Workshop Discussion Draft

2020 Mobile Source Strategy

September 30, 2020

CALIFORNIA
AIR RESOURCES BOARD

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Executive Summary

The California Air Resources Board (CARB or Board) has over 50 years of experience reducing mobile source emissions that have improved air quality and reduced climate pollutants. Through these efforts, the State and our most polluted regions have seen dramatic improvements in ambient air quality and, as a byproduct, CARB has helped California become a world leader in environmental policies and clean technologies. Even with our progress, many areas of the State exceed current health-based ambient air quality standards that the State must legally meet; in addition, many near-source, low-income and disadvantaged communities continue to experience disproportionately high levels of air pollution and the resulting detrimental impacts to their health. Further, climate change is causing extreme heat, devastating wildfires, historic droughts, torrential storms, causing billions of dollars in property damage and threatening human health and the economy of the residents of California – the unprecedented number of acres burned by wildfires in 2020 reemphasizes that climate change is here now. These immediate threats of climate change demand action and have resulted in a number of Statewide targets and CARB policies to date.

Mobile sources including cars, trucks, tractors, and a myriad of other on-road vehicles and off-road equipment, contribute a majority of smog-forming oxides of nitrogen (NOx), the largest portion of greenhouse gas (GHG) emissions, and are a significant source of toxic air contaminants that directly impact community health. The 2016 Mobile Source Strategy (2016 Strategy or 2016 MSS) was CARB's first integrated planning effort looking specifically at mobile sources to identify complementary policies to reduce emissions of precursors to criteria pollutants, greenhouse gases, and toxics.

In recognition of the value of the 2016 Strategy in relation to the State's ongoing air quality, climate, and community risk reduction challenges, and the ever-evolving vehicle market, the California Legislature passed Senate Bill 44,[1] which Governor Newsom signed into law on September 20, 2019. SB 44 acknowledged the ongoing need to evaluate opportunities for mobile source emissions reductions and requires CARB to update the 2016 Strategy by January 1, 2021, and every five years thereafter. Specifically, SB 44 requires CARB to update the 2016 Strategy to include a comprehensive strategy for the deployment of medium and heavy-duty vehicles for the purpose of meeting air quality standards and reducing GHG emissions. It also directs CARB to set reasonable and achievable goals for reducing emissions by 2030 and 2050 from medium- and heavy-duty vehicles that are consistent with the State's overall goals and maximizes the reduction of criteria air pollutants.

[1] Skinner, Chapter 297, Statutes of 2019

This document, the 2020 Mobile Source Strategy (2020 Strategy or 2020 MSS), continues this multi-pollutant planning approach to determine the pathways forward for the various mobile sectors that are necessary in order to achieve California's numerous goals and targets over the next 30 years. Because meeting all of the State's near- and longer-term goals requires action across the full spectrum of mobile sources, this document also discusses light-duty on-road vehicles, as well as a wide range of off-road equipment sectors.

More recently, on September 23, 2020, Governor Newsom signed Executive Order N-79-20[2] which established a goal that 100 percent of California sales of new passenger car and trucks be zero-emission by 2035. In addition, the Governor's order set a goal to transition all drayage trucks to zero-emission by 2035, all off-road equipment to zero-emission where feasible by 2035, and the remainder of medium- and heavy-duty vehicles to zero-emission where feasible by 2045. With this order and many other recent actions, Governor Newsom has recognized that climate change is happening now, impacting California in unprecedented way and affecting the health and safety of too many Californians. Under the order, CARB is tasked to work with our State agency partners to develop regulations to achieve these goals taking into account technological feasibility and cost effectiveness.

Consistent with Executive Order N-79-20 and SB 44, in the 2020 Strategy, staff have identified a suite of strategy concepts, many of which CARB is actively pursuing through individual public processes that will enable the State to achieve the technology trajectories identified through scenario planning and, consequently, meet California's many goals. Further, these concepts maximize the criteria pollutant reductions by going to zero-emission where feasible. Specifically for medium- and heavy-duty vehicles, the scenarios call for the deployment of approximately 1.4 million medium- and heavy-duty zero-emission vehicles (ZEVs) in California by 2045. Statewide, the concepts in the 2020 Strategy could achieve criteria pollutant NOx reductions of over 600 tons per day in 2037, and reduce mobile source fuel consumption by 9.5 billion gallons of gasoline and 3.0 billion gallons of diesel equivalent in 2045. This equates to a well-to-wheel GHG emissions reduction of approximately 93 million metric tons of carbon dioxide equivalent in 2045.

For on-road light-duty vehicles, the 2020 Strategy includes the following concepts to move the State towards the goal of 100 percent of sales as electric vehicles by 2035:

- Manufacturer requirements to foster clean technology production and sales;
- In-use requirements to accelerate penetration of newer technology; and
- Incentive programs to promote and accelerate the use of advanced clean technologies.

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[2] Executive Order N-79-20 https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

For on-road medium- and heavy-duty vehicles, the 2020 Strategy includes the following concepts to move the State towards the goal of 100 percent of sales of California-registered trucks will be ZEVs by 2035:

- Manufacturer requirements to foster clean technology production and sales;
- In-use requirements to accelerate penetration of newer technology;
- Incentive programs to promote and accelerate the use of advanced clean technologies;
- Enhanced enforcement strategies to ensure programs are achieving their anticipated benefits;
- Outreach and education to bridge the knowledge gap and increase consumer acceptance of advanced vehicle and equipment technologies; and
- Infrastructure planning and development to support the transition to cleaner technologies.

For off-road vehicles and equipment, the 2020 Strategy includes the following concepts to move the State towards the goal of electrification where technologically feasible:

- Manufacturer requirements to foster clean technology production and sales;
- In-use requirements to accelerate penetration of newer technology;
- Incentive programs to promote and accelerate the use of advanced clean technologies;
- Outreach and education to bridge the knowledge gap and increase consumer acceptance of advanced vehicle and equipment technologies; and
- Infrastructure planning and development to support the transition to cleaner technologies.

In the near-term, incentive programs to promote and accelerate the use of advanced technologies will be essential to meeting our pre-2030 air quality goals and setting us on the trajectory for the future goals. The funding needed over the next five years to provide early reduction and put us on the path to meet our 2030 and 2050 climate goals is approximately $15 to $30 billion for vehicle and equipment costs alone to accelerate the use of advanced technologies. In addition to funding, it is critical that clean transportation is accessible to all Californians particularly those in low-income or disadvantaged communities who experience a disproportionate share of pollution impacts.

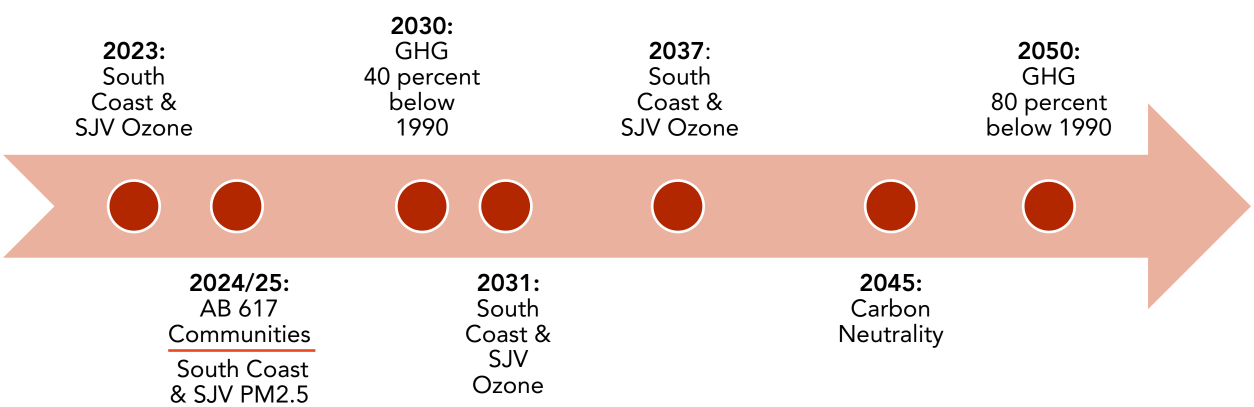
While the concepts contained in the 2020 Strategy are less defined than the measures included in the 2016 Strategy, they will be translated into measures that will be included in the next State Implementation Plan (SIP) strategy being developed for the 70 parts per billion (ppb) 8-hour ozone standard, the next Climate Change Scoping Plan, community emission reduction plans, or other CARB planning documents to be released in the coming years. In addition, the forthcoming State SIP Strategy will include further discussion on the programs and measures needed to achieve near-term and longer-term SIP targets.

Chapter 1 - Introduction

Over the last 50 years, California air pollution control efforts have resulted in dramatic improvements in smog levels, as well as reductions in a variety of harmful pollutants in urban and rural areas. Despite this progress, the State still has more work to meet many federal and State ambient air quality standards and other health and climate stabilization targets over the next 30 years. Emissions must be reduced from all sources of air pollution in California to not only meet the federal standards, but to minimize negative health effects in the State's most impacted and disadvantaged communities, and to lessen climate impacts.

To that end, much needs to be accomplished. The State of California and CARB have a multitude of standards, targets and goals to meet over the next 30 years (Figure 1).

Figure 1 – California's Air Quality Targets and Greenhouse Gas Reduction Goals

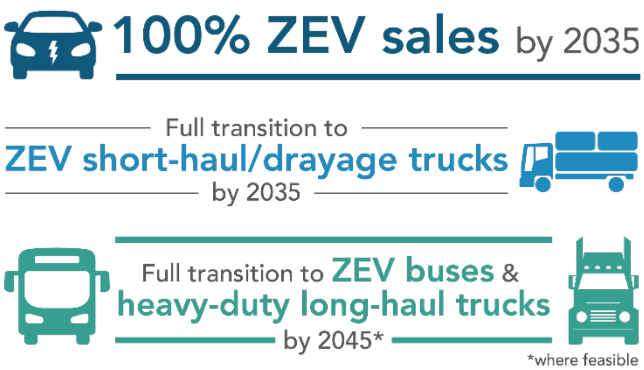


The State's climate goals include the mid-term target in 2030 for 40 percent GHG emissions reduction below 1990 levels, codified under Senate Bill (SB) 32,[3] and longer-term targets for economy wide carbon neutrality in 2045, and 80 percent GHG emissions reduction below 1990 levels by 2050 as directed by Executive Order S-03-05, a target that serves as a backstop to ensure these reductions are achieved in the transportation sector. While our future climate goals are 10, 25, and 30 years into the future, the existential threat of climate change is a crisis of the present and is already causing extreme heat, torrential storms, historic droughts, and the devastating wildfires that California is currently experiencing.

In recognition of the severity of the climate crisis and the need for immediate action, Governor Newsom signed Executive Order N-79-20 on September 23, 2020. This order established a first-in-the-nation goal for 100 percent of in-state sales of new

[3] Pavley, Chapter 249, Statutes of 2016

passenger cars and trucks to be zero-emission by 2035. In addition, the Governor's order set a goal to transition 100 percent of the drayage truck fleet to zero-emission by 2035, all off-road equipment where feasible to zero-emission by 2035, and the remainder of medium- and heavy-duty vehicles to zero-emission where feasible by 2045. Under the order, CARB will work with our State agency partners to develop regulations and strategies to achieve these goals taking into account technological feasibility and cost-effectiveness.



For the national ambient air quality standards (standards), there are legally-obligated deadlines by which areas must attain; these are established by the federal Clean Air Act (CAA or Act) and implemented by the United States Environmental Protection Agency (U.S. EPA) each time a new standard is promulgated based on updated information showing health impacts at increasingly lower levels. California has the two areas with the most critical air quality challenges in the nation, the South Coast Air Basin and the San Joaquin Valley. The near-term targets for these areas are a 2023 deadline for attainment of the 80 ppb 8-hour ozone standard, 2024 for the 35 microgram per cubic meter ($\mu g/m^3$) 24-hour fine particulate matter (PM2.5) standard, and 2025 for the 12 $\mu g/m^3$ annual PM2.5 standard. There are also mid-term attainment years of 2031 and 2037 for the more recent 8-hour ozone standards of 75 ppb and 70 ppb, respectively.

In addition to regional air pollutant levels, many communities in the State experience measurable harm in the form of negative health impacts from high levels of localized pollution. There is an immediate need to reduce emissions and exposure in these highly-impacted, low-income and disadvantaged communities throughout the State, and specifically, communities with Community Emissions Reduction Plans (CERPs) under Assembly Bill (AB) 617.[4] Communities selected for CERPs set five and ten-year targets to reduce community exposure; the targets for the first CERPs adopted by the Board begin in 2024.

As research continues to show harmful effects from air pollution at increasingly lower levels, achieving the State's complementary goals, targets and standards will provide much-needed public health protection for the millions of Californians that still breathe unhealthy air and will reduce exposure in the State's most highly-impacted and disadvantaged communities. Meeting California's GHG emissions reduction targets is an essential part of the worldwide action needed to slow global warming and achieve

[4] C. Garcia, Chapter 136, Statutes of 2017

climate stabilization. Finally, actions to meet California's public health and climate goals will also reduce our dependence on petroleum and establish a more secure energy future.

Mobile sources and the fossil fuels that power them continue to contribute a majority of NOx emissions, a significant precursor to smog and particulate matter, and are the largest portion of GHG emissions in California. The 2016 Strategy demonstrated how the State could simultaneously meet air quality standards, achieve greenhouse gas emission reduction targets, decrease health risk from transportation emissions, and reduce petroleum consumption through 2031 through a combination of efforts including widespread actions to deploy both zero-emission and cleaner combustion technologies. The 2016 Strategy included mechanisms to deploy zero-emission technologies across a broad spectrum of mobile sources including passenger vehicles, targeted truck and bus applications, forklifts, and other off-road equipment and transport refrigeration units. Actions were also discussed to require cleaner combustion technologies for sectors such as heavy-duty trucks, locomotives, and ocean-going vessels; these measures would provide the bulk of the NOx reductions needed to meet federal air quality standards by statutory deadlines in 2031.

Elements of the 2016 Mobile Source Strategy were incorporated into the 2016 State SIP Strategy and supported complementary efforts including the 2017 Climate Change Scoping Plan, the California Sustainable Freight Action Plan, and CARB's Short-Lived Climate Pollutant Reduction Strategy. Each of these plans drew from the 2016 Strategy to incorporate and build upon the actions and policies relevant to meet individual program goals.

With the passing of SB 44, the California Legislature acknowledged the value of the 2016 Strategy in relation to the State's many air quality, climate, and community risk reduction challenges. By requiring CARB to update the Mobile Source Strategy every five years, SB 44 further acknowledged the ongoing need to evaluate opportunities for mobile source emissions reductions in California as the vehicle and equipment market continues to evolve. Specifically, SB 44 requires CARB to update the 2016 Strategy to include a comprehensive strategy for the deployment of medium and heavy-duty vehicles for the purpose of meeting air quality standards and reducing GHG emissions. In addition to providing a status on the measures in the 2016 Strategy, it also directs CARB to set reasonable and achievable goals for reducing emissions from medium- and heavy-duty vehicles that are consistent with the State's overall goals. Because meeting all of the State's near- and longer-term goals requires action across the full spectrum of mobile sources, this document also discusses light-duty on-road vehicles, as well as a wide range of off-road equipment sectors.

Defining the scope of actions necessary to implement a strategic vision to meet all of California's goals requires an integrated planning process. In order to identify the strategies and program concepts that will best help CARB and the State meet all of its targets, it is imperative to look comprehensively at the potential benefits to all three categories of pollutants that CARB strives to reduce: criteria pollutants, toxics, and greenhouse gases. As we know that significant emission reductions from mobile sources are needed from all pollutants, this type of coordinated planning effort is essential to address the interplay between pollutants and sources, and consider the benefits of different technologies and energy sources. This planning effort serves as a foundation, but does not substitute for the public process that will take place if CARB pursues each of the individual program concepts.

To take an integrated approach, CARB uses scenario planning tools to quantify changes in ozone and PM2.5 precursor emissions, GHG emissions, diesel toxics emissions, and petroleum usage as various technologies are projected to populate the vehicle and equipment fleets. CARB's tools, known as the Mobile Emissions Toolkit for Analysis (META) and Vision, are used to evaluate scenarios with varying assumptions about potential technology and fuel mixes, and explore different rates at which those technologies could become widely used. These tools are discussed further in Chapter 5.

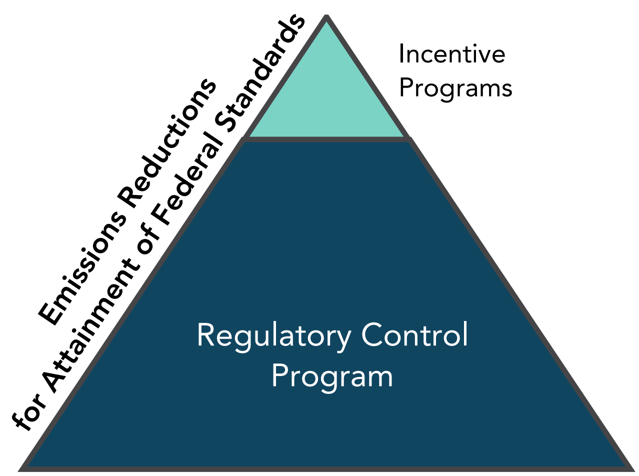
The analysis illustrates scenarios for meeting the State's public health, climate, and community risk reduction goals with a strategy consisting of cleaner vehicle technologies, energy and fuel supply sources, and a reduction in vehicle miles traveled. Technologies, energy sources, and vehicle travel, as well as the best policy tools, will vary by sector based on the status of technology development in various applications, the multi-pollutant benefits, and the interactions between regulatory and programmatic strategies. The scenario analysis identifies the types of technologies and level of penetration into the respective fleets that will be necessary to meet the various goals. While a scenario may outline the overall approach for a sector and include program concepts that will move the state in the needed direction, the specific strategies for each sector will continue to be refined as the planning and public process for implementing specific actions moves forward. The concepts contained in the 2020 Strategy are less defined than the measures included in the 2016 Strategy, in part due to the accelerated timeframe required under SB 44. The concepts, though, will continue to be developed and translated into measures for the next State SIP Strategy and other CARB planning documents over the coming years.

It is clear that the rate of natural vehicle fleet turnover will not be sufficient to meet near- and long-term air quality or climate goals; as such, actions to accelerate the deployment of cleaner technologies through regulations, incentives, system efficiency improvements, and support for the use of advanced transportation technologies such as intelligent transportation systems and autonomous and connected vehicles, are critical to achieving both near- and long-term goals in California. Existing mobile source regulatory programs and the many regulatory efforts underway will drive technology development and provide for significant reductions in emissions, but the development and implementation of new regulations takes substantial time. Therefore, strategic use of incentive funding is essential to achieve earlier penetration of cleaner combustion and zero-emission technologies than would happen through natural turnover, and the associated emissions reductions which are necessary to meet near-term goals.

Where We Are Today

While CARB has made substantial progress through its many regulatory and programmatic efforts, there remains a great need for emissions reductions in the immediate future to alleviate negative health impacts and meet federal and State air quality deadlines. Statewide, more than 28 million Californians live in areas that exceed the federal health-based ozone and PM2.5 standards;[5] within those, there are many low-income and disadvantaged communities that experience criteria pollutant levels significantly higher than the federal standards, as well as exposure to toxics, which can have immediate and detrimental health effects.

Of CARB's many goals, the air quality standards that need to be met in the next 5 years pose immediate challenges and will drive policies and the need for considerable, strategic investment to accelerate the transition to cleaner technologies beyond what would occur through natural turnover. Attainment of the ozone standard in 2023 remains a challenge for the South Coast Air Basin. While some of the needed reductions will be achieved through regulatory measures included in the 2016 Strategy and related SIPs, reductions from federal measures and/or funding are needed to achieve a majority of the remaining NOx reductions that are necessary to meet this standard.



In the San Joaquin Valley, attainment of PM2.5 standards in 2024 and 2025 is the near-term challenge driving many policies. The 2018 Plan for the 1997, 2006, and 2012 PM2.5 Standards and the San Joaquin Valley Supplement to the 2016 State SIP Strategy (Valley State SIP Strategy) included State commitments to achieve 32 tons per day (tpd) of NOx and 0.9 tpd of PM2.5 emissions reductions beyond the preexisting 2024 commitments for the San Joaquin Valley. Almost 90 percent of the reductions needed to meet these PM2.5 standards will come from ongoing implementation of the existing control program, combined with regulatory measures identified in the Valley State SIP Strategy. Since

[5] Based on 2019 monitored ozone and PM2.5 design values contoured over population by census tract

deployment of cleaner technologies through new incentive funding will also be critical, CARB continues to look for innovative opportunities to reduce emissions in the San Joaquin Valley in the near-term.

Another near-term driver is reducing exposure to air pollution for residents of disadvantaged communities throughout the State. The passage of AB 617 and creation of CARB's Community Air Protection Program (CAPP) has given the State the opportunity to take a closer look at and dedicate targeted resources towards helping to reduce exposure to harmful pollutants in the State's most heavily-impacted communities. Under the direction of AB 617 and guidelines created under the CAPP, beginning in 2018, CARB annually considers disadvantaged communities to begin new monitoring programs and emission reduction programs. CERPs are developed through coordination between CARB, local air districts, and community groups, and set five and ten-year targets to reduce community exposure – the targets of current CERPs adopted by the Board begin in 2024, with many programs including a focus on the turnover of dirty mobile sources and their engines to zero-emission technologies, as sought by communities and their representatives.

In support of the goals of AB 617 and the CAPP, the Legislature has appropriated funding to support early actions to address localized air pollution through targeted incentive funding to deploy cleaner technologies in these communities, as well as grants to support community participation in the AB 617 process. Further, AB 617 includes new requirements for the accelerated retrofit of pollution controls on industrial sources, increased penalties, and greater transparency and availability of air quality and emissions data, which will help advance air pollution control efforts throughout the State. The legislation also requires the development of new resources that work together to support emissions reductions in communities, including a Technology Clearinghouse to be used to identify rules, regulations, technologies, or practices that could offer emissions or exposure reduction opportunities within the selected community. Once complete, this tool will allow users to easily find existing mobile source rules and identify next generation technologies that are beyond existing regulatory requirements. CARB will prioritize adding sources that are of high importance to existing AB 617 community members to the system as it is developed.

Further, to ensure clean transportation is available to all Californians, Senate Bill 350[6] directed CARB to conduct a study on the barriers for low-income Californians to access clean transportation options, including those in disadvantaged communities, as well as recommendations on how to increase access. In February 2018, CARB released the Final Guidance Document - Low Income Barriers Study, Part B: Overcoming Barriers to Clean Transportation Access for Low-Income Residents (Barriers Report). CARB's Barriers Report is an initial step in identifying the main barriers low-income residents, including those in disadvantaged and tribal

[6] De León, Chapter 547, Statutes of 2015

communities, face in accessing clean transportation and mobility options. This effort, together with the CAPP, provide an opportunity to better integrate community, regional, and State-level programs to increase access to clean transportation and provide clean air for all Californians. Ongoing funding will be critical to support the CAPP and related programs and to provide the reductions needed in these impacted communities.

In 2006, California's first greenhouse gas reduction target was established under the Global Warming Solutions Act of 2006 (AB 32, Nunez, 2006). AB 32 created a comprehensive, multi-year process to reduce GHG emissions in California and required CARB to develop a Climate Change Scoping Plan. The first Climate Change Scoping Plan, completed in 2008, described California's approach to achieving the goal of reducing GHG emissions to 1990 levels by 2020. In 2016, four years ahead of schedule, California emissions fell below the 1990 levels of 431 million metric tons carbon dioxide equivalent. Going forward, the next greenhouse gas reduction target is a 40 percent reduction from 1990 levels by 2030 as codified in SB 32. The 2017 Climate Change Scoping Plan demonstrated how California will meet the 2030 target and showed that there are substantial emissions reductions still needed. We know that the transition of the transportation sector to zero-emission vehicles, and more accessible, efficient mobility, will both be major factors in meeting this and other future climate goals.

What We Are Learning from the COVID-19 Lockdown

The COVID-19 pandemic and the resulting health and economic crisis have had drastic and wide-ranging impacts on the lives, livelihoods, and behaviors of people around the world. It has taken more than 1,000,000 lives worldwide, and has had a direct impact on countless more. As it pertains to air quality, this pandemic has reemphasized the need to reduce emissions and achieve cleaner air, as air pollution may be a key factor in increasing the vulnerability of individuals to contracting COVID-19, as well as increasing the severity of illness and mortality risk from the virus.[7]

The measures put into place to slow the spread of COVID-19 resulted in significant changes in human activity that present opportunities to evaluate the real-world effect of those changes on air quality. Most notable are the reductions in both heavy-duty and light-duty vehicle miles traveled (VMT) across the State's highways and local roads, and the resulting emission reductions. In California, VMT fell to its lowest point in early- to mid-April, with an approximately 25 percent reduction in heavy-duty VMT

[7] Petroni et al (2020). Hazardous air pollutant exposure as a contributing factor to COVID-19 mortality in the United States. Environ. Res. Lett. 15 0940a9; Liang, Donghai et al. "Urban Air Pollution May Enhance COVID-19 Case-Fatality and Mortality Rates in the United States." medRxiv : the preprint server for health sciences 2020.05.04.20090746. 7 May. 2020, doi:10.1101/2020.05.04.20090746. Preprint.

and 50 to 60 percent reduction in light-duty VMT. Since that time, both heavy-duty and light-duty VMT have steadily increased, with heavy-duty VMT returning to pre-lockdown levels in early June. However, the reductions in VMT in April and May do provide an opportunity to test the real-world implications of emissions reductions associated with the on-road mobile sector. Such analysis, though, is complicated by several factors:

1) There is a natural, seasonal reduction in pollution levels (e.g., NOx and carbon monoxide) from March to May, which occurs every year as winter transitions to spring, and separating meteorological effects from VMT-related emissions changes is non-trivial;
2) The largest reductions in heavy-duty VMT occurred outside of the peak ozone season, and ozone chemical regimes can change from spring to summer due to seasonal variations in emission sources including biogenic emissions; and
3) The largest reductions in VMT occurred over a relatively short time period (less than two months).

CARB staff are currently working on quantifying the effect of reduced VMT on ambient pollution levels, assessing how changes in ozone precursor emissions may have influenced ozone levels during April and May, and determining how this can inform the State's emission control strategy moving forward. While the 2020 Strategy is a long-term planning document and COVID-19 stay-at-home orders and related closures are temporary measures, there is potential for changes made during this time to have far-reaching implications for transportation mode choice, shared mobility, vehicle choice, and VMT into the future.

Before the COVID-19 pandemic, Californians were continuing to drive more, and carpool less to work. Auto ownership was increasing and transit ridership was falling across California, and there continues to be a relatively small percentage of people that walk and bike to work.[8] Mobility in California dropped dramatically after shelter-in-place orders were enacted early in the COVID-19 pandemic, as people and organizations (including CARB) successfully operationalized widespread teleworking, and continued teleworking is a promising source of commute VMT reduction into the future. However, telework is not a panacea for VMT reduction – only a subset of jobs can support a telework arrangement. Essential workers largely cannot telework, many of whom are lower income or depend on transit services. Transit service has been decimated by fears raised by of the pandemic, and we must provide viable modes of transportation that can support our essential workforce.

[8] CARB. 2018. *2018 PROGRESS REPORT: California's Sustainable Communities and Climate Protection Act*. Available: https://ww2.arb.ca.gov/sites/default/files/2018-11/Final2018Report_SB150_112618_02_Report.pdf

Mobility rebounded as mandates eased, but vehicle travel in California is now more distributed throughout the day and the roadway network is largely uncongested. We have now experienced the profound impacts that getting cars off the road has on reducing congestion, especially during peak commute times. We know building more roads only leads to more congestion[9] and now we have seen a future where we can be more efficient with, and prioritize fixing and maintaining, our existing rights-of-way. Total light-duty VMT in California will continue to grow as the State's population grows. As discussed in more detail later, per capita VMT growth must be reduced but continue to accommodate essential travel. Our roadway network was extremely congested prior to the pandemic, and it will be again if we do not provide viable alternatives to single occupancy vehicle travel while simultaneously adding 10 million vehicles to our roadways.

Health Impacts

Despite decades of progress in improving air quality, large areas of California still suffer some of the worst air quality in the nation. Mobile source emissions contribute to a wide range of heart and lung illnesses, chronic health conditions, increased cancer rates, and premature death. Every year, over 5,000 premature deaths and hundreds of illnesses and emergency room visits for respiratory and cardiovascular disease in California are linked to PM2.5 pollution, of which more than half is produced by mobile sources. [10] Recent research demonstrates that fine particulate pollution impacts not only the heart and respiratory system, but also brain health and adverse birth outcomes.[11] The current COVID-19 pandemic demonstrates that air pollution may be a key factor in increasing the vulnerability of individuals to contracting COVID-19, as well as increasing mortality risk from the virus, and the severity of illness in people suffering from COVID-19.[12,13] Moreover, for the millions of California residents living in low-income and disadvantaged communities and experiencing

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[9] S. Handy, M. Boarnet. 2014. *Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions.* https://ww2.arb.ca.gov/sites/default/files/2020-06/Impact_of_Highway_Capacity_and_Induced_Travel_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf

[10] CARB. (2016). Mobile Source Strategy. https://ww2.arb.ca.gov/resources/documents/2016-state-strategy-state-implementation-plan-federal-ozone-and-pm25-standards

[11] USEPA. (2019a). Integrated Science Assessment for Ozone and Related Photochemical Oxidants (External Review Draft). Retrieved from https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=344670. U.S. EPA (2019b). Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter, External Review Draft

[12] Petroni et al (2020). Hazardous air pollutant exposure as a contributing factor to COVID-19 mortality in the United States. Environ. Res. Lett. 15 0940a9.

[13] Liang, Donghai et al. "Urban Air Pollution May Enhance COVID-19 Case-Fatality and Mortality Rates in the United States." medRxiv : the preprint server for health sciences 2020.05.04.20090746. 7 May. 2020, doi:10.1101/2020.05.04.20090746. Preprint.

disproportionate levels of negative health impacts from air pollution, [14] actions to reduce fossil fuel combustion and move to cleaner power sources are even more important.

Health Impacts from Mobile Source Emissions

Fossil fuel combustion from cars, trucks, buses, and on- and off-road equipment emits criteria air pollutants and their precursors, including NOx and oxides of sulfur (SOx) emissions. While NOx and SOx emissions are harmful in themselves, NOx is a precursor to ozone, which can cause irritation and damage lung tissue, worsen asthma and chronic illnesses including obstructive pulmonary disease and reduce lung function. [15] Studies have linked short-term ozone exposure with increased risk of death.[16]

In addition to contributing to ozone, the biggest impact on health from NOx and SOx comes when they are converted to PM2.5 in the atmosphere. PM2.5 pollution contributes to more fatalities than other air pollutants, and can lodge deep in the lungs or pass through the lungs to enter the blood stream and affect the heart, brain, and other organs.[17] Short-term exposure to PM2.5 pollution is associated with increased hospitalizations and emergency room visits for heart and lung illnesses, and can lead to premature death.[18] Adverse health effects from long-term exposure to PM2.5 pollution include increased risk of heart attacks and heart disease, impaired lung development in children, the development and exacerbation of asthma, and premature death.[19] Other possible impacts from PM2.5 exposure that are being investigated include low birth weight and impacts to the brain.[20][21]

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[14] American Lung Association. (2020). State of the Air; Union of Concerned Scientists, U. (2019). Inequitable Exposure to Air Pollution from Vehicles in California (2019); Cushing et al. (2015). Racial/ethnic disparities in cumulative environmental health impacts in California: evidence from a statewide environmental justice screening tool (CalEnviroScreen 1.1). American journal of public health, 105(11), 2341-2348.

[15] U.S. EPA (2019b). Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter, External Review Draft.

[16] Ibid.

[17] U.S. EPA. (2019a). Integrated Science Assessment for Ozone and Related Photochemical Oxidants (External Review Draft).

[18] Ibid.

[19] Ibid.

[20] Boothe, V. L., Shendell, D. G. (2008). Potential health effects associated with residential proximity to freeways and primary roads: review of scientific literature, 1999–2006. Journal of Environmental Health, 70(8), 33-41.; Wang et al (2020). Traffic-related Metrics and Adverse Birth Outcomes: A Systematic Review and Meta-analysis. Environmental Research, 109752.
Woods et al (2017). The influence of the built environment on adverse birth outcomes. Journal of Neonatal-Perinatal Medicine, 10(3), 233-248.

[21] CARB (2018) Air Pollution and the Brain https://ww2.arb.ca.gov/resources/fact-sheets/air-pollution-and-brain

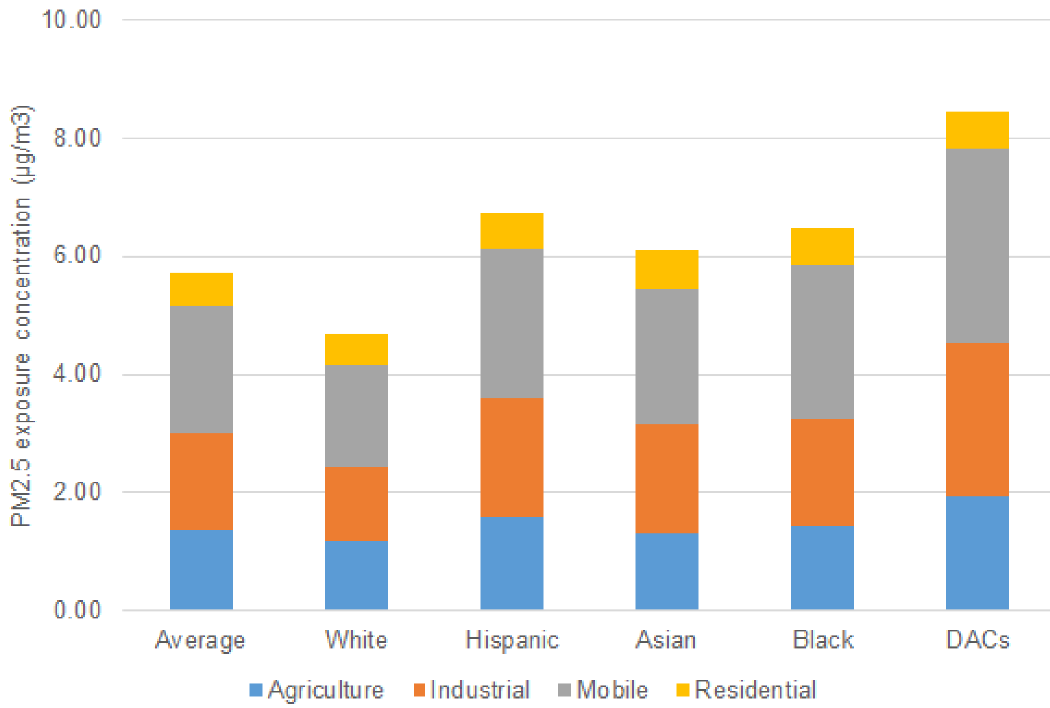
Diesel engines emit a complex mixture of air pollutants, including both gaseous and solid material. The solid material in diesel exhaust is known as diesel particulate matter (DPM or diesel PM). More than 90 percent of DPM is less than 1 μm in diameter (about 1/70th the diameter of a human hair), and thus is a subset of PM2.5.[22] DPM is typically composed of carbon particles ("soot", also called black carbon) and numerous organic compounds, including over 40 known cancer-causing organic substances such as benzene and formaldehyde. In 1998, CARB identified DPM as a toxic air contaminant which has been linked to increased cancer risk, respiratory and cardiac illnesses and premature deaths.[23] CARB estimates that about 70 percent of total known cancer risk related to air toxics in California is attributable to DPM.[24] Diesel exhaust also contains gaseous pollutants, including volatile organic compounds and NOx that lead to the formation of PM2.5 and ozone. Most major sources of diesel emissions, such as ships, trains, and trucks, operate in and around ports, rail yards, and heavily traveled roadways, which are often located near highly-populated and disadvantaged communities.

Environmental Justice and Pollution Exposure Disparities

Recent research demonstrates large disparities in exposure to pollution between white and non-white populations in California, and between environmental justice communities and other communities, with Black and Latino populations experiencing significantly greater air pollution impacts than white populations. Mobile source pollution shows some of the highest disparities; a CARB-funded study indicated that on average, mobile sources contribute to over 30 percent of total PM2.5 exposures.[25] Figure 2 compares the contributions of several top PM2.5 sources to average PM2.5 exposure concentration by race and in disadvantaged communities. This figure shows that mobile sources are the largest sources of pollution exposure disparity for Black populations and disadvantaged community residents, when compared to the average population in California. Specifically, mobile sources accounted for 45 percent of exposure disparity for the Black population, and 37 percent of exposure disparity for people in disadvantaged communities.

[22] CARB (2020). Overview: Diesel Exhaust & Health https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health
[23] Ibid.
[24] Ibid.
[25] Apte et al (2019). A Method to Prioritize Sources for Reducing High PM2.5 Exposures in Environmental Justice Communities in California. CARB Research Contract Number 17RD006

Figure 2 – Top Sources of PM2.5 and their Shares of Contribution to PM2.5 Exposures by Race and in Disadvantaged Communities



Communities located near major roadways are also at increased risk of asthma attacks and other respiratory and cardiac effects; often, these communities are low-income communities and communities of color. Studies consistently show that mobile source pollution exposure near major roadways contributes to and exacerbates asthma, impairs lung function, and increases cardiovascular mortality.[26] The exposure to mobile sources' mixture of gaseous and particulate pollutants (including PM, NOx, and benzene) is associated with higher rates of heart attacks, strokes, lung cancer, autism, and dementia.[27] Individuals living in communities located near ports and freight hubs are also subject to higher cancer risks than surrounding communities.[28]

People living in areas near freight and other significant sources, and those who work near diesel engines, are at risk of exposure to high quantities of diesel emission fumes.[29] Prolonged exposure to diesel emissions over many years is associated with an increase in workers' risk of cardiovascular, cardiopulmonary and respiratory disease,

[26] Hot Spot Pollution, 1052 and 1057.
[27] USC Environmental Health Centers. (2018). Living Near Busy Roads or Traffic Pollution.
[28] South Coast AQMD (2015). Multiple Air Toxics Exposure Study in the South Coast Air Basin
[29] Garshick et al. (2012). Lung cancer and elemental carbon exposure in trucking industry workers; Pronk et al. (2009). Occupational exposure to diesel engine exhaust: a literature review

and lung cancer.[30] The use of diesel-powered on- and off-road equipment can be a major source of exposure to toxic diesel exhaust for workers in a wide range of occupations including agriculture, construction, energy extraction, mining, rail, shipping, transport/logistics, tunneling, vehicle repair, and warehousing.

Children living in these communities are also unduly burdened by adverse health impacts. Results from a groundbreaking, long-term study demonstrated that particle pollution may significantly reduce lung function growth in children, [31] and indicates these effects are likely permanent. [32] Additionally, increased exposure to vehicular traffic pollution was associated with a number of adverse childhood health impacts, including slower lung development,[33] increased symptoms and medication use in asthmatic children,[34] and even increases in the development of asthma in children.[35]

Health Impacts of Climate Change

As stated earlier, mobile sources are the largest contributor of greenhouse gases in California; on- and off-road vehicles produce greenhouse gases from burning gasoline and diesel, contributing to almost 40 percent of the total State GHG emissions. Diesel engines also emit black carbon, a short lived climate pollutant with over 1,000 times the climate forcing potential of carbon dioxide. Several recent summaries and reports discuss in detail the ways that climate change can impact human health[36] including

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[30] HEI. (1995). Diesel Exhaust: A Critical Analysis of Emissions, Exposure and Health Effects. A Special Report of the Institute's Diesel Working Group. Health Effects Institute; Garshick et al. (2008). Lung cancer and vehicle exhaust in trucking industry workers; Brown-McCammon, J. (1988). NIOSH Current Intelligence Bulletin 50-carcinogenic effects of exposure to diesel exhaust; Mauderly, J. L. (1992). Diesel Exhaust, Chapter 5, Environmental Toxicants: Human Exposures and Their Health Effects; Wade, J. F., 3rd, & Newman, L. S. (1993). Diesel asthma. Reactive airways disease following overexposure to locomotive exhaust

[31] Peters et al. (1999). A study of twelve Southern California communities with differing levels and types of air pollution: II. Effects on pulmonary function. American journal of respiratory and critical care medicine, 159(3), 768-775.; Avol, E. L et al. (2001). Respiratory effects of relocating to areas of differing air pollution levels. American journal of respiratory and critical care medicine, 164(11), 2067-2072; Gauderman et al. (2002). Association between air pollution and lung function growth in southern California children: results from a second cohort. Am J Respir Crit Care Med, 166(1), 76-84. doi:10.1164/rccm.2111021

[32] Gauderman et al. (2004). The effect of air pollution on lung development from 10 to 18 years of age. New England Journal of Medicine, 351(11), 1057-1067

[33] Gauderman et al. (2007). Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study. The Lancet, 369(9561), 571-577

[34] Gauderman et al. (2005). Childhood asthma and exposure to traffic and nitrogen dioxide. Epidemiology, 737-743; McConnell et al. (2006). Traffic, susceptibility, and childhood asthma. Environmental Health Perspectives, 114(5), 766-772

[35] McConnell et al. (2010). Childhood incident asthma and traffic-related air pollution at home and school. Environmental Health Perspectives, 118(7), 1021-1026. doi:10.1289/ehp.0901232

[36] USGCRP. (2018). Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program; World Health Organization. (2003). Climate change and human health: risks and responses: World Health Organization; NRDC. (2019). Climate Change and Health in California

increased smog formation;[37] a lengthened pollen season; more frequent and severe wildfires;[38] an increased number of extreme heat days[39] which could result in more heat-related sickness and deaths;[40] more pronounced drought extremes;[41] more frequent and severe extreme precipitation events leading to severe flooding;[42] and an increased prevalence of infectious diseases.[43] Climate change is already taking a toll on human health, proving in many ways that taking action to reduce greenhouse gas emissions is urgently needed.

[37] Kleeman et al. (2010). Climate change impact on air quality in California: California Environmental Protection Agency, Air Resources Board

[38] Singleton et al. (2019). Increasing trends in high-severity fire in the southwestern USA from 1984 to 2015

[39] Milanes, C. (2011). Indicators of Climate Change in California

[40] CARB (2020). Health & Air Pollution. Retrieved from https://ww2.arb.ca.gov/resources/health-air-pollution

[41] Mann, M. E., & Gleick, P. H. (2015). Climate change and California drought in the 21st century

[42] Swain et al. (2018). Increasing precipitation volatility in twenty-first-century California; Dettinger, M. (2011). Climate change, atmospheric rivers, and floods in California–a multimodel analysis of storm frequency and magnitude changes; Solomon et al. (2006). Airborne mold and endotoxin concentrations in New Orleans, Louisiana, after flooding, October through November 2005

[43] Lindgren et al. (2012). Monitoring EU emerging infectious disease risk due to climate change

Chapter 2 – Implementing the 2016 Mobile Source Strategy

The 2016 Strategy included a suite of ambitious emission reduction measures designed to help the State meet a number of challenging air quality standards, achieve greenhouse gas emission reductions, decrease health risks from transportation emissions, and reduce petroleum consumption through 2031. Since the 2016 Strategy was released, a number of measures have been developed into regulations and, where applicable, adopted by the Board. These measures are listed in Table 1.

Table 1 – Completed 2016 Mobile Source Strategy Measures

2016 Mobile Source Strategy Measure Title	Final Regulation / Project Title	Adopted / Completed
Innovative Technology Certification Flexibility	Regulation to Provide Certification Flexibility for Innovative Heavy-Duty Engines	October 2016
More Stringent National Locomotive Emission Standards (CARB Petition)	CARB Locomotive Emission Standards Petition to U.S. EPA for Rulemaking	April 2017
Medium and Heavy-Duty GHG Phase 2	GHG Emissions Standards for Medium- and Heavy-Duty Engines and Vehicles (Phase 2)	February 2018
Incentive Funding to Achieve Further Emission Reductions from On-Road Heavy-Duty Vehicles	South Coast On-Road Heavy-Duty Vehicle Incentive Measure	March 2018
Lower In-Use Emission Performance Level	• Amendments to the Heavy-Duty Vehicle Inspection Program and Periodic Smoke Inspection Program • Amendments to the Emission Control System Warranty Regulations and Maintenance Provisions • Heavy-Duty Omnibus Regulation	• May 2018 • June 2018 • Aug 2020
Advanced Clean Transit	Innovative Clean Transit Regulation	December 2018
Zero-Emission Airport Shuttle Buses	Zero-Emission Airport Shuttle Bus Regulation	June 2019
Last Mile Delivery	Advanced Clean Truck Regulation	June 2020
Low-NOx Engine Standard – California Action	Heavy-Duty Omnibus Regulation	Aug 2020
At-Berth Regulation Amendments	Control Measure for Ocean-Going Vessels At Berth	Aug 2020

To address federally-regulated locomotives, CARB petitioned the United States Environmental Protection Agency (U.S. EPA) to undertake rulemaking to strengthen the existing Emission Standards for Locomotives and Locomotive Engines regulation. The petition, submitted pursuant to the federal CAA and relevant codes,[44] was sent to U.S. EPA in April 2017 and California air districts, as well as environmental groups and other entities, submitted letters to U.S. EPA in support of the petition. Since that time, there has been no action at the federal level, but CARB has taken steps to identify the programmatic mechanisms available under State authority to reduce emissions from locomotives in California.

Progress has been made in finalizing actions to control emissions from on-road heavy-duty vehicles. The first regulatory success was the adoption of California's Regulation to Provide Certification Flexibility for Innovative Heavy Duty Engines.[45] This regulation encouraged manufacturers to accelerate development and market launch of a diversity of cleaner medium- and heavy-duty vehicles and engines by providing defined certification and on-board diagnostic (OBD) compliance flexibility. The GHG Emission Standards for Medium- and Heavy-Duty Engines and Vehicles (Phase 2) regulation was adopted by the Board in February 2018. This new round of vehicle and engine GHG standards built upon the Phase 1 standards adopted federally in 2011 and in California in 2013. In addition to harmonizing with the federal Phase 2 standards finalized by U.S. EPA in October 2016, the CARB program includes some more stringent, California-only provisions that are necessary to meet California's unique air quality challenges. Shortly thereafter, the Board adopted the South Coast On-Road Heavy-Duty Vehicle Incentive Measure in March 2018 and submitted it to U.S. EPA for inclusion in the California SIP. This action consisted of a measure to report on emission reductions from the turnover of heavy-duty trucks to cleaner technologies funded through the Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program) in the South Coast Air Basin.

In mid-2018, two elements of the Lower In-Use Emission Performance Level were adopted, the lower opacity limits for heavy-duty vehicles included as part of the Amendments to the Heavy-Duty Vehicle Inspection Program and Periodic Smoke Inspection Program in May 2018,[46] and Amendments to the Emission Control System Warranty Regulations and Maintenance Provisions in June 2018.[47] Together, these two regulatory changes ensure lower levels of engine deterioration while heavy-duty vehicles are in operation. The lower opacity levels also provide CARB's enforcement

[44] Title 5, United States Code (U.S.C.) section 553(e)
[45] https://ww3.arb.ca.gov/regact/2016/itr2016/itr2016.htm
[46] https://ww2.arb.ca.gov/rulemaking/2018/heavy-duty-vehicle-inspection-program-and-periodic-smoke-inspection-program
[47] https://ww2.arb.ca.gov/rulemaking/2018/hd-warranty-2018

team with the tools needed to take corrective action against trucks with high exhaust PM emissions.

The Innovative Clean Transit (ICT) Regulation targets reductions in transit fleets by requiring transit agencies to gradually transition their buses to zero-emission technologies. ICT was adopted by the Board in December 2018 and has helped to advance heavy-duty zero-emission vehicle deployment, with buses acting as a beachhead in the heavy-duty sector. The Zero-Emission Airport Shuttle Regulation was adopted in June 2019 and targets airport shuttle buses, another beachhead market for zero-emission heavy-duty vehicles. The regulation requires airport shuttle operators to begin adding zero-emission shuttles to their fleets in 2027, and to complete the transition to zero-emission vehicles (ZEV) by the end of 2035.

The Last Mile Delivery measure in the 2016 Strategy envisioned a regulation with a strong focus on last mile delivery vehicles. Through the regulatory development process, the program has evolved substantially into the Advanced Clean Trucks (ACT) Regulation which requires medium-and heavy-duty manufacturers to sell ZEVs as an increasing portion of their annual sales beginning in 2024. The rule has expanded to include many other heavy-duty vehicle applications beyond last mile delivery, and at the direction of the Board, has been strengthened in order to achieve greater reductions earlier than previously planned. Moreover, in addition to the ACT manufacturer sales requirements adopted in June 2020, CARB staff is now working on complementary fleet requirements that will likely be brought to the Board for consideration in 2021 and begin implementation in 2024. The ultimate goal of this rulemaking is to transition the State's fleet to zero-emission by 2045 where feasible, and move quicker in certain well suited segments such as last mile delivery, public fleets, drayage, refuse, buses, and utility fleets.

The need for more stringent heavy-duty engine standards at both the State and federal level was discussed in the 2016 Strategy. Because vehicles originally purchased out-of-state contribute a significant portion of the on-road heavy-duty vehicles miles travelled in California, a more stringent national heavy-duty engine standard to complement the State program is needed to achieve the emissions reductions required from this sector. While CARB recently adopted the Heavy-Duty Omnibus Regulation, efforts at the federal level are not expected to be finalized until 2021 or 2022. The national program, known as the U.S. EPA Cleaner Trucks Initiative, was announced in November 2018, and an Advanced Notice of Proposed Rulemaking was released on January 21, 2020.[48]

CARB staff is coordinating closely with U.S. EPA technical staff to ensure that the California program will meet the State's needs while preserving the ability to

[48] *Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine Standards*, 85 Fed. Reg. 3306 (Jan. 21, 2020). https://www.govinfo.gov/content/pkg/FR-2020-01-21/pdf/2020-00542.pdf

harmonize with the federal program. Furthermore, CARB's Heavy-Duty Omnibus Regulation also contains other requirements including longer useful life emission compliance, longer warranty periods, and more stringent in-use performance standards, all of which will improve the real world emissions performance of heavy-duty vehicles. The Omnibus Regulation will result in 23.2 tpd of NOx emission benefits in 2031, the equivalent of taking 16 million light-duty cars off the road. This rule is estimated to prevent 3,900 premature deaths and 3,150 hospitalizations statewide over the life of the rule.

The Control Measure for Ocean-Going Vessels At Berth is designed to reduce emissions from ships while docked at a port or marine terminal, otherwise known as at berth. While docked, vessels generate toxic and harmful exhaust that impacts surrounding communities, many of which are disadvantaged. Since 2014, emissions from container, refrigerated cargo (reefer), and cruise vessels have been controlled at berth through CARB's existing At-Berth Regulation which results in a reduction of 80 percent of NOx and PM emissions from those vessel types (around 4,000 visits) by 2020. The recently adopted Control Measure for Ocean-Going Vessels At Berth expands the regulation to include additional vessel types and visits, as well as additional ports and terminals, as originally envisioned in the 2016 Strategy. At the direction of the Board, implementation has been accelerated in order to achieve reductions earlier than previously planned.

In addition to those measures already adopted, there are number of other measures that are progressing through the regulatory development process and are slated to be considered by the Board in the next 12 months. These measures are listed in Table 2.

Table 2 – 2016 Mobile Source Strategy Measures in Progress

2016 Mobile Source Strategy Measure Title	Working Regulation / Project Title	Anticipated Adoption / Completion
Transport Refrigeration Units Used for Cold Storage	Transport Refrigeration Units	Early 2021
Small Off-Road Engines	Small Off-Road Engines	2021
Lower In-Use Emission Performance Level	Heavy-Duty Inspection and Maintenance Program	2021
Advanced Clean Cars 2	Light-duty Regulations for ZEVs, Criteria Emissions and GHG Emissions	2021
Low-Emission Diesel Requirement	Low-Emission Diesel Requirement	2021
Zero-Emission Forklift Regulation Phase 1	Zero-Emission Forklift Regulation	2022
Lower In-Use Performance Assessment	Lower In-Use Performance Assessment	Ongoing
Incentivize Low-Emission Efficient Ship Visits	Incentivize Low-Emission Efficient Ship Visits	Ongoing

The Heavy-Duty Inspection and Maintenance Program, otherwise known as Heavy-Duty I/M, was part of the Lower In-Use Emission Performance Level measure in the 2016 Strategy and the 2016 State SIP Strategy, but was developed further in the Valley State SIP Strategy (October 2018). The Heavy-Duty I/M Program will ensure that in-use emission control components and systems on heavy-duty trucks (those above 14,000 pounds gross vehicle weight rating) are properly functioning, so that these vehicles continue to operate at their cleanest possible levels for the duration of their on-road operation. In the past two years, CARB staff has held a series of public workshops and workgroup meetings, and expects to bring a regulation to the Board in 2021. To expand on the emission reduction opportunities, California Senate Bill 210[49] was passed by the Legislature and signed into law by Governor Newsom on September 20, 2019. SB 210 enhanced the relevant regulatory authority by requiring that on-road heavy-duty diesel vehicles comply with the forthcoming Heavy-Duty I/M program in order to register annually with the California Department of Motor Vehicles. This direct tie-in to vehicle registration ensures that the program will achieve maximum emissions reductions.

The Advanced Clean Cars (ACC) regulatory program, adopted in 2012 to control emissions from passenger vehicles, combined the control of smog-causing pollutants and GHG emissions into a single coordinated package of regulations: the

[49] Leyva, Chapter 298, Statutes of 2019

Low-Emission Vehicle III Regulation for criteria (LEV III Criteria) and GHG (LEV III GHG) emissions, and a technology-forcing mandate for ZEVs. The program was developed in coordination with U.S. EPA and the National Highway Traffic Safety Administration (NHTSA) and includes emissions standards for vehicle model years through 2025. Because federal agencies have since reversed course and rolled back the national standards for model years 2021 through 2026, in addition to their decision to preempt California's authority to regulate light-duty vehicle GHG emissions and ZEV technology, it is even more important that CARB move forward with California standards for model years 2026 and beyond to preserve the critical emissions reductions from the passenger vehicle sector.[50] The Advanced Clean Cars II measure as discussed in the 2016 Strategy would increase the number of new ZEVs and plug-in hybrid electric vehicles (PHEVs) sold in California, and maximize criteria and GHG emissions reductions by setting standards for post-2025 model year vehicles. Advanced Clean Cars II is currently planned for consideration by the Board in late 2021.

The "Lower In-Use Emission Performance Assessment" measure is an ongoing effort to ensure in-use light-duty vehicles continue to operate at their cleanest possible level. As such, both CARB and the Bureau of Automotive Repair (BAR) are continuously improving both the Smog Check Program and the On-Board Diagnostic Program through various activities. Since the 2016 Strategy was released, CARB staff have presented results of an internal study that documented the effectiveness of the OBD program in improving air quality at the 2019 SAE OBD Symposium, implemented a test program to investigate and analyze in-use vehicles that had passing OBD smog check inspections but high tailpipe emissions,[51] and proposed changes to the OBD regulation to improve OBD functionality (2021 proposed board hearing date). Additionally, BAR staff have created yearly Smog Check Performance Reports that include various assessments of Smog Check Program data and data collected as part of BAR's Random Roadside Inspection Program. BAR staff have also implemented improved smog inspection procedures and methods to mitigate fraud, such as implementing permanent diagnostic trouble codes as a new inspection failure criteria, blocking vehicle inspection certification if fraudulent vehicle testing is suspected, and improving enforcement efforts against smog stations and technicians performing fraudulent inspections.

Other efforts that were included as measures in the 2016 Strategy focused on the off-road and fuels sectors. The Zero-Emission Forklift Regulation is under development by CARB staff, and is anticipated to be considered by the Board in early 2022. The Low-Emission Diesel Fuel Requirement has been discussed at CARB

[50] Adopting new California light-duty vehicle regulations will depend on either a different Federal administration reversing its decision and reinstating the State's authority to regulate GHGs and ZEVs, or California succeeding in the litigation challenging the current federal rules.
[51] Project no. 2S19V01, May 2019

workshops and is planned to be brought to the Board in 2021. Finally, the measure from the 2016 Strategy to Incentivize Low-Emission Efficient Ship Visits is continuing to be explored by staff in conjunction with the South Coast Air Quality Management District and other local entity partners.

The 2016 Strategy identified a need for incentive funding for mobile source turnover in specific regions and throughout the State. Natural fleet turnover does not occur at a rate sufficient to meet air quality standards and climate change goals and, as such, incentives will play a critical role in achieving our goals and mandates. Since release of the 2016 Strategy, the Legislature has identified and appropriated significant amounts of funding to a variety of CARB's incentive programs. Funding has been allocated to previously existing programs including the Moyer Program, the Low Carbon Transportation Program, the Air Quality Improvement Program (AQIP), and to more recently established programs include the Funding Agricultural Replacement Measures for Emission Reductions (FARMER) Program and AB 617 CAP incentives. Despite the substantial incentive allocations over the last few years, funding has not yet reached the levels needed to meet our near-term goals; due to California's current budget crisis resulting from the COVID-19 pandemic, it is likely that less funding will be allocated to these programs in the immediate future.

Ongoing Push to Identify Potential New Controls

Regardless of near-term challenges with levels of incentive funding or timing of federal regulatory action, CARB is moving forward to address mobile source emissions and will take action where possible to lower emissions now. For the near-term, there is potential for emissions reductions from newer programs that are expected to be considered by the Board over the next year including the Clean Miles Standard program to regulate ride-hailing services, the Advanced Clean Fleets rule to require fleets to incorporate ZEVs into their fleet in combination with the ACT regulation, the locomotive emission reduction measure, and amendments to the Commercial Harbor Craft regulation. In addition, there are newer regulatory concepts discussed later that are in earlier phases of development, but will likely achieve reductions in time for the mid-term 2030, 2031, and 2037 deadlines.

Chapter 3 - Pathways Forward to Meet California Goals

Defining the scope of actions necessary to implement a strategic vision to meet all of California's goals requires an integrated planning process. In order to identify the strategies and program concepts that will best help CARB and the State meet all of its targets, it is imperative to look comprehensively at the potential benefits to all three categories of pollutants that CARB strives to reduce: criteria pollutants, toxics, and greenhouse gases. To do this, CARB uses scenario planning tools to quantify changes in ozone and PM2.5 precursor emissions, GHG emissions, diesel toxics emissions, and petroleum usage as various technologies are projected to populate the vehicle and equipment fleets. CARB's tools, known as the Mobile Emissions Toolkit for Analysis (META) and Vision, are used to evaluate scenarios with varying assumptions about potential technology and fuel mixes, and explore different rates at which those technologies could become widely used.

Integrated planning is critical to evaluate strategy concept scenarios for meeting the State's public health, climate, and community risk reduction goals. Technologies, energy sources, and vehicle travel, as well as the best policy tools, will vary by sector based on the status of technology development in various applications, the multi-pollutant benefits, and the interactions between regulatory and programmatic strategies. CARB staff have identified a suite of strategy concepts, many of which CARB is actively pursuing through individual public processes, that will enable the State to achieve the technology trajectories identified through scenario planning and, consequently, meet California's many goals. The concepts contained in the 2020 Strategy are less defined than the measures included in the 2016 Strategy, in part due to the accelerated timeframe. The concepts, though, will continue to be developed and translated into measures for the next State SIP Strategy and other CARB planning documents over the coming years. By maximizing the use of zero-emission technology, these concepts maximize the emission reductions of criteria pollutants, greenhouse gases, and toxics.

For on-road light-duty vehicles, these concepts include:

- manufacturer requirements to foster clean technology production and sales;
- in-use requirements to accelerate penetration of newer technology; and
- incentive programs to promote and accelerate the use of advanced clean technologies.

For on-road medium- and heavy-duty vehicles, concepts include:

- manufacturer requirements to foster clean technology production and sales;
- in-use requirements to accelerate penetration of newer technology;
- incentive programs to promote and accelerate the use of advanced clean technologies;

- enhanced enforcement strategies to ensure programs are achieving their anticipated benefits;
- outreach and education to bridge the knowledge gap and increase consumer acceptance of advanced vehicle and equipment technologies; and
- infrastructure planning and development to support the transition to cleaner technologies.

For off-road vehicles and equipment, concepts include:

- manufacturer requirements to foster clean technology production and sales;
- in-use requirements to accelerate penetration of newer technology;
- incentive programs to promote and accelerate the use of advanced clean technologies;
- outreach and education to bridge the knowledge gap and increase consumer acceptance of advanced vehicle and equipment technologies; and
- infrastructure planning and development to support the transition to cleaner technologies.

In the near term, incentive programs to promote and accelerate the use of advanced technologies will be key to meeting our pre-2030 air quality goals. This document estimates the funding needed over the next five years to provide early reduction in addition to putting us on the path to meet our 2030 and 2050 climate goals.

Potential Emissions Reductions of Scenario Trajectories

A summary of scenario assumptions, along with the total statewide fuel use and NOx emissions reductions from the 2020 Mobile Source Strategy scenarios, is provided in Table 3, and Figure 3 and Figure 4. As shown, the scenarios in the 2020 MSS would achieve an overall statewide NOx emissions reduction of 523 and 603 tpd in 2031 and 2037 respectively, which are equivalent to 47 and 56 percent reduction from projected baseline NOx emissions (including stationary and area source) in those years.[52] Also, as a result of these strategies, mobile source NOx emissions in 2031 and 2037 will be 74 and 83 percent below 2017 baseline. The scenarios will also reduce mobile source fuel consumption by 9.5 billion gallons of gasoline and 3.0 billion gallons of diesel equivalent in 2045. This equates to a well-to-wheel (WTW) GHG emissions reduction of approximately 93 million metric tons of carbon dioxide equivalent (MMT CO_2e) in 2045, or 70 percent reduction from 2020.

[52] According to 2016 South Coast AQMP, the preliminary projections, based upon ozone "isopleths" developed for the 2031 emission scenarios indicate that 2037 Basin NOx carrying capacity to meet the 70 ppb standard could be as low as 75 tpd. This is additional 62 percent NOx reduction beyond the projected 2037 baseline and 25 tpd of additional NOx emission reductions between 2031 and 2037.

Table 3 - Summary of the 2020 MSS Scenarios

Category		Scenario Assumptions
On Road	Light-Duty Vehicles	• 70% ZEV + PHEV sales in 2030 • 100% ZEV + PHEV sales in 2035 • 7.9 M ZEV by 2030 • 27.9 M ZEV+PHEV by 2045
	VMT	• ~25% reduction in statewide per capita GHG by 2035 relative to 2005
	Medium-Duty Vehicles	• 100% ZEV sales starting 2035
	Heavy-Duty Vehicles	• Reflect HD Omnibus, ACT, and HD I/M starting in 2024, and federal 0.02 g/bhp-hr starting in 2027 • 100% of model year 2035 and newer vehicles registered in California will be ZEV • Accelerated turnover of older trucks
Off Road	Off-Road Efficiency Improvement[53]	• Zero-emissions and hybridization where feasible with the goal of 12 percent reduction in GHG by 2030, and 30 percent by 2040
	Off-Road Tier V Standard	• Tier 5 being introduced starting in 2028-2030 • 50 – 90% NOx reduction from current Tier 4f standard
	Rail	• 100% of replaced locomotive will be Tier 4 • Remanufacturing limit • Tier 5 being introduced in 2028
	Ocean Going Vessels *(out to 100 nm)*	• 100% of Tier 0/1/2 visits are phased out by 2031 • Tier 3 visits begin in 2025 (begin replacing all Tier 0-2) • Tier 4 visits begin in 2028 (no additional Tier 3 visits)
	Construction	• Full turnover of Tier 0/1/2 to Tier 4f by 2033
	SORE	• 100% of new sales will be zero-emission equipment (ZEE) starting 2025

[53] Excluding categories such as CHE and TRU that are going to zero-emission in other scenarios. This is done to avoid double counting

Category		Scenario Assumptions
Off Road	Aircraft	• 25 percent derate during take-off • 40 percent reduction in Taxi time • Single engine taxiing • 40 percent reduction in APU usage
	Transport Refrigeration Units	• Accelerated penetration of electric TRU (from 10% in 2024 to 100% in 2034)
	Commercial Harbor Craft	• All vessels (including commercial fishing) being Tier 4/5 by 2031 • Introduction of Plug-in hybrid for excursions and diesel-electric for tugs by 2030
	Cargo Handling Equipment	• Begin transition to full electric operation beginning in 2026 (accelerated turnover)
	Agriculture	• An incentive based concept consistent with the 2018 SJV SIP
	Airport Ground Support Equipment	• Full electrification transition from 2024-2034
	Forklifts	• Transition to zero-emission technology starting in 2025 with fully electric fleet by 2034
	Recreational Watercraft	• New THC + NOx standards of 40 and 70 percent below current levels • Electrification of small outboard and PWC engines

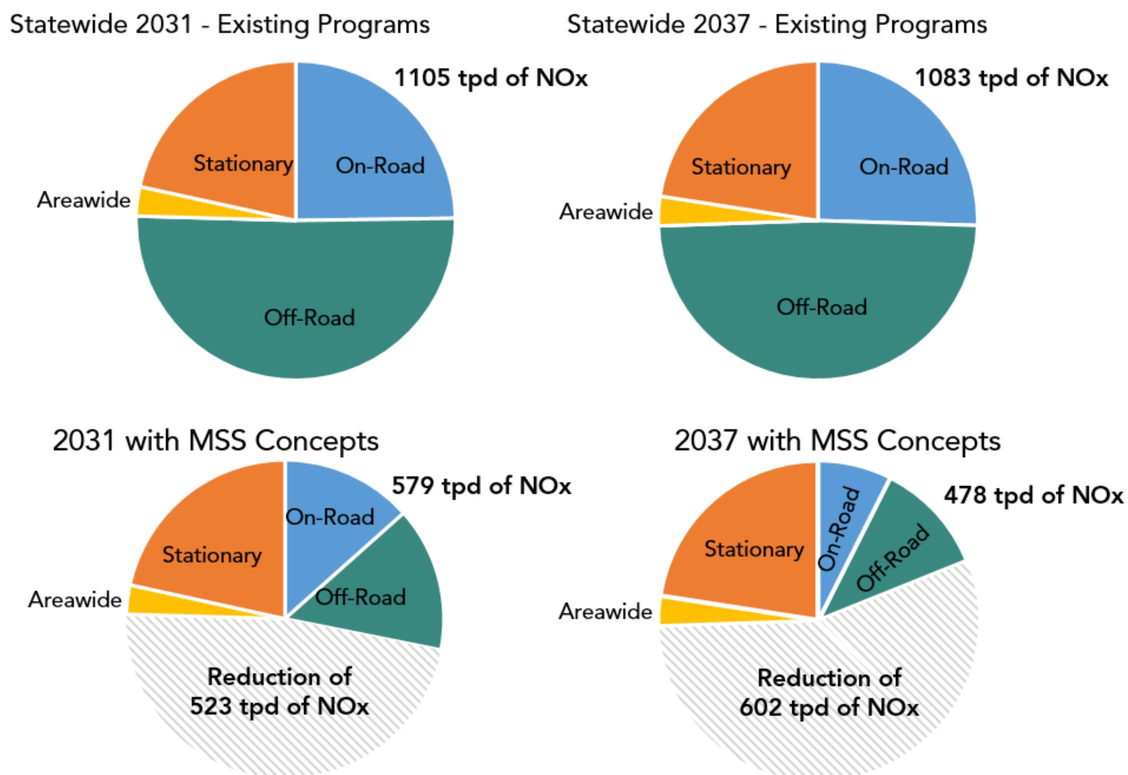
CARB staff will continue to develop the concepts in order to translate them into measures that will be included in the State SIP Strategy being developed for the 70 ppb 8-hour ozone standard, along with other CARB planning documents to be released in the coming years.

The 2020 MSS scenarios illustrate that even with extremely aggressive electrification, accelerated turnover, coupled with aggressive VMT reductions and fuel decarbonization,[54] the mobile source sector alone cannot become carbon neutral by 2045. This emphasized the importance of CDR strategies such as mechanical and land-based sequestration. This economy-wide approach that includes consideration of

[54] Fuel decarbonization refers to a group of strategies, including SB 100 electric grid requirements, liquid fuel carbon reductions through the Low Carbon Fuel Standard (LCFS), and other actions.

CDR is introduced in a recent report by Energy and Environmental Economics (E3). [55] The E3 report provides insights into the types of economy-wide transformation that will be necessary to achieve carbon neutrality by mid-century.

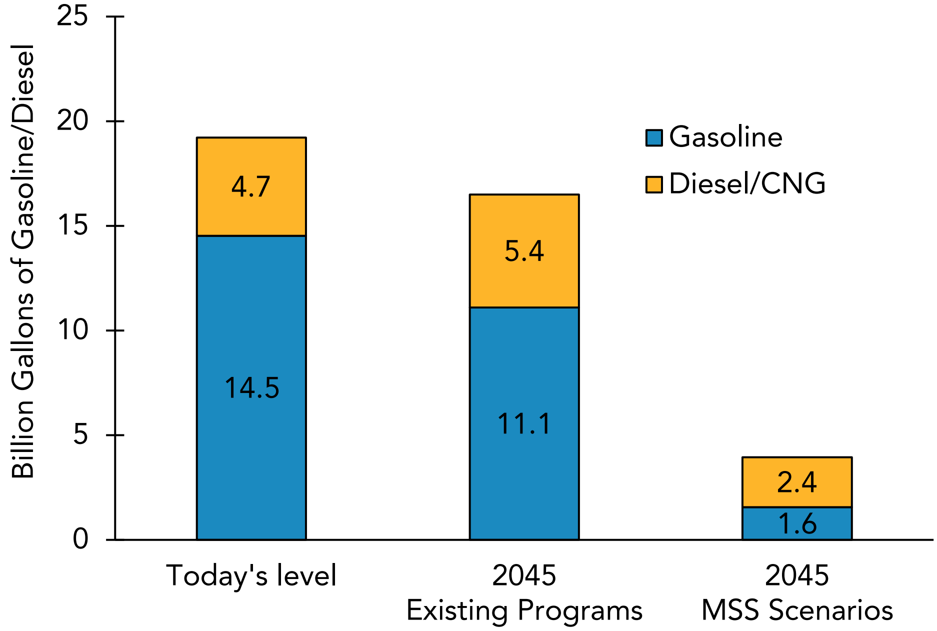
Figure 3 - Impact of 2020 MSS Scenarios on Statewide NOx Emissions in 2031 and 2037



* Emissions from ocean going vessels are considered out to 100 nm

[55] Achieving Carbon Neutrality in California: PATHWAYS Scenarios Developed for the California Air Resources Board https://ww2.arb.ca.gov/sites/default/files/2020-08/e3_cn_draft_report_aug2020.pdf

Figure 4 - Impact of 2020 MSS Scenarios on Mobile Source Liquid Fuel Consumption in 2045



Additional Health Benefits of the Transition Away from Combustion

Shifting to electric transportation will reduce pollution-related death and illness. State and regional emissions will decline substantially as fossil fuel burning vehicles are replaced by ZEVs and vehicles using renewable energy sources. The potential health benefits of phasing out fossil fuels in the transportation and off-road sectors and of reducing emissions of criteria air pollutants and climate pollutants are substantial.

A 2018 review looking at 65 articles demonstrated there was consistent agreement that increasing the adoption of ZEVs would reduce emissions of GHGs and some criteria pollutants.[56] Few studies have been conducted looking at the health impacts of switching to cleaner cars, but a study completed in the U.S. estimates that 3700 to 6400 premature deaths would be avoided with a transition to hydrogen fuel cell vehicles in combination with a renewable energy infrastructure for vehicle charging.[57]

In addition, shifting to active transportation and public transportation will reduce pollution-related death and illness, and improve health. Active transportation such as walking and biking can enhance health benefits from increased physical activity. Most public transit is accompanied by other forms of transportation such as walking and/or

[56] Requia et al. (2018). How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. Atmospheric Environment.
[57] Jacobson et al. (2005). Cleaning the air and improving health with hydrogen fuel-cell vehicles. Science.

biking. State and regional emissions will decline substantially since riding public transportation can significantly replace passenger car trips and in addition can increase individual's physical wellbeing from walking or biking to the public transportation. Even after considering exposure to air pollutants and potential traffic injury, the health benefits of active transportation and public transit can still be substantial.[58] Active transportation and public transit will not only contribute to a reduction in fossil fuel burning vehicles, but also will improve various health outcomes such as mental illness, cardiovascular diseases, and cancer.[59] Additionally, walking, biking, and other variants of active transportation such as scooters will create a more social and cohesive environment, and improve an individual's quality of life and increased life expectancy.[60] The potential health benefits from replacing fossil fuels in the transportation sector with public transportation and active transport are substantial.

Role of Cleaner Combustion and Zero-Emission On-Road HD Vehicles

As we look forward, it is evident that there are certain areas where CARB, other State and local agencies, and other partners, will need to dedicate extra attention to fully analyze and determine the best path into the future. In order to meet our numerous standards, targets, and goals over the next thirty years, California will need to see a substantial transition of the mobile fleet, with zero-emission vehicles dominating the on-road fleet and certain off-road sectors, and penetrating into the remaining off-road sectors wherever possible, with cleaner combustion engine technologies and renewable fuels everywhere else.

All forms of cleaner heavy-duty trucks and buses will be critical to achieving ambient air quality standards, near-term risk reduction goals, and climate targets. CARB has a number of programs already in place or under development to require and otherwise encourage the adoption of clean on-road heavy-duty vehicles; these include the Truck and Bus Regulation, the Heavy-Duty Omnibus Regulation, the Advanced Clean Trucks Rule, and various incentive programs including the Moyer Program.

Trucks certified to CARB's previous optional low NOx standard are currently in-use, and as such, are highly important for achieving more near-term SIP deadlines including attainment of the 80 ppb ozone standard in the South Coast Air Basin in 2023, attainment of PM2.5 standards in the San Joaquin Valley in 2024 and 2025, and attainment of the 75 ppb ozone standard throughout the State by 2031. CARB's recently adopted Heavy-Duty Omnibus Regulation includes more stringent engine

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[58] Maizlish et al. (2013). Health cobenefits and transportation-related reductions in greenhouse gas emissions in the San Francisco Bay area

[59] Furie, G. L., & Desai, M. M. (2012). Active Transportation and Cardiovascular Disease Risk Factors in U.S. Adults; Mueller et al. (2015). Health impact assessment of active transportation: A systematic review

[60] Sallis et al. (2004). Active transportation and physical activity: opportunities for collaboration on transportation and public health research

standards which will phase in statewide starting in 2024. It is expected that trucks manufactured to meet this standard or already certified to meet the pre-existing optional standard (0.02 grams per brake horsepower-hour) will contribute significant near-term NOx reductions for attainment, as well as to near-source risk reduction in and around disadvantaged communities.

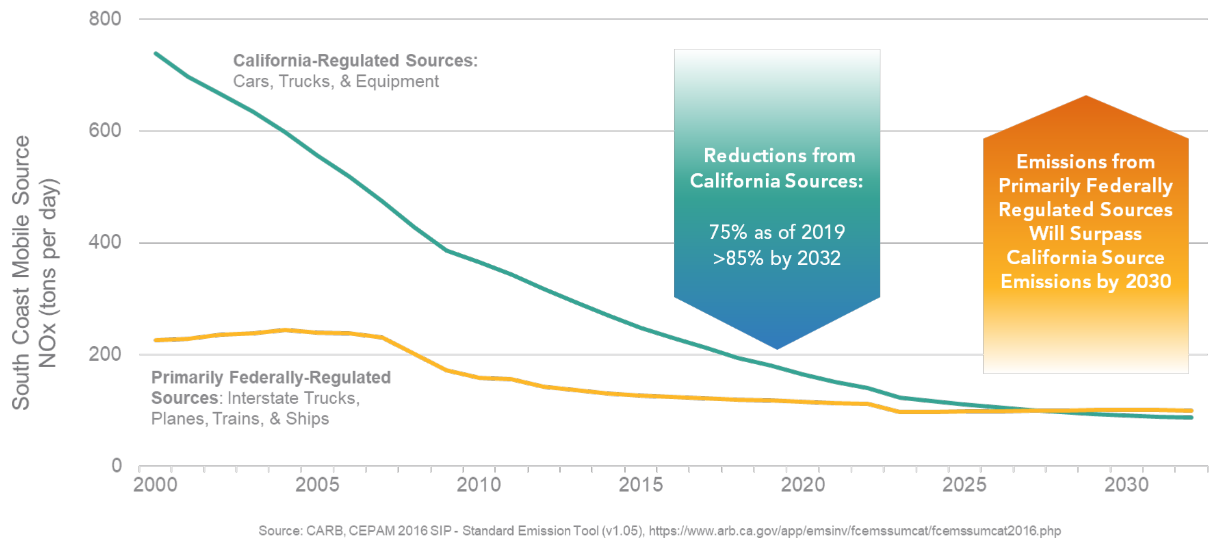
That said, as emphasized by Governor Newsom's recent executive order, zero-emission trucks already play an important role in reducing emissions throughout the State and will be especially critical to meet long-term climate goals. In order to put California on track to meet climate goals in 2045 and 2050, 1.4 million medium- and heavy-duty ZEVs are necessary. An important first step to move the State in this direction is the Advanced Clean Trucks Rule, which was adopted by the Board in June 2020 and will implement manufacturer sales requirements beginning in 2024. CARB staff is also working to develop and bring to the Board a complementary regulation to implement fleet purchasing requirements – in June 2020, the Board gave staff a goal to bring this back to the Board for consideration by the end of 2021.

Furthermore, the State of California recently announced a Memorandum of Agreement with 14 other states and the District of Columbia to accelerate truck and bus electrification, with a goal of ensuring that 100 percent of all new medium- and heavy-duty vehicle sales are ZEV by 2050, and an interim target of 30 percent ZEV sales by 2030. While California will need to see 100 percent of on-road heavy-duty vehicle sales be ZEV by 2035, increased out-of-state sales of ZEV trucks will also be important for emissions reductions given that it's estimated that around 50 percent of heavy-duty vehicle miles travelled on California roads is driven by trucks first sold out-of-state.

Addressing Emissions from Primarily-Federally Regulated Sources

In addition to reducing emissions from on-road vehicles and off-road equipment, another critical effort will be to ensure reductions in emissions from sources that are primarily regulated at the federal and international level. In the 2016 Strategy, CARB discussed actions we could take at the State level and those that could be taken by U.S. EPA to achieve reductions from these sectors, which include ships, locomotives, aircraft, and certain off-road equipment. Since that time, CARB and our local partners in California have taken concrete actions to not only petition federal agencies for action, but also to directly reduce emissions using programmatic mechanisms within our respective authorities. Unfortunately, since the release of the 2016 Strategy and the subsequent petitions, action by U.S. EPA to limit emissions from these sources has yet to materialize, making it more challenging to meet federal air quality standards and reduce air pollution that harms public health in California and across the U.S.

Figure 5 - Federal Action is Increasingly Critical



While engine standards do exist at the federal and international level for new aircraft, locomotives, and ocean-going vessel engines and equipment, these standards do not reflect the current state of technology. In addition, equipment in these categories tends to remain in operation for long periods of time. As a result, emissions from these categories have not decreased at the same pace as those for other mobile sources in California. Achieving the magnitude of emission reductions necessary from these categories will require strong action at the federal and international level, coupled with State and local advocacy and action to facilitate these efforts. It is critical to continue to reduce emissions from in-use equipment through new national emission standards for newly manufactured and remanufactured locomotives, adoption of more stringent emission standards for new ocean-going vessels and efficiency requirements for existing vessels, and by spurring the early implementation of clean technologies via mechanisms to incentivize the use of those technologies in California.

In addition to off-road sources that are primarily regulated at the federal level, heavy-duty trucks are another category where action at the federal level is essential to California's success. As mentioned previously, approximately half of heavy-duty VMT within California is driven by trucks first sold out-of-state. Without a more stringent federal engine standard, newer model year 2024+ vehicles certified or first sold outside of California will lack stringent standards. This will make it very challenging for California to meet federal air quality standards, particularly in areas with extreme air quality issues such as the South Coast Air Basin and the San Joaquin Valley. Currently, U.S. EPA is developing the Cleaner Trucks Initiative, which has many of the same elements as CARB's recently-adopted Heavy-Duty Omnibus Regulation and begins in 2027. On January 21, 2020, U.S. EPA released an Advanced Notice of Proposed Rulemaking for pre-proposal comments.

Regardless of the timing of federal action on emission standards, CARB is moving forward and will take action where possible to lower emissions now. As described earlier, CARB has identified strategies available to lower emissions from locomotives, aircraft, and ocean-going vessels. This includes partnerships with ports and engine manufacturers to incentivize the use of cleaner technologies in California and to encourage the production of cleaner, more efficient engine technologies.

Targeting Benefits in Low-Income and Disadvantaged Communities

CARB has long worked to reduce negative effects of air pollution in the State's most highly-impacted populations through programs to control emissions from freight transport and other significant sources affecting low-income and disadvantaged communities. In recent years, CARB and the State have been enabled through AB 617 programs to renew our focus on and engagement with these communities. As discussed earlier, disadvantaged communities experience the highest levels of air pollution impacts in California. In addition, populations in these communities are generally more likely to be impacted by the COVID-19 health and economic crisis, in part due to already-high pollution exposure and impacts. As such, the need is greater than ever to reduce emissions and exposure in disadvantaged communities throughout the State.

CARB's CAPP is a first-of-its-kind statewide effort that includes community air monitoring and CERPs with the primary purpose of reducing exposure in communities most impacted by air pollution. While the program has only been in existence for a few years, together with partners in the communities and at the local agency level, we have made significant progress in establishing the framework of the program and continue to progress in developing CERPs and monitoring programs. Despite the immense ramifications of the COVID-19 pandemic, including the inability to hold in-person meetings in communities, CARB is continuing to engage with community groups and air districts to carry out the mission of AB 617 through implementation, monitoring, planning, and funding. Throughout the AB 617 process to date, many communities and their representatives have continually sought a transition of the dirtiest mobile sources in their communities to zero-emission technology as fast as possible. Since its establishment in 2017, $740 million has been appropriated by the Legislature for use under AB 617, much of which has already been allocated and distributed to local air districts.

CAPP provides an opportunity to continue to enhance our air quality planning efforts and better integrate community, regional, and State level programs to provide clean air for all Californians, but it is not the only mechanism through which CARB works to improve air quality in highly-impacted communities. In addition, there are a number of Low Carbon Transportation projects designed to advance equity including Clean Cars 4 All, the Clean Vehicle Assistance Program, and the Statewide Clean Mobility

Options Pilot project. Other significant factors in CARB's ability to target benefits in disadvantaged communities are the investment minimums for GGRF created under Assembly Bill 1550.[61] AB 1550 requires at least 25 percent of California Climate Investment funds go to projects within and benefitting disadvantaged communities, and at least an additional 10 percent is for low-income households or communities. CARB and other State agencies are continually striving to go beyond the requirements of AB 1550, with 57 percent of projects implemented using California Climate Investment funds to date benefiting California's disadvantaged communities and low-income communities and households.[62] Because mobile sources are such a significant source of emissions throughout the State, much of California Climate Investment funding allocated to CARB, including a considerable portion of CAPP funds, is used to incentivize development and deployment of cleaner mobile source technology.

Moving forward, CARB will continue to go above and beyond our various mandates to improve air quality and reduce exposure to criteria pollutants and toxics in low-income and disadvantaged communities, through AB 617 and other processes. Many of the measures proposed in the 2016 Strategy have since been adopted by CARB as regulations and will provide substantial emissions and health benefits in these communities. In addition, programs under development and new concepts discussed here in the 2020 Strategy, including the Heavy-Duty Inspection and Maintenance Program and the Locomotive Emission Reduction Measure, have immense potential to provide additional benefits.

Ramifications of the Current Health and Economic Crisis

The COVID-19 pandemic has already had extreme effects on lives and livelihoods, as well as on federal, State, and local budgets. In California, the State is confronting a budget deficit of $54.3 billion, and the 2020 State Budget reflects estimated spending of $5.7 billion to respond directly to the COVID-19 pandemic. While allocations from California Climate Investments and other funding sources available to achieve mobile source emissions reductions may look different from those in recent years, all efforts to reduce emissions and exposure are especially critical during this time. Air pollution can have a wide variety of negative effects on respiratory health, and COVID-19 has been shown to pose greater risk to individuals suffering from respiratory illnesses. In addition, both COVID-19 and air pollution are seen to have a disproportionate impact on disadvantaged communities and people of color.

[61] Gomez, Chapter 369, Statutes of 2016

[62] 2020 California Climate Investments Annual Report https://ww2.arb.ca.gov/sites/default/files/classic//cc/capandtrade/auctionproceeds/2020_cci_annual_report.pdf

Even prior to the current crisis, incentive funding was not yet at the levels needed to achieve the level of vehicle and equipment turnover necessary for attainment of near-term SIP deadlines. Given the reduced monetary resources available for incentives in the near-term due to COVID-19, increased emissions reductions from regulatory programs may be necessary.

Ongoing Need for Incentive Funding to Support Clean Technology

While regulations take considerable time to develop and in many instances, lead-time and transition periods are necessary for industry to feasibly comply, significant emissions reductions are needed from mobile sources in California over the next 5, 10, and 30 years. In recent years, the Board has repeatedly directed staff to advance regulatory deadlines where feasible in order to reduce emissions earlier than previously planned. To the extent possible, CARB will continue to explore areas where it may be possible to achieve emissions reductions earlier than currently scheduled in a developing regulation or by amending an existing regulation.

Despite the likelihood of less substantial allocations in the 2020 State Budget specifically dedicated to incentive-based turnover of mobile source vehicles and equipment, there is the potential to leverage other funding that may be available in this year's budget and in coming years to achieve emission reductions from the mobile fleet and from other sources of air pollution Statewide. As California has shown for decades, clean technologies and the markets evolving around them are compatible with and contribute to a thriving State economy. As the State moves forward and works to revive California from the current economic crisis, it is imperative that we use the funds that are available to achieve the maximum benefit possible for all Californians, and this includes reducing mobile source emissions through a transition to zero-emission technologies, and otherwise supporting the green economy.

Chapter 4 - Costs to Achieve California's Goals

The scenarios summarized above and detailed in the next chapter show that in order to meet ambient air quality standards, near-term risk reduction goals, and climate targets, a sweeping transformation of the mobile sector will be needed. As the State moves forward, it is important to recognize that significant public and private investment will be necessary in order to reach the levels of cleaner technology needed in the specified timeframes. To estimate the scope of investment and funding needed, this chapter identifies the cost of the needed cleaner engines and vehicle technologies that must replace our existing, higher-emitting vehicles and equipment. As the vehicles and engines called for in this document are the cleanest technologies available – indeed, some technologies are still emerging, as they progress along the path towards commercialization – the cost of the newer equipment tends to be greater than the older generations of vehicles and engines that CARB seeks to retire.

Included in this chapter are estimates of the costs, in 2020 dollars, of zero-emission and other clean technologies. The quantified costs consist of initial capital investments for vehicles and equipment, and have been developed to reflect the unique technological and market characteristics of each mobile source type. These costs are used to calculate the total costs of turning over a given vehicle or equipment population to the levels of cleaner technology reflected in the scenarios generated by the Vision and META scenario planning tools.

CARB's mobile source control program consists of a suite of policy and regulatory mechanisms that are intended to create a market environment in which vehicle and equipment manufacturers develop progressively cleaner vehicle and engine technologies over time. This suite of mechanisms includes: the establishment of emissions and performance standards for cleaner technologies to encourage development of new vehicles, engines, and fuels; setting mandates and sales requirements to establish markets for the advanced technologies; creating pilot programs to ensure in-use performance of emergent technologies, and implementing incentive and other programs to accelerate the deployment of cleaner technologies.

While the regulatory mechanisms have and will continue to achieve a majority of the necessary emissions reductions, incentive funding is of critical importance, especially in the near-term to advance technology development and deployment and accelerate the rate of fleet turnover to the levels needed to meet targets. In addition to estimates of the incremental costs to transition the mobile fleet to the levels identified in the scenarios, this chapter includes the estimated amount of incentive funding needed to achieve the first five years of the scenario trajectories, and put California's mobile sector on the path towards meeting our numerous goals.

Role of Technology Evolution

The scenarios demonstrate that the introduction of currently available and widespread technologies and the resultant natural turnover of new vehicles to these technologies will not be sufficient to meet air quality and climate change goals. As seen in the technology trajectories for the various sectors, significant percentages of all mobile categories need to be turned over to cleaner technologies, including engines and technologies that are not yet commercially available. As the private sector is developing cleaner combustion and zero-emission technologies at an unprecedented rate, it is important to acknowledge the role that technology evolution and commercialization generally has on the costs of adoption.

Newly conceptualized and recently developed technologies typically have a higher incremental cost to manufacturers and consumers compared to relevant conventional technology. As a technology progresses through the stages of development and commercialization shown in Figure 6, costs generally decrease. As the technology achieves market acceptance and demand increases, manufacturing volumes increase in response. Over time, market forces drive down the per-unit cost of the technology, causing the cost differential between the incumbent and emerging technologies to narrow. In the long-term, upon reaching full market commercialization, the cleaner technologies can approach, or become lower than, the per-unit production cost of the conventional technology, a point known as cost-parity.

Figure 6 - Commercialization Path

As a given technology moves along the commercialization path and matures, the per-unit production cost tends to decrease over time and with increased production volume. One major factor driving down costs is known as economies of scale: producing more units in greater volumes drives down manufacturers' costs, for example as they invest in more efficient production processes, or pay cheaper prices for input products by buying in bulk. Another effect driving down costs over time is a phenomenon known as learning by doing: producing more units in greater volumes enables the manufacturing sector to gain experience in producing and manufacturing a new technology, and through this experience, errors are reduced, improvements and adjustments are made, and the process becomes more efficient – in turn decreasing costs of production.

Furthermore, cost reductions are likely to occur through beneficial technological spillover between the complementary vehicle, engine, and emission control technologies that are called for among the various mobile source sectors. For example, many engine technologies that are currently in-use in certain applications have great potential for expanding their market into use in other types of equipment or vehicles - this is true for both on- and off-road mobile sources. A primary example that is key to this 2020 Strategy is the use of electric and other zero-emission drivetrains in heavy-duty trucks and buses. In the light-duty vehicle sector, electric drivetrains have become popularized over the last 15 years and are now widely-accepted, in part due to the reduced costs of producing electric technologies today, compared with when the technology was emerging. Reduced battery costs, improved battery performance, innovations in battery technologies, and sufficient market demand to drive manufacturing volumes to commercial scale, among other factors, have all contributed toward the downward pressure on costs over time – so much so, that for light-duty ZEVs, cost-parity with conventional combustion vehicles is expected to be achieved in model year 2029.[63]

When looking forward at expanding the application of electric drivetrain technologies from light-duty market into the heavier applications (where the use of zero-emission and electric drivetrains is still in the earlier stages of commercialization), the cost reductions and experience gained in the light-duty market are anticipated to beneficially 'spillover' into heavier applications, translating into lower per-unit costs for the initial generations of heavy-duty electric engines, relative to what their production cost would have been if the market for light-duty ZEVs hadn't already been developed to its current stage of commercial availability. Furthermore, there are complementary efforts underway in the light-duty sector to secure public and private funding for infrastructure investments, which will help facilitate the heavy-duty sector's more rapidly growth toward achieving commercialization. These include an expanding infrastructure network for ZEV charging, as well as major private sector investments in battery production facilities.

While there are more than 98 different models of zero-emission vans, trucks and buses that already are commercially available from more than 25 manufacturers,[64] their share of the fleet in 2020 is small and production capacity remains a limiting factor for many equipment manufacturers. For this reason, it is important that investments spur the development, improvement, and commercialization of advanced technologies for the future. Just as there is a range of regulations affecting heavy-duty vehicles and off-road equipment, there are incentives at the local, State, and federal levels that

[63] CARB (2020). Clean Miles Standard and Incentive Program Standardized Regulatory Impact Assessment.
http://www.dof.ca.gov/Forecasting/Economics/Major_Regulations/Major_Regulations_Table/documents/Clean_Miles_Standard_SRIA.pdf

[64] CALSTART (2020): Drive to Zero's Zero-emission Technology Inventory (ZETI) Tool Version 5.5. Available online at https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

support technology advancement at the demonstration, pilot, and commercial deployment stages.

California's Successful History of Funding Cleaner Technologies

The State, in partnership with the local air districts, has a well-established history of using incentive programs to advance technology development and deployment, and to achieve early emission reductions. Since 1998, CARB and air districts have been administering incentive funding for cleaner vehicles, starting with the Moyer Program. In recognition of the key role that incentives play in complementing State and local air quality regulations to reduce emissions, the scope and scale of California's air quality incentive programs has since greatly expanded, with many new programs building on the success of the Moyer Program.

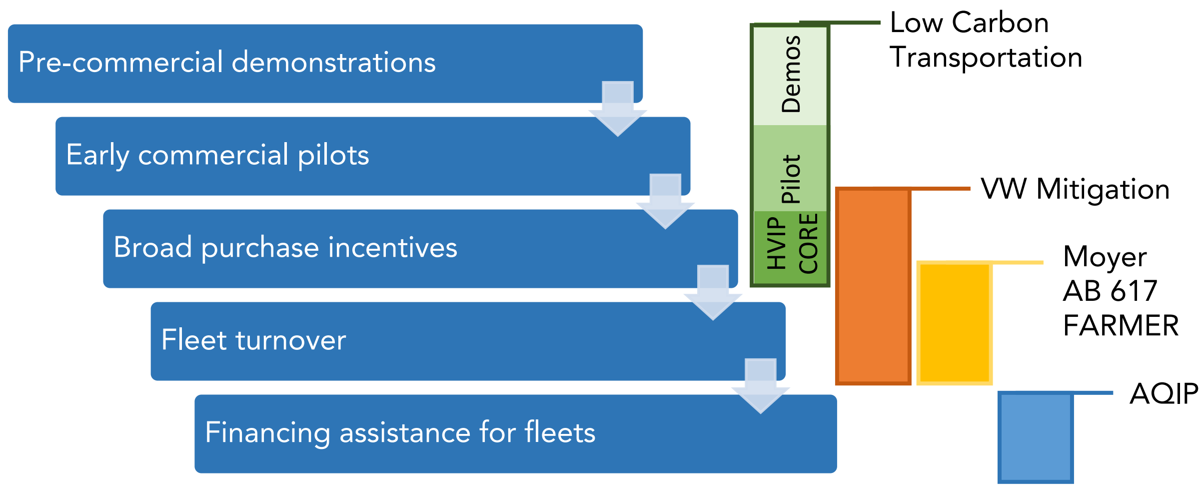
Each of CARB's incentive programs has its own statutory requirements, goals, and categories of eligible projects to make the portfolio diverse and far reaching. In total, these programs address multiple goals, including:

- Turning over the legacy fleet to achieve cost-effective, near-term emission reductions in support of SIP, air toxics, and community air protection goals;
- Accelerating the introduction and deployment of zero-emission technologies to meet California's air quality and mid-century climate change goals;
- Improving access to clean transportation for low-income households, and investing in the disadvantaged and low-income communities most impacted by pollution; and
- Supporting a green economy.

CARB staff work each year to prioritize expenditure of available funding between the programs and projects described below to achieve the complementary program goals. This is accomplished with input from the public and interested stakeholders as part of an ongoing public process. The annual Funding Plan for Clean Transportation Incentives is the principle result of this prioritization effort, and serves as the blueprint for expending the Clean Transportation Incentives funds appropriated to CARB each year in the State budget. The plan establishes CARB's priorities for the funding cycle, describes the projects CARB intends to fund, and sets funding targets for each project. While the annual Funding Plan for Clean Transportation Incentives includes only programs funded through Low Carbon Transportation Investments and AQIP, funding to the rest of CARB's incentive portfolio is also prioritized on a regular basis to meet the respective program goals.

As can be seen in Figure 7, CARB's portfolio of incentive programs are used to accelerate all stages of technology commercialization by promoting the purchase of cleaner vehicles and equipment, assisting vehicle and equipment owners with the cost of upgrading their vehicles, and increasing development and deployment of cleaner and advanced zero-emission technologies. These programs include the Moyer Program, Low Carbon Transportation Investments, AQIP, the Truck Loan Assistance Program, and the Proposition 1B: Goods Movement Emission Reduction (Prop 1B) Program. More recently established programs include the FARMER Program, AB 617 CAPP incentives, and funds available through the Volkswagen (VW) Environmental Mitigation Trust.

Figure 7 - CARB's Incentive Portfolio



The Moyer Program, funded by dedicated revenue from the Department of Motor Vehicle smog abatement fee and a fee on the purchase of new tires, provides approximately $94 million in grant funding annually through local air districts for cleaner-than-required engines and equipment. Due to the passing of Assembly Bill 1274,[65] funding for the Moyer Program is expected to increase in future years.

The Low Carbon Transportation and AQIP programs provide incentive funding with goals of improving access to clean transportation and mobility and reducing greenhouse gas emissions, criteria pollutants, and air toxics by funding accelerated development and early commercial deployment of the cleanest technologies. The 2019 State Budget included $476 million for the Low Carbon Transportation program which is funded by Cap-and-Trade auction proceeds that support the Greenhouse Gas Reduction Fund (GGRF). The 2019 State Budget also included $48 million for AQIP projects, funding which is appropriated from the Air Quality Improvement Fund.

Along with the multitude of grant and rebate opportunities available under the Low Carbon Transportation investments and AQIP, the Truck Loan Assistance Program was created through a one-time appropriation of approximately $35 million in the 2008 State Budget to implement a heavy-duty loan program that assists on-road fleets affected by the Truck and Bus Regulation and the Heavy-Duty Tractor-Trailer

[65] O'Donnell, Chapter 633, Statutes of 2017

Greenhouse Gas Regulation. Since that time, CARB has continued to operate this program with AQIP funds, appropriating around $28 million annually to continue to provide financing opportunities to small-business truckers who fall below conventional lending criteria and are unable to qualify for traditional financing for cleaner trucks.

In addition to these programs, the Prop 1B Program was created to reduce exposure for populations living near freight facilities that were being adversely impacted by emissions from goods movement. This program provided incentives to owners of equipment used in freight movement to upgrade to cleaner technologies sooner than required by law or regulation. Voters approved $1 billion in total funding for the air quality element of the Prop 1B Program to complement $2 billion in freight infrastructure funding under the same ballot initiative. While all Prop 1B Program funds have been awarded to the local air districts for implementation, the program framework exists to serve as a mechanism to award clean truck funds through newer funding programs.

In 2015, after a CARB-led investigation, in concert with U.S. EPA, VW admitted to deliberately installing emission defeat devices on nearly 600,000 VW, Audi, and Porsche diesel vehicles sold in the United States, approximately 85,000 of which were sold in California. The VW California settlement agreement includes both a Mitigation Trust to mitigate the excess NOx emissions caused by the company's use of illegal defeat devices in their vehicles, as well as a ZEV Investment Commitment to help grow the State's expanding ZEV program. The Mitigation Trust includes approximately $423 million for California to be used as specified in the settlement agreement. Per the Beneficiary Mitigation Plan approved by CARB in 2018, this funding will be used to replace older heavy-duty trucks, buses, and freight vehicles and equipment with cleaner models, with a focus on zero-emission technologies where available and cleaner combustion everywhere else, as well as to fund light-duty ZEV infrastructure.

Since 2017, the Legislature through various budget bills has established a number of new incentive programs that are implemented through CARB. In addition to the planning and monitoring aspects of the aforementioned AB 617 CAPP, the State Legislature provided funding to achieve early emissions reductions in the communities most impacted by air pollution. In 2017, the Legislature appropriated $250 million from GGRF to the program and directed that the program be implemented using the existing Moyer Program and Prop 1B Program framework for the first year.

The Legislature also appropriated $245 million from GGRF for Community Air Protection incentives in the 2018 State Budget, and an additional $245 million in the 2019 State Budget. Alongside the 2018 funding allocation, the Legislature expanded the possible uses of AB 617 funds to include: Moyer and Proposition 1B eligible projects with a priority on zero-emission projects; zero-emission charging infrastructure; stationary source projects; and additional projects consistent with the CERPs. CARB and air districts partner to run the program, with CARB developing guidelines and the districts administering funds for their regions. In most cases throughout the State, selected communities have identified mobile source emissions as a target for reductions; therefore, it is likely that a significant portion of the AB 617-allocated funding will incentivize the accelerated turnover of dirty vehicles and equipment in and around disadvantaged communities.

In addition, CARB operates a number of projects funded through the Low Carbon Transportation Program that aim to increase equity by providing mobility and advanced technology transportation access to people in disadvantaged communities and low-income populations. Clean Cars 4 All is a program that focuses on providing incentives to lower-income California drivers to scrap their older, high-polluting car and replace it with a zero- or near zero-emission replacement. The Statewide Financing for Low-Income Consumers program, otherwise known as the Clean Vehicle Assistance Program, helps lower-income residents finance used or new conventional hybrid electric, plug-in hybrid electric, battery electric, or fuel cell electric vehicles. And finally, the Statewide Clean Mobility Options Pilot project supports zero-emission car-sharing, ride-sharing, bike-sharing, and innovative transit services for low-income and disadvantaged communities. All of these projects are specifically designed to benefit members of California's communities most vulnerable to the effects of climate change and poor air quality, and support the State's equity goals under SB 350.

As part of the 2017 State Budget, the Legislature appropriated $135 million to CARB to reduce agricultural sector emissions through grants, rebates, and other financial incentives for agricultural harvesting equipment, trucks, agricultural pump engines, tractors, and other equipment used in agricultural operations. CARB developed the FARMER Program and approved guidelines that establish the program framework, eligible projects, reporting requirements, and oversight provisions. CARB is directing this funding to air districts to administer for agricultural truck and equipment replacement projects. The State Legislature appropriated an additional $132 million and $65 million for the FARMER program in the 2018 and 2019 State Budgets, respectively.

Another more recently-established project under the Low Carbon Transportation investments is the Clean Off-Road Equipment Voucher Incentive Project, known as CORE. CORE is designed to accelerate deployment of cleaner off-road technologies by providing a streamlined way for fleets ready to purchase specific zero-emission equipment to receive funding to offset the higher cost of such technologies. This project is analogous to the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), but specifically targets zero-emission off-road freight equipment that is currently in the early stages of commercial deployment. Born out of a $40 million allocation of Low Carbon Transportation funds in the Fiscal Year 2017-2018 CARB Low Carbon Transportation and AQIP Funding Plan, CORE provides vouchers to California purchasers and lessees of zero-emission off-road freight equipment on a first-come, first-serve basis, with increased incentives for equipment located in disadvantaged communities.

Given the COVID-19 pandemic and the resulting health and economic crisis, California's 2020 State Budget is drastically different from those enacted in recent years. In January 2020, the State was projecting a surplus of $5.6 billion; by the May Revision, the State confronted a budget deficit of $54.3 billion – a four-month swing of almost $60 billion caused by the COVID-19 recession. The 2020 State Budget reflects estimated spending of $5.7 billion to respond directly to the COVID-19 pandemic.

While funding allocations for incentives to achieve mobile source emissions reductions may not be as substantial as in recent years, these funds and the resulting emissions reductions are especially critical during this time. Studies have shown that air pollution may be a key factor in increasing the vulnerability of individuals to contracting COVID-19, as well as increasing the severity of illness and mortality risk from the virus.[66][67] Compounding these issues is the fact that both COVID-19 and air pollution are seen to have a disproportionate impact on disadvantaged communities and people of color; as such, we must continue to strive to protect residents of these communities directly through CAPP and through other funding and emission reduction programs.

Additionally, promoting economic recovery is one of the central goals of the 2020 State Budget; providing financial support to businesses to turn over engines and equipment is one of many ways to support economic recovery in freight and other transportation sectors. CARB's incentive programs, in cooperation with other State and local incentive funding programs, will continue to operate with the funds available and will leverage all funding, including any made available through economic recovery packages, to have the greatest impact and potential for emissions reductions in disadvantaged communities and throughout the State.

Costs of Cleaner Technology in an Evolving World

The figures in the next chapter show the trajectories needed in the different sectors of the mobile fleet in order to achieve the State's many goals and mandates over the next 30 years. From the outputs from the scenario modeling, it is evident that a transition of the mobile fleet, both on- and off-road, to zero-emission vehicles wherever possible is essential. Further, we know that natural rates of turnover to

[66] Petroni et al (2020). Hazardous air pollutant exposure as a contributing factor to COVID-19 mortality in the United States. Environ. Res. Lett. 15 0940a9. Retrieved from: https://iopscience.iop.org/article/10.1088/1748-9326/abaf86

[67] Liang, Donghai et al. "Urban Air Pollution May Enhance COVID-19 Case-Fatality and Mortality Rates in the United States." medRxiv : the preprint server for health sciences 2020.05.04.20090746. 7 May. 2020, doi:10.1101/2020.05.04.20090746. Preprint. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7273261/

cleaner and zero-emission technologies will not occur at the pace needed to meet air quality, climate, and community risk reduction targets and regulatory efforts alone cannot achieve the volume of turnover required; as such, incentives will play a critical role in achieving our goals and mandates.

While we anticipate that incentives will be needed to accelerate the turnover of certain categories of vehicles and equipment for many years to come, CARB staff has estimated the funding that is needed to achieve the technology trajectories over the next five years. Especially in the near term, incentive funding to achieve the turnover needed to meet is key to achieving the volume of turnover required in the first few years of the 2020 Strategy. The mobile technology market is rapidly evolving and we will continue to reevaluate and estimate funding needs as a part of the five-year update to the Mobile Source Strategy, and through related CARB efforts including the annual Funