088	851,136	59%	41%
2039	573,298	20,175,045	35	570,183	390,723	960,906	59%	41%
2040	609,667	22,361,362	37	631,898	433,014	1,064,912	59%	41%
2041	648,178	24,762,485	38	699,675	479,458	1,179,133	59%	41%
2042	679,210	27,014,425	40	763,205	522,993	1,286,198	59%	41%
2043	713,632	29,531,415	41	834,205	571,646	1,405,852	59%	41%
2044	738,970	31,804,637	43	898,297	615,566	1,513,863	59%	41%
2045	768,833	34,383,859	45	971,032	665,408	1,636,440	59%	41%
2046	790,339	36,707,901	46	1,036,539	710,297	1,746,836	59%	41%
2047	807,527	38,911,156	48	1,098,655	752,863	1,851,517	59%	41%
2048	828,277	41,311,163	50	1,166,429	799,305	1,965,734	59%	41%
2049	836,615	43,017,876	51	1,214,783	832,441	2,047,224	59%	41%
2050	754,352	39,850,379	53	1,125,610	771,334	1,896,944	59%	41%

Notes:
[1] Values in shaded cells are zero or not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.
[2] Obtained from EMFAC2021 data.

Abbreviations:
cVMT - combustion vehicle mile traveled
EMFAC - EMission FACtor Model
eVMT - electric vehicle mile traveled
ICEV - internal combustion engine vehicle
LDA - light duty auto
mi - mile
MY - model year
PHEV - plug-in hybrid electric vehicle
VMT - vehicle miles traveled

Table A-25. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2006	9.48E-03	8.19E-05	8.27E-07	7.14E-09	3.90E-07	3.37E-09	N/A	N/A	N/A	N/A	N/A	N/A
2007	9.48E-03	8.19E-05	8.41E-07	7.26E-09	4.21E-07	3.63E-09	N/A	N/A	N/A	N/A	N/A	N/A
2008	9.48E-03	8.19E-05	7.84E-07	6.77E-09	4.09E-07	3.53E-09	N/A	N/A	N/A	N/A	N/A	N/A
2009	9.48E-03	8.19E-05	7.49E-07	6.46E-09	4.25E-07	3.67E-09	N/A	N/A	N/A	N/A	N/A	N/A
2010	9.48E-03	8.19E-05	7.69E-07	6.64E-09	4.57E-07	3.95E-09	9.48E-03	8.19E-05	9.45E-07	8.16E-09	3.79E-07	3.27E-09
2011	9.48E-03	8.19E-05	7.40E-07	6.39E-09	4.32E-07	3.73E-09	9.48E-03	8.19E-05	8.96E-07	7.74E-09	3.65E-07	3.15E-09
2012	9.48E-03	8.19E-05	7.07E-07	6.10E-09	4.41E-07	3.81E-09	9.48E-03	8.19E-05	8.66E-07	7.48E-09	3.57E-07	3.08E-09
2013	9.48E-03	8.19E-05	6.79E-07	5.86E-09	4.44E-07	3.83E-09	9.48E-03	8.19E-05	8.34E-07	7.20E-09	3.48E-07	3.01E-09
2014	9.48E-03	8.19E-05	6.63E-07	5.72E-09	4.34E-07	3.74E-09	9.48E-03	8.19E-05	7.96E-07	6.87E-09	3.37E-07	2.91E-09
2015	9.48E-03	8.19E-05	6.44E-07	5.56E-09	4.33E-07	3.74E-09	9.48E-03	8.19E-05	7.61E-07	6.57E-09	3.27E-07	2.82E-09
2016	9.48E-03	8.19E-05	7.05E-07	6.08E-09	4.40E-07	3.80E-09	9.48E-03	8.19E-05	7.30E-07	6.30E-09	3.17E-07	2.74E-09
2017	9.48E-03	8.19E-05	6.42E-07	5.55E-09	4.25E-07	3.67E-09	9.48E-03	8.19E-05	6.98E-07	6.03E-09	3.07E-07	2.65E-09
2018	9.48E-03	8.19E-05	6.03E-07	5.21E-09	4.19E-07	3.62E-09	9.48E-03	8.19E-05	6.68E-07	5.77E-09	2.98E-07	2.57E-09
2019	9.48E-03	8.19E-05	5.61E-07	4.85E-09	4.18E-07	3.60E-09	9.48E-03	8.19E-05	6.55E-07	5.66E-09	2.94E-07	2.54E-09
2020	9.48E-03	8.19E-05	5.41E-07	4.67E-09	4.23E-07	3.65E-09	9.48E-03	8.19E-05	6.39E-07	5.52E-09	2.89E-07	2.49E-09
2021	9.48E-03	8.19E-05	5.04E-07	4.35E-09	4.24E-07	3.66E-09	9.48E-03	8.19E-05	6.26E-07	5.41E-09	2.85E-07	2.46E-09
2022	9.48E-03	8.19E-05	4.60E-07	3.97E-09	4.22E-07	3.64E-09	9.48E-03	8.19E-05	6.49E-07	5.60E-09	2.92E-07	2.52E-09
2023	9.48E-03	8.19E-05	4.21E-07	3.64E-09	4.18E-07	3.61E-09	9.48E-03	8.19E-05	6.40E-07	5.52E-09	2.89E-07	2.50E-09
2024	9.48E-03	8.19E-05	3.81E-07	3.29E-09	4.11E-07	3.55E-09	9.48E-03	8.19E-05	6.32E-07	5.45E-09	2.87E-07	2.48E-09
2025	9.48E-03	8.19E-05	3.16E-07	2.73E-09	3.90E-07	3.36E-09	9.48E-03	8.19E-05	6.26E-07	5.40E-09	2.85E-07	2.46E-09
2026	9.48E-03	8.19E-05	3.08E-07	2.66E-09	3.88E-07	3.35E-09	9.48E-03	8.19E-05	6.03E-07	5.21E-09	2.78E-07	2.40E-09
2027	9.48E-03	8.19E-05	2.97E-07	2.56E-09	3.80E-07	3.28E-09	9.48E-03	8.19E-05	5.80E-07	5.01E-09	2.70E-07	2.33E-09
2028	9.48E-03	8.19E-05	2.88E-07	2.49E-09	3.72E-07	3.21E-09	9.48E-03	8.19E-05	5.58E-07	4.82E-09	2.63E-07	2.27E-09
2029	9.48E-03	8.19E-05	2.80E-07	2.42E-09	3.64E-07	3.14E-09	9.48E-03	8.19E-05	5.38E-07	4.64E-09	2.56E-07	2.21E-09
2030	9.48E-03	8.19E-05	2.71E-07	2.34E-09	3.56E-07	3.07E-09	9.48E-03	8.19E-05	5.19E-07	4.48E-09	2.49E-07	2.15E-09
2031	9.48E-03	8.19E-05	2.64E-07	2.28E-09	3.48E-07	3.01E-09	9.48E-03	8.19E-05	5.00E-07	4.32E-09	2.43E-07	2.10E-09
2032	9.48E-03	8.19E-05	2.56E-07	2.21E-09	3.40E-07	2.94E-09	9.48E-03	8.19E-05	4.83E-07	4.17E-09	2.37E-07	2.04E-09
2033	9.48E-03	8.19E-05	2.48E-07	2.14E-09	3.32E-07	2.87E-09	9.48E-03	8.19E-05	4.66E-07	4.03E-09	2.31E-07	1.99E-09
2034	9.48E-03	8.19E-05	2.41E-07	2.08E-09	3.24E-07	2.79E-09	9.48E-03	8.19E-05	4.51E-07	3.89E-09	2.25E-07	1.95E-09

Table A-25. Tailpipe Greenhouse Gas Emission Factors for ICEV and PHEV Light Duty Autos in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle						Plug-in Hybrid Electric Vehicle[1]					
	CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]		CO_2 Emission Factor[2]		CH_4 Emission Factor[2]		N_2O Emission Factor[2]	
	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)	(tons/gal)	(tons/MJ)
2035	9.48E-03	8.19E-05	2.33E-07	2.01E-09	3.15E-07	2.72E-09	9.48E-03	8.19E-05	4.36E-07	3.76E-09	2.20E-07	1.90E-09
2036	9.48E-03	8.19E-05	2.26E-07	1.95E-09	3.07E-07	2.65E-09	9.48E-03	8.19E-05	4.22E-07	3.64E-09	2.15E-07	1.86E-09
2037	9.48E-03	8.19E-05	2.19E-07	1.89E-09	2.98E-07	2.57E-09	9.48E-03	8.19E-05	4.08E-07	3.52E-09	2.10E-07	1.81E-09
2038	9.48E-03	8.19E-05	2.11E-07	1.83E-09	2.89E-07	2.49E-09	9.48E-03	8.19E-05	3.95E-07	3.41E-09	2.05E-07	1.77E-09
2039	9.48E-03	8.19E-05	2.04E-07	1.76E-09	2.79E-07	2.41E-09	9.48E-03	8.19E-05	3.83E-07	3.31E-09	2.01E-07	1.73E-09
2040	9.48E-03	8.19E-05	1.97E-07	1.70E-09	2.70E-07	2.33E-09	9.48E-03	8.19E-05	3.71E-07	3.21E-09	1.97E-07	1.70E-09
2041	9.48E-03	8.19E-05	1.90E-07	1.64E-09	2.60E-07	2.25E-09	9.48E-03	8.19E-05	3.60E-07	3.11E-09	1.92E-07	1.66E-09
2042	9.48E-03	8.19E-05	1.83E-07	1.58E-09	2.50E-07	2.16E-09	9.48E-03	8.19E-05	3.50E-07	3.02E-09	1.88E-07	1.63E-09
2043	9.48E-03	8.19E-05	1.76E-07	1.52E-09	2.40E-07	2.07E-09	9.48E-03	8.19E-05	3.39E-07	2.93E-09	1.85E-07	1.59E-09
2044	9.48E-03	8.19E-05	1.69E-07	1.46E-09	2.29E-07	1.98E-09	9.48E-03	8.19E-05	3.30E-07	2.85E-09	1.81E-07	1.56E-09
2045	9.48E-03	8.19E-05	1.62E-07	1.40E-09	2.19E-07	1.89E-09	9.48E-03	8.19E-05	3.20E-07	2.77E-09	1.77E-07	1.53E-09
2046	9.48E-03	8.19E-05	1.55E-07	1.34E-09	2.07E-07	1.79E-09	9.48E-03	8.19E-05	3.11E-07	2.69E-09	1.74E-07	1.50E-09
2047	9.48E-03	8.19E-05	1.48E-07	1.28E-09	1.96E-07	1.69E-09	9.48E-03	8.19E-05	3.03E-07	2.61E-09	1.71E-07	1.47E-09
2048	9.48E-03	8.19E-05	1.41E-07	1.22E-09	1.84E-07	1.59E-09	9.48E-03	8.19E-05	2.95E-07	2.54E-09	1.67E-07	1.45E-09
2049	9.48E-03	8.19E-05	1.34E-07	1.16E-09	1.71E-07	1.48E-09	9.48E-03	8.19E-05	2.88E-07	2.48E-09	1.65E-07	1.42E-09
2050	9.48E-03	8.19E-05	1.28E-07	1.10E-09	1.58E-07	1.37E-09	9.48E-03	8.19E-05	2.81E-07	2.43E-09	1.62E-07	1.40E-09

Notes:

[1] Values in shaded cells are not available as the light duty auto vehicle fleet in EMFAC2021 does not include MY 2009 and earlier PHEVs.

[2] Tailpipe greenhouse gas emission factors were estimated as a ratio of the greenhouse gas emissions (CO_2, CH_4, N_2O) to the gasoline fuel consumption outputs for each model year from EMFAC2021 data.

[3] California Reformulated Gasoline (CaRFG) energy density for the conversion factor from gal to MJ was obtained from CARB's Low Carbon Fuel Standard (LCFS) Regulation. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: May 2022.

Conversion Factor

CaRFG Energy Density[3]	115.83	MJ/gal

Abbreviations:

CARB - California Air Resources Board
CaRFG - California Reformulated Gasoline
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
gal - gallon
ICEV - internal combustion engine vehicle
LCFS - Low Carbon Fuel Standard
MJ - megajoule
MY - model year
N_2O - Nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-26. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2026

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	85%	706,862	127,779,786	4%	34,449	1,220,027	3,088,034	11%	89,660	6,866,855

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of hydrogen/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**CO_2**	**CH_4**	**N_2O**
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	0%	0	0	10,714	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-27. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	85%	735,995	116,097,140	4%	35,869	1,108,113	2,804,580	11%	93,356	6,216,252
2027	85%	753,379	123,273,035	4%	36,682	1,175,675	2,972,420	11%	97,957	6,763,472
2028	85%	774,987	131,327,881	4%	37,500	1,244,657	3,146,136	11%	103,726	7,417,910
2029	84%	786,767	137,631,182	4%	37,726	1,292,471	3,268,769	12%	107,741	7,961,945
2030	84%	712,577	128,326,917	4%	33,914	1,195,950	3,027,919	12%	101,252	7,716,317

Table A-27. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2030

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	0%	0	0	9,735	0.16	0.21
2027	0%	0	0	0%	0	0	10,336	0.16	0.21
2028	0%	0	0	0%	0	0	11,010	0.16	0.21
2029	0%	0	0	0%	0	0	11,536	0.16	0.21
2030	0%	0	0	0%	0	0	10,754	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-28. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	85%	611,788	79,227,267	4%	29,815	754,625	1,930,143	11%	77,601	4,248,646
2027	85%	641,056	86,348,005	4%	31,213	822,291	2,099,102	11%	83,353	4,746,114
2028	85%	673,388	94,321,799	4%	32,584	892,959	2,275,365	11%	90,128	5,333,845
2029	84%	697,604	101,572,012	4%	33,451	953,218	2,424,492	12%	95,531	5,873,508
2030	84%	724,988	109,636,518	4%	34,505	1,021,517	2,594,022	12%	103,016	6,575,282
2031	84%	747,432	117,336,964	4%	35,573	1,093,525	2,772,634	12%	106,205	7,033,396
2032	84%	766,329	124,786,645	4%	36,472	1,163,085	2,945,735	12%	108,890	7,476,741
2033	84%	789,556	133,116,841	4%	37,578	1,240,654	3,141,258	12%	112,190	7,976,623
2034	84%	801,955	139,496,654	4%	38,168	1,299,952	3,293,065	12%	113,952	8,366,832
2035	84%	727,792	130,218,515	4%	34,638	1,213,298	3,076,767	12%	103,414	7,823,380

Table A-28. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	0%	0	0	6,645	0.14	0.18
2027	0%	0	0	0%	0	0	7,241	0.14	0.19
2028	0%	0	0	0%	0	0	7,909	0.15	0.20
2029	0%	0	0	0%	0	0	8,514	0.15	0.20
2030	0%	0	0	0%	0	0	9,189	0.16	0.21
2031	0%	0	0	0%	0	0	9,834	0.16	0.21
2032	0%	0	0	0%	0	0	10,458	0.16	0.21
2033	0%	0	0	0%	0	0	11,156	0.17	0.21
2034	0%	0	0	0%	0	0	11,691	0.17	0.21
2035	0%	0	0	0%	0	0	10,913	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-29. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	85%	424,233	44,379,743	4%	20,675	421,047	1,090,413	11%	53,811	2,380,112
2027	85%	468,739	51,160,857	4%	22,823	485,341	1,253,824	11%	60,947	2,812,115
2028	85%	508,037	57,813,793	4%	24,583	545,508	1,406,015	11%	67,997	3,270,853
2029	84%	549,764	65,186,938	4%	26,362	610,009	1,568,829	12%	75,286	3,773,157
2030	84%	583,369	72,028,242	4%	27,764	669,514	1,718,317	12%	82,893	4,325,829
2031	84%	621,402	79,845,628	4%	29,575	742,704	1,902,479	12%	88,297	4,795,314
2032	84%	652,332	87,185,723	4%	31,047	811,564	2,074,749	12%	92,692	5,235,411
2033	84%	686,690	95,441,034	4%	32,682	888,696	2,267,776	12%	97,574	5,728,006
2034	84%	712,396	102,926,116	4%	33,905	958,694	2,441,908	12%	101,227	6,173,591
2035	84%	742,681	111,447,763	4%	35,347	1,038,360	2,640,531	12%	105,530	6,681,472
2036	84%	764,974	119,166,985	4%	36,408	1,110,551	2,819,782	12%	108,697	7,140,339
2037	84%	783,440	126,588,190	4%	37,287	1,179,840	2,992,407	12%	111,321	7,581,528
2038	84%	805,975	134,822,728	4%	38,359	1,256,478	3,185,885	12%	114,524	8,075,024
2039	84%	817,118	140,992,663	4%	38,889	1,313,727	3,332,835	12%	116,107	8,451,703
2040	84%	739,955	131,287,793	4%	35,217	1,222,994	3,106,042	12%	105,142	7,882,098

Table A-29. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	0%	0	0	3,723	0.09	0.12
2027	0%	0	0	0%	0	0	4,291	0.10	0.13
2028	0%	0	0	0%	0	0	4,848	0.11	0.15
2029	0%	0	0	0%	0	0	5,465	0.12	0.16
2030	0%	0	0	0%	0	0	6,038	0.13	0.17
2031	0%	0	0	0%	0	0	6,693	0.14	0.18
2032	0%	0	0	0%	0	0	7,308	0.14	0.19
2033	0%	0	0	0%	0	0	8,000	0.15	0.20
2034	0%	0	0	0%	0	0	8,627	0.16	0.21
2035	0%	0	0	0%	0	0	9,341	0.16	0.21
2036	0%	0	0	0%	0	0	9,987	0.16	0.22
2037	0%	0	0	0%	0	0	10,609	0.17	0.22
2038	0%	0	0	0%	0	0	11,299	0.17	0.22
2039	0%	0	0	0%	0	0	11,816	0.17	0.21
2040	0%	0	0	0%	0	0	11,003	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-30. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2045

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	85%	219,761	18,208,793	4%	10,710	171,981	451,908	11%	27,875	979,732
2027	85%	258,741	22,456,424	4%	12,598	212,114	555,489	11%	33,642	1,237,162
2028	85%	300,679	27,310,373	4%	14,549	256,617	669,890	11%	40,244	1,547,489
2029	84%	343,168	32,595,097	4%	16,455	303,793	790,664	12%	46,994	1,888,561
2030	84%	386,794	38,383,317	4%	18,409	355,407	922,379	12%	54,961	2,306,853
2031	84%	431,003	44,656,861	4%	20,513	413,850	1,071,177	12%	61,243	2,683,184
2032	84%	477,078	51,574,684	4%	22,706	478,352	1,235,027	12%	67,790	3,098,236
2033	84%	518,165	58,405,552	4%	24,661	542,144	1,396,451	12%	73,628	3,508,235
2034	84%	561,504	65,947,281	4%	26,724	612,627	1,574,494	12%	79,786	3,960,912
2035	84%	597,713	73,101,152	4%	28,447	679,589	1,742,931	12%	84,931	4,390,345
2036	84%	636,105	80,962,667	4%	30,274	753,214	1,927,965	12%	90,386	4,862,426
2037	84%	667,180	88,329,199	4%	31,753	822,345	2,100,691	12%	94,802	5,304,019
2038	84%	701,654	96,602,944	4%	33,394	899,667	2,293,959	12%	99,700	5,797,554
2039	84%	727,252	104,086,433	4%	34,612	969,669	2,467,860	12%	103,338	6,242,847
2040	84%	757,391	112,590,629	4%	36,047	1,049,189	2,665,871	12%	107,620	6,749,460
2041	84%	779,333	120,269,438	4%	37,091	1,121,019	2,843,979	12%	110,738	7,205,621
2042	84%	797,208	127,609,859	4%	37,942	1,189,565	3,014,512	12%	113,278	7,641,631
2043	84%	818,902	135,699,051	4%	38,974	1,264,855	3,204,367	12%	116,360	8,126,069
2044	84%	828,649	141,621,489	4%	39,438	1,319,800	3,345,305	12%	117,745	8,487,539
2045	84%	748,769	131,560,435	4%	35,636	1,225,722	3,110,204	12%	106,395	7,896,358

Table A-30. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	0%	0	0	1,528	0.04	0.06
2027	0%	0	0	0%	0	0	1,884	0.05	0.07
2028	0%	0	0	0%	0	0	2,291	0.06	0.08
2029	0%	0	0	0%	0	0	2,733	0.07	0.09
2030	0%	0	0	0%	0	0	3,218	0.08	0.11
2031	0%	0	0	0%	0	0	3,744	0.09	0.12
2032	0%	0	0	0%	0	0	4,324	0.10	0.13
2033	0%	0	0	0%	0	0	4,896	0.11	0.15
2034	0%	0	0	0%	0	0	5,528	0.12	0.16
2035	0%	0	0	0%	0	0	6,128	0.13	0.17
2036	0%	0	0	0%	0	0	6,786	0.14	0.18
2037	0%	0	0	0%	0	0	7,404	0.15	0.19
2038	0%	0	0	0%	0	0	8,097	0.15	0.20
2039	0%	0	0	0%	0	0	8,724	0.16	0.21
2040	0%	0	0	0%	0	0	9,436	0.16	0.22
2041	0%	0	0	0%	0	0	10,080	0.17	0.22
2042	0%	0	0	0%	0	0	10,695	0.17	0.22
2043	0%	0	0	0%	0	0	11,372	0.17	0.22
2044	0%	0	0	0%	0	0	11,869	0.17	0.21
2045	0%	0	0	0%	0	0	11,026	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-31. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	85%	84,407	5,416,910	4%	4,114	50,877	136,660	11%	10,706	295,109
2027	85%	103,307	6,979,357	4%	5,030	65,571	175,255	11%	13,432	388,383
2028	85%	126,564	8,992,281	4%	6,124	84,058	223,637	11%	16,940	513,531
2029	84%	154,469	11,529,035	4%	7,407	106,921	283,234	12%	21,153	672,043
2030	84%	186,433	14,603,793	4%	8,873	134,574	355,060	12%	26,491	881,507
2031	84%	223,318	18,340,139	4%	10,628	169,173	444,687	12%	31,732	1,105,371
2032	84%	263,400	22,659,223	4%	12,536	209,209	548,060	12%	37,427	1,364,096
2033	84%	306,740	27,615,605	4%	14,599	255,208	666,413	12%	43,586	1,661,080
2034	84%	350,568	33,005,323	4%	16,685	305,290	794,782	12%	49,813	1,984,022
2035	84%	396,387	38,990,628	4%	18,865	360,976	937,068	12%	56,324	2,343,007
2036	84%	441,302	45,323,709	4%	21,003	419,968	1,087,267	12%	62,706	2,722,815
2037	84%	488,028	52,297,119	4%	23,227	484,984	1,252,421	12%	69,345	3,141,091
2038	84%	529,547	59,167,502	4%	25,203	549,142	1,414,757	12%	75,245	3,553,333
2039	84%	573,298	66,745,954	4%	27,285	619,964	1,593,644	12%	81,462	4,008,057
2040	84%	609,667	73,915,132	4%	29,016	687,067	1,762,410	12%	86,629	4,438,238
2041	84%	648,178	81,784,379	4%	30,849	760,761	1,947,591	12%	92,102	4,910,573
2042	84%	679,210	89,145,447	4%	32,326	829,839	2,120,143	12%	96,511	5,351,582
2043	84%	713,632	97,406,694	4%	33,964	907,037	2,313,062	12%	101,402	5,844,049
2044	84%	738,970	104,857,227	4%	35,170	976,725	2,486,125	12%	105,002	6,287,030
2045	84%	768,833	113,315,730	4%	36,591	1,055,810	2,682,995	12%	109,246	6,790,499
2046	84%	790,339	120,930,825	4%	37,615	1,127,036	2,859,529	12%	112,302	7,242,409
2047	84%	807,527	128,164,176	4%	38,433	1,194,575	3,027,460	12%	114,744	7,671,556
2048	84%	828,277	136,082,929	4%	39,420	1,268,267	3,213,196	12%	117,693	8,145,301
2049	84%	836,615	141,751,914	4%	39,817	1,320,843	3,348,041	12%	118,877	8,491,081
2050	84%	754,352	131,380,558	4%	35,902	1,223,884	3,105,533	12%	107,188	7,881,262

Table A-31. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 0 in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	0%	0	0	455	0.02	0.02
2027	0%	0	0	0%	0	0	586	0.02	0.02
2028	0%	0	0	0%	0	0	755	0.02	0.03
2029	0%	0	0	0%	0	0	967	0.03	0.04
2030	0%	0	0	0%	0	0	1,225	0.04	0.05
2031	0%	0	0	0%	0	0	1,538	0.04	0.06
2032	0%	0	0	0%	0	0	1,900	0.05	0.07
2033	0%	0	0	0%	0	0	2,316	0.06	0.08
2034	0%	0	0	0%	0	0	2,767	0.07	0.09
2035	0%	0	0	0%	0	0	3,269	0.08	0.11
2036	0%	0	0	0%	0	0	3,800	0.09	0.12
2037	0%	0	0	0%	0	0	4,384	0.10	0.14
2038	0%	0	0	0%	0	0	4,960	0.11	0.15
2039	0%	0	0	0%	0	0	5,595	0.12	0.16
2040	0%	0	0	0%	0	0	6,196	0.13	0.18
2041	0%	0	0	0%	0	0	6,855	0.14	0.19
2042	0%	0	0	0%	0	0	7,472	0.15	0.20
2043	0%	0	0	0%	0	0	8,164	0.15	0.21
2044	0%	0	0	0%	0	0	8,788	0.16	0.21
2045	0%	0	0	0%	0	0	9,497	0.17	0.22
2046	0%	0	0	0%	0	0	10,135	0.17	0.22
2047	0%	0	0	0%	0	0	10,741	0.17	0.22
2048	0%	0	0	0%	0	0	11,405	0.17	0.22
2049	0%	0	0	0%	0	0	11,880	0.17	0.21
2050	0%	0	0	0%	0	0	11,011	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-32. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2026

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	65%	540,131	97,639,769	4%	34,449	1,220,027	3,088,034	31%	256,391	19,581,287

Table A-32. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2026

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	0%	0	0	8,247	0.11	0.14

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-33. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2030

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	65%	562,392	88,712,763	4%	35,869	1,108,113	2,804,580	31%	266,958	17,769,266
2027	57%	506,170	82,823,038	4%	36,682	1,175,675	2,972,420	39%	345,166	23,832,150
2028	49%	448,945	76,077,298	4%	37,500	1,244,657	3,146,136	47%	429,769	30,729,889
2029	41%	382,216	66,862,077	4%	37,726	1,292,471	3,268,769	55%	512,292	37,813,655
2030	32%	271,278	48,854,015	4%	33,914	1,195,950	3,027,919	64%	542,551	41,225,912

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	0%	0	0	7,493	0.12	0.16
2027	0%	0	0	0%	0	0	7,024	0.11	0.14
2028	0%	0	0	0%	0	0	6,486	0.10	0.12
2029	0%	0	0	0%	0	0	5,742	0.08	0.10
2030	0%	0	0	0%	0	0	4,248	0.06	0.07

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-34. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	65%	467,482	60,539,560	4%	29,815	754,625	1,930,143	31%	221,906	12,112,622
2027	57%	430,704	58,014,343	4%	31,213	822,291	2,099,102	39%	293,704	16,679,184
2028	49%	390,089	54,639,940	4%	32,584	892,959	2,275,365	47%	373,427	22,053,612
2029	41%	338,901	49,344,310	4%	33,451	953,218	2,424,492	55%	454,235	27,888,884
2030	32%	276,003	41,738,586	4%	34,505	1,021,517	2,594,022	64%	552,001	35,207,048
2031	24%	213,410	33,502,607	4%	35,573	1,093,525	2,772,634	72%	640,226	42,397,675
2032	18%	164,104	26,722,257	4%	36,472	1,163,085	2,945,735	78%	711,115	48,851,635
2033	12%	112,719	19,004,076	4%	37,578	1,240,654	3,141,258	84%	789,027	56,118,670
2034	6%	57,245	9,957,437	4%	38,168	1,299,952	3,293,065	90%	858,663	63,001,878
2035	0%	0	0	4%	34,638	1,213,298	3,076,767	96%	831,206	62,721,943

Table A-34. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	0%	0	0	5,115	0.10	0.14
2027	0%	0	0	0%	0	0	4,922	0.10	0.13
2028	0%	0	0	0%	0	0	4,660	0.09	0.12
2029	0%	0	0	0%	0	0	4,238	0.08	0.10
2030	0%	0	0	0%	0	0	3,630	0.06	0.08
2031	0%	0	0	0%	0	0	2,970	0.05	0.06
2032	0%	0	0	0%	0	0	2,429	0.04	0.05
2033	0%	0	0	0%	0	0	1,813	0.03	0.03
2034	0%	0	0	0%	0	0	1,085	0.02	0.02
2035	0%	0	0	0%	0	0	252	0.007	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-35. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2040

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	65%	324,168	33,911,685	4%	20,675	421,047	1,090,413	31%	153,877	6,765,602
2027	57%	314,930	34,373,272	4%	22,823	485,341	1,253,824	39%	214,756	9,851,828
2028	49%	294,302	33,491,115	4%	24,583	545,508	1,406,015	47%	281,732	13,479,728
2029	41%	267,079	31,668,216	4%	26,362	610,009	1,568,829	55%	357,971	17,854,418
2030	32%	222,088	27,421,128	4%	27,764	669,514	1,718,317	64%	444,173	23,081,327
2031	24%	177,426	22,797,903	4%	29,575	742,704	1,902,479	72%	532,274	28,801,012
2032	18%	139,693	18,670,261	4%	31,047	811,564	2,074,749	78%	605,331	34,091,054
2033	12%	98,033	13,625,389	4%	32,682	888,696	2,267,776	84%	686,230	40,200,527
2034	6%	50,852	7,346,988	4%	33,905	958,694	2,441,908	90%	762,771	46,463,120
2035	0%	0	0	4%	35,347	1,038,360	2,640,531	96%	848,210	53,678,440
2036	0%	0	0	4%	36,408	1,110,551	2,819,782	96%	873,671	57,410,409
2037	0%	0	0	4%	37,287	1,179,840	2,992,407	96%	894,762	60,992,337
2038	0%	0	0	4%	38,359	1,256,478	3,185,885	96%	920,499	64,954,134
2039	0%	0	0	4%	38,889	1,313,727	3,332,835	96%	933,225	67,913,671
2040	0%	0	0	4%	35,217	1,222,994	3,106,042	96%	845,097	63,223,164

Table A-35. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	0%	0	0	2,866	0.07	0.09
2027	0%	0	0	0%	0	0	2,917	0.07	0.09
2028	0%	0	0	0%	0	0	2,857	0.07	0.09
2029	0%	0	0	0%	0	0	2,721	0.06	0.08
2030	0%	0	0	0%	0	0	2,386	0.05	0.07
2031	0%	0	0	0%	0	0	2,022	0.04	0.05
2032	0%	0	0	0%	0	0	1,698	0.04	0.04
2033	0%	0	0	0%	0	0	1,301	0.03	0.03
2034	0%	0	0	0%	0	0	801	0.02	0.02
2035	0%	0	0	0%	0	0	216	0.007	0.004
2036	0%	0	0	0%	0	0	231	0.007	0.004
2037	0%	0	0	0%	0	0	245	0.008	0.004
2038	0%	0	0	0%	0	0	261	0.008	0.005
2039	0%	0	0	0%	0	0	273	0.008	0.005
2040	0%	0	0	0%	0	0	254	0.007	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-36. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	65%	167,925	13,913,800	4%	10,710	171,981	451,908	31%	79,711	2,769,255
2027	57%	173,839	15,087,722	4%	12,598	212,114	555,489	39%	118,544	4,311,126
2028	49%	174,181	15,820,703	4%	14,549	256,617	669,890	47%	166,741	6,346,215
2029	41%	166,713	15,834,899	4%	16,455	303,793	790,664	55%	223,449	8,896,336
2030	32%	147,252	14,612,516	4%	18,409	355,407	922,379	64%	294,502	12,256,579
2031	24%	123,062	12,750,639	4%	20,513	413,850	1,071,177	72%	369,184	16,051,691
2032	18%	102,163	11,044,387	4%	22,706	478,352	1,235,027	78%	442,705	20,096,591
2033	12%	73,974	8,338,115	4%	24,661	542,144	1,396,451	84%	517,818	24,526,102
2034	6%	40,081	4,707,395	4%	26,724	612,627	1,574,494	90%	601,209	29,692,084
2035	0%	0	0	4%	28,447	679,589	1,742,931	96%	682,644	35,131,652
2036	0%	0	0	4%	30,274	753,214	1,927,965	96%	726,491	38,937,712
2037	0%	0	0	4%	31,753	822,345	2,100,691	96%	761,982	42,511,445
2038	0%	0	0	4%	33,394	899,667	2,293,959	96%	801,354	46,508,679
2039	0%	0	0	4%	34,612	969,669	2,467,860	96%	830,590	50,127,457
2040	0%	0	0	4%	36,047	1,049,189	2,665,871	96%	865,011	54,238,284
2041	0%	0	0	4%	37,091	1,121,019	2,843,979	96%	890,071	57,951,532
2042	0%	0	0	4%	37,942	1,189,565	3,014,512	96%	910,486	61,495,065
2043	0%	0	0	4%	38,974	1,264,855	3,204,367	96%	935,263	65,387,212
2044	0%	0	0	4%	39,438	1,319,800	3,345,305	96%	946,394	68,227,630
2045	0%	0	0	4%	35,636	1,225,722	3,110,204	96%	855,164	63,364,207

Table A-36. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2045

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	0%	0	0	1,176	0.03	0.04
2027	0%	0	0	0%	0	0	1,281	0.04	0.05
2028	0%	0	0	0%	0	0	1,350	0.04	0.05
2029	0%	0	0	0%	0	0	1,361	0.04	0.05
2030	0%	0	0	0%	0	0	1,272	0.03	0.04
2031	0%	0	0	0%	0	0	1,132	0.03	0.04
2032	0%	0	0	0%	0	0	1,005	0.03	0.03
2033	0%	0	0	0%	0	0	797	0.02	0.02
2034	0%	0	0	0%	0	0	514	0.01	0.01
2035	0%	0	0	0%	0	0	143	0.006	0.003
2036	0%	0	0	0%	0	0	158	0.006	0.003
2037	0%	0	0	0%	0	0	172	0.006	0.003
2038	0%	0	0	0%	0	0	188	0.007	0.004
2039	0%	0	0	0%	0	0	202	0.007	0.004
2040	0%	0	0	0%	0	0	218	0.007	0.004
2041	0%	0	0	0%	0	0	233	0.008	0.004
2042	0%	0	0	0%	0	0	247	0.008	0.004
2043	0%	0	0	0%	0	0	262	0.008	0.005
2044	0%	0	0	0%	0	0	274	0.008	0.005
2045	0%	0	0	0%	0	0	255	0.007	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-37. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fuel Consumption[3] (MJ of electricity/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of electricity/day)**
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	65%	64,497	4,139,198	4%	4,114	50,877	136,660	31%	30,616	823,259
2027	57%	69,408	4,689,197	4%	5,030	65,571	175,255	39%	47,331	1,336,696
2028	49%	73,318	5,209,164	4%	6,124	84,058	223,637	47%	70,186	2,082,624
2029	41%	75,042	5,600,876	4%	7,407	106,921	283,234	55%	100,580	3,134,673
2030	32%	70,975	5,559,659	4%	8,873	134,574	355,060	64%	141,949	4,643,985
2031	24%	63,763	5,236,564	4%	10,628	169,173	444,687	72%	191,287	6,564,034
2032	18%	56,405	4,852,327	4%	12,536	209,209	548,060	78%	244,422	8,791,260
2033	12%	43,791	3,942,469	4%	14,599	255,208	666,413	84%	306,534	11,546,749
2034	6%	25,024	2,355,959	4%	16,685	305,290	794,782	90%	375,357	14,797,195
2035	0%	0	0	4%	18,865	360,976	937,068	96%	452,711	18,660,792
2036	0%	0	0	4%	21,003	419,968	1,087,267	96%	504,008	21,710,427
2037	0%	0	0	4%	23,227	484,984	1,252,421	96%	557,374	25,071,454
2038	0%	0	0	4%	25,203	549,142	1,414,757	96%	604,792	28,388,128
2039	0%	0	0	4%	27,285	619,964	1,593,644	96%	654,759	32,049,293
2040	0%	0	0	4%	29,016	687,067	1,762,410	96%	696,296	35,518,231
2041	0%	0	0	4%	30,849	760,761	1,947,591	96%	740,279	39,327,879
2042	0%	0	0	4%	32,326	829,839	2,120,143	96%	775,721	42,898,853
2043	0%	0	0	4%	33,964	907,037	2,313,062	96%	815,034	46,889,677
2044	0%	0	0	4%	35,170	976,725	2,486,125	96%	843,972	50,492,203
2045	0%	0	0	4%	36,591	1,055,810	2,682,995	96%	878,079	54,580,526
2046	0%	0	0	4%	37,615	1,127,036	2,859,529	96%	902,640	58,262,615
2047	0%	0	0	4%	38,433	1,194,575	3,027,460	96%	922,271	61,754,060
2048	0%	0	0	4%	39,420	1,268,267	3,213,196	96%	945,970	65,563,567
2049	0%	0	0	4%	39,817	1,320,843	3,348,041	96%	955,492	68,281,503
2050	0%	0	0	4%	35,902	1,223,884	3,105,533	96%	861,541	63,269,189

Table A-37. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1a in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	0%	0	0	350	0.01	0.01
2027	0%	0	0	0%	0	0	398	0.01	0.02
2028	0%	0	0	0%	0	0	445	0.01	0.02
2029	0%	0	0	0%	0	0	482	0.01	0.02
2030	0%	0	0	0%	0	0	484	0.01	0.02
2031	0%	0	0	0%	0	0	465	0.01	0.02
2032	0%	0	0	0%	0	0	442	0.01	0.02
2033	0%	0	0	0%	0	0	377	0.01	0.01
2034	0%	0	0	0%	0	0	258	0.008	0.008
2035	0%	0	0	0%	0	0	77	0.004	0.002
2036	0%	0	0	0%	0	0	89	0.004	0.002
2037	0%	0	0	0%	0	0	103	0.004	0.002
2038	0%	0	0	0%	0	0	116	0.005	0.003
2039	0%	0	0	0%	0	0	130	0.005	0.003
2040	0%	0	0	0%	0	0	144	0.006	0.003
2041	0%	0	0	0%	0	0	159	0.006	0.003
2042	0%	0	0	0%	0	0	174	0.006	0.003
2043	0%	0	0	0%	0	0	189	0.007	0.004
2044	0%	0	0	0%	0	0	204	0.007	0.004
2045	0%	0	0	0%	0	0	220	0.007	0.004
2046	0%	0	0	0%	0	0	234	0.008	0.004
2047	0%	0	0	0%	0	0	248	0.008	0.004
2048	0%	0	0	0%	0	0	263	0.008	0.005
2049	0%	0	0	0%	0	0	274	0.008	0.005
2050	0%	0	0	0%	0	0	254	0.008	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-38. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2026

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	65%	540,131	97,639,769	7%	58,168	2,059,650	5,213,221	28%	232,672	17,772,525

Table A-38. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	0%	0	0	8,421	0.12	0.14

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-39. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	65%	562,392	88,712,763	7%	60,565	1,871,040	4,735,510	28%	242,261	16,125,728
2027	57%	506,170	82,823,038	9%	76,370	2,447,705	6,188,454	34%	305,478	21,091,873
2028	49%	448,945	76,077,298	10%	93,454	3,101,764	7,840,373	41%	373,815	26,729,208
2029	41%	382,216	66,862,077	12%	110,004	3,768,193	9,530,078	47%	440,015	32,480,322
2030	32%	271,278	48,854,015	14%	115,293	4,064,433	10,290,377	54%	461,172	35,046,471

Table A-39. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	0%	0	0	7,651	0.13	0.16
2027	0%	0	0	0%	0	0	7,288	0.12	0.15
2028	0%	0	0	0%	0	0	6,871	0.11	0.13
2029	0%	0	0	0%	0	0	6,254	0.10	0.11
2030	0%	0	0	0%	0	0	4,842	0.08	0.08

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-40. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2035

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	65%	467,482	60,539,560	7%	50,344	1,273,939	3,258,418	28%	201,377	10,993,889
2027	57%	430,704	58,014,343	9%	64,983	1,711,595	4,369,269	34%	259,934	14,763,399
2028	49%	390,089	54,639,940	10%	81,202	2,224,910	5,669,333	41%	324,809	19,184,252
2029	41%	338,901	49,344,310	12%	97,537	2,779,042	7,068,436	47%	390,149	23,955,597
2030	32%	276,003	41,738,586	14%	117,301	3,472,448	8,817,878	54%	469,205	29,927,118
2031	24%	213,410	33,502,607	15%	135,160	4,154,869	10,534,670	61%	540,639	35,802,764
2032	18%	164,104	26,722,257	16%	149,517	4,768,321	12,076,679	66%	598,069	41,085,042
2033	12%	112,719	19,004,076	18%	165,321	5,458,416	13,820,362	70%	661,284	47,032,540
2034	6%	57,245	9,957,437	19%	179,366	6,108,530	15,474,249	75%	717,465	52,642,980
2035	0%	0	0	20%	173,169	6,063,983	15,377,477	80%	692,675	52,272,334

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	0%	0	0	5,223	0.11	0.14
2027	0%	0	0	0%	0	0	5,107	0.10	0.13
2028	0%	0	0	0%	0	0	4,938	0.10	0.12
2029	0%	0	0	0%	0	0	4,619	0.09	0.11
2030	0%	0	0	0%	0	0	4,139	0.08	0.09
2031	0%	0	0	0%	0	0	3,605	0.07	0.08
2032	0%	0	0	0%	0	0	3,177	0.06	0.06
2033	0%	0	0	0%	0	0	2,687	0.06	0.05
2034	0%	0	0	0%	0	0	2,082	0.05	0.04
2035	0%	0	0	0%	0	0	1,259	0.04	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-41. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	65%	324,168	33,911,685	7%	34,910	710,651	1,840,421	28%	139,641	6,141,720
2027	57%	314,930	34,373,272	9%	47,516	1,009,971	2,609,145	34%	190,063	8,721,643
2028	49%	294,302	33,491,115	10%	61,263	1,358,780	3,502,176	41%	245,052	11,727,734
2029	41%	267,079	31,668,216	12%	76,867	1,777,825	4,572,229	47%	307,466	15,338,648
2030	32%	222,088	27,421,128	14%	94,388	2,275,019	5,838,867	54%	377,550	19,622,661
2031	24%	177,426	22,797,903	15%	112,370	2,820,780	7,225,594	61%	449,479	24,324,307
2032	18%	139,693	18,670,261	16%	127,276	3,325,924	8,502,665	66%	509,102	28,674,484
2033	12%	98,033	13,625,389	18%	143,782	3,908,860	9,974,635	70%	575,130	33,694,327
2034	6%	50,852	7,346,988	19%	159,335	4,504,684	11,473,962	75%	637,341	38,824,156
2035	0%	0	0	20%	176,711	5,190,882	13,200,325	80%	706,846	44,732,852
2036	0%	0	0	20%	182,016	5,552,276	14,097,691	80%	728,063	47,841,806
2037	0%	0	0	20%	186,410	5,899,072	14,961,705	80%	745,638	50,825,913
2038	0%	0	0	20%	191,772	6,282,159	15,928,844	80%	767,086	54,127,540
2039	0%	0	0	20%	194,423	6,567,623	16,661,603	80%	777,691	56,595,445
2040	0%	0	0	20%	176,063	6,112,778	15,524,648	80%	704,251	52,689,327

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	0%	0	0	2,927	0.07	0.09
2027	0%	0	0	0%	0	0	3,028	0.07	0.09
2028	0%	0	0	0%	0	0	3,029	0.07	0.09
2029	0%	0	0	0%	0	0	2,967	0.07	0.08
2030	0%	0	0	0%	0	0	2,723	0.06	0.07
2031	0%	0	0	0%	0	0	2,458	0.06	0.06
2032	0%	0	0	0%	0	0	2,225	0.05	0.05
2033	0%	0	0	0%	0	0	1,932	0.05	0.04
2034	0%	0	0	0%	0	0	1,541	0.04	0.03
2035	0%	0	0	0%	0	0	1,081	0.04	0.02
2036	0%	0	0	0%	0	0	1,154	0.04	0.02
2037	0%	0	0	0%	0	0	1,225	0.04	0.02
2038	0%	0	0	0%	0	0	1,304	0.04	0.02
2039	0%	0	0	0%	0	0	1,364	0.04	0.02
2040	0%	0	0	0%	0	0	1,271	0.04	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-42. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	65%	167,925	13,913,800	7%	18,084	290,156	762,432	28%	72,337	2,514,676
2027	57%	173,839	15,087,722	9%	26,228	441,199	1,155,422	34%	104,913	3,817,619
2028	49%	174,181	15,820,703	10%	36,258	638,899	1,667,826	41%	145,032	5,522,683
2029	41%	166,713	15,834,899	12%	47,981	884,975	2,303,275	47%	191,924	7,644,321
2030	32%	147,252	14,612,516	14%	62,582	1,207,122	3,132,813	54%	250,329	10,421,769
2031	24%	123,062	12,750,639	15%	77,939	1,571,107	4,066,536	61%	311,757	13,558,663
2032	18%	102,163	11,044,387	16%	93,082	1,959,517	5,059,160	66%	372,328	16,905,784
2033	12%	73,974	8,338,115	18%	108,496	2,383,535	6,139,495	70%	433,983	20,559,277
2034	6%	40,081	4,707,395	19%	125,587	2,877,296	7,394,855	75%	502,346	24,813,410
2035	0%	0	0	20%	142,218	3,395,806	8,709,165	80%	568,873	29,280,231
2036	0%	0	0	20%	151,353	3,764,012	9,634,558	80%	605,413	32,451,688
2037	0%	0	0	20%	158,747	4,109,890	10,498,771	80%	634,988	35,429,237
2038	0%	0	0	20%	166,950	4,496,790	11,465,849	80%	667,799	38,759,563
2039	0%	0	0	20%	173,040	4,847,192	12,336,363	80%	692,162	41,774,287
2040	0%	0	0	20%	180,212	5,245,171	13,327,383	80%	720,847	45,199,074
2041	0%	0	0	20%	185,432	5,604,787	14,219,115	80%	741,730	48,292,355
2042	0%	0	0	20%	189,685	5,947,906	15,072,761	80%	758,742	51,244,390
2043	0%	0	0	20%	194,847	6,324,292	16,021,877	80%	779,390	54,487,900
2044	0%	0	0	20%	197,166	6,598,270	16,724,671	80%	788,666	56,856,466
2045	0%	0	0	20%	178,160	6,126,708	15,546,194	80%	712,640	52,806,238

Table A-42. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	0%	0	0	1,202	0.04	0.04
2027	0%	0	0	0%	0	0	1,330	0.04	0.05
2028	0%	0	0	0%	0	0	1,432	0.04	0.05
2029	0%	0	0	0%	0	0	1,485	0.04	0.05
2030	0%	0	0	0%	0	0	1,453	0.04	0.05
2031	0%	0	0	0%	0	0	1,377	0.04	0.04
2032	0%	0	0	0%	0	0	1,318	0.04	0.04
2033	0%	0	0	0%	0	0	1,185	0.04	0.03
2034	0%	0	0	0%	0	0	991	0.03	0.02
2035	0%	0	0	0%	0	0	713	0.03	0.01
2036	0%	0	0	0%	0	0	789	0.03	0.02
2037	0%	0	0	0%	0	0	860	0.03	0.02
2038	0%	0	0	0%	0	0	939	0.03	0.02
2039	0%	0	0	0%	0	0	1,010	0.03	0.02
2040	0%	0	0	0%	0	0	1,091	0.04	0.02
2041	0%	0	0	0%	0	0	1,164	0.04	0.02
2042	0%	0	0	0%	0	0	1,234	0.04	0.02
2043	0%	0	0	0%	0	0	1,312	0.04	0.02
2044	0%	0	0	0%	0	0	1,369	0.04	0.02
2045	0%	0	0	0%	0	0	1,273	0.04	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	65%	64,497	4,139,198	7%	6,946	85,755	230,344	28%	27,783	748,124
2027	57%	69,408	4,689,197	9%	10,472	136,243	364,145	34%	41,888	1,184,450
2028	49%	73,318	5,209,164	10%	15,262	209,057	556,198	41%	61,048	1,813,344
2029	41%	75,042	5,600,876	12%	21,597	311,157	824,254	47%	86,390	2,694,697
2030	32%	70,975	5,559,659	14%	30,164	456,649	1,204,821	54%	120,658	3,950,154
2031	24%	63,763	5,236,564	15%	40,383	641,707	1,686,787	61%	161,532	5,546,074
2032	18%	56,405	4,852,327	16%	51,392	856,381	2,243,442	66%	205,566	7,397,087
2033	12%	43,791	3,942,469	18%	64,227	1,121,299	2,927,997	70%	256,907	9,680,969
2034	6%	25,024	2,355,959	19%	78,408	1,433,012	3,730,649	75%	313,633	12,367,796
2035	0%	0	0	20%	94,315	1,802,770	4,679,868	80%	377,261	15,554,800
2036	0%	0	0	20%	105,002	2,097,661	5,430,694	80%	420,009	18,096,250
2037	0%	0	0	20%	116,120	2,422,690	6,256,345	80%	464,480	20,897,143
2038	0%	0	0	20%	125,999	2,743,476	7,068,030	80%	503,996	23,660,975
2039	0%	0	0	20%	136,409	3,097,610	7,962,540	80%	545,636	26,711,814
2040	0%	0	0	20%	145,063	3,433,210	8,806,594	80%	580,250	29,602,343
2041	0%	0	0	20%	154,226	3,801,780	9,732,766	80%	616,903	32,776,753
2042	0%	0	0	20%	161,609	4,147,412	10,596,165	80%	646,437	35,751,957
2043	0%	0	0	20%	169,800	4,533,716	11,561,556	80%	679,199	39,076,891
2044	0%	0	0	20%	175,828	4,882,572	12,427,947	80%	703,314	42,078,016
2045	0%	0	0	20%	182,934	5,278,405	13,413,338	80%	731,736	45,483,984
2046	0%	0	0	20%	188,051	5,635,041	14,297,285	80%	752,204	48,551,228
2047	0%	0	0	20%	192,141	5,973,156	15,138,009	80%	768,563	51,459,783
2048	0%	0	0	20%	197,078	6,341,586	16,066,621	80%	788,312	54,634,347
2049	0%	0	0	20%	199,062	6,603,759	16,739,054	80%	796,247	56,900,758
2050	0%	0	0	20%	179,489	6,117,808	15,523,574	80%	717,954	52,726,433

Table A-43. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1b in Calendar Year 2050

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	0%	0	0	358	0.01	0.01
2027	0%	0	0	0%	0	0	414	0.01	0.02
2028	0%	0	0	0%	0	0	472	0.02	0.02
2029	0%	0	0	0%	0	0	526	0.02	0.02
2030	0%	0	0	0%	0	0	554	0.02	0.02
2031	0%	0	0	0%	0	0	567	0.02	0.02
2032	0%	0	0	0%	0	0	581	0.02	0.02
2033	0%	0	0	0%	0	0	563	0.02	0.02
2034	0%	0	0	0%	0	0	498	0.02	0.01
2035	0%	0	0	0%	0	0	383	0.02	0.009
2036	0%	0	0	0%	0	0	445	0.02	0.01
2037	0%	0	0	0%	0	0	512	0.02	0.01
2038	0%	0	0	0%	0	0	579	0.02	0.01
2039	0%	0	0	0%	0	0	652	0.03	0.01
2040	0%	0	0	0%	0	0	721	0.03	0.01
2041	0%	0	0	0%	0	0	797	0.03	0.02
2042	0%	0	0	0%	0	0	868	0.03	0.02
2043	0%	0	0	0%	0	0	947	0.03	0.02
2044	0%	0	0	0%	0	0	1,018	0.04	0.02
2045	0%	0	0	0%	0	0	1,098	0.04	0.02
2046	0%	0	0	0%	0	0	1,171	0.04	0.02
2047	0%	0	0	0%	0	0	1,239	0.04	0.02
2048	0%	0	0	0%	0	0	1,315	0.04	0.02
2049	0%	0	0	0%	0	0	1,370	0.04	0.02
2050	0%	0	0	0%	0	0	1,271	0.04	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-44. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	65%	540,131	97,639,769	4%	34,449	1,220,027	3,088,034	31%	256,391	19,581,287

Table A-44. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	0%	0	0	8,247	0.11	0.14

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-45. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2030

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	65%	562,392	88,712,763	4%	35,869	1,108,113	2,804,580	31%	266,958	17,769,266
2027	57%	506,170	82,823,038	4%	36,682	1,175,675	2,972,420	39%	345,166	23,832,150
2028	49%	448,945	76,077,298	4%	37,500	1,244,657	3,146,136	47%	429,769	30,729,889
2029	41%	382,216	66,862,077	4%	37,726	1,292,471	3,268,769	55%	512,292	37,813,655
2030	32%	271,278	48,854,015	11%	96,110	3,388,276	8,578,476	57%	480,355	36,503,084

Table A-45. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2030

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	0%	0	0	7,493	0.12	0.16
2027	0%	0	0	0%	0	0	7,024	0.111	0.143
2028	0%	0	0	0%	0	0	6,486	0.099	0.124
2029	0%	0	0	0%	0	0	5,742	0.084	0.103
2030	0%	0	0	0%	0	0	4,702	0.073	0.078

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-46. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2035

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	65%	467,482	60,539,560	4%	29,815	754,625	1,930,143	31%	221,906	12,112,622
2027	57%	430,704	58,014,343	4%	31,213	822,291	2,099,102	39%	293,704	16,679,184
2028	49%	390,089	54,639,940	4%	32,584	892,959	2,275,365	47%	373,427	22,053,612
2029	41%	338,901	49,344,310	4%	33,451	953,218	2,424,492	55%	454,235	27,888,884
2030	32%	276,003	41,738,586	11%	97,784	2,894,717	7,350,796	57%	488,721	31,171,698
2031	24%	213,410	33,502,607	17%	151,894	4,669,292	11,838,991	59%	523,905	34,694,565
2032	18%	164,104	26,722,257	18%	162,392	5,178,913	13,116,584	64%	585,195	40,200,521
2033	12%	112,719	19,004,076	18%	166,766	5,506,139	13,941,195	64%	603,670	42,934,541
2034	6%	57,245	9,957,437	18%	168,918	5,752,729	14,572,928	68%	651,167	47,779,136
2035	0%	0	0	19%	160,651	5,625,686	14,266,011	69%	594,609	44,875,060

Table A-46. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2035

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	0%	0	0	5,115	0.10	0.14
2027	0%	0	0	0%	0	0	4,922	0.10	0.13
2028	0%	0	0	0%	0	0	4,660	0.09	0.12
2029	0%	0	0	0%	0	0	4,238	0.08	0.10
2030	0%	0	0	0%	0	0	4,019	0.08	0.09
2031	0%	0	0	0%	0	0	3,712	0.08	0.08
2032	0%	0	0	0%	0	0	3,262	0.07	0.06
2033	6%	56,169	3,787,976	0%	0	0	2,697	0.06	0.05
2034	8%	76,745	5,339,785	0%	0	0	2,008	0.05	0.04
2035	13%	110,583	7,914,341	0%	0	0	1,168	0.03	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-47. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	65%	324,168	33,911,685	4%	20,675	421,047	1,090,413	31%	153,877	6,765,602
2027	57%	314,930	34,373,272	4%	22,823	485,341	1,253,824	39%	214,756	9,851,828
2028	49%	294,302	33,491,115	4%	24,583	545,508	1,406,015	47%	281,732	13,479,728
2029	41%	267,079	31,668,216	4%	26,362	610,009	1,568,829	55%	357,971	17,854,418
2030	32%	222,088	27,421,128	11%	78,683	1,896,571	4,867,575	57%	393,255	20,437,935
2031	24%	177,426	22,797,903	17%	126,282	3,169,977	8,120,082	59%	435,566	23,572,048
2032	18%	139,693	18,670,261	18%	138,235	3,612,279	9,234,728	64%	498,143	28,057,602
2033	12%	98,033	13,625,389	18%	145,039	3,943,033	10,061,837	64%	525,021	30,759,919
2034	6%	50,852	7,346,988	18%	150,054	4,242,306	10,805,654	68%	578,448	35,237,411
2035	0%	0	0	19%	163,938	4,815,669	12,246,165	69%	606,774	38,400,274
2036	0%	0	0	18%	165,245	5,040,700	12,798,757	68%	621,364	40,830,105
2037	0%	0	0	18%	171,983	5,442,528	13,803,780	69%	641,862	43,750,953
2038	0%	0	0	18%	173,156	5,672,337	14,382,598	68%	656,521	46,324,739
2039	0%	0	0	18%	175,550	5,930,109	15,044,275	68%	665,597	48,438,322
2040	0%	0	0	18%	160,244	5,563,583	14,129,856	68%	602,698	45,094,194

Table A-47. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2040

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	0%	0	0	2,866	0.07	0.09
2027	0%	0	0	0%	0	0	2,917	0.07	0.09
2028	0%	0	0	0%	0	0	2,857	0.07	0.09
2029	0%	0	0	0%	0	0	2,721	0.06	0.08
2030	0%	0	0	0%	0	0	2,644	0.06	0.07
2031	0%	0	0	0%	0	0	2,531	0.06	0.06
2032	0%	0	0	0%	0	0	2,285	0.06	0.05
2033	6%	48,851	2,715,872	0%	0	0	1,939	0.05	0.04
2034	8%	68,174	3,939,903	0%	0	0	1,486	0.04	0.03
2035	13%	112,845	6,773,504	0%	0	0	1,003	0.03	0.02
2036	14%	123,469	7,693,588	0%	0	0	1,048	0.03	0.02
2037	13%	118,203	7,639,708	0%	0	0	1,130	0.04	0.02
2038	13%	129,181	8,643,687	0%	0	0	1,178	0.04	0.02
2039	13%	130,967	9,039,251	0%	0	0	1,232	0.04	0.02
2040	13%	117,372	8,329,984	0%	0	0	1,157	0.03	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-48. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2045

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	65%	167,925	13,913,800	4%	10,710	171,981	451,908	31%	79,711	2,769,255
2027	57%	173,839	15,087,722	4%	12,598	212,114	555,489	39%	118,544	4,311,126
2028	49%	174,181	15,820,703	4%	14,549	256,617	669,890	47%	166,741	6,346,215
2029	41%	166,713	15,834,899	4%	16,455	303,793	790,664	55%	223,449	8,896,336
2030	32%	147,252	14,612,516	11%	52,170	1,006,357	2,611,771	57%	260,741	10,854,269
2031	24%	123,062	12,750,639	17%	87,589	1,765,571	4,569,872	59%	302,108	13,139,739
2032	18%	102,163	11,044,387	18%	101,097	2,128,204	5,494,682	64%	364,313	16,542,390
2033	12%	73,974	8,338,115	18%	109,444	2,404,371	6,193,162	64%	396,173	18,770,171
2034	6%	40,081	4,707,395	18%	118,271	2,709,727	6,964,190	68%	455,927	22,522,711
2035	0%	0	0	19%	131,938	3,150,375	8,079,711	69%	488,335	25,138,012
2036	0%	0	0	18%	137,408	3,417,243	8,746,950	68%	516,688	27,698,846
2037	0%	0	0	18%	146,461	3,791,849	9,686,329	69%	546,611	30,500,627
2038	0%	0	0	18%	150,744	4,060,311	10,352,921	68%	571,544	33,174,722
2039	0%	0	0	18%	156,243	4,376,689	11,138,907	68%	592,396	35,754,101
2040	0%	0	0	18%	164,020	4,773,900	12,129,938	68%	616,901	38,681,600
2041	0%	0	0	18%	168,771	5,101,194	12,941,520	68%	634,772	41,327,871
2042	0%	0	0	18%	172,642	5,413,474	13,718,442	68%	649,331	43,853,423
2043	0%	0	0	18%	177,341	5,756,043	14,582,282	68%	667,002	46,629,251
2044	0%	0	0	18%	179,451	6,005,420	15,221,972	68%	674,940	48,657,601
2045	0%	0	0	18%	162,153	5,576,255	14,149,450	68%	609,877	45,193,705

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	0%	0	0	1,176	0.03	0.04
2027	0%	0	0	0%	0	0	1,281	0.04	0.05
2028	0%	0	0	0%	0	0	1,350	0.04	0.05
2029	0%	0	0	0%	0	0	1,361	0.04	0.05
2030	0%	0	0	0%	0	0	1,410	0.04	0.04
2031	0%	0	0	0%	0	0	1,418	0.04	0.04
2032	0%	0	0	0%	0	0	1,354	0.04	0.04
2033	6%	36,862	1,661,990	0%	0	0	1,190	0.04	0.03
2034	8%	53,734	2,524,392	0%	0	0	956	0.03	0.02
2035	13%	90,819	4,442,897	0%	0	0	662	0.03	0.01
2036	14%	102,670	5,227,063	0%	0	0	716	0.03	0.01
2037	13%	100,662	5,330,745	0%	0	0	793	0.03	0.02
2038	13%	112,460	6,193,359	0%	0	0	848	0.03	0.02
2039	13%	116,563	6,673,137	0%	0	0	912	0.03	0.02
2040	13%	120,138	7,143,681	0%	0	0	993	0.03	0.02
2041	13%	123,618	7,630,888	0%	0	0	1,060	0.03	0.02
2042	13%	126,454	8,096,626	0%	0	0	1,123	0.04	0.02
2043	13%	129,895	8,609,871	0%	0	0	1,194	0.04	0.02
2044	13%	131,441	8,985,639	0%	0	0	1,246	0.04	0.02
2045	13%	118,770	8,347,283	0%	0	0	1,158	0.03	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-49. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	65%	64,497	4,139,198	4%	4,114	50,877	136,660	31%	30,616	823,259
2027	57%	69,408	4,689,197	4%	5,030	65,571	175,255	39%	47,331	1,336,696
2028	49%	73,318	5,209,164	4%	6,124	84,058	223,637	47%	70,186	2,082,624
2029	41%	75,042	5,600,876	4%	7,407	106,921	283,234	55%	100,580	3,134,673
2030	32%	70,975	5,559,659	11%	25,146	380,730	1,004,516	57%	125,676	4,113,703
2031	24%	63,763	5,236,564	17%	45,383	721,111	1,895,508	59%	156,532	5,375,018
2032	18%	56,405	4,852,327	18%	55,817	930,086	2,436,526	64%	201,141	7,238,307
2033	12%	43,791	3,942,469	18%	64,788	1,131,099	2,953,586	64%	234,524	8,839,470
2034	6%	25,024	2,355,959	18%	73,841	1,349,569	3,513,416	68%	284,652	11,227,112
2035	0%	0	0	19%	87,498	1,672,493	4,341,677	69%	323,850	13,356,070
2036	0%	0	0	18%	95,328	1,904,433	4,930,439	68%	358,456	15,447,846
2037	0%	0	0	18%	107,133	2,235,234	5,772,259	69%	399,835	17,992,179
2038	0%	0	0	18%	113,768	2,477,213	6,382,055	68%	431,351	20,254,083
2039	0%	0	0	18%	123,168	2,796,970	7,189,731	68%	466,989	22,865,056
2040	0%	0	0	18%	132,029	3,124,778	8,015,428	68%	496,578	25,336,854
2041	0%	0	0	18%	140,369	3,460,229	8,858,376	68%	527,945	28,053,244
2042	0%	0	0	18%	147,089	3,774,800	9,644,183	68%	553,221	30,598,885
2043	0%	0	0	18%	154,543	4,126,387	10,522,814	68%	581,258	33,443,696
2044	0%	0	0	18%	160,030	4,443,888	11,311,334	68%	601,896	36,011,198
2045	0%	0	0	18%	166,498	4,804,145	12,208,162	68%	626,220	38,925,172
2046	0%	0	0	18%	171,155	5,128,726	13,012,656	68%	643,736	41,549,099
2047	0%	0	0	18%	174,877	5,436,451	13,777,817	68%	657,736	44,037,378
2048	0%	0	0	18%	179,371	5,771,778	14,622,992	68%	674,638	46,754,135
2049	0%	0	0	18%	181,176	6,010,410	15,235,046	68%	681,428	48,694,986
2050	0%	0	0	18%	163,362	5,568,149	14,128,846	68%	614,425	45,124,868

Table A-49. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 1c in Calendar Year 2050

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	0%	0	0	350	0.01	0.01
2027	0%	0	0	0%	0	0	398	0.01	0.02
2028	0%	0	0	0%	0	0	445	0.01	0.02
2029	0%	0	0	0%	0	0	482	0.01	0.02
2030	0%	0	0	0%	0	0	537	0.02	0.02
2031	0%	0	0	0%	0	0	584	0.02	0.02
2032	0%	0	0	0%	0	0	597	0.02	0.02
2033	6%	21,821	785,830	0%	0	0	565	0.02	0.02
2034	8%	33,548	1,263,409	0%	0	0	481	0.02	0.01
2035	13%	60,228	2,369,748	0%	0	0	355	0.02	0.008
2036	14%	71,228	2,926,162	0%	0	0	404	0.02	0.009
2037	13%	73,632	3,156,177	0%	0	0	473	0.02	0.01
2038	13%	84,875	3,793,317	0%	0	0	523	0.02	0.01
2039	13%	91,887	4,279,183	0%	0	0	589	0.02	0.01
2040	13%	96,706	4,689,788	0%	0	0	656	0.03	0.01
2041	13%	102,814	5,189,078	0%	0	0	725	0.03	0.01
2042	13%	107,737	5,656,125	0%	0	0	790	0.03	0.02
2043	13%	113,197	6,180,287	0%	0	0	862	0.03	0.02
2044	13%	117,216	6,653,010	0%	0	0	926	0.03	0.02
2045	13%	121,953	7,189,688	0%	0	0	1000	0.03	0.02
2046	13%	125,364	7,672,852	0%	0	0	1,065	0.03	0.02
2047	13%	128,090	8,131,796	0%	0	0	1,128	0.04	0.02
2048	13%	131,382	8,634,227	0%	0	0	1,197	0.04	0.02
2049	13%	132,704	8,993,915	0%	0	0	1,247	0.04	0.02
2050	13%	119,656	8,335,870	0%	0	0	1,157	0.03	0.02

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-50. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2026

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	65%	540,131	97,639,769	4%	34,449	1,220,027	3,088,034	11%	89,660	6,866,855

Table A-50. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	20%	166,731	12,056,007	0%	0	0	8,247	0.11	0.14

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	65%	562,392	88,712,763	4%	35,869	1,108,113	2,804,580	11%	93,356	6,216,252
2027	57%	506,170	82,823,038	4%	36,682	1,175,675	2,972,420	11%	97,957	6,763,472
2028	49%	448,945	76,077,298	4%	37,500	1,244,657	3,146,136	11%	103,726	7,417,910
2029	41%	382,216	66,862,077	4%	37,726	1,292,471	3,268,769	12%	107,741	7,961,945
2030	32%	271,278	48,854,015	4%	33,914	1,195,950	3,027,919	12%	101,252	7,716,317

Table A-51. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	20%	173,603	10,953,751	0%	0	0	7,493	0.12	0.16
2027	28%	247,209	16,179,999	0%	0	0	7,024	0.11	0.14
2028	36%	326,043	22,100,233	0%	0	0	6,486	0.10	0.12
2029	43%	404,551	28,307,642	0%	0	0	5,742	0.08	0.10
2030	52%	441,299	31,789,161	0%	0	0	4,248	0.06	0.07

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-52. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	65%	467,482	60,539,560	4%	29,815	754,625	1,930,143	11%	77,601	4,248,646
2027	57%	430,704	58,014,343	4%	31,213	822,291	2,099,102	11%	83,353	4,746,114
2028	49%	390,089	54,639,940	4%	32,584	892,959	2,275,365	11%	90,128	5,333,845
2029	41%	338,901	49,344,310	4%	33,451	953,218	2,424,492	12%	95,531	5,873,508
2030	32%	276,003	41,738,586	4%	34,505	1,021,517	2,594,022	12%	103,016	6,575,282
2031	24%	213,410	33,502,607	4%	35,573	1,093,525	2,772,634	12%	106,205	7,033,396
2032	18%	164,104	26,722,257	4%	36,472	1,163,085	2,945,735	12%	108,890	7,476,741
2033	12%	112,719	19,004,076	4%	37,578	1,240,654	3,141,258	12%	112,190	7,976,623
2034	6%	57,245	9,957,437	4%	38,168	1,299,952	3,293,065	12%	113,952	8,366,832
2035	0%	0	0	4%	34,638	1,213,298	3,076,767	12%	103,414	7,823,380

Table A-52. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2035

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	20%	144,305	7,475,083	0%	0	0	5,115	0.10	0.14
2027	28%	210,352	11,333,465	0%	0	0	4,922	0.10	0.13
2028	36%	283,299	15,872,743	0%	0	0	4,660	0.09	0.12
2029	43%	358,704	20,891,081	0%	0	0	4,238	0.08	0.10
2030	52%	448,985	27,159,173	0%	0	0	3,630	0.06	0.08
2031	60%	534,022	33,533,743	0%	0	0	2,970	0.05	0.06
2032	66%	602,224	39,225,755	0%	0	0	2,429	0.04	0.05
2033	72%	676,837	45,645,106	0%	0	0	1,813	0.03	0.03
2034	78%	744,711	51,815,687	0%	0	0	1,085	0.02	0.02
2035	84%	727,792	52,087,406	0%	0	0	252	0.007	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-53. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	65%	324,168	33,911,685	4%	20,675	421,047	1,090,413	11%	53,811	2,380,112
2027	57%	314,930	34,373,272	4%	22,823	485,341	1,253,824	11%	60,947	2,812,115
2028	49%	294,302	33,491,115	4%	24,583	545,508	1,406,015	11%	67,997	3,270,853
2029	41%	267,079	31,668,216	4%	26,362	610,009	1,568,829	12%	75,286	3,773,157
2030	32%	222,088	27,421,128	4%	27,764	669,514	1,718,317	12%	82,893	4,325,829
2031	24%	177,426	22,797,903	4%	29,575	742,704	1,902,479	12%	88,297	4,795,314
2032	18%	139,693	18,670,261	4%	31,047	811,564	2,074,749	12%	92,692	5,235,411
2033	12%	98,033	13,625,389	4%	32,682	888,696	2,267,776	12%	97,574	5,728,006
2034	6%	50,852	7,346,988	4%	33,905	958,694	2,441,908	12%	101,227	6,173,591
2035	0%	0	0	4%	35,347	1,038,360	2,640,531	12%	105,530	6,681,472
2036	0%	0	0	4%	36,408	1,110,551	2,819,782	12%	108,697	7,140,339
2037	0%	0	0	4%	37,287	1,179,840	2,992,407	12%	111,321	7,581,528
2038	0%	0	0	4%	38,359	1,256,478	3,185,885	12%	114,524	8,075,024
2039	0%	0	0	4%	38,889	1,313,727	3,332,835	12%	116,107	8,451,703
2040	0%	0	0	4%	35,217	1,222,994	3,106,042	12%	105,142	7,882,098

Table A-53. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2040

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	20%	100,066	4,187,223	0%	0	0	2,866	0.07	0.09
2027	28%	153,809	6,715,034	0%	0	0	2,917	0.07	0.09
2028	36%	213,735	9,729,071	0%	0	0	2,857	0.07	0.09
2029	43%	282,685	13,407,489	0%	0	0	2,721	0.06	0.08
2030	52%	361,281	17,842,846	0%	0	0	2,386	0.05	0.07
2031	60%	443,977	22,819,090	0%	0	0	2,022	0.04	0.05
2032	66%	512,639	27,406,185	0%	0	0	1,698	0.04	0.04
2033	72%	588,656	32,726,258	0%	0	0	1,301	0.03	0.03
2034	78%	661,545	38,231,651	0%	0	0	801	0.02	0.02
2035	84%	742,681	44,579,105	0%	0	0	216	0.007	0.004
2036	84%	764,974	47,666,794	0%	0	0	231	0.007	0.004
2037	84%	783,440	50,635,276	0%	0	0	245	0.008	0.004
2038	84%	805,975	53,929,091	0%	0	0	261	0.008	0.005
2039	84%	817,118	56,397,065	0%	0	0	273	0.008	0.005
2040	84%	739,955	52,515,117	0%	0	0	254	0.007	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-54. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	65%	167,925	13,913,800	4%	10,710	171,981	451,908	11%	27,875	979,732
2027	57%	173,839	15,087,722	4%	12,598	212,114	555,489	11%	33,642	1,237,162
2028	49%	174,181	15,820,703	4%	14,549	256,617	669,890	11%	40,244	1,547,489
2029	41%	166,713	15,834,899	4%	16,455	303,793	790,664	12%	46,994	1,888,561
2030	32%	147,252	14,612,516	4%	18,409	355,407	922,379	12%	54,961	2,306,853
2031	24%	123,062	12,750,639	4%	20,513	413,850	1,071,177	12%	61,243	2,683,184
2032	18%	102,163	11,044,387	4%	22,706	478,352	1,235,027	12%	67,790	3,098,236
2033	12%	73,974	8,338,115	4%	24,661	542,144	1,396,451	12%	73,628	3,508,235
2034	6%	40,081	4,707,395	4%	26,724	612,627	1,574,494	12%	79,786	3,960,912
2035	0%	0	0	4%	28,447	679,589	1,742,931	12%	84,931	4,390,345
2036	0%	0	0	4%	30,274	753,214	1,927,965	12%	90,386	4,862,426
2037	0%	0	0	4%	31,753	822,345	2,100,691	12%	94,802	5,304,019
2038	0%	0	0	4%	33,394	899,667	2,293,959	12%	99,700	5,797,554
2039	0%	0	0	4%	34,612	969,669	2,467,860	12%	103,338	6,242,847
2040	0%	0	0	4%	36,047	1,049,189	2,665,871	12%	107,620	6,749,460
2041	0%	0	0	4%	37,091	1,121,019	2,843,979	12%	110,738	7,205,621
2042	0%	0	0	4%	37,942	1,189,565	3,014,512	12%	113,278	7,641,631
2043	0%	0	0	4%	38,974	1,264,855	3,204,367	12%	116,360	8,126,069
2044	0%	0	0	4%	39,438	1,319,800	3,345,305	12%	117,745	8,487,539
2045	0%	0	0	4%	35,636	1,225,722	3,110,204	12%	106,395	7,896,358

Table A-54. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	20%	51,836	1,717,997	0%	0	0	1,176	0.03	0.04
2027	28%	84,901	2,947,481	0%	0	0	1,281	0.04	0.05
2028	36%	126,498	4,595,868	0%	0	0	1,350	0.04	0.05
2029	43%	176,455	6,704,079	0%	0	0	1,361	0.04	0.05
2030	52%	239,541	9,508,321	0%	0	0	1,272	0.03	0.04
2031	60%	307,941	12,762,489	0%	0	0	1,132	0.03	0.04
2032	66%	374,915	16,212,119	0%	0	0	1,005	0.03	0.03
2033	72%	444,190	20,026,975	0%	0	0	797	0.02	0.02
2034	78%	521,423	24,495,954	0%	0	0	514	0.01	0.01
2035	84%	597,713	29,240,461	0%	0	0	143	0.006	0.003
2036	84%	636,105	32,385,067	0%	0	0	158	0.006	0.003
2037	84%	667,180	35,331,680	0%	0	0	172	0.006	0.003
2038	84%	701,654	38,641,177	0%	0	0	188	0.007	0.004
2039	84%	727,252	41,634,573	0%	0	0	202	0.007	0.004
2040	84%	757,391	45,036,251	0%	0	0	218	0.007	0.004
2041	84%	779,333	48,107,775	0%	0	0	233	0.008	0.004
2042	84%	797,208	51,043,944	0%	0	0	247	0.008	0.004
2043	84%	818,902	54,279,621	0%	0	0	262	0.008	0.005
2044	84%	828,649	56,648,596	0%	0	0	274	0.008	0.005
2045	84%	748,769	52,624,174	0%	0	0	255	0.007	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-55. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2050

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	65%	64,497	4,139,198	4%	4,114	50,877	136,660	11%	10,706	295,109
2027	57%	69,408	4,689,197	4%	5,030	65,571	175,255	11%	13,432	388,383
2028	49%	73,318	5,209,164	4%	6,124	84,058	223,637	11%	16,940	513,531
2029	41%	75,042	5,600,876	4%	7,407	106,921	283,234	12%	21,153	672,043
2030	32%	70,975	5,559,659	4%	8,873	134,574	355,060	12%	26,491	881,507
2031	24%	63,763	5,236,564	4%	10,628	169,173	444,687	12%	31,732	1,105,371
2032	18%	56,405	4,852,327	4%	12,536	209,209	548,060	12%	37,427	1,364,096
2033	12%	43,791	3,942,469	4%	14,599	255,208	666,413	12%	43,586	1,661,080
2034	6%	25,024	2,355,959	4%	16,685	305,290	794,782	12%	49,813	1,984,022
2035	0%	0	0	4%	18,865	360,976	937,068	12%	56,324	2,343,007
2036	0%	0	0	4%	21,003	419,968	1,087,267	12%	62,706	2,722,815
2037	0%	0	0	4%	23,227	484,984	1,252,421	12%	69,345	3,141,091
2038	0%	0	0	4%	25,203	549,142	1,414,757	12%	75,245	3,553,333
2039	0%	0	0	4%	27,285	619,964	1,593,644	12%	81,462	4,008,057
2040	0%	0	0	4%	29,016	687,067	1,762,410	12%	86,629	4,438,238
2041	0%	0	0	4%	30,849	760,761	1,947,591	12%	92,102	4,910,573
2042	0%	0	0	4%	32,326	829,839	2,120,143	12%	96,511	5,351,582
2043	0%	0	0	4%	33,964	907,037	2,313,062	12%	101,402	5,844,049
2044	0%	0	0	4%	35,170	976,725	2,486,125	12%	105,002	6,287,030
2045	0%	0	0	4%	36,591	1,055,810	2,682,995	12%	109,246	6,790,499
2046	0%	0	0	4%	37,615	1,127,036	2,859,529	12%	112,302	7,242,409
2047	0%	0	0	4%	38,433	1,194,575	3,027,460	12%	114,744	7,671,556
2048	0%	0	0	4%	39,420	1,268,267	3,213,196	12%	117,693	8,145,301
2049	0%	0	0	4%	39,817	1,320,843	3,348,041	12%	118,877	8,491,081
2050	0%	0	0	4%	35,902	1,223,884	3,105,533	12%	107,188	7,881,262

Table A-55. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 1d and 1d-1 in Calendar Year 2050

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	20%	19,909	511,085	0%	0	0	350	0.01	0.01
2027	28%	33,898	916,064	0%	0	0	398	0.01	0.02
2028	36%	53,247	1,513,247	0%	0	0	445	0.01	0.02
2029	43%	79,427	2,371,263	0%	0	0	482	0.01	0.02
2030	52%	115,458	3,617,654	0%	0	0	484	0.01	0.02
2031	60%	159,555	5,241,430	0%	0	0	465	0.01	0.02
2032	66%	206,994	7,122,759	0%	0	0	442	0.01	0.02
2033	72%	262,949	9,469,254	0%	0	0	377	0.01	0.01
2034	78%	325,544	12,259,745	0%	0	0	258	0.008	0.008
2035	84%	396,387	15,596,251	0%	0	0	77	0.004	0.002
2036	84%	441,302	18,129,484	0%	0	0	89	0.004	0.002
2037	84%	488,028	20,918,848	0%	0	0	103	0.004	0.002
2038	84%	529,547	23,667,001	0%	0	0	116	0.005	0.003
2039	84%	573,298	26,698,382	0%	0	0	130	0.005	0.003
2040	84%	609,667	29,566,053	0%	0	0	144	0.006	0.003
2041	84%	648,178	32,713,752	0%	0	0	159	0.006	0.003
2042	84%	679,210	35,658,179	0%	0	0	174	0.006	0.003
2043	84%	713,632	38,962,677	0%	0	0	189	0.007	0.004
2044	84%	738,970	41,942,891	0%	0	0	204	0.007	0.004
2045	84%	768,833	45,326,292	0%	0	0	220	0.007	0.004
2046	84%	790,339	48,372,330	0%	0	0	234	0.008	0.004
2047	84%	807,527	51,265,670	0%	0	0	248	0.008	0.004
2048	84%	828,277	54,433,171	0%	0	0	263	0.008	0.005
2049	84%	836,615	56,700,766	0%	0	0	274	0.008	0.005
2050	84%	754,352	52,552,223	0%	0	0	254	0.008	0.004

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-56. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	65%	540,131	97,639,769	24%	201,179	7,122,038	18,026,732	11%	89,660	6,866,855

Table A-56. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	0%	0	0	9,470	0.15	0.16

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-57. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	65%	562,392	88,712,763	24%	209,471	6,470,997	16,377,775	11%	93,356	6,216,252
2027	57%	506,170	82,823,038	32%	283,891	9,098,918	23,004,500	11%	97,957	6,763,472
2028	49%	448,945	76,077,298	40%	363,543	12,066,027	30,499,462	11%	103,726	7,417,910
2029	41%	382,216	66,862,077	47%	442,277	15,149,570	38,314,540	12%	107,741	7,961,945
2030	32%	271,278	48,854,015	56%	475,213	16,751,030	42,410,446	12%	101,252	7,716,317

Table A-57. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2030

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	0%	0	0	8,604	0.16	0.18
2027	0%	0	0	0%	0	0	8,664	0.16	0.17
2028	0%	0	0	0%	0	0	8,726	0.17	0.16
2029	0%	0	0	0%	0	0	8,611	0.17	0.15
2030	0%	0	0	0%	0	0	7,472	0.15	0.12

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-58. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fuel Consumption[3] (MJ of electricity/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of electricity/day)**
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	65%	467,482	60,539,560	24%	174,121	4,405,065	11,267,062	11%	77,601	4,248,646
2027	57%	430,704	58,014,343	32%	241,564	6,361,596	16,239,550	11%	83,353	4,746,114
2028	49%	390,089	54,639,940	40%	315,883	8,654,239	22,052,020	11%	90,128	5,333,845
2029	41%	338,901	49,344,310	47%	392,155	11,172,708	28,417,556	12%	95,531	5,873,508
2030	32%	276,003	41,738,586	56%	483,490	14,312,319	36,344,465	12%	103,016	6,575,282
2031	24%	213,410	33,502,607	64%	569,594	17,509,546	44,395,455	12%	106,205	7,033,396
2032	18%	164,104	26,722,257	70%	638,697	20,369,220	51,588,926	12%	108,890	7,476,741
2033	12%	112,719	19,004,076	76%	714,415	23,588,087	59,723,539	12%	112,190	7,976,623
2034	6%	57,245	9,957,437	82%	782,879	26,661,420	67,539,241	12%	113,952	8,366,832
2035	0%	0	0	88%	762,430	26,697,090	67,700,364	12%	103,414	7,823,380

Table A-58. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2035

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	0%	0	0	5,879	0.13	0.15
2027	0%	0	0	0%	0	0	6,079	0.14	0.15
2028	0%	0	0	0%	0	0	6,279	0.15	0.15
2029	0%	0	0	0%	0	0	6,367	0.15	0.14
2030	0%	0	0	0%	0	0	6,393	0.16	0.13
2031	0%	0	0	0%	0	0	6,378	0.16	0.13
2032	0%	0	0	0%	0	0	6,412	0.17	0.12
2033	0%	0	0	0%	0	0	6,446	0.17	0.12
2034	0%	0	0	0%	0	0	6,345	0.18	0.11
2035	0%	0	0	0%	0	0	5,543	0.16	0.09

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle

CH_4 - methane

CO_2 - carbon dioxide

EMFAC - EMission FACtor Model

ICEV - internal combustion engine vehicle

MJ - megajoule

N_2O - nitrous oxide

PHEV - plug-in hybrid electric vehicle

Table A-59. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	65%	324,168	33,911,685	24%	120,741	2,456,781	6,362,489	11%	53,811	2,380,112
2027	57%	314,930	34,373,272	32%	176,632	3,753,160	9,695,864	11%	60,947	2,812,115
2028	49%	294,302	33,491,115	40%	238,318	5,284,446	13,620,346	11%	67,997	3,270,853
2029	41%	267,079	31,668,216	47%	309,047	7,146,500	18,379,446	12%	75,286	3,773,157
2030	32%	222,088	27,421,128	56%	389,045	9,375,775	24,063,052	12%	82,893	4,325,829
2031	24%	177,426	22,797,903	64%	473,551	11,886,096	30,446,929	12%	88,297	4,795,314
2032	18%	139,693	18,670,261	70%	543,686	14,206,290	36,318,127	12%	92,692	5,235,411
2033	12%	98,033	13,625,389	76%	621,338	16,890,765	43,101,880	12%	97,574	5,728,006
2034	6%	50,852	7,346,988	82%	695,450	19,661,005	50,078,899	12%	101,227	6,173,591
2035	0%	0	0	88%	778,027	22,854,249	58,117,967	12%	105,530	6,681,472
2036	0%	0	0	88%	801,381	24,445,808	62,069,943	12%	108,697	7,140,339
2037	0%	0	0	88%	820,727	25,973,021	65,874,884	12%	111,321	7,581,528
2038	0%	0	0	88%	844,334	27,659,635	70,132,899	12%	114,524	8,075,024
2039	0%	0	0	88%	856,007	28,915,842	73,357,488	12%	116,107	8,451,703
2040	0%	0	0	88%	775,172	26,912,195	68,349,021	12%	105,142	7,882,098

Table A-59. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2040

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	0%	0	0	3,297	0.09	0.10
2027	0%	0	0	0%	0	0	3,608	0.10	0.11
2028	0%	0	0	0%	0	0	3,857	0.11	0.11
2029	0%	0	0	0%	0	0	4,098	0.12	0.11
2030	0%	0	0	0%	0	0	4,215	0.12	0.10
2031	0%	0	0	0%	0	0	4,359	0.13	0.10
2032	0%	0	0	0%	0	0	4,502	0.14	0.10
2033	0%	0	0	0%	0	0	4,644	0.14	0.10
2034	0%	0	0	0%	0	0	4,702	0.15	0.09
2035	0%	0	0	0%	0	0	4,758	0.16	0.09
2036	0%	0	0	0%	0	0	5,082	0.16	0.09
2037	0%	0	0	0%	0	0	5,393	0.17	0.10
2038	0%	0	0	0%	0	0	5,742	0.18	0.10
2039	0%	0	0	0%	0	0	6,006	0.18	0.10
2040	0%	0	0	0%	0	0	5,596	0.16	0.09

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-60. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	65%	167,925	13,913,800	24%	62,546	1,002,674	2,634,686	11%	27,875	979,732
2027	57%	173,839	15,087,722	32%	97,499	1,639,041	4,292,360	11%	33,642	1,237,162
2028	49%	174,181	15,820,703	40%	141,047	2,484,175	6,484,862	11%	40,244	1,547,489
2029	41%	166,713	15,834,899	47%	192,910	3,556,786	9,257,046	12%	46,994	1,888,561
2030	32%	147,252	14,612,516	56%	257,950	4,974,048	12,909,018	12%	54,961	2,306,853
2031	24%	123,062	12,750,639	64%	328,454	6,619,481	17,133,367	12%	61,243	2,683,184
2032	18%	102,163	11,044,387	70%	397,621	8,368,951	21,607,289	12%	67,790	3,098,236
2033	12%	73,974	8,338,115	76%	468,852	10,298,591	26,527,044	12%	73,628	3,508,235
2034	6%	40,081	4,707,395	82%	548,147	12,556,980	32,272,327	12%	79,786	3,960,912
2035	0%	0	0	88%	626,161	14,949,637	38,341,070	12%	84,931	4,390,345
2036	0%	0	0	88%	666,380	16,570,887	42,415,687	12%	90,386	4,862,426
2037	0%	0	0	88%	698,933	18,093,950	46,221,243	12%	94,802	5,304,019
2038	0%	0	0	88%	735,048	19,797,683	50,479,837	12%	99,700	5,797,554
2039	0%	0	0	88%	761,864	21,340,809	54,313,494	12%	103,338	6,242,847
2040	0%	0	0	88%	793,438	23,093,397	58,677,697	12%	107,620	6,749,460
2041	0%	0	0	88%	816,424	24,677,159	62,604,937	12%	110,738	7,205,621
2042	0%	0	0	88%	835,150	26,188,211	66,364,303	12%	113,278	7,641,631
2043	0%	0	0	88%	857,877	27,845,352	70,543,046	12%	116,360	8,126,069
2044	0%	0	0	88%	868,087	29,051,020	73,635,778	12%	117,745	8,487,539
2045	0%	0	0	88%	784,405	26,973,776	68,444,515	12%	106,395	7,896,358

Table A-60. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	0%	0	0	1,355	0.04	0.05
2027	0%	0	0	0%	0	0	1,587	0.05	0.05
2028	0%	0	0	0%	0	0	1,826	0.06	0.06
2029	0%	0	0	0%	0	0	2,054	0.07	0.06
2030	0%	0	0	0%	0	0	2,253	0.08	0.06
2031	0%	0	0	0%	0	0	2,447	0.09	0.07
2032	0%	0	0	0%	0	0	2,673	0.10	0.07
2033	0%	0	0	0%	0	0	2,854	0.11	0.07
2034	0%	0	0	0%	0	0	3,028	0.11	0.07
2035	0%	0	0	0%	0	0	3,139	0.12	0.06
2036	0%	0	0	0%	0	0	3,473	0.13	0.07
2037	0%	0	0	0%	0	0	3,784	0.14	0.07
2038	0%	0	0	0%	0	0	4,133	0.15	0.08
2039	0%	0	0	0%	0	0	4,447	0.15	0.08
2040	0%	0	0	0%	0	0	4,804	0.16	0.09
2041	0%	0	0	0%	0	0	5,126	0.17	0.09
2042	0%	0	0	0%	0	0	5,433	0.17	0.10
2043	0%	0	0	0%	0	0	5,776	0.18	0.10
2044	0%	0	0	0%	0	0	6,029	0.18	0.10
2045	0%	0	0	0%	0	0	5,604	0.16	0.10

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-61. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	65%	64,497	4,139,198	24%	24,023	296,043	795,196	11%	10,706	295,109
2027	57%	69,408	4,689,197	32%	38,928	505,776	1,351,812	11%	13,432	388,383
2028	49%	73,318	5,209,164	40%	59,371	812,427	2,161,469	11%	16,940	513,531
2029	41%	75,042	5,600,876	47%	86,834	1,250,068	3,311,433	12%	21,153	672,043
2030	32%	70,975	5,559,659	56%	124,331	1,881,108	4,963,106	12%	26,491	881,507
2031	24%	63,763	5,236,564	64%	170,183	2,703,072	7,105,273	12%	31,732	1,105,371
2032	18%	56,405	4,852,327	70%	219,530	3,656,882	9,579,853	12%	37,427	1,364,096
2033	12%	43,791	3,942,469	76%	277,548	4,844,114	12,649,212	12%	43,586	1,661,080
2034	6%	25,024	2,355,959	82%	342,228	6,253,137	16,279,177	12%	49,813	1,984,022
2035	0%	0	0	88%	415,252	7,935,655	20,600,419	12%	56,324	2,343,007
2036	0%	0	0	88%	462,305	9,233,976	23,906,101	12%	62,706	2,722,815
2037	0%	0	0	88%	511,255	10,665,010	27,541,275	12%	69,345	3,141,091
2038	0%	0	0	88%	554,750	12,077,399	31,115,059	12%	75,245	3,553,333
2039	0%	0	0	88%	600,583	13,636,644	35,053,579	12%	81,462	4,008,057
2040	0%	0	0	88%	638,683	15,114,332	38,770,069	12%	86,629	4,438,238
2041	0%	0	0	88%	679,027	16,737,200	42,848,155	12%	92,102	4,910,573
2042	0%	0	0	88%	711,536	18,259,200	46,650,176	12%	96,511	5,351,582
2043	0%	0	0	88%	747,596	19,960,328	50,901,391	12%	101,402	5,844,049
2044	0%	0	0	88%	774,140	21,496,670	54,716,951	12%	105,002	6,287,030
2045	0%	0	0	88%	805,424	23,239,836	59,056,434	12%	109,246	6,790,499
2046	0%	0	0	88%	827,953	24,810,504	62,949,469	12%	112,302	7,242,409
2047	0%	0	0	88%	845,960	26,299,555	66,652,019	12%	114,744	7,671,556
2048	0%	0	0	88%	867,698	27,921,700	70,740,561	12%	117,693	8,145,301
2049	0%	0	0	88%	876,432	29,075,425	73,699,707	12%	118,877	8,491,081
2050	0%	0	0	88%	790,255	26,934,839	68,345,548	12%	107,188	7,881,262

Table A-61. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 2a and 2b in Calendar Year 2050

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	0%	0	0	404	0.02	0.02
2027	0%	0	0	0%	0	0	495	0.02	0.02
2028	0%	0	0	0%	0	0	603	0.02	0.02
2029	0%	0	0	0%	0	0	730	0.03	0.02
2030	0%	0	0	0%	0	0	862	0.04	0.03
2031	0%	0	0	0%	0	0	1,010	0.04	0.03
2032	0%	0	0	0%	0	0	1,182	0.05	0.03
2033	0%	0	0	0%	0	0	1,358	0.06	0.04
2034	0%	0	0	0%	0	0	1,526	0.07	0.04
2035	0%	0	0	0%	0	0	1,687	0.08	0.04
2036	0%	0	0	0%	0	0	1,957	0.09	0.04
2037	0%	0	0	0%	0	0	2,255	0.10	0.05
2038	0%	0	0	0%	0	0	2,547	0.11	0.06
2039	0%	0	0	0%	0	0	2,870	0.12	0.06
2040	0%	0	0	0%	0	0	3,174	0.12	0.07
2041	0%	0	0	0%	0	0	3,508	0.13	0.07
2042	0%	0	0	0%	0	0	3,819	0.14	0.08
2043	0%	0	0	0%	0	0	4,167	0.15	0.08
2044	0%	0	0	0%	0	0	4,480	0.16	0.09
2045	0%	0	0	0%	0	0	4,835	0.16	0.09
2046	0%	0	0	0%	0	0	5,154	0.17	0.09
2047	0%	0	0	0%	0	0	5,457	0.17	0.10
2048	0%	0	0	0%	0	0	5,792	0.18	0.10
2049	0%	0	0	0%	0	0	6,034	0.18	0.10
2050	0%	0	0	0%	0	0	5,596	0.17	0.10

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-62. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle Fleet Mix[1] (%)	Internal Combustion Engine Vehicle Population[2] (vehicles)	Internal Combustion Engine Vehicle Fuel Consumption[3] (MJ of gasoline/day)	Plug-in Hybrid Electric Vehicle Fleet Mix[1] (%)	Plug-in Hybrid Electric Vehicle Population[2] (vehicles)	Plug-in Hybrid Electric Vehicle Fuel Consumption[3] (MJ of gasoline/day)	Plug-in Hybrid Electric Vehicle Fuel Consumption[3] (MJ of electricity/day)	Battery Electric Vehicle Fleet Mix[1] (%)	Battery Electric Vehicle Population[2] (vehicles)	Battery Electric Vehicle Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	65%	540,131	97,639,769	4%	34,449	1,220,027	3,088,034	11%	89,660	6,866,855

Table A-62. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	20%	166,731	21,378,386	9,997	0.14	0.17

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-63. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	65%	562,392	88,712,763	4%	35,869	1,108,113	2,804,580	11%	93,356	6,216,252
2027	57%	506,170	82,823,038	4%	36,682	1,175,675	2,972,420	11%	97,957	6,763,472
2028	49%	448,945	76,077,298	4%	37,500	1,244,657	3,146,136	11%	103,726	7,417,910
2029	41%	382,216	66,862,077	4%	37,726	1,292,471	3,268,769	12%	107,741	7,961,945
2030	32%	271,278	48,854,015	4%	33,914	1,195,950	3,027,919	12%	101,252	7,716,317

Table A-63. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2030

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	20%	173,603	19,423,803	9,083	0.15	0.20
2027	0%	0	0	28%	247,209	28,691,278	9,373	0.15	0.19
2028	0%	0	0	36%	326,043	39,189,369	9,695	0.15	0.19
2029	0%	0	0	43%	404,551	50,196,693	9,852	0.14	0.18
2030	0%	0	0	52%	441,299	56,370,317	8,863	0.12	0.15

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-64. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2035

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	65%	467,482	60,539,560	4%	29,815	754,625	1,930,143	11%	77,601	4,248,646
2027	57%	430,704	58,014,343	4%	31,213	822,291	2,099,102	11%	83,353	4,746,114
2028	49%	390,089	54,639,940	4%	32,584	892,959	2,275,365	11%	90,128	5,333,845
2029	41%	338,901	49,344,310	4%	33,451	953,218	2,424,492	12%	95,531	5,873,508
2030	32%	276,003	41,738,586	4%	34,505	1,021,517	2,594,022	12%	103,016	6,575,282
2031	24%	213,410	33,502,607	4%	35,573	1,093,525	2,772,634	12%	106,205	7,033,396
2032	18%	164,104	26,722,257	4%	36,472	1,163,085	2,945,735	12%	108,890	7,476,741
2033	12%	112,719	19,004,076	4%	37,578	1,240,654	3,141,258	12%	112,190	7,976,623
2034	6%	57,245	9,957,437	4%	38,168	1,299,952	3,293,065	12%	113,952	8,366,832
2035	0%	0	0	4%	34,638	1,213,298	3,076,767	12%	103,414	7,823,380

Table A-64. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2035

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	20%	144,305	13,255,235	6,200	0.13	0.17
2027	0%	0	0	28%	210,352	20,097,133	6,567	0.13	0.17
2028	0%	0	0	36%	283,299	28,146,436	6,964	0.13	0.17
2029	0%	0	0	43%	358,704	37,045,232	7,271	0.13	0.17
2030	0%	0	0	52%	448,985	48,160,163	7,573	0.13	0.17
2031	0%	0	0	60%	534,022	59,463,907	7,838	0.13	0.17
2032	0%	0	0	66%	602,224	69,557,302	8,124	0.13	0.17
2033	0%	0	0	72%	676,837	80,940,453	8,440	0.13	0.16
2034	0%	0	0	78%	744,711	91,882,472	8,607	0.12	0.15
2035	0%	0	0	84%	727,792	92,364,300	7,814	0.11	0.13

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-65. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	65%	324,168	33,911,685	4%	20,675	421,047	1,090,413	11%	53,811	2,380,112
2027	57%	314,930	34,373,272	4%	22,823	485,341	1,253,824	11%	60,947	2,812,115
2028	49%	294,302	33,491,115	4%	24,583	545,508	1,406,015	11%	67,997	3,270,853
2029	41%	267,079	31,668,216	4%	26,362	610,009	1,568,829	12%	75,286	3,773,157
2030	32%	222,088	27,421,128	4%	27,764	669,514	1,718,317	12%	82,893	4,325,829
2031	24%	177,426	22,797,903	4%	29,575	742,704	1,902,479	12%	88,297	4,795,314
2032	18%	139,693	18,670,261	4%	31,047	811,564	2,074,749	12%	92,692	5,235,411
2033	12%	98,033	13,625,389	4%	32,682	888,696	2,267,776	12%	97,574	5,728,006
2034	6%	50,852	7,346,988	4%	33,905	958,694	2,441,908	12%	101,227	6,173,591
2035	0%	0	0	4%	35,347	1,038,360	2,640,531	12%	105,530	6,681,472
2036	0%	0	0	4%	36,408	1,110,551	2,819,782	12%	108,697	7,140,339
2037	0%	0	0	4%	37,287	1,179,840	2,992,407	12%	111,321	7,581,528
2038	0%	0	0	4%	38,359	1,256,478	3,185,885	12%	114,524	8,075,024
2039	0%	0	0	4%	38,889	1,313,727	3,332,835	12%	116,107	8,451,703
2040	0%	0	0	4%	35,217	1,222,994	3,106,042	12%	105,142	7,882,098

Table A-65. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2040

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	20%	100,066	7,425,018	3,474	0.08	0.11
2027	0%	0	0	28%	153,809	11,907,473	3,892	0.09	0.12
2028	0%	0	0	36%	213,735	17,252,133	4,270	0.10	0.13
2029	0%	0	0	43%	282,685	23,774,908	4,668	0.10	0.14
2030	0%	0	0	52%	361,281	31,639,931	4,976	0.10	0.14
2031	0%	0	0	60%	443,977	40,464,086	5,335	0.11	0.14
2032	0%	0	0	66%	512,639	48,598,179	5,677	0.11	0.15
2033	0%	0	0	72%	588,656	58,032,030	6,052	0.11	0.15
2034	0%	0	0	78%	661,545	67,794,501	6,352	0.12	0.15
2035	0%	0	0	84%	742,681	79,050,161	6,688	0.12	0.15
2036	0%	0	0	84%	764,974	84,525,424	7,151	0.12	0.15
2037	0%	0	0	84%	783,440	89,789,302	7,596	0.12	0.16
2038	0%	0	0	84%	805,975	95,630,079	8,090	0.12	0.16
2039	0%	0	0	84%	817,118	100,006,428	8,461	0.12	0.15
2040	0%	0	0	84%	739,955	93,122,741	7,878	0.11	0.13

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-66. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	65%	167,925	13,913,800	4%	10,710	171,981	451,908	11%	27,875	979,732
2027	57%	173,839	15,087,722	4%	12,598	212,114	555,489	11%	33,642	1,237,162
2028	49%	174,181	15,820,703	4%	14,549	256,617	669,890	11%	40,244	1,547,489
2029	41%	166,713	15,834,899	4%	16,455	303,793	790,664	12%	46,994	1,888,561
2030	32%	147,252	14,612,516	4%	18,409	355,407	922,379	12%	54,961	2,306,853
2031	24%	123,062	12,750,639	4%	20,513	413,850	1,071,177	12%	61,243	2,683,184
2032	18%	102,163	11,044,387	4%	22,706	478,352	1,235,027	12%	67,790	3,098,236
2033	12%	73,974	8,338,115	4%	24,661	542,144	1,396,451	12%	73,628	3,508,235
2034	6%	40,081	4,707,395	4%	26,724	612,627	1,574,494	12%	79,786	3,960,912
2035	0%	0	0	4%	28,447	679,589	1,742,931	12%	84,931	4,390,345
2036	0%	0	0	4%	30,274	753,214	1,927,965	12%	90,386	4,862,426
2037	0%	0	0	4%	31,753	822,345	2,100,691	12%	94,802	5,304,019
2038	0%	0	0	4%	33,394	899,667	2,293,959	12%	99,700	5,797,554
2039	0%	0	0	4%	34,612	969,669	2,467,860	12%	103,338	6,242,847
2040	0%	0	0	4%	36,047	1,049,189	2,665,871	12%	107,620	6,749,460
2041	0%	0	0	4%	37,091	1,121,019	2,843,979	12%	110,738	7,205,621
2042	0%	0	0	4%	37,942	1,189,565	3,014,512	12%	113,278	7,641,631
2043	0%	0	0	4%	38,974	1,264,855	3,204,367	12%	116,360	8,126,069
2044	0%	0	0	4%	39,438	1,319,800	3,345,305	12%	117,745	8,487,539
2045	0%	0	0	4%	35,636	1,225,722	3,110,204	12%	106,395	7,896,358

Table A-66. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	20%	51,836	3,046,449	1,426	0.04	0.05
2027	0%	0	0	28%	84,901	5,226,638	1,709	0.05	0.06
2028	0%	0	0	36%	126,498	8,149,650	2,017	0.05	0.07
2029	0%	0	0	43%	176,455	11,888,048	2,334	0.06	0.08
2030	0%	0	0	52%	239,541	16,860,685	2,652	0.07	0.09
2031	0%	0	0	60%	307,941	22,631,158	2,984	0.07	0.10
2032	0%	0	0	66%	374,915	28,748,236	3,359	0.08	0.10
2033	0%	0	0	72%	444,190	35,512,951	3,705	0.08	0.11
2034	0%	0	0	78%	521,423	43,437,595	4,071	0.09	0.12
2035	0%	0	0	84%	597,713	51,850,819	4,388	0.09	0.12
2036	0%	0	0	84%	636,105	57,427,010	4,860	0.10	0.13
2037	0%	0	0	84%	667,180	62,652,109	5,301	0.10	0.14
2038	0%	0	0	84%	701,654	68,520,696	5,798	0.11	0.15
2039	0%	0	0	84%	727,252	73,828,753	6,247	0.11	0.15
2040	0%	0	0	84%	757,391	79,860,798	6,757	0.12	0.15
2041	0%	0	0	84%	779,333	85,307,396	7,217	0.12	0.16
2042	0%	0	0	84%	797,208	90,513,974	7,657	0.12	0.16
2043	0%	0	0	84%	818,902	96,251,657	8,143	0.12	0.16
2044	0%	0	0	84%	828,649	100,452,456	8,498	0.12	0.15
2045	0%	0	0	84%	748,769	93,316,127	7,895	0.11	0.13

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-67. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2050

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	65%	64,497	4,139,198	4%	4,114	50,877	136,660	11%	10,706	295,109
2027	57%	69,408	4,689,197	4%	5,030	65,571	175,255	11%	13,432	388,383
2028	49%	73,318	5,209,164	4%	6,124	84,058	223,637	11%	16,940	513,531
2029	41%	75,042	5,600,876	4%	7,407	106,921	283,234	12%	21,153	672,043
2030	32%	70,975	5,559,659	4%	8,873	134,574	355,060	12%	26,491	881,507
2031	24%	63,763	5,236,564	4%	10,628	169,173	444,687	12%	31,732	1,105,371
2032	18%	56,405	4,852,327	4%	12,536	209,209	548,060	12%	37,427	1,364,096
2033	12%	43,791	3,942,469	4%	14,599	255,208	666,413	12%	43,586	1,661,080
2034	6%	25,024	2,355,959	4%	16,685	305,290	794,782	12%	49,813	1,984,022
2035	0%	0	0	4%	18,865	360,976	937,068	12%	56,324	2,343,007
2036	0%	0	0	4%	21,003	419,968	1,087,267	12%	62,706	2,722,815
2037	0%	0	0	4%	23,227	484,984	1,252,421	12%	69,345	3,141,091
2038	0%	0	0	4%	25,203	549,142	1,414,757	12%	75,245	3,553,333
2039	0%	0	0	4%	27,285	619,964	1,593,644	12%	81,462	4,008,057
2040	0%	0	0	4%	29,016	687,067	1,762,410	12%	86,629	4,438,238
2041	0%	0	0	4%	30,849	760,761	1,947,591	12%	92,102	4,910,573
2042	0%	0	0	4%	32,326	829,839	2,120,143	12%	96,511	5,351,582
2043	0%	0	0	4%	33,964	907,037	2,313,062	12%	101,402	5,844,049
2044	0%	0	0	4%	35,170	976,725	2,486,125	12%	105,002	6,287,030
2045	0%	0	0	4%	36,591	1,055,810	2,682,995	12%	109,246	6,790,499
2046	0%	0	0	4%	37,615	1,127,036	2,859,529	12%	112,302	7,242,409
2047	0%	0	0	4%	38,433	1,194,575	3,027,460	12%	114,744	7,671,556
2048	0%	0	0	4%	39,420	1,268,267	3,213,196	12%	117,693	8,145,301
2049	0%	0	0	4%	39,817	1,320,843	3,348,041	12%	118,877	8,491,081
2050	0%	0	0	4%	35,902	1,223,884	3,105,533	12%	107,188	7,881,262

Table A-67. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 2c in Calendar Year 2050

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	20%	19,909	906,284	424	0.01	0.02
2027	0%	0	0	28%	33,898	1,624,416	531	0.02	0.02
2028	0%	0	0	36%	53,247	2,683,374	664	0.02	0.03
2029	0%	0	0	43%	79,427	4,204,857	826	0.02	0.03
2030	0%	0	0	52%	115,458	6,415,025	1,009	0.03	0.04
2031	0%	0	0	60%	159,555	9,294,397	1,226	0.03	0.04
2032	0%	0	0	66%	206,994	12,630,474	1,476	0.04	0.05
2033	0%	0	0	72%	262,949	16,791,411	1,752	0.05	0.06
2034	0%	0	0	78%	325,544	21,739,666	2,038	0.05	0.07
2035	0%	0	0	84%	396,387	27,656,145	2,341	0.06	0.08
2036	0%	0	0	84%	441,302	32,148,214	2,721	0.07	0.09
2037	0%	0	0	84%	488,028	37,094,470	3,140	0.07	0.10
2038	0%	0	0	84%	529,547	41,967,649	3,552	0.08	0.11
2039	0%	0	0	84%	573,298	47,343,063	4,007	0.09	0.12
2040	0%	0	0	84%	609,667	52,428,177	4,437	0.09	0.13
2041	0%	0	0	84%	648,178	58,009,853	4,909	0.10	0.13
2042	0%	0	0	84%	679,210	63,231,075	5,350	0.11	0.14
2043	0%	0	0	84%	713,632	69,090,797	5,846	0.11	0.15
2044	0%	0	0	84%	738,970	74,375,479	6,293	0.12	0.15
2045	0%	0	0	84%	768,833	80,375,114	6,800	0.12	0.16
2046	0%	0	0	84%	790,339	85,776,520	7,257	0.12	0.16
2047	0%	0	0	84%	807,527	90,907,152	7,691	0.12	0.16
2048	0%	0	0	84%	828,277	96,523,942	8,166	0.13	0.16
2049	0%	0	0	84%	836,615	100,544,967	8,506	0.12	0.15
2050	0%	0	0	84%	754,352	93,188,539	7,884	0.11	0.13

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-68. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 3a, 3a-1, 3a-2 and 3b in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	85%	706,862	127,779,786	4%	34,449	1,220,027	3,088,034	11%	89,660	6,866,855

Table A-68. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 3a, 3a-1, 3a-2 and 3b in Calendar Year 2026

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	0%	0	0	10,714	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	85%	735,995	116,097,140	4%	35,869	1,108,113	2,804,580	11%	93,356	6,216,252
2027	85%	753,379	123,273,035	4%	36,682	1,175,675	2,972,420	11%	97,957	6,763,472
2028	85%	774,987	131,327,881	4%	37,500	1,244,657	3,146,136	11%	103,726	7,417,910
2029	84%	786,767	137,631,182	4%	37,726	1,292,471	3,268,769	12%	107,741	7,961,945
2030	84%	712,577	128,326,917	4%	33,914	1,195,950	3,027,919	12%	101,252	7,716,317

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	0%	0	0	9,735	0.16	0.21
2027	0%	0	0	0%	0	0	10,336	0.16	0.21
2028	0%	0	0	0%	0	0	11,010	0.16	0.21
2029	0%	0	0	0%	0	0	11,536	0.16	0.21
2030	0%	0	0	0%	0	0	10,754	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-70. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 3a, 3a-1, 3a-2 and 3b in Calendar Year 2035

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	85%	611,788	79,227,267	4%	29,815	754,625	1,930,143	11%	77,601	4,248,646
2027	85%	641,056	86,348,005	4%	31,213	822,291	2,099,102	11%	83,353	4,746,114
2028	85%	673,388	94,321,799	4%	32,584	892,959	2,275,365	11%	90,128	5,333,845
2029	84%	697,604	101,572,012	4%	33,451	953,218	2,424,492	12%	95,531	5,873,508
2030	84%	724,988	109,636,518	4%	34,505	1,021,517	2,594,022	12%	103,016	6,575,282
2031	84%	747,432	117,336,964	4%	35,573	1,093,525	2,772,634	12%	106,205	7,033,396
2032	84%	766,329	124,786,645	4%	36,472	1,163,085	2,945,735	12%	108,890	7,476,741
2033	84%	789,556	133,116,841	4%	37,578	1,240,654	3,141,258	12%	112,190	7,976,623
2034	84%	801,955	139,496,654	4%	38,168	1,299,952	3,293,065	12%	113,952	8,366,832
2035	84%	727,792	130,218,515	4%	34,638	1,213,298	3,076,767	12%	103,414	7,823,380

Table A-70. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 3a, 3a-1, 3a-2 and 3b in Calendar Year 2035

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	0%	0	0	6,645	0.14	0.18
2027	0%	0	0	0%	0	0	7,241	0.14	0.19
2028	0%	0	0	0%	0	0	7,909	0.15	0.20
2029	0%	0	0	0%	0	0	8,514	0.15	0.20
2030	0%	0	0	0%	0	0	9,189	0.16	0.21
2031	0%	0	0	0%	0	0	9,834	0.16	0.21
2032	0%	0	0	0%	0	0	10,458	0.16	0.21
2033	0%	0	0	0%	0	0	11,156	0.17	0.21
2034	0%	0	0	0%	0	0	11,691	0.17	0.21
2035	0%	0	0	0%	0	0	10,913	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-71. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 3a, 3a-1, 3a-2 and 3b in Calendar Year 2040

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	85%	424,233	44,379,743	4%	20,675	421,047	1,090,413	11%	53,811	2,380,112
2027	85%	468,739	51,160,857	4%	22,823	485,341	1,253,824	11%	60,947	2,812,115
2028	85%	508,037	57,813,793	4%	24,583	545,508	1,406,015	11%	67,997	3,270,853
2029	84%	549,764	65,186,938	4%	26,362	610,009	1,568,829	12%	75,286	3,773,157
2030	84%	583,369	72,028,242	4%	27,764	669,514	1,718,317	12%	82,893	4,325,829
2031	84%	621,402	79,845,628	4%	29,575	742,704	1,902,479	12%	88,297	4,795,314
2032	84%	652,332	87,185,723	4%	31,047	811,564	2,074,749	12%	92,692	5,235,411
2033	84%	686,690	95,441,034	4%	32,682	888,696	2,267,776	12%	97,574	5,728,006
2034	84%	712,396	102,926,116	4%	33,905	958,694	2,441,908	12%	101,227	6,173,591
2035	84%	742,681	111,447,763	4%	35,347	1,038,360	2,640,531	12%	105,530	6,681,472
2036	84%	764,974	119,166,985	4%	36,408	1,110,551	2,819,782	12%	108,697	7,140,339
2037	84%	783,440	126,588,190	4%	37,287	1,179,840	2,992,407	12%	111,321	7,581,528
2038	84%	805,975	134,822,728	4%	38,359	1,256,478	3,185,885	12%	114,524	8,075,024
2039	84%	817,118	140,992,663	4%	38,889	1,313,727	3,332,835	12%	116,107	8,451,703
2040	84%	739,955	131,287,793	4%	35,217	1,222,994	3,106,042	12%	105,142	7,882,098

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	0%	0	0	3,723	0.09	0.12
2027	0%	0	0	0%	0	0	4,291	0.10	0.13
2028	0%	0	0	0%	0	0	4,848	0.11	0.15
2029	0%	0	0	0%	0	0	5,465	0.12	0.16
2030	0%	0	0	0%	0	0	6,038	0.13	0.17
2031	0%	0	0	0%	0	0	6,693	0.14	0.18
2032	0%	0	0	0%	0	0	7,308	0.14	0.19
2033	0%	0	0	0%	0	0	8,000	0.15	0.20
2034	0%	0	0	0%	0	0	8,627	0.16	0.21
2035	0%	0	0	0%	0	0	9,341	0.16	0.21
2036	0%	0	0	0%	0	0	9,987	0.16	0.22
2037	0%	0	0	0%	0	0	10,609	0.17	0.22
2038	0%	0	0	0%	0	0	11,299	0.17	0.22
2039	0%	0	0	0%	0	0	11,816	0.17	0.21
2040	0%	0	0	0%	0	0	11,003	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-72. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 3a, 3a-1, 3a-2 and 3b in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	85%	219,761	18,208,793	4%	10,710	171,981	451,908	11%	27,875	979,732
2027	85%	258,741	22,456,424	4%	12,598	212,114	555,489	11%	33,642	1,237,162
2028	85%	300,679	27,310,373	4%	14,549	256,617	669,890	11%	40,244	1,547,489
2029	84%	343,168	32,595,097	4%	16,455	303,793	790,664	12%	46,994	1,888,561
2030	84%	386,794	38,383,317	4%	18,409	355,407	922,379	12%	54,961	2,306,853
2031	84%	431,003	44,656,861	4%	20,513	413,850	1,071,177	12%	61,243	2,683,184
2032	84%	477,078	51,574,684	4%	22,706	478,352	1,235,027	12%	67,790	3,098,236
2033	84%	518,165	58,405,552	4%	24,661	542,144	1,396,451	12%	73,628	3,508,235
2034	84%	561,504	65,947,281	4%	26,724	612,627	1,574,494	12%	79,786	3,960,912
2035	84%	597,713	73,101,152	4%	28,447	679,589	1,742,931	12%	84,931	4,390,345
2036	84%	636,105	80,962,667	4%	30,274	753,214	1,927,965	12%	90,386	4,862,426
2037	84%	667,180	88,329,199	4%	31,753	822,345	2,100,691	12%	94,802	5,304,019
2038	84%	701,654	96,602,944	4%	33,394	899,667	2,293,959	12%	99,700	5,797,554
2039	84%	727,252	104,086,433	4%	34,612	969,669	2,467,860	12%	103,338	6,242,847
2040	84%	757,391	112,590,629	4%	36,047	1,049,189	2,665,871	12%	107,620	6,749,460
2041	84%	779,333	120,269,438	4%	37,091	1,121,019	2,843,979	12%	110,738	7,205,621
2042	84%	797,208	127,609,859	4%	37,942	1,189,565	3,014,512	12%	113,278	7,641,631
2043	84%	818,902	135,699,051	4%	38,974	1,264,855	3,204,367	12%	116,360	8,126,069
2044	84%	828,649	141,621,489	4%	39,438	1,319,800	3,345,305	12%	117,745	8,487,539
2045	84%	748,769	131,560,435	4%	35,636	1,225,722	3,110,204	12%	106,395	7,896,358

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	0%	0	0	1,528	0.04	0.06
2027	0%	0	0	0%	0	0	1,884	0.05	0.07
2028	0%	0	0	0%	0	0	2,291	0.06	0.08
2029	0%	0	0	0%	0	0	2,733	0.07	0.09
2030	0%	0	0	0%	0	0	3,218	0.08	0.11
2031	0%	0	0	0%	0	0	3,744	0.09	0.12
2032	0%	0	0	0%	0	0	4,324	0.10	0.13
2033	0%	0	0	0%	0	0	4,896	0.11	0.15
2034	0%	0	0	0%	0	0	5,528	0.12	0.16
2035	0%	0	0	0%	0	0	6,128	0.13	0.17
2036	0%	0	0	0%	0	0	6,786	0.14	0.18
2037	0%	0	0	0%	0	0	7,404	0.15	0.19
2038	0%	0	0	0%	0	0	8,097	0.15	0.20
2039	0%	0	0	0%	0	0	8,724	0.16	0.21
2040	0%	0	0	0%	0	0	9,436	0.16	0.22
2041	0%	0	0	0%	0	0	10,080	0.17	0.22
2042	0%	0	0	0%	0	0	10,695	0.17	0.22
2043	0%	0	0	0%	0	0	11,372	0.17	0.22
2044	0%	0	0	0%	0	0	11,869	0.17	0.21
2045	0%	0	0	0%	0	0	11,026	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-73. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenarios 3a, 3a-1, 3a-2 and 3b in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	85%	84,407	5,416,910	4%	4,114	50,877	136,660	11%	10,706	295,109
2027	85%	103,307	6,979,357	4%	5,030	65,571	175,255	11%	13,432	388,383
2028	85%	126,564	8,992,281	4%	6,124	84,058	223,637	11%	16,940	513,531
2029	84%	154,469	11,529,035	4%	7,407	106,921	283,234	12%	21,153	672,043
2030	84%	186,433	14,603,793	4%	8,873	134,574	355,060	12%	26,491	881,507
2031	84%	223,318	18,340,139	4%	10,628	169,173	444,687	12%	31,732	1,105,371
2032	84%	263,400	22,659,223	4%	12,536	209,209	548,060	12%	37,427	1,364,096
2033	84%	306,740	27,615,605	4%	14,599	255,208	666,413	12%	43,586	1,661,080
2034	84%	350,568	33,005,323	4%	16,685	305,290	794,782	12%	49,813	1,984,022
2035	84%	396,387	38,990,628	4%	18,865	360,976	937,068	12%	56,324	2,343,007
2036	84%	441,302	45,323,709	4%	21,003	419,968	1,087,267	12%	62,706	2,722,815
2037	84%	488,028	52,297,119	4%	23,227	484,984	1,252,421	12%	69,345	3,141,091
2038	84%	529,547	59,167,502	4%	25,203	549,142	1,414,757	12%	75,245	3,553,333
2039	84%	573,298	66,745,954	4%	27,285	619,964	1,593,644	12%	81,462	4,008,057
2040	84%	609,667	73,915,132	4%	29,016	687,067	1,762,410	12%	86,629	4,438,238
2041	84%	648,178	81,784,379	4%	30,849	760,761	1,947,591	12%	92,102	4,910,573
2042	84%	679,210	89,145,447	4%	32,326	829,839	2,120,143	12%	96,511	5,351,582
2043	84%	713,632	97,406,694	4%	33,964	907,037	2,313,062	12%	101,402	5,844,049
2044	84%	738,970	104,857,227	4%	35,170	976,725	2,486,125	12%	105,002	6,287,030
2045	84%	768,833	113,315,730	4%	36,591	1,055,810	2,682,995	12%	109,246	6,790,499
2046	84%	790,339	120,930,825	4%	37,615	1,127,036	2,859,529	12%	112,302	7,242,409
2047	84%	807,527	128,164,176	4%	38,433	1,194,575	3,027,460	12%	114,744	7,671,556
2048	84%	828,277	136,082,929	4%	39,420	1,268,267	3,213,196	12%	117,693	8,145,301
2049	84%	836,615	141,751,914	4%	39,817	1,320,843	3,348,041	12%	118,877	8,491,081
2050	84%	754,352	131,380,558	4%	35,902	1,223,884	3,105,533	12%	107,188	7,881,262

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	0%	0	0	455	0.02	0.02
2027	0%	0	0	0%	0	0	586	0.02	0.02
2028	0%	0	0	0%	0	0	755	0.02	0.03
2029	0%	0	0	0%	0	0	967	0.03	0.04
2030	0%	0	0	0%	0	0	1,225	0.04	0.05
2031	0%	0	0	0%	0	0	1,538	0.04	0.06
2032	0%	0	0	0%	0	0	1,900	0.05	0.07
2033	0%	0	0	0%	0	0	2,316	0.06	0.08
2034	0%	0	0	0%	0	0	2,767	0.07	0.09
2035	0%	0	0	0%	0	0	3,269	0.08	0.11
2036	0%	0	0	0%	0	0	3,800	0.09	0.12
2037	0%	0	0	0%	0	0	4,384	0.10	0.14
2038	0%	0	0	0%	0	0	4,960	0.11	0.15
2039	0%	0	0	0%	0	0	5,595	0.12	0.16
2040	0%	0	0	0%	0	0	6,196	0.13	0.18
2041	0%	0	0	0%	0	0	6,855	0.14	0.19
2042	0%	0	0	0%	0	0	7,472	0.15	0.20
2043	0%	0	0	0%	0	0	8,164	0.15	0.21
2044	0%	0	0	0%	0	0	8,788	0.16	0.21
2045	0%	0	0	0%	0	0	9,497	0.17	0.22
2046	0%	0	0	0%	0	0	10,135	0.17	0.22
2047	0%	0	0	0%	0	0	10,741	0.17	0.22
2048	0%	0	0	0%	0	0	11,405	0.17	0.22
2049	0%	0	0	0%	0	0	11,880	0.17	0.21
2050	0%	0	0	0%	0	0	11,011	0.15	0.18

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-74. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	73%	606,608	109,656,971	5%	42,758	1,514,177	3,832,564	11%	89,660	6,866,855

Table A-74. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2026

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	11%	91,943	11,789,077	10,257	0.14	0.17

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-75. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	73%	631,610	99,631,257	5%	44,521	1,375,394	3,481,055	11%	93,356	6,216,252
2027	64%	568,332	92,994,289	6%	54,442	1,744,909	4,411,596	11%	97,957	6,763,472
2028	54%	494,755	83,840,288	7%	64,986	2,156,932	5,452,106	11%	103,726	7,417,910
2029	45%	419,506	73,385,206	8%	75,016	2,569,747	6,499,106	12%	107,741	7,961,945
2030	33%	279,755	50,380,703	9%	76,301	2,690,028	6,810,644	13%	109,730	8,360,042

Table A-75. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2030

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	11%	95,733	10,711,226	9,319	0.16	0.20
2027	0%	0	0	19%	167,287	19,415,503	9,564	0.15	0.19
2028	0%	0	0	28%	252,746	30,379,278	9,798	0.15	0.19
2029	0%	0	0	35%	329,972	40,942,951	9,892	0.15	0.18
2030	0%	0	0	45%	381,957	48,790,134	8,677	0.12	0.14

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-76. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	73%	525,019	67,990,583	5%	37,007	936,560	2,395,486	11%	77,601	4,248,646
2027	64%	483,597	65,138,911	6%	46,325	1,220,255	3,115,002	11%	83,353	4,746,114
2028	54%	429,894	60,215,445	7%	56,467	1,547,259	3,942,598	11%	90,128	5,333,845
2029	45%	371,964	54,158,389	8%	66,514	1,895,198	4,820,398	12%	95,531	5,873,508
2030	33%	284,628	43,042,917	9%	77,630	2,298,109	5,835,781	13%	111,641	7,125,303
2031	16%	142,274	22,335,072	10%	88,925	2,733,603	6,931,051	14%	123,989	8,211,111
2032	8%	72,935	11,876,559	11%	100,291	3,198,380	8,100,506	15%	136,241	9,355,831
2033	0%	0	0	12%	112,724	3,721,781	9,423,313	16%	149,763	10,649,111
2034	0%	0	0	13%	124,035	4,224,185	10,700,790	17%	161,656	11,866,577
2035	0%	0	0	14%	121,222	4,245,070	10,764,948	18%	155,365	11,742,105

Table A-76. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	11%	79,577	7,309,578	6,361	0.13	0.17
2027	0%	0	0	19%	142,346	13,599,811	6,702	0.13	0.17
2028	0%	0	0	28%	219,611	21,818,886	7,039	0.13	0.17
2029	0%	0	0	35%	292,577	30,215,957	7,303	0.13	0.17
2030	0%	0	0	45%	388,610	41,684,009	7,415	0.13	0.17
2031	0%	0	0	60%	534,022	59,463,907	7,265	0.13	0.16
2032	0%	0	0	66%	602,224	69,557,302	7,330	0.12	0.15
2033	0%	0	0	72%	676,837	80,940,453	7,398	0.12	0.14
2034	0%	0	0	70%	668,385	82,465,361	7,628	0.12	0.14
2035	0%	0	0	68%	589,257	74,782,771	7,004	0.11	0.12

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-77. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	73%	364,065	38,085,431	5%	25,662	522,506	1,353,168	11%	53,811	2,380,112
2027	64%	353,606	38,594,551	6%	33,873	720,113	1,860,331	11%	60,947	2,812,115
2028	54%	324,333	36,908,576	7%	42,601	945,015	2,435,721	11%	67,997	3,270,853
2029	45%	293,135	34,757,798	8%	52,418	1,212,509	3,118,344	12%	75,286	3,773,157
2030	33%	229,029	28,278,038	9%	62,466	1,505,758	3,864,548	13%	89,833	4,686,126
2031	16%	118,284	15,198,602	10%	73,931	1,856,008	4,754,274	14%	103,082	5,594,761
2032	8%	62,086	8,297,894	11%	85,372	2,231,017	5,703,556	15%	115,974	6,545,924
2033	0%	0	0	12%	98,038	2,665,328	6,801,387	16%	130,252	7,641,664
2034	0%	0	0	13%	110,183	3,115,112	7,934,557	17%	143,603	8,754,408
2035	0%	0	0	14%	123,702	3,633,767	9,240,607	18%	158,543	10,036,171
2036	0%	0	0	15%	136,516	4,164,332	10,573,585	19%	172,403	11,326,732
2037	0%	0	0	16%	149,132	4,719,374	11,969,659	20%	185,885	12,664,897
2038	0%	0	0	17%	163,011	5,339,970	13,539,859	21%	200,821	14,165,172
2039	0%	0	0	18%	174,985	5,911,028	14,995,868	22%	213,318	15,525,813
2040	0%	0	0	19%	167,264	5,807,308	14,748,846	23%	201,977	15,124,334

Table A-77. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	11%	55,181	4,094,515	3,564	0.09	0.11
2027	0%	0	0	19%	104,083	8,057,835	3,972	0.09	0.12
2028	0%	0	0	28%	165,686	13,373,712	4,316	0.10	0.13
2029	0%	0	0	35%	230,572	19,392,012	4,689	0.10	0.14
2030	0%	0	0	45%	312,699	27,385,272	4,874	0.11	0.14
2031	0%	0	0	60%	443,977	40,464,086	4,946	0.10	0.13
2032	0%	0	0	66%	512,639	48,598,179	5,125	0.11	0.13
2033	0%	0	0	72%	588,656	58,032,030	5,308	0.11	0.13
2034	0%	0	0	70%	593,742	60,846,186	5,631	0.11	0.13
2035	0%	0	0	68%	601,311	64,002,976	5,997	0.11	0.13
2036	0%	0	0	66%	601,159	66,424,848	6,304	0.12	0.13
2037	0%	0	0	64%	597,030	68,425,079	6,582	0.12	0.13
2038	0%	0	0	62%	595,027	70,600,721	6,889	0.12	0.13
2039	0%	0	0	60%	583,811	71,452,118	7,078	0.12	0.13
2040	0%	0	0	58%	511,073	64,318,157	6,473	0.11	0.11

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-78. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	73%	188,593	15,626,267	5%	13,293	213,382	560,696	11%	27,875	979,732
2027	64%	195,188	16,940,600	6%	18,698	314,629	823,959	11%	33,642	1,237,162
2028	54%	191,955	17,435,060	7%	25,213	444,407	1,160,110	11%	40,244	1,547,489
2029	45%	182,978	17,379,767	8%	32,720	603,637	1,571,051	12%	46,994	1,888,561
2030	33%	151,854	15,069,157	9%	41,417	799,032	2,073,706	13%	59,562	2,497,989
2031	16%	82,041	8,500,426	10%	51,278	1,033,837	2,675,905	14%	71,498	3,128,387
2032	8%	45,406	4,908,616	11%	62,436	1,314,527	3,393,898	15%	84,817	3,870,236
2033	0%	0	0	12%	73,977	1,625,355	4,186,579	16%	98,286	4,674,991
2034	0%	0	0	13%	86,845	1,989,837	5,114,021	17%	113,186	5,609,168
2035	0%	0	0	14%	99,556	2,377,278	6,096,962	18%	127,596	6,584,696
2036	0%	0	0	15%	113,519	2,823,202	7,226,411	19%	143,360	7,700,149
2037	0%	0	0	16%	127,002	3,288,080	8,399,445	20%	158,300	8,845,232
2038	0%	0	0	17%	141,911	3,822,420	9,746,350	21%	174,828	10,156,567
2039	0%	0	0	18%	155,741	4,362,607	11,103,067	22%	189,858	11,463,740
2040	0%	0	0	19%	171,206	4,983,044	12,661,348	23%	206,737	12,964,109
2041	0%	0	0	21%	194,709	5,885,170	14,930,435	24%	221,997	14,450,228
2042	0%	0	0	23%	218,143	6,840,270	17,334,125	25%	236,573	15,970,562
2043	0%	0	0	25%	243,564	7,905,571	20,027,869	26%	252,754	17,663,262
2044	0%	0	0	27%	266,180	8,907,835	22,578,739	27%	265,620	19,148,336
2045	0%	0	0	29%	258,336	8,883,750	22,542,040	29%	257,831	19,114,547

Table A-78. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	11%	28,585	1,679,959	1,463	0.04	0.05
2027	0%	0	0	19%	57,453	3,536,887	1,744	0.05	0.06
2028	0%	0	0	28%	98,060	6,317,542	2,040	0.06	0.07
2029	0%	0	0	35%	143,926	9,696,491	2,345	0.06	0.08
2030	0%	0	0	45%	207,330	14,593,409	2,598	0.07	0.08
2031	0%	0	0	60%	307,941	22,631,158	2,768	0.07	0.09
2032	0%	0	0	66%	374,915	28,748,236	3,033	0.08	0.09
2033	0%	0	0	72%	444,190	35,512,951	3,250	0.08	0.10
2034	0%	0	0	70%	467,982	38,985,640	3,611	0.09	0.10
2035	0%	0	0	68%	483,939	41,981,025	3,936	0.09	0.11
2036	0%	0	0	66%	499,887	45,129,386	4,286	0.10	0.11
2037	0%	0	0	64%	508,433	47,744,836	4,597	0.10	0.12
2038	0%	0	0	62%	518,010	50,586,704	4,940	0.10	0.12
2039	0%	0	0	60%	519,604	52,748,816	5,228	0.11	0.12
2040	0%	0	0	58%	523,116	55,158,378	5,553	0.11	0.12
2041	0%	0	0	55%	510,456	55,875,571	5,797	0.11	0.12
2042	0%	0	0	52%	493,711	56,055,334	6,009	0.12	0.12
2043	0%	0	0	49%	477,919	56,173,405	6,239	0.12	0.12
2044	0%	0	0	46%	454,032	55,039,824	6,355	0.12	0.11
2045	0%	0	0	42%	374,633	46,689,015	5,668	0.11	0.10

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-79. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	73%	72,435	4,648,637	5%	5,106	63,096	169,481	11%	10,706	295,109
2027	64%	77,932	5,265,063	6%	7,465	97,197	259,783	11%	13,432	388,383
2028	54%	80,799	5,740,711	7%	10,613	145,462	387,002	11%	16,940	513,531
2029	45%	82,363	6,147,303	8%	14,728	212,290	562,357	12%	21,153	672,043
2030	33%	73,193	5,733,398	9%	19,963	302,330	797,667	13%	28,709	953,785
2031	16%	42,508	3,491,042	10%	26,569	422,328	1,110,127	14%	37,045	1,287,157
2032	8%	25,069	2,156,590	11%	34,471	574,562	1,505,169	15%	46,828	1,701,409
2033	0%	0	0	12%	43,793	764,692	1,996,805	16%	58,183	2,209,858
2034	0%	0	0	13%	54,221	991,090	2,580,166	17%	70,667	2,804,792
2035	0%	0	0	14%	66,023	1,262,125	3,276,391	18%	84,618	3,507,790
2036	0%	0	0	15%	78,754	1,573,418	4,073,466	19%	99,457	4,304,066
2037	0%	0	0	16%	92,899	1,938,309	5,005,480	20%	115,793	5,228,312
2038	0%	0	0	17%	107,102	2,332,093	6,008,183	21%	131,944	6,212,439
2039	0%	0	0	18%	122,771	2,787,972	7,166,600	22%	149,666	7,344,085
2040	0%	0	0	19%	137,813	3,261,655	8,366,537	23%	166,414	8,505,538
2041	0%	0	0	21%	161,941	3,991,943	10,219,595	24%	184,637	9,824,069
2042	0%	0	0	23%	185,855	4,769,579	12,185,731	25%	201,557	11,158,614
2043	0%	0	0	25%	212,254	5,667,200	14,452,086	26%	220,262	12,680,449
2044	0%	0	0	27%	237,373	6,591,554	16,777,936	27%	236,874	14,175,574
2045	0%	0	0	29%	265,259	7,653,819	19,449,674	29%	264,740	16,455,874
2046	0%	0	0	31%	291,484	8,734,530	22,161,339	31%	290,950	18,775,038
2047	0%	0	0	33%	317,037	9,856,021	24,978,510	33%	316,492	21,183,213
2048	0%	0	0	35%	344,892	11,098,127	28,117,477	35%	344,332	23,856,539
2049	0%	0	0	37%	368,269	12,217,195	30,967,861	37%	367,704	26,274,045
2050	0%	0	0	39%	350,007	11,929,675	30,270,840	39%	349,498	25,672,714

Table A-79. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4a in Calendar Year 2050

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	11%	10,979	499,769	435	0.01	0.02
2027	0%	0	0	19%	22,939	1,099,249	542	0.02	0.02
2028	0%	0	0	28%	41,276	2,080,130	672	0.02	0.03
2029	0%	0	0	35%	64,784	3,429,693	830	0.03	0.03
2030	0%	0	0	45%	99,932	5,552,389	989	0.03	0.04
2031	0%	0	0	60%	159,555	9,294,397	1,138	0.03	0.04
2032	0%	0	0	66%	206,994	12,630,474	1,334	0.04	0.05
2033	0%	0	0	72%	262,949	16,791,411	1,538	0.04	0.05
2034	0%	0	0	70%	292,179	19,511,549	1,809	0.05	0.06
2035	0%	0	0	68%	320,935	22,391,802	2,102	0.06	0.07
2036	0%	0	0	66%	346,800	25,263,881	2,402	0.06	0.07
2037	0%	0	0	64%	371,908	28,268,312	2,724	0.07	0.08
2038	0%	0	0	62%	390,948	30,983,413	3,029	0.08	0.09
2039	0%	0	0	60%	409,607	33,825,447	3,356	0.08	0.09
2040	0%	0	0	58%	421,086	36,211,173	3,650	0.09	0.10
2041	0%	0	0	55%	424,551	37,995,927	3,948	0.09	0.10
2042	0%	0	0	52%	420,635	39,159,026	4,204	0.10	0.10
2043	0%	0	0	49%	416,483	40,322,062	4,484	0.10	0.11
2044	0%	0	0	46%	404,896	40,751,749	4,710	0.11	0.11
2045	0%	0	0	42%	384,672	40,214,217	4,885	0.11	0.11
2046	0%	0	0	38%	357,821	38,834,824	4,994	0.11	0.10
2047	0%	0	0	34%	327,175	36,831,648	5,061	0.11	0.10
2048	0%	0	0	30%	296,167	34,514,000	5,128	0.11	0.10
2049	0%	0	0	26%	259,335	31,167,115	5,087	0.11	0.09
2050	0%	0	0	22%	197,938	24,452,151	4,480	0.10	0.08

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-80. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	65%	540,667	97,736,781	4%	34,449	1,220,027	3,088,034	11%	89,660	6,866,855

Table A-80. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2026

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	20%	166,194	21,309,575	9,999	0.14	0.17

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-81. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2030
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	65%	562,951	88,800,905	4%	35,869	1,108,113	2,804,580	11%	93,356	6,216,252
2027	60%	531,375	86,947,141	4%	36,682	1,175,675	2,972,420	11%	97,957	6,763,472
2028	54%	490,961	83,197,345	5%	46,662	1,548,748	3,914,793	11%	103,726	7,417,910
2029	47%	438,150	76,646,771	6%	56,371	1,931,109	4,883,937	12%	107,741	7,961,945
2030	31%	263,273	47,412,456	7%	59,346	2,092,397	5,297,554	12%	101,252	7,716,317

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	20%	173,044	19,361,284	9,085	0.15	0.20
2027	0%	0	0	25%	222,005	25,766,042	9,471	0.15	0.19
2028	0%	0	0	30%	274,864	33,037,841	9,837	0.15	0.19
2029	0%	0	0	35%	329,972	40,942,951	10,027	0.15	0.18
2030	0%	0	0	50%	423,871	54,144,169	8,748	0.12	0.15

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-82. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	65%	467,947	60,599,710	4%	29,815	754,625	1,930,143	11%	77,601	4,248,646
2027	60%	452,150	60,903,118	4%	31,213	822,291	2,099,102	11%	83,353	4,746,114
2028	54%	426,597	59,753,673	5%	40,545	1,111,059	2,831,110	11%	90,128	5,333,845
2029	47%	388,496	56,565,428	6%	49,983	1,424,208	3,622,445	12%	95,531	5,873,508
2030	31%	267,859	40,506,985	7%	60,380	1,787,472	4,539,077	12%	103,016	6,575,282
2031	5%	44,956	7,057,548	8%	71,141	2,186,911	5,544,912	12%	106,205	7,033,396
2032	0%	508	82,780	8%	72,940	2,326,111	5,891,318	12%	108,890	7,476,741
2033	0%	524	88,306	8%	75,151	2,481,218	6,282,285	12%	112,190	7,976,623
2034	0%	532	92,539	8%	76,331	2,599,611	6,585,387	12%	113,952	8,366,832
2035	0%	483	86,384	8%	69,272	2,426,007	6,152,039	12%	103,414	7,823,380

Table A-82. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2035

Model Year	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	20%	143,841	13,212,570	6,201	0.13	0.17
2027	0%	0	0	25%	188,905	18,048,119	6,636	0.13	0.17
2028	0%	0	0	30%	238,830	23,728,309	7,067	0.13	0.18
2029	0%	0	0	35%	292,577	30,215,957	7,402	0.13	0.18
2030	0%	0	0	50%	431,254	46,258,246	7,475	0.13	0.17
2031	0%	0	0	75%	666,907	74,260,870	7,112	0.12	0.15
2032	0%	0	0	80%	729,353	84,240,710	7,386	0.12	0.15
2033	0%	0	0	80%	751,459	89,864,241	7,879	0.12	0.15
2034	0%	0	0	80%	763,260	94,171,112	8,257	0.12	0.15
2035	0%	0	0	80%	692,675	87,907,646	7,708	0.11	0.13

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-83. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	65%	324,490	33,945,378	4%	20,675	421,047	1,090,413	11%	53,811	2,380,112
2027	60%	330,612	36,084,860	4%	22,823	485,341	1,253,824	11%	60,947	2,812,115
2028	54%	321,846	36,625,537	5%	30,589	678,677	1,749,251	11%	67,997	3,270,853
2029	47%	306,163	36,302,589	6%	39,390	911,259	2,343,586	12%	75,286	3,773,157
2030	31%	215,535	26,611,999	7%	48,585	1,171,260	3,006,055	12%	82,893	4,325,829
2031	5%	37,376	4,802,531	8%	59,146	1,484,907	3,803,675	12%	88,297	4,795,314
2032	0%	433	57,837	8%	62,089	1,622,680	4,148,353	12%	92,692	5,235,411
2033	0%	456	63,313	8%	65,360	1,777,012	4,534,581	12%	97,574	5,728,006
2034	0%	473	68,279	8%	67,806	1,917,102	4,883,085	12%	101,227	6,173,591
2035	0%	493	73,932	8%	70,689	2,076,523	5,280,561	12%	105,530	6,681,472
2036	0%	0	0	10%	91,012	2,776,250	7,049,129	19%	172,403	11,326,732
2037	0%	0	0	12%	111,850	3,539,529	8,977,241	20%	185,885	12,664,897
2038	0%	0	0	14%	134,245	4,397,626	11,150,481	21%	200,821	14,165,172
2039	0%	0	0	16%	155,543	5,254,271	13,329,721	22%	213,318	15,525,813
2040	0%	0	0	20%	176,067	6,112,929	15,525,032	23%	201,977	15,124,334

Table A-83. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2040

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	20%	99,744	7,401,119	3,474	0.08	0.11
2027	0%	0	0	25%	138,127	10,693,440	3,933	0.09	0.12
2028	0%	0	0	30%	180,185	14,544,078	4,333	0.10	0.13
2029	0%	0	0	35%	230,572	19,392,012	4,752	0.10	0.14
2030	0%	0	0	50%	347,013	30,390,423	4,913	0.11	0.14
2031	0%	0	0	75%	554,455	50,533,145	4,842	0.10	0.13
2032	0%	0	0	80%	620,857	58,857,157	5,163	0.10	0.13
2033	0%	0	0	80%	653,556	64,430,136	5,651	0.11	0.14
2034	0%	0	0	80%	678,023	69,483,149	6,094	0.11	0.14
2035	0%	0	0	80%	706,846	75,235,925	6,598	0.12	0.15
2036	0%	0	0	71%	646,663	71,452,786	6,427	0.11	0.14
2037	0%	0	0	68%	634,312	72,697,923	6,687	0.11	0.14
2038	0%	0	0	65%	623,792	74,013,815	6,973	0.12	0.13
2039	0%	0	0	62%	603,253	73,831,644	7,136	0.12	0.13
2040	0%	0	0	57%	502,270	63,210,288	6,446	0.11	0.11

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-84. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2045

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fuel Consumption[3] (MJ of electricity/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of electricity/day)**
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	65%	168,092	13,927,624	4%	10,710	171,981	451,908	11%	27,875	979,732
2027	60%	182,495	15,839,002	4%	12,598	212,114	555,489	11%	33,642	1,237,162
2028	54%	190,483	17,301,357	5%	18,104	319,213	833,297	11%	40,244	1,547,489
2029	47%	191,110	18,152,201	6%	24,588	453,715	1,180,857	12%	46,994	1,888,561
2030	31%	142,907	14,181,338	7%	32,214	621,582	1,613,175	12%	54,961	2,306,853
2031	5%	25,924	2,686,007	8%	41,023	827,174	2,140,996	12%	61,243	2,683,184
2032	0%	316	34,213	8%	45,409	956,166	2,468,668	12%	67,790	3,098,236
2033	0%	344	38,745	8%	49,319	1,083,750	2,791,515	12%	73,628	3,508,235
2034	0%	372	43,748	8%	53,444	1,224,720	3,147,617	12%	79,786	3,960,912
2035	0%	397	48,493	8%	56,891	1,358,665	3,484,543	12%	84,931	4,390,345
2036	0%	0	0	10%	75,680	1,882,298	4,818,027	19%	143,360	7,700,149
2037	0%	0	0	12%	95,252	2,466,168	6,299,860	20%	158,300	8,845,232
2038	0%	0	0	14%	116,869	3,147,939	8,026,567	21%	174,828	10,156,567
2039	0%	0	0	16%	138,437	3,877,902	9,869,466	22%	189,858	11,463,740
2040	0%	0	0	20%	180,216	5,245,301	13,327,713	23%	206,737	12,964,109
2041	0%	0	0	24%	222,523	6,725,903	17,063,339	24%	221,997	14,450,228
2042	0%	0	0	39%	369,891	11,598,758	29,392,748	27%	260,284	17,572,280
2043	0%	0	0	39%	379,957	12,332,715	31,243,537	31%	301,465	21,069,402
2044	0%	0	0	39%	384,479	12,866,810	32,613,574	34%	339,557	24,478,734
2045	0%	0	0	39%	347,416	11,946,961	30,314,775	38%	338,003	25,053,589

Table A-84. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	20%	51,669	3,036,643	1,426	0.04	0.05
2027	0%	0	0	25%	76,245	4,693,753	1,727	0.05	0.06
2028	0%	0	0	30%	106,641	6,870,405	2,047	0.05	0.07
2029	0%	0	0	35%	143,926	9,696,491	2,377	0.06	0.08
2030	0%	0	0	50%	230,082	16,194,832	2,619	0.07	0.09
2031	0%	0	0	75%	384,569	28,262,682	2,709	0.07	0.09
2032	0%	0	0	80%	454,059	34,816,931	3,055	0.07	0.09
2033	0%	0	0	80%	493,163	39,428,299	3,460	0.08	0.10
2034	0%	0	0	80%	534,411	44,519,554	3,906	0.09	0.11
2035	0%	0	0	80%	568,873	49,348,974	4,330	0.09	0.12
2036	0%	0	0	71%	537,726	48,545,393	4,369	0.09	0.12
2037	0%	0	0	68%	540,182	50,726,291	4,669	0.10	0.12
2038	0%	0	0	65%	543,052	53,032,248	4,999	0.10	0.12
2039	0%	0	0	62%	536,908	54,505,478	5,271	0.11	0.12
2040	0%	0	0	57%	514,106	54,208,285	5,529	0.11	0.12
2041	0%	0	0	52%	482,641	52,830,899	5,722	0.12	0.12
2042	0%	0	0	34%	318,252	36,133,933	5,365	0.12	0.10
2043	0%	0	0	30%	292,814	34,416,639	5,376	0.12	0.10
2044	0%	0	0	27%	261,795	31,735,973	5,268	0.12	0.09
2045	0%	0	0	23%	205,381	25,595,798	4,578	0.10	0.08

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-85. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2050
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	65%	64,561	4,143,310	4%	4,114	50,877	136,660	11%	10,706	295,109
2027	60%	72,864	4,922,692	4%	5,030	65,571	175,255	11%	13,432	388,383
2028	54%	80,180	5,696,688	5%	7,620	104,526	278,092	11%	16,940	513,531
2029	47%	86,024	6,420,517	6%	11,068	159,606	422,796	12%	21,153	672,043
2030	31%	68,881	5,395,608	7%	15,527	235,228	620,624	12%	26,491	881,507
2031	5%	13,432	1,103,117	8%	21,256	337,943	888,314	12%	31,732	1,105,371
2032	0%	175	15,032	8%	25,071	417,982	1,094,979	12%	37,427	1,364,096
2033	0%	203	18,320	8%	29,196	509,950	1,331,609	12%	43,586	1,661,080
2034	0%	233	21,895	8%	33,367	610,090	1,588,286	12%	49,813	1,984,022
2035	0%	263	25,865	8%	37,728	721,435	1,872,797	12%	56,324	2,343,007
2036	0%	0	0	10%	52,504	1,049,122	2,716,103	19%	99,457	4,304,066
2037	0%	0	0	12%	69,675	1,453,867	3,754,460	20%	115,793	5,228,312
2038	0%	0	0	14%	88,202	1,920,643	4,948,162	21%	131,944	6,212,439
2039	0%	0	0	16%	109,131	2,478,256	6,370,464	22%	149,666	7,344,085
2040	0%	0	0	20%	145,066	3,433,295	8,806,812	23%	166,414	8,505,538
2041	0%	0	0	24%	185,075	4,562,152	11,679,361	24%	184,637	9,824,069
2042	0%	0	0	39%	315,142	8,087,255	20,662,015	27%	221,758	12,275,351
2043	0%	0	0	39%	331,114	8,840,642	22,544,769	31%	262,712	15,122,020
2044	0%	0	0	39%	342,870	9,521,030	24,234,533	34%	302,809	18,119,847
2045	0%	0	0	39%	356,726	10,293,022	26,156,346	38%	347,060	21,572,837
2046	0%	0	0	39%	366,704	10,988,602	27,880,394	41%	389,677	25,148,333
2047	0%	0	0	39%	374,679	11,648,044	29,520,107	42%	402,955	26,973,923
2048	0%	0	0	39%	384,307	12,366,497	31,330,933	42%	413,310	28,638,221
2049	0%	0	0	39%	388,175	12,877,580	32,641,789	42%	417,470	29,830,638
2050	0%	0	0	39%	350,007	11,929,675	30,270,840	42%	376,421	27,649,542

Table A-85. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4b in Calendar Year 2050

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	20%	19,845	903,367	424	0.01	0.02
2027	0%	0	0	25%	30,442	1,458,798	537	0.02	0.02
2028	0%	0	0	30%	44,888	2,262,167	674	0.02	0.03
2029	0%	0	0	35%	64,784	3,429,693	841	0.03	0.03
2030	0%	0	0	50%	110,898	6,161,686	997	0.03	0.04
2031	0%	0	0	75%	199,258	11,607,209	1,113	0.03	0.04
2032	0%	0	0	80%	250,690	15,296,741	1,343	0.04	0.05
2033	0%	0	0	80%	291,939	18,642,686	1,637	0.05	0.06
2034	0%	0	0	80%	333,653	22,281,165	1,956	0.05	0.07
2035	0%	0	0	80%	377,261	26,321,712	2,310	0.06	0.08
2036	0%	0	0	71%	373,051	27,176,196	2,447	0.06	0.08
2037	0%	0	0	68%	395,132	30,033,544	2,766	0.07	0.08
2038	0%	0	0	65%	409,848	32,481,264	3,064	0.08	0.09
2039	0%	0	0	62%	423,248	34,951,915	3,383	0.08	0.10
2040	0%	0	0	57%	413,833	35,587,442	3,635	0.09	0.10
2041	0%	0	0	52%	401,417	35,925,521	3,898	0.10	0.10
2042	0%	0	0	34%	271,146	25,242,373	3,758	0.10	0.09
2043	0%	0	0	30%	255,173	24,704,749	3,868	0.10	0.09
2044	0%	0	0	27%	233,463	23,497,466	3,908	0.10	0.08
2045	0%	0	0	23%	210,884	22,046,191	3,946	0.10	0.08
2046	0%	0	0	20%	183,874	19,956,099	3,916	0.10	0.08
2047	0%	0	0	19%	183,069	20,608,997	4,104	0.10	0.08
2048	0%	0	0	19%	187,774	21,882,345	4,357	0.11	0.08
2049	0%	0	0	19%	189,664	22,793,926	4,539	0.11	0.08
2050	0%	0	0	19%	171,015	21,126,196	4,208	0.10	0.07

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-86. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2026
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1982	100%	4,657	174,227	0%	0	0	0	0%	1	9
1983	100%	5,273	206,541	0%	0	0	0	0%	1	9
1984	100%	7,858	329,345	0%	0	0	0	0%	1	13
1985	100%	10,024	435,286	0%	0	0	0	0%	0	0
1986	100%	10,647	463,741	0%	0	0	0	0%	0	0
1987	100%	12,832	586,622	0%	0	0	0	0%	1	18
1988	100%	12,139	592,716	0%	0	0	0	0%	0	0
1989	100%	14,970	774,940	0%	0	0	0	0%	1	14
1990	100%	18,044	991,990	0%	0	0	0	0%	0	0
1991	100%	21,281	1,234,023	0%	0	0	0	0%	0	0
1992	100%	18,332	1,127,213	0%	0	0	0	0%	0	0
1993	100%	20,138	1,231,512	0%	0	0	0	0%	3	46
1994	100%	22,840	1,473,479	0%	0	0	0	0%	0	7
1995	100%	29,675	2,022,331	0%	0	0	0	0%	2	31
1996	100%	29,436	2,128,971	0%	0	0	0	0%	0	0
1997	100%	39,761	2,978,637	0%	0	0	0	0%	4	95
1998	100%	48,817	3,777,000	0%	0	0	0	0%	5	107
1999	100%	56,921	4,546,344	0%	0	0	0	0%	4	98
2000	100%	76,964	6,529,441	0%	0	0	0	0%	1	31
2001	100%	87,221	7,793,387	0%	0	0	0	0%	6	155
2002	100%	102,135	9,644,077	0%	0	0	0	0%	37	1,030
2003	100%	127,287	12,720,322	0%	0	0	0	0%	7	196
2004	100%	143,690	15,732,253	0%	0	0	0	0%	5	155
2005	100%	191,623	21,752,720	0%	0	0	0	0%	7	213
2006	100%	225,488	26,980,154	0%	0	0	0	0%	11	389
2007	100%	275,180	33,665,694	0%	0	0	0	0%	23	834
2008	100%	258,265	33,318,492	0%	0	0	0	0%	126	4,586
2009	100%	229,086	29,357,696	0%	0	0	0	0%	34	1,333
2010	100%	292,924	35,681,010	0%	11	154	687	0%	161	6,445
2011	99%	307,002	40,824,099	0%	548	8,280	37,013	1%	1,890	79,947
2012	98%	465,759	61,806,971	1%	5,585	88,399	392,722	1%	2,528	111,558
2013	97%	592,447	79,686,217	2%	11,199	185,018	819,056	1%	8,583	395,185
2014	96%	599,553	84,574,041	3%	16,462	284,537	1,256,341	1%	9,356	449,554
2015	96%	738,821	106,767,996	2%	12,602	227,577	1,002,629	2%	14,202	712,794
2016	95%	754,102	111,262,248	2%	13,790	259,774	1,141,452	3%	23,130	1,205,441
2017	91%	794,462	122,943,456	4%	36,125	706,874	3,105,093	5%	43,901	2,385,744
2018	86%	705,513	113,371,002	4%	33,412	680,299	2,980,537	10%	78,294	4,428,841
2019	88%	622,322	102,867,416	3%	24,317	533,860	2,191,127	8%	58,438	3,447,620
2020	86%	508,892	85,019,301	4%	24,600	571,597	2,264,467	9%	55,310	3,416,834
2021	85%	619,444	104,948,162	4%	32,604	811,289	3,029,262	10%	73,983	4,748,184
2022	84%	724,703	124,757,619	5%	39,994	1,137,171	3,486,691	11%	93,245	6,212,763
2023	84%	731,635	127,883,688	5%	40,571	1,231,754	3,543,090	11%	98,996	6,843,258
2024	83%	747,543	132,487,563	5%	41,200	1,332,140	3,598,733	12%	106,645	7,641,910
2025	83%	758,530	135,969,595	5%	41,866	1,438,799	3,640,575	12%	111,956	8,303,968
2026	73%	606,608	109,656,971	5%	42,758	1,514,177	3,832,564	11%	89,660	6,866,855

Table A-86. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2026

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1982	0%	0	0	0%	0	0	14	0.008	0.003
1983	0%	0	0	0%	0	0	17	0.009	0.003
1984	0%	0	0	0%	0	0	27	0.01	0.005
1985	0%	0	0	0%	0	0	36	0.02	0.006
1986	0%	0	0	0%	0	0	38	0.02	0.007
1987	0%	0	0	0%	0	0	48	0.02	0.009
1988	0%	0	0	0%	0	0	49	0.02	0.009
1989	0%	0	0	0%	0	0	63	0.03	0.01
1990	0%	0	0	0%	0	0	81	0.04	0.01
1991	0%	0	0	0%	0	0	101	0.05	0.02
1992	0%	0	0	0%	0	0	92	0.04	0.02
1993	0%	0	0	0%	0	0	101	0.05	0.02
1994	0%	0	0	0%	0	0	121	0.06	0.02
1995	0%	0	0	0%	0	0	166	0.08	0.03
1996	0%	0	0	0%	0	0	174	0.09	0.04
1997	0%	0	0	0%	0	0	244	0.11	0.05
1998	0%	0	0	0%	0	0	309	0.11	0.05
1999	0%	0	0	0%	0	0	372	0.09	0.06
2000	0%	0	0	0%	0	0	535	0.08	0.07
2001	0%	0	0	0%	0	0	638	0.09	0.07
2002	0%	0	0	0%	0	0	790	0.11	0.09
2003	0%	0	0	0%	0	0	1,041	0.13	0.11
2004	0%	0	0	0%	0	0	1,288	0.07	0.04
2005	0%	0	0	0%	0	0	1,781	0.08	0.05
2006	0%	0	0	0%	0	0	2,209	0.09	0.06
2007	0%	0	0	0%	0	0	2,756	0.11	0.08
2008	0%	0	0	0%	0	0	2,728	0.10	0.08
2009	0%	0	0	0%	0	0	2,404	0.09	0.07
2010	0%	0	0	0%	0	0	2,921	0.11	0.09
2011	0%	0	0	0%	0	0	3,345	0.12	0.10
2012	0%	0	0	0%	0	0	5,092	0.18	0.15
2013	0%	0	0	0%	0	0	6,591	0.22	0.19
2014	0%	0	0	0%	0	0	7,027	0.23	0.20
2015	0%	0	0	0%	0	0	8,823	0.28	0.24
2016	0%	0	0	0%	0	0	9,203	0.32	0.26
2017	0%	0	0	0%	0	0	10,320	0.32	0.27
2018	0%	0	0	0%	0	0	9,526	0.28	0.24
2019	0%	0	0	0%	0	0	8,601	0.23	0.21
2020	0%	0	0	0%	0	0	7,146	0.19	0.17
2021	0%	0	0	0%	0	0	8,840	0.21	0.21
2022	0%	0	0	0%	0	0	10,500	0.23	0.24
2023	0%	0	0	0%	0	0	10,760	0.21	0.23
2024	0%	0	0	0%	0	0	11,142	0.20	0.22
2025	0%	0	0	0%	0	0	11,430	0.16	0.20
2026	0%	0	0	11%	91,943	11,789,077	10,257	0.14	0.17

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-8) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-10. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-87. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2030

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1986	100%	9,277	319,606	0%	0	0	0	0%	0	0
1987	100%	11,036	395,358	0%	0	0	0	0%	1	13
1988	100%	10,287	394,106	0%	0	0	0	0%	0	0
1989	100%	12,682	513,141	0%	0	0	0	0%	1	10
1990	100%	15,335	660,988	0%	0	0	0	0%	0	0
1991	100%	17,755	806,207	0%	0	0	0	0%	0	0
1992	100%	14,968	722,403	0%	0	0	0	0%	0	0
1993	100%	15,722	757,504	0%	0	0	0	0%	2	30
1994	100%	16,938	862,749	0%	0	0	0	0%	0	4
1995	100%	21,266	1,147,175	0%	0	0	0	0%	1	18
1996	100%	20,041	1,148,835	0%	0	0	0	0%	0	0
1997	100%	25,571	1,519,989	0%	0	0	0	0%	3	55
1998	100%	29,544	1,816,366	0%	0	0	0	0%	3	55
1999	100%	32,392	2,061,329	0%	0	0	0	0%	2	47
2000	100%	41,346	2,802,701	0%	0	0	0	0%	1	14
2001	100%	44,766	3,209,806	0%	0	0	0	0%	3	65
2002	100%	49,911	3,795,455	0%	0	0	0	0%	18	424
2003	100%	59,781	4,832,777	0%	0	0	0	0%	3	76
2004	100%	65,751	5,844,031	0%	0	0	0	0%	2	59
2005	100%	86,903	8,039,211	0%	0	0	0	0%	3	81
2006	100%	103,055	10,092,547	0%	0	0	0	0%	5	144
2007	100%	128,610	12,929,139	0%	0	0	0	0%	11	328
2008	100%	125,543	13,361,675	0%	0	0	0	0%	60	1,794
2009	100%	116,809	12,395,606	0%	0	0	0	0%	18	572
2010	100%	158,274	16,020,574	0%	6	69	311	0%	86	2,863
2011	99%	175,648	19,479,572	0%	313	3,932	17,791	1%	1,076	37,957
2012	98%	282,481	31,367,919	1%	3,387	44,658	200,590	1%	1,526	56,296
2013	97%	378,095	42,683,040	2%	7,146	98,660	441,197	1%	5,433	209,483
2014	96%	402,992	47,862,257	3%	11,064	160,332	714,692	1%	6,227	251,167
2015	97%	518,113	63,218,662	2%	8,836	134,191	596,394	2%	9,879	417,410
2016	95%	553,278	69,108,331	2%	10,115	160,689	711,773	3%	16,817	738,736
2017	91%	604,853	79,402,357	4%	27,493	454,641	2,012,619	5%	33,194	1,524,212
2018	86%	555,971	75,960,952	4%	26,314	453,896	2,003,609	10%	61,332	2,941,765
2019	88%	505,059	71,135,364	3%	19,734	368,011	1,521,560	8%	47,387	2,378,873
2020	86%	424,894	60,588,792	4%	20,540	406,324	1,621,195	9%	46,181	2,435,627
2021	85%	528,088	76,514,975	4%	27,796	590,252	2,219,126	10%	63,072	3,464,139
2022	84%	629,123	92,802,888	5%	34,719	844,508	2,607,459	11%	80,947	4,626,137
2023	84%	652,013	97,885,688	5%	36,155	941,473	2,725,229	11%	88,223	5,242,684
2024	83%	670,253	102,369,934	5%	36,940	1,028,217	2,790,931	12%	95,619	5,905,793
2025	83%	697,118	108,259,056	5%	38,476	1,144,799	2,904,428	12%	102,891	6,603,088
2026	73%	631,610	99,631,257	5%	44,521	1,375,394	3,481,055	11%	93,356	6,216,252
2027	64%	568,332	92,994,289	6%	54,442	1,744,909	4,411,596	11%	97,957	6,763,472
2028	54%	494,755	83,840,288	7%	64,986	2,156,932	5,452,106	11%	103,726	7,417,910
2029	45%	419,506	73,385,206	8%	75,016	2,569,747	6,499,106	12%	107,741	7,961,945
2030	33%	279,755	50,380,703	9%	76,301	2,690,028	6,810,644	12%	101,252	7,716,317

Table A-87. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2030

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1986	0%	0	0	0%	0	0	26	0.01	0.005
1987	0%	0	0	0%	0	0	32	0.02	0.006
1988	0%	0	0	0%	0	0	32	0.02	0.006
1989	0%	0	0	0%	0	0	42	0.02	0.008
1990	0%	0	0	0%	0	0	54	0.03	0.010
1991	0%	0	0	0%	0	0	66	0.03	0.01
1992	0%	0	0	0%	0	0	59	0.03	0.01
1993	0%	0	0	0%	0	0	62	0.03	0.01
1994	0%	0	0	0%	0	0	71	0.04	0.01
1995	0%	0	0	0%	0	0	94	0.05	0.02
1996	0%	0	0	0%	0	0	94	0.05	0.02
1997	0%	0	0	0%	0	0	124	0.06	0.02
1998	0%	0	0	0%	0	0	149	0.06	0.03
1999	0%	0	0	0%	0	0	169	0.05	0.03
2000	0%	0	0	0%	0	0	229	0.04	0.03
2001	0%	0	0	0%	0	0	263	0.04	0.03
2002	0%	0	0	0%	0	0	311	0.05	0.04
2003	0%	0	0	0%	0	0	396	0.05	0.04
2004	0%	0	0	0%	0	0	478	0.03	0.01
2005	0%	0	0	0%	0	0	658	0.03	0.02
2006	0%	0	0	0%	0	0	826	0.04	0.02
2007	0%	0	0	0%	0	0	1,059	0.05	0.03
2008	0%	0	0	0%	0	0	1,094	0.05	0.03
2009	0%	0	0	0%	0	0	1,015	0.04	0.03
2010	0%	0	0	0%	0	0	1,312	0.06	0.04
2011	0%	0	0	0%	0	0	1,596	0.06	0.05
2012	0%	0	0	0%	0	0	2,585	0.10	0.08
2013	0%	0	0	0%	0	0	3,531	0.13	0.11
2014	0%	0	0	0%	0	0	3,977	0.15	0.12
2015	0%	0	0	0%	0	0	5,225	0.19	0.16
2016	0%	0	0	0%	0	0	5,716	0.22	0.18
2017	0%	0	0	0%	0	0	6,666	0.24	0.20
2018	0%	0	0	0%	0	0	6,383	0.22	0.18
2019	0%	0	0	0%	0	0	5,949	0.19	0.17
2020	0%	0	0	0%	0	0	5,093	0.15	0.14
2021	0%	0	0	0%	0	0	6,446	0.18	0.18
2022	0%	0	0	0%	0	0	7,811	0.20	0.21
2023	0%	0	0	0%	0	0	8,237	0.19	0.21
2024	0%	0	0	0%	0	0	8,610	0.18	0.21
2025	0%	0	0	0%	0	0	9,101	0.16	0.20
2026	0%	0	0	11%	95,733	10,711,226	9,319	0.16	0.20
2027	0%	0	0	19%	167,287	19,415,503	9,564	0.15	0.19
2028	0%	0	0	28%	252,746	30,379,278	9,798	0.15	0.19
2029	0%	0	0	35%	329,972	40,942,951	9,892	0.15	0.18
2030	1%	8,477	610,675	45%	381,957	48,790,134	8,677	0.12	0.14

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-11) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-13. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-88. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2035
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1991	100%	14,887	496,519	0%	0	0	0	0%	0	0
1992	100%	12,386	437,879	0%	0	0	0	0%	0	0
1993	100%	12,876	454,610	0%	0	0	0	0%	2	20
1994	100%	13,908	519,028	0%	0	0	0	0%	0	3
1995	100%	17,011	673,579	0%	0	0	0	0%	1	11
1996	100%	15,726	662,566	0%	0	0	0	0%	0	0
1997	100%	19,249	841,793	0%	0	0	0	0%	3	36
1998	100%	21,231	962,917	0%	0	0	0	0%	2	32
1999	100%	21,841	1,026,080	0%	0	0	0	0%	2	27
2000	100%	26,428	1,326,406	0%	0	0	0	0%	0	7
2001	100%	26,524	1,412,096	0%	0	0	0	0%	2	30
2002	100%	27,790	1,574,561	0%	0	0	0	0%	11	189
2003	100%	30,887	1,866,413	0%	0	0	0	0%	2	31
2004	100%	31,459	2,100,346	0%	0	0	0	0%	1	22
2005	100%	38,743	2,705,815	0%	0	0	0	0%	1	29
2006	100%	43,503	3,231,279	0%	0	0	0	0%	2	47
2007	100%	51,445	3,941,697	0%	0	0	0	0%	4	103
2008	100%	48,196	3,931,397	0%	0	0	0	0%	23	522
2009	100%	43,832	3,583,029	0%	0	0	0	0%	7	170
2010	100%	59,373	4,651,159	0%	2	20	92	0%	32	847
2011	99%	67,186	5,797,667	0%	120	1,161	5,375	1%	409	11,360
2012	98%	112,410	9,761,699	1%	1,348	13,798	63,245	1%	603	17,549
2013	97%	158,581	14,066,520	2%	2,997	32,296	147,122	1%	2,255	68,707
2014	96%	180,829	16,955,018	3%	4,964	56,441	255,982	1%	2,764	88,302
2015	97%	248,911	24,094,495	2%	4,244	50,842	229,574	2%	4,701	157,841
2016	95%	285,862	28,441,636	2%	5,224	65,752	295,555	3%	8,578	300,098
2017	91%	332,615	34,903,768	4%	15,110	198,715	892,263	5%	18,042	661,811
2018	86%	327,985	35,952,376	4%	15,507	213,599	955,739	9%	35,779	1,376,403
2019	88%	314,542	35,673,840	3%	12,281	183,606	769,058	8%	29,273	1,183,116
2020	86%	281,575	32,424,569	4%	13,612	216,540	874,542	9%	30,604	1,303,564
2021	85%	366,087	42,975,928	4%	19,269	330,198	1,255,839	10%	43,723	1,945,314
2022	84%	459,912	55,139,274	5%	25,381	499,808	1,561,702	11%	59,175	2,747,832
2023	84%	491,823	60,167,945	5%	27,272	576,729	1,688,911	11%	66,548	3,223,016
2024	83%	528,134	65,889,598	5%	29,108	659,860	1,811,619	12%	75,344	3,803,598
2025	83%	560,849	71,323,875	5%	30,955	752,392	1,930,200	12%	82,779	4,355,000
2026	73%	525,019	67,990,583	5%	37,007	936,560	2,395,486	11%	77,601	4,248,646
2027	64%	483,597	65,138,911	6%	46,325	1,220,255	3,115,002	11%	83,353	4,746,114
2028	54%	429,894	60,215,445	7%	56,467	1,547,259	3,942,598	11%	90,128	5,333,845
2029	45%	371,964	54,158,389	8%	66,514	1,895,198	4,820,398	12%	95,531	5,873,508
2030	33%	284,628	43,042,917	9%	77,630	2,298,109	5,835,781	12%	103,016	6,575,282
2031	16%	142,274	22,335,072	10%	88,925	2,733,603	6,931,051	12%	110,651	7,327,824
2032	8%	72,935	11,876,559	11%	100,291	3,198,380	8,100,506	13%	118,007	8,103,104
2033	0%	0	0	12%	112,724	3,721,781	9,423,313	13%	126,280	8,978,806
2034	0%	0	0	13%	124,035	4,224,185	10,700,790	14%	133,034	9,766,730
2035	0%	0	0	14%	121,222	4,245,070	10,764,948	14%	125,060	9,456,182

Table A-88. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2035

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1991	0%	0	0	0%	0	0	41	0.02	0.008
1992	0%	0	0	0%	0	0	36	0.02	0.007
1993	0%	0	0	0%	0	0	37	0.02	0.007
1994	0%	0	0	0%	0	0	42	0.02	0.008
1995	0%	0	0	0%	0	0	55	0.03	0.01
1996	0%	0	0	0%	0	0	54	0.04	0.01
1997	0%	0	0	0%	0	0	69	0.04	0.01
1998	0%	0	0	0%	0	0	79	0.03	0.01
1999	0%	0	0	0%	0	0	84	0.03	0.01
2000	0%	0	0	0%	0	0	109	0.02	0.01
2001	0%	0	0	0%	0	0	116	0.02	0.01
2002	0%	0	0	0%	0	0	129	0.02	0.02
2003	0%	0	0	0%	0	0	153	0.02	0.02
2004	0%	0	0	0%	0	0	172	0.01	0.006
2005	0%	0	0	0%	0	0	222	0.01	0.007
2006	0%	0	0	0%	0	0	265	0.01	0.008
2007	0%	0	0	0%	0	0	323	0.02	0.01
2008	0%	0	0	0%	0	0	322	0.02	0.01
2009	0%	0	0	0%	0	0	293	0.01	0.010
2010	0%	0	0	0%	0	0	381	0.02	0.01
2011	0%	0	0	0%	0	0	475	0.02	0.02
2012	0%	0	0	0%	0	0	804	0.04	0.03
2013	0%	0	0	0%	0	0	1,164	0.05	0.04
2014	0%	0	0	0%	0	0	1,409	0.06	0.05
2015	0%	0	0	0%	0	0	1,991	0.08	0.07
2016	0%	0	0	0%	0	0	2,353	0.11	0.08
2017	0%	0	0	0%	0	0	2,931	0.12	0.10
2018	0%	0	0	0%	0	0	3,022	0.12	0.10
2019	0%	0	0	0%	0	0	2,984	0.11	0.10
2020	0%	0	0	0%	0	0	2,726	0.10	0.09
2021	0%	0	0	0%	0	0	3,621	0.12	0.12
2022	0%	0	0	0%	0	0	4,642	0.14	0.15
2023	0%	0	0	0%	0	0	5,064	0.14	0.16
2024	0%	0	0	0%	0	0	5,543	0.14	0.16
2025	0%	0	0	0%	0	0	5,997	0.13	0.17
2026	0%	0	0	11%	79,577	7,309,578	6,361	0.13	0.17
2027	0%	0	0	19%	142,346	13,599,811	6,702	0.13	0.17
2028	0%	0	0	28%	219,611	21,818,886	7,039	0.13	0.17
2029	0%	0	0	35%	292,577	30,215,957	7,303	0.13	0.17
2030	1%	8,625	521,732	45%	388,610	41,684,009	7,415	0.13	0.17
2031	2%	13,338	837,565	60%	534,022	59,463,907	7,265	0.13	0.16
2032	2%	18,234	1,187,656	66%	602,224	69,557,302	7,330	0.12	0.15
2033	3%	23,483	1,583,673	72%	676,837	80,940,453	7,398	0.12	0.14
2034	3%	28,622	1,991,487	70%	668,385	82,465,361	7,628	0.12	0.14
2035	4%	30,305	2,168,869	68%	589,257	74,782,771	7,004	0.11	0.12

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-14) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-16. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-89. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2040
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Model Year	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
1996	100%	13,224	407,390	0%	0	0	0	0%	0	0
1997	100%	15,957	507,603	0%	0	0	0	0%	2	27
1998	100%	17,428	573,388	0%	0	0	0	0%	2	23
1999	100%	17,981	612,358	0%	0	0	0	0%	2	19
2000	100%	21,212	772,196	0%	0	0	0	0%	0	5
2001	100%	20,869	808,569	0%	0	0	0	0%	1	19
2002	100%	20,957	866,980	0%	0	0	0	0%	8	114
2003	100%	22,226	985,080	0%	0	0	0	0%	1	18
2004	100%	21,228	1,041,890	0%	0	0	0	0%	1	12
2005	100%	24,808	1,278,892	0%	0	0	0	0%	1	16
2006	100%	25,795	1,417,856	0%	0	0	0	0%	1	22
2007	100%	28,657	1,630,516	0%	0	0	0	0%	2	44
2008	100%	24,894	1,513,071	0%	0	0	0	0%	12	206
2009	100%	20,958	1,283,229	0%	0	0	0	0%	3	64
2010	100%	26,447	1,559,497	0%	1	7	31	0%	15	295
2011	99%	28,341	1,849,619	0%	51	367	1,752	1%	172	3,720
2012	98%	44,963	2,967,860	1%	539	4,153	19,596	1%	240	5,433
2013	97%	60,869	4,125,844	2%	1,150	9,385	43,891	1%	858	20,372
2014	96%	67,874	4,888,299	3%	1,863	16,131	74,982	1%	1,028	25,649
2015	97%	93,376	6,979,373	2%	1,592	14,608	67,463	2%	1,750	45,992
2016	95%	109,366	8,447,742	2%	1,998	19,377	88,913	3%	3,230	88,645
2017	91%	132,055	10,809,831	4%	5,994	61,088	279,650	5%	7,052	203,451
2018	87%	137,285	11,794,487	4%	6,483	69,602	317,087	9%	14,800	449,301
2019	88%	141,083	12,595,274	3%	5,505	64,430	274,520	8%	13,018	416,452
2020	86%	135,652	12,343,563	4%	6,558	82,023	336,557	9%	14,744	498,290
2021	85%	189,590	17,659,856	4%	9,979	135,046	521,355	10%	22,644	801,678
2022	84%	253,809	24,240,958	5%	14,007	218,733	693,952	11%	32,657	1,210,322
2023	84%	291,017	28,467,215	5%	16,137	271,680	807,271	11%	39,377	1,526,695
2024	83%	329,600	32,998,938	5%	18,166	329,087	916,198	12%	47,021	1,906,128
2025	83%	371,783	38,066,268	5%	20,520	399,967	1,039,937	12%	54,873	2,325,226
2026	73%	364,065	38,085,431	5%	25,662	522,506	1,353,168	11%	53,811	2,380,112
2027	64%	353,606	38,594,551	6%	33,873	720,113	1,860,331	11%	60,947	2,812,115
2028	54%	324,333	36,908,576	7%	42,601	945,015	2,435,721	11%	67,997	3,270,853
2029	45%	293,135	34,757,798	8%	52,418	1,212,509	3,118,344	12%	75,286	3,773,157
2030	33%	229,029	28,278,038	9%	62,466	1,505,758	3,864,548	12%	82,893	4,325,829
2031	16%	118,284	15,198,602	10%	73,931	1,856,008	4,754,274	12%	91,993	4,995,176
2032	8%	62,086	8,297,894	11%	85,372	2,231,017	5,703,556	13%	100,453	5,672,249
2033	0%	0	0	12%	98,038	2,665,328	6,801,387	13%	109,828	6,445,628
2034	0%	0	0	13%	110,183	3,115,112	7,934,557	14%	118,177	7,205,918
2035	0%	0	0	14%	123,702	3,633,767	9,240,607	14%	127,619	8,079,263
2036	0%	0	0	15%	136,516	4,164,332	10,573,585	15%	136,000	8,934,507
2037	0%	0	0	16%	149,132	4,719,374	11,969,659	15%	143,943	9,805,502
2038	0%	0	0	17%	163,011	5,339,970	13,539,859	16%	152,878	10,781,757
2039	0%	0	0	18%	174,985	5,911,028	14,995,868	16%	159,852	11,635,052
2040	0%	0	0	19%	167,264	5,807,308	14,748,846	17%	149,158	11,174,023

Table A-89. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2040

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
1996	0%	0	0	0%	0	0	33	0.02	0.007
1997	0%	0	0	0%	0	0	42	0.03	0.009
1998	0%	0	0	0%	0	0	47	0.02	0.009
1999	0%	0	0	0%	0	0	50	0.02	0.008
2000	0%	0	0	0%	0	0	63	0.01	0.009
2001	0%	0	0	0%	0	0	66	0.01	0.009
2002	0%	0	0	0%	0	0	71	0.01	0.009
2003	0%	0	0	0%	0	0	81	0.01	0.010
2004	0%	0	0	0%	0	0	85	0.007	0.003
2005	0%	0	0	0%	0	0	105	0.008	0.004
2006	0%	0	0	0%	0	0	116	0.007	0.004
2007	0%	0	0	0%	0	0	133	0.008	0.005
2008	0%	0	0	0%	0	0	124	0.007	0.004
2009	0%	0	0	0%	0	0	105	0.006	0.004
2010	0%	0	0	0%	0	0	128	0.007	0.005
2011	0%	0	0	0%	0	0	152	0.008	0.006
2012	0%	0	0	0%	0	0	245	0.01	0.009
2013	0%	0	0	0%	0	0	341	0.02	0.01
2014	0%	0	0	0%	0	0	406	0.02	0.02
2015	0%	0	0	0%	0	0	577	0.03	0.02
2016	0%	0	0	0%	0	0	699	0.04	0.03
2017	0%	0	0	0%	0	0	908	0.04	0.03
2018	0%	0	0	0%	0	0	992	0.05	0.04
2019	0%	0	0	0%	0	0	1,054	0.05	0.04
2020	0%	0	0	0%	0	0	1,038	0.04	0.04
2021	0%	0	0	0%	0	0	1,489	0.06	0.05
2022	0%	0	0	0%	0	0	2,041	0.07	0.07
2023	0%	0	0	0%	0	0	2,397	0.08	0.08
2024	0%	0	0	0%	0	0	2,777	0.08	0.10
2025	0%	0	0	0%	0	0	3,202	0.08	0.10
2026	0%	0	0	11%	55,181	4,094,515	3,564	0.09	0.11
2027	0%	0	0	19%	104,083	8,057,835	3,972	0.09	0.12
2028	0%	0	0	28%	165,686	13,373,712	4,316	0.10	0.13
2029	0%	0	0	35%	230,572	19,392,012	4,689	0.10	0.14
2030	1%	6,940	342,764	45%	312,699	27,385,272	4,874	0.11	0.14
2031	2%	11,089	569,948	60%	443,977	40,464,086	4,946	0.10	0.13
2032	2%	15,521	829,789	66%	512,639	48,598,179	5,125	0.11	0.13
2033	3%	20,424	1,135,449	72%	588,656	58,032,030	5,308	0.11	0.13
2034	3%	25,426	1,469,398	70%	593,742	60,846,186	5,631	0.11	0.13
2035	4%	30,924	1,856,231	68%	601,311	64,002,976	5,997	0.11	0.13
2036	4%	36,403	2,268,342	66%	601,159	66,424,848	6,304	0.12	0.13
2037	5%	41,942	2,710,805	64%	597,030	68,425,079	6,582	0.12	0.13
2038	5%	47,943	3,207,935	62%	595,027	70,600,721	6,889	0.12	0.13
2039	6%	53,466	3,690,215	60%	583,811	71,452,118	7,078	0.12	0.13
2040	6%	52,819	3,748,591	58%	511,073	64,318,157	6,473	0.11	0.11

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-17) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-19. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-90. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2045
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of gasoline/day)**	**Fuel Consumption[3] (MJ of electricity/day)**	**Fleet Mix[1] (%)**	**Population[2] (vehicles)**	**Fuel Consumption[3] (MJ of electricity/day)**
2001	100%	17,581	492,838	0%	0	0	0	0%	1	13
2002	100%	17,396	519,815	0%	0	0	0	0%	7	79
2003	100%	18,261	584,063	0%	0	0	0	0%	1	12
2004	100%	17,485	620,429	0%	0	0	0	0%	1	8
2005	100%	19,931	744,101	0%	0	0	0	0%	1	11
2006	100%	20,294	810,536	0%	0	0	0	0%	1	13
2007	100%	21,610	895,705	0%	0	0	0	0%	2	26
2008	100%	17,913	797,202	0%	0	0	0	0%	8	112
2009	100%	14,142	635,358	0%	0	0	0	0%	2	35
2010	100%	16,923	735,246	0%	1	3	15	0%	9	147
2011	99%	16,799	809,857	0%	30	158	790	1%	101	1,691
2012	98%	25,037	1,225,371	1%	300	1,692	8,301	1%	133	2,322
2013	97%	31,446	1,584,333	2%	594	3,560	17,255	1%	442	8,105
2014	96%	32,442	1,745,658	3%	890	5,695	27,363	1%	489	9,437
2015	97%	41,547	2,333,580	2%	708	4,833	22,999	2%	777	15,810
2016	95%	46,072	2,687,564	2%	841	6,105	28,783	3%	1,354	28,787
2017	91%	52,700	3,274,039	4%	2,391	18,339	86,121	5%	2,789	62,457
2018	87%	52,549	3,444,774	4%	2,479	20,175	94,087	9%	5,607	132,466
2019	88%	52,919	3,622,227	3%	2,063	18,391	80,115	8%	4,832	120,601
2020	86%	51,080	3,577,777	4%	2,469	23,635	98,982	9%	5,552	146,669
2021	85%	72,808	5,249,034	4%	3,832	39,919	157,067	10%	8,696	241,288
2022	84%	101,322	7,527,271	5%	5,592	67,570	218,488	11%	13,037	379,660
2023	84%	122,476	9,364,450	5%	6,792	88,932	269,022	11%	16,572	506,226
2024	83%	148,333	11,660,897	5%	8,175	115,750	327,717	12%	21,161	677,755
2025	83%	179,162	14,468,745	5%	9,889	151,350	399,826	12%	26,443	887,822
2026	73%	188,593	15,626,267	5%	13,293	213,382	560,696	11%	27,875	979,732
2027	64%	195,188	16,940,600	6%	18,698	314,629	823,959	11%	33,642	1,237,162
2028	54%	191,955	17,435,060	7%	25,213	444,407	1,160,110	11%	40,244	1,547,489
2029	45%	182,978	17,379,767	8%	32,720	603,637	1,571,051	12%	46,994	1,888,561
2030	33%	151,854	15,069,157	9%	41,417	799,032	2,073,706	12%	54,961	2,306,853
2031	16%	82,041	8,500,426	10%	51,278	1,033,837	2,675,905	12%	63,806	2,794,484
2032	8%	45,406	4,908,616	11%	62,436	1,314,527	3,393,898	13%	73,465	3,355,569
2033	0%	0	0	12%	73,977	1,625,355	4,186,579	13%	82,874	3,945,769
2034	0%	0	0	13%	86,845	1,989,837	5,114,021	14%	93,146	4,620,214
2035	0%	0	0	14%	99,556	2,377,278	6,096,962	14%	102,708	5,304,658
2036	0%	0	0	15%	113,519	2,823,202	7,226,411	15%	113,089	6,078,593
2037	0%	0	0	16%	127,002	3,288,080	8,399,445	15%	122,582	6,853,300
2038	0%	0	0	17%	141,911	3,822,420	9,746,350	16%	133,090	7,734,893
2039	0%	0	0	18%	155,741	4,362,607	11,103,067	16%	142,272	8,592,249
2040	0%	0	0	19%	171,206	4,983,044	12,661,348	17%	152,673	9,574,300
2041	0%	0	0	21%	194,709	5,885,170	14,930,435	17%	161,732	10,526,066
2042	0%	0	0	23%	218,143	6,840,270	17,334,125	18%	170,183	11,485,753
2043	0%	0	0	25%	243,564	7,905,571	20,027,869	18%	179,686	12,554,052
2044	0%	0	0	27%	266,180	8,907,835	22,578,739	19%	186,753	13,462,578
2045	0%	0	0	29%	258,336	8,883,750	22,542,040	20%	182,113	13,505,452

Table A-90. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2045

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2001	0%	0	0	0%	0	0	40	0.01	0.006
2002	0%	0	0	0%	0	0	43	0.01	0.006
2003	0%	0	0	0%	0	0	48	0.01	0.006
2004	0%	0	0	0%	0	0	51	0.005	0.002
2005	0%	0	0	0%	0	0	61	0.005	0.002
2006	0%	0	0	0%	0	0	66	0.005	0.002
2007	0%	0	0	0%	0	0	73	0.005	0.003
2008	0%	0	0	0%	0	0	65	0.005	0.003
2009	0%	0	0	0%	0	0	52	0.003	0.002
2010	0%	0	0	0%	0	0	60	0.004	0.003
2011	0%	0	0	0%	0	0	66	0.004	0.003
2012	0%	0	0	0%	0	0	101	0.006	0.004
2013	0%	0	0	0%	0	0	131	0.008	0.006
2014	0%	0	0	0%	0	0	145	0.009	0.006
2015	0%	0	0	0%	0	0	193	0.01	0.008
2016	0%	0	0	0%	0	0	222	0.01	0.009
2017	0%	0	0	0%	0	0	275	0.02	0.01
2018	0%	0	0	0%	0	0	290	0.02	0.01
2019	0%	0	0	0%	0	0	303	0.02	0.01
2020	0%	0	0	0%	0	0	301	0.01	0.01
2021	0%	0	0	0%	0	0	443	0.02	0.02
2022	0%	0	0	0%	0	0	634	0.03	0.03
2023	0%	0	0	0%	0	0	789	0.03	0.03
2024	0%	0	0	0%	0	0	982	0.03	0.04
2025	0%	0	0	0%	0	0	1,217	0.04	0.04
2026	0%	0	0	11%	28,585	1,679,959	1,463	0.04	0.05
2027	0%	0	0	19%	57,453	3,536,887	1,744	0.05	0.06
2028	0%	0	0	28%	98,060	6,317,542	2,040	0.06	0.07
2029	0%	0	0	35%	143,926	9,696,491	2,345	0.06	0.08
2030	1%	4,602	182,656	45%	207,330	14,593,409	2,598	0.07	0.08
2031	2%	7,691	318,766	60%	307,941	22,631,158	2,768	0.07	0.09
2032	2%	11,351	490,862	66%	374,915	28,748,236	3,033	0.08	0.09
2033	3%	15,411	694,843	72%	444,190	35,512,951	3,250	0.08	0.10
2034	3%	20,040	941,479	70%	467,982	38,985,640	3,611	0.09	0.10
2035	4%	24,888	1,217,544	68%	483,939	41,981,025	3,936	0.09	0.11
2036	4%	30,271	1,541,123	66%	499,887	45,129,386	4,286	0.10	0.11
2037	5%	35,718	1,891,513	64%	508,433	47,744,836	4,597	0.10	0.12
2038	5%	41,737	2,298,544	62%	518,010	50,586,704	4,940	0.10	0.12
2039	6%	47,586	2,724,265	60%	519,604	52,748,816	5,228	0.11	0.12
2040	6%	54,063	3,214,741	58%	523,116	55,158,378	5,553	0.11	0.12
2041	7%	60,266	3,720,156	55%	510,456	55,875,571	5,797	0.11	0.12
2042	7%	66,390	4,250,840	52%	493,711	56,055,334	6,009	0.12	0.12
2043	8%	73,068	4,843,180	49%	477,919	56,173,405	6,239	0.12	0.12
2044	8%	78,867	5,391,525	46%	454,032	55,039,824	6,355	0.12	0.11
2045	9%	75,718	5,321,533	42%	374,633	46,689,015	5,668	0.11	0.10

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-20) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-22. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-91. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2050

	Internal Combustion Engine Vehicle			Plug-in Hybrid Electric Vehicle				Battery Electric Vehicle		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	Fuel Consumption[3] (MJ of electricity/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of electricity/day)
2006	100%	17,095	495,171	0%	0	0	0	0%	1	9
2007	100%	17,938	537,342	0%	0	0	0	0%	2	18
2008	100%	14,711	473,301	0%	0	0	0	0%	6	73
2009	100%	11,643	378,435	0%	0	0	0	0%	2	24
2010	100%	13,584	427,686	0%	0	2	9	0%	8	94
2011	99%	13,206	463,001	0%	24	89	472	1%	79	1,039
2012	98%	18,883	674,484	1%	226	915	4,745	1%	100	1,368
2013	97%	22,656	836,306	2%	428	1,850	9,427	1%	314	4,504
2014	96%	21,908	865,904	3%	601	2,783	14,018	1%	326	4,894
2015	97%	26,586	1,101,721	2%	453	2,250	11,180	2%	491	7,761
2016	95%	27,295	1,177,776	2%	498	2,640	12,955	3%	790	13,009
2017	91%	29,325	1,351,831	4%	1,329	7,482	36,484	5%	1,525	26,393
2018	87%	27,113	1,322,228	4%	1,278	7,675	37,071	9%	2,868	52,384
2019	89%	25,304	1,294,975	3%	986	6,516	29,339	8%	2,292	44,244
2020	86%	22,760	1,198,129	4%	1,100	7,856	33,925	9%	2,474	50,596
2021	85%	30,740	1,673,570	4%	1,618	12,642	51,178	10%	3,671	78,995
2022	84%	40,577	2,287,454	5%	2,239	20,404	67,892	11%	5,221	118,112
2023	84%	47,100	2,747,369	5%	2,612	25,936	80,590	11%	6,373	151,554
2024	83%	55,817	3,364,077	5%	3,076	33,204	96,428	12%	7,963	198,997
2025	83%	67,473	4,197,128	5%	3,724	43,672	118,177	12%	9,959	261,533
2026	73%	72,435	4,648,637	5%	5,106	63,096	169,481	11%	10,706	295,109
2027	64%	77,932	5,265,063	6%	7,465	97,197	259,783	11%	13,432	388,383
2028	54%	80,799	5,740,711	7%	10,613	145,462	387,002	11%	16,940	513,531
2029	45%	82,363	6,147,303	8%	14,728	212,290	562,357	12%	21,153	672,043
2030	33%	73,193	5,733,398	9%	19,963	302,330	797,667	12%	26,491	881,507
2031	16%	42,508	3,491,042	10%	26,569	422,328	1,110,127	12%	33,060	1,150,817
2032	8%	25,069	2,156,590	11%	34,471	574,562	1,505,169	13%	40,561	1,476,533
2033	0%	0	0	12%	43,793	764,692	1,996,805	13%	49,059	1,866,872
2034	0%	0	0	13%	54,221	991,090	2,580,166	14%	58,155	2,312,330
2035	0%	0	0	14%	66,023	1,262,125	3,276,391	14%	68,113	2,828,333
2036	0%	0	0	15%	78,754	1,573,418	4,073,466	15%	78,456	3,400,494
2037	0%	0	0	16%	92,899	1,938,309	5,005,480	15%	89,666	4,054,250
2038	0%	0	0	17%	107,102	2,332,093	6,008,183	16%	100,445	4,735,158
2039	0%	0	0	18%	122,771	2,787,972	7,166,600	16%	112,154	5,509,269
2040	0%	0	0	19%	137,813	3,261,655	8,366,537	17%	122,895	6,287,011
2041	0%	0	0	21%	161,941	3,991,943	10,219,595	17%	134,514	7,162,592
2042	0%	0	0	23%	185,855	4,769,579	12,185,731	18%	144,994	8,031,750
2043	0%	0	0	25%	212,254	5,667,200	14,452,086	18%	156,587	9,018,092
2044	0%	0	0	27%	237,373	6,591,554	16,777,936	19%	166,542	9,968,351
2045	0%	0	0	29%	265,259	7,653,819	19,449,674	20%	186,993	11,623,187
2046	0%	0	0	31%	291,484	8,734,530	22,161,339	22%	206,327	13,312,214
2047	0%	0	0	33%	317,037	9,856,021	24,978,510	23%	225,225	15,070,796
2048	0%	0	0	35%	344,892	11,098,127	28,117,477	25%	245,793	17,025,566
2049	0%	0	0	37%	368,269	12,217,195	30,967,861	26%	263,197	18,805,200
2050	0%	0	0	39%	350,007	11,929,675	30,270,840	28%	250,779	18,424,345

Table A-91. Light Duty Auto Fleet Mix and Tailpipe GHG Emissions for Scenario 4c in Calendar Year 2050

Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

	Fuel Cell Electric Vehicle			Hybrid Electric Vehicle			Tailpipe Emission Estimates[4] (tons/day)		
Model Year	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of hydrogen/day)	Fleet Mix[1] (%)	Population[2] (vehicles)	Fuel Consumption[3] (MJ of gasoline/day)	CO_2	CH_4	N_2O
2006	0%	0	0	0%	0	0	41	0.004	0.002
2007	0%	0	0	0%	0	0	44	0.004	0.002
2008	0%	0	0	0%	0	0	39	0.003	0.002
2009	0%	0	0	0%	0	0	31	0.002	0.001
2010	0%	0	0	0%	0	0	35	0.003	0.002
2011	0%	0	0	0%	0	0	38	0.003	0.002
2012	0%	0	0	0%	0	0	56	0.004	0.003
2013	0%	0	0	0%	0	0	69	0.005	0.003
2014	0%	0	0	0%	0	0	72	0.005	0.003
2015	0%	0	0	0%	0	0	91	0.006	0.004
2016	0%	0	0	0%	0	0	97	0.007	0.005
2017	0%	0	0	0%	0	0	114	0.008	0.005
2018	0%	0	0	0%	0	0	111	0.007	0.005
2019	0%	0	0	0%	0	0	108	0.006	0.005
2020	0%	0	0	0%	0	0	101	0.006	0.004
2021	0%	0	0	0%	0	0	141	0.008	0.006
2022	0%	0	0	0%	0	0	193	0.009	0.009
2023	0%	0	0	0%	0	0	232	0.01	0.01
2024	0%	0	0	0%	0	0	283	0.01	0.01
2025	0%	0	0	0%	0	0	353	0.01	0.01
2026	0%	0	0	11%	10,979	499,769	435	0.01	0.02
2027	0%	0	0	19%	22,939	1,099,249	542	0.02	0.02
2028	0%	0	0	28%	41,276	2,080,130	672	0.02	0.03
2029	0%	0	0	35%	64,784	3,429,693	830	0.03	0.03
2030	1%	2,218	69,496	45%	99,932	5,552,389	989	0.03	0.04
2031	2%	3,985	130,914	60%	159,555	9,294,397	1,138	0.03	0.04
2032	2%	6,267	215,659	66%	206,994	12,630,474	1334	0.039	0.047
2033	3%	9,123	328,539	72%	262,949	16,791,411	1,538	0.04	0.05
2034	3%	12,512	471,192	70%	292,179	19,511,549	1,809	0.05	0.06
2035	4%	16,505	649,413	68%	320,935	22,391,802	2,102	0.06	0.07
2036	4%	21,000	862,736	66%	346,800	25,263,881	2,402	0.06	0.07
2037	5%	26,127	1,119,909	64%	371,908	28,268,312	2,724	0.07	0.08
2038	5%	31,500	1,407,816	62%	390,948	30,983,413	3,029	0.08	0.09
2039	6%	37,512	1,746,949	60%	409,607	33,825,447	3,356	0.08	0.09
2040	6%	43,519	2,110,460	58%	421,086	36,211,173	3,650	0.09	0.10
2041	7%	50,123	2,529,742	55%	424,551	37,995,927	3,948	0.09	0.10
2042	7%	56,563	2,969,544	52%	420,635	39,159,026	4,204	0.10	0.10
2043	8%	63,675	3,476,503	49%	416,483	40,322,062	4,484	0.10	0.11
2044	8%	70,331	3,991,911	46%	404,896	40,751,749	4,710	0.11	0.11
2045	9%	77,747	4,583,546	42%	384,672	40,214,217	4,885	0.11	0.11
2046	9%	84,623	5,179,312	38%	357,821	38,834,824	4,994	0.11	0.10
2047	10%	91,267	5,794,057	34%	327,175	36,831,648	5,061	0.11	0.10
2048	10%	98,539	6,475,841	30%	296,167	34,514,000	5,128	0.11	0.10
2049	11%	104,507	7,082,894	26%	259,335	31,167,115	5,087	0.11	0.09
2050	11%	98,719	6,877,273	22%	197,938	24,452,151	4,480	0.10	0.08

Notes:

[1] Fleet mix percentages for each alternative vehicle technology are determined based on the specific fleet mix assumptions in each scenario, as described in Section 2 of the report.

[2] Population in each model year is calculated based on the fleet mix percentages for each vehicle type and the total population in the EMFAC data. As described in Section 2 of the report, only ICEVs in the EMFAC2021 default fleet are replaced with other vehicle types as applicable in each scenario. Therefore, the existing population of PHEVs and BEVs in EMFAC2021 defaults serves as the minimum population of these vehicle technologies in all scenarios.

[3] Fuel consumption values are calculated based on fuel economies for each vehicle technology (obtained from Table A-23) and the daily average VMT per vehicle. Refer to Sections 3.1 and 3.3 of the report for additional details.

[4] Tailpipe emissions from vehicles in each model year shown here are calculated based on fuel consumption and emission factors for each vehicle technology shown in Table A-25. Reductions in tailpipe emission from the use of renewable drop-in fuels are accounted for separately.

[5] Values in shaded cells are zero. Numbers may not add due to rounding.

Abbreviations:

BEV - battery electric vehicle
CH_4 - methane
CO_2 - carbon dioxide
EMFAC - EMission FACtor Model
ICEV - internal combustion engine vehicle
MJ - megajoule
N_2O - nitrous oxide
PHEV - plug-in hybrid electric vehicle

Table A-92. GREET 2021 Model U.S. Electricity Grid Mix Inputs for Model Year 2026 Light Duty Autos

Country	Year	Overall Electricity Mix[1,2] (% per Energy Source)						Electricity Mix for the "Others" Energy Source in the Overall Electric Mix[1,3] (% per Energy Source)				
		Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Others	Hydroelectric	Geothermal	Wind	Solar PV	Others
United States	2020	1%	41%	19%	20%	2%	18%	38%	2%	46%	12%	2%

Notes:

[1] Electricity mixes obtained from the USEPA's Emissions & Generation Resource Integrated Database (eGRID) 2020 summary data. Available online at: https://www.epa.gov/system/files/documents/2022-01/egrid2020_summary_tables.pdf. Accessed: May 2022.

[2] Electricity mix columns are based on available input fields in the GREET1 model of GREET2021. See 'Fuel_Prod_TS' tab, section 'Electric Generation Mixes'. Available at: https://greet.es.anl.gov/greet_excel_model.models. Accessed: May 2022.

[3] Renewable electricity mix columns are based on available input fields in the GREET1 model of GREET2021. See 'Fuel_Prod_TS' tab, section 'Shares of Technologies for Other Power Plants'. Available at: https://greet.es.anl.gov/greet_excel_model.models. Accessed: May 2022.

Abbreviations:

% - percentage

eGRID - Emissions & Generation Resource Integrated Database

GREET - Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model

PV - photovoltaic

U.S. - United States

USEPA - United States Environmental Protection Agency

Table A-93. GREET 2021 Model International Electricity Grid Mix Inputs for Model Year 2026 Light Duty Autos

Country	Year	Electricity Mix[1,2] (% per Energy Source)						
		Petroleum	Natural Gas	Coal	Biomass	Nuclear	Hydroelectric	Others
Chile	2020	40%	14%	16%	21%	0%	5%	4%
South Africa for PGM Production	2019	16%	3%	72%	6%	2%	0%	1%
Australia	2020	32%	29%	30%	5%	0%	1%	3%
Brazil	2019	36%	11%	5%	32%	1%	12%	2%
Canada	2020	32%	38%	4%	5%	9%	11%	1%
China	2019	19%	7%	61%	4%	3%	3%	3%
Finland	2020	24%	7%	9%	32%	20%	5%	2%
Japan	2020	37%	24%	28%	4%	3%	2%	3%
New Caledonia[3]	2016	58%	0%	39%	0%	0%	2%	1%
Norway	2020	33%	15%	3%	6%	0%	40%	3%
Russia	2019	19%	54%	16%	1%	7%	2%	0%
Alberta[4]	2020	32%	38%	4%	5%	9%	11%	1%
Congo for Cobalt Production	2019	22%	25%	0%	50%	0%	2%	0%
Korea	2020	36%	18%	27%	3%	15%	0%	1%
Europe	2019	32%	26%	14%	9%	12%	3%	4%
Chile Grid for Lithium	2020	40%	14%	16%	21%	0%	5%	4%
Singapore	2019	70%	27%	1%	2%	0%	0%	0%
Indonesia	2019	31%	16%	29%	13%	0%	1%	10%

Notes:

[1] Electricity mixes obtained from most recent International Energy Agency (IEA) energy supply data for each region, unless otherwise noted. Available at: https://www.iea.org/countries. Accessed: May 2022.

[2] Electricity mix columns are based on available input fields in the GREET1 model of GREET2021. See 'Electric' tab. Available at: https://greet.es.anl.gov/greet_excel_model.models. Accessed: May 2022.

[3] New Caledonia electric mix obtained from International Renewable Energy Agency (IRENA) country profile data. Available at: https://islands.irena.org/-/media/Files/IRENA/Sids/CountryProfile/New-Caledonia_Oceania_RE_CP.ashx?la=en&hash=6E9BEE26AA69FD35630BE47B3628F4A780C0DD10. Accessed: May 2022.

[4] Alberta electricity mix is assumed to be equivalent to national Canadian electric grid mix.

Abbreviations:

% - percentage

GREET - Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model

IEA - International Energy Agency

IRENA - International Renewable Energy Agency

PGM - platinum group metals

Table A-94. GREET 2021 Model Inputs for Model Year 2026 Light Duty Autos

GREET Input Parameter	Input for ICEV[1]	Input for HEV[1]	Input for BEV[1]	Input for PHEV[1]
Battery Chemistry	N/A	Ni-MH	Li-ion	Li-ion
Cathode Material[2]	N/A	N/A	NMC622	NMC111
Percent Recycled Battery Materials in Li-ion Battery (%)	N/A	N/A	0%	0%
Li-ion/Ni-MH Battery Replacement	N/A	0	0	0
Peak Battery Power (kW)	N/A	36	N/A	N/A
Peak Battery Energy[3,4] (kWh)	N/A	N/A	81	14
Battery Specific Power (W/kg)	N/A	800	N/A	N/A
Battery Specific Energy (Wh/kg)	N/A	N/A	241 Wh/kg	174 Wh/kg
Battery Production and Assembly Share by Country[5] (% by Country)	N/A	100% US	77% US 13% Japan 5% Korea 4% Europe 1% Other (China)	77% US 13% Japan 5% Korea 4% Europe 1% Other (China)
Battery Materials Production Share by Country (% by Country)	N/A	N/A	LiOH - 80% Ore-China/ 20% Brine-Chile Li_2CO_3 - 45% Brine-Chile/ 55% Ore-China	LiOH - 80% Ore-China/ 20% Brine-Chile Li_2CO_3 - 45% Brine-Chile/ 55% Ore-China
Energy Input of Battery Assembly	N/A	Ni-MH: 2.3 MMBtu/ton	Li-ion: 0.161 MMBtu/kWh	Li-ion: 0.161 MMBtu/kWh
Energy Use of Vehicle Assembly, Disposal, and Recycling[6]	GREET 2021 default	GREET 2021 default	GREET 2021 default	GREET 2021 default
Transportation Distance for Vehicle Materials[7]	GREET 2021 default	GREET 2021 default	GREET 2021 default	GREET 2021 default

Notes:

[1] GREET 2021 default inputs used unless otherwise noted. Non-default values are indicated by the shaded cells.

[2] For BEVs, a battery cathode material of NMC622 is assumed since this is the NMC ratio most commonly used in BEV batteries as of 2021 (Reference A). For PHEVs, there is no option for NMC622 in the GREET model, and so the GREET 2021 default battery chemistry of NMC111 is used.

[3] Peak battery energy for BEVs is calculated as a function of the minimum range from the draft ACC II regulation (200 miles, Reference B), fuel economy from EMFAC2021 (2.59 miles/kWh, Reference C), and the BEV battery SOC utilization from the October 2021 version of the CARB cost workbook (95%, Reference D). A newer version of the CARB cost workbook was released in late April 2022 (after completion of this analysis), which assumed a lower SOC utilization for BEV batteries of 92.5%. However, this does not change the overall conclusions of the analysis.

[4] Peak battery energy for PHEVs is calculated as a function of the minimum range from the draft ACC II regulation (40 miles for US06 cycle, Reference B), fuel economy from EMFAC2021 for electric vehicle miles travelled (3.31 miles/kWh, Reference C), and the PHEV battery SOC utilization from the October 2021 version of the CARB cost workbook (85%, Reference D). A newer version of the CARB cost workbook was released in late April 2022 (after completion of this analysis), which assumed a lower SOC utilization for PHEV batteries of 80%. However, this does not change the overall conclusions of the analysis.

[5] Li-ion battery production and assembly shares by country are based on BEV sales and production data for 2020 (Reference E, Figure A-60).

[6] Includes energy use for multiple vehicle processes including assembly, disposal, and recycling. Refer to tab "Vehi_Inputs" in the GREET 2021 model for further details.

[7] Includes distances for multiple modes of transport across various countries. Refer to tab "GREET2_Factors_T&D" in the GREET 2021 model for further details.

References:

[A] ICCT. 2021. "A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars". July 20. Available at: https://theicct.org/publication/a-global-comparison-of-the-life-cycle-greenhouse-gas-emissions-of-combustion-engine-and-electric-passenger-cars/. Accessed: May 2022.

[B] CARB. 2022. Appendix A-5: Proposed Regulation Order for Section 1962.4 Zero-Emission Vehicle Standards for 2026 and Subsequent Model Year Passenger Cars and Light-Duty Trucks. April 12. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appa5.pdf. Accessed: May 2022.

[C] CARB. 2022. EMFAC2021 v1.0.1 Model. Available at: https://arb.ca.gov/emfac/emissions-inventory/. Accessed: January 2022.

[D] CARB. 2021. "ZEV Cost Modeling Workbook October 2021". Available at: https://ww2.arb.ca.gov/sites/default/files/2021-11/ZEV_Cost_Modeling_Workbook_Update_October2021.xlsx. Accessed: January 2022.

[E] Zhou, Yan, Gohlke, David, Rush, Luke, Kelly, Jarod, and Dai, Qiang. 2021. "Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010–2020". Available at: https://www.osti.gov/biblio/1778934-lithium-ion-battery-supply-chain-drive-vehicles-united-states. Accessed: May 2022.

Abbreviations:

% - percentage
ACC - Advanced Clean Cars
BEV - battery electric vehicle
CARB - California Air Resources Board
EMFAC - EMission FACtors Model
GREET - Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model
HEV - hybrid electric vehicle
ICCT - International Council on Clean Transportation
ICEV - internal combustion engine vehicle
kg - kilogram
kW - kilowatts
kWh - kilowatt-hours
LCA - life cycle assessment
Li - lithium
Li-ion - lithium-ion
LiOH - lithium hydroxide
Li_2CO_3 - lithium carbonate
Ni-MH - nickel metal hydride
MMBtu - Million British Thermal Units
MPGe - Miles per Gallon Equivalent
NMC - nickel manganese cobalt
PHEV - plug-in hybrid electric vehicle
SOC - state of charge
US - United States
VMT - Vehicle Miles Travelled
W - watt
Wh - watt-hour
ZEV - zero emission vehicle

Table A-95. Vehicle Cycle Emission Factors for Model Year 2026 Light-Duty Autos

Vehicle Life Cycle Stage	Vehicle Cycle GHG Emissions[1] (MT CO_2e / vehicle)			
	Internal Combustion Engine Vehicle	**Hybrid Electric Vehicle**	**Battery Electric Vehicle**	**Plug-in Hybrid Electric Vehicle**
Vehicle Material Production[2]	4.89	4.73	3.81	5.35
Vehicle Assembly[3]	0.69	0.69	0.69	0.69
Lead Acid Battery Assembly[4,5,6]	0.01	0.01	0.01	0.01
Lead Acid Battery Materials[4,5,6]	0.03	0.02	0.02	0.02
Ni-MH Battery Assembly[5]	N/A	0.01	N/A	N/A
Ni-MH Battery Materials[5]	N/A	0.31	N/A	N/A
Li-ion Battery Assembly[6]	N/A	N/A	1.14	0.20
Li-ion Battery Materials[6]	N/A	N/A	4.25	0.91
End of Life[7]	0.18	0.18	0.18	0.18
Total	**5.8**	**5.9**	**10.1**	**7.4**

Notes:

[1] Emissions are estimated using the Argonne National Laboratory (ANL) 2021 Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) Model. Available online at: https://greet.es.anl.gov/. Accessed: May 2022. Refer to Table A-94 for further details on GREET model inputs.

[2] Vehicle material production incorporates emissions associated with the production of vehicle components, fluids, and paints.

[3] Vehicle assembly incorporates emissions associated with vehicle painting, HVAC & lighting, heating, material handling, welding, and compressed air processes. GREET assumes equivalent emissions for vehicle assembly across all vehicle technologies.

[4] Battery materials and assembly for ICEVs incorporate emissions associated with the production and assembly of lead-acid batteries. The values presented in the table account for two lead-acid battery replacements over the vehicle lifetime, based on GREET default assumptions.

[5] Battery materials and assembly for HEVs are emissions associated with the production and assembly of both lead-acid and Ni-MH batteries. The values presented include two lead-acid battery replacements but no Ni-MH battery replacements over the vehicle lifetime, based on GREET default assumptions.

[6] Battery materials and assembly for BEVs and PHEVs are emissions associated with the production and assembly of both lead-acid and Li-ion batteries. The values presented include two lead-acid battery replacements but no Li-ion battery replacements over the vehicle lifetime, based on GREET default assumptions.

[7] End of life emissions are based on vehicle disposal and recycling, and exclude any emissions associated with lithium-ion battery disposal and recycling.

Abbreviations:

ANL - Argonne National Laboratory
BEV - battery electric vehicle
CO_2e - carbon dioxide equivalent
GHG - greenhouse gas
GREET - Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model
HEV - hybrid electric vehicle
HVAC - heating, ventilation, and cooling
ICEV - internal combustion engine vehicle
Li-ion - lithium ion
MT - metric ton
Ni-MH - Nickel–metal hydride
N/A - not applicable
PHEV - plug-in hybrid electric vehicle

Table A-96. Estimating Vehicle Cycle Emissions for Scenario Analysis
Appendix A Tables - Scenario Analysis Assumptions and Detailed Methodology

Scenario	Calendar Year	Model Year	Peak Vehicle Population[1]	Fleet Mix[2]				Vehicle Population for Each Vehicle Technology[3]				Vehicle Cycle Emissions[4] (MT CO_2e)				Total Vehicle Cycle Emissions for Calendar Year[5] (MT CO_2e)
				ICEV	HEV	PHEV	BEV	ICEV	HEV	PHEV	BEV	ICEV	HEV	PHEV	BEV	
S0 - ACC I	2026	2026	917,512	85%	0%	4%	11%	780,478	0	38,036	98,998	4,526,980	0	279,738	999,462	5,806,180
	2030	2030	936,884	84%	0%	4%	12%	787,505	0	37,480	111,899	4,567,739	0	275,646	1,129,709	5,973,094
	2035	2035	958,020	84%	0%	4%	12%	805,271	0	38,326	114,423	4,670,786	0	281,864	1,155,195	6,107,846
	2040	2040	975,203	84%	0%	4%	12%	819,714	0	39,013	116,476	4,754,561	0	286,920	1,175,915	6,217,395
	2045	2045	988,060	84%	0%	4%	12%	830,521	0	39,527	118,011	4,817,244	0	290,702	1,191,418	6,299,364
	2050	2050	996,489	84%	0%	4%	12%	837,607	0	39,865	119,018	4,858,342	0	293,182	1,201,582	6,353,107
S1a – ACC II (BEV)	2026	2026	917,512	65%	0%	4%	31%	596,383	0	38,036	283,093	3,459,180	0	279,738	2,858,047	6,596,964
	2030	2030	936,884	32%	0%	4%	64%	299,803	0	37,480	599,601	1,738,937	0	275,646	6,053,448	8,068,031
	2035	2035	958,020	0%	0%	4%	96%	0	0	38,326	919,694	0	0	281,864	9,285,043	9,566,907
	2040	2040	975,203	0%	0%	4%	96%	0	0	39,013	936,190	0	0	286,920	9,451,579	9,738,498
	2045	2045	988,060	0%	0%	4%	96%	0	0	39,527	948,533	0	0	290,702	9,576,186	9,866,888
	2050	2050	996,489	0%	0%	4%	96%	0	0	39,865	956,625	0	0	293,182	9,657,885	9,951,067
S1b – ACC II (BEV + PHEV)	2026	2026	917,512	65%	0%	7%	28%	596,383	0	64,226	256,903	3,459,180	0	472,347	2,593,643	6,525,171
	2030	2030	936,884	32%	0%	14%	54%	299,803	0	127,416	509,665	1,738,937	0	937,079	5,145,471	7,821,487
	2035	2035	958,020	0%	0%	20%	80%	0	0	191,604	766,416	0	0	1,409,146	7,737,576	9,146,722
	2040	2040	975,203	0%	0%	20%	80%	0	0	195,041	780,162	0	0	1,434,421	7,876,356	9,310,777
	2045	2045	988,060	0%	0%	20%	80%	0	0	197,612	790,448	0	0	1,453,332	7,980,196	9,433,528
	2050	2050	996,489	0%	0%	20%	80%	0	0	199,298	797,192	0	0	1,465,731	8,048,279	9,514,010
S2a – PHEV S2b – PHEV + Low-CI Gas	2026	2026	917,512	65%	0%	24%	11%	596,383	0	222,131	98,998	3,459,180	0	1,633,659	999,462	6,092,301
	2030	2030	936,884	32%	0%	56%	12%	299,803	0	525,182	111,899	1,738,937	0	3,862,438	1,129,709	6,731,084
	2035	2035	958,020	0%	0%	88%	12%	0	0	843,597	114,423	0	0	6,204,207	1,155,195	7,359,403
	2040	2040	975,203	0%	0%	88%	12%	0	0	858,727	116,476	0	0	6,315,485	1,175,915	7,491,400
	2045	2045	988,060	0%	0%	88%	12%	0	0	870,048	118,011	0	0	6,398,747	1,191,418	7,590,165
	2050	2050	996,489	0%	0%	88%	12%	0	0	877,471	119,018	0	0	6,453,338	1,201,582	7,654,920
S2c – HEV + Low-CI Gas	2026	2026	917,512	65%	20%	4%	11%	596,383	184,095	38,036	98,998	3,459,180	1,092,870	279,738	999,462	5,831,249
	2030	2030	936,884	32%	52%	4%	12%	299,803	487,702	37,480	111,899	1,738,937	2,895,216	275,646	1,129,709	6,039,508
	2035	2035	958,020	0%	84%	4%	12%	0	805,271	38,326	114,423	0	4,780,446	281,864	1,155,195	6,217,506
	2040	2040	975,203	0%	84%	4%	12%	0	819,714	39,013	116,476	0	4,866,188	286,920	1,175,915	6,329,022
	2045	2045	988,060	0%	84%	4%	12%	0	830,521	39,527	118,011	0	4,930,342	290,702	1,191,418	6,412,462
	2050	2050	996,489	0%	84%	4%	12%	0	837,607	39,865	119,018	0	4,972,405	293,182	1,201,582	6,467,170
S3a – Low-CI Gas S3a1 – Low-CI Gas (Upper Range) S3a2 – Low-CI Gas (Lower Range) S3b – Low-CI Gas (Delayed)	2026	2026	917,512	85%	0%	4%	11%	780,478	0	38,036	98,998	4,526,980	0	279,738	999,462	5,806,180
	2030	2030	936,884	84%	0%	4%	12%	787,505	0	37,480	111,899	4,567,739	0	275,646	1,129,709	5,973,094
	2035	2035	958,020	84%	0%	4%	12%	805,271	0	38,326	114,423	4,670,786	0	281,864	1,155,195	6,107,846
	2040	2040	975,203	84%	0%	4%	12%	819,714	0	39,013	116,476	4,754,561	0	286,920	1,175,915	6,217,395
	2045	2045	988,060	84%	0%	4%	12%	830,521	0	39,527	118,011	4,817,244	0	290,702	1,191,418	6,299,364
	2050	2050	996,489	84%	0%	4%	12%	837,607	0	39,865	119,018	4,858,342	0	293,182	1,201,582	6,353,107
S4a – Custom Fleet Mix 1	2026	2026	917,512	73%	11%	5%	11%	669,784	101,519	47,212	98,998	3,884,925	602,661	347,216	999,462	5,834,264
	2030	2030	936,884	33%	45%	9%	13%	309,172	422,120	84,324	121,268	1,793,279	2,505,893	620,160	1,224,295	6,143,627
	2035	2035	958,020	0%	68%	14%	18%	0	651,988	134,128	171,905	0	3,870,489	986,437	1,735,514	6,592,440
	2040	2040	975,203	0%	58%	19%	23%	0	566,162	185,293	223,748	0	3,360,986	1,362,735	2,258,914	6,982,635
	2045	2045	988,060	0%	42%	29%	29%	0	415,536	286,542	285,982	0	2,466,806	2,107,367	2,887,209	7,461,383
	2050	2050	996,489	0%	22%	39%	39%	0	219,783	388,636	388,070	0	1,304,731	2,858,211	3,917,876	8,080,819
S4b – Custom Fleet Mix 2	2026	2026	917,512	65%	20%	4%	11%	596,976	183,502	38,036	98,998	3,462,617	1,089,352	279,738	999,462	5,831,169
	2030	2030	936,884	31%	50%	7%	12%	290,956	468,442	65,587	111,899	1,687,625	2,780,880	482,354	1,129,709	6,080,569
	2035	2035	958,020	0%	80%	8%	12%	534	766,416	76,646	114,423	3,098	4,549,786	563,693	1,155,195	6,271,773
	2040	2040	975,203	0%	57%	20%	23%	0	556,409	195,045	223,748	0	3,303,094	1,434,456	2,258,914	6,996,463
	2045	2045	988,060	0%	23%	39%	38%	0	227,805	385,348	374,907	0	1,352,350	2,834,033	3,784,982	7,971,364
	2050	2050	996,489	0%	19%	39%	42%	0	189,889	388,636	417,965	0	1,127,263	2,858,211	4,219,687	8,205,161

Notes:

[1] Peak population for model year vehicle occurs in the calendar year subsequent to that model year. Since EMFAC2021 does not output fleet data for CY 2051, Ramboll estimated the peak population of MY 2050 vehicles (which would occur in CY 2051) by applying the percentage increase in MY 2049 vehicles from CY 2049 to CY 2050 to the MY 2050 vehicle population in CY 2050 Please see section 3.2.2 of the report for more details.

[2] Fleet mix for the calendar year and model year for each scenario were obtained from Tables A-26 to A-91.

[3] Estimated as a product of the fleet mix and peak vehicle population.

[4] Calculated as a product of the vehicle population for each vehicle technology type and the vehicle cycle emissions obatained from Table A-95.

[5] Calculated as a sum of the vehicle cycle emissions across all vehicle technology types.

Abbreviations:

ACC - Advanced Clean Cars
BEV - battery electric vehicle
CI - carbon intensity
CO_2e - carbon dioxide equivalent
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
MT - metric ton
PHEV - plug-in hybrid electric vehicle

Table A-97. Vehicle Cycle Emission Factors for Battery Replacement in BEVs

Vehicle Life Cycle Stage	Vehicle Cycle GHG Emissions for BEVs ($MT\ CO_2e$/vehicle)	
	Model Year 2026 to 2050 Vehicles[1]	Pre-2026 Model Year Vehicles[2]
Li-ion Battery Replacement	5.4	4.2

Notes:

[1]Calculated as a sum of Li-ion battery production and Li-ion battery assembly emissions for a model year 2026 BEV with a 81 kWh Li-ion battery, obtained from Table A-95.

[2] Estimated by scaling down the GHG emissions for Li-ion battery replacements in model year 2026-2050 BEVs by the ratio of the Li-ion battery size for MY Pre-2026 vehicles[3] (63 kWh) to the Li-ion battery size for MY 2026-2050 vehicles (81 kWh).

[3] A Li-ion battery size of 63 kWh was used for Pre-2026 model year BEVs. This value is calculated as a weighted average of the battery sizes and cumulative sales of various BEV models from 2010-2020 in the United States, which are detailed in the *Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States 2010-2020* (available at: https://www.osti.gov/biblio/1778934-lithium-ion-battery-supply-chain-drive-vehicles-united-states, accessed: May 2022).

Abbreviations:

ANL - Argonne National Laboratory
BEV - battery electric vehicle
CO_2e - carbon dioxide equivalent
EMFAC - EMission FACtor Model
kWh - kilowatt-hour
Li-ion - lithium ion
MT - metric ton
MY - model year
GREET - Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model
GHG - greenhouse gas

Table A-98. Estimating Battery Replacement Emissions for Battery Electric Vehicles in the Scenario Analysis

Scenario	Calendar Year	Model Year[1]	Battery Electric Vehicle Population[2]	BEV Battery Replacement Emissions for Calendar Year[3] (MT CO_2e)
S0 - ACC I	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	77,601	418,146
	2040	2031	88,297	475,782
	2045	2036	90,386	487,040
	2050	2041	92,102	496,283
S1a – ACC II (BEV)	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	221,906	1,195,725
	2040	2031	532,274	2,868,120
	2045	2036	726,491	3,914,650
	2050	2041	740,279	3,988,946
S1b – ACC II (BEV + PHEV)	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	201,377	1,085,106
	2040	2031	449,479	2,421,985
	2045	2036	605,413	3,262,226
	2050	2041	616,903	3,324,139
S2a – PHEV S2b – PHEV + Low-CI Gas	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	77,601	418,146
	2040	2031	88,297	475,782
	2045	2036	90,386	487,040
	2050	2041	92,102	496,283
S2c – HEV + Low-CI Gas	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	77,601	418,146
	2040	2031	88,297	475,782
	2045	2036	90,386	487,040
	2050	2041	92,102	496,283
S3a – Low-CI Gas S3a1 – Low-CI Gas (Upper Range) S3a2 – Low-CI Gas (Lower Range) S3b – Low-CI Gas (Delayed)	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	77,601	418,146
	2040	2031	88,297	475,782
	2045	2036	90,386	487,040
	2050	2041	92,102	496,283
S4a – Custom Fleet Mix 1	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	77,601	418,146
	2040	2031	103,082	555,453
	2045	2036	143,360	772,485
	2050	2041	184,637	994,904
S4b – Custom Fleet Mix 2	2026	2017	43,901	183,990
	2030	2021	63,072	264,335
	2035	2026	77,601	418,146
	2040	2031	88,297	475,782
	2045	2036	143,360	772,485
	2050	2041	184,637	994,904

Notes:

[1] Battery replacement emissions are assumed to occur in the ninth year of the battery electric vehicle lifetime. See section 3.3.3 in the report for more details.

[2] Population of BEV for each respective model year that are still in the overall fleet in the respective calendar year. Please see Tables A-26 to A-91.

[3] Battery replacement emissions are estimated based on the GHG emission factor calculated in Table A-97.

Abbreviations:

ACC - Advanced Clean Cars
BEV - battery electric vehicle
CI - carbon intensity
CO_2e - carbon dioxide equivalent
FCEV - fuel cell electric vehicle
GHG - greenhouse gas
HEV - hybrid electric vehicle
ICEV - internal combustion engine vehicle
MT - metric ton
PHEV - plug-in hybrid electric vehicle

WSPA

AFPM American Fuel & Petrochemical Manufacturers

CIPA California Independent Petroleum Association

ATTACHMENT E

"Impact of the Advanced Clean Cars II (Internal Combustion Engine Ban) Regulation on California Businesses" by Capitol Matrix Consulting dated May 17, 2022

Capitol Matrix Consulting
Analysis, Advice, Advocacy

Date: May 17, 2022

To: Western States Petroleum Association

From: Brad Williams
Chief Economist
Capitol Matrix Consulting

Subject: Impact of the Advanced Clean Cars II (Internal Combustion Engine Ban) Regulation on California Businesses

This memo is in response to your request that we identify and discuss the impacts of the *Advanced Clean Cars II* (ACC II) regulatory proposal on California businesses**.** ACC II implements Governor Newsom's executive order N-79-20 with respect to the light-duty vehicle segment of the transportation market by curtailing and eventually banning sales of internal combustion engine powered passenger vehicles and trucks in California. As shown in Figure 1, the proposed regulation requires the zero-emission vehicles' (ZEV) share of new light-duty vehicle sales to rise from about 12 percent today to 26 percent by 2026, 61 percent by 2030, and 100 percent by 2035. A second set of provisions require more rigid emissions standards for new gasoline and diesel-powered internal combustion engine (ICE) vehicles sold during this transition period.

Figure 1
Key Provisions of the Advanced Clean Cars II (Internal Combustion Engine Ban) Proposed Regulation

Provision	Main Features
ZEV & PHEV Provisions	
Zero emission vehicle ("ZEV") and plug-in hybrid electric vehicle ("PHEV") percent sales requirement for light duty vehicles.	➢ Starts at 26% in 2026, rising to 61% by 2030 and 100% by 2035. ➢ Covers all major manufacturers (small manufacturers of custom cars subject to different rules).
Minimum technical requirements and assurance standards for vehicles to count toward standard.	➢ Includes minimum range, direct current (DC) charging capability, durability, and warranty requirements.
Environmental justice flexibilities.	➢ Provides enhanced ZEV sales credits for cars sold at discount or placed (after lease) with households in economically disadvantage communities.

Provision	Main Features
Provisions Affecting Internal Combustion Engine (ICE) Vehicles	
Prevent emission "backsliding" of remaining fleet.	➢ Requires that emissions standards apply to remaining ICE vehicles sold rather than whole fleet. (Otherwise, increased ZEV sales would allow for higher emissions in remaining ICE fleet.)
Reduce cold-start emissions from light-duty vehicles.	➢ Requires emissions tests and standards to be based on "real-world" laboratory conditions. ➢ This includes shorter warm-up period between start and initiation of driving.
Reduce emissions from driving.	➢ Lower the evaporative emissions cap. ➢ Control in-use emissions for medium-duty vehicles while towing. ➢ Lower fleet average caps for medium-duty fleets. ➢ Limit emissions from medium-duty vehicles under aggressive driving conditions.

Key Impacts of the ACC II Regulatory Proposal on Businesses

There are approximately 790,000 businesses operating in California, employing about 15.5 million workers. The ACC II regulation would have multiple effects on most of these businesses, as highlighted in Figure 2.

Figure 2
Key Effects of the ACC II (Internal Combustion Engine Ban) on California Businesses

Type of impact	Businesses Affected	Consequences
Higher ZEV prices	Those opting to purchase ZEVs.	➢ $5,000 to $8,000 price increase for small car in 2026. ➢ $12,000 to $16,000 price increase for pickup with towing capability in 2026. ➢ Offsetting future operational and fueling related savings are highly uncertain. ACC II SRIA estimates do not take into productivity losses.
Higher costs for ICE vehicles and petroleum-based fuels	Those continuing to purchase and use ICE vehicles	➢ Compliance with new emissions provisions – ($80 to $660 depending on type of vehicle). ➢ Fewer suppliers of replacement parts, potentially leading to higher prices. ➢ Phaseout of petroleum-based fuel supplies and retail outlets, leading to higher gasoline and diesel costs and fewer retail fueling options.

Type of impact	Businesses Affected	Consequences
Reduction in fuel tax revenues to state and local governments	All businesses	➢ $31 billion reduction in excise taxes between 2026 and 2040, resulting in: • Less maintenance and fewer road improvements. • More traffic. • Deterioration of roads. • Faster depreciation of vehicles. • Longer travel times and lost productivity.
Increase in utility rates to cover costs of electrification of transportation system.	All businesses	➢ Higher costs for heating, cooling, lighting, cooking, industrial boilers, and other equipment.
Greater exposure to electrical power disruptions	All businesses, but especially those converting to ZEVs	➢ Widespread loss of charging capabilities. ➢ Major disruptions to vehicle transportation.
Customer-related impacts	All businesses	➢ Loss of customer discretionary income tied to higher ZEV purchase prices, and lower demand in regions affected by phase-out of Oil & Gas (O&G) industry. ➢ Pressure for business-financed installation of charging outlets in parking facilities.

ACC II will have disparate impacts on small businesses. The impacts shown in Figure 2 will have different effects on small businesses throughout the state. Clearly, businesses with large vehicle fleets and significant travel requirements will be hit hard by the regulation. But other businesses will also bear disproportionate impacts. For example, businesses located in hot inland regions will be hit harder by rising electricity rates stemming from the regulation because of their higher electricity requirements for air conditioning and refrigeration as compared to their counterparts located on the coast. Also, contractors located in rural areas that purchase ZEVs – especially those needing to travel long distances – will face greater challenges than their urban counterparts in finding shared charging stations, especially during the transition period when the charging network has yet to be built out. Similarly, rural businesses that retain ICE vehicles and need to travel long distances will be hit particularly hard by rising gasoline costs and fewer fueling stations as petroleum supplies phase out.

In the following sections, we discuss each of the impacts identified in Figure 2 in greater detail.

Higher ZEV prices

Businesses purchasing ZEVs will face significantly higher purchase costs. Today, the incremental cost for a ZEV compared to an ICE vehicle with similar features, capabilities, and range is well over $10,000 for small vehicles, and well over $20,000 for high-end sedans, SUVs, and pickup trucks. [1]

[1] For example, a Hyundai Kona gasoline-powered vehicle has a base MSRP of approximately $22,500, compared to $34,000 for the EV version. The range for the EV is 258 miles, and the gasoline-powered vehicle is 462 miles. As another example, the Lariat extended range EV version of 2023 Ford F-150 pickup will have an MSRP of $79,000

The California Air Resources Board (CARB)-issued Standard Regulatory Impact Report (SRIA) for the ACC II proposed regulation assumes that the current price increments will diminish sharply between now and 2035, due to improved and simplified battery cell and pack designs, introduction of new battery chemistries, new manufacturing techniques, and economies of scale from increasing production volumes.

Even if the SRIA's optimistic assumptions are realized, however, price differentials will remain significant through 2035 for larger vehicles used by businesses, such as pickups and vans. For example, CARB estimates that the incremental manufacturing cost for a high-end battery-powered electric vehicle (EV) pickup with towing capacity will be $11,600 in 2026 and remain at $4,000 above a comparable ICE vehicle in 2035. The implication is that it will take many years of operational savings to offset the higher up-front incremental costs resulting from purchases of more expensive ZEVs.

CARB estimates of future ZEV price declines may be overstated. While it is reasonable to assume *some* reduction in ZEV prices as the market achieves scale and technological advances continue, recent trends suggest that the size of the reductions may be significantly less than assumed by CARB in the ACC II SRIA projections. The CARB projections are based on the assumption that battery costs, measured as dollars per kilowatt hours (kWh) of battery capacity, will decline steadily by 7 percent per year between 2020 and 2030, and by 5 percent annually between 2030 and 2035. However, battery prices are rising in 2022 due to sharp price increases for battery-related metals such as cobalt, nickel sulfate and lithium carbonate, and it is probable that these upward pricing pressures will continue for several years. Key factors pushing up battery prices are growing worldwide demand for battery-powered vehicles and supply constraints caused by long lead times needed to open new mines and strong resistance to new mining in the U.S. and other western countries.

As an illustration of the impact of slower price-declines in battery costs on future vehicle price differentials, if we (1) take into account the recent uptick in battery prices and (2) then assume that future price decline in battery costs from 2022 levels are one-half that assumed in the SRIA (i.e., 3.5 percent instead of 7 percent annually through 2030 and 2.5 percent instead of 5 percent annually between 2030 and 2035), the resulting incremental price for the EV pickup would be $16,000 in 2026 and nearly $10,000 in 2035.

It is important to note that these differentials reflect only manufacturing costs. The full price difference is magnified significantly when dealer markup, sales taxes, vehicle license fees, and financing costs are included. Also, the price increment does not consider the additional expense of on-site chargers, which can range from the high hundreds of dollars to several thousands of dollars for level-2 chargers, depending on whether electrical upgrades are needed. For rapid chargers, annual costs can easily exceed $75,000 for the charger and installation costs combined.

Future operational and refueling cost-savings are highly uncertain. According to estimates presented in the ACC II SRIA, higher upfront costs for ZEVs will be offset by lower costs for refueling and maintenance. However, in calculating the offsets, business owners will need to consider that (1) the operational savings will occur over many years, and (2) any prospective savings will be subject to uncertainties regarding both the future costs of electricity versus gasoline and future business conditions (which in turn will impact the usage of the newly purchased vehicle). From a business perspective, future savings related to operation and maintenance costs

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(https://www.caranddriver.com/ford/f-150). This compares to $56,400 for the 2022 gas-powered version Lariat model with a V-8 engine. (https://www.caranddriver.com/ford/f-150-lightning) need to be discounted to reflect these uncertainties, making it even less likely that total costs of ownership over the lifetime of the ZEV vehicle will be comparable to the ICE vehicle counterpart. We also note that one of the key assumptions in the SRIA is that much charging will be accomplished through overnight charging on level 1 and level 2 chargers, which holds down prices per kilowatt hour.[2] This is a reasonable assumption for businesses that (1) have access to garages or storage facilities for overnight charging; and (2) use their vehicles at predictable times and on local routes. However, the assumption is less applicable to businesses that are reliant on public or private shared chargers, especially those that use vehicles for longer and more variable routes or operate their vehicles on a continuous schedule. These businesses will need to recharge "on the road," using more expensive rapid chargers, and hence will achieve relatively less fueling-related savings over time.

A closely related factor is that "time is money" for businesses. The added costs involved in planning and altering routes to match locations of public chargers, and the additional time spent recharging (up to 45 minutes for rapid charges and up to 8 hours for level 2 chargers, versus less than 5 minutes for gasoline vehicles), translates into lost productivity, higher expenses and lower revenues for these businesses.

Higher costs for ICE vehicles and petroleum-based fuels

Businesses that are unable (or unwilling) to incur the higher costs and lost productivity for ZEVs can purchase ICE vehicles through the 2026-to-2035 transition period, and all car owners can continue to drive light-duty vehicles after 2035, either by holding onto existing vehicles or purchasing ICE vehicles on the used-car market, Businesses that continue to use ICE vehicles will avoid costs associated with purchasing ZEVs. However, they will still face higher costs associated with continued purchases and operation of ICE vehicles under the ACC II regulation.

A relatively small portion of these higher costs are directly related to the ACC II regulatory proposal provisions focused on reducing emissions from ICE vehicles sold during the transition period. According to CARB calculations, these provisions will increase per-vehicle costs by $80 for light duty vehicles, and $660 for medium and heavy-duty vehicles sold in 2026.

However, the much larger impact relates to the phase-out of petroleum fuels and ICE vehicles that will result from the government-mandated shift to an all-ZEV market. According to Stillwater Associates (a transportation fuels consulting firm), the ACC II regulation will reduce gasoline sales by 66 percent by 2035, and by 90 percent by 2050. Stillwater also projects that diesel sales will fall by 34 percent by 2035 and by 60 percent by 2050. Declines of this magnitude will likely result in a major consolidation, and perhaps the entire elimination, of the petroleum refining industry in California, as well as an over 50 percent decline in retail fueling stations by 2035, and an 80 percent decline in fueling stations by 2050. Per-gallon petroleum fuel costs will rise, as the fixed costs related to the distribution and sales of gasoline are spread over fewer and fewer customers.

The CARB SRIA acknowledges the job and income-related impacts of declining O&G production, refining and distribution in California. However, the SRIA does not address the very important impact that the O&G declines will have on businesses that continue to rely on ICE vehicles. These vehicle operators will have to travel further and pay more to cover the increased per-gallon cost of

[2] In the ACC II SRIA, CARB specifically estimates that the "all in" cost of charging (including capital recovery of up-front investments) will be 24 cents per kilowatt hour (kWh) for public level 2 (L2) chargers, 25 cents/kWh for home charging, and 40 cents/kWH for direct current (DC) fast chargers.

gasoline and diesel as the oil and gas industry phases out, which will raise expenses and depress bottom-line earnings.

Deteriorating roads and more traffic

The reduction in gasoline and diesel sales will also result in a major decline in excise and sales taxes, which are major funding sources for California's transportation infrastructure. According to the CARB SRIA, total losses in excise and sales tax revenues on gasoline and diesel will be $41 billion over the 2026 through 2040 period, which will be only partially offset by $12 billion in new revenues from the $100 road improvement fee levied on ZEVs.

While the SRIA acknowledges the reduction in excise and sales taxes available for transportation infrastructure, it does not address the consequences of such a reduction, which would be severe. Absent the replacement of the gasoline excise tax with an alternative statewide funding source, the decline in gasoline sales will result in less maintenance, fewer road expansions, and fewer road improvements – all of which will lead to more traffic, longer travel times, faster vehicle depreciation, and, ultimately, reduced business productivity and earnings in the state.

Higher utility rates

Utilities will incur major *up-front* costs associated with installing an adequate-sized ZEV fueling network. According to the California Energy Commission's assessment of charging infrastructure needs outlined in its July 2021 report,[3] 1.2 million public and shared private chargers are needed to support almost 8 million ZEVs in 2030, which is consistent with the number that would be on the road under the Clean Cars II proposal. That is about 1 million more than the 193,000 chargers that are currently online or in planning stages throughout California. Charging needs will continue to expand sharply after 2030 to accommodate the growing fleet of ZEVs mandated by the ACC II proposed regulation.

Utilities will also incur major costs for upgrades to the electric grid needed to accommodate an all-electric transportation system. Based on annual data contained in the CARB 2021 study titled "2021 SB 100 Joint Agency Report" (SB 100 report), we estimate that full electrification of California's economy will require total utility investments of $1.8 trillion during the 30-year period from 2020 to 2050, about 50 percent above that required by a "business as usual" baseline. About 60 percent of the added costs relative to the baseline is directly attributable to upgrades needed to accommodate a fully electrified transportation system, with the balance needed to accommodate electrification of the commercial, industrial, and residential sectors of the economy.

Funding for additional chargers and grid upgrades has traditionally come from utility ratepayers (although in 2021-22 and 2022-23 the state has used surplus General Fund resources to support one-time commitments to charging subsidies). The projected funding needs imply substantial increases in electricity rates paid by businesses, which already pay rates that are among the highest in the U.S.

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[3] California Energy Commission. "Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment," July 2021. (https://www.energy.ca.gov/programs-and-topics/programs/electric-vehicle-charging-infrastructure-assessment-ab-2127)

This is demonstrated in Figure 3, which shows that the average electricity rate paid by commercial businesses in California was 19.29 cents per Kilowatt hour during February 2022. This was more than double the average paid by commercial businesses in neighboring states (Oregon, Washington, Arizona and Nevada) and about 64 percent above the national average. Rates paid by industrial users were also more than double those in neighboring rates and were about 87 percent above the national average.

Figure 3
Comparison of Electricity Rates
February 2022 (Cents per Kilowatt Hour)

Location	Residential	Commercial	Industrial
California	25.59	19.29	13.93
Neighboring States Average	11.96	9.43	6.26
U.S. Average	13.83	11.78	7.46

Further ratepayer increases will have substantial impacts on all California businesses, irrespective of their usage of electrical vehicles. This is because electricity is a major power source for lighting, heating, cooking, air conditioning, refrigeration, and for a variety of other appliances and machinery used by businesses.

Greater exposure to electrical power disruptions

Full electrification of the transportation system will put all ZEV owners, including businesses, at greater risk of electrical power disruptions. Such disruptions are due to unplanned shortages caused by such factors as (1) high demand and lower-than-expected generation from solar, wind, or hydroelectric power, and (2) planned power outages adopted by utilities in windy, hot and dry weather conditions to preempt the risks of their grids sparking major fires. The frequency of outages will likely rise in the future as the risk of major wildfires grows and the state shuts down natural gas and nuclear power plants over the next several years. Such outages will delay recharging, thereby disrupting travel plans and reducing business productivity.

Customer-related impacts

Finally, California businesses will face indirect customer-related effects from the proposed ACC II regulation. For example, higher costs for ZEVs will leave less room in household's budgets for purchases of other goods and services supplied by businesses. Those businesses operating in the Central Valley, Southern California and other regions significantly impacted by the phase-out of the O&G industry will face reduced demand for their product and services due to higher unemployment and weaker economic conditions. Retail businesses in all regions will face increased pressure to install chargers in parking lots and garages – at a significant cost – to attract and retain customers that are ZEV owners without access to overnight charging at home and thus in need of shared charging. While these costs could presumably be recovered through charging fees, the up-front investments may prove challenging to businesses without access to adequate cash-flows or credit to cover the up-front investment.

Impacts of Other Executive Order N-79-20 Provisions

As noted above, the ACC II regulatory proposal primarily implements the provisions in the Governor's EO N-79-20 relating to the light-duty vehicle segment of the market. However, it is important to note that the other provisions of executive order 79-20 affecting the medium- and heavy-duty vehicle segments will have even more serious impacts on California businesses. These provisions require that all medium- and heavy-duty drayage trucks on the road be ZEVs by 2035, and that all other medium- and heavy-duty vehicles on the road be ZEV by 2045.

The potentially major impacts arise because achieving the Governor's executive order will require large improvements in big-rig battery power and range capabilities relative to today's level – and even than the up-front incremental costs for vehicles and chargers will be substantial.[4] These higher costs will be reflected in higher shipping rates for virtually all major products, which will in turn drive up the wholesale price of goods in the state. Such cost increases will depress profits and put California businesses that sell products on national or regional markets at a competitive disadvantage against businesses operating in other states.

Conclusion

The ACC II regulation will have wide-ranging impacts on California businesses. Those purchasing ZEVs will face higher costs with no assurance that projected savings in future years will fully offset those costs. Those that continue to purchase and use ICE vehicles will face higher costs for fuel and spare parts as the market for ICE vehicles and petroleum-based fuels is phased out. Reductions in excise taxes and local sales taxes on gasoline will impair the ability of state and local governments to maintain and improve roadways, resulting in more traffic congestion, longer travel times, and added depreciation and repair costs. Businesses will also be affected by higher utility rates, and in some cases, falling demand from customers and pressures to make costly installations of charging facilities to attract customers requiring shared charging during the day. Many of these impacts will have disproportionate effects on small businesses located in hotter inland regions and rural regions of the state. While some of the impacts are covered in the ACC II SRIA, many are not, and should be fully vetted before the regulation is finalized.

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[4] For example, the estimates made by the energy consulting firm E3 in October 2020 (summarized in a report titled "Achieving Carbon Neutrality in California") assumed that a battery-powered EV version of a Class 8 tractor would be $170,748 and a fuel cell powered version would be $190,155, compared $130,000 for a diesel-powered vehicle. The CARB report issued in 2018 titled "Deep Decarbonization in a Highly Renewables Future," found that incremental costs associated with decarbonizing the medium and heavy-duty transportation were among the highest of all solutions they considered. Finally, in its analysis released in March 2021 titled "Proposed Rule 2305 – Warehouse Indirect Source Rule – Warehouse Actions and Investments to Reduce Emissions (WAIRE) Program and Proposed Rule 316 – Fees for Rule 2305," the South Coast Air Quality Management District estimated that chargers for Class 7 or 8 big-rigs will cost as much as $140,000 to purchase and $80,000 to install.

WSPA

AFPM American Fuel & Petrochemical Manufacturers

CIPA California Independent Petroleum Association

ATTACHMENT F
"Distributional Impacts of the Advanced Clean Cars II (Internal Combustion Engine Ban) Regulator Proposal" by Capitol Matrix Consulting dated May 26, 2022

Capitol Matrix Consulting
Analysis, Advice, Advocacy

Date: May 26, 2022

To: Western States Petroleum Association

From: Brad Williams
Chief Economist
Capitol Matrix Consulting

Subject: Distributional Impacts of the Advanced Clean Cars II (Internal Combustion Engine Ban) Regulatory Proposal

This memo is in response to your request that we evaluate the impact of the proposed Advanced Clean Cars II (ACC II) regulation on lower and moderate-income households. As discussed in my previous memos, the ACC II proposed regulation would phase out sales of internal combustion engine (ICE) vehicle sales in California over the 2026-2025 period, requiring that all passenger vehicles requiring sold in the state be zero emissions vehicles (ZEVs) by 2035.[1] The proposed regulation would also impose more stringent emission standards on ICE vehicles sold during the 2026-2025 transition period.

While California Air Resources Board's (CARB) Standardized Regulatory Impact Assessment (SRIA) addresses many of the aggregate impacts of the proposed regulation, it does not cover distributional impacts in any meaningful way. We believe this is a major omission, especially for a proposal that is as far-reaching as the ACC II regulation. The mandated phase-out and eventual ban of ICE vehicles will have substantial distributional impacts in California, disproportionately affecting those at the lower end of the state's income spectrum. This is significant because income inequality is already a major issue in California, a state that has extreme wealth and income at the top end, but also a large number of families that are struggling to make ends meet due to limited resources and the high cost of living in the state.[2] According to data from the *U.S. Consumer Expenditure Survey* for California, the bottom 60 percent of families in California (approximately 8.6 million) spend virtually all of their income each year.[3] Similarly, data from the Federal Reserve on U.S. consumer finances finds that the bottom 60 percent of the U.S.

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[1] In this memo, ZEVs refer to battery-powered electric vehicles (BEVs), hydrogen powered fuel cell electric vehicles (FCEVs) and, during the 2026-2035 ramp up period, some plug-in hybrid electric vehicles (PHEVs). Most of the references in this memo refer to BEVs, however, as they are assumed in the CARB SRIA to comprise the great majority of ZEVs during the projection period. This partly reflects their more favorable economics relative to FCEVs and PHEVs.

[2] For example, the Public Policy Institute of California reported that 17.6 percent of Californians were in poverty (as measured by the Supplemental Poverty Measure, which takes into account housing costs), and another 17 percent had incomes that were within 50 percent of the poverty line. See "Poverty in California," Public Policy Institute of California. Accessed May 28, 2021. https://www.ppic.org/publication/poverty-in-California.

[3] U.S. Bureau of Labor Statistics, *Consumer Expenditures Surveys, California: Quintiles of income before taxes, 2018-19.* https://www.bls.gov/cex/tables/geographic/mean/cu-state-ca-income-quintiles-before-taxes-2-year-average-2019.htm.)

income distribution have a median of just $2,400 in their combined checking and savings accounts.[4] Together, these data indicate that over one-half of California's households are living paycheck-to-paycheck and likely have little if any room for unexpected expenses.

Workers in the lower- and middle-income tiers have struggled for decades with lagging wages and job losses in industries such as manufacturing and mining that have historically been the source of good salaries and benefits for workers with high-school degrees and technical skills.[5]

Impacts of Proposal on Low- and Moderate-Income Households

The ACC II regulation would have multiple impacts on low- and moderate-income households. As highlighted in **Figure 1** (next page), those families that purchase new battery-powered electric vehicles (BEVs) would have to pay much more for these vehicles. Lower-income BEV owners would likely pay more for electricity to charge their vehicles than their higher-income counterparts that have access to overnight charging. Those that stay with ICE vehicles will also pay higher prices for gasoline and repairs. Lower- and moderate-income households will be hard-hit by regressive increases in utility rates to cover costs of electrifying the transportation system. And lower- and moderate-income households would be negatively affected by the loss of good-paying job opportunities as a result of the regulation's impact on traditional energy jobs. In the following sections we discuss these impacts in more detail.

Higher Purchase Prices for BEVs

Currently, the incremental cost for a BEV compared to an ICE vehicle with similar features, capabilities, and range is $12,000 or more for small passenger vehicles, and well over $20,000 for high-end sedans, SUVs, and pickup trucks.[6] (The price differences for fuel cell hydrogen vehicles are even greater.) The California Air Resources Board (CARB) Standard Regulatory Impact Report (SRIA) for the ACC II proposed regulation assumes that this difference will fall by over 50 percent between 2020 and 2026 – and further in subsequent years – due to improved and simplified battery cell and pack designs, introduction of new battery chemistries, new manufacturing techniques, and economies of scale.

Unfortunately, recent trends are moving in the opposite direction. Price differentials between BEV and comparable ICE vehicles are expanding rather than contracting for several models in 2022 due to strong demand and soaring costs for battery metals such as cobalt, nickel sulfate and lithium carbonate. These increases are not expected to ease for several years as worldwide demand for battery-powered vehicles grows and battery supplies are constrained by supply shortages, long lead times needed to open new mines, and strong resistance to new mining in the U.S. and other western countries.

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[4] Board of Governors of the Federal Reserve System, *Survey of Consumer Finances.* https://www.federalreserve.gov/econres/scfindex.htm

[5] Between 1990 and 2019 California lost just under one-third of its manufacturing base. The loss between 1990 and 2021 was 35 percent. See California Employment Development Department, Labor Market Information Division. https://www.labormarketinfo.edd.ca.gov/data/employment-by-industry.html

[6] For example, a Hyundai Kona gasoline-powered vehicle has a base MSRP of approximately $22,500, compared to $34,000 for the EV version. The range for the EV is 258 miles, and the gasoline-powered vehicle is 462 miles. As another example, the Lariat extended range EV version of the 2023 Ford F-150 pickup will have an MSRP of $79,000 (https://www.caranddriver.com/ford/f-150). This compares to $56,400 for the 2022 gas-powered version of the Lariat model with a V-8 engine. (https://www.caranddriver.com/ford/f-150-lightning)

Figure 1
Key Effects of the ACC II (Internal Combustion Engine Ban) on Low- and Moderate-Income Households

Type of Impact	Comments
Higher costs for BEV purchases.	➢ BEV models of small passenger cars are currently at least $12,000 more than comparable ICE models. ➢ CARB assumes price differential will fall by more than one-half by 2026, but current trends are toward a widening, rather than narrowing, gap. ➢ Financing higher-priced cars – if even possible - will have a disproportionate impact on lower-income owners, due to higher credit costs. ➢ Insurance, sales tax, and vehicle fees add to increase.
Higher costs for charging.	➢ CARB asserts that higher up-front costs will be more than offset over time by lower fuel and maintenance costs. ➢ However, the magnitude of fuel-related cost-savings is highly dependent on both the extent of future BEV price declines and the access to home charging. ➢ Low-income BEV owners living in older high-density multi-family dwellings are less likely to have access to home charging. ➢ Therefore, low-income BEV owners will likely have to rely on more-expensive direct charging, making it less likely that their operational savings will be sufficient to offset higher BEV prices.
Higher prices for petroleum-based fuels, and repairs of ICE vehicles.	➢ Will impact lower-income owners that that can't afford EVs and continue to use ICE vehicles. ➢ Causes: ▪ Phase-out of petroleum-based fuel supplies and retail outlets, leading to higher gasoline prices and fewer retail fueling options. ▪ Fewer suppliers of replacement parts, putting upward pressure on prices.
Increase in utility rates to cover costs of electrification of transportation system.	➢ Utility rate increases are regressive, hitting budgets of lower-income households the hardest. ➢ Low-income households also less able to avoid higher utility costs through investments in rooftop solar. ➢ Disproportionate impacts on households in hotter inland regions of the state, which have lower median household incomes and higher energy needs.
Phase-out of petroleum industry.	➢ Will result in major declines in good-paying jobs with benefits that have been available to workers with high-school diplomas. ➢ Industry reductions will also affect workers in building and trades that work on major refinery maintenance projects. ➢ Bottom line – fewer opportunities for good paying jobs and upward mobility.

In short, there is no assurance that price differentials will narrow as much as assumed in the ACC II regulation SRIA, yet there is no provision in the regulation that would alter the phase-out period for ICE vehicles if the economics were less favorable than assumed.

While price differentials of $10,000 (or more) for a small vehicle may be only a moderate inconvenience for those at the top of California's income distribution, the incremental price will have major impacts on lower- and moderate-income households in the state. As noted above, these households are much more likely to have limited or non-existent liquid savings and virtually no room in their budgets to finance more-expensive BEV purchases.

Of particular concern is that low-income owners attempting to cover the higher costs through increased borrowing will face higher financing charges due to poorer loan-to-value and loan-to-income ratios. The impacts will be especially significant for younger households with limited credit histories or those with weaker credit scores. As an indication of how significant additional financing costs can be, financing an additional $10,000 to cover the incremental price of a BEV would cost low-income owners $15,660 over the life of a 7-year loan.[7] Beyond the direct costs, these households also will have to pay more for insurance, sales taxes, and annual vehicle fees.

Higher Costs for Charging

The SRIA asserts that the higher incremental purchase price paid for a BEV will be offset by reductions in fuel and maintenance costs. This is illustrated in **Figure 2**, which is extracted from the SRIA report, and is based on CARB's assumptions of rapidly falling BEV prices.

Figure 2
ACC II SRIA Estimate: Total Cost of Ownership of Small BEV vs. ICE Vehicle (Assumes 10-Year Ownership and 5-Year Financing Period Beginning in 2026)

Cost/Savings	BEV With 300 Mile Range	
	With Home Charger	No Home Charger
Costs		
Incremental vehicle price	$4,936	$4,936
Home Level 2 Charger	$680	--
Incremental Finance Costs (including sales tax)	$1,185	$1,042
Incremental Insurance Costs	$1,003	$1,003
Incremental Registration	$806	$806
Savings		
Incremental fuel savings	-$4,871	-$2,912
Incremental Maintenance Savings	-$4,540	-$4,540
Total Cost of Ownership (10 years)	**-$1,732**	**-$484**

[7] This incremental financing cost is based on the following assumptions: (1) price of EV version is $33,000 versus $23,000 for the ICE version; (2) 10 percent down payment and sales tax are included in the loan, (3) interest rate of 5 percent on the ICE vehicle but 8 percent for the more expensive EV vehicle because of deterioration in various financial metrics, such as debt-service to income ratio.

Figure 2 specifically shows CARB's estimated total cost of ownership over the 10-year life of a small passenger vehicle purchased in 2026. It shows that – for an owner with access to overnight charging – the projected savings from lower fuel and maintenance expenses more than offsets the higher upfront costs for the car and charger, yielding a net savings of $1,732 over the life of the vehicle. For an owner <u>without</u> access to a home charger, there is still a net savings, but it is much less – $484 over the life of the vehicle. The lower net savings occurs because this owner would have to rely on more expensive electricity from shared direct-current chargers.

Again, it is important to note that the net reduction in total ownership costs is highly dependent on CARB's assumption that relative prices of BEVs will fall sharply from today's levels. At current price differentials, total costs of ownership would be several thousand dollars higher for BEV owners with chargers – and even more for BEV owners without home chargers.

Regardless of the bottom-line costs or savings, however, the key takeaway from **Figure 2** is the much lower total cost of ownership for owners having access to chargers as compared to owners that do not. This is important because:

- Lower income households are *more likely* to be renters (according to the 2018-19 Consumer Expenditure Survey for California, about 56 percent of the bottom 60 percent of households are renters, versus 22 percent of the top 20 percent of households); and

- Renters living in older high density multi-family dwellings are *less likely* to have garages or other points of access to inexpensive overnight charging.

Those that have access to overnight charging will pay much less per charge than those that are required rapid chargers during peak hours of the day. The SRIA recognizes a significant difference in charging costs, by assuming average home charging rates of $0.26/kWh versus rapid charging rates of $0.40/kWh. It is because of this difference that CARB shows the lower cost of ownership in **Figure 2** for those with home chargers. We note that the actual difference is likely to be even larger than shown in **Figure 2**, given the recent outsized increases in rapid charging rates. For example, current rates for Tesla superchargers during daytime hours are 0.58/kWh.

Higher Costs for ICE Vehicles and Petroleum-Based Fuels

Low- and moderate-income households that cannot afford the higher upfront costs for BEVs can purchase ICE vehicles during the 2026-to-2035 transition period. And they can avoid BEV purchases beyond 2035 by holding on to their aging ICE vehicle or purchasing ICE vehicles on the used-car market. These individuals will avoid costs associated with purchasing BEVs. However, they will still face higher costs associated with continued maintenance and operation of ICE vehicles under the ACC II regulation. A small portion of these higher costs are directly related to the ACC II regulatory proposal provisions focused on reducing emissions from ICE vehicles sold during the transition period. However, the great majority of the impact is related to the phase-out of the markets for petroleum fuels and ICE vehicles as the government-mandated ban on new ICE vehicle sales takes hold.

CARB estimates that a 2035 ban on ICE vehicle sales will reduce gasoline sales in California by 66 percent by 2035, and by 90 percent by 2050. Declines of this magnitude will likely result in a major consolidation, and perhaps the entire elimination, of the petroleum refining industry in California. Recent estimates made by Stillwater Associates (a transportation consulting firm) indicate that gasoline sales declines of these magnitudes will lead to an over 50 percent drop in retail fueling stations by 2035, and an 80 percent decline in fueling stations by 2050. A key result of this decline is that per-gallon gasoline prices will rise significantly, as the fixed costs related to the distribution and sales of gasoline are spread over fewer and fewer customers. The rise in fixed costs per-gallon sold, combined with higher expenses related to the Low-Carbon-Fuel-Standard and Cap and Trade programs, will add $1.70 to the price per gallon by 2035, and $4.27 to the price per gallon by 2050. All projections as to possible future costs of transportation fuels are only projections, and the actual costs will be determined by fuels market dynamics such as supply and demand.

Any higher costs will have a major impact on lower-income households, which are the most likely to hold onto ICE vehicles in the face of higher costs for BEV's.[8] If we assume (1) the average vehicle is driven 12,500 per year in this state; and (2) the average mileage of California's light passenger fleet will be about 25 miles per gallon by 2030 – the cost per household of a $1.70 per gallon price increase is about **$1,275 per year**. If we further assume that the fleetwide mileage rate increases to 29 miles per gallon by 2050, the $4.27 per gallon increase in that year would translate into **$2,815 per year**. These cost increases are particularly significant in view of the extremely tight budgets and limited liquid savings held by low- and moderate-income households in this state.

Increases in Utility Costs

To accommodate an all-electric transportation system, utilities and state and local governments will need to incur major up-front costs associated with installing a BEV-charging network that has sufficient capacity in all areas of California to avoid fueling bottlenecks and give prospective BEV owners confidence that they will be able to complete longer trips, regardless of destination. According to the California Energy Commission's assessment of charging infrastructure needs released in its July 2021[9] report, 1.2 million public and shared private chargers are needed to support almost 8 million BEVs in 2030, which is consistent with the number that would be on the road under the Clean Cars II proposal. That is about 1 million more than the 193,000 chargers that are online or in planning stages throughout California. We estimate that another 1 million chargers would be needed by 2035 to fully support the number of BEVs on the road under the ACC II regulation. A key finding of the CEC report is that more public funding will be needed, starting immediately, to achieve even the 2030 goals.

Beyond the costs of chargers, the state will incur expenses for developing additional power generation and upgrading its electrical grid. In March 2021, the California Energy Commission (CEC), CARB, and California Public Utilities Commission (CPUC) jointly issued an updated analysis on California's progress toward its zero carbon electricity goals.[10] The report indicated that under a "high electrification scenario," which is consistent with the Governor's ZEV goals, electricity demand from the state's transportation sector will grow from 3,000 Gigawatt-hours in 2020 to an estimated 81,000 Gigawatt-

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[8] According to the 2018-19 Consumer Expenditure Survey for California, 70 percent of households in bottom 20 percent of household income own or lease at least one car. The rate for households in the 20-40th percentile is 88 percent, and in the 40-60 percentile its 94 percent.

[9] California Energy Commission. "Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment," July 2021. https://www.energy.ca.gov/programs-and-topics/programs/electric-vehicle-charging-infrastructure-assessment-ab-2127

[10] SB 100 Joint Agency Report: Charting a path to a 100% Clean Energy Future. March 15, 2021. https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity

hours in 2045. Expanding the grid to accommodate those and related needs will require record build rates for utility-scale solar and other power sources.

Combined costs for light vehicle chargers and upgrades to the grid will be in the multiple tens of billions of dollars. Funding for these types of capital improvements has traditionally come primarily from California utility ratepayers, which already face among the highest and fastest rising rates in the U.S. (see **Figure 3**).

Figure 3
Comparison of Electricity Rates
February 2021 and February 2022 (Cents per Kilowatt Hour)

Location	February 2021	February 2022	% Increase: 2021 to 2022
California	22.53	25.59	13.6%
Neighboring States' Average	11.17	11.96	7.1%
U.S. Average	13.35	13.83	3.6%

Higher utility rates will disproportionately affect lower- and moderate-income households mainly because these households devote a much larger share of their annual income to electricity consumption than do their higher-income counterparts. According to the 2018-19 *Consumer Expenditure*, households in the bottom 20 percent of California's income distribution devoted 7.7 percent of their income to electricity purchases in the 2018-19 period. This percentage is ten times more than the 0.7 percent that their counterparts in the top 20 percent of the income distribution devoted to electricity purchases. This difference occurs because the average income of the top 20 percent of households ($237,713) is 19 times that of the bottom 20 percent of households ($12,460), yet electricity consumption by this top group is less than double the size of the bottom group. The relatively small difference in consumption rates reflects the fact that electricity is a necessity, used by all households regardless of income to keep the lights on and appliances working.

Two other factors are also behind the disproportionate impact. First, lower-income households are less likely to be homeowners, and thus less likely to benefit from rooftop solar systems that would otherwise enable them to avoid higher utility costs, at least partially. Second, lower-income households tend to be located in inland regions of the state, where temperatures are hotter and cooling needs are greater. As shown in **Figure 4** (next page), average per-household consumption of electricity in the state's inland counties is nearly double that of counties in the Bay Area, and about one-third higher than Southern California coastal counties. At the same time, median incomes in these inland counties are about 50 percent lower than the Bay Area counties and about 25 percent lower than the Southern California coastal counties. Similarly, poverty rates in the inland counties are, on average, nearly double that of the Bay Area counties, and about 50 percent higher than the Southern California coastal counties.

In summary, higher utility costs resulting from electrification of the transportation system will disproportionately affect low-income households, especially those in inland regions of the state where electricity consumption is much higher than in coastal counties. Because low- and moderate-income families will likely be later adopters of ZEVs, they will also pay higher utility rates without receiving the benefit of avoided gasoline expenses.

Figure 4
Median Household Income and Electricity Consumption – 2019*

Counties	Median Household Income	Poverty Rate	Average Annual Household Electricity Consumption (kWh)
Bay Area Counties			
Marin	$110,843	6.0%	2,512
San Francisco	$135,968	10.0%	4,077
San Mateo	$138,500	5.5%	5,844
Santa Clara	$133,076	6.6%	6,270
South Coast Counties			
Los Angeles	$72,797	13.2%	6,211
Orange	$107,171	9.0%	6,703
San Diego	$85,507	9.5%	5,813
Inland Counties			
Kern	$53,057	18.3%	8,597
San Bernardino	$67,903	14.3%	8,321
Fresno	$57,518	17.1%	8,929
San Joaquin	$68,997	13.9%	8,099
Stanislaus	$63,057	13.0%	10,286
Sacramento	$82,121	12.5%	8,610

* Sources: U.S. Census Bureau (for median household income) and the California Energy Commission (for residential electricity consumption).

Fewer Job Opportunities

CARB estimates that the ACC II regulatory proposal will reduce employment by 60,084 jobs in 2030, 86,929 in 2034, and 93,117 jobs by 2038. CARB attributes the employment losses to the impact of higher ZEV prices on consumer spending on other goods and services in California's economy, as well as the reduction in state and local revenues on employment in the public sector.

We believe that the job losses, though significant, are understated, in that they fail to consider the likely impact of an ICE ban on California's petroleum industry. CARB's estimate shows only a 1,536 decline in jobs related to the petroleum refining industry by 2040, a reduction of about 15 percent from current levels. Absent a shift in refining activities to hydrogen or biofuels, we would expect a rapid phase-out of gasoline-powered vehicles to due to lower demand, resulting in a rise in unit costs of production and forcing more rapid consolidations and more job losses in the refinery industry. Reductions in this industry would have major consequences for the broader economy due to the hundreds of millions of dollars spent by refineries each year for major maintenance and modernization investments. Consolidations in the refinery industry will affect multiple thousands of workers employed in supplying industries. These include construction workers and electricians, many of them in trade unions, working on refinery turnaround projects.[11] The losses in petroleum and construction industries are of particular importance because of their negative impacts on job opportunities that are so important to upward mobility of workers in this state with high-school diplomas and technical training.

Conclusion

The ACC II regulatory proposal will have a disproportionate impact on low- and moderate- income households, whose budgets are already stretched because of many years of lagging income growth and California's high cost-of-living. The disproportionate impacts are related to higher BEV prices (which are amplified because of financing costs), relatively higher charging costs, higher utility-related electricity costs, and (for those that defer purchases of BEVs) higher costs for petroleum-based fuels. Lower- and moderate-income households will also be disproportionately affected by the reduction in jobs in the construction and petroleum industries, which will mean fewer good-paying jobs opportunities for workers with high school and technical degrees. While the state budgets enacted in 2021-22 and proposed for 2022-23 begin to address some of these issues, the ACC II SRIA is largely silent on the disproportionate impacts that the ACC II regulation would have on millions of lower-income Californians.

[11] Turnaround work includes major maintenance, upgrades, and modernization of refineries.

Tanya DeRivi
Vice President, Climate Policy
Western States Petroleum Association

June 24, 2022

(Submitted via the Draft 2022 Climate Change Scoping Plan and by email to Rajinder.Sahota@arb.ca.gov.)

Ms. Rajinder Sahota
California Air Resources Board
1001 I Street,
Sacramento, CA 95814

Re: Comments on the Draft 2022 Scoping Plan Update

Dear Ms. Sahota:

The Western States Petroleum Association (WSPA) appreciates the opportunity to present these comments on the Draft 2022 Scoping Plan documents[1] released by the California Air Resources Board (CARB). WSPA is a non-profit trade association that represents companies that explore for, produce, refine, transport and market petroleum, petroleum products, natural gas, and other energy supplies in California and four other western states. It has been an active participant in air quality planning issues for over 30 years.

Our members form the backbone of California's economy, providing jobs, fueling air, road, and marine transport, and supplying necessary energy to the manufacturing and agriculture sectors. Our industry generates more than $152 billion in total economic output and make significant fiscal contributions to California's state and local governments, including more than $21 billion in state and local tax revenues, $11 billion in sales taxes, $7 billion in property taxes, and $1 billion in income taxes.

While the economic impact numbers are compelling, our industry's greatest asset and contribution to the state's economy are the more than 366,000 jobs supported in the State. We produce 42 million gallons of gasoline and 10 million gallons a day of diesel to support the State's 35 million registered vehicles. All these contributions to the state occur while our members continue to lower the carbon intensity (CI) of their fuels consistent with the low carbon fuel standard (LCFS) program and spur investment in emission reduction technologies and renewable fuels.

1 2022 Scoping Plan Documents. Available at: https://ww2.arb.ca.gov/resources/documents/2022-scoping-plan-documents. Accessed: June 2022.

A summary of our key comments on the Draft 2022 Climate Change Scoping Plan is provided below with additional details in **Attachment A** (Technical Comments) and **Attachment B** (Legal Comments):

1. **WSPA agrees with CARB that Alternatives 1 and 2 are infeasible for the reasons stated in the Draft 2022 Scoping Plan Update and are not the right choice for California due to the significant economic impacts and very real concerns over technical feasibility and scalability of the technologies assumed under both alternatives.**

These alternatives raise very real questions as to their technical feasibility and would have the highest costs when compared to the Proposed Scenario, ultimately resulting in a drastic setback for industries across the State, the State's economy and California consumers. WSPA commends CARB for acknowledging the cost burdens and infeasibilities that accompany Alternatives 1 and 2. Specifically, Alternatives 1 and 2 would slow job and economic growth between 3-8 times more than the Proposed Scenario, as noted in **Comment A.1** in **Attachment A**.[2] This impact to the economy is simply unacceptable.

In these alternatives, there is likewise a large economic impact associated with the reliance on zero emission (ZE) technologies. Alternative 1 would mandate early retirement of combustion vehicles, appliances and industrial equipment to achieve a ZE-only outcome by 2035. Alternative 2 would mandate early retirements of medium- and heavy-duty (M/HD) vehicles to achieve a statewide ZE M/HD vehicle fleet by 2045.[3] These early retirements would essentially force certain California businesses to decide whether to move out of the state (leading to economic and environmental leakage) or simply close leading to gross domestic product (GDP) and job losses. It is also critical to consider the impact on consumers and residents throughout the state as early retirement mandates for vehicles and appliances prior to end of life would put significant cost pressures on consumers. Low income consumers would not be economically equipped to commit to such exorbitant transitions without extreme financial incentives from the State.[4]

Alternatives 1 and 2 likewise would assume unprecedented levels of growth in emerging technologies and accompanying infrastructure improvements. The complete elimination of combustion under Alternative 1 would mandate a dramatic reconstruction of California's economy at a pace that is not technically feasible. This is not to mention the significant changes required to daily life and consumer behavior required for this plan to succeed. CARB has simply not demonstrated this scenario to be feasible at any cost.

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2 Draft 2022 Scoping Plan Update. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

3 2022 CARB Draft Scoping Plan: AB 32 Source Emissions Initial Modeling Results. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-03/SP22-Model-Results-E3-ppt.pdf. Accessed: June 2022.

4 Draft 2022 Scoping Plan Update. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

Alternative 1 would require annual buildout rates for solar capacity of 10 gigawatts (GW) and battery storage of 5 GW. Alternative 2 would require annual buildout rates for solar capacity of 5 GW and battery storage of 3 GW. The current build rates for these technologies are 2.7 GW/year and 0.3 GW/year.[5] To put it in other terms, the buildout rates would need to increase four-fold under Alternative 1 and two-fold under Alternative 2 by next year and sustain that rate through 2035 in order to achieve carbon neutrality. Any delay would mean even higher build rates in subsequent years. This protracted level of increase in generation and storage would also have to be accompanied by an equally large increase in electrical infrastructure improvements, expansions, and upgrades. Such development is not technically or economically feasible on the assumed timetables. To expand existing generation and grid capacity in this manner would require trillions of dollars in electric infrastructure upgrades to be funded and delivered at an unprecedented schedule.

The alternatives also require significant buildout of negative emissions technologies to offset emissions left in the system. While WSPA strongly supports the use of negative emissions technologies to achieve carbon neutrality, their deployment will take time and the extra 10 years between 2035 and 2045 will be necessary for the technologies to achieve the scales needed to achieve carbon neutrality.

The buildout mandate for zero emission vehicles (ZEVs) under these scenarios also assumes a phase out of in-state refining and oil & gas production. Alternative 1 would completely eradicate petroleum refining, and Alternative 2 would only allow 25% and 8% of current petroleum refining in 2035 and 2045, respectively.[6] These assumptions are inconsistent with the reality that there will be ongoing demand in California for petroleum products for on-road, off-road, aviation, railroad and marine transport in 2035 and beyond. The scenarios also fail to recognize that regardless of the actions California takes, fuels produced in California are exported to meet demand in neighboring markets, such as Arizona and Nevada. A complete phase out of oil and gas production and refining in California under Alternative 1 would simply shift the demand for fuels from these neighboring states to producers outside of California, causing a leakage of economic activity and emissions that is specifically prohibited in Assembly Bill (AB) 32. Even though Alternative 2 does not strictly eliminate the industry, it also does not account for the ongoing demand for fuel exports from California. Ultimately, in both alternatives there would still exist significant petroleum products demand and failure to acknowledge such would leave millions inside and outside of California stranded.

Recommendation: CARB should eliminate Alternatives 1 and 2 from consideration.

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5 Ibid.

6 Ibid.

2. **WSPA has reviewed the Proposed Scenario (Alternative 3) along with its key assumptions and believes that significant improvements can be made to improve the feasibility of the Alternative to achieve the State's goals in a more cost-effective manner.**

WSPA continues to be concerned with CARB's reliance on a ZEV-only approach in achieving the state's greenhouse gas (GHG) and air quality goals within the transportation sector. As we have commented during the Scoping Plan's development and through the Advanced Clean Trucks (ACT), Advanced Clean Fleets (ACF), and Advanced Clean Cars II (ACC II) rulemakings, CARB's analyses fail to evaluate the cost-effective air quality and GHG reduction benefits that other technology options such as near-zero emissions vehicles and low-carbon and renewable fuels could deliver. Ramboll's case studies of the heavy-heavy duty truck (HHDT) fleet[7] and the light duty automobile (LDA) fleet[8] demonstrate that there are alternative pathways using renewable other low carbon fuels that can dramatically reduce transportation sector carbon emissions without ZEV mandates. As we recommended in our previous letters outlined in **Attachment C**, we again request CARB undertake this analysis and consider the benefits of utilizing these technologies and timelines for achieving carbon neutrality and improving air quality in highly-impacted communities.

There are other examples throughout the Scoping Plan where constraints are placed on sectors that are not cost-effective. Removing or relaxing these constraints could reduce economic costs without sacrificing the overarching carbon neutrality goal. Examples of unnecessary constraints include not allowing any emissions from hydrogen production in 2045 (as is allowed for every other sector), not allowing CCS on natural gas power plants in the electricity sector, and limits on renewable fuels. As shown in the study conducted by NERA Economic Consulting ("NERA Study") (**Attachment D**), a market-based scenario without these multiple mandates and constraints could achieve emission reductions equivalent to the Proposed Scenario at lower cost. The NERA Study also shows how a rigid ZEV-only approach in the transportation system has a very concerning ripple effect on other sectors. Allowing a more flexible approach in the transportation system, opens up the range of possible solutions which can achieve carbon neutrality more cost-effectively.

The Proposed Scenario acknowledges that any effort to achieve carbon neutrality will be heavily reliant on carbon sequestration and negative emissions technologies. WSPA strongly supports the use of carbon capture and storage (CCS) and carbon dioxide removal technologies (CDR) (e.g., direct air capture [DAC]). We also strongly agree with CARB that significant effort needs to be undertaken within the state to streamline and speed up permitting for CCS and other low-carbon technology options. As detailed in the NERA Study (**Attachment D**), an increase in the use of DAC from the Proposed Scenario could be used to

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7 The Ramboll HHDT study is available here: https://www.arb.ca.gov/lists/com-attach/78-sp22-kickoff-ws-B2oFdgBtUnUAbwAt.pdf. Accessed: June 2022.

8 Ramboll. 2022. Multi-Technology Pathways To Achieve California's Greenhouse Gas Goals: Light-Duty Auto Case Study. Available as Attachment D at: https://www.arb.ca.gov/lists/com-attach/477-accii2022-AHcAdQBxBDZSeVc2.pdf. Accessed: June 2022.

more cost effectively balance emissions from sectors that are more costly to decarbonize. That would reduce the overall costs of this Scoping Plan Update. If DAC proves to be less costly than the costs assumed by NERA, it is possible to push DAC even harder to balance out emissions at a lower costs. Both CCS and DAC can be further supported economically with reasonable changes to the Cap-and-Trade and the LCFS programs. These changes would provide important market signals to project proponents that the state is supportive of these technologies for the long-term.

As CARB recognized in the 2008 Scoping Plan, there is an important role for Cap-and-Trade in ensuring the state's GHG reductions. For the current Scoping Plan update, WSPA believes that Cap-and-Trade can continue to ensure that economy-wide emissions reductions are accomplished more cost effectively as is required by AB 32 while providing flexibility to accommodate the considerable uncertainties in multi-decade planning forecasts. This becomes even more critical as lower cost emission reduction options are completed and all that is left is extremely costly options. WSPA suggests that CARB should expand Cap-and-Trade's role in achieving carbon neutrality.

WSPA agrees with CARB that a complete phaseout of oil and gas extraction and refining is simply not feasible by 2045 due to real concerns over leakage. California refineries supply fuels to other U.S. states including states in the Southwest. Through the possible future application of CCS technologies for industrial emissions and production of low-carbon and renewable liquid fuels at California refineries, California's exports could play a pivotal role in reducing the CI of fuels consumed in other states compared to fuels produced elsewhere.

The Proposed Scenario does pose significant potential for leakage of emissions due to its technology forcing mandates. The Draft 2022 Scoping Plan ignores the life cycle emissions of "zero emission" vehicles and does not assess the leakage of emissions that would be caused by increased mining activities, battery production, recycling, and disposal under the proposed LDV and medium-duty vehicle (MDV)/heavy-duty vehicle (HDV) ZEV mandates. It also does not consider the life cycle emissions that would be caused by a dramatic development of electric infrastructure, including solar panels, wind turbines, and grid-scale battery production impacts. All of these have considerable embedded GHG emissions and would largely be produced outside California. Further, actions to phase down California's oil and gas extraction and refining would cause increased production and refining of liquid fuels outside of California from operations with higher GHG intensities. All of these unconsidered impacts would represent emissions leakage. AB32 requires CARB to minimize "leakage" of GHG emissions from California's economy.[9]

Recommendation: CARB should modify the Proposed Scenario to reduce the number technology mandates and constraints, and place greater emphasis on the power of market mechanisms such as Cap-and-Trade that encourage innovation and are more likely to deliver cost-effective reductions.

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[9] Health & Safety Code section 38562(b)(8).

3. WSPA believes that Alternative 4 faces many similar challenges to those presented under the Proposed Scenario (Alternative 3).

While Alternative 4 does ease some of the technology implementation timelines, it does not address the main underlying concerns with heavy electrification. Alternative 4 will still require unprecedented deployment of solar and battery storage technology (annual buildout of 6 GW and 2 GW in comparison to the historic annual maximums of 2.7 GW and 0.3 GW respectively), does not address the significant concerns with grid reliability and infrastructure expenditures required to support electrification, nor does it abate the leakage of emissions that would be associated with global mineral mining, battery production, and battery recycling as a result of the Scoping Plan.

Recommendation: While Alternative 4 has fewer technology mandates than Alternative 3, it still relies too heavily on unprecedented deployment of electricity expansion. Again, CARB should modify its recommended Alternative to more fully embrace other low-carbon solutions.

4. A study conducted by NERA Economic Consulting shows that a market-based approach to the Scoping Plan has the capability to achieve carbon neutrality by 2045 at less economic cost.

Given the criticality of this Draft 2022 Scoping Plan, WSPA commissioned a study with NERA Economic Consulting ("NERA"), provided in **Attachment D**, to explore additional scenarios that could achieve the state's climate goals. Scenarios were required to achieve net-zero emissions by 2045. From this work, two primary comparative scenarios were developed and explored more deeply. One scenario, which approximates the Proposed Scenario, relies to a greater extent on sector-specific mandates (the "Regulatory" scenario), while the other relies to a greater degree on market forces by use of a unifying price signal (the "Market" scenario).

Comparative results from the two studies are compelling. While both scenarios achieved carbon neutrality by 2045, the Market scenario did so with just over half the adverse economic impact as projected by differences in state gross domestic product (GDP). Perhaps even more notably, the Market scenario actually resulted in a greater volume of earlier emission reductions in its trajectory to reach carbon neutrality. As CARB is well aware, achieving earlier emission reductions when feasible is a desired outcome of climate policy.

The report illuminates there are important trade-offs for CARB to consider between these two scenarios, with an important underlying message that forcing deeper emission cuts in certain sectors leads to unnecessarily higher costs to achieve the same 2045 goal. This conclusion, coupled with the recognition that a mandate-heavy approach carries greater technology risks, makes it compelling to update the Draft 2022 Scoping Plan to rely more on market-based approaches.

The full NERA report ("NERA Study") that documents this analysis is provided as **Attachment D**. WSPA would welcome the opportunity to further explore these important conclusions with you with an aim to develop a plan that achieves the state's objectives at lower cost.

Recommendation: WSPA maintains that a technology neutral, market-based approach to achieving California's GHG reduction goals is more technologically and economically feasible and CARB should make serious considerations as to what approach would best serve California.

5. WSPA agrees with CARB that an improved and streamlined project environmental review and permitting process is necessary to deliver the Draft 2022 Scoping Plan Update.

The environmental review process under the California Environmental Quality Act (CEQA) has proved to be a significant barrier to projects and permitting certainty in the past. The following actions should be considered while creating a streamlined process for obtaining permits and for review and litigation under CEQA for eligible low carbon projects:

- Create a new agency under to Office of Planning and Research to act as a lead agency for eligible low carbon projects that opt into the streamlined process for environmental review and litigation.
- Streamline the environmental review process under CEQA by establishing aggressive timelines for completeness determination, preparation of environmental impact report or negative declaration, recirculation period, and project approval.
- Streamline the litigation process to facilitate quick resolution including expedited preparation of the administrative record.
- Provide flexibility for local, regional or state agencies that act as lead agency for eligible low carbon projects to access aspects of the expedited environmental review and litigation process.

Recommendation: CARB should work with the Office of Planning and Research to develop an improved and streamlined project environmental review (under CEQA) and permitting process for the low-carbon projects that are essential for the implementation and delivery of the Draft 2022 Scoping Plan Update.

Conclusion

The Draft 2022 Scoping Plan should ultimately be constructed with an eye towards supporting and fostering technological innovation. Doing so could create a foundational framework that would attract more investment into the market which would help the state achieve its long-term climate goals. WSPA strongly recommends that CARB remove technology mandates and restriction in the Proposed Scenario (Alternative 3) and rely more heavily on technology-neutral market-based approaches, to achieve emission reductions with additional support from the Cap-and-Trade program. As noted in our previous comment letters, we believe that such market-based approaches will achieve carbon neutrality in the most cost-effective manner.

Thank you for the consideration of our comments. WSPA would welcome the opportunity to discuss these comments and recommendations in more detail with you. Please feel free to contact us at tderivi@wspa.org, jverburg@wspa.org, and sellinghouse@wspa.org, with any questions or concerns.

Sincerely,

Tanya DeRivi
Vice President
Climate Policy
WSPA

cc: Jim Verburg, WSPA Director Fuels

Sophie Ellinghouse, WSPA Vice President, General Counsel and Corporate Secretary

Attachment A:	Technical Comments
Attachment B:	Legal Comments
Attachment C:	List of Previous WSPA Comments on the Draft 2022 Climate Change Scoping Plan
Attachment D:	Economic Impacts of Achieving California's 2022 Draft Scoping Plan's "Proposed Scenario" by NERA Economic Consulting dated June 2022

WSPA

ATTACHMENT A
Technical Comments

As noted in the cover letter, detailed technical comments on the Draft 2022 Climate Change Scoping Plan are provided below:

Alternative 1 and 2

A.1 CARB's own economic modeling shows that Alternatives 1 and 2 are economically infeasible.

Alternatives 1 and 2 are not economically feasible pathways to meet the State's GHG goal. Consider the following outcomes of the two alternatives that are described in the Draft 2022 Scoping Plan Update.[10]

- Alternatives 1 and 2 would slow job growth 5 times and 3 times more, respectively, than the Proposed Scenario.
- Alternatives 1 and 2 would slow economic growth 8 times more than the Proposed Scenario in 2035 and 5-6 times more in 2045.
- In terms of scenarios for the Natural and Working Lands (NWL), Alternative 1 would result in direct costs 25 times greater than those relative to the Proposed Scenario.
- Alternative 1 would also require the highest stock costs in both 2035 and 2045 to meet the demand for ZEVs and appliances and the elimination of fossil fuel combustion. The replacement of this equipment near 2045 would likewise result in additional stock costs.

CARB must allow for an economic turnover of vehicles and appliances that allows for consumer choice, to comply with the economic limitations faced by both industries and consumers. CARB should also consider the unprecedented cost of incentives and funding that would be needed to meet the demands of Alternatives 1 and 2.

A.2 CARB's modeling shows that an all-electrification option by itself will not reach the State's GHG reduction targets.

Alternative 1 presents an all-electrification scenario with a near complete phaseout of all fossil fuel, biomass-derived, and hydrogen combustion technologies. Alternative 1 calls for early retirement of internal combustion engine vehicles (ICEVs), appliances, and industrial equipment by 2035. To appease this goal, the state would need to establish buy-back programs to account for forced replacement of vehicles and appliances before end of life. It would similarly require forced retrofits of equipment that utilizes high-global warming potential (GWP) equivalent materials and mandatory replacements of existing equipment that utilizes high-GWP equivalent materials to meet its building electrification demands. Alternative 1 likewise entails a complete eradication of petroleum refining, as well as solar and battery development targets at levels impossibly greater than current levels.

CARB's modeling shows how difficult and costly the transition to achieve carbon neutrality by 2035 and 2045 would be under Alternatives 1 and 2. Even with the drastic ambitions mentioned above, Alternative 1 would still require CDR to compensate for non-combustion emissions and short-lived climate pollutants. Without CDR, it would not achieve its 2035 carbon neutrality goal.

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10 Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

Alternative 1 also presents the highest degree of uncertainty around the availability of solar to support the electrification of existing sectors. As referenced in **Comment 1**, these extreme buildouts of electrical generation, grid capacity, and technology production are neither cost effective nor feasible.

WSPA believes that market-based approaches would allow greater innovation within existing markets to accomplish California's GHG targets without the systemic risks associated with an all-electrification approach (e.g., infrastructure readiness, ZE technology readiness, cost). Alternatives 2 through 4 acknowledge the continued use of liquid and gaseous fuels in the State's transportation and industrial sectors through at least 2045. The California fuels industry is already responding to the need to reduce GHG emissions by increasing production of renewable fuels.[11]

Reference Scenario Modeling Assumptions

A.3 CARB has updated their reference scenario modeling assumptions for the light-duty vehicle (LDV) sector to include 40% ZEV LDV sales by 2030, without giving appropriate basis for why this is an appropriate assumption to make.

In CARB's 2017 Scoping Plan, the business as usual (BAU) scenario projected that there would be approximately 3 million LDV ZEVs by 2030 and 4.7 million LDV ZEVs by 2045. However, the BAU scenario in the Draft 2022 Scoping Plan projects that there will be 40% LDV sales by 2030,[12] 3.6 million LDV ZEVs by 2030, and 11.3 million LDV ZEVs by 2045.[13] In the Reference Scenario assumptions table for the Draft 2022 Scoping Plan Update (Appendix H, Table H-14),[14] this sales target of 40% LDV ZEVs is noted and followed by a statement that this is "aligned with CA Institute of Transportation Studies BAU scenario".[15] In the BAU Scenario from the Institute of Transportation Studies, the assumption for ZEV share of LDV sales is reported as 20% by 2030 along with a stock of around 3 million vehicles.[16] This does not align with the value given in CARB's Reference Scenario assumptions table (Table H-14).[17] CARB must give

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11 S&P Global Commodity Insights. 2022. California approves Marathon's and Plillips 66's refinery -to-renewable repurposing. May 4. Available at: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/050422-california-approves-marathons-and-phillips-66s-refinery-to-renewable-repurposing. Accessed: June 2022.

12 CARB. 2022. Appendix H - AB 32 GHG Inventory Sector Modeling. May 2. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-appendix-h-ab-32-ghg-inventory-sector-modeling.pdf. Accessed: June 2022.

13 CARB. 2022. California PATHWAYS Model Outputs. May 2. Available here: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-PATHWAYS-data-E3.xlsx. Accessed: June 2022.

14 CARB. 2022. Appendix H - AB 32 GHG Inventory Sector Modeling. May 2. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-appendix-h-ab-32-ghg-inventory-sector-modeling.pdf. Accessed: June 2022.

15 Ibid.

16 University of California Institute of Transportation Studies. 2021. "Driving California's Transportation Emissions to Zero." April 22. Available at: https://doi.org/10.7922/G2MC8X9X. Accessed: June 2022.

17 CARB. 2022. Appendix H - AB 32 GHG Inventory Sector Modeling. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-appendix-h-ab-32-ghg-inventory-sector-modeling.pdf. Accessed: June 2022.

reasoning for increasing the baseline number of ZEV sales beyond this California Institute of Transportation Studies BAU scenario. This is critical because CARB's costs modeled for the alternatives are relative to the BAU. Thus, all the costs associated with the BAU are not captured by the economic analysis presented for the Scoping Plan. We request that CARB include the costs of the BAU in the Scoping Plan as the Plan is meant to lay out a pathway to achieving carbon neutrality from now until 2045, not from 2030 to 2045.

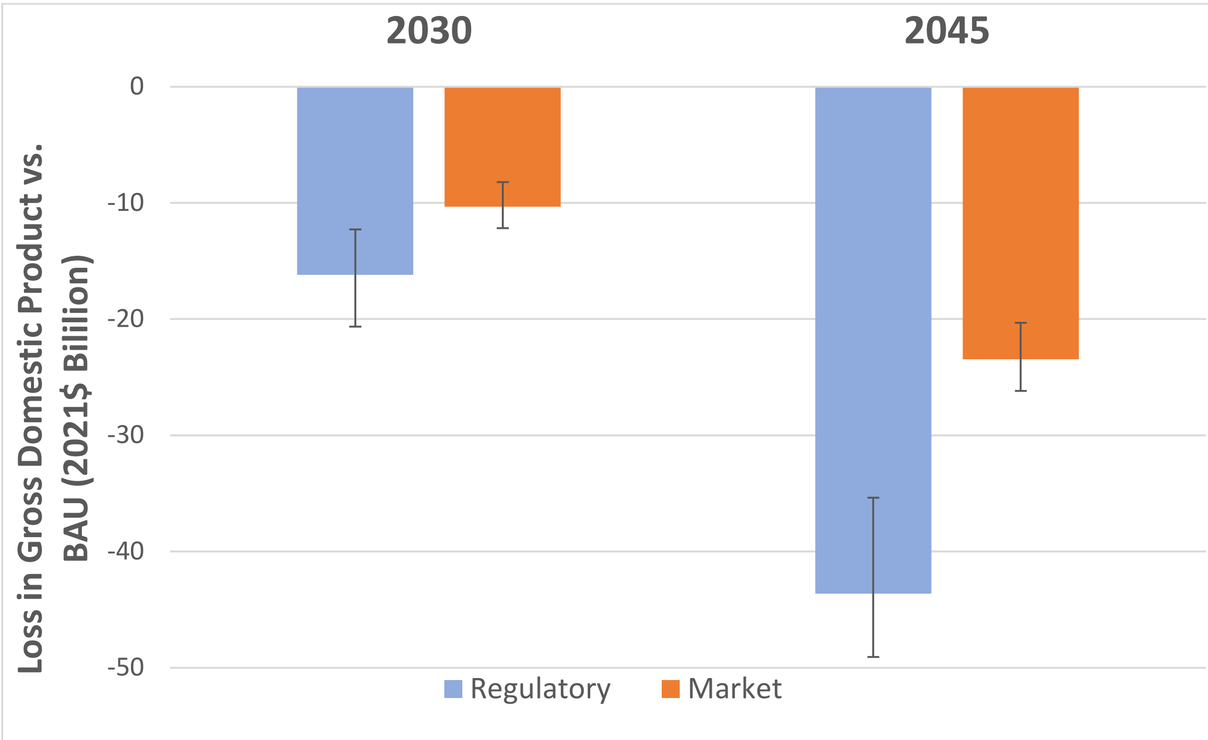
General Comments on Proposed Scenario (Alternative 3)

A.4 Despite addressing many of the feasibility concerns presented in Alternatives 1 and 2, CARB's Proposed Scenario (Alternative 3) is not the most cost-effective path to achieve carbon neutrality. Improvements can be made to Alternative 3 to bring it more in line with a cost-optimized approach like that shown by the NERA Study.

The modeling work that CARB utilized to support the Proposed Scenario (Alternative 3) in the Draft 2022 Scoping Plan, imposes unnecessary technology mandates that would preclude outcomes that would be more cost-effective and technically feasible. For example, CARB placed arbitrary limits on low-carbon and renewable fuels, DAC and other applications for CCS, limits on (plug-in) hybrid electric vehicles (HEVs/PHEVs) that provide important flexibility when there are grid constraints, and unnecessary constraints regarding the production (and use of) hydrogen fuels.

NERA's Scenario Modeling analysis (included in **Attachment D**), identified a market-based approach that delivered the Proposed Scenario results at a much lower cost. Their Market Scenario resulted in approximately 37% less GDP loss in 2030 (i.e., $10 billion versus $16 billion) and 48% less GDP loss in 2045 (i.e., $23 billion versus $44 billion) when compared to a Regulatory Scenario that embodied elements of CARB's Proposed Scenario. This is shown in **Figure A-1**. Expressed in household impacts, the Market Scenario reduced per household consumption impacts from $1,890 to $820 in 2045.

Figure A-1: Loss in Gross Domestic Product vs. BAU



This study shows that the required emission reductions to achieve carbon neutrality by 2045 are achievable with a Market Scenario at much lower cost impacts as compared to the Proposed Scenario. Such a strategy could also reduce the systemic risks inherent to the all electrification option. CARB should replace the constraints on the transportation sector (**Comments A.11, A.12,** and **A.14**), oil & gas sector (**Comments A.15** through **A.20**), and hydrogen sectors (**Comment A.21**) in the Proposed Scenario and increase the reliance on market-based mechanisms (**Comments A.5, A.9,** and **A.10**).

A.5 CARB is missing opportunities to optimize the Scoping Plan by viewing emission reductions for individual sectors rather than across the economy as a whole.

The Draft 2022 Scoping Plan Update is intended to be a long-range road map for California's climate policies through 2045. Optimally, CARB should ensure that multiple decarbonization pathways are available without unnecessarily constraining pathways for individual sectors. While understanding the dynamics of a specific sector is important, there are interface and decision points between them that serve as key points for optimization. The actual optimum will only be apparent many years into the future. The Scoping Plan workshop process has been useful in highlighting current and potential future technologies, but mandating specific pathways for individual sectors at this point, as indicated by overreliance on direct measures and mandates in the Proposed Scenario (Alternative 3), is naïve and more likely to fail to meet the program's goals. Instead, CARB should maintain and prudently expand the role of the Cap-and-Trade Program to enable the most cost-effective emissions reductions to meet the State's climate goals over the next two decades. The NERA Study (**Attachment D**) clearly shows that market-based programs like Cap-and-Trade will allow industries across all sectors to find the most cost-effective technologies to meet the desired emission reduction targets. Such programs will play an increasingly pivotal role year-by-year as the cost per ton of GHG emission reductions increase. We strongly urge CARB to rely more heavily on Cap-and-Trade post-2030 as opposed to suite of direct measures and technology mandates. Refer to **Comments A.9** and **A.10** for further details.

A.6 CARB should publicly post the detailed modeling files that track how emissions benefits were derived for each sector and how the cost impacts for the associated changes to California's economy were determined.

We request that CARB publicly post these to allow the public to understand the full impact of the Proposed Scenario on the State's economy and provide comments, if warranted.

As noted in Appendix H of the Draft 2022 Scoping Plan,[18] the direct costs include the cost of CDR, cost of purchasing capital stock, cost and savings from changing fuel expenditures, and the costs of energy efficiency measures across sectors. While references for the economic and financial assumptions and inputs to the PATHWAYS model are provided in Appendix H, details of the specific financial inputs, copies of the economic modeling files, and a description of uncertainties associated with these inputs and outputs of the model have not been made available in Appendix H or the AB 32 GHG Inventory Modeling Data Spreadsheet. WSPA requests CARB provide these details and files so stakeholders can review and provide appropriate feedback as part of the public process.

A.7 CARB should present the potential range of the cumulative direct costs of the Proposed Scenario relative to the Reference Scenario rather than suggesting single cost value for calendar years 2035 and 2045.

The economic analysis in Draft 2022 Scoping Plan estimates the direct costs for the Proposed Scenario (Alternative 3) relative to the Reference Scenario as $18 billion and $27 billion for calendar year 2035 and 2045 respectively. Based on the description of the economic analysis provided in Chapter 3 of the Draft 2022 Scoping Plan, it appears that the annualized costs were computed for each year from 2022 through 2045. We request that CARB present these costs for each year 2022 through 2045 and the cumulative costs from 2022 to 2035 and 2022 to 2045 to allow public to understand the full impact of the Proposed Scenario on the State's economy. CARB must also provide the range in projected costs associated with the quantitative uncertainties of this proposal to better portray the magnitude of these changes.

It is critical that stakeholders and the public understand the full cost of the transition. While we appreciate the economics shared, it is all relative to the BAU. Since the BAU includes significant actions and costs, CARB should include the total cost of the transition alongside the costs of achieving Alternative 3 compared with the BAU. Since the Scoping Plan is focused on achieving carbon neutrality in 2045 and the BAU is an important part of that process, CARB should be transparent on the costs of the full transition.

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18 CARB. Draft 2022 Scoping Plan Update. Appendix B Draft Environmental Assessment. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-appendix-b-draft-environmental-analysis.pdf. Accessed: June 2022.

A.8 CARB should analyze the critical mineral demand that would directly result from the technology forcing mandates within this Scoping Plan given the high level of demand for critical mineral resources in ZEVs, solar technology, and grid battery storage.

While the draft environmental analysis (draft EA) for the Proposed Scenario acknowledges the 2022 Scoping Plan could result in additional mining for critical minerals for the manufacture of batteries and fuel cells, it fails to assess the amount of mineral resources that would directly result from the Proposed Scenario. Hence, CARB has no factual basis to conclude that the effects on mineral resources "would be less than significant."[19] CARB has also not developed the factual record needed to conclude that mineral resources needed to meet the Proposed Scenario will be accessible.

The findings of the 2021 International Energy Agency's report titled *The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions*,[20] indicated that a typical battery electric car requires six times the amount of mineral inputs needed for a conventional vehicle. This report also stated that the rapid deployment of clean energy technologies (including battery electric vehicles [BEVs]) would result in a significant impact on mineral resources, and that there are currently not enough of these mineral resources to meet such a demand level.

CARB must provide a basis for their significance argument, including but not limited to an estimate of the minerals volumes and GHG emissions required to manufacture the solar panels, batteries and fuel cells suggested under the Proposed Scenario, the potential strain on global mineral resources, and impacts to the global supply chains for lithium, cobalt, nickel, and other critical minerals. The assessment should include sensitivity analysis to determine how costs and availability may be affected by mineral scarcity and global supply chain disruptions.

While CARB did not provide mineral resource estimates for the proposed regulation, CARB does acknowledge that the Proposed Scenario (Alternative 3) would involve unprecedented levels of growth for solar panels, batteries, and fuel cell production to upgrade and expand electric grid infrastructure (i.e., 90 GW solar generation and 40 GW battery storage by 2045), increased hydrogen generation (41 GW of additional solar generation needed by 2045), and increased penetration of battery electric, plug-in hybrid, and fuel cell electric vehicles (FCEVs) (19.2 million BEVs, 3.8 million PHEVs, and 3.8 million FCEV by 2045). The unprecedented ramp-up in production would require a similar scale of mineral extraction growth that cannot be assumed or disregarded. CARB must characterize and evaluate these impacts; not rush to suggest that they are "not significant".

It is also important to note that mineral resources critical to the production of solar panels, batteries, and fuel cells are primarily found outside the State. So, GHG emissions associated

19 CARB. Draft 2022 Scoping Plan Update. Appendix H AB32 Inventory Sector Modeling. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-appendix-h-ab-32-ghg-inventory-sector-modeling.pdf. Accessed: June 2022.

20 International Energy Agency (IEA). 2021. The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions. Available at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions. Accessed: June 2022.

with mining and processing these minerals that occur outside the State boundary must be included in CARB's analyses. The vehicle life cycle emissions associated with the additional production, use, and disposal of BEVs under the Proposed Scenario would equate to ~110 million metric tonnes (MMT) CO_2e,[21] under the Proposed Scenario's 2045 electric vehicle goal. CARB must acknowledge the extent of these emissions, encompassing raw material mining and vehicle disposal, as well as the environmental burden they place on countries outside of California.

The Use of Cap-and-Trade in Proposed Scenario (Alternative 3)

A.9 We agree with CARB that Cap-and-Trade should be one of the main tools to ensure the state achieves carbon neutrality. CARB should further utilize Cap-and-Trade to minimize the costs of future emission reductions instead of using the program as an emissions backstop.

WSPA agrees with CARB that the Cap-and-Trade Program should be one of the main tools that CARB utilizes to achieve carbon neutrality. The program serves as a global model of a well-designed technology-neutral market-based program to achieve emission reductions. While the Draft 2022 Scoping Plan Update recognizes the need for the Cap-and-Trade Program to "fill the gap" to meet the State's 2030 reduction target, given the uncertain outcomes of sector-specific mandates, it also assumes that this program will play a reduced role with continued addition of legislation or prescriptive policies for individual sectors. WSPA believes that the Cap-and-Trade Program can and must be allowed to do more beyond 2030 as the cost per ton of GHG emission reductions increase. The speculative cost forecasts for potential technologies to eliminate the final hard-to-abate emissions, as well as their uncertain availability, demand a program that can provide flexibility well into the future. Cap-and-Trade should be allowed to play this important role.

A.10 Cap-and-Trade can provide a critical funding source for CCS and DAC (similar to how the LCFS functions now). CARB should create a protocol for projects that deliver negative emissions to generate credits.

As CARB has extensively documented in its Draft 2022 Scoping Plan,[22] CCS and CDR will have to play a significant role if California is to achieve carbon neutrality by 2045. The NERA Study (**Attachment D**) came to a similar conclusion in all of its modeled scenarios. CCS and CDR are capital intensive and need a significant time horizon for deployment and to recover large capital investments, expected to cumulatively be at least in the tens of billions of dollars.[23] Without a clear, reliable basis for creating value to provide value to operators of such technologies, those

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21 Estimated based on the incremental BEV vehicle stock projections for the Proposed Scenario versus Business as Usual (BAU) in 2045 as provided in the 2022 Scoping Plan Documents and Ramboll's estimates for incremental vehicle life cycle emissions for BEVs as compared to ICEVs (presented in **Figure A-5**).

22 Draft 2022 Scoping Plan Update. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

23 Global CCS Institute. 2021. The Global Status of CCS 2021. Available at: https://www.globalccsinstitute.com/wp-content/uploads/2021/11/Global-Status-of-CCS-2021-Global-CCS-Institute-1121.pdf. Accessed: June 2022.

investments will not get made. It is imperative that CARB prioritize creation of such credit generation in the Cap-and-Trade program and provide the accounting necessary to support it.

Transportation in Proposed Scenario (Alternative 3)

A.11 The ZEV strategy in the Proposed Scenario not only interferes with efforts to achieve the federal ozone standard, but actively impedes near-term progress toward attainment.

CARB's narrow reading of the Governor's Executive Order N-79-20 has led to a series of modeling scenarios centered almost exclusively around the accelerated adoption of ZEVs. While the Proposed Scenario (Alternative 3) may not be as aggressive at Alternatives 1 and 2, it still aims to achieve the following actions: 100% of LDV sales are ZEV by 2035 and 100% of MD/HDV sales are ZEV by 2040. These actions would obstruct deployment of near-zero emission (NZE) technologies that could help California attain the Federal ozone standards. AB 32 requires CARB to "ensure that activities undertaken pursuant to the regulations complement, and do not interfere with, efforts to achieve and maintain federal and state ambient air quality standards and to reduce toxic air contaminant emissions." NZE vehicles and other strategies may be more feasible and cost-effective in achieving the Federal ozone standards while still achieving the necessary GHG reductions.

Ramboll's HHDT case study on "Multi-Technology Pathways to Achieve California's Air Quality and Greenhouse Gas Goals"[24] ("Ramboll HHDT Study") highlighted the inconsistencies between CARB's mandate to make reasonable progress toward the ozone standard and its proposed all-ZEV strategy. Ramboll's analysis of multi-technology pathways, which included a combination of lower-emission (75% to 100% lower) vehicle technologies and fuel mixes (including lower carbon-intensity liquid and gaseous fuels), demonstrated that there are faster paths to meeting near-term Federal air quality standards, while making meaningful progress on State climate goals.

The Proposed Scenario (Alternative 3) would depend on current, proposed, and future CARB regulations that would further delay attainment of the federal ozone standard by making it near impossible to invest in existing NZE technologies due to the ZEV mandate.

Again, we recommend that CARB utilize a technology-neutral performance-based approach versus adopting a ZEV mandate for the on-road vehicles (see **Comment A.13** for further details).

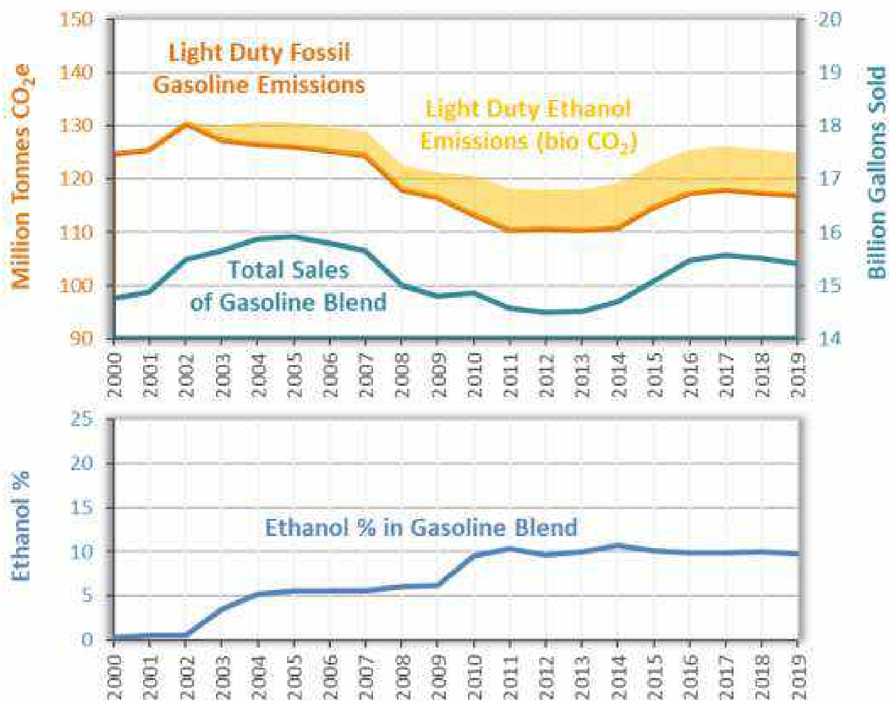
A.12 The California fuels industry is providing low-carbon renewable liquid and gaseous transportation fuels today, with projects announced for even more supply in the next few years. CARB must consider a technology-neutral, performance-based approach that embraces renewable liquid fuels rather than a ZEV mandate that has major feasibility challenges and cost impacts.

As transportation becomes more electrified in the future, the nexus of transportation fuel and power generation will become more consequential. While renewable natural gas (RNG) can

[24] The Ramboll HHDT study is available here: https://www.arb.ca.gov/lists/com-attach/78-sp22-kickoff-ws-B2oFdgBtUnUAbwAt.pdf. Accessed: April 2022.

and should continue to play a role as a transportation fuel, particularly for medium- and heavy-duty applications, it can also play a needed role in light-duty transportation by being the fuel for the generation of low- or negative-emission electricity for this tranche of vehicles. CARB's report on "California Greenhouse Gas Emissions for 2000 to 2019"[25] showed that renewable fuels and biofuels have already offset significant amounts of GHG emissions from both the light-duty and heavy-duty sectors. Because carbon emitted from biogenic fuels is considered carbon neutral, the 10% ethanol blend in LDV gasoline and approximately 27% bio-component percentage in heavy-duty diesel fuels has resulted in a 6.4% and 25% reduction in GHG emissions respectively in in 2019. This is shown in **Figures A-2** and **A-3**.

Figure A-2: Trends in On-Road Light-Duty Gasoline Emissions[26]



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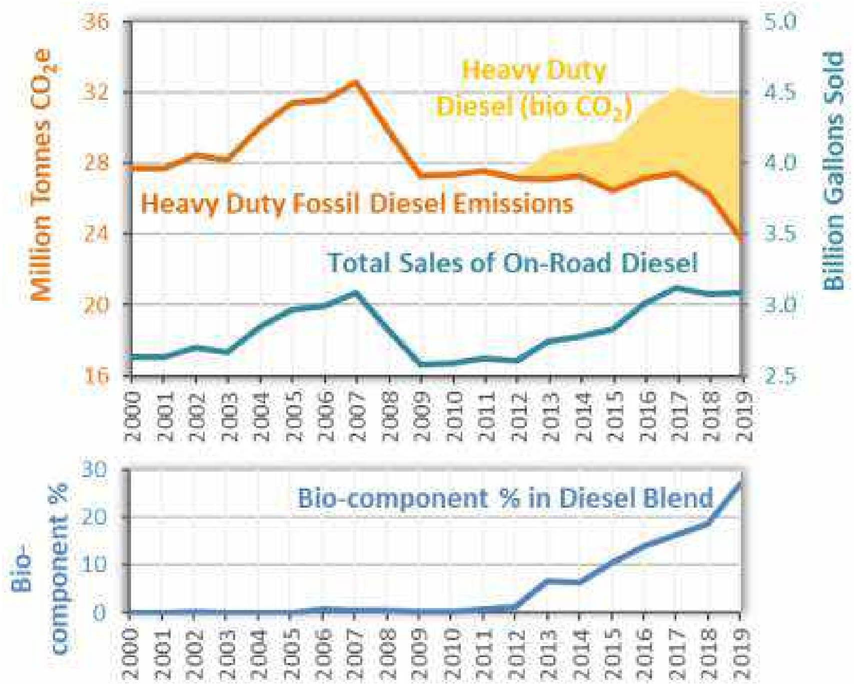
[25] CARB. 2021. California Greenhouse Gas Emissions for 2000 to 2019. July 28. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/2000_2019_ghg_inventory_trends_20220516.pdf. Accessed: June 2022.

[26] Ibid.

Figure A-3: Trends in On-Road Diesel Vehicle Emissions[27]



The use of renewable and low carbon fuels continues to grow in California and throughout the United States. If all proposed projects and projects currently under production come online, U.S. renewable diesel production would total 5.1 billion gallons per year by the end of 2024, which is over 7% of today's total U.S. diesel production and 142% of California's total diesel consumption in 2020 (diesel, biodiesel, and renewable diesel).[28,29]

The Scoping Plan focuses on the transition of the statewide on-road vehicle fleet to ZE technology.

The Ramboll LDA Study"[30] evaluated whether alternative vehicle technology and fuel pathways could achieve life cycle GHG emission reductions similar or greater than the ACC II proposal, which is reflected in the Draft 2022 Scoping Plan Update as the action to achieve 100% LDA ZEV sales by 2035. This study conclusively showed that performance standards could be an alternative to a ZEV mandate.

27 Ibid.

28 Energy Information Administration. U.S. renewable diesel capacity could increase due to announced and developing projects. Available at: https://www.eia.gov/todayinenergy/detail.php?id=48916. Accessed: June 2022.

29 "Diesel fuel explained". US Energy Information Administration. Available at: https://www.eia.gov/energyexplained/diesel-fuel/where-our-diesel-comes-from.php#:~:text=In%202020%2C%20U.S.%20refineries%20produced,barrels%20(57.43%20billion%20gallons). Accessed: June 2022.

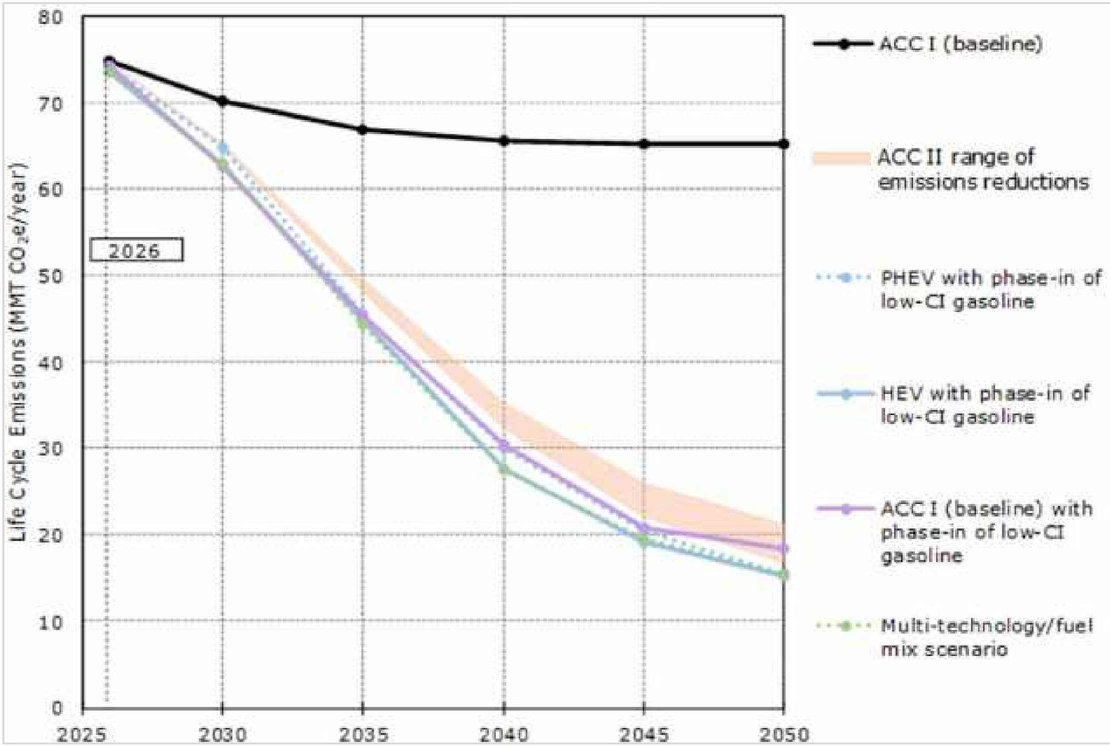
30 Ramboll. 2022. Multi-Technology Pathways To Achieve California's Greenhouse Gas Goals: Light-Duty Auto Case Study. Available as Attachment D at: https://www.arb.ca.gov/lists/com-attach/477-accii2022-AHcAdQBxBDZSeVc2.pdf. Accessed: June 2022.

Unlike CARB's analysis, Ramboll evaluated the full life cycle impacts of ZEV technologies under the LDA proposal to more completely characterize the potential GHG emissions performance and considered other technology/fuel pathways that would not require a replacement of the entire transportation infrastructure system. These alternative pathways would also not require the wholesale transformation of electric energy production and distribution infrastructure on an unprecedented time scale, but they could utilize existing battery, hydrogen, and low-CI gaseous and liquid fueled vehicles to achieve the State's GHG targets for light-duty transportation. The NERA Study (**Attachment D**) further indicated that the magnitude of grid expansion is reduced by two-thirds in a scenario that allows more flexibility to arrive at an optimal solution for LDAs and HHDTs.

The Ramboll LDA Study showed that a gradual transition to low-CI gasoline with current vehicle technologies (represented by the purple line in **Figure A-4**) could achieve similar life cycle GHG emissions as the current ACC II proposal (represented by the pink shaded region in **Figure A-4**). Importantly, **GHG emissions associated with ZEVs are not zero.** In fact, the GHG emissions from producing BEVs (the "vehicle cycle") is *significantly higher* than other vehicle technology types (see **Comment A.13** for additional details). The failure to analyze these real world GHG emissions distorts the claimed benefits attributed to these vehicles.

Other technologies also achieve similar or lower emissions on a life cycle basis compared to the ACC II proposal. These include HEVs coupled with low-CI fuel (represented by the blue solid line), PHEVs coupled with low-CI fuels (represented by the blue dotted line), and a combination of HEVs, PHEVs, and BEVs with low-CI fuels (represented by the green dotted line).

Figure A-4: Life Cycle Emissions for Key Scenarios in the Ramboll LDA Study California Light Duty Automobile Fleet (2026 to 2050)



The Ramboll HHDT Study performed a similar analysis to identify multiple vehicle and fuel technology pathways that could achieve the near term federally mandated air quality goals while being consistent with the State's long-term climate goals. This study found that expanded implementation of low-NO_X and ZE vehicles, coupled with increased introduction of renewable liquid and gaseous fuels, could deliver **earlier and more cost-effective benefits** when compared to a ZEV-only approach.

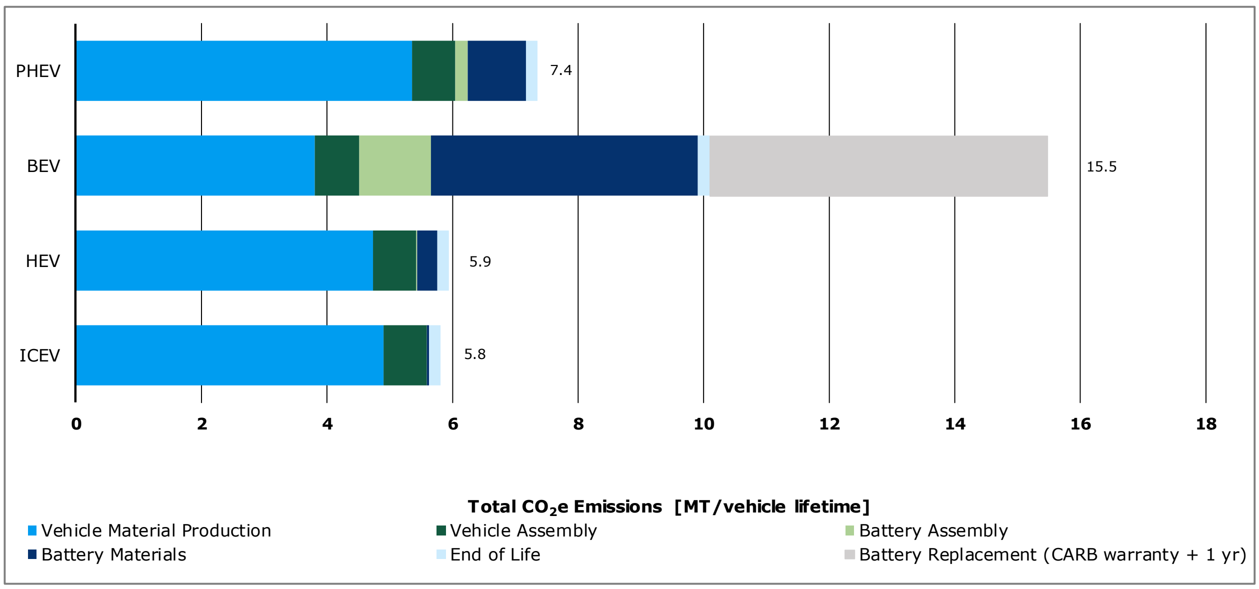
By allowing a technology neutral performance-based strategy for on-road vehicles in the Proposed Scenario, CARB would maintain equitable emission reductions across the transportation sector while significantly abating the technological and economic concerns surrounding the proposed ZEV mandates. We continue to ask CARB to fairly evaluate a plan that allows for this alternative pathway to achieve carbon neutrality with fewer feasibility challenges and lower costs.

A.13 CARB must account for the full life cycle GHG emissions of the vehicle/fuel system for the on-road vehicles in part to ensure that there is no leakage of emissions due to the proposed ZEV strategy.

The Draft 2022 Scoping Plan does not consider the life cycle emissions of "zero emission" vehicles or assess the leakage that would occur as a result of the ZEV strategy that includes the following actions: 100% of LDV sales are ZEV by 2035 and 100% of MD/HDV sales are ZEV by 2040. This is problematic given that AB 32 specifically directs CARB to adopt emission reduction measures which "minimize leakage" with leakage being defined as "a reduction in emissions of greenhouse gases within the state that is offset by an increase in emissions of greenhouse gases outside the state"[31]. Specifically, the vehicle life cycle emissions[32] due to additional BEVs in the fleet in the Proposed Scenario in 2045 (see **Comment A.8**) were not considered but should be included due to the significant differences in these emissions between BEVs and ICEVs, which lead to an additional ~110 MMT CO_2e not considered in the inventory sector modeling for the Proposed Scenario.

The Ramboll LDA Study[33] found that the vehicle cycle emissions for a model year 2026 BEV (10.1 metric tons (MT) CO_2e per vehicle) was about 74% higher than those for a model year 2026 ICEV (5.8 MT CO_2e per vehicle) (see **Figure A-5**). If the BEV undergoes a battery replacement during its lifetime, its vehicle cycle emissions increase to 15.5 MT CO_2e per vehicle, which is ~167% higher than those of an ICEV. The significant emission increases associated with the production of a BEV, as compared to an ICEV, must be included in the emission analysis to fully understand the impacts of the ZEV strategy. It is also important to note that mineral resources critical to the production of batteries are primarily found outside the State. So, GHG emissions associated with mining and processing of these minerals that occur outside the State boundary should be included in CARB's analyses.

Figure A-5: Vehicle Cycle GHG Emission Factors for Different Light Duty Auto Vehicle Technologies



[31] Assembly Bill No. 32 California Global Warming Solutions Act. Available at: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32. Accessed: June 2022.

[32] Emissions associated with vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling.

[33] Ramboll. 2022. Multi-Technology Pathways To Achieve California's Greenhouse Gas Goals: Light-Duty Auto Case Study. Available as Attachment D at: https://www.arb.ca.gov/lists/com-attach/477-accii2022-AHcAdQBxBDZSeVc2.pdf. Accessed: June 2022.

A.14 CARB's transportation energy demand projections for the E3 scenarios appear to assume significant vehicle miles traveled (VMT) reductions despite the State's previous failure to achieve VMT reductions under Senate Bill (SB) 375. The increased use of low carbon-intensity fuels could provide GHG reductions with much greater certainty than VMT reduction assumptions.

Even with a complete transition to ZEVs, the Proposed Scenarios (Alternative 3) is unable to achieve the State's GHG emission reduction targets without assuming VMT reductions from the remaining vehicles. The proposed VMT reductions of 12% below 2019 levels by 2030 and 22% below 2019 levels by 2045 are highly optimistic given historical increases in VMT and previous failures to reduce VMT. Under SB 375, metropolitan planning organizations were directed to meet GHG emissions reduction targets by incorporating a Sustainable Communities Strategy (SCS) as part of the long-range regional transportation plans. As noted in the CARB's 2018 Progress Report,[34] the anticipated performance of the SCS was a 10% reduction in VMT per capital by 2020 as compared to 2000. However, by 2016, the VMT per capita had increased by ~3%. As noted in the progress report, there are numerous challenges associated with these types of VMT reductions which are dependent on factors outside CARB's purview such as employment rates, fuel prices, job and housing balances, and availability of affordable housing.

CARB should consider the implementation of technology-neutral vehicle/fuel pathways that could achieve the GHG reductions contemplated within these Proposed Scenario (see **Comment A.12** for further details). The increased use of low and negative carbon-intensity drop-in fuels along with the penetration of fuel-efficient vehicle technologies such as HEVs and PHEVs could provide GHG reductions with much greater certainty than the VMT reductions.

<u>Oil and Gas in Proposed Scenario (Alternative 3)</u>

A.15 WSPA agrees with CARB that a complete phaseout of oil and gas extraction and refining is not feasible by 2045. As called for in AB 32, CARB must study and quantify the leakage risk associated with its current policies and the Draft 2022 Scoping Plan Update, as they could eliminate the potential to provide low-CI fuels to other regions and achieve global GHG benefits.

WSPA agrees with CARB's assertion that a complete phaseout of oil and gas extraction and refining is not feasible and would lead to significant leakage, so CARB should refrain from sending artificial market signals.[35] Moreover, California is a critical provider of liquid fuels to other jurisdictions, including to neighboring states (particularly Nevada and Arizona)[36] as well as exports to countries such as Mexico. Given that California refineries have responded to

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[34] 2018 Progress Report: California's Sustainable Communities and Climate Protection Act. Available at: https://ww2.arb.ca.gov/sites/default/files/2018-11/Final2018Report_SB150_112618_02_Report.pdf. Accessed: June 2022.

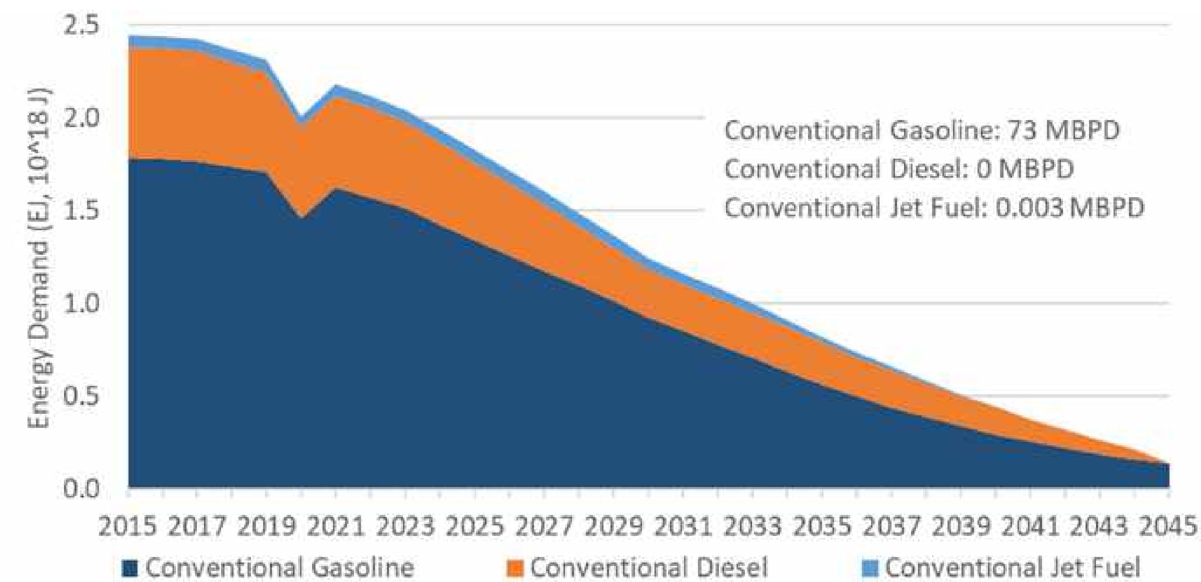
[35] Draft 2022 Scoping Plan Update. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

[36] Energy Information Administration, West Coast Transportation Fuels Markets, September 2015. See Figure 5 on page 14. Available at: https://www.eia.gov/analysis/transportationfuels/padd5/pdf/transportation_fuels.pdf. Accessed: June 2022.

regulations that result in provision of lower-emission fuels, this benefit is exported to these jurisdictions. This benefit will only grow as greater emission reductions ensue with in-state activities.

Furthermore, CARB's modeling for the residual refining products demand in the state indicates an infeasible outcome. For the Proposed Scenario, CARB models the 2045 in-state demand for refined petroleum products as 73 million barrels per day (MBPD) of conventional gasoline with essentially no simultaneous production of conventional diesel or jet fuel (see **Figure A-6** below).[37] CARB must recognize that refineries cannot operate in a way that only produces gasoline. Refineries will continue to produce the range of products that exist today, and for which there will be demand.

Figure A-6: Energy Demand Under CARB's Proposed Scenario[38]



While the premise for continued use of liquid fuels in Alternative 3 is correct, the basis for the volume of its continued use is flawed. CARB ignores the production of other fuels (e.g., jet fuel) and the continued use of refineries to produce new renewable liquid fuels and hydrogen, as discussed in **Comment A.12** and **Comment A.17**. CARB presumes that other jurisdictions will reduce the use of liquid fuel at the same pace as California. Further, it only considers fuels currently regulated by CARB, which excludes aviation and marine fuels that will be required from California refineries for an even longer period of time. Given that each jurisdiction will be on its own unique decarbonization pathway, it is illogical to premise that California's trajectory will resemble theirs; CARB needs to revisit these assumptions.

In addition to the above concerns about the concluding position for liquid fuels, WSPA is also concerned about the logistical constraints created by the implied loss of refining capacity to

37 Data gathered from CARB Draft 2022 Scoping Plan Update, "AB 32 GHG Inventory Sectors Modeling Data Spreadsheet," "Energy Demand" tab. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-PATHWAYS-data-E3.xlsx. Accessed: June 2022.

38 Ibid.

in-state liquid fuel supply and distribution capabilities. CARB must consider the implications of any such losses, which create a likelihood of inefficient fuels distribution and increased GHG emissions. These concerns would exist both in the concluding position of the Draft 2022 Scoping Plan Update and throughout the transition, during which efficient, effective and reliable supply of fuels for Californians must be maintained.

Further, while we agree with CARB that a production ban is infeasible and would lead to leakage, WSPA believes that CARB should study the leakage risk that could result from potential policies to limit future oil and gas development. These policies could actually result in production volumes well below the rate that would be needed to supply future demand for fuels refined for demand in California and neighboring jurisdictions. As CARB has noted in the Draft 2022 Scoping Plan Update, there is an uncertainty and risk that their direct policies will not be 100% effective in achieving their objectives especially when considering a time period extending all the way out to 2045. In the case of the proposed ZEV mandates, any ban on production would only further exacerbate leakage especially if the proposed ZEV mandates do not fully achieve their goals.

CARB's singular focus on non-electrical emissions occurring within the state ignores the global context of California products and industries. California's suite of climate policies have been successfully incentivizing the production of low CI fuels at existing and new facilities,[39,40] which further reduce transportation emissions within the state and within the states to which California exports fuels. While the achievement of carbon neutrality in California is significant, what is more important is the attainment of global GHG reductions. Towards this aim, the 2022 Scoping Plan Update must consider and give appropriate credit and support to the export of low-CI fuels to help other jurisdictions outside the state achieve their climate goals.

In conclusion, California will be optimally positioned by a Draft 2022 Scoping Plan Update that recognizes the important role that the State's oil and gas industry will play long-term as an integral part of a clean energy future. These facilities can create and preserve good-paying jobs for Californians, many in areas of the State where such jobs are difficult to obtain. The failure to acknowledge the value of the exporting these low-CI fuels outside of the State and adopting a proposal that disincentivizes or eliminates the in-State capacity to produce these fuels would put blue-collar jobs at risk when they could produce a lower-CI fuel and displace higher-CI fuels from jurisdictions outside of California.

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39 Phillips 66 New Releases. 2022. Phillips 66 Makes Final Investment Decision to Convert San Francisco Refinery to a Renewable Fuels Facility. Available at: https://investor.phillips66.com/financial-information/news-releases/news-release-details/2022/Phillips-66-Makes-Final-Investment-Decision-to-Convert-San-Francisco-Refinery-to-a-Renewable-Fuels-Facility/default.aspx. Accessed: June 2022.

40 Martinez Renewable Fuels. Available at: https://www.marathonmartinezrenewables.com/. Accessed: June 2022.

A.16 WSPA continues to request that CARB include modeling for CCS on upstream oil and gas production and that it does so in a timeframe that recognizes the ongoing statutory, regulatory, and permitting challenges facing CCS adoption within the state.

CCS has been acknowledged as an essential technology to deploy for California to meet its climate ambitions.[41] CCS is a versatile technology that can be employed on many existing CO_2 sources, as well as being utilized in tandem with DAC to remove CO_2 from the atmosphere. Given this, WSPA remains concerned that modeling work has failed to include the utilization of this important technology on upstream oil and gas production, where it can effectively be employed as part of the production process. Indeed, many of the earliest cost-effective applications of this technology are likely in upstream production; recognizing this provides a platform for early implementation of CCS assets that can provide earlier CO_2 reductions through their useful life as a production asset, and then be pivoted for further utilization (for example, DAC). CARB should include this technology as part of the modeling scenario that supports the selected alternative in this Scoping Plan. This is a prime opportunity for California to be a leader in advancing a technology which will be critical to achieving carbon neutrality.

As CARB recognizes in its Scoping Plan, the vast majority of CCS implementation, regardless of where and how it is being deployed, will not occur until the 2030s. For this reason, it is important to recognize that the pathway to utilize CCS in upstream production needs to be included now, as the timeline for CCS projects through the existing labyrinth of statutes, regulations, and multiple permitting regimes makes it critical that in be included in now to meet the GHG reduction schedule. Early adopters to this important technology should not be sidelined or this technology will not be implemented in a timely fashion. WSPA appreciates that CARB has recognized the potential for refineries to contribute to onsite and offsite emission reductions through the production of low-CI fuels.

A.17 WSPA agrees that biodiesel, renewable diesel, sustainable aviation fuels (SAF), and hydrogen will continue to play pivotal roles in decarbonizing the economy but asks CARB to expand their scope to include low-CI crude oil supplies, finished fuels such as low carbon or renewable gasoline, and other fuels that could significantly reduce carbon emissions through the application of CCS technologies.

As stated in previous comments (**Comment A.12**), low-CI gasoline could achieve similar life cycle GHG emissions reductions as the current ACC II proposal. CARB must look into expanding programs that incentivize and support the use of low-CI fuels in the combustion-powered fleet that will exist through and beyond 2045, per CARB's modeling assumptions.[42] These fuels could bring immediate tailpipe emissions reductions to existing

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41 Draft 2022 Scoping Plan Update. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

42 CARB. 2022. California PATHWAYS Model Outputs. May 2. Available here: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-PATHWAYS-data-E3.xlsx. Accessed: June 2022.

combustion-- powered vehicles on the road without a need for the turnover of the entire vehicle fleet.

The Stanford Pathways to Carbon Neutrality in California found that “the production of vehicle fuel from biogas becomes economically feasible only when the LCFS and the Renewable Fuel Standard credits are harvested.”[43] Continued support for programs that incentivize production of low-CI fuels is vital to the renewable fuel industry in California;.

A.18 We also request that CARB take into consideration the onsite emissions reductions associated with processing of renewables as opposed to petroleum.

The processing of bio-feedstocks in refineries produces carbon neutral, renewable combustion fuels. The complex operations that create and isolate a broad range of molecules through multiple process steps generate a variety of co-products such RNG, renewable fuel gas, renewable propane, and other liquid fuels, providing multiple revenue streams and fuel products from a single feedstock. To further encourage the transition of refinery feedstocks to renewable sources, the value of these and other such streams needs to be accounted for in Cap-and-Trade to offset the significant costs to reconfigure refineries.

A.19 CARB should allow and model the use of CCS on natural gas power plants. This is a better alternative to decarbonize the electric grid and more cost-effective than the existing plans to construct large amounts of new battery and hydrogen storage.

According to the Stanford study “Decarbonizing the Electricity Sector”,[44] the size of the future grid will likely drive the total costs for decarbonization. Diversifying generation resources is the most effective way to reduce system generation capacity. Gas generation will likely be needed for reliability in California’s energy mix through 2040 and by 2045.

The Proposed Scenario represents unprecedented development of solar and storage (90 GW solar generation and 40 GW battery storage by 2045). The Scenario should consider including RNG, hydrogen and other sources of dispatchable electricity generation to support renewables integration and make the grid more reliable. Low-carbon oil and gas with CCS can achieve the same level of CI reduction as solar and battery storage systems and should be considered as part of the portfolio in the Proposed Scenario to allow for increased reliability while still achieving emission reduction goals.

Currently, natural gas fills a vital role as the marginal generator that fills the gaps left by intermittent or seasonal generation resources, according to the Stanford study.[45] This reliability that natural gas provides will need to be fulfilled by a clean source of dispatchable electricity generation by 2045. There are many low-CI alternatives such as natural gas with CCS, RNG and hydrogen from renewable feedstocks that could fill this role. Further, with appropriate

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43 Stanford. 2022. The Bioenergy Opportunity. Available at: https://sccs.stanford.edu/sites/g/files/sbiybj17761/files/media/file/the-bioenergy-opportunity.pdf. Accessed: June 2022.

44 Stanford. 2022. Pathways to Carbon Neutrality in California. Available at: https://sccs.stanford.edu/sites/g/files/sbiybj17761/files/media/file/DecarbonizingTheElectricitySector_FullReport_0.pdf. Accessed: June 2022.

45 Ibid.

incentives to transition to greater use of RNG in these facilities, a negative emissions pathway is possible. CARB must consider these options in the Proposed Scenario to ensure reliability of the grid, decreased system costs, and sufficient diversification of California's energy mix through 2045.

Sufficient diversification of the grid allows for decreased required system capacity, which in turns reduces the need for overbuilding of renewable resources that are intermittent/seasonal, according to the Stanford study. It would be prudent for the State to utilize existing infrastructure to reduce the amount of stranded assets that would result from the Scoping Plan. There could be potential for converting existing liquid fuels infrastructure from carrying fossil fuels to renewable fuels, allowing for utilization of existing capacity while still meeting CI reduction goals in the grid. The decarbonization of California's economy will be expensive; any use of existing assets that can be adapted to a lower carbon future should be given a pathway in the current Scoping Plan, as this will reduce the timeline and costs for achieving the state's climate goals. The scale of upgrade needed on the grid to meet the Scoping Plan Proposed Scenario is unprecedented, and CARB must ensure that this transition is smooth and reduces risks from hazards such as public safety shut-off (PSPS) events and systemic risks due to dependence on intermittent technologies that may or may not materialize at the scale needed.[46]

CARB should encourage and model the use of CCS on natural gas power plants. This provides a path that allows existing assets to be cost-effectively utilized. This enhances reliability of the grid, given that natural gas power plants are dispatchable. Further, with appropriate incentives to transition to greater use of RNG in these facilities, a zero or negative emissions pathway is possible thus allowing it to meet the requirements under SB-100.

The NERA Study (**Attachment D**), which was not constrained by limits on how to best reduce emissions for dispatchable power, also concluded that utilization of CCS on existing natural gas generating assets was the most cost-effective outcome. That multiple approaches draw the same conclusion is not surprising; making use of existing infrastructure to mitigate the extreme costs of battery storage for worst-case periods (e.g., extended absence of wind, extended duration of low solar energy) makes intuitive sense and the model corroborates the approach.

A.20 WSPA encourages CARB to expand the allowances for low-carbon fuels and broaden incentives for hard-to-abate sectors. Specifically, WSPA encourages CARB to update the LCFS to connect industrial processes that are associated with transportation fuels.

As noted in **Comment A.12**, the blend of renewable fuels within existing fuel stocks have reduced GHG emissions in the transportation sector by 6.4% for LDVs and 25% for HDVs. Similar reductions could be achieved in hard to abate sectors in the commercial, residential, and industrial space. The industrial sector represents 18-19% of the GHG inventory under Alternative 3 through 2045 and additional emission reductions achieved though the deployment of low-carbon fuels would aid in achieving carbon neutrality. The LCFS should be enhanced with extension of the use of book and claim accounting to better incentivize this transition by combining the beneficial capture of methane from non-fossil sources and utilizing this

46 Ibid.

renewable fuel source to provide reliable, low-carbon fuel for transportation and industrial processes in the State.

Hydrogen in Proposed Scenario (Alternative 3)

A.21 We appreciate CARB's recognition that hydrogen will be critical to achieving carbon neutrality. It is unclear why the Proposed Scenario requires that all hydrogen produced in 2045 must be zero-carbon instead of allowing this sector, like every other sector, to have a small amount of carbon emissions that are offset by DAC and other negative emissions technologies.

WSPA appreciates CARB's recognition that low-carbon hydrogen will play a critical role in reducing GHG emissions from the transportation sector (for heavy-duty vehicles, ocean-going vessels, rail, and aviation) and the industrial manufacturing sector. As noted by CARB, hydrogen can also play a dual role in the electricity sector as a zero or low-carbon fuel for existing combustion turbines and as energy storage for later use. However, it is unclear why the Proposed Scenario suggests that all hydrogen produced in 2045 be zero-carbon while the electricity production is allowed to maintain residual GHG emissions of ~30 MMT of CO_2e in 2045.

In order to produce this zero-carbon hydrogen by electrolysis, the Proposed Scenario (Alternative 3) contemplates the new development of extensive "off-grid" solar (41 GW solar generation needed in 2045) which would be in addition to all the solar development required for the California electric grid (90 GW solar generation by 2045). With the enormous amount of renewables buildout already required to meet the electricity demands from other sectors in the Proposed Scenario, CARB must expect other technology options for the production of low-carbon hydrogen including the use of steam methane reformers (SMR) with CCS. Of note, the Proposed Scenario includes the installation of CCS on refineries across the state, including SMR facilities that currently produce hydrogen for use inside refineries. CARB's modeling shrinks the refining sector significantly from 2030 to 2045 but does not appear to repurpose the SMRs with CCS for low-carbon hydrogen production. There would be an opportunity to utilize SMRs with CCS already equipped for low-carbon hydrogen production for use in other sectors.

The discussions on hydrogen infrastructure during the recent ACF working group meetings made it clear that access to hydrogen and other low carbon combustion fueling sources would be pivotal to transitioning the heavy-duty vehicle fleet. Our industry offers great opportunities to support this transition and minimize carbon emissions in the long term. CARB must allow other options for the production of hydrogen necessary for use within California.

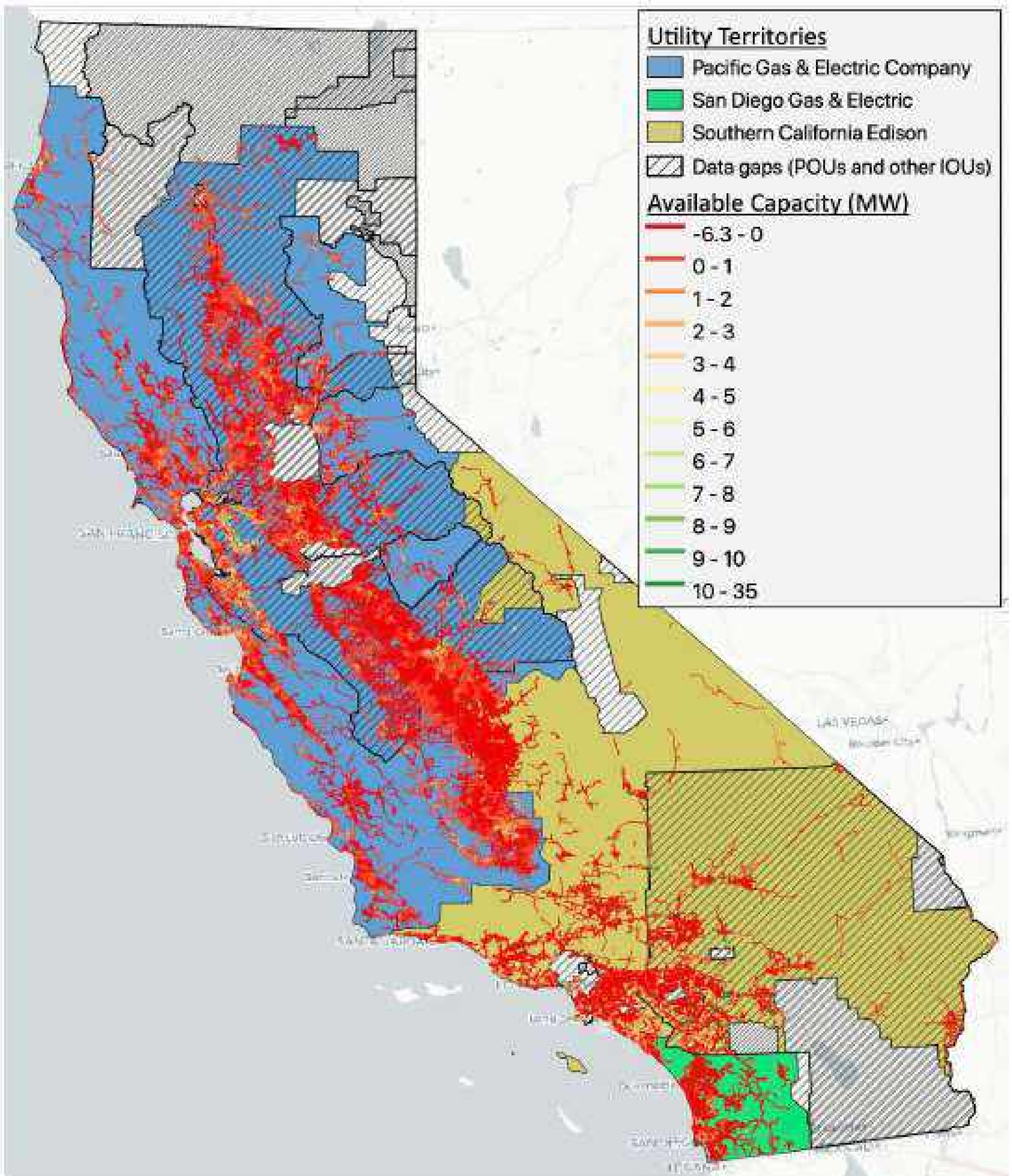
Electricity in Proposed Scenario (Alternative 3)

A.22 CARB understates the impact that the dramatic increase in electrical generation and transmission/distribution infrastructure will have on the State's energy sector as a direct result of this Scoping Plan.

CARB has not provided any analysis of the feasibility of the Proposed Scenario given the significant increase of electric vehicle charging infrastructure, electrical generation and transmission and distribution infrastructure that would be required to support 19.2 million BEVs and 3.8 million PHEVs by 2045. The Capacity Analysis from the California Energy

Commission's (CEC's) EDGE Model (**Figure A-7** below, obtained from the Draft EA for the ACC II Program[47]) shows the grid has no additional capacity to add electrical load for charging for most of these circuits.

Figure A-7: Capacity Analysis from CEC's EDGE Model[48] (dark red indicates no available additional capacity)



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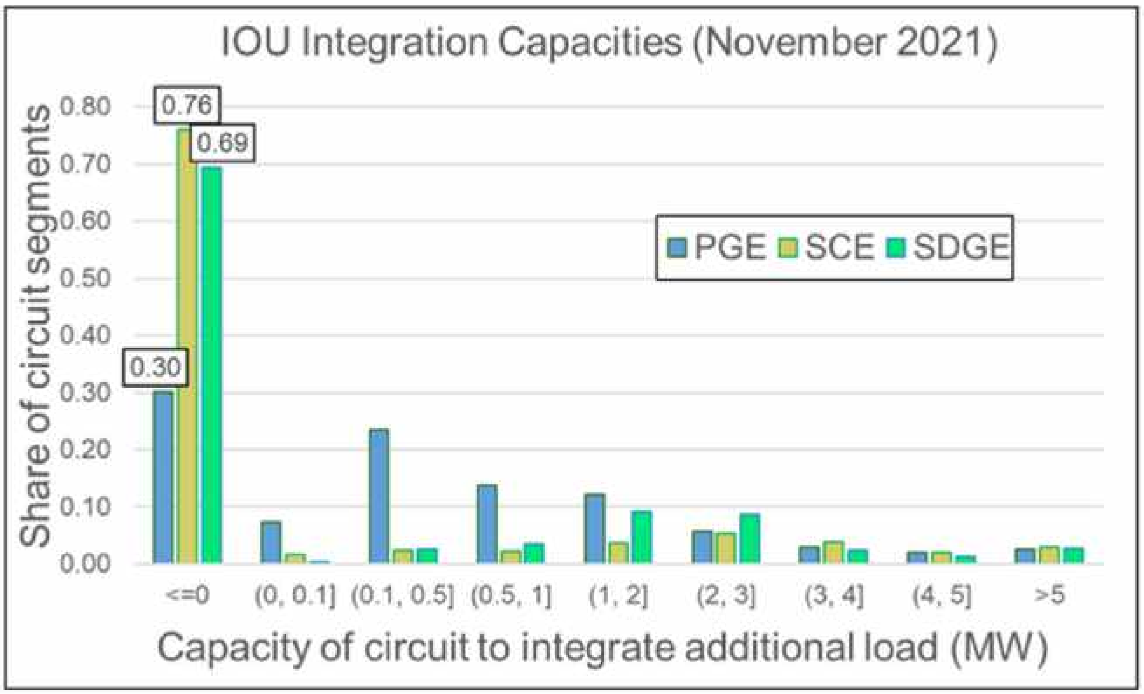
47 Draft Environmental Analysis (EA) for the Proposed ACC II Program. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/appe1.pdf. Accessed: June 2022.

48 Ibid.

You can see this in numerical terms in **Figure A-8** (obtained from Virtual Medium and Heavy-Duty Infrastructure Workgroup Meeting - Electricity and the Grid on January 12, 2022[49]), which details the capacity of circuits to integrate additional load. This figure illustrates that 30% to 76% of circuit segments have no capacity to integrate additional load. Thus, no appreciable charging capacity can be added to most of these circuits without the expenditure and time for additional construction of needed transmission and distribution infrastructure.

Figure A-8: Capacity of circuits to integrate additional loads[50]



While the economic analysis in the Draft 2022 Scoping Plan appears to account for the costs associated with increase of electric vehicle charging infrastructure, electrical generation and transmission and distribution infrastructure under "cost and savings from changing fuel expenditures" category,[51] the 2022 Scoping Plan documents do not provide sufficient detail for the public to understand the assumptions used in the economic analysis and the cumulative costs associated with these improvements from 2022 to 2035.

49 Virtual Medium and Heavy-Duty Infrastructure Workgroup Meeting - 01/12/22. Available at: https://www.youtube.com/watch?v=_mr0TmwxGZQ. Accessed: June 2022.

50 Ibid.

51 CARB. Draft 2022 Scoping Plan Update. Appendix B Draft Environmental Assessment. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-appendix-b-draft-environmental-analysis.pdf. Accessed: June 2022.

As noted in our September 7, 2021, comment letter,[52] Ramboll's meta-study of published literature on the Transportation Electrification Costs in California,[53] estimates that the cumulative transportation infrastructure costs (generation, transmission, distribution, maintenance, and electric vehicle chargers) from 2020 to 2050 as at least $2.1 to $3.3 trillion. While the economic analysis for the Draft 2022 Scoping Plan potentially estimates these cumulative costs, it was not disclosed as part of the Scoping Plan Documents. Therefore, we respectfully request CARB to release the details input and outputs of the economic analysis so the public and stakeholders can review and comment on it.

Carbon Capture & Sequestration in Proposed Scenario (Alternative 3)

A.23 CCS and CDR technologies are essential to achieving carbon neutrality, but adoption of these technologies must be driven by federal and state government and market-based mechanisms such as LCFS and Cap-and-Trade.

CARB appropriately acknowledges the role of engineered carbon removal, point source carbon capture, and geological sequestration in meeting California's carbon neutrality goal by 2045. We do want to caution the Board however, that the adoption of CCS technologies by any industrial emitter would be enhanced by the existing market--based mechanisms in place including Cap-and-Trade and the LCFS, rather than be subject to any statutory or regulatory mandate. Such a mandate could have the opposite intended effect and rather than drive adoption within California, instead would drive the exportation of emissions to other jurisdictions where a mandate to install CCS on industrial facilities does not exist.

The identified "Strategies for Achieving Success" for CDR and CCS[54] appropriately note the challenges facing wide scale adoption of this safe and reliable tool for California to meet 2045 goals, while simultaneously identifying the critical role that mechanical CDR and CCS can and should play in meeting these challenges.

There are also longstanding gaps in the accounting protocols of Mandatory Reporting of Greenhouse Gases Regulation (MRR) used in the Cap-and-Trade program, which makes it impossible to credit the avoidance of GHG emissions or negative emissions. Once this key aspect of the Cap-and-Trade program is addressed, stakeholders will more clearly be able to understand and quantify the emissions credits available through CCS and mechanical CDR, making both technologies much more economically viable.

Additionally, the LCFS CCS Protocol must be revisited and updated so changes necessary to enable development of CCS are operative before 2025. As noted in **Comment A.10**, CCS

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52 September 7, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/80-sp22-concepts-ws-AmNWJVA2VFgEM1Bn.pdf. Accessed: June 2022.

53 Attachment to the September 7, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/80-sp22-concepts-ws-AmNWJVA2VFgEM1Bn.pdf. Accessed: June 2022.

54 Draft 2022 Scoping Plan Update. Pages 177-178. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

projects have lengthy timelines for permitting and development,[55] and it is imperative that CCS protocol enhancements are in hand so that financial and approval barriers are mitigated and California CCS projects can obtain critical LCFS crediting. An unclear understanding of the value for such projects will present a significant market barrier. Indeed, without such clarity, financing for such projects, either internal or external, will be difficult to obtain.

Key areas within the CCS Protocol that should be further evaluated and revised, as they have significant impacts on CCS project economics, include buffer account requirements and fracture pressure gradient specifications. Specifically, CARB should evaluate its CCS Protocol to ensure alignment with the federal 45Q program and the U.S. EPA Class VI UIC program to ensure a project operator can comply with all relevant provisions without unnecessary conflicts. In addition, issues such as pore space rights and eminent domain, while not in CARB's direct control, must be acknowledged as critical barriers that need to be addressed for the state to achieve its ambitions for CCS/CDR.

A.24 California must streamline permitting for CCS and mechanical CDR projects to ensure that CEQA and other regulatory proceedings do not unjustly stall or halt technologies that are crucial to meeting the goals of the 2022 Scoping Plan Update.

CARB rightly identifies the challenging permitting environment currently present in California as numerous federal, state, regional, and local entities play key roles in approving a CCS project. Among these many agencies, delays with obtaining the otherwise simple approval required in sequence can lead to a cascade of delays and recycle of effort. The uncertainty in schedule that results from these delays can undermine the economics and financing for such opportunities. Further, the utilization of CEQA and the associated environmental impact report (EIR) to stall projects, even those that are broadly recognized as positive, is well-known. While a robust EIR process is important to ensure that all relevant community impacts are being evaluated, the process cannot be allowed to hold CCS and similar such projects hostage. Given that CARB have identified CCS and mechanical CDR among the critical technologies for the state to achieve its climate goals, California needs to consider how to ensure these projects can be permitted and implemented on a timely basis. Everything that CARB can do to support a broader effort within California to streamline permitting and approvals of such projects will be vitally important (See **Comment 5** for further details).

A.25 The proposed timeline to deploy CCS "on a majority of refinery operations by 2030" is likely infeasible given the current delays in processes and lack of economic incentives in California's market-based program to support these projects.

CARB's premise in its chosen scenario that CCS would be "on majority of refinery operations by 2030" [56] needs further discussion. The timeline for permitting and implementing such

55 Lawrence Livermore National Laboratory (LLNL). 2021. Permitting Carbon Capture & Storage Projects in California. February. Available at: https://gs.llnl.gov/sites/gs/files/CA_CCS_PermittingReport.pdf. Accessed: June 2022.

56 Draft 2022 Scoping Plan Update. Table 2-2 on Page 59. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

projects, which will easily exceed 5 years, [57] would not permit such a comprehensive extent of CCS being installed by this time, particularly considering that most major refineries are in major metropolitan areas and the preferred sequestration locations[58] will be substantial distances away from the CO_2 sources.

WSPA agrees with CARB's assessment in its Draft 2022 Scoping Plan Update that CCS technology is currently focused on the capture of nearly pure CO_2 streams that arise from non-combustion processes. Indeed, the majority of CCS installations today are found at ethanol and fertilizer plants, [59] which have such streams available. Within or alongside refineries, operations that have a byproduct stream approaching such CO_2 purity are from hydrogen SMRs. These produce a CO_2 rich stream, the majority of which is also a normal, non--combustion process byproduct. Like ethanol and fertilizer plants, vents from hydrogen plants are strong candidates for early sequestration.

The extension of application of CCS to the remaining refinery operations, including combustion-intensive units, is an exciting longer-term prospect. Unlike streams from fertilizer, ethanol and hydrogen plants, the concentration of CO_2 in combustion streams is much lower, and it will be likely more costly to employ CCS. As acknowledged by CARB, the application of CCS for such streams today is very limited. The first tranche of such facilities is only expected to start up in the second half of the 2020s, even though they are being characterized as being in the "advanced development phase," with only two such plants in construction and only a single such facility (Boundary Dam, Saskatchewan, Canada) in operation today.[60] Timing for implementation of CCS on these streams in refining operations, or any other combustion activity, will have to be assessed for cost-effectiveness as this technology develops.

While WSPA does present some concerns related to the ***timing*** for CCS in the Scoping Plan as it relates to refinery operations, we want to be clear that we believe CCS is a critical technology to achieve carbon neutrality and we are excited to work towards its implementation in our sector.

57 LLNL. 2021. Permitting Carbon Capture & Storage Projects in California. February. Available at: https://gs.llnl.gov/sites/gs/files/CA_CCS_PermittingReport.pdf. Accessed: June 2022.

58 LLNL. 2020. Getting to Neutral: Options for Negative Carbon Emissions in California. August. Available at: https://gs.llnl.gov/sites/gs/files/2021-08/getting_to_neutral.pdf. Accessed: June 2022.

59 Draft 2022 Scoping Plan Update. Page 176. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf. Accessed: June 2022.

60 Global CCS Institute. 2021. The Global Status of CCS 2021. Available at: https://www.globalccsinstitute.com/wp-content/uploads/2021/11/Global-Status-of-CCS-2021-Global-CCS-Institute-1121.pdf. Accessed: June 2022.

Alternative 4 Assumptions

A.26 Similar to the Proposed Scenario (Alternative 3), Alternative 4 is technologically infeasible given the unprecedented level of growth in solar, battery storage, and grid capacity required, the proposed ZEV mandates for the transportation sector, and phase down of oil and gas extraction and refining in line with demand.

While Alternative 4 represents a slightly more conservative timeline for the deployment of the aforementioned strategy, it does not address the key issues present within the Proposed Scenario. Although under Alternative 4 LDV and MDV)/HDV sales are **required to be ZEV five years later than the Proposed Scenario, the required annual deployment of solar technology and battery storage to complete this transition (6 GW and 2 GW) still dramatically outpace the historic maximum build rates for these technologies.**

Alternative 4 does not address any of the concerns regarding need for grid resiliency under an electrification-centric Scoping Plan, the impacts of global mineral mining, battery production, and battery recycling, nor does it address the feasibility of achieving these levels of electrification across the transportation, residential, and industrial sectors.

WSPA maintains that a technology-neutral, market-based approach to achieving California's GHG reduction goals is more technologically and economically feasible and CARB should make serious considerations as to what approach would best serve California.

WSPA

ATTACHMENT B
Legal Comments

B.1 CARB Does Not Have Unfettered Regulatory Authority.

CARB proposes to adopt a broad-sweeping Scoping Plan that "lays out the transformations needed across our society and economy to reduce emissions and reach our climate goals." The California Legislature, however, in directing CARB to adopt the Scoping Plan, set forth express requirements and limitations on CARB's authority in adopting and implementing the Scoping Plan. Importantly, CARB must consider technological feasibility, cost-effectiveness, total potential costs, and environmental impacts of the proposed Scoping Plan and avoid relying on policies it does not have the statutory authority to implement.

AB 32 requires CARB to prepare a scoping plan "for achieving the maximum technologically feasible and cost-effective reductions in greenhouse gas emissions." Cal. Health & Safety Code § 38561(a). The statute also requires CARB to account for the plan's total potential costs and benefits "using the best available economic models, emission estimation techniques, and other scientific methods." Id. § 38561(d). Likewise, Executive Order N-79-20 requires that CARB, in developing zero-emission vehicle strategies, to "act consistently with technological feasibility and cost-effectiveness." Executive Order N-79-20(2).

Similarly, the California Environmental Quality Act ("CEQA") Guidelines require consideration of environmental impacts, as well as the mitigation of such impacts where feasible. See 14 C.C.R. § 15021(a). CARB should also evaluate a "range of reasonable alternatives" which would "feasibly attain" most of the Draft Scoping Plan proposals' basic objectives "but would avoid or substantially lessen any of the significant effects" of the proposals. *See id.* § 15126.6(a). Specifically, when considering the feasibility of alternatives, the CEQA Guidelines provide the following factors to consider: "site suitability, economic viability, availability of infrastructure, general plan consistency, other plans, or regulatory limitations, [and] jurisdictional boundaries." Id. § 15126.6(f)(1).

B.2 The Draft Scoping Fails To Adequately Consider Required Statutory Factors.

Currently, the Draft Scoping Plan does not meet CARB's obligation to consider the potential negative environmental and economic externalities associated with the proposals described in the plan. Accordingly, WSPA urges CARB to consider the following technological feasibility and economic and environmental impacts[61] before finalizing the Scoping Plan.

- The proposed technology mandates are not cost-effective or technically feasible. The Draft Scoping Plan's arbitrary exclusion of mature technologies contradicts AB32's mandate that the plan "achiev[e] the maximum technologically feasible and cost-effective reductions in greenhouse gas emissions." The Draft Scoping Plan imposes limits on renewable fuels, direct air capture, and other applications for carbon capture, as well as certain vehicle technologies in pursuit of specific mandated technologies. These limits preclude other technologies that could achieve similar outcomes in a feasible and cost-effective manner. To maximize emission reductions all options must be on the table.
- CARB fails to adequately consider cumulative direct costs. The Health & Safety Code requires CARB to utilize "best available economic models." Health & Saf. Code § 38561(d).

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61 See Attachment A, Technical Comments for further detail.

In evaluating the potential range of costs resulting from the Draft Scoping Plan, CARB limits this evaluation to a single cost value for calendar years 2035 and 2045. This formula does not accurately portray the vast cumulative direct costs associated with the proposed policies over the course of the multiple decades covered by this Scoping Plan.

- CARB fails to adequately evaluate, and minimize, leakage. Under AB 32, CARB has an obligation to minimize leakage resulting from its regulatory activities. Health & Saf. Code § 38562. While CARB acknowledges the risk of leakage resulting from policies such as those impacting electricity grid demand that may result in increased production of dirtier power outside of California, residual liquid fuel demand that may result in increased imports, or emissions associated with production of ZEVs (mining/processing of minerals critical to battery production), it fails to adequately calculate, evaluate, and set forth policies to minimize such leakage.
- CARB fails to consider the negative impacts of curtailing oil production and refining. Consistent with AB 32 and CEQA, CARB must carefully consider all of the social and environmental impacts, both positive and negative, associated with curtailing oil production in the Scoping Plan. See Cal. Health & Safety Code § 38561(a); 14 Cal. Code Regs., tit. 14 § 15021(a). The Draft Scoping Plan fails to consider the full scope of the negative consequences of its preferred Alternative. For example, the plan would require the reduction of petroleum use by 91 percent in 2045 from 2022 levels but does not evaluate whether this would inadvertently increase emissions by increasing fuel imports to California via marine vessels. Similarly, CARB does not meaningfully consider the social consequences of the preferred Alternative—merely acknowledging that there will be significant job losses is insufficient consideration and fails to represent the full scope of social impacts that will be experienced. By way of example, CARB does not consider the impact of increased marine vessels and distribution activities on nearby communities, nor does it consider the economic and environmental impacts of closing retail stations, many of which are owned by small businesses. CARB must also address the significant social and environmental effects of lost jobs, lost tax revenue, and increased costs associated with the loss of a major industry sector that is tightly integrated into myriad aspects of California's economy and into the daily lives of Californians.
- CARB fails to consider the negative impacts of increased vehicle electrification. Similarly, the Draft Scoping Plan emphasizes the anticipated benefits it hopes to gain from increased electrification of the vehicle fleet while glossing over negative impacts associated with increased electrical demand. These may include increased loading on power plants, which may result in increased localized emissions near power plants as well as increased fire risk due to strain on the electrical grid. Power shortages would endanger Californians' lives and property—especially during hot summer months when demand is at its peak in many areas. The Draft Scoping Plan also does not recognize the impacts on roadways resulting from loss of gas tax revenue to fund maintenance, nor does it acknowledge the consequences of increased loading on roadways attributable to the extremely heavy batteries required to power heavy-duty vehicles. Finally, and most significantly, CARB does not acknowledge the lifecycle emissions, social impacts, or national security considerations associated with minerals sourcing and battery production. CARB must grapple with both the positive and

negative social and environmental effects of vehicle electrification, as required by AB 32 and CEQA.

B.3 The Draft Scoping Plan Mandates Actions That Violate Constitutional Rights.

Before finalizing the Scoping Plan, CARB must consider that elimination of an entire industry likely would constitute a regulatory taking, a violation of the Contract Clause, and a deprivation of vested rights under the California and U.S. Constitutions. As such, the companies affected by such policies would be entitled to just compensation from the state. At a minimum, should CARB continue down this path, CARB must quantify and evaluate the cost burden this would place on the State.

First, both the federal Constitution and the California Constitution provide that property owners are entitled to "just compensation" when the government takes their property for public use. Cal. Const. art. I, § 19; U.S. Const. 5th Amend. Article 1, § 19(a) of the California Constitution states, "Private property may be taken or damaged for a public use and only when just compensation, ascertained by a jury unless waived, has first been paid to, or into court for, the owner." These constitutional provisions are "designed to bar [g]overnment from forcing some people alone to bear public burdens which, in all fairness and justice, should be borne by the public as a whole." Penn Central Transp. Co. v. New York City, 438 U.S. 104, 123 (1978) (citation and quotation marks omitted).

A per se taking occurs where a government regulation completely deprives an owner of all economically beneficial or productive use of the property. *Jefferson St. Ventures, LLC v. City of Indio*, 236 Cal. App. 4th 1175, 1193 (2015). Shutting down domestic oil facilities and petroleum refineries would constitute a per se taking under this standard. Such properties may have no other economical or productive use, resulting in stranded assets. Additionally, even if some sites can be redeveloped for some other economically productive use, the oil in the ground owned by WSPA members constitutes real property that the state would permanently prevent them from accessing. Forcing this oil to remain in the ground would deprive WSPA members of "all economically beneficial or productive use" of the oil, thereby constituting a per se taking. *See Lucas v. South Carolina Coastal Council*, 505 U.S. 1003, 1015 (1992).

Second, policies that would effectively shut down oil facilities violate the Contract Clause under the California and Federal Constitution, to the extent that such policies impair the obligations of companies under existing contracts. *See* Cal. Const. art. I, § 9 ("A law . . . impairing the obligation of contracts may not be passed."); U.S. Const. art. I, § 10, cl. 1; *Birkhofer v. Krumm*, 81 P.2d 609, 621 (Cal App. 1938) ("[I]t follows that such provisions of state constitutions as merely parallel and iterate provisions of the Federal Constitution must be so construed as to harmonize with the construction placed by the federal courts upon the latter.") If the state imposes production quotas or policies equivalent to this, fuel producers may not be able to meet existing contracts with fuel purchasers. In addition, such regulations would undoubtedly impair production leases, royalty agreements and transportation contracts between California residents and oil companies. Notably, the "severity of the impairment" increases the level of scrutiny which regulations are subject to, and "[t]otal destruction of contractual expectations is not necessary for a finding of substantial impairment." *Energy Reserves Grp., Inc. v. Kansas Power & Light Co.*, 459 U.S. 400, 411 (1983).

While courts have upheld state regulations that impair contracts but have a "significant and legitimate public purpose," id. at 411, the contracting parties in such cases are still entitled to just compensation from the state for any resulting impairment. *See Lynch v. United States*, 292 U.S. 571, 579 (1934) ("The Fifth Amendment commands that property be not taken without making just compensation. Valid contracts are property, whether the obligor be a private individual, a municipality, a state, or the United States."). As such, even if the aforementioned policies do not violate the Contract Clause, the state would still owe WSPA members, local business owners, and California families that lease their land to WSPA members just compensation for any existing contracts that such policies impair.

Finally, California courts have held that businesses have "the right to continue operating an established business in which he has made a substantial investment."[62] Vested rights are rights that are "already possessed" or "legitimately acquired."[63] California courts have recognized both vested rights in economic interests (ability to continue operation of a business) and as it relates to land use development (ability to develop land in accordance with a valid government authorization).[64] In addition, where the real property is legitimately acquired, the business activity is "undertaken in accordance with applicable statutory mandates," and the right has a "potentially massive economic aspect," then, "[c]ertainly, a fundamental vested right is at issue."[65] When these types of rights are at stake, they are considered too important to be relegated to "exclusive administrative extinction."[66]

While California courts have been careful to require more than economic burden by way of increasing the cost of doing business, the express goal of the Draft Scoping Plan is to phase out the petroleum industry through the rapid electrification of the transportation industry. While some facilities that serve the residual liquid-fueled fleet or export fuel outside of California may remain while likely operating at fraction of their prior production capacity, for other facilities, including small business owners of gas stations, the rule forecloses all business opportunities. These businesses have lawfully operated within in the state of California for decades and have invested heavily in their operations within the state. The shutting down of these businesses goes well beyond an additional costs of doing business and falls squarely within the scope of interests Courts have looked to protect—where a company will be driven out of business or

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62 *Id.* at 1529.

63 *Harlow v. Carleson,* 16 Cal. 3d 731, 735 (1976).

64 *Goat Hill Tavern v. City of Costa Mesa*, 6 Cal. App. 4th 1519, 1526 (1992).

65 *The Termo Co. v. Luther*, 169 Cal. App. 4th 394, 407–08 (2008) (Finding a fundamental vested right where the Director of Conservation ordered the plugging of 28 oil wells that had been lawfully in operation for over 20 years).

66 *Id.* at 406 (citing *Goat Hill Tavern*, 6 Cal. App. 4th at 1526).

"forced to operate at a loss and close."[67] Like the cases described above, the interests at stake here are not purely economic privilege, but rather the extinction of an entire industry.

67 *Mobil Oil Corp. v. Superior Court*, 59 Cal. App. 3d 293, 305 (1976) (Determining a fundamental vested right was not impacted because "[w]e are not presented with the enforcement of a rule which effectively drives the Oil Companies out of business. At most it puts an economic burden on them increasing the cost of doing business"); *Standard Oil Co. v. Feldstein*, 105 Cal. App. 3d 590, 604 (1980) (Concluding that the action did not impact a fundamental vested right because "[t]here is no contention that Standard will be driven to financial ruin by the action of the District; there is not even a contention that this particular facility will be forced to operate at a loss and close."); *San Marcos Mobilehome Park Owners' Ass'n v. City of San Marcos*, 192 Cal. App. 3d 1492, 1502 (Holding that "there is no contention, nor does the evidence suggest, that if the Commission denied the requested rent increases, the park owners would be in such an unfavorable economic position they would go out of business.").

ATTACHMENT C
List of Previous WSPA Comments on the Draft 2022 Climate Change Scoping Plan

April 4, 2022 Comments[68]

1. CARB's modeling analysis unreasonably constrains the scope of decarbonization strategies in the transportation sector, to the detriment of the environment and consumers.
2. The scenarios in the E3 modeling presentation clearly show that an all-electrification option by itself will not reach the State's GHG reduction targets. WSPA maintains its position that CARB should conduct a multi-technology analysis to evaluate how a technology/fuel-neutral market-based approach, could achieve the emission reduction targets and do so faster and with more cost-effectiveness. Such a strategy could also reduce the significant systemic risks inherent to the all-electrification option.
3. AB 32 requires CARB to "ensure that activities undertaken pursuant to the regulations complement, and do not interfere with, efforts to achieve and maintain federal and state ambient air quality standards and to reduce toxic air contaminant emissions." The scenarios presented not only interfere with efforts to achieve the federal ozone standard, but actively impede near-term progress toward attainment.
4. CARB's scenarios all depend on unprecedented levels of growth within the solar energy and battery storage sectors. Inclusion of natural gas and RNG power plants with carbon capture, utilization, and storage (CCUS) to meet the State's electrical demand and reliability requirements and can help alleviate the infrastructure redundancy that would be necessary with an all-renewable electric grid.
5. CARB's scenarios and Scoping Plan should consider all options of hydrogen generation.
6. Trillions of dollars would be required for the electric infrastructure upgrades needed to sustain the all-sector transition to electrification contemplated in CARB's scenarios. Adopting technology-neutral, market-based approaches for GHG emissions reductions could be more cost-effective.
7. CARB's transportation energy demand projections for the E3 scenarios appear to assume VMT reductions ranging from 10% by 2030 for Alternative 4 to 30% by 2035 in Alternative 1 as compared to the 2020 VMT baseline. This is despite the State's previous failure to achieve VMT reductions under Senate Bill (SB) 375. The increased use of low carbon-intensity fuels could provide GHG reductions with much greater certainty than VMT reduction assumptions.
8. CARB is obligated under AB 32 to minimize the "leakage" potential of any of their regulatory activities. The presented scenarios appear to set an emissions inventory boundary that fails to account for California GHG emissions that would be caused outside the California border. Such emissions leakage would likely be a direct result of certain CARB policy concepts presented in these scenarios. CARB must estimate the emissions increases outside of California which result from leakage and policy-driven demand.

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68 April 4, 2022 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/41-sp22-modelresults-ws-AWBUMF0DUjIGMgVa.pdf Accessed: June 2022.

9. WSPA agrees that carbon removal technologies including CCS critical tool for industries to choose to invest in and will be pivotal to the overall success of the Scoping Plan to achieve carbon neutrality by 2045. Each of the scenarios considered by E3 would require CCS technologies and/or CDR to reach carbon neutrality. CARB may be compromising the viability for these technologies by undercutting the very market tools on which they would depend, specifically the LCFS.

November 19, 2021 Electricity Sector Comments[69]

1. WSPA concurs with the position of both the CPUC and CEC with regard to the importance of natural gas in our energy future. As noted by more than one stakeholder during the Workshop, strategically-located natural gas power plants and the continuous improvements in facility efficiency and clean fuels are an important consideration in any strategic planning in the electricity sector for California.
2. WSPA is a strong supporter of CCS as a critical tool towards achieving deep carbon reductions in California and globally.

November 19, 2021 Technical Workshop Comments[70]

1. WSPA urges CARB to model an alternative that relies more heavily on market-based approaches, such as cap and trade, to achieve emission reductions. Specifically, WSPA requests the inclusion of an “Alternative 5” that prioritizes “least cost” emissions reductions across the economy, inclusive of certain policy constraints. “Alternative 5” would evaluate the potential roles (and additional benefits) that market mechanisms and a price on carbon could contribute (in place of bans and mandates) to pursuing carbon neutrality.
2. WSPA believes that biofuels should hold a more prominent role in the Scoping Plan (particularly beyond 2035), as a carbon emissions-reducing tool. We encourage CARB to include in the PATHWAYS modeling assumptions greater use of biofuels in multiple applications (e.g., light-duty vehicles, medium and heavy-duty vehicles, off-road engines, railroad, aviation, etc.), and that the volumetric use increase with time as supply grows and the LCFS CI targets become more stringent (as noted in previous WSPA comment letters).
3. WSPA strongly supports further education on the application of CCS and other carbon removal technologies such as DAC and their important role in the Scoping Plan and recommends that CARB consider in the PATHWAYS modeling different rates of implementation CCS over the time periods identified in CARB’s Alternatives 1-4.

69 November 19, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/24-sp22-electricity-ws-BVpQIVEjBCdQNwNc.pdf. Accessed: June 2022.

70 November 19, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/96-sp22-inputs-ws-VwhUJVwuV3RXMFMM.pdf. Accessed: June 2022.

October 11, 2021 Comments[71]

1. An alternative prioritizing the lowest cost of implementation should be included as part of CARB's modeling. WSPA believes that CARB should allow market and price signals to drive reductions in the oil and gas sectors to meet the carbon neutrality goals of the state, while minimizing impacts to the economy and consumers.
2. Market-based approaches will be critical to pursuing carbon neutrality in the most cost-effective manner. WSPA encourages CARB and the state's policymakers to focus on programs that will complement and allow for integration with the global economy, rather than a framework based on bans and mandates that could contribute to a patchwork of impractical policies across the world.
3. The impact of market mechanisms currently in place is still unclear. CARB should develop a new Alternative 5 to evaluate the potential roles (and additional benefits) that market mechanisms and a price on carbon could contribute (in place of bans and mandates) to pursuing carbon neutrality.
4. WSPA generally finds CARB's proposed Alternatives 3 and 4 to be more realistic and balanced approaches than Alternatives 1 and 2.
5. CARB should evaluate a wider range of alternatives, including a flat (0%) VMT per capita improvement over time as well as a middle value of 10% improvement.
6. CARB should assume continuing fuel economy improvements for internal combustion LDVs to 2035 and then beyond to 2045 in Alternative 4. WSPA believes that there is potential for efficiency gains above 2% depending on the level of hybridization there is in the fleet.
7. WSPA recommends that CARB include at least one alternative that does not evaluate a ban on the internal combustion engine, and instead models a more gradual increase in ZEV sales extending to 2045.
8. WSPA recommends review and use of the assumptions in the December 2020 Princeton University "Net Zero in America" study for MDV/HDV ZEV vehicle sales, stock inventory, and truck transportation within port operations in the "E-" case.
9. WSPA recommends that Alternatives 3 and 4, at a minimum, should assume some use of renewable SAF, consistent with expected SAF supply and per CARB's biofuels supply modeling assumptions.
10. Alternative 4 should model a majority of rail service using liquid fuels in 2045 to better bracket the assumptions of full or near-full adoption of electrification technologies in the other Alternatives. CARB should also consider how rail transportation originating outside the state or country is likely to be powered. Alternative 4 should assume consumption of

[71] October 11, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/93-sp22-inputs-ws-AnUBdF0sWGoEXQFi.pdf. Accessed: June 2022.

biofuels consistent with expected annual production capacity of those fuels (for which CARB has assumed zero GHG emissions).

11. WSPA believes that CARB should include: 1) improved energy efficiency and electrification in the upstream O&G sector including the pre-combustion capture of carbon to increase combustion efficiency; 2) expanded application of and use of renewables (renewable power or renewable fuels or hydrogen) in the upstream O&G sector to power operations; and 3) the use of CCUS on upstream combustion sources similar to the manner in which CARB is applying CCUS for the refining industry in the Alternatives. This is especially critical to Alternative 4.

12. WSPA requests that CARB adjust its approach in Alternative 4 as to the relationship between oil production and fuel demand in the state. WSPA specifically requests that CARB use an in-state oil production decline rate in step with the long term (20+ years) oil production in California from data collected by government agencies such as the US Energy Information Administration (EIA) or the CEC.

13. WSPA believes CARB is underestimating the potential for emission reductions at refineries by only modeling the application of CCS for refinery emission reductions. Just like the O&G production sector, there is potential for continued emission reductions at refineries through improvements in energy efficiency and the use of renewables (renewable electricity and renewable fuel gas).

14. We urge CARB to: 1) model the amount of biofuels that can be cost-effectively put into the fuel supply system; 2) incorporate biofuels into the baselines of Alternatives 2, 3, and 4; and 3) model varying levels in each alternative, with a maximum in Alternative 4.

15. WSPA believes that it is suboptimal for CARB to dictate an order of emission reductions. A better approach would be to evaluate all potential options simultaneously to determine which can provide emissions reductions most efficiently, and with the least economic dislocation.

16. Alternative 4 should model the findings from the Lawrence Livermore National Laboratories report at 100 MMt/year at $200/tonne. Alternative 4 should further include an assumption for carbon removal from the atmosphere via DAC. Finally, if appropriate for the modeling, Alternative 4 should include reasonable assumptions for carbon removal from Natural and Working Lands.

17. WSPA recommends that CARB take a different approach to modeling in the commercial and residential buildings sector and suggests the modeling of a non-zero but increasing efficiency standard for sales in this sector in at least one of the modeled alternatives

September 22, 2021 Comments[72]

1. WSPA's members would like to request access to the emission reduction data by sub-sector to better inform our members' understanding of the calculations.
2. WSPA would like to ask CARB to clarify the approach to their scenario modeling conducted to evaluate how fugitive methane from oil and gas sources will change based on: 1) the Governor's directive to phase out in-state oil and gas production by 2045 or sooner; 2) Changes in natural gas demand; and 3) RNG utilization in existing fossil gas infrastructure.

September 7, 2021 Comments[73]

1. WPSA recommends that CARB expand the range of options and alternatives being considered for modeling decarbonization in multiple different sectors.
2. CARB should consult with more academic centers of excellence, national labs, and others to identify a stronger modeling construct. In particular, the model should be capable of evaluating the effects of a price on carbon to allow markets to determine the solutions rather than employing arbitrarily mandated targets and handpicked solutions.
3. CARB should include a peer review in the modeling process and broaden the range of assumed economic and technology assumptions
4. CARB should evaluate the potential role (and additional benefit) that market mechanisms and a price on carbon could contribute (in place of bans and mandates) to pursuing carbon neutrality.
5. CARB should make some additions to the concepts illustrated in slide 10 (Transition from Fossil Fuels to Alternatives). In addition to items already listed, CARB should add elements to the arrow diagram and "Alternatives" list such as low carbon petroleum fuels, low carbon petroleum fuels with CCS, and low carbon gasoline for the light-duty sector.
6. The Scoping Plan should include a detailed summary of the assumptions and forecasts related to achieving the 2030 goal. CARB should continue to support the science of a cumulative emissions approach to planning. We welcome CARB evaluating, as directed by Governor Newsom in 2021, an accelerated goal of achieving carbon net-neutrality by 2035, so long as that evaluation transparently identifies the technological and economic hurdles to full implementation and fairly recognizes that it will be exponentially more difficult to achieve that goal. CARB should also model options on the other end of the spectrum.
7. More specificity is needed regarding levels of engineered carbon removal to be evaluated. CARB should not only model deployment of engineered carbon removal as part of its

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[72] September 22, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/28-sp22-slcp-ws-ViECd1cmU2ECWwJx.pdf. Accessed: June 2022.

[73] September 7, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/80-sp22-concepts-ws-AmNWJVA2VFgEM1Bn.pdf. Accessed: June 2022.

scenarios, but it should also evaluate the trade-offs of not deploying significant negative emissions technologies as part of its modeling exercise. We believe evaluation of these trade-offs should include a look at cost-effectiveness as well as an evaluation of the impact to employment and labor income.

8. CARB should ensure that modeling scenarios include potential increasing electricity generation and increasing electricity consumption. WSPA strongly supports the inclusion of Scenarios C and D which use the widest possible range of technologies to meet the SB-100 goals. Of note, WSPA strongly believes that natural gas power plants equipped with CCS can play a large role in meeting our SB-100 goals while ensuring grid reliability. This should be included in the modeling.

9. CARB should evaluate a wider range of scenarios including a flat (0%) VMT per capita change over time as well as a middle value of 10%. If the assumptions for VMT are too optimistic and not achieved in practice, the state will fall short of achieving its goals.

10. CARB should include one or more scenario that account for and evaluates different EV adoption rates, including slower adoption than those shown in workshop slides. CARB should also model at least one scenario where renewable and low-carbon fuels are used in combination with higher efficiency vehicles to compete with ZEVs on a lifecycle emissions AND cost basis. CARB should assess the full range of emissions, impacts, and costs generated outside of California for electric vehicles (e.g., from mining, battery production, recycling, etc.) and incorporate those into the model for the transportation system. CARB should develop a ZEV supply chain analysis and incorporate those findings into the Scoping Plan modeling.

11. CARB should include multiple scenarios that allow market forces and a price on carbon to drive the emission reductions from this sector as there are many opportunities to reduce emissions (efficiency, fuel switching, CCS, use of renewable power and feedstocks, etc.) that are not directly related to a decrease in production. We believe that cost and feasibility should be the driving factors that determine what the reductions in this sector are over time.

12. WSPA supports CARB's modeling scenarios and appreciates that many allow all SLCP methane/woody/solid biomass waste to include fuels derived from those sources.

13. CARB should model scenarios where renewable and low-carbon fuels and energy efficiency improvements exist alongside electrification options.

14. CARB should revise Option A as any scenario which forces facilities or sectors to shut down is very likely to lead to leakage from that sector which is exactly the type of impact AB32 was written to avoid. Additionally, WSPA is concerned that the option to use CCS for the industrial sector is not specifically listed in the other options. WSPA strongly believes that CCS offers a significant opportunity for the state to decarbonize the industrial sector and believes it should be specifically called out in the options.

<u>August 16, 2021 Comments</u>[74]

1. Deployment of engineered carbon removal is essential to meeting carbon neutrality. CCUS can help the state significantly reduce carbon emissions from sectors such as crude production, refining, biofuels, cement manufacturing, power generation, agriculture, dairy, and others.
2. Deployment of CCUS technologies will lead to reduction in air quality impacts.
3. WSPA member companies are in the process of designing and permitting facilities that could benefit California through engineered carbon removal.

<u>July 9, 2021 Comments</u>[75]

1. CARB should approach the Scoping Plan with an open mind by looking at and leaving on the table all available options to achieve carbon neutrality. Doing so will increase the likelihood of meeting the state's goal.
2. We encourage CARB to clearly communicate the potential pros and cons (or risks) of electrification in the Scoping Plan.
3. CARB should remain cognizant of its obligations and boundaries under the relevant authorizing statutes as CARB develops the Scoping Plan.
4. Approaches that recognize the important impact of low carbon liquid fuels available today could allow the state to help meet its goals, particularly in the short-term, and foster technologies that could become a linchpin of California's low carbon future.
5. Ultimately the California energy system must work to foster an optimum outcome for the state. CARB, can help facilitate this via thoughtful approaches in the 2022 Scoping Plan. An approach that relies too heavily on a single approach, such as electrification, will lead to unreliability and unintended consequences.
6. It is important that this reality is acknowledged early in the 2022 Scoping Plan development process to allow for a robust discussion and evaluation. In defining carbon neutrality, we also encourage CARB to clearly define early in the Scoping Plan process the broadest range of sources and sinks and geographic boundaries possible.

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74 August 16, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/41-sp22-co2-removal-ws-VyAFcFcmWGpVDFQy.pdf. Accessed: June 2022.

75 July 9, 2021 WSPA Comments on CARB 2022 Scoping Plan Update. Available at: https://www.arb.ca.gov/lists/com-attach/77-sp22-kickoff-ws-ViFSJwd2AzEGXwlq.pdf. Accessed: June 2022.

7. Given that GHGs are measured on a global basis, California should embrace the most cost-effective emission reductions or removals wherever they can be achieved. CARB should continue to lean into the cap-and-trade program and allow it to play a bigger role in the 2022 Scoping Plan.
8. CARB staff should evaluate and publicly vet multiple scenario analyses; then they should present a range of low-risk, cost-effective approaches for public comment before presenting to the CARB Board. All this should be done without prejudgment.
9. Liquid fuels will still be needed beyond 2045 and can provide early benefits. Some of our WSPA member companies are pursuing major projects in California to produce non-traditional lower-carbon liquid fuels such as renewable diesel and gasoline, RNG, lower carbon gasoline, and sustainable jet fuel. These must be a part of any Scoping Plan and should be included in the modeling of potential pathways.
10. The support of the technologies that would occur by valuing lower-carbon fuels could help ensure that there are fuel options ready for longer-distance modes of transportation that are even more difficult to decarbonize. These include fuels for the aviation industry as well as global shipping.
11. Forcing in-state crude oil production decline through policy and tax approaches only serves to prop up jurisdictions who do not share California's values. Preserving the capabilities of this industry allows for production of lower carbon crudes that will be needed for California to meet its climate goals.
12. WSPA encourages CARB to consider the synergy between farming practices and biofuels. Recognition of sustainable farming practices in a biofuel lifecycle will connect the farmer to a market-based incentive program and drive this behavior while at the same time providing substantial near-term emission reductions.
13. The Scoping Plan process will fall short if it does not utilize a fully transparent approach that provides multiple opportunities for public meetings to discuss data and assumptions for CARB's modeling work. The modeling work should exhaustively consider a range of scenarios by which the state can reach carbon neutrality.
14. WSPA implores CARB to hold multiple workshops regarding the model work performed to support the 2022 Scoping Plan. We also suggest that California consider modeling scenarios where critical technologies do not advance at the pace predicted by CARB as well as where critical technologies advance much faster than CARB predicts.
15. Modeling work should consider the costs and risks of the full supply chain. We encourage CARB to not ignore these environmental costs, outsourcing the environmental impacts that result. CARB should seek to understand these impacts and model those emissions.
16. Negative emissions opportunities should be supported for optimal outcomes. As GHGs are a global challenge, progressing technology that supports negative emissions should be appropriately valued.

17. CARB should remain cognizant of its obligations and boundaries under relevant authorizing statutes.

18. WSPA emphasizes that CARB must consider technological feasibility, cost-effectiveness, total potential costs, and environmental impacts of proposals and cautions CARB against relying on policies it lacks the current statutory authority to implement.

19. Consistent with its obligations under AB 32 and CEQA, as CARB evaluates proposals, it should consider the following: 1) the environmental impacts of ZEV manufacturing; 2) a full-life cycle analysis of mass scale BEV battery production, including end-of-life battery recycling and disposal; 3) the environmental impacts of an increased statewide fleet inventory; 4) the environmental impacts and health and safety issues associated with the transport of hazardous materials in ZEVs; 5) the changes in non-exhaust particulate matter (PM) emissions from increased ZEV operation; 6) the near-term air quality benefits of low- and ultra-low NOx technologies; 7) an assessment of the impacts resulting from updates and improvements to existing infrastructure; 8) the effects of increased ZEV use on the reliability of the electricity grid; and 9) the impact of energy price increases as a result of fuel production restrictions.

20. Consistent with AB 32 and CEQA, CARB must carefully consider all of the social and environmental impacts, both positive and negative, associated with such proposals. CARB must fully evaluate the detrimental social and environmental impacts of proposals to shut down domestic oil production.

21. When considering the total potential impacts of transportation sector policies for inclusion in the Scoping Plan, CARB should evaluate the constitutional implications of shutting down California oil production via production quotas, burdensome excise taxes, or restrictive setbacks.

22. CARB lacks statutory authority to unilaterally impose policies that shut down oil facilities. Until the legislature passes a bill that imposes production quotas, additional excise taxes, or setbacks on fuel companies, CARB cannot do so unilaterally. Because the California legislature has already rejected such bills, WSPA cautions CARB about relying on policies that may never ultimately pass to meet Scoping Plan goals.

ATTACHMENT D
Economic Impacts of Achieving California's 2022 Draft Scoping Plan's "Proposed Scenario" by NERA Economic Consulting dated June 2022

NERA
ECONOMIC CONSULTING

Economic Impact Analysis of California's 2022 Draft Scoping Plan's "Proposed Scenario"
Volume I: *Scenario Modeling and Key Study Results*

Prepared for:

Western States Petroleum Association

June 2022

Project Team

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About NERA

NERA Economic Consulting (www.nera.com) is a global firm of experts dedicated to applying economic, finance, and quantitative principles to complex business and legal challenges. For over half a century, NERA's economists have been creating strategies, studies, reports, expert testimony, and policy recommendations for government authorities and the world's leading law firms and corporations. We bring academic rigor, objectivity, and real-world industry experience to bear on issues arising from competition, regulation, public policy, strategy, finance, and litigation.

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EXECUTIVE SUMMARY

SYNOPSIS

This report compares the relative economic impacts of two different approaches that attain a similar amount of cumulative economy-wide CO_2 emissions reductions in California from 2024 through 2045. They are: (1) a set of "regulatory" policies that promote carbon-reducing actions on a sector-specific basis without a unifying price signal., and (2) the application of an economy-wide CO_2 emissions limit or cap that has a trajectory similar to what is attained in the regulatory approach. The first scenario contains the key sector-specific mandates that are part of the California Air Resources Board's (CARB) 2022 Draft Scoping Plan's "Proposed Scenario" which we refer to as the "Regulatory scenario".[1] In the second scenario, carbon reductions are achieved through the imposition of an economy-wide emission cap, an approach typically proposed as an alternative to a regulatory approach, which we refer to as the "Market scenario."[2] Both scenarios also achieve net-zero emissions by 2045. The economic impacts of each scenario on the California economy have been projected using NERA's macroeconomic model of the U.S. economy, which contains substantial detail on economic sectors, regions, and available and projected future energy technologies. The impacts from each of these scenarios are compared to a business-as-usual (or "BAU") case which reflects a continuation of existing policies.

Because both scenarios attain a similar level of cumulative CO_2 emissions reductions from 2024 to 2045 and net-zero emissions by 2045, their economic impacts can be compared to each other to assess their relative cost-effectiveness. In brief, our analysis finds a very wide gap in cost-effectiveness between the Regulatory and the Market scenarios. The Market scenario is projected to be far less costly than the Regulatory scenario, whether assessed in terms of gross domestic product (GDP) or consumer-focused metrics such as consumption per household. The gap in economic costs is projected to widen over time as both policies achieve deeper emissions cuts. For example, by 2045:

- The reduction in annual GDP relative to the BAU is projected to be about $23 billion in the Market scenario compared to about $44 billion in the Regulatory scenario,[3] and
- The reduction in annual consumption per household relative to the BAU is projected to be about $820 in the Market scenario compared to about $1,890 in the Regulatory scenario.

The greater cost-effectiveness of a uniform emissions price signal over a patchwork of sector-specific regulatory measures is not a surprising result for policy analysts. This study, however, is able to illustrate why this result is reasonable to expect via multiple, specific examples of how the Regulatory scenario's

[1] The Regulatory scenario that is modeled in this study is based on key elements of the "Proposed Scenario."

[2] We also consider two sets of sensitivity scenarios (referred to as the "High Alternative Vehicle Cost" and "Low Alternative Vehicle Cost" scenarios) whose impacts are used to bound the range of results from the two core scenarios. These sensitivity scenarios differ from the core scenarios in the vehicle purchase cost trajectories assumed for battery-electric vehicles in the personal transportation sector and for battery-electric and fuel-cell electric vehicles in the commercial trucking sector. The inputs for these sensitivity scenarios are outlined in Appendix II of Volume II: Technical Appendices.

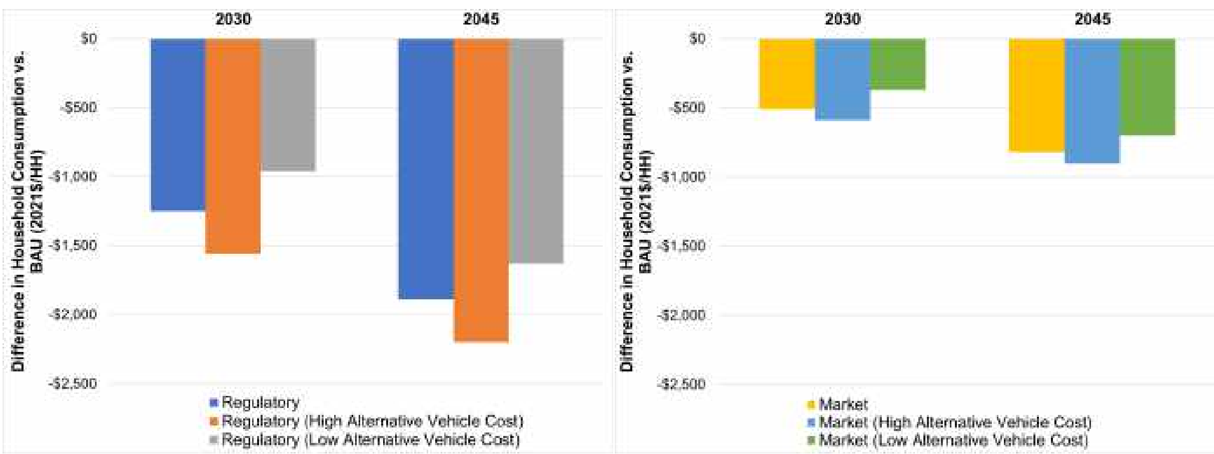
[3] All impacts are stated in 2021$, unless otherwise noted.

lack of ability to equalize marginal cost of reducing emissions across all sectors distorts incentives for selecting the most cost-effective reduction actions from an economy-wide perspective.

SUMMARY OF KEY RESULTS

The central question addressed in this analysis is how the projected economic impacts of a purely regulatory approach compare to those of a market-based approach that would achieve similar cumulative CO_2 emission reductions by 2045 across the California economy. Our analysis finds that the Regulatory scenario would likely have higher economic costs, whether assessed in terms of household consumption[4], or gross domestic product (GDP). As Figure1 illustrates the projected difference in annual household consumption (relative to the BAU) is projected to be larger in the Regulatory scenario than in the Market scenario. In 2030, the difference in per-household consumption (relative to the BAU) is projected to be about $1,250 in the Regulatory scenario compared to about $510 in the Market scenario. The gap is projected to widen over time as both policies achieve deeper emission cuts such that by 2045, per-household consumption is $1,890 lower than the BAU in the Regulatory scenario compared to $820 in the Market scenario. In 2045, the range of impacts for this metric for the Low Alternative Vehicle Cost cases are projected to range between $700 and $1,630 for the Market and Regulatory scenarios respectively and between $900 and $2,200 for the corresponding High Alternative Vehicle Cost cases.

Figure 1: Projected Differences in Annual Household Consumption Cost per Household in 2030 and 2045 (Relative to the BAU (2021$/Household)



As Figure 2 illustrates, the difference in GDP (relative to the BAU) is projected to be about $16 billion in the Regulatory scenario compared to about $10 billion in the Market scenario in 2030. By 2045, the difference in GDP (relative to the BAU) is projected to be about $44 billion in the Regulatory scenario compared to about $23 billion in the Market scenario. For the same time period, the GDP impacts range between 0.5% (about $20 billion) and 0.8% (about $35 billion) in the Low Alternative Vehicle Cost cases

[4] Consumption is the market value of all goods and services that households are projected to be able to purchase, after accounting for their income, government taxes, and savings decisions in each time period covered by the model. It is equal to economic welfare without inclusion of the utility-value of leisure. Annual consumption cost per household is the loss in consumption value divided by the number of households in each model year.

for the Market and Regulatory scenarios respectively. The corresponding impacts for the High Alternative Vehicle Cost cases range between 0.6% (about $26 billion) and 1.1% (about $49 billion).

Figure 2: Projected Differences in GDP in 2030 and 2045 (Relative to the BAU) (2021$, Billions)

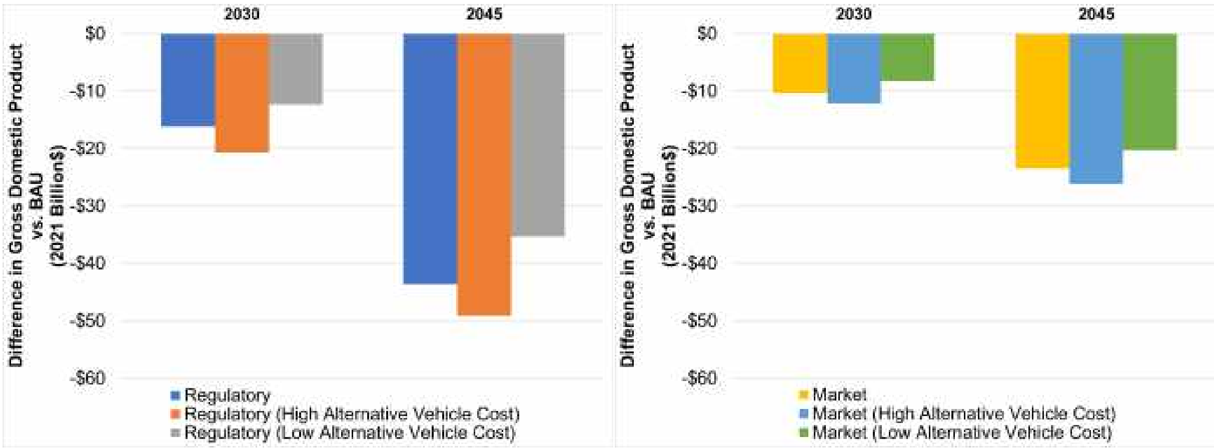


Figure 3 shows the projected economy-wide CO_2 emissions in California under each scenario. Although the total reductions under the Regulatory and Market scenarios differ somewhat from year to year (with the Regulatory scenario achieving greater reductions in emissions in the long run as the stringencies of the mandates increase over time; while in the Market scenario the carbon prices induce greater emissions reductions in the short run), both scenarios achieve about a 50% reduction in CO_2 emissions relative to the BAU by 2045. The CO_2 emission reductions (relative to the BAU) for the Low Alternative Vehicle Cost and High Alternative Vehicle Cost cases for the Market and Regulatory scenarios are also projected to be similar to each other in 2045. Figure 4 illustrates the projected CO_2 emissions in California by sector in 2030 and 2045 while Figure 5 shows the CO_2 emissions by sector on a cumulative basis from 2024 to 2045 for the different scenarios. A higher level of emission reductions (relative to the BAU) are projected in the residential, commercial, and industrial sectors in the Market scenario while for the electric and transportation sectors, the emission reductions are projected to be higher in the Regulatory scenario. Figure 4 also shows the amount of DAC deployed in California in 2045 in the various scenarios to offset the economy-wide CO_2 emissions.

Figure 3: Projected Economy-wide CO_2 Emissions in California

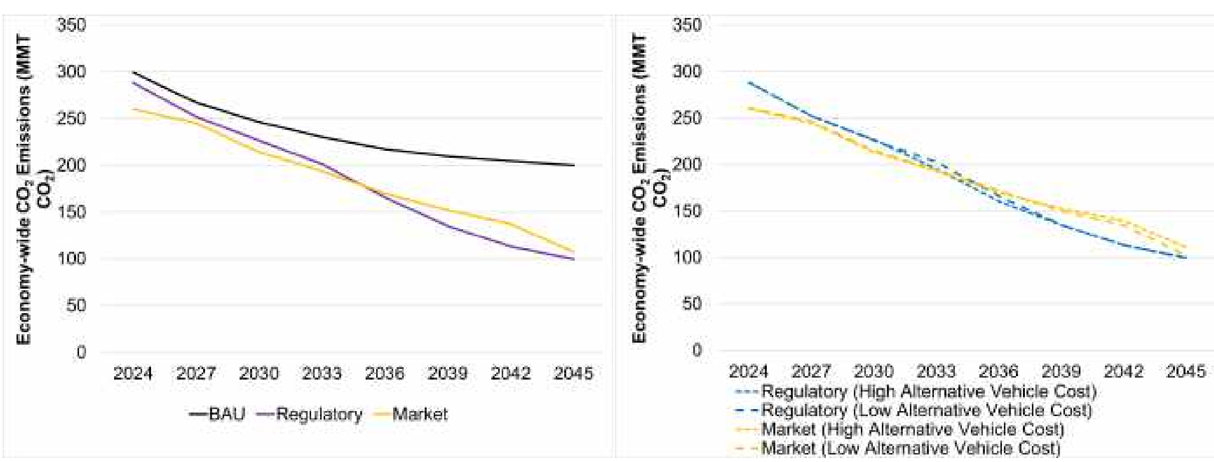


Figure 4: Projected CO_2 Emissions in California by Sector

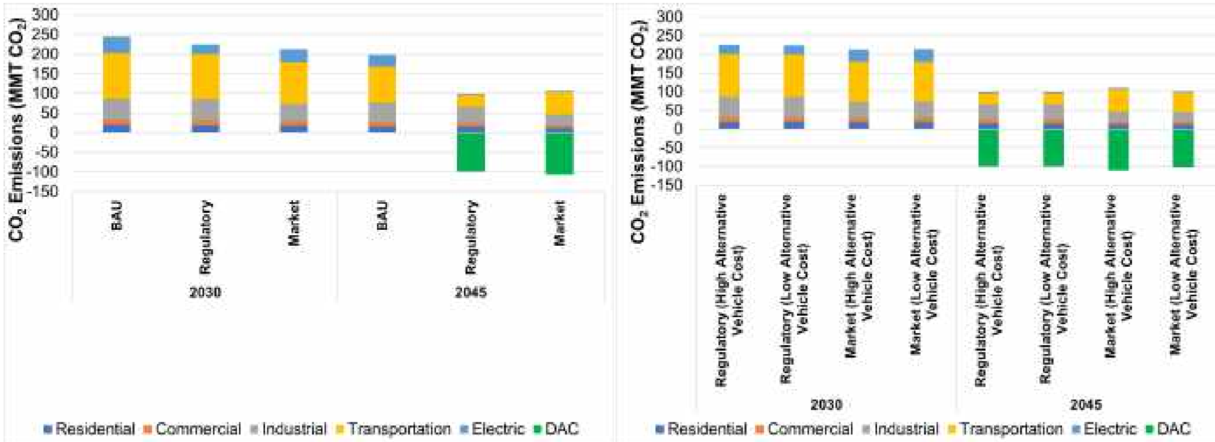
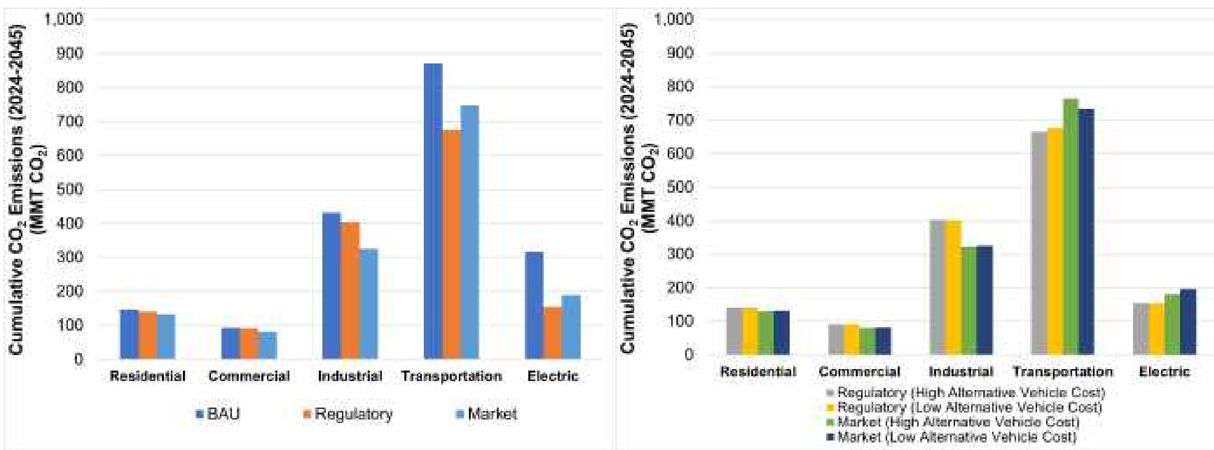


Figure 5: Cumulative CO_2 Emissions in California by Sector (2024-2045)



CONCLUSION

Our study has modeled the economic and energy market impacts of two different policy approaches - the first approach which we refer to as the "Regulatory" scenario containing certain key sector-specific mandates that are part of CARB's 2022 Draft Scoping Plan's Proposed Scenario and a second approach in which a similar level cumulative emission reductions are achieved by 2045 modeled using a cap-and-trade approach which we refer to as the "Market" scenario. Under both policy scenarios, a net-zero emission target is achieved in 2045 by deploying DAC as a carbon dioxide removal technology.

For this study, we also modeled two sets of sensitivities around the Regulatory and Market scenarios to bound the range of impacts from these approaches. These sensitivity scenarios (which we refer to as Low Alternative Vehicle Cost and High Alternative Vehicle Cost scenarios) take into account uncertainties that are associated with the technology costs in the transportation sector. Specifically, for these scenarios we employ a range of costs assumptions that relate to the vehicle purchase costs of battery electric vehicles in the personal transportation sector and battery-electric and fuel-cell electric vehicles in the commercial trucking sector.

We use a CGE model of the U.S. economy called NewERA with regional disaggregation (where California is represented as a separate region) and sectoral disaggregation (containing 12 economic sectors) to estimate the economic impacts of these scenarios. The costs of each of these scenarios are reported relative to a business-as-usual (or a "BAU") case which reflects a continuation of existing policies.

The results indicate a trade-off between reducing carbon emissions and the costs that households would incur under these policy approaches in California. In both scenarios, California's carbon emissions are reduced to about 100 MMT CO_2 by 2045 (a reduction of about 75% relative to 2005 levels) with a similar level of cumulative emissions reduction from 2024 to 2045. Both scenarios also achieve net-zero emissions by 2045 by deploying DAC. In 2045, the reduction in annual consumption per household relative to the BAU is projected to be about $820 in the Market scenario compared to about $1,890 in the Regulatory scenario. The underlying driver behind the difference in costs between the two scenarios is that businesses and consumers would face higher energy and transportation costs under the Regulatory scenario, from prescriptive regulations, which would in turn would lead to increased costs of other goods and services throughout the California economy. As a consequence, household disposable income and household consumption would fall. In addition, capital would be diverted to sectors that are affected by the regulations and away from rest of the economy. Wages and returns on investment would also fall, resulting in lower growth in productivity. Thus, the results imply that that the Market approach is more cost effective in reducing emissions than the Regulatory approach for similar levels of cumulative emissions reductions.

At the sectoral level, the Regulatory scenario is projected to result in a larger reduction in emissions from the transportation sector than the Market scenario while a larger reduction in emissions is projected from the industrial sector – the implication of this being that it is more cost-effective to achieve emission reductions in the industrial sector than from the transportation sector in California. The results also imply that there are trade-offs in how carbon reduction policy is designed i.e., emissions reductions have a net cost and that sector specific mandates that target deeper emissions cuts are costlier than a market-based approach.

I. INTRODUCTION

This study evaluates the economic impacts of representative regulations and mandates that are based on the Proposed Scenario from CARB's 2022 Draft Scoping Plan's (collectively referred to as the "Regulatory" scenario) on the California economy and energy sectors.[5] The study also evaluates the economic impacts of a cap-and-trade scenario (referred to as the "Market" scenario) that achieves the same level of cumulative emissions and net-zero emissions by 2045.

A. Background

Under a regulatory approach, mandates are imposed on sectors, and in particular energy intensive sectors, to reduce greenhouse gas emissions directly or indirectly by encouraging fuel substitution from high to low carbon content fuels or by substituting technologies that are less carbon intensive. Greenhouse gas emissions largely arise due to the combustion of fossil fuels in transportation, heating, various industrial and commercial processes, and electricity production. Sector specific technology specific mandates implicitly subsidize clean technology while taxing carbon intensive technology, which leads to emission reductions. These sector specific mandates limit sectoral output thereby increasing the cost of production. Mandates that target fuels directly would increase the cost of fossil fuels, leading to increases in costs to consumers and businesses as well as other economic impacts. The marginal cost of reducing emissions would vary across sectors and will depend upon the stringency of the mandate on the sectors. The cap-and-trade scenario, on the other hand, will still impose costs on emissions but will ensure that the marginal costs of reducing emissions are equalized across all sectors and that emissions are reduced in the most cost-effective manner.

The increased costs from mandates or from an emissions cap under the cap-and-trade scenario would encourage companies to switch to lower-emitting fuels and would result in households and companies reducing their energy use. The net effect of these changes whether from a purely regulatory or market-based approach would be to reduce CO_2 emissions.

B. Objectives of This Study

The principal objective of this study is to provide estimates of the economic impacts of certain key mandates that are part of the Proposed Scenario from CARB's 2022 Draft Scoping Plan on the California economy. We compare the economic impacts from these mandates (which we refer to collectively in our modeling as the Regulatory scenario) and a corresponding market-based scenario (which we refer to as the Market scenario) on California GDP and other measures of economic activity, on CO_2 emissions across sectors, and the adoption of technologies in the transportation sector compared to a business-as-usual case that does include policies or mandates that reduce emissions. We use a state-of-the-art integrated energy and economic model, the NewERA model, to estimate these effects. The NewERA

[5] CARB released their Draft 2022 Scoping Plan Update in May 2022 whose objective is to assess progress towards achieving the SB 32 target (reducing GHG emissions by at least 40% below 1990 levels by 2030) and lay out a path to achieve carbon neutrality no later than 2045. The Scoping Plan's Proposed Scenario (also referred to as "Alternative 3") incorporates a goal for carbon neutrality by 2045 and includes deployment of a broad portfolio of existing and emerging fossil fuel alternatives and clean technologies. *See* Draft 2022 Scoping Plan Update, May 10, 2022, California Air Resources Board (available at https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf).

model allows us to estimate detailed effects on energy markets as well as impacts on different sectors and the California economy. We consider two core scenarios and sensitivities around these scenarios. These scenarios are described in greater detail in Section III.

A. **Regulatory Scenario**: This scenario incorporates regulations to increase fuel economy and increase electric vehicle penetration in the transportation sector, regulation to phase out oil and gas extraction, mandates to promote the uptake of clean technologies in the electric sector as well as energy efficiency targets in various sectors of the economy. The scenario also incorporates a constraint to achieve a net-zero emission target in California by 2045.

B. **Market Scenario**: This scenario incorporates an emissions limit or cap that is similar to the CO_2 emission trajectory in the Regulatory scenario and is modeled as a cap-and-trade scenario with banking and a net-zero emissions target in California by 2045.

C. Outline of the Report

The remainder of the report is organized as follows. Section II provides an overview of the N$_{ew}$ERA model that is used to analyze these scenarios. Section III describes the two core scenarios and sensitivities around these core scenarios that we modeled. Section IV discusses some key results of the analyses. The technical appendices provide details on the NewERA model and the modeling assumptions for the baseline and the scenarios.

II. OVERVIEW OF THE NEWERA MODEL

A. General Features of the NewERA Framework

NERA's NewERA model is an energy-economy modeling framework that integrates a bottom-up representation of the U.S. electricity sector with a top-down representation of the production, consumption, and investment decisions across the rest of the U.S, economy, including household decisions that affect overall energy use and related GHG emissions[6]. The modeling framework assesses the economic impacts from policies by accounting for important sectoral and regional interactions that take place in the economy in addition to the direct costs or other effects of the policy.

The top-down portion of NewERA is a forward-looking dynamic computable general equilibrium (CGE) model of the U.S. economy regions including California as a separate region. It simulates all key economic interactions in the regional economy including those among industries, households, and the government. Industries and households maximize profits and utility, respectively, with foresight about future economic conditions. The theoretical construct behind the model is based on the circular flow of goods, services, and payments in the economy—every economic transaction has a buyer and a seller whereby goods and services go from a seller to a buyer and payment goes from the buyer to the seller.

The CGE model is centered around the decisions of a representative household that characterizes the economic behavior of an average consumer. Households provide labor and capital to businesses, taxes to the government, and savings to the financial markets, while also consuming goods and services and receiving government subsidies. One of the services decided upon by households is how to meet personal transportation needs. In addition to deciding on the quantity of personal vehicle miles traveled (VMT), households in NewERA choose between two different types of vehicles - internal combustion engine vehicles (ICEs) and battery-operated Electric vehicles (BEVs). The household's vehicle choice depends upon relative vehicle life-cycle cost differences and consumers' preferences for different vehicles.[7]

The economic sectors in the model, in aggregate, account for all of the production and commercial activities of the economy. Each economic sector uses labor, capital, energy resources, other sector's outputs, and imported inputs to produce their own specific category of goods or services. Economic sectors pay their share of FICA and health insurance, and corporate taxes to the government. Industries are both consumers and producers of capital for investment in the rest of the economy.

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[6] The model accounts for carbon dioxide (CO_2) emissions from fossil fuel combustion and emissions from industrial processes (e.g., cement production, ammonia production) involving chemical or physical transformations other than fuel combustion. Non-CO_2 GHG including methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) are not modeled.

[7] Consumers choose to buy a certain vehicle over another considering the level of satisfaction they receive from the vehicle attributes and the vehicle life-cycle cost differences between the vehicle types. In our model, consumers are assumed to have the same preference over ICE vehicles and BEVs in the long-term, that is, the elasticity of substitution between the two types of vehicles is infinite. However, we restrict consumer's desire to completely shift from ICE vehicles to BEVs in the short-term if the cost advantage shifts toward BEVs by including an elasticity of substitution between BEV costs and a market constraint. The market constraint is included to capture the buildup of electric vehicle infrastructure and equipment markets. A higher elasticity value allows for higher degree of deployment of BEVs at any given level of cost advantage of BEVs over ICE.

One of the sectors in N_{ew}ERA is the electricity sector. This sector is modeled in a bottom-up (i.e., technology-specific) manner that is fully integrated with the rest of the economy (which is simulated in the CGE framework described above). The model includes all existing electric generating units, while future capacity investment and economic retirement decisions are represented simultaneously with dispatch decisions.[8] The model dispatches electricity to load duration curves. Long-term investment and retirement decisions and short-term unit dispatch decisions are projected by solving a dynamic, non-linear program with an objective function that minimizes the present value of total system costs, while complying with all system constraints, such as meeting demand, renewable portfolio standards, reserve margin requirements, emissions limits, transmission limits, clean energy standards, and other environmental and electric specific policy mandates.

Lastly, the CGE portion of N_{ew}ERA represents the government. In the model, the government collects revenues from taxes imposed on labor and capital. Revenues are used to pay for government services. The model also holds overall government debt the same in all scenarios by either returning excess revenues to the consumers, or by increasing taxes . The rebates or revenue-raising actions may be performed on a lump-sum basis (e.g., by changing the standard deduction) or by altering tax rates. Unless otherwise stated, the model uses the lump-sum transfer assumption.

Within the circular flow of the above macroeconomy, an equilibrium is found whereby demand for goods and services equals their supply, and investments are optimized for the long term. Thus, supply equals demand in all markets for all time periods.

The model produces integrated projections of the energy sector and other economic activities for future years and estimates the energy market and macroeconomic impacts of a potential policy by comparing projections of the future with and without the policy's requirements included in the model's input assumptions. More details on the structure of N_{ew}ERA are provided in Appendix I of Volume II: Technical Appendices.

B. Model Details Specific to This Study

The version of the macroeconomic model used in each analysis is produced by calibrating the N_{ew}ERA computations framework to reflect a specific set of baseline projections (trends) over the policy impact time period of concern. This analysis estimates economic impacts for the period from 2024 through 2045 with estimates for every third year in that time period.

The model also includes sectoral disaggregation tailored to match policy implementation and impact considerations. The version of the N_{ew}ERA model used in this analysis includes 12 economic sectors. Five of these are energy sectors, which include coal mining (COL), natural gas extraction and gathering (GAS), crude oil (CRU), petroleum refining (OIL), and the electricity sector (ELE). (The labels used to

[8] The electricity sector represents, with extensive disaggregation, over 17,000 existing units in the U.S. electricity generation system. It also disaggregates its projections of new capacity builds by type (which differ endogenously in each policy scenario). The new technology options included in this analysis are: onshore wind, offshore wind, photovoltaic solar, concentrated solar thermal, onshore wind-with-storage, photovoltaic solar-with-storage, nuclear, hydro, natural gas combined cycle (CC), natural gas CC with carbon capture and sequestration (CCS), natural gas combustion turbine (CT), coal with CCS, biomass, and biomass with CCS.

identify each sector in the model are indicated in parentheses.) The seven non-energy sectors[9] represented in this analysis are as follows:

- Motor vehicle manufacturing (M_V)
- Energy-intensive sectors (EIS)[10]
- Other manufacturing (MAN)[11]
- Agriculture (AGR)
- Commercial trucking (TRK)
- Commercial transportation other than trucking (TRN)
- Services (SRV)

This study has been conducted to produce national average energy and macroeconomic outcomes for two core policy scenarios that produce comparable CO_2 emissions reductions through 2045 while achieving net-zero emissions by 2045.[12] The first of these scenarios reflects key sector-specific mandates that are part of the California Air Resources Board's (CARB) 2022 Draft Scoping Plan's "Proposed Scenario"[13] (which we hereafter refer to as the "Regulatory scenario"). In the second scenario (which we hereafter refer to as the "Market scenario"), an emissions limit or cap equal to the CO_2 emissions trajectory in the Regulatory scenario is imposed which, in aggregate, achieve about the same cumulative emissions through 2045 and reductions *in* 2045 as is projected for the Regulatory scenario. We also consider two sets of sensitivity scenarios (referred to as High Alternative Vehicle Cost and Low Alternative Vehicle Cost scenarios) whose impacts are used to bound the range of results from the two core scenarios. These sensitivity scenarios differ from the core scenarios in the vehicle purchase cost trajectories assumed for BEVs in the personal transportation sector and for BEVs and fuel-cell electric vehicles (FCEVs) in the commercial trucking sector. We provide a more detailed description of the scenarios modeled in Section III below. The differences in the economic impact of these scenarios relative to the BAU are characterized by comparing the estimated changes for several model outputs that are commonly considered to be relevant measures of economic and energy market impact:

[9] The non-energy manufacturing sub-sectors are aggregated to 3-digit NAICS code and are consistent with U.S. Energy Information Administration's (EIA) Manufacturing Energy Consumption Survey (MECS) sectors.

[10] This comprises pulp and paper, chemicals, glass, cement, iron and steel, alumina and aluminum and mining.

[11] This comprises construction, food, beverage, and tobacco products, fabricated metal products, machinery, computer and electronic products, transportation equipment, electrical equipment, appliances, and components, wood and furniture, plastics, and other manufacturing sectors.

[12] Direct Air Capture (DAC) is employed as a carbon dioxide removal technology to achieve net-zero emissions by 2045.

[13] Draft 2022 Scoping Plan Update, May 10, 2022, California Air Resources Board (available at https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf).

- California gross domestic product,
- Household consumption,
- Economy-wide electricity generation mix, and
- Sectoral emissions by fossil fuel.

Because the two core scenarios are constructed to have comparable emissions reductions and are analyzed under identical assumptions about technological, behavioral, and other baseline conditions, the differences in the above metrics for the two scenarios relative to the BAU provide an indication of how different the cost of compliance and market impacts of carbon-reduction policies may be due to differences in policy design choices. We also report here a variety of other model outputs of interest that are associated with the above economic impacts for each policy scenario. These include the projected mix of electricity generation, the mix of personal vehicles on the road (internal combustion vs. electric), the projected mix of vehicle types in the commercial trucking sector, and CO_2 emissions over time. More detailed documentation of the N_{ew}ERA modeling framework is provided in Appendix I while a description of the baseline conditions for this analysis are provided in Appendix II of Volume II: Technical Appendices.

III. SCENARIO DESCRIPTION

The following are the specifications that relate to the baseline scenario, the core Market and Regulatory scenarios and the sensitivity cases around these scenarios that were modeled.

Baseline: The baseline (which we hereafter refer to as the "BAU") contains projected fuel prices, CO_2 emissions and economic output that is largely consistent with the Energy Information Administration's *Annual Energy Outlook 2021's* "Reference" case. The baseline includes compliance with all existing national and state rules and regulations on energy and environmental outcomes. A description of the baseline conditions for this analysis are provided in Appendix II of Volume II: Technical Appendices.

Regulatory Scenario: The Regulatory scenario incorporates the following sector-specific mandates that are part of CARB's 2022 Draft Scoping Plan's "Proposed Scenario".

- Personal Transportation Sector
  - Advanced Clean Cars I (ACC I) GHG standards for model year (MY) 2017-2025 and 2% annual fuel improvement for 2026-2035.
  - 100% of light-duty vehicle (LDV) sales are zero-emission vehicles (ZEVs) by 2035.
- Commercial Trucking Sector
  - 100% of medium-duty (MD)/heavy-duty (HD) vehicle sales are ZEVs by 2040.
- Electric Sector
  - RPS: 60% of electric retail sales comes from renewable resources by 2030.
  - SB 100: 100% of retail sales to end-use customers by 2045 to come from renewable and zero-carbon resources.
- Energy Efficiency
  - Energy efficiency targets for electricity and natural gas use in the residential, commercial, and industrial sectors.
- Oil and Gas Extraction
  - Phasing out of resource extraction operations by 2045.

A description of the assumptions that relate to each of these mandates are provided in Appendix II of Volume II: Technical Appendices.

Market Scenario: In this scenario, an emissions limit or cap was modeled which was set approximately equal to the emissions trajectory projected in the Regulatory scenario.

Sensitivity Scenarios: For the Low Alternative Vehicle Cost and High Alternative Vehicle Cost sensitivity scenarios, the following assumptions were employed.[14] The same set of assumptions were employed for the sensitivity scenarios around the Market and Regulatory cases.

[14] The default cost markups for BEVs relative to the cost of a typical ICE vehcile in the personal transportation sector were 1.28 in 2024 declining to 1.15 by 2045. In the commercial trucking sector, the default cost markups for BEVs were 1.78 in 2024 declining to 1.23 by 2045 while for FCEVs they were 1.48 in 2024 declining to 1.16 in 2045. These are the cost markups employed in the modeling of the BAU case.

- **Low Alternative Vehicle Cost:** A lower cost markup ratio for BEVs in the personal transportation sector relative to gasoline internal combustion vehicles (ICEVs)[15] and for BEVs and FCEVs in the commercial trucking sector relative to diesel ICEVs was employed.[16]
- **High Alternative Vehicle Cost:** A higher cost markup ratio for BEVs in the personal transportation sector relative to gasoline internal combustion vehicles (ICEVs)[17] and for BEVs and FCEVs in the commercial trucking sector relative to diesel ICEVs employed.[18]

A description of the assumptions that relate to each of these cost markup ratios are provided in Appendix II of Volume II: Technical Appendices.

[15] The cost markup declines from 1.32 in 2024 to 0.96 by 2045.

[16] For BEVs, the cost markup declines from 1.34 in 2024 to 1.05 by 2045. For FCEVs, the cost markups decline from 1.58 in 2024 to 1.02 by 2045.

[17] The cost markup declines from 1.89 in 2024 to 1.27 by 2045.

[18] For BEVs, the cost markup declines from 3.80 in 2024 to 1.76 by 2045. For FCEVs, the cost markups decline from 1.63 in 2024 to 1.20 by 2045.

IV. STUDY RESULTS

A. Projected Impacts on the California Economy and California Households

Consumption and gross domestic product (GDP) are two of the most commonly reported metrics of economic impact models. Consumption is the market value of all goods and services that households are projected to purchase, after accounting for their income, government taxes, and savings decisions in each time period covered by the model while the GDP in any year is defined as the sum of consumption, investment, government spending, and net exports in that specific year. Table 1 shows the projected difference in the impacts on GDP for the different scenarios relative to the BAU. By 2045, the GDP in the Regulatory scenario is about $44 billion lower than in the BAU while in the Market scenario, the GDP is about $23 billion lower than in the BAU. In 2045, the GDP impacts are projected to be $35 million and $20 million lower than in the BAU for the Low Alternative Vehicle Cost cases in the Regulatory and Market scenarios respectively while for the High Alternative Vehicle Cost cases, they are projected to be $49 million and $26 million lower in the BAU for the Regulatory and Market scenarios respectively.

Table 1: Projected Differences in GDP by Year (Relative to the BAU) (2021$, Billions)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	-$13	-$13	-$16	-$23	-$28	-$34	-$40	-$44
Regulatory (High Alternative Vehicle Cost)	-$16	-$16	-$21	-$28	-$34	-$41	-$47	-$49
Regulatory (Low Alternative Vehicle Cost)	-$10	-$10	-$12	-$17	-$21	-$25	-$31	-$35
Market	-$8	-$10	-$10	-$12	-$13	-$13	-$14	-$23
Market (High Alternative Vehicle Cost)	-$10	-$12	-$12	-$14	-$15	-$16	-$19	-$26
Market (Low Alternative Vehicle Cost)	-$7	-$8	-$8	-$9	-$9	-$9	-$10	-$20

Table 2 shows the projected difference in percentage impacts on GDP for the different scenarios relative to the BAU. By 2045, the GDP in the Regulatory scenario is about 1% lower than in the BAU while in the Market scenario, it is about 0.5% lower than the BAU. In 2045, the GDP impacts are projected to be about 0.8% and 0.5% lower than in the BAU for the Low Alternative Vehicle Cost cases in the Regulatory and Market scenarios respectively while for the High Alternative Vehicle Cost cases, they are projected to be 1.1% and 0.6% lower in the BAU for the Regulatory and Market scenarios respectively.

Table 2: Projected Differences in GDP by Year (Relative to the BAU) (%)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	-0.4%	-0.4%	-0.5%	-0.7%	-0.8%	-0.9%	-1.0%	-1.0%
Regulatory (High Alternative Vehicle Cost)	-0.5%	-0.5%	-0.6%	-0.8%	-0.9%	-1.1%	-1.2%	-1.1%
Regulatory (Low Alternative Vehicle Cost)	-0.3%	-0.3%	-0.4%	-0.5%	-0.6%	-0.6%	-0.7%	-0.8%

Market	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.5%
Market (High Alternative Vehicle Cost)	-0.3%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.5%	-0.6%
Market (Low Alternative Vehicle Cost)	-0.2%	-0.3%	-0.2%	-0.3%	-0.3%	-0.2%	-0.2%	-0.5%

Table 3 shows the projected difference in percentage impacts on household consumption for the different scenarios relative to the BAU. By 2045, the consumption in the Regulatory scenario is about 1.2% lower than in the BAU while in the Market scenario, it is about 0.5% lower than the BAU. In 2045, the consumption impacts are projected to be about 1.1% and 0.5% lower than in the BAU for the Low Alternative Vehicle Cost cases in the Regulatory and Market scenarios respectively while for the High Alternative Vehicle Cost cases, they are projected to be 1.4% and 0.6% lower in the BAU for the Regulatory and Market scenarios respectively.

Table 3: Projected Differences in Household Consumption by Year (Relative to the BAU) (%)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	-0.9%	-0.8%	-0.8%	-0.9%	-0.9%	-1.0%	-1.1%	-1.2%
Regulatory (High Alternative Vehicle Cost)	-1.1%	-1.0%	-1.0%	-1.1%	-1.2%	-1.3%	-1.3%	-1.4%
Regulatory (Low Alternative Vehicle Cost)	-0.7%	-0.6%	-0.6%	-0.6%	-0.7%	-0.8%	-0.9%	-1.1%
Market	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.4%	-0.4%	-0.5%
Market (High Alternative Vehicle Cost)	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.6%
Market (Low Alternative Vehicle Cost)	-0.2%	-0.3%	-0.2%	-0.3%	-0.3%	-0.3%	-0.3%	-0.5%

As consumption has a direct implication for household dollar spending, in Table 4 we also report the projected difference in spending on goods and services on a dollars per household basis under the different scenarios relative to the BAU. By 2045, the Regulatory scenario is projected to reduce household consumption per household by about $1,890 while in the Market scenario, household consumption is projected to decline by about $820. In 2045 in the Low Alternative Vehicle Cost cases, the household consumption impacts are projected to be about $1,630 and $700 lower than the BAU in the Regulatory and Market scenarios respectively while in the High Alternative Vehicle Cost cases, they are projected to be $2,200 and $900 lower than the BAU.[19] The Market scenario allows for the most cost-effective reduction of emissions. The Regulatory approach on the other hand, incorporates sector-specific targeted mandates which may not necessarily be the least cost-way of reducing emissions since it could force in technologies that would otherwise not be adopted. The stringency of the specific mandates determine the costs of the Regulatory scenario and how it compares to the costs of the Market scenario..

[19] These changes in consumption are relative to an average current baseline household consumption of $133,000 in California. It is important to note that this is significantly larger than the more commonly-reported figure of median household consumption of $79,000 because of the impact of very high-income households in California.

Table 4: Projected Dollar Difference in Annual Consumption per Household (Relative to the BAU) (2021$/HH)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	-$1,300	-$1,260	-$1,250	-$1,310	-$1,430	-$1,580	-$1,710	-$1,890
Regulatory (High Alternative Vehicle Cost)	-$1,600	-$1,550	-$1,560	-$1,650	-$1,770	-$1,920	-$2,040	-$2,200
Regulatory (Low Alternative Vehicle Cost)	-$1,010	-$960	-$960	-$980	-$1,110	-$1,260	-$1,410	-$1,630
Market	-$480	-$520	-$510	-$530	-$550	-$560	-$540	-$820
Market (High Alternative Vehicle Cost)	-$550	-$590	-$590	-$610	-$630	-$640	-$660	-$900
Market (Low Alternative Vehicle Cost)	-$340	-$380	-$370	-$380	-$400	-$400	-$400	-$700

B. Projected Changes in the California Transportation Sector

There are opportunities for changes in the introduction of two very different types of LDVs: internal combustion engines (ICEs) and battery electric vehicles (BEVs) in the transportation sector. There are also flexibilities to alter the fuel efficiency of vehicles, and to decide on the amount of income to spend on personal transportation services or VMT. The assumptions about changing technology costs and consumer preferences for the two types of vehicles are the same in both scenarios, but the two scenarios create different economic and regulatory pressures on these consumer decisions, resulting in different amounts of adoption of BEVs, vehicle mileage, and VMT. In the Market scenario, the amount of response to any of these is determined entirely by the cost implications of the allowance price on uses of each alternative vehicle type. In the Regulatory scenario, the light-duty vehicles ZEV mandate applied determines the penetration of the two vehicle types.

Table 5 reports the projected VMT in each scenario, disaggregated by vehicle type. Total VMT decreases in the Market scenario in response to the carbon price signal that leads to a higher cost of compliance of transportation fuels and electricity prices while in the Regulatory scenario, the decline in VMT is a consequence of an increase in the cost-per-mile derived coupled together with the increase in electricity prices in response to the light-duty vehicles ZEV mandate. Table 6 shows the differences in the projected VMT in the Regulatory and Market scenarios relative to the BAU. By 2045, the decrease in the Total VMT in both the Regulatory and Market scenarios are about the same while the BEV VMT levels are higher in the Regulatory scenario compared to the Market scenario. Conversely, in 2045 the ICE VMT levels are higher in the Market scenario compared to the Regulatory scenario.

Table 5: Projected VMT by Vehicle Type by Year (Billions of Miles)

	2024	2027	2030	2033	2036	2039	2042	2045
BAU								
All ICE Vehicles	322	314	297	268	257	254	254	270
All BEVs	5	10	19	33	48	58	63	70
Total	327	324	316	301	305	312	317	339

Regulatory								
All ICE Vehicles	312	306	293	249	190	140	98	70
All BEVs	11	15	19	47	106	159	202	246
Total	324	321	313	296	296	299	300	316
Regulatory (High Alternative Vehicle Cost)								
All ICE Vehicles	312	305	294	249	190	140	98	70
All BEVs	11	15	18	47	105	159	201	245
Total	323	320	312	296	295	299	299	315
Regulatory (Low Alternative Vehicle Cost)								
All ICE Vehicles	313	306	292	250	191	140	98	70
All BEVs	11	15	21	47	106	160	202	246
Total	324	322	313	297	297	300	300	316
Market								
All ICE Vehicles	318	309	291	258	244	236	232	217
All BEVs	5	11	20	37	54	67	75	99
Total	323	320	311	295	298	304	307	316
Market (High Alternative Vehicle Cost)								
All ICE Vehicles	323	315	298	267	253	248	243	232
All BEVs	0	5	13	29	44	55	63	85
Total	323	320	311	295	298	303	307	317
Market (Low Alternative Vehicle Cost)								
All ICE Vehicles	319	309	289	254	236	225	215	192
All BEVs	5	11	22	42	62	79	92	123
Total	324	321	312	296	298	304	307	315

Table 6: Differences in the Projected VMTs by Year (Relative to the BAU) (%)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	-0.9%	-1.0%	-1.0%	-1.6%	-2.9%	-4.2%	-5.6%	-7.0%
Regulatory (High Alternative Vehicle Cost)	-1.2%	-1.2%	-1.3%	-1.8%	-3.1%	-4.4%	-5.8%	-7.2%
Regulatory (Low Alternative Vehicle Cost)	-0.8%	-0.8%	-0.9%	-1.4%	-2.7%	-4.0%	-5.4%	-6.8%
Market	-1.1%	-1.3%	-1.5%	-2.0%	-2.4%	-2.8%	-3.3%	-6.8%
Market (High Alternative Vehicle Cost)	-1.1%	-1.3%	-1.5%	-2.0%	-2.4%	-2.8%	-3.4%	-6.6%
Market (Low Alternative Vehicle Cost)	-0.9%	-1.2%	-1.4%	-1.9%	-2.3%	-2.8%	-3.4%	-7.1%

Table 7 presents the percentage share of VMT of the total stock for the different vehicle types. In the Market scenario (where there is no BEV mandate), the share of the VMT from electric vehicles (of the total stock vehicles) rises to 31% in 2045 purely due to the economic incentives created by the allowance price. However, the more stringent light-duty vehicle ZEV mandate imposed in the Regulatory scenario results in a greater penetration of electric vehicles, with the share of VMT from electric vehicles rising to 78% in 2045. In 2045, it can be seen that for both the Low Alternative Vehicle Cost and High Alternative Vehicle Cost Regulatory scenario cases, the share of VMT from electric vehicles are about the same as in the core scenario (as per as the mandate) while they are about 27% and 39% in the High Alternative Vehicle Cost and Low Alternative Vehicle Cost cases for the Market scenario respectively.

Table 7: Share of Vehicle Miles Traveled per Year by Type of Vehicle (%)

	2024	2027	2030	2033	2036	2039	2042	2045
BAU								
All ICE Vehicles	98%	97%	94%	89%	84%	81%	80%	79%
All BEVs	2%	3%	6%	11%	16%	19%	20%	21%
Regulatory								
All ICE Vehicles	97%	95%	94%	84%	64%	47%	33%	22%
All BEVs	3%	5%	6%	16%	36%	53%	67%	78%
Regulatory (High Alternative Vehicle Cost)								
All ICE Vehicles	97%	95%	94%	84%	64%	47%	33%	22%
All BEVs	3%	5%	6%	16%	36%	53%	67%	78%
Regulatory (Low Alternative Vehicle Cost)								
All ICE Vehicles	97%	95%	93%	84%	64%	47%	33%	22%
All BEVs	3%	5%	7%	16%	36%	53%	67%	78%
Market								
All ICE Vehicles	98%	97%	93%	87%	82%	78%	76%	69%
All BEVs	2%	3%	7%	13%	18%	22%	24%	31%
Market (High Alternative Vehicle Cost)								
All ICE Vehicles	100%	99%	96%	90%	85%	82%	79%	73%
All BEVs	0%	1%	4%	10%	15%	18%	21%	27%
Market (Low Alternative Vehicle Cost)								
All ICE Vehicles	98%	96%	93%	86%	79%	74%	70%	61%
All BEVs	2%	4%	7%	14%	21%	26%	30%	39%

Unlike the light-duty vehicles in the personal transportation sector, the NewERA model does not simulate the vehicles miles traveled by these truck vehicle types. Instead, these vehicle types provides value-added services in the model. Table 8 presents the projected change in output from the commercial trucking sector disaggregated by vehicle type. In 2045, a greater reduction in the output (relative to the BAU) from diesel trucks is projected in the Regulatory scenario compared to the Market scenario while the increase in the output from battery-electric and fuel-cell trucks relative to the BAU are projected to be about the same in both scenarios. In 2045, for both the Low Alternative Vehicle Cost and High Alternative Vehicle Cost Regulatory scenario cases, the output impacts are projected to be about the same as in the core scenario. For the Market scenario, a larger increase in the total output from battery-electric and fuel-cell trucks are projected in the Low Alternative Vehicle Cost case than in the High Alternative Vehicle Cost case in 2045.

Table 8: Projected Change in Output from the Commercial Trucking Sector by Vehicle Type and Year (Relative to the BAU) (2021$, Billions)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory								
Diesel	0	0	0	-1	-8	-18	-24	-27
Battery-Electric	0	0	0	1	2	3	4	5
Fuel-Cell	0	0	0	0	1	2	3	4
Regulatory (High Alternative Vehicle Cost)								
Diesel	0	0	0	-12	-19	-18	-24	-27
Battery-Electric	0	0	0	0	1	3	4	5
Fuel-Cell	0	0	0	1	1	2	3	4
Regulatory (Low Alternative Vehicle Cost)								
Diesel	0	0	0	0	-8	-18	-24	-27
Battery-Electric	0	0	0	1	2	3	4	5
Fuel-Cell	0	0	0	0	1	2	3	4
Market								
Diesel	-1	-1	-1	-1	-1	-2	-2	-4
Battery-Electric	0	0	0	0	0	0	4	5
Fuel-Cell	0	0	0	0	0	2	3	4
Market (High Alternative Vehicle Cost)								
Diesel	-1	-1	-1	-1	-2	-2	-2	-4
Battery-Electric	0	0	0	0	0	0	0	0
Fuel-Cell	0	0	0	0	0	0	0	4
Market (Low Alternative Vehicle Cost)								
Diesel	-1	-1	-1	-1	-1	-2	-2	-4
Battery-Electric	0	0	0	1	2	3	4	5
Fuel-Cell	0	0	0	0	0	2	3	4

C. Projected Changes in the California Energy System

The purpose of both scenarios is to reduce CO_2 emissions, most of which come from fossil fuel combustion. Although both scenarios achieve comparable carbon emissions reductions by 2045, they have somewhat different impacts with respect to the electricity demand, delivered electricity prices and electricity generation. Table 9 reports the percentage changes in projected electricity consumption for the different scenarios relative to the BAU. By 2045, the electricity demand in the Regulatory scenario is projected to about 8.6% greater than in the BAU while in the Market scenario, it is projected to be only about 0.1% higher than in the BAU. This is a consequence of the significantly high levels of BEV penetration in the Regulatory scenario, a direct result of the more stringent light-duty vehicle ZEV mandate. This also results in significantly higher delivered electricity prices to households by 2045 in the Regulatory scenario compared to the Market scenario as shown in Table 10.

Table 9: Projected Change in California Retail Electricity Consumption (Relative to the BAU) (%)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	-0.7%	0.2%	1.1%	3.2%	7.1%	8.1%	9.6%	8.6%
Regulatory (High Alternative Vehicle Cost)	-0.7%	0.1%	1.0%	3.1%	7.3%	8.2%	9.3%	8.7%
Regulatory (Low Alternative Vehicle Cost)	-0.7%	0.2%	1.2%	3.8%	7.7%	8.6%	9.3%	7.8%
Market	-2.4%	-2.7%	-2.9%	-2.0%	-2.6%	-2.5%	-0.6%	0.1%
Market (High Alternative Vehicle Cost)	-3.3%	-3.5%	-4.1%	-3.5%	-4.2%	-3.7%	-3.7%	-3.0%
Market (Low Alternative Vehicle Cost)	-2.4%	-2.4%	-2.4%	-0.7%	-0.7%	-0.1%	0.9%	2.3%

Table 10: Projected Change in Delivered Electricity Price to Residential Customers (Relative to the BAU (%)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	4%	0%	-4%	-3%	3%	13%	21%	37%
Regulatory (High Alternative Vehicle Cost)	3%	0%	-4%	-5%	1%	14%	23%	38%
Regulatory (Low Alternative Vehicle Cost)	4%	0%	-3%	-4%	1%	12%	23%	42%
Market	5%	5%	6%	4%	6%	7%	7%	9%
Market (High Alternative Vehicle Cost)	5%	5%	7%	5%	7%	6%	7%	8%
Market (Low Alternative Vehicle Cost)	5%	5%	5%	4%	6%	7%	7%	10%

Table 11 shows the projected electricity generation by asset type over time in terms of levels of TWh for the different scenarios. It can be seen that natural gas generation levels are lower until 2042 in the Regulatory scenario compared to the Market scenario. This is a consequence of the more stringent RPS and SB100 targets in the Regulatory scenario that mandates significant amounts of renewables or zero-carbon resources. The economic incentives created by the allowance price motivates natural gas with CCS generation in the long-run and higher nuclear generation in 2024 in the Market scenario compared to the Regulatory scenario. The RPS and SB100 mandates in the Regulatory scenario also motivates higher generation from renewable resources leading to higher renewable penetration levels in the Regulatory scenario compared to the Market scenario.

Table 11: Projected Gross Electricity Generation in California by Year and Type of Energy Source (TWh)

	2024	2027	2030	2033	2036	2039	2042	2045
Natural Gas (No CCS)								
BAU	117	116	108	100	93	94	95	86
Regulatory	95	84	63	53	36	23	12	11
Regulatory (High Alternative Vehicle Cost)	95	84	63	53	37	23	12	10
Regulatory (Low Alternative Vehicle Cost)	95	84	63	53	36	23	13	9
Market	102	110	90	73	51	35	20	8
Market (High Alternative Vehicle Cost)	101	108	87	70	49	31	16	7
Market (Low Alternative Vehicle Cost)	103	110	91	77	61	38	22	9
CCS*								
BAU	0	0	0	0	0	0	0	0
Regulatory	0	0	0	0	0	0	0	0
Regulatory (High Alternative Vehicle Cost)	0	0	0	0	0	0	0	0
Regulatory (Low Alternative Vehicle Cost)	0	0	0	0	0	0	0	0
Market	0	0	0	0	0	1	11	26
Market (High Alternative Vehicle Cost)	0	0	0	0	0	4	11	25
Market (Low Alternative Vehicle Cost)	0	0	0	0	0	1	11	28
Nuclear								
BAU	0	0	0	0	0	0	0	0
Regulatory	0	0	0	0	0	0	0	0
Regulatory (High Alternative Vehicle Cost)	0	0	0	0	0	0	0	0
Regulatory (Low Alternative Vehicle Cost)	0	0	0	0	0	0	0	0
Market	18	0	0	0	0	0	0	0
Market (High Alternative Vehicle Cost)	18	0	0	0	0	0	0	0
Market (Low Alternative Vehicle Cost)	18	0	0	0	0	0	0	0
Solar								

BAU	46	65	83	104	129	158	187	220
Regulatory	78	119	160	202	239	271	310	344
Regulatory (High Alternative Vehicle Cost)	78	119	160	202	239	271	310	338
Regulatory (Low Alternative Vehicle Cost)	78	119	160	202	239	271	311	341
Market	42	59	100	141	183	223	255	293
Market (High Alternative Vehicle Cost)	40	58	98	140	182	222	254	292
Market (Low Alternative Vehicle Cost)	42	60	100	142	184	223	256	294
Wind**								
BAU	29	41	52	63	74	85	96	107
Regulatory	29	41	54	67	80	93	106	119
Regulatory (High Alternative Vehicle Cost)	29	41	54	67	80	93	106	119
Regulatory (Low Alternative Vehicle Cost)	29	41	54	67	80	93	107	120
Market	29	41	52	63	74	87	100	114
Market (High Alternative Vehicle Cost)	29	41	52	63	74	87	100	113
Market (Low Alternative Vehicle Cost)	29	41	52	63	76	89	102	115
Storage***								
BAU	0	0	0	0	0	0	0	0
Regulatory	0	0	0	0	28	54	82	107
Regulatory (High Alternative Vehicle Cost)	0	0	0	0	29	55	82	106
Regulatory (Low Alternative Vehicle Cost)	0	0	0	0	28	55	83	107
Market	0	0	0	0	10	20	35	37
Market (High Alternative Vehicle Cost)	0	0	0	0	7	18	25	26
Market (Low Alternative Vehicle Cost)	0	0	0	0	2	25	38	41
Other Renewables****								
BAU	87	83	83	83	83	82	82	87
Regulatory	87	81	70	71	72	72	72	72
Regulatory (High Alternative Vehicle Cost)	87	81	70	71	72	72	72	72

Regulatory (Low Alternative Vehicle Cost)	87	81	70	71	72	72	72	72
Market	87	81	76	74	70	70	71	74
Market (High Alternative Vehicle Cost)	87	81	74	72	70	70	74	76
Market (Low Alternative Vehicle Cost)	87	81	76	76	76	70	70	74

* *Includes generation from coal with CCS, natural gas with CCS and biomass with CCS resources. We disallow coal with CCS builds in California in the model. The model does not project any biomass with CCS generation over the model horizon*

** *Includes generation from onshore and offshore wind resources. The model however does not project any offshore wind generation over the model horizon.*

*** *Includes generation from solar with co-located storage and wind with co-located storage.*

**** *Includes generation from pumped storage hydro, conventional hydro, biomass, landfill gas, municipal solid waste and geothermal resources.*

D. Projected Reductions in the California CO_2 Emissions

Table 12 reports the projected percentage changes in economy-wide CO_2 emissions for each scenario relative to the BAU. In the Regulatory scenario, CO_2 emissions from the electric and non-electric sectors are projected to be reduced by 88% and 43% by 2045 respectively. This results in a reduction in economy-wide CO_2 emissions by about 50% by 2045 relative to the BAU. In the Market scenario by 2045, the projected reductions in electric sector CO_2 emissions are about the same (88%) while those from the non-electric sector are slightly lower (39%). This results in the projected economy-wide CO_2 emissions in 2045 for the Market scenario to be slightly lower than in the Market scenario (47%). Larger reductions in CO_2 emissions are projected in the residential, commercial, and industrial sector CO_2 emissions in the Market scenario by 2045 relative to the BAU while the same is true for the transportation sector in the Regulatory scenario. Table 13 reports the projected percentage changes in economy-wide CO_2 emissions for each scenario relative to 2005 levels.[20] By 2045, similar levels of reductions in CO_2 emissions are projected for both scenarios.

The sectoral reductions in CO_2 emissions projected in the Regulatory scenario is a reflection of the mandate design and its stringency. Since the mandates in the Regulatory scenario are more targeted towards the transportation sector, there are greater emission reductions achieved in this sector compared to other sectors in the economy (such as the industrial sector). Under the Market scenario, however, the industrial sector is subject to allowance prices under the emissions cap. Under this approach (as shown in Table 12), it is relatively cost-effective to achieve emission reductions from the industrial sector than from the transportation sector.

[20] Based on the CARB's 2014 Edition of California's Greenhouse Gas Emission Inventory (2000-2012), the CO_2 Emissions in California in 2005 was reported to be 425.3 MMT CO_2 (available at https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2012/ghg_inventory_00-12_report.pdf).

Table 12: Projected Change in California CO_2 Emissions by Sector and Year (Relative to the BAU) (%)

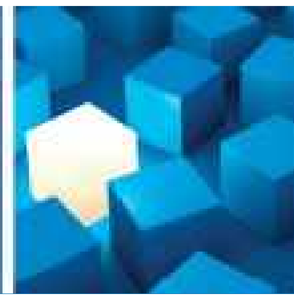
	2024	2027	2030	2033	2036	2039	2042	2045
Residential								
Regulatory	-4%	-4%	-4%	-4%	-4%	-4%	-5%	-5%
Regulatory (High Alternative Vehicle Cost)	-4%	-4%	-4%	-4%	-4%	-5%	-5%	-5%
Regulatory (Low Alternative Vehicle Cost)	-3%	-4%	-4%	-4%	-4%	-4%	-4%	-4%
Market	-5%	-6%	-7%	-8%	-10%	-12%	-14%	-25%
Market (High Alternative Vehicle Cost)	-5%	-6%	-8%	-9%	-11%	-13%	-15%	-25%
Market (Low Alternative Vehicle Cost)	-4%	-6%	-7%	-8%	-10%	-11%	-13%	-25%
Commercial								
Regulatory	-1%	-1%	-1%	-1%	-1%	-2%	-2%	-2%
Regulatory (High Alternative Vehicle Cost)	-1%	-1%	-1%	-1%	-1%	-2%	-2%	-2%
Regulatory (Low Alternative Vehicle Cost)	-1%	-1%	-1%	-1%	-1%	-2%	-2%	-2%
Market	-5%	-7%	-9%	-10%	-12%	-14%	-17%	-29%
Market (High Alternative Vehicle Cost)	-6%	-7%	-9%	-11%	-13%	-15%	-18%	-29%
Market (Low Alternative Vehicle Cost)	-5%	-7%	-8%	-10%	-12%	-14%	-16%	-30%
Industrial								
Regulatory	0%	0%	1%	-2%	-7%	-12%	-15%	-19%
Regulatory (High Alternative Vehicle Cost)	0%	1%	1%	-3%	-7%	-12%	-15%	-18%
Regulatory (Low Alternative Vehicle Cost)	0%	0%	0%	-2%	-7%	-12%	-16%	-19%
Market	-14%	-16%	-20%	-21%	-25%	-28%	-30%	-46%
Market (High Alternative Vehicle Cost)	-14%	-17%	-21%	-22%	-26%	-29%	-31%	-45%
Market (Low Alternative Vehicle Cost)	-13%	-16%	-20%	-21%	-25%	-28%	-31%	-47%
Transportation								
Regulatory	-2%	-1%	-1%	-8%	-26%	-44%	-58%	-68%

Regulatory (High Alternative Vehicle Cost)	-2%	-1%	-1%	-13%	-31%	-44%	-58%	-68%
Regulatory (Low Alternative Vehicle Cost)	-1%	-1%	-2%	-7%	-25%	-44%	-58%	-68%
Market	-5%	-6%	-9%	-11%	-15%	-19%	-22%	-38%
Market (High Alternative Vehicle Cost)	-4%	-5%	-9%	-9%	-13%	-16%	-18%	-34%
Market (Low Alternative Vehicle Cost)	-4%	-6%	-9%	-12%	-17%	-22%	-26%	-43%
Electric								
Regulatory	-15%	-28%	-42%	-47%	-60%	-74%	-86%	-88%
Regulatory (High Alternative Vehicle Cost)	-15%	-28%	-42%	-47%	-60%	-74%	-86%	-88%
Regulatory (Low Alternative Vehicle Cost)	-15%	-28%	-42%	-47%	-60%	-74%	-86%	-90%
Market	-27%	-6%	-18%	-28%	-46%	-61%	-77%	-88%
Market (High Alternative Vehicle Cost)	-28%	-8%	-20%	-31%	-48%	-65%	-81%	-90%
Market (Low Alternative Vehicle Cost)	-27%	-6%	-17%	-24%	-35%	-58%	-76%	-87%
Non-Electric								
Regulatory	-1%	-1%	-1%	-5%	-16%	-28%	-36%	-43%
Regulatory (High Alternative Vehicle Cost)	-1%	-1%	-1%	-9%	-19%	-28%	-36%	-43%
Regulatory (Low Alternative Vehicle Cost)	-1%	-1%	-1%	-5%	-16%	-28%	-36%	-43%
Market	-7%	-9%	-12%	-13%	-17%	-21%	-23%	-39%
Market (High Alternative Vehicle Cost)	-7%	-9%	-12%	-13%	-17%	-19%	-22%	-36%
Market (Low Alternative Vehicle Cost)	-6%	-8%	-12%	-14%	-18%	-22%	-25%	-42%

Table 13: Projected Change in Total California CO_2 Emissions Relative to 2005 Levels by Year (%)

	2024	2027	2030	2033	2036	2039	2042	2045
Regulatory	-32%	-41%	-47%	-53%	-61%	-68%	-73%	-76%
Regulatory (High Alternative Vehicle Cost)	-32%	-41%	-47%	-54%	-62%	-68%	-73%	-77%
Regulatory (Low Alternative Vehicle Cost)	-32%	-41%	-47%	-52%	-61%	-68%	-73%	-77%

Market	-39%	-42%	-50%	-54%	-60%	-64%	-68%	-75%
Market (High Alternative Vehicle Cost)	-39%	-42%	-50%	-55%	-60%	-64%	-67%	-74%
Market (Low Alternative Vehicle Cost)	-39%	-42%	-49%	-54%	-60%	-65%	-68%	-76%



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Economic Impact Analysis of California's 2022 Draft Scoping Plan's "Proposed Scenario"
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APPENDIX I. NEWERA MODELING FRAMEWORK

A. Introduction

NERA's N_{ew}ERA model evaluates impacts of policy and regulatory shocks to the U.S. economy, with emphasis on the energy sector. The N_{ew}ERA model couples a multi-sector macroeconomic model with a detailed electricity sector model that characterizes electricity production at the generation asset level. This coupling allows for a comprehensive understanding of the direct and indirect policy impacts to all aspects of the economy, including the complex interdependencies between energy consumption, electricity supply, and macroeconomic growth.

The main benefit of this separate, yet integrated framework, is that the electric sector can be modeled with full technological detail in a multi-sector macroeconomic setting, while maintaining solution tractability. The electric sector model is a nonlinear program characterizing electricity production. Each electricity generating asset, which amounts to more than 17,000 units in the United States, is represented in the model. The model also provides a detailed account of technologies available to produce electricity, according to realistic engineering specifications. To obtain a solution, the model minimizes costs while meeting all specified operational constraints, such as demand, peak demand, emissions limits, and transmission limits. The electricity model outputs generation resource planning and unit dispatch decisions, along with overall supply and consumption of electricity in the U.S. economy.

The macroeconomic model, a computable general equilibrium (CGE) model of the U.S. economy, takes from the electricity model, information regarding supply and demand for electricity, and the resource inputs used to produce electricity. The macroeconomic model in turn, creates price responses of electricity and electricity sector inputs that are consistent with the rest of the economy.

The integrated N_{ew}ERA model hence outputs demand, supply and prices of all goods and services, and trade effects; i.e., changes in imports and exports. Model outputs also include gross regional or state product, aggregate consumption, sectoral output and investment levels, and changes in "job equivalents" based on labor wage income.[1]

B. Overview

NERA's N_{ew}ERA modeling system is an integrated energy-economy model that consists of a multi-sector macroeconomic model and a detailed electric sector model. The electric sector model includes unit-level details of power generation to assess the sector's response to economic shocks that can affect major investment or unit operations decisions. The macroeconomic model represents all other sectors of the economy to provide a comprehensive impact assessment of such shocks. The time horizon used in model projections can be flexibly adapted to the analysis, with typical model time horizons running between

[1] N_{ew}ERA assumes full employment given the supply of labor and does not model for involuntary unemployment.

fifteen and thirty years[2]. The model produces a standard set of reports that includes the following information:

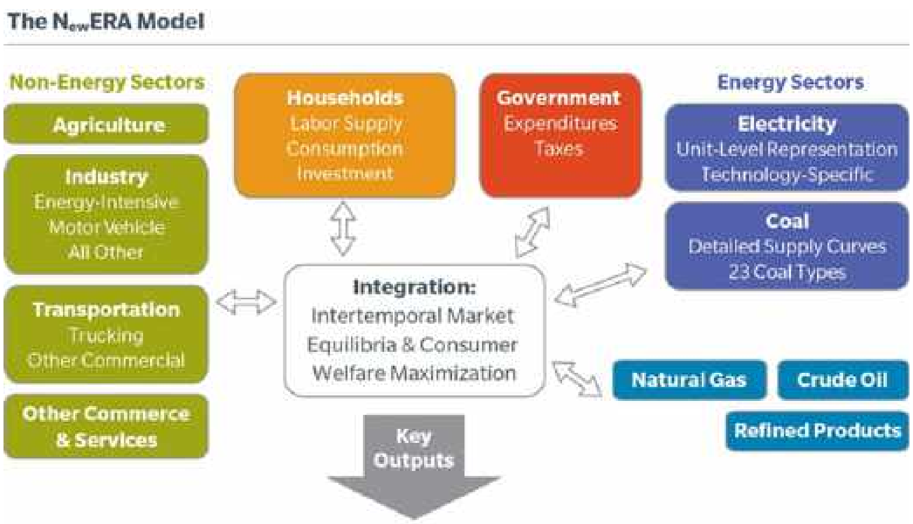
- *Unit-level investments in the electric sector*: Retrofits in response to environmental policies; new builds and retirements based on economic resource planning; and a full range of power generating technologies is represented in the model.

- *Prices*: Wholesale electricity prices for each of the 64 U.S. electricity regions, capacity prices for each U.S. electricity region, delivered electricity prices to sectors of the economy, Henry Hub natural gas prices and delivered natural gas prices, mine-mouth coal prices for 23 different coals, delivered coal prices by coal generation unit, refined oil product prices (gasoline and diesel fuel), renewable energy credit (REC) prices for each state/regional renewable portfolio standard (RPS), and emissions prices for all national programs with tradable credits.

- *Macroeconomic results:* Gross domestic product (and gross regional/state product for each macroeconomic region), changes in household consumption, changes in labor income and wage rates (used to estimate labor market changes in terms of an equivalent number of jobs), economy-wide energy usages, fuel prices, economy-wide CO_2 emissions by sector.

Figure 1 provides a simplified representation of the key elements of the N_{ew}ERA modeling system.

Figure 1: N_{ew}ERA Modeling System Representation



Macroeconomic (National/Regional)	Primary Energy (National/Regional)	Electricity (National/Regional/Generating Unit)
Welfare	Demand	Prices
GDP, consumption, investment	Prices	Builds, retrofits, retirements
Output by sector	Production	Load and Dispatch

[2] As noted in the report body, we set N_{ew}ERA to begin in year 2024 and model every third year thereafter until 2048. We extend the model beyond 2045 (the final year of interest for the analysis) to capture the full life of the electric and non-electric capital.

C. Electric Sector Model

The N_{ew}ERA modeling system's electric sector model is a detailed bottom-up model of the electric and coal sectors. The model is fully dynamic and includes perfect foresight (under the assumption that future conditions are known). Thus, all decisions within the model are based on minimizing the present value of costs over the entire time horizon of the model while meeting all specified constraints, regarding demand, peak demand, emissions limits, transmission limits, RPS regulations, CES regulations, fuel availability and costs, new build limits and CCS retrofit build or retire requirements for coal units. The model set-up is intended to mimic decisions made by electric sector investors and system operators. In determining the least-cost method of satisfying specified constraints, the model determines the following:

1. Investment decisions (*e.g.*, addition of retrofits, build new capacity, repower unit, add fuel switching capacity, or retire units);

2. Unit operations decisions (*e.g.*, unit dispatch by fuel and technology and optimal power generation mix); and

3. Demand response – the model assesses the trade-off between the amount of demand-side management (DSM) to be undertaken and the level of electricity usage.

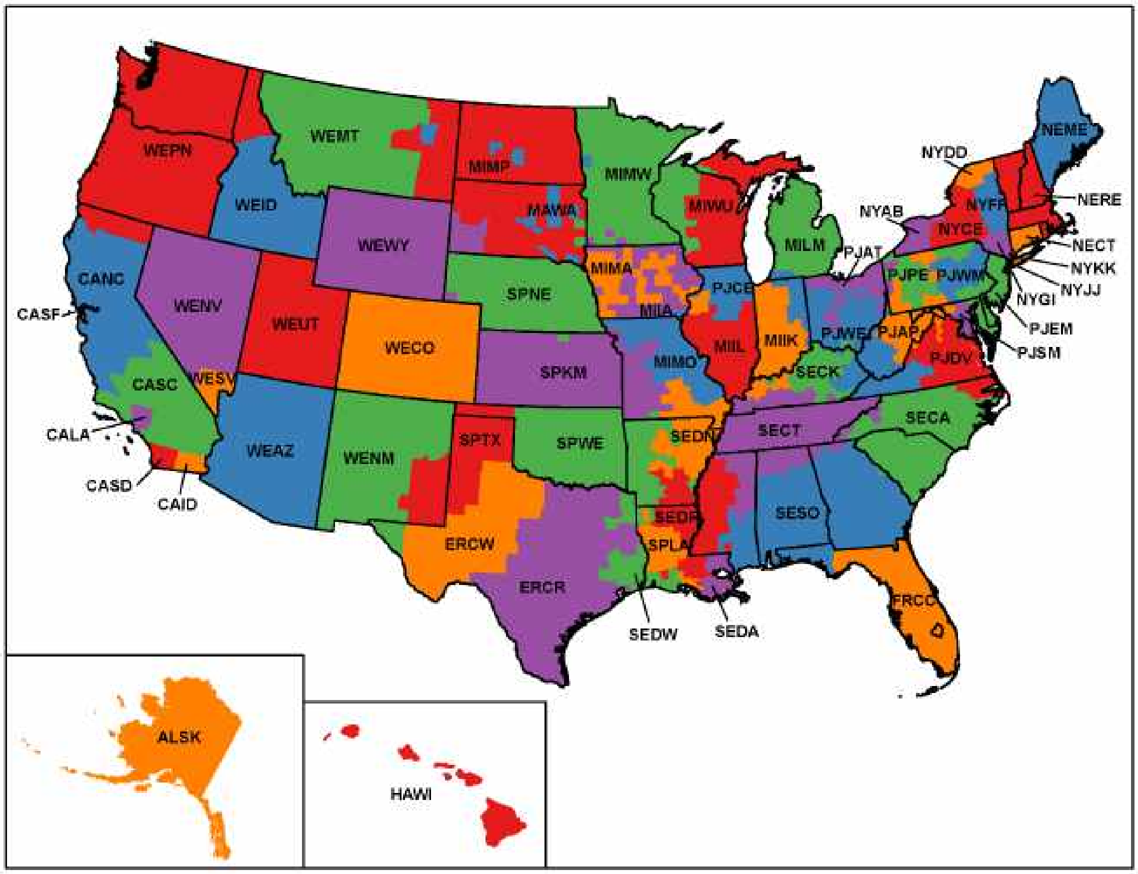
Each unit in the model has certain number of actions it can take. For example, all units can retire, and most can undergo retrofits. Any publicly-announced actions, such as planned retirements, planned retrofits (for existing units), or new units under construction can be specified. Coal units have more potential actions than other types of units. These include retrofits to reduce emissions of SO_2, NO_X, mercury, and CO_2. The costs, timing, and need for retrofits may be specified as scenario inputs or left for the model to endogenously determine. Coal units can also switch the type of coal they burn (with realistic unit-specific limitations). Coal units may choose to retire when it is no longer economic to operate, given net profits from generation and capacity services.

In the model, coal units in particular are responsive to environmental limits specified in the model. Such limits include emission caps (for SO_2, NO_X, Hg, and CO_2) that can be applied at the national, regional, state or unit level. The user can also specify allowance prices for emissions, emission rates (especially for toxics such as Hg), and heat rate levels that must be met by assets.

Similar to investment decisions, the operation of each unit in a given year depends on the policies in place (*e.g.*, unit-level standards), electricity demand, and operating costs – especially energy prices. The model accounts for these conditions in determining dispatch decisions of each unit. On top of unit-level regulations, the model also considers system-wide operational issues such as environmental regulations, limits on the share of generation from intermittent resources, transmission limits, and operational reserve margin requirements in addition to annual reserve margin constraints.

To meet increasing electricity demand and reserve margin requirements over time, the electric sector must build new generating capacity. Future environmental regulations and forecasted energy prices influence decisions on technology type and location of asset. For example, if a national CES policy is to take effect, some share of new generating capacity will need to come from "clean" power. On the other hand, if there is a policy to address emissions, it might elicit a response to retrofit existing fossil-fired units with pollution control technology or enhance existing coal-fired units to burn different types of coals, biomass, or natural gas. Policies that call for improved heat rates may lead to capital expenditure spent on repowering existing units. Policies will also likely affect retirement decisions – an asset will be retired if the model deems it uneconomic to keep that asset operating given future regulatory, technological, and economic constraints. All model decisions hence optimize over all current and future assumptions that may impact resource planning. The model contains 64 U.S. electricity regions (and 11 Canadian electricity regions).[3] Figure 2 shows the U.S. electricity regions in the electric sector model.

Figure 2: N$_{ew}$ERA Electric Sector Model – U.S. Regions



1. Generator Representation

In the model, we represent over 17,000 electricity generating units in the United States. Larger coal units (greater than 200 MW) are individually represented in the model and smaller units are aggregated based on region, size, and existing controls for ease of computation[4]. All other types of units are included in different regional aggregates based on their operating characteristics.

[3] The N$_{ew}$ERA electric sector model regions are based on the model regions in EPA's Integrated Planning Model (IPM) and are designed to be approximately consistent with the configuration of the NERC assessment regions in the NERC Long-Term Reliability Assessments (available at https://www.epa.gov/airmarkets/clean-air-markets-power-sector-modeling).

[4] The system of non-linear equations become increasingly difficult to solve in the dimensionality of the model.

Table 1 shows the existing generating technologies in the electric sector model.

Table 1: Existing Generating Technologies in the Electric Sector Model

Coal	Pumped Storage Hydroelectric
Natural Gas Combined Cycle	Biomass
Natural Gas Combustion Turbine	Geothermal
Gas/Oil Steam	Landfill Gas
Oil Combustion Turbine	Municipal Solid Waste
Onshore Wind	Solar Photovoltaic
Hydroelectric (Run-of-River)	Concentrated Solar Thermal

New technology types that the model can build, in addition to existing types, include advanced coal with carbon capture and storage (CCS), natural gas combined cycle with CCS, offshore wind, onshore wind with storage, photovoltaic solar with storage, and biomass with CCS. Annual build limits can be specified to reflect real world constraints. The model can also accommodate joint build limits that apply to multiple new technology types.

For this study, NERA incorporated two additional electricity generating technologies – photovoltaic solar co-located with storage ("Solar with Storage") and onshore wind co-located with storage ("Wind with Storage"). The representative technology that formed the basis for each of these technologies was a Solar PV module of 100 MW co-located with 60 MW Li-Ion battery storage system with a 4-hour discharge duration and a round-trip efficiency of 87%.[5] This translates to a capacity factor of 60% at full discharge for the battery storage system. We also assumed that the battery storage system would discharge during the top 25% of the peak hours in each season (summer, spring, fall, winter).[6] We developed technology cost estimates and an adjusted capacity factor for these combined technologies as follows:

- **Obtaining the Number of Hours to Apply Storage Discharge.** Based on our assumption that the battery storage system would only discharge during the top 25% of the peak hours in each season, we first obtained both the number of hours and the percentage of total number of hours in each seasonal load block in which discharge takes place.

- **Obtaining Unadjusted and Adjusted Daily Generation by Season.** We obtained the total unadjusted daily generation for each season, based on the default capacity factor for each of the standalone technologies, and the number of hours present in each seasonal load block. An adjusted daily generation was computed for each season by subtracting the generation losses that occur during discharge of the battery storage system from the unadjusted daily generation.

- **Obtaining the Adjusted Capacity Factor.** A maximum capacity factor of 60% for the combined technology with storage was assigned to each of the hours in a seasonal load block, in

[5] Fu, Ran, Timothy Remo, and Robert Margolis. 2018. "2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark," National Renewable Energy Laboratory (available at https://www.nrel.gov/docs/fy19osti/71714.pdf).

[6] Storage Discharge Duration (4 hours)/Number of Daily Peak Hours (16) = 25%.

which the battery storage system discharges completely. We then computed an adjustment factor to be applied to the capacity factor in all other hours of the season to make total daily generation (that considers the storage discharge) consistent with the adjusted daily capacity factor. An adjusted capacity factor was calculated for these hours by multiplying the adjustment factor with the unadjusted capacity factor in each of the hours. In a seasonal load block that requires the storage system to discharge only a portion of the hours, the adjusted capacity factor was computed as the weighted average of two elements: the capacity factor during complete discharge (60%) and the adjusted capacity factor corresponding to non-discharge hours. The two elements were weighted using the fraction of hours in the load block that the discharge applies to.

2. Electricity Demand

Electricity demand within the model is represented by load duration curves.[7] These region-specific curves are created by sorting the hourly demand by load within a season, and then aggregating the hours into a load block based on load characteristics.[8] The model has four seasons and a total of 25 load blocks (ten in the summer and five each in winter, spring, and fall).[9] Four seasons are used to better capture differences between hydroelectric generation in the spring and fall. Peak demand is also a model input and is used in conjunction with reserve margins to determine capacity prices within the model.[10]

The electric sector model is a non-linear program that is linked with the macroeconomic model, so electricity demand can respond to changes in equilibrium conditions affecting all sectors of the economy and model inputs. Furthermore, the electric sector model's demand constraint allows demand to be satisfied either through electricity production or demand-side management programs. Therefore, in the face of a policy such as a nationwide cap or carbon tax on greenhouse gas emissions, the model can choose between meeting demand as forecasted, meeting a lower level of demand (which results in lower values of consumer wellbeing), or implementing DSM programs.

3. Coal Representation

The steam coal sector is represented within the electric sector model of the N_{ew}ERA modeling system. The model includes 23 steam coals types. Existing coal units each have an initial coal type specified and a maximum percentage of PRB coal that the unit can burn (based on recent historical percentages). Units can switch to burn more PRB coal than they currently burn, but they would incur capital costs as well as heat rate and capacity penalties in order to make the switch. Moreover, units can switch to burning other coals if the coal type can be delivered to the unit (and if the unit can be reasonably expected to be able to

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[7] Baseline assumptions relating to electricity demand for the different N_{ew}ERA electric sector regions are drawn from the total net energy for load projections for the various electricity market module regions from the AEO 2021 Reference case.

[8] Hourly demand for each of the N_{ew}ERA electric sector regions are aggregated into load blocks based on a mapping of hours to load blocks based on EPA's IPM assumptions.

[9] There are in aggregate about 3,672 hours across the ten load blocks in the summer, 1,464 hours across the five load blocks each in the spring and fall and 2,160 hours across the five load blocks in the winter.

[10] Baseline assumptions relating to peak demand for the different N_{ew}ERA electric sector regions are drawn from the North American Electric Reliability Corporation's (NERC) 2018 Electricity Supply and Demand Projections (available at https://www.nerc.com/pa/RAPA/ESD/Pages/default.aspx).

burn such a coal). In the near term, the model limits excessive switching in the first few years of the analysis to reflect realistic coal market conditions. Coal exports, and coal use in non-electric sectors are exogenous inputs to the model, although this can be changed depending on the study.

The model utilizes coal supply curves that are paired with inputs for non-electric demand, export demand, and endogenously-determined electric sector demand to produce coal prices for each coal type available in the model.[11] The supply curves are built up from mine-level data and include prices at each step of the curve, along with annual production levels and total reserves at each price step. Demand in prior years depletes the total reserves going forward, which would generally lead to higher coal prices if total reserves at a price step are fully depleted.

There is a complete coal transportation matrix within the model that maps each generating unit to the coals that can be delivered to it.[12] The matrix assigns a transportation cost for each of the deliverable coals. More specifically, the matrix accounts for costs associated with the different modes of transportation that can be used to deliver the coal, along with the distance that the coal must travel.

D. Macroeconomic Model

1. Overview

The N_{ew}ERA macroeconomic model is a forward-looking, dynamic, computable general equilibrium (CGE) model of the United States. The model simulates all economic interactions in the U.S. economy, including those among industry, households, and the government. Additional background information on CGE models can be found in Burfisher (2011).[13]

The N_{ew}ERA CGE framework uses a standard theoretical macroeconomic structure to capture the flow of goods and factors of production within the economy. A simplified version of these interdependent macroeconomic flows is shown in Figure 3. The model solution assumes an Arrow-Debreu general equilibrium. This general equilibrium is characterized by three principles – i. zero-profit, which states any economic activity must earn zero profit as the value of inputs equal the value of outputs; ii. market clearance, which states supply must equal demand for all positively priced goods; and iii. income balance, which states all agents' income must equal its factor endowments plus any net transfers received.

Accordingly, in the model, households supply factors of production, including labor and capital, to firms. Firms provide households with payments for the factors of production in return. Firm output is produced from a combination of production factors and intermediate inputs of goods and services supplied by other sectors of the economy (both domestic and foreign). Similarly, each firm's final output is either consumed within the United States or exported abroad. In addition to consuming goods and services,

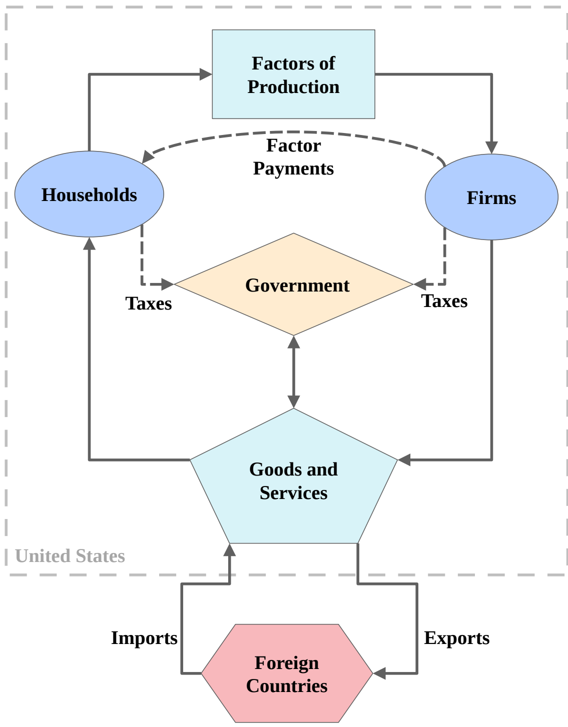
[11] The coal supply curves were developed by NERA based on the coal supply regions and associated coal types in EPA's IPM model documentation.

[12] NERA engaged Hellerworx to create a coal transportation matrix going out in time with the mapping of available coals to the coal-fired power plants based on coal deliverability, the total cost of the delivered coal (commodity plus delivery costs), the heat content of the coal, the rank of the coal, and the emissions contents of the coal.

[13] Burfisher ME. 2011. *Introduction to Computable General Equilibrium Models*. New York: Cambridge University Press.

households can accumulate savings, which they provide to firms for investments in new production capacity. The government agent receives taxes from both households and firms, contributes to the production of goods and services, and purchases goods and services. Although the model assumes equilibrium, there exist capital flow within regions as they run deficits or surpluses. In aggregate, the value of firm output must equal the sum of its production inputs (zero-profit), the sum of regional commodities and factors of production must equal their demands (market clearance), and household income must equal its factor endowments plus any tax revenue received (income balance).

Figure 3: Interdependent Economic Flows in N_{ew}ERA's Macroeconomic Model



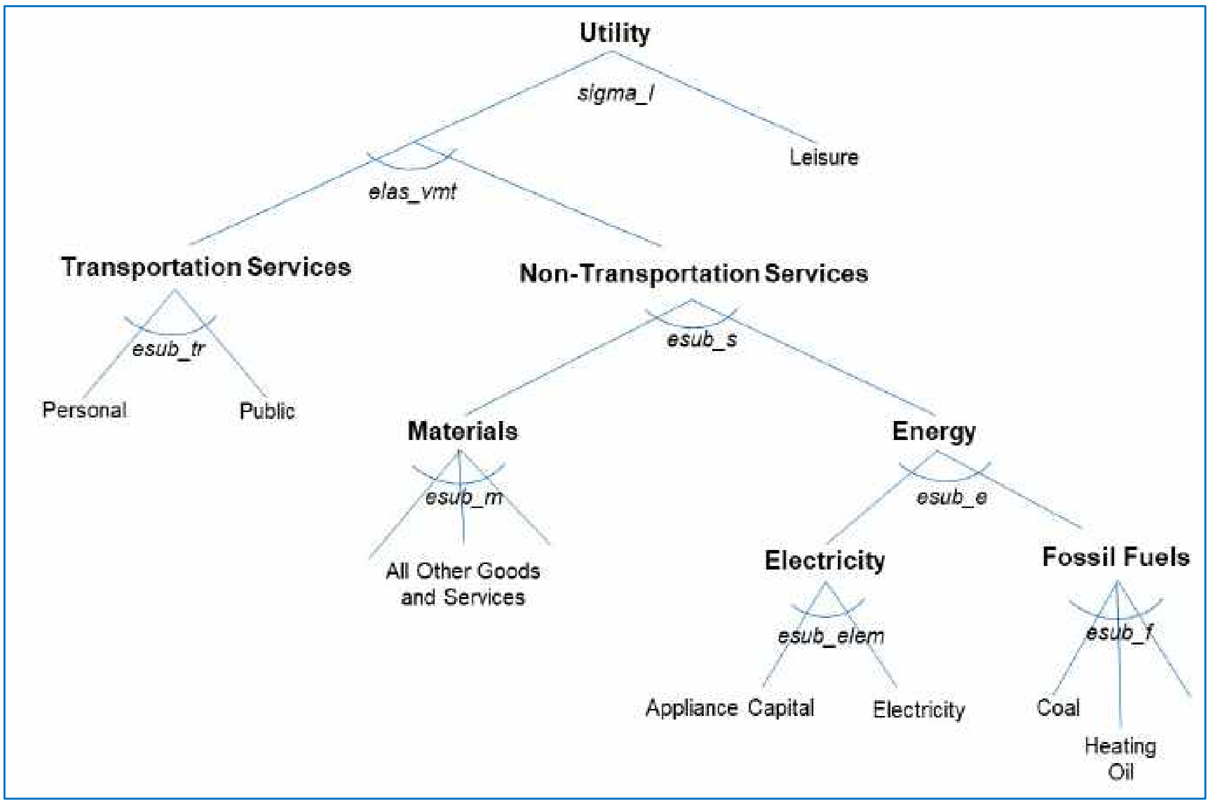
2. Household Behavior Representation

The model assumes that households seek to maximize their overall welfare, or utility, across time periods. Households have utility functions that reflect trade-offs between leisure (which reduces the amount of time available for earning income) and an aggregate consumption good. Households in the model demand leisure, personal transportation, energy inputs, and other intermediate goods and services inputs. Household utility is represented by a nested CES utility function where the trade-off between inputs to the utility function are optimized. The trade-offs between inputs are determined by the elasticities of substitution among goods in utility input nests. For example, if the elasticity of substitution between goods is greater than unity (substitution is elastic), then substitution between goods in response to relative price changes would take place relatively easily. Similarly, if the elasticity of substitution is small (substitution is inelastic), scope for substitution would be limited and the household will likely reduce its overall consumption as a result of reducing demand for the good for which the relative price has risen. The elasticity parameter values are drawn from MIT's USREP and EPPA models.[14,15]

Households maximize their utility over all time periods, subject to lifetime budget constraints based on their income from supplying labor and capital to firms, and owning initial capital stock and economic resources. In each time period, household income is used to consume goods and services, or saved to fund investment. Within consumption, households distinguish between energy goods (including electricity, coal, natural gas, and petroleum), transportation, and other goods and services.

Figure 4 illustrates the nesting structure of the household utility function, while Table 2 displays the elasticity values used in the structure.

Figure 4: **Consumption Structure in N_{ew}ERA's Macroeconomic Model**



[14] Mei Yuan, Sebastian Rausch, Justin Caron, Sergey Paltsev and John Reilly, 2019, The MIT U.S. Regional Energy Policy (USREP) Model: The Base Model and Revisions. Joint Program Technical Note TN #18, August 2019. (available at http://globalchange.mit.edu/publication/17331).

[15] Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005, The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. Joint Program Report Series Report 125, August 2005 (available at http://globalchange.mit.edu/publication/14578).

Table 2: Elasticity of Substitution Values for Consumption

Elasticity	Description	Short-run	Long-Run
sigmal_l	Elasticity based on compensated labor supply of 0.32		
elas_vmt	Elasticity between transportation and other goods	0.40	0.80
elas_tr	Elasticity between transportation services	0.20	0.20
elas_s	Elasticity between energy and materials	0.00	0.00
elas_m	Elasticity between materials	0.20	0.50
elas_e	Elasticity between energy goods	0.20	0.50
elas_elem	Elasticity between electricity and appliance capital	0.20	0.20
elas_f	Elasticity between electricity fuels	1.00	1.00

3. Transportation Sector Representation

The NewERA model explicitly models personal transportation services, which are represented by vehicle miles traveled, namely from light duty vehicles and the trucking transportations services.

We categorize personal travel into two main types of technologies, ICE and BEV vehicles. Under a partial putty-clay structure, the model differentiates the extant – vehicles that have been built prior to the initial model time period (2020) – from the new – vehicles that are newly built during the model horizon. We assume that these pre-2020 vintage vehicles (clay vehicles) are assumed to maintain the same technology going forward and depreciate at a fixed rate of 10%. Inputs for personal transportation services from vehicles include fuel (gasoline or electricity), vehicle specific capital, and maintenance and insurance costs. We assume that clay vehicles, which are already built, cannot substitute between inputs since the technology is fixed. In contrast, consumers of putty ICE and BEV vehicles can flexibly substitute between fuel and capital. That is, if the relative price of fuel to capital increases (as a consequence of a carbon tax or fuel economy standards), the representative consumer will substitute away from fuel to capital or reduce vehicle miles travelled.

The structure of inputs for the personal transportation sector that characterize the use of ICE and BEV vehicles follows the structure presented in Karplus et al. (2013), Paltsev et al. (2005), and Gandhi et al. (2019).[16,17,18] The model calibration procedure regarding vehicle usage also follows the procedure outlined in these studies. Assumptions on gasoline input for ICE vehicles are taken from EIA's AEO 2021 Reference case, while electricity input assumptions are described in the baseline assumptions section of Appendix II. Cost assumptions relating to vehicle services and maintenance are based on

[16] Karplus, V., S. Paltsev, M. Babiker & J. Reilly, 2013, Applying engineering and fleet detail to represent passenger vehicle transport in a computable general equilibrium model, *Economic Modelling* 30, 295–305.

[17] Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005, The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. Joint Program Report Series Report 125, August 2005 (available at http://globalchange.mit.edu/publication/14578).

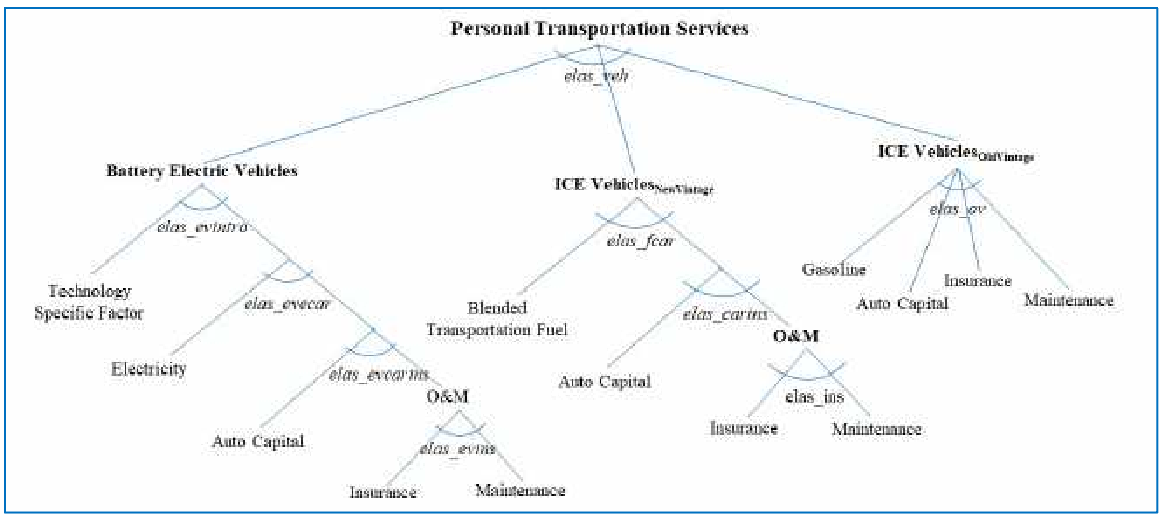
[18] Ghandi, A. and S. Paltsev, 2019, Representing a Deployment of Light-Duty Internal Combustion and Electric Vehicles in Economy-Wide Models, February 2019 (available at https://globalchange.mit.edu/publication/17199).

estimates from the 2018 Consumer Expenditure Survey.[19] Figure 5 illustrates the nesting structure in the production of personal transportation services within households, and

Table 3 displays the elasticity parameters used in the structure.

To capture the deployment of new vehicle technologies, we have adopted an approach in the NewERA model that is different from the approach typically adopted in a technology-based bottom-up model. In a bottom-up model, the extent of penetration of new technologies are restricted by capacity limits and cost assumptions that embed learning-by-doing. Top-down economic models (such as NewERA) tend to use technology-specific fixed factors. The fixed factor represents the adoption dynamics of the new vehicle technology[20] and is modeled as an input to the cost structure. The fixed factor assumption is a function of supply and grows as the potential for the new technology grows. It also grows as the inputs to the technology becomes competitive with respect to its alternatives (Paltsev et al 2005).[21]

Figure 5: **Household Personal Transportation Services in NewERA's Macroeconomic Model**



[19] Based on the Consumer Expenditure Survey 2018, about 4.7% of consumer expenditure is attributed towards repair/maintenance, insurance and other finance charges. This amounts to about $585 million which is comprised of $398 billion towards insurance and repair and the rest towards finance and insurance charges. This forms the basis for calibrating insurance and maintenance costs in the model. (available at https://www.bls.gov/cex/2018/combined/cucomp.pdf).

[20] J.F. Morris, J.M. Reilly, Y.H. Henry Chen, 2019, Advanced technologies in energy-economy models for climate change assessment, *Energy Economics* 80, 476-490.

[21] Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005, The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. Joint Program Report Series Report 125, August 2005 (available at http://globalchange.mit.edu/publication/14578).

Table 3: Elasticity of Substitution Values for Personal Transportation

Vehicle Type	Elasticity	Description	Short-run	Long-Run
Diesel Vehicles	**elas_veh**	Elasticity between vehicle types	Perfect Substitute	
	elas_s	Elasticity between energy and other goods	0.30	0.50
	elas_m	Elasticity between materials	0.00	0.00
	elas_eva	Elasticity between energy and value added	0.50	0.50
	elas_e	Elasticity between energy goods	0.20	0.50
	elas_va	Elasticity between value added inputs	0.80	0.80
Battery Electric Vehicles	**elas_evintro**	Elasticity between vehicle types	0.40	1.00
	elas_evcar	Elasticity between fuel and vehicle	0.40	0.40
	elas_evcarins	Elasticity between vehicle and insurance/maintenance	1.00	1.00
	elas_evins	Elasticity between insurance and maintenance	0.00	0.00

The trucking transportation services sector is also characterized in a manner similar to the personal transportation sector. Trucking sector services are provided by diesel-fueled trucks, battery-electric trucks, and hydrogen based fuel-cell trucks. These vehicle types are used to represent the medium and heavy-duty trucking sector in the NewERA model. Unlike the light-duty vehicles in the personal transportation sector, the NewERA model does not simulate the vehicles miles traveled by these truck vehicle types. Instead, these vehicle types provides value-added services in the model. Figure 6 illustrates the nesting structure in the production of trucking transportation services, and

Table 4 displays the elasticity parameters used in the structure.

Figure 6: **Trucking Transportation Services in N$_{ew}$ERA's Macroeconomic Model**

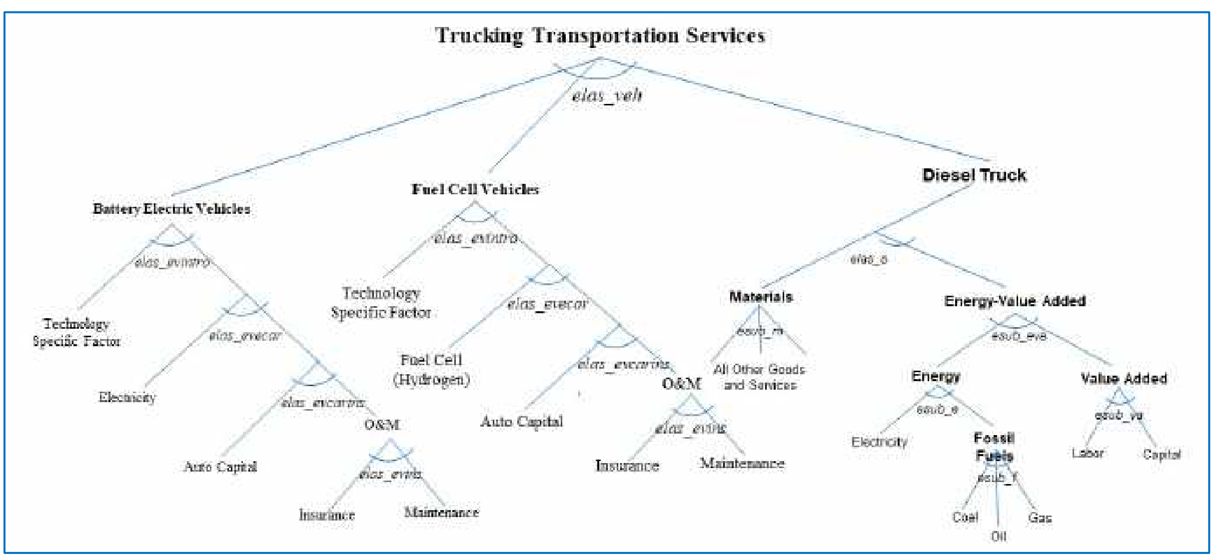


Table 4: Elasticity of Substitution Values for Trucking Transportation

Vehicle Type	Elasticity	Description	Short-run	Long-Run
Diesel Vehicles	**elas_veh**	Elasticity between vehicle types	Perfect Substitute	
	elas_s	Elasticity between energy and other goods	0.30	0.50
	elas_m	Elasticity between materials	0.00	0.00
	elas_eva	Elasticity between energy and value added	0.50	0.50
	elas_e	Elasticity between energy goods	0.20	0.50
	elas_va	Elasticity between value added inputs	0.80	0.80
Battery Electric Vehicles and Fuel Cell Vehicles	**elas_evintro**	Elasticity between vehicle types	0.40	1.00
	elas_evcar	Elasticity between fuel and vehicle	0.40	0.40
	elas_evcarins	Elasticity between vehicle and insurance/maintenance	1.00	1.00
	elas_evins	Elasticity between insurance and maintenance	0.00	0.00

4. Production Sectors Representation

Production sectors are characterized by a nested Constant Elasticity of substitution (CES) production function, in which inputs can be substituted as shown in Figure 7. The model assumes that all industries maximize profits subject to technological constraints. Inputs to production are energy (including the same four types noted above for household consumption), capital, and labor. Production also uses inputs from intermediate products provided by other firms. The N_{ew}ERA model allows producers to change the technology and the energy source they use to manufacture goods. If, for example, petroleum prices rise, an industry can shift to a cheaper energy source. It can also choose to use more capital or labor in place of petroleum, increasing energy efficiency and maximizing profits with respect to industry constraints.

For the bulk chemicals and iron and steel sectors – sectors that produce process emissions from feedstock use – we employ specialized production structures that incorporate energy feedstock inputs in the production process. Using assumptions from the AEO 2021 Reference case, we model natural gas and petroleum product feedstock as inputs to the bulk chemicals sector, and metallurgical coal feedstock as input to the iron and steel sector. We assume that these feedstocks are consumed in fixed proportion to the respective sectoral output. Figure 7 illustrates the nesting structure for industrial sector production while Table 5 shows the elasticity parameters used in the structure.

Figure 7: Production Structure for Manufacturing and Energy-Intensive Sectors in N$_{ew}$ERA's Macroeconomic Model

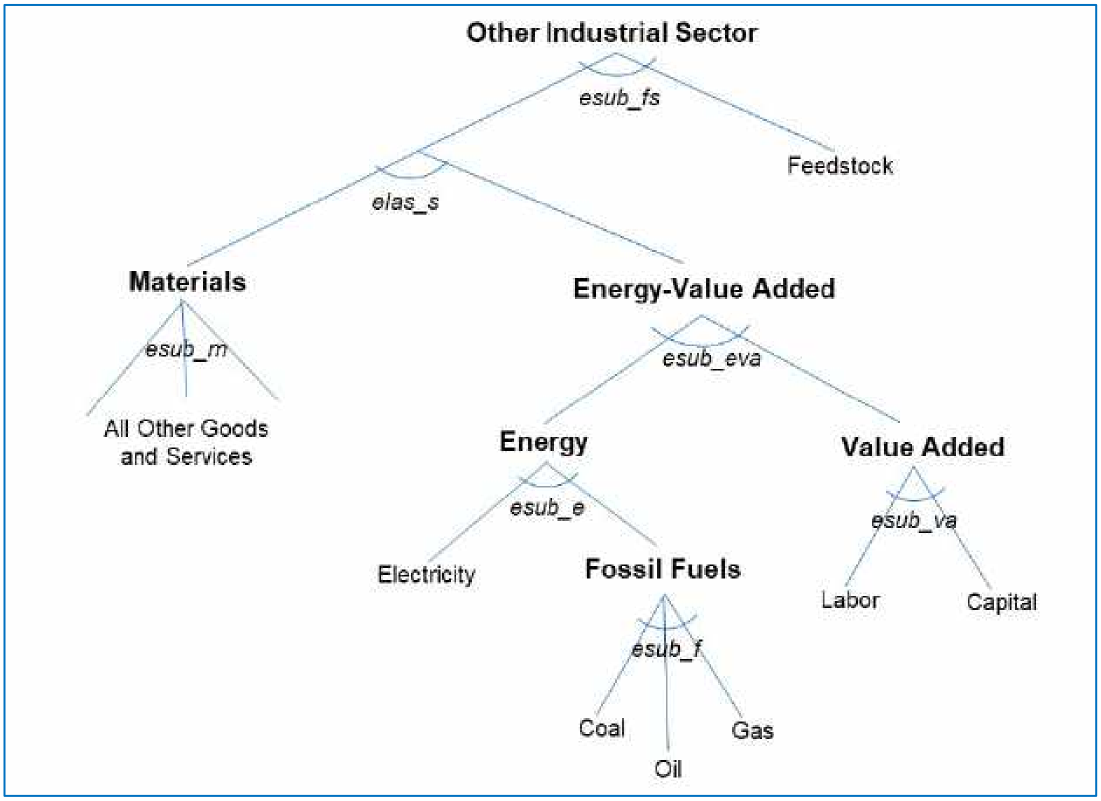


Table 5: Elasticity of Substitution Values for Industrial Sector Production

Elasticity	Description	Short-run	Long-Run
elas_fs	Elasticity between crude and other inputs	0.00	0.00
elas_s	Elasticity between energy and other goods	0.30	0.50
elas_m	Elasticity between materials	0.00	0.00
elas_eva	Elasticity between energy and value added	0.50	0.50
elas_e	Elasticity between energy goods	0.20	0.50
elas_va	Elasticity between value added inputs	0.80	0.80

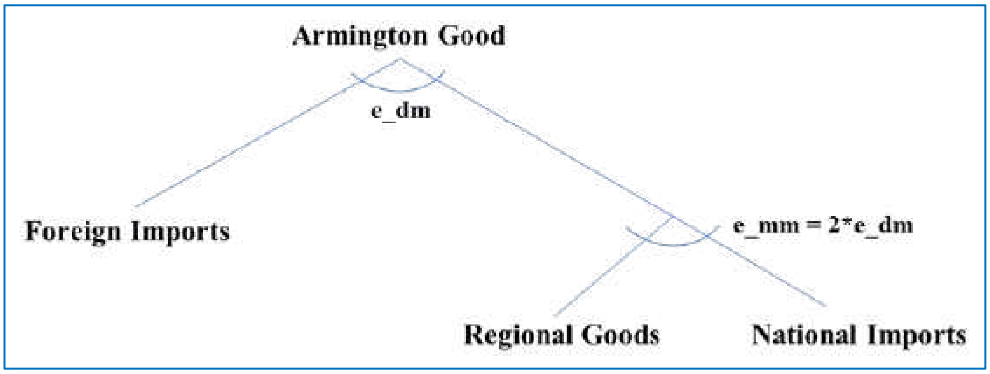
5. Trade Representation

All goods and services, except crude oil, are treated as Armington goods, which means domestic and foreign goods are differentiated and are thus imperfect substitutes.[22] As shown in Figure 8, these goods are either produced domestically or imported from foreign countries. The level of imports depends upon the elasticity of substitution between the imported and domestic goods. Using the "rule of two" discussed

[22] Armington P. 1969. "A Theory of Demand for Products Distinguished by Place of Production." *International Monetary Fund Staff Papers*, XVI: 159-78.

in Jomini et al. (1991),[23] the Armington elasticity among imported goods is assumed to be twice as that between the domestic and foreign imported goods, indicating greater substitutability among imported goods. The elasticity value at the top of the trade nest is assumed to be 2, based on the elasticity assumptions in MIT's EPPA modeling framework,[24] while the elasticity value between local goods and domestic imports is set at 4.

Figure 8: Trade Representation in NewERA's Macroeconomic Model



6. Exhaustible Resource Sector Representation

Crude oil, natural gas, and coal production are also characterized by a nested CES production function as shown in Figure 9. The N$_{ew}$ERA model does not explicitly model resource depletion. However, the resource constraints that arise from limited availability of the natural resource is represented by a fixed factor input, to mimic decreasing returns to scale in non-renewable resources. This implies that additional exhaustible resources can be harvested with rising marginal costs of production over time. Following model documentation on MIT's EPPA model and the EPA's EMPAX-CGE model,[25] we assume that the share of total production costs attributed to resource factors are 10% for coal, 33% for crude oil, and 25% for natural gas.

The top-level elasticity of substitution parameter that governs substitution between the natural resource and the materials - value added composite good, is calibrated to be consistent with each resource's short and long-run supply elasticity.

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[23] Jomini, P., Zeitsch, J. F., McDougall, R., Welsh, A., Brown, S., Hambley, J., & Kelly, J. (1991). SALTER: A General Equilibrium Model of the World Economy, vol. 1, Model Structure. Database and Parameters, Industry Commission, Canberra.

[24] Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005, The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. Joint Program Report Series Report 125, August 2005 (available at http://globalchange.mit.edu/publication/14578).

[25] RTI International (2008). 'EMPAX-CGE Model Documentation (Interim Report), March 2008, North Carolina, USA: Research Triangle Park.

A literature review of natural gas elasticity estimates included in a 2018 NERA report on LNG exports[26] suggests that the short-run supply elasticity for natural gas ranges between 0.25 and 0.4, while the long-run elasticity ranges from 0.7 to 2. We use 0.25 as the short-run elasticity which is consistent with the implied supply elasticity used in a 2012 study on LNG exports commissioned by the Department of Energy.[27] We assume that the long-run supply elasticity of natural gas is equal to unity, consistent with a study conducted by Medlock et al. (2015).[28] From this study we take the implied elasticity value in 2035 scenario in which U.S. LNG exports amounts to 12 billion cubic feet per day (Bcf/d).

For crude oil, we use 0.3 as the short-run and 1 as the long-run elasticity, which is in line with the 0.3-0.9 range presented in Bjørnland et al. (2019).[29] Lastly, we assume an elasticity value (both short and long-run) of 5 for the non-electric sector coal supply (note that we model coal supplied to the electric sector explicitly via coal supply curves). This elasticity value is supported by a literature survey conducted by Dahl and Duggan (1996),[30] which finds a wide range of coal supply elasticity estimates between 0.05 and 7.9.

The short and long-run elasticity parameters are used to construct a time-varying elasticity parameter for each resource that initially takes the short-run and converges logarithmically over time to the long-run elasticity value.

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[26] "Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports," Prepared by: NERA Economic Consulting, June 7, 2018 (available at https://www.energy.gov/sites/prod/files/2018/06/f52/Macroeconomic%20LNG%20Export%20Study%202018.pdf)

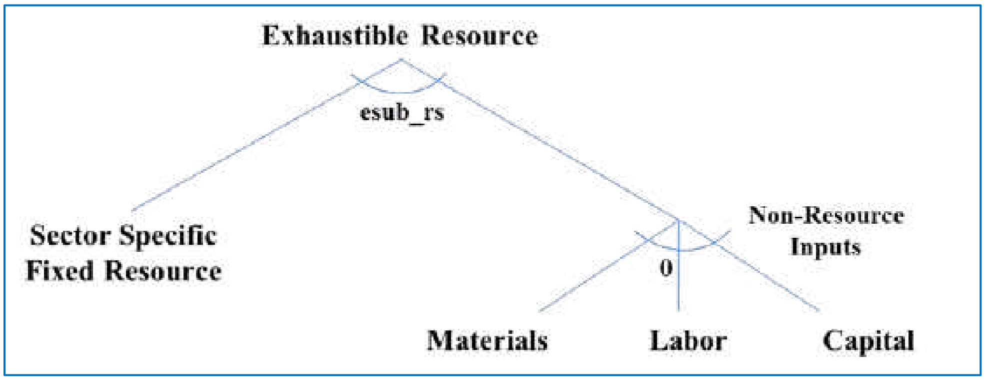
[27] "Effects of Increased Natural Gas Exports on Domestic Energy Markets, as requested by the Office of Fossil Energy," January 2012 (available at https://www.energy.gov/sites/prod/files/2013/04/f0/fe_eia_lng.pdf).

[28] Cooper, Adrian, Michael Kleiman, Scott Livermore, and Kenneth B. Medlock III. "The Macroeconomic Impact of Increasing US LNG Exports." (2015). (available at https://www.energy.gov/sites/prod/files/2015/12/f27/20151113_macro_impact_of_lng_exports_0.pdf).

[29] Hilde C. Bjørnland & Frode Martin Nordvik & Maximilian Rohrer, 2019."Supply flexibility in the shale patch: Evidence from North Dakota," CAMA Working Papers 2019-56, Centre for Applied Macroeconomic Analysis, Crawford School of Public Policy, The Australian National University. (available at https://cama.crawford.anu.edu.au/sites/default/files/publication/cama_crawford_anu_edu_au/2019-08/56_2019_bjornland_nordvik_rohrer.pdf).

[30] Dahl, C. and Duggan, T. E. (1996). US energy product supply elasticities: A survey and application to the US oil market. *Resource and Energy Economics*, 18(3):243-263.

Figure 9: Resources Sector Representation in NewERA's Macroeconomic Model



For each resource, we can construct the elasticity of substitution (*esub_rs* in Figure 9) between the resource and non-resource inputs using the value share of each component (resource and non-resource) in the resource production function, and the supply elasticity. Following Rutherford's method of benchmarking decreasing returns to scale production functions, presented in his documentation of MPSGE (1998),[31] we use the following expression to obtain elasticities of substitution between resource and non-resource inputs:

$$esub_{rs} = \frac{\theta\eta}{(1-\theta)},$$

where θ denotes the benchmark value share of the sector specific resource factor, and η, the time-varying supply elasticity parameter. The elasticity of substitution between the resource-specific resource and other goods in the production of fossil fuel is based on the supply elasticity of the resource. For natural gas and crude oil, we assume the supply elasticity to vary from 0.5 to 1.5 and 0.3 to 1.0, respectively. The values of the computed elasticities of substitution are displayed in Table 6.

Table 6: Elasticities of Substitution between Resource and Non-Resource Inputs in the Resource Sector

esub_rs	**2024**	**2027**	**2030**	**2033**	**2036**	**2039**	**2042**	**2045**
Natural Gas	0.393	0.660	0.980	1.220	1.386	1.505	1.578	1.633
Crude Oil	0.413	0.673	0.928	1.143	1.320	1.488	1.687	1.792

In terms of trade, production from the crude oil and natural gas sectors is either supplied to the domestic market or exported abroad. The N_{ew}ERA model represents the domestic and international crude oil and refined petroleum markets. The international markets are represented by flat supply curves with exogenously specified prices. Because crude oil is treated as a homogeneous good, the international price for crude oil sets the U.S. price for crude oil. Crude oil that is supplied to the domestic market is mixed with imported crude oil and is supplied to the domestic refinery sectors.

[31] Rutherford, Thomas F. "Economic equilibrium modeling with GAMS." Washington: GAMS Development Corporation (1998).

The natural gas module also accounts for foreign imports (as opposed to national imports) and U.S. exports of natural gas, by using a supply (demand) curve for U.S. imports (exports) that represents how the global LNG market price would react to changes in U.S. imports or exports. This makes it possible to provide a consistent analysis of the linkages between U.S. import levels, export policy, and the domestic price of natural gas.

We note that in the model, consumption of electricity as a transportation fuel can also affect the natural gas market. Along with alternative transportation fuels (including biofuels), the model also includes different vehicle choices that consumers can employ in response to changes in the fuel prices.

7. Investment Dynamics

Business investment decisions are informed by future policies and outlook. The forward-looking characteristic of the model enables businesses and consumers to determine optimal savings and investment levels through anticipation of future economic conditions. Intertemporal decisions are also linked through capital and investment dynamics. Capital turnover in the model is represented by a standard process that assumes capital in the next time period equals extant capital (minus the depreciated value of capital) plus investment. Such capital accumulation dynamics along with assumptions on perfect foresight allows for intertemporal decisions to optimize the tradeoff between present and future welfare.

8. Sectoral Aggregation

The N_{ew}ERA model for this study includes a standard set of 12 economic sectors: five energy (coal, natural gas, crude oil, electricity, and refined petroleum products) and seven non-energy sectors (motor vehicle manufacturing, energy-intensive sectors,[32] other manufacturing,[33] agriculture, commercial transportation other than trucking, trucking, and services). These sectors are aggregated up from 440 IMPLAN sectors. The model has the flexibility to represent sectors at different levels of aggregation, when warranted, to better meet the needs of specific analyses.

9. Tax Rates

The model accounts for personal income taxes on capital and labor, payroll taxes collected for Social Security under the Federal Insurance Contributions Act (FICA) and Medicare hospital insurance (HI), and the corporate income tax. The corporate income tax rates in the model are consistent with the Tax Cuts and Jobs Act (TCJA) which created as single corporate tax rate of 20%. We take tax rates from NBER's TAXSIM model[34] and other secondary sources. Based on TAXSIM data, we apply personal income tax rates to reflect the average marginal rate on labor income and the capital gains rate on capital income. A

[32] This comprises pulp and paper, chemicals, glass, cement, iron and steel, alumina and aluminum and mining.

[33] This comprises construction, food, beverage, and tobacco products, fabricated metal products, machinery, computer and electronic products, transportation equipment, electrical equipment, appliances, and components, wood and furniture, plastics, and other manufacturing sectors.

[34] Feenberg, Daniel, and Elisabeth Coutts. "An introduction to the TAXSIM model." *Journal of Policy Analysis and Management* 12.1 (1993): 189-194.

combined state and federal corporate income tax rate of 20%, consistent with TCJA[35] is applied to the corporate profit component of the total capital income. In addition, we apply a payroll tax rate of 12.4% to reflect Social Security's Old-age, Survivors, and Disability Insurance program and an additional 2.9% to reflect Medicare's Hospital Insurance (HI) program.

We differentiate tax rates at the state level in the database and hold the benchmark tax rates constant over the model horizon. These rates vary somewhat from state to state, as estimated by the NBER and Tax Foundation, due to differences in state income distributions. For 2013-2022, the baseline average marginal federal personal income (PIT) tax rate is 25% on labor earnings and 12% to 15% (depending on the state) on capital earnings. The Baseline average marginal corporate income tax rate is 19% to 21% depending on the state. The model estimates a weighted average of the state-specific levels to obtain a single rate for the U.S. as a whole.

10. Macroeconomic Outputs

As with other CGE models, the N_{ew}ERA macroeconomic model outputs include demand and supply of all goods and services, prices of all commodities, and terms of trade effects (including changes in imports and exports). The model outputs also include gross regional product, consumption, investment, cost of living or burden on consumers, and changes in "full-time job equivalents" based on changes in labor wage income. All model outputs are indexed by time, sector, and region.

11. Economic Database and Model Calibration

To model the inter-relationships of sectors in the economy, the model relies on a social accounting matrix (SAM), an economic database that portrays a snapshot of the economy in equilibrium. The N_{ew}ERA macroeconomic model uses the IMPLAN 2008 database as the benchmark data, which includes regional detail on economic interactions among 440 economic sectors.

The benchmark data is used to simulate forward a balanced dynamic equilibrium over the model time horizon. To calibrate the dynamic equilibrium, we adjust the benchmark data each year to incorporate forecasts in macroeconomic indices including GDP, sector output, population, energy use and carbon emissions. In this study, forecasts are drawn from the EIA's AEO 2021 Reference case.

E. Integrated NewERA Model

The N_{ew}ERA modeling framework fully integrates the macroeconomic model and the electric sector model so that the final solution is a consistent equilibrium for both models and thus for the entire U.S. economy.

We solve the integrated N_{ew}ERA model iteratively using a block decomposition method developed by Böhringer and Rutherford[36] using the Mathematical Programming System for General Equilibrium

[35] "The United States' Corporate Income Tax Rate is Now More in Line with Those Levied by Other Major Nations," February 12, 2018 (available at https://taxfoundation.org/us-corporate-income-tax-more-competitive/).

[36] Böhringer, Christoph, and Thomas F. Rutherford. "Combining top-down and bottom-up in energy policy analysis: a decomposition approach." ZEW-Centre for European Economic Research Discussion Paper 06-007 (2006).

(MPSGE) modeling framework[37] in GAMS.[38] The top-down macroeconomic model solves for equilibrium prices throughout all sectors, while the bottom-up model solves for equilibrium quantities in the electricity sector. The solution process is iterated until key prices and quantities converge.

To analyze a policy scenario, the system first solves for a consistent baseline solution between the two models. To obtain the baseline solution, the electric sector model is solved first under projections on electricity demand and energy prices. The equilibrium solution provides baseline electricity demand and supply by region, as well as the inputs—capital, labor, energy, and materials— used for production in the electric sector. These solution values are saved and passed on to the macroeconomic model.

Holding fixed electricity supply and intermediate goods consumption obtained from the electric sector model, the macroeconomic model solves for its baseline solution under the same energy price forecasts used to solve the electric sector baseline. In addition to energy price forecasts, the macroeconomic model's non-electric energy sectors are calibrated to exogenous target forecasts (e.g., EIA's latest AEO forecast) that include projections on energy consumption, energy production, and macroeconomic growth. The macroeconomic model solves for equilibrium prices and quantities in all model markets, subject to these exogenous forecasts.

After establishing baseline results, the integrated N_{ew}ERA modeling system solves for the counterfactual scenario. First the electric sector model reads in the scenario definition (often relative to the baseline) and solves for the equilibrium level of electricity demand, electricity supply, and inputs used by the electric sector (i.e., capital, labor, energy, emissions permits). Again, the electric sector model passes these equilibrium solution quantities to the macroeconomic model, which solves for the equilibrium prices and quantities in all markets. In turn, the macroeconomic model passes on to the electric sector model the following elements:

- Electricity prices by region;
- Prices of non-coal fuels used by the electric sector (*e.g.*, natural gas and oil); and
- Prices of any permits that are tradable between the non-electric and electric sectors (*e.g.*, carbon permits under a nationwide greenhouse gas cap-and-trade program).

The electric sector model then solves for the new electric sector equilibrium, taking the prices from the macroeconomic model as exogenous inputs. The models iterate—prices being sent from the macroeconomic model to the electric sector model, and quantities being sent from the electric sector model to the macroeconomic model—until the prices and quantities in the two models differ by less than a fraction of a percent.

This decomposition algorithm allows the N_{ew}ERA model to retain high-dimensional model details of the electricity model, while also considering impacts – to and from – the rest of the economy. N_{ew}ERA's

[37] Rutherford, Thomas F. "Applied general equilibrium modeling with MPSGE as a GAMS subsystem: An overview of the modeling framework and syntax." *Computational Economics* 14.1-2 (1999): 1-46.

[38] Brooke, A., Kendrick, D., Meeraus, A., Raman, R., & America, U. (1998). The general algebraic modeling system. GAMS Development Corporation, 1050.

detailed electricity sector model allows for the simulation and analysis of current regulatory policies imposed on the electricity sector at the generation unit level.

APPENDIX II. BASELINE AND SCENARIO INPUT ASSUMPTIONS

A. Baseline Modeling Assumptions

The NewERA baseline for this analysis was calibrated to match projections developed by Federal government agencies, notably those of the EIA as defined in its *Annual Energy Outlook 2021* (hereafter referred to as *AEO 2021*) Reference case.[39] This baseline includes the effects of continuing implementation of energy and environmental regulations that have already been promulgated (e.g., the Regional Greenhouse Gas Initiative (RGGI), the California GHG cap-and-trade program, federal vehicle fuel economy standards, federal appliance energy efficiency standards, and state renewable portfolio standards).

1. Fuel Prices

The references for assumptions related to fuel prices are presented in Table 7 below.

Table 7: References for Fuel Price Assumptions

Assumption	Description
Natural gas (Henry Hub), Distillate fuel oil price and Biomass trajectories	AEO 2021, EIA, Reference Case[40]
Natural gas basis differentials	EPA IPM Power Sector Modeling Platform Reference Case [41]

2. Technology Cost Assumptions

The references for assumptions related to technology capital costs are presented in Table 8 below.

Table 8: References for Technology Capital Costs

Assumption	Description
Cost characteristics of existing generating units	S&P Capital IQ Pro, S&P Global Market Intelligence[42]
Cost characteristics of new fossil, nuclear, and renewable electric generating units	Cost and Performance Characteristics of New Central Station Generating Technologies, AEO 2021, EIA [43,44]

[39] U.S. Energy Information Administration, *Annual Energy Outlook 2021*, February 2021 (available at https://www.eia.gov/outlooks/aeo/).

[40] U.S. Energy Information Administration, *Annual Energy Outlook 2021*, February 2021 (available at https://www.eia.gov/outlooks/aeo/).

[41] EPA's Power Sector Modeling Platform v6 using IPM January 2020 Reference Case (available at https://www.epa.gov/airmarkets/epas-power-sector-modeling-platform-v6-using-ipm-january-2020-reference-case).

[42] S&P Capital IQ Pro, S&P Global Market Intelligence (available at https://www.spglobal.com/marketintelligence/en/solutions/sp-capital-iq-pro).

[43] Cost and Performance Characteristics of New Generating Technologies, *Annual Energy Outlook 2021*, February 2021 (available at https://www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf).

[44] Except for new Biomass with CCS (BECCS) generating units in California and for new geothermal units in California and the rest of the U.S.

Regional cost factors for new fossil, nuclear, and renewable electric generating units	Total Overnight Capital Costs of New Electricity Generating Technologies by Region, AEO 2021, EIA[45]
Cost characteristics of new biomass with CCS generating units in California	Morris et al. (2019) [46]
Cost characteristics of new geothermal generating units in California	EPA IPM Power Sector Modeling Platform Reference Case[47]
Cost characteristics of direct air capture (DAC) units in California	Low: Pradhan et al. (2021) [48]; High: Keith et al. (2018) [49]

3. CO_2 Emissions

The references related to the assumptions for the baseline CO_2 emission inputs are presented in Table 9 below

Table 9: References for Baseline CO_2 Emissions

Assumption	Description
Baseline non-electric sector CO_2 emissions forecast for California	California 2000-2019 GHG Inventory (2021 Edition), CARB[50]; BAU Reference GHG Emission Projections, Draft 2022 Scoping Plan, CARB[51]
Baseline non-electric sector CO_2 emissions forecast for Rest of the U.S.	AEO 2021, EIA, Reference Case [52,53]

[45] Total Overnight Capital Costs of New Electricity Generating Technologies by Region, Assumptions to the Annual Energy Outlook 2021: Electricity Market Module, *Annual Energy Outlook 2021*, February 2021 (available at https://www.eia.gov/outlooks/archive/aeo21/assumptions/pdf/electricity.pdf).

[46] Morris et al. (2019). Representing the costs of low-carbon power generation in multi-region multi-sector energy-economic models. *International Journal of Greenhouse Gas Control*, *87*, 170-187.

[47] EPA's Power Sector Modeling Platform v6 using IPM January 2020 Reference Case (available at https://www.epa.gov/airmarkets/epas-power-sector-modeling-platform-v6-using-ipm-january-2020-reference-case).

[48] Pradhan et al. (2021). Effects of Direct Air Capture Technology Availability on Stranded Assets and Committed Emissions in the Power Sector. *Frontiers in Climate, 3:660787*.

[49] Keith et al. (2018). A Process for Capturing CO_2 from the Atmosphere. *Joule*, *2*(8), 1573-1594.

[50] California Greenhouse Gas Emissions for 2000 to 2019, California Air Resources Board (available at https://ww2.arb.ca.gov/ghg-inventory-data).

[51] 2022 Scoping Plan Documents, California Air Resources Board (available at https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents).

[52] U.S. Energy Information Administration, *Annual Energy Outlook 2021*, February 2021 (available at https://www.eia.gov/outlooks/aeo/).

[53] The non-electric CO_2 emissions represented in the NewERA model includes CO_2 emissions from fossil fuel combustion and process CO_2 emissions from the industrial sector (which relate to emissions from the chemical transformation of raw materials). Non-CO_2 emissions as well as CO_2 emissions that relate to fugitive emissions from oil and gas production and processing, emissions from flaring and feedstock emissions are not explicitly modeled in the NewERA modeling framework.

The baseline CO_2 emissions forecast for the electric sector in California and for the rest of the U.S. are exogenous outcomes of the NewERA electricity sector model.

4. Renewable Portfolio Standards

For the baseline, we assume the RPS specification in California to be 60% by 2045 consistent with the assumption for the reference baseline per the SB100 Joint Agency Report.[54] For other regions in the electricity model, the baseline RPS specifications are based on the Lawrence Berkeley National Laboratory's RPS Annual Status Update publication.[55]

5. Electricity and Peak Demand

The references related to the assumptions for the baseline electricity and peak demand are presented in Table 10 below

Table 10: References for Baseline Electricity and Peak Demand

Assumption	Description
Baseline electricity demand	Net Energy for Load Projections, AEO 2021, EIA, Reference Case [56]
Baseline peak demand	Electricity Supply and Demand (2020 Update), NERC [57]

6. Capacity Potential and Build Limits

The references related to the assumptions for capacity potential and annual build limits in the electricity sector model are presented in Table 11 below.

Table 11: References for Capacity Potential and Annual Build Limits

Assumption	Description
Capacity potential	EPA IPM Power Sector Modeling Platform Reference Case [58]

[54] SB 100 Joint Agency Report: Charting a path to a 100% Clean Energy Future, California Energy Commission, March 2021 (available at https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity). The following resources in California are included under the RPS in the NewERA electricity sector model: Solar Photovoltaic, Concentrated Solar Thermal (Existing only), Onshore Wind, Offshore wind, Solar Photovoltaic with Storage, Onshore Wind with Storage, Geothermal and Small Hydro (Existing facilities smaller than 30 MW).

[55] Lawrence Berkeley National Laboratory, U.S. Renewable Portfolio Standards: 2021 Annual Status Update, Electricity Markets and Policy Group, February 2021 (available at: https://emp.lbl.gov/projects/renewables-portfolio).

[56] U.S. Energy Information Administration, *Annual Energy Outlook 2021*, February 2021 (available at https://www.eia.gov/outlooks/aeo/).

[57] North American Electric Reliability Corporation, *Electricity Supply and Demand (ES&D, 2020* (available at https://www.nerc.com/pa/RAPA/ESD/Pages/default.aspx).

[58] EPA's Power Sector Modeling Platform v6 using IPM January 2020 Reference Case (available at https://www.epa.gov/airmarkets/epas-power-sector-modeling-platform-v6-using-ipm-january-2020-reference-case).

Annual build limits (Natural gas with CCS generating units in California)	An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions, October 2020 [59]; Baik et al. (2022) [60]
Annual build limits (Renewable generating units in California)	CAISO 20-Year Transmission Outlook [61]
Annual build limits (DAC in California)	Getting to Neutral: Options for Negative Carbon Emissions in California, January, LLNL (2020) [62]

7. Transmission Flow Limits and Costs

The assumptions relating to the flow limits and costs associated with electricity transmission between the various regions in the U.S. are drawn from the EPA IPM Power Sector Modeling Platform's Reference Case.[63]

8. Carbon Capture and Storage (CCS) Transport and Storage Costs

The assumptions relating to the transport and storage costs of CO_2 captured at new coal and natural gas plants equipped with CCS are drawn from the EPA IPM Power Sector Modeling Platform's Reference Case.[64]

9. Biofuel Characteristics

The relative cost of biofuels relative to conventional fuels (motor gasoline and diesel) and the assumptions relating to the carbon intensity of biofuels, conversion efficiencies and blend wall assumptions are drawn from CARB's Biofuel Scenario model.[65] The biofuels that can be substituted for gasoline in the model include imported sugar ethanol, corn ethanol, cellulosic ethanol, biomass-to-liquid (BTL) fuel and compressed natural gas (CNG). For the diesel market, we include bio-diesel from waste grease and corn, CNG and BTL diesel.

10. Low Carbon Fuel Standard (LCFS)

The LCFS sets annual carbon intensity (CI) standards or benchmarks for gasoline, diesel, and the fuels that replace them.[66] Under the current LCFS regulation, the benchmarks for gasoline and

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[59] Energy Futures Initiative and Stanford University. An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions, October 2020 (available at https://sccs.stanford.edu/california-projects/opportunities-and-challenges-for-CCS-in-California).

[60] Baik et al. (2022). California's approach to decarbonizing the electricity sector and the role of dispatchable, low-carbon technologies. *International Journal of Greenhouse Gas Control*, 113: 103527.

[61] 20-Year Transmission Outlook, CAISO, January 2022 (available at http://www.caiso.com/InitiativeDocuments/Draft20-YearTransmissionOutlook.pdf).

[62] Lawrence Berkeley National Laboratory, U.S. Renewable Portfolio Standards: 2021 Annual Status Update, Electricity Markets and Policy Group, February 2021 (available at: https://emp.lbl.gov/projects/renewables-portfolio).

[63] EPA's Power Sector Modeling Platform v6 using IPM January 2020 Reference Case (available at https://www.epa.gov/airmarkets/epas-power-sector-modeling-platform-v6-using-ipm-january-2020-reference-case).

[64] *Ibid*

[65] The Biofuel Scenario Model (Draft Version 0.91 BETA), California Air Resources Board (available at https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2017-scoping-plan-documents).

[66] The carbon intensity is expressed in grams of carbon dioxide equivalent per megajoule of energy provided by that fuel. The CI takes into account the GHG emissions associated with all steps of producing, transporting, and

diesel CI are equal to a 6.5 percent reduction relative to 2010, increasing to 20 percent to 2030 and then stays flat post-2030.[67] The data on the initial endowment of LCFS permits are drawn from CARB's LCFS quarterly reports. The most recent data for the endowment of LCFS permits is for Q4 2021 and was reported to be about 9.45 MMT (and is the sum of the previous quarter's banked credits, that quarter's total credits minus any deficits).[68]

11. Combined Heat and Power (CHP) Capacity and Technology Costs

The references for assumptions related to CHP capacity and technology costs are presented in Table 12 below.

Table 12: References for California CHP Capacity and Technology Costs

Assumption	Description
Capacity of existing CHP installations in California	U.S. DOE CHP and Microgrid Installation Database [69]
Cost characteristics of CHP installations	U.S. DOE CHP Technology Fact Sheet Series [70]

12. Transportation Sector Vehicle Cost Markups

Table 13: References for Cost Markups for Electric Vehicles

Assumption	Description
Cost markups for battery-electric vehicles relative to gasoline ICE vehicles (Personal transportation sector)	AEO 2021, EIA, Reference Case [71]
Cost markups for battery-electric and fuel-cell electric H_2 vehicles (Trucking sector)	UC Davis Research Report on Zero-Emissions Medium and Heavy-Duty Vehicle Technologies

consuming a fuel. The LCFS lets the market determine which mix of fuels will be used to reach the program targets. The fuels and fuel blendstocks introduced into the California fuel system that have a CI higher than the benchmark generate deficits. Similarly, fuels and fuel blendstocks with CIs below the benchmark generate credits. Annual compliance is achieved when a regulated party uses credits to match its deficits.

[67] LCFS Basics, Low Carbon Fuel Standard, California Air Resources Board (available at https://ww2.arb.ca.gov/resources/documents/lcfs-basics); California Climate Policy Fact Sheet: Low Carbon Fuel Standard, Center for Law, Energy and the Environment, Berkeley Law (available at https://www.law.berkeley.edu/wp-content/uploads/2019/12/Fact-Sheet-LCFS.pdf).

[68] Low Carbon Fuel Standard Reporting Tool Quarterly Summaries, California Air Resources Board (available at https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries).

[69] Full CHP data set, U.S. Department of Energy Combined Heat and Power and Microgrid Installation Databases, U.S. Department of Energy (available at https://doe.icfwebservices.com/downloads/chp).

[70] Combined Heat and Power Technology, Fact Sheet Series, U.S. Department of Energy (available at https://www.energy.gov/sites/default/files/2017/12/f46/CHP%20Overview-120817_compliant_0.pdf).

[71] U.S. Energy Information Administration, *Annual Energy Outlook 2021*, February 2021 (available at https://www.eia.gov/outlooks/aeo/).

13. Vehicles Miles Traveled and Fuel Economy

The references that relate to vehicle fuel economy and miles traveled are presented in Table 14 below.

Table 14: References for Vehicle Fuel Economy

Assumption	Description
Fuel Economy (Electric Vehicles)	MIT U.S. Regional Energy Policy (USREP) Model [72]
Vehicle Miles Traveled and Fuel Economy (Stock)	EMFAC 2021, April 2021, CARB [73]

14. Generator Retirements and Planned Capacity Additions

The NewERA electricity sector model incorporates the most up-to-date data on the retirement of electric generators and planned capacity additions per the monthly electric generator EIA-860M form.[74] It is assumed that natural gas generators in California remain online for the entirety of the model horizon to meet reliability requirements. [75]

B. Scenario Modeling Assumptions

The following assumptions were incorporated in NewERA to model some of the key elements of the Proposed Scenario (also referred to as "Alternative 3") from CARB's 2022 draft scoping plan.[76]

1. Personal Transportation Sector

- Fuel Economy Standards –ACC I GHG standards for 2017-2025 model years and a 2% annual fuel economy improvement for 2026-2035 model years.[77]

[72] The MIT U.S. Regional Energy Policy (USREP) Model: The Base Model and Revisions (available at https://globalchange.mit.edu/publication/17331).

[73] Emission Factor (EMFAC) Model, California Air Resources Board, Updated April 2021 (available https://arb.ca.gov/emfac/).

[74] Monthly Electric Generator Inventory (based on Form EIA-860M as a supplement to Form EIA-860) (available at: https://www.eia.gov/electricity/data/eia860m/).

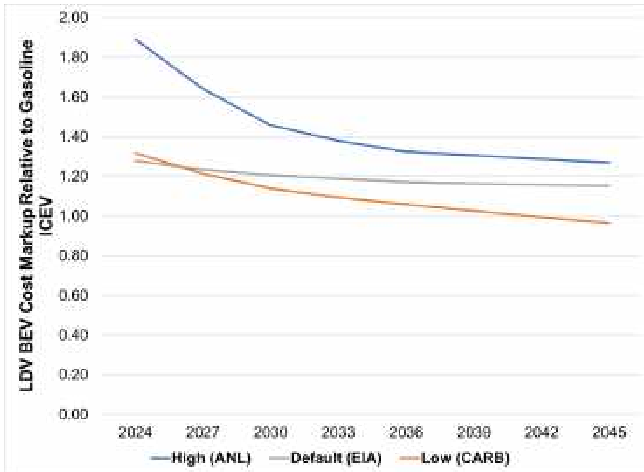
[75] This is consistent with the assumptions that underlie the 38 MMT GHG target for the electricity sector in 2030 in the CARB draft 2022 scoping plan and based on CPUC's 2021 IRP planning cycle. *See* Sections 4.1.4 and 4.1.5, Decision Adopting 2021 Preferred System Plan, February 10, 2022 (available at https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M449/K173/449173804.PDF).

[76] Draft 2022 Scoping Plan Update, California Air Resources Board, May 10, 2022 (available at https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf).

[77] Using data from the April 2021 version of the California Air Resources Board's EMFAC model (available at https://arb.ca.gov/emfac/), the percentage improvement in fuel economy for the LDV stock was calculated to be about 15% by 2050.

- Zero Emission Vehicle (ZEVs) Mandate – 100% of LDV sales are ZEVs by 2035[78, 79]
- Cost markups of BEVs (relative to Gasoline ICE vehicles): Low - ZEV Cost Modeling Workbook, ACC II workshop, CARB, May 2021[80]; High - Argonne National Laboratory (ANL) Total Cost of Ownership Study[81]. Figure 10 presents these LDV sector cost markups for the default, high, and low cases.[82]

Figure 10: Cost Markups of BEVs in the LDV Sector Relative to Gasoline ICE Vehicles



2. Commercial Trucking Sector

- Zero Emission Vehicle (ZEVs) Mandate – 100% of MD/HDV sales are ZEV by 2040[83,84]
- Cost markups of BEVs and FCEVs (relative to Diesel ICE vehicles): Low – CARB Draft Advanced Clean Fleets Total Cost of Ownership Discussion Document[85]; High – NREL

[78] Governor Newsom's Zero-Emission by 2035 Executive Order (N-79-20) (available at https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf).

[79] Using data from the April 2021 version of the California Air Resources Board's EMFAC model (available at https://arb.ca.gov/emfac/), it was determined that the mandate of 100% ZEV sales by 2035 translates to a share of ZEVs in the LDV vehicle stock of about 92% by 2050. This was the target that was imposed in the NewERA model to implement the ZEV mandate.

[80] "ZEV Cost Modeling Workbook, ACC II workshop, CARB, May 2021", Public Workshop on Advanced Clean Cars II (available at https://ww2.arb.ca.gov/events/public-workshop-advanced-clean-cars-ii-1).

[81] Burnham et al., Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains, April 2021 (available at https://www.osti.gov/biblio/1780970-comprehensive-total-cost-ownership-quantification-vehicles-different-size-classes-powertrains).

[82] The default assumptions are used in the BAU case while the low and the high assumptions are used in the "High Alternative Vehicle Cost" and "Low Alternative Vehicle Cost" sensitivity cases.

[83] AB-74 Budget Act of 2019 (available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201920200AB74); AB 74 ITS Report (available at https://www.ucits.org/research-project/2179/).

[84] Using data from the April 2021 version of the California Air Resources Board's EMFAC model (available at https://arb.ca.gov/emfac/), it was determined that the mandate of 100% ZEV sales by 2040 translates to a share of ZEVs in the trucking vehicle stock of about 90% by 2050. This was the target that was imposed in the NewERA model to implement the ZEV mandate.

[85] Draft Advanced Clean Fleets Total Cost of Ownership Discussion Document, Advanced Clean Fleets Workshop, September 9, 2021 (available at https://ww2.arb.ca.gov/sites/default/files/2021-08/210909costdoc_ADA.pdf).

Market Segmentation Analysis of Medium and Heavy Duty Trucks with a Fuel Cell Emphasis.[86] Figure 11 and Figure 12 presents these commercial trucking sector cost markups for the default, high, and low cases.[87]

Figure 11: Cost Markups of BEVs in the Commercial Trucking Sector Relative to Diesel ICE Vehicles

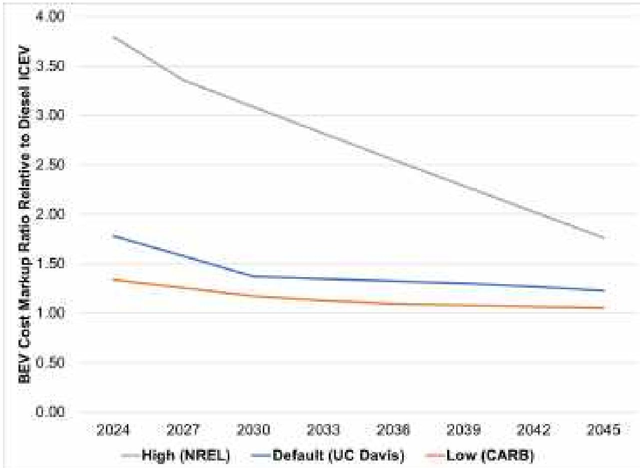
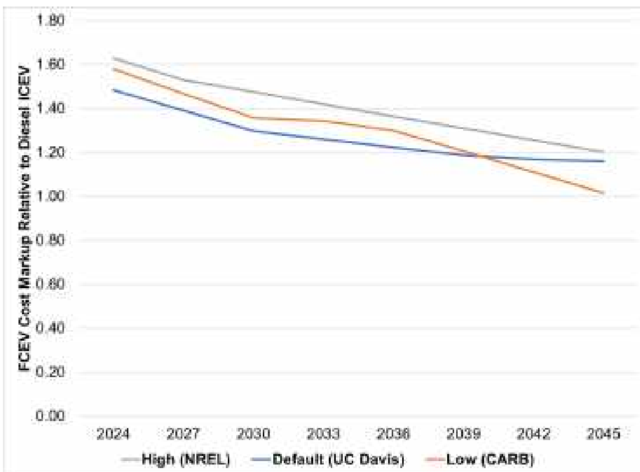


Figure 12: Cost Markups of FCEVs in the Commercial Trucking Sector Relative to Diesel ICE Vehicles



3. Electric Sector

- RPS specification in California requiring 60% of electric retail sales to end-use customers to come from renewable resources by 2030[88]

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[86] Hunter et al., Market Segmentation Analysis of Medium and Heavy Duty Trucks with a Fuel Cell Emphasis, May 31, 2020 (available at https://www.hydrogen.energy.gov/pdfs/review20/sa169_hunter_2020_o.pdf).

[87] The default assumptions are used in the BAU case while the low and the high assumptions are used in the "High Alternative Vehicle Cost" and "Low Alternative Vehicle Cost" sensitivity cases.

[88] Per the specification in Senate Bill No. 100 (available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100). The following resources in California are included under the RPS in the NewERA electricity sector model: Solar Photovoltaic, Concentrated Solar Thermal (Existing only), Onshore Wind, Offshore wind, Solar Photovoltaic with Storage, Onshore Wind with Storage, Geothermal and Small Hydro (Existing facilities smaller than 30 MW).

- SB100 specification in California requiring 100% of electric retail sales to end-use customers to come from renewable and zero-carbon resources by 2045.[89]

4. Energy Efficiency

- The electric energy efficiency targets by sector and the associated avoided costs are drawn from California's Public Utilities Commission's (CPUC) Updated 2021 Energy Efficiency Potential and Goals Study.[90]
- The natural gas efficiency targets by sector are drawn from the California Energy Commission's (CEC) Senate Bill 350 Doubling Energy Savings by 2030 Method Report.[91]

5. Curtailment

The model assumptions that relate to solar and wind curtailment in California were developed using data on solar and wind production and curtailment from CAISO for 2021.[92] The inputs to the model are specified as percentage of generation to be curtailed for different levels of solar and wind penetration percentages by load block.[93,94]

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[89] Per the specification in Senate Bill No. 100 (available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100). In addition to the resources that qualify towards the RPS, , Large Hydro (Existing facilities larger than 30 MW), Nuclear (Existing only) and Natural gas equipped with CCS also qualify towards meeting SB100 requirements in our model. These eligibility criteria are consistent with Attachment B of CARB's 2022 Scoping Plan Scenario Assumptions released as part of the 2022 Scoping Plan Update (available at https://ww2.arb.ca.gov/sites/default/files/2021-12/Revised_2022SP_ScenarioAssumptions_15Dec.pdf).

[90] 2021 Potential and Goals Study, California Public Utilities Commission, July 2021 (available at https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/energy-efficiency-potential-and-goals-studies/2021-potential-and-goals-study). We specify electric efficiency targets (in units of GWh) and avoided costs (in units of $/MWh) for five sectors: commercial, energy-intensive industrial sectors, other industrial sectors, refineries, and the residential sector. The energy-intensive industrial sectors are comprised of chemicals, paper, primary metals, printing and publishing, stone, glass, and clay manufacturing, and mining. The other industrial sectors are comprised of agriculture, electronics, fabricated metals, food, industrial machinery, lumber and furniture, plastics, textiles, transportation equipment manufacturing and all other industrial sectors.

[91] Senate Bill 350 Doubling Energy Savings by 2030 Method Report, December 2019 (available at https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=17-IEPR-06). We specify the energy efficiency targets as a percentage improvement in energy intensity versus the BAU case for the building, industrial and residential sectors.

[92] Production and Curtailment Data – 2021, Oversupply and Curtailments, California ISO (available at http://www.caiso.com/informed/Pages/ManagingOversupply.aspx).

[93] Under a typical 8 load block (LB) definition, LB1 and LB2 correspond to the peak and off-peak hours in summer respectively. LB3 and LB4 correspond to the peak and off-peak hours in spring respectively. LB5 and LB6 correspond to the peak and off-peak hours in the fall season. LB7 and LB8 correspond to the peak and off-peak hours in the winter season.

[94] The NewERA model for this study was run in 4 LB mode where each LB is representative of the hours in a season. Under such a load-block definition, the model does not distinguish between on-peak and off-peak hours. Thus, the typical curtailment assumptions described above do not apply in the 4 LB runs that we have carried out for this study.

6. CCS Cost Markups for the Industrial Sector

A. CCS in the Refinery Sector

To model CCS as a technology in the refinery sector, we developed cost markups for capital costs, non-energy (fixed operations and maintenance) costs and fuel (electricity and natural gas) costs that represent the differences in costs between refinery configurations with and without CCS. The data to develop the cost markups were drawn from a SINTEF study on the cost of retrofitting CO_2 capture in an integrated oil refinery[95] and from Chapter 2 of a National Petroleum Council Report presenting a roadmap for the at-scale deployment of carbon capture, use, and storage.[96] The markup for capital costs was estimated to range between 1.34 and 1.56. The markup for non-energy costs was estimated to range between 1.10 and 1.17. The markup for fuel costs was estimated to be 1.23.

B. CCS in the Energy-Intensive Sectors

To model CCS as a technology in the energy-intensive sectors, we developed cost markups for capital costs, non-energy (labor) costs and fuel (electricity and natural gas) costs that represent the differences in costs between processes in EIS with and without CCS. The data to develop the cost markups were drawn from a paper on the role of CCS in emissions mitigation in hard-to-abate sectors.[97] In this paper, the cost markups were calculated as the difference between the cost input shares that correspond to electricity, natural gas, labor, and capital between a reference plant with no CCS and a plant with natural gas-fired post combustion capture. The cost markup for natural gas use was estimated to be about 16.24 while the markup for electricity use was estimated to be 1.28. The cost markup for labor costs was estimated to be about 1.46 while the markup for capital costs was estimated to be 5.91.

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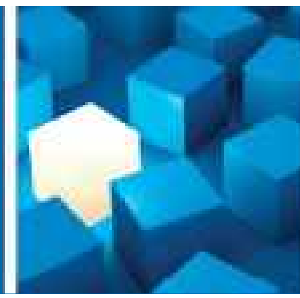
[95] Sigurd Sannan, Kristin Jodal, Simon Roussanaly, Chiara Giraldi, Annalisa Clapis, Understanding the Cost of Retrofitting CO_2 Capture in an Integrated Oil Refinery, Reference Base Case Plants: Economic Evaluation, SINTEF, August 2017 (available at https://www.sintef.no/globalassets/project/recap/deliverable-d3_reference-plants-economic-evaluation_final_code.pdf).

[96] National Petroleum Council Report, Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage, December 2019 (available at https://dualchallenge.npc.org/).

[97] Sergey Paltsev, Jennifer Morris, Haroon Kheshgi, Howard Herzog, Hard-to-Abate Sectors: The role of industrial carbon capture and storage (CCS) in emission mitigation, *Applied Energy* 300 (2021): 117322.



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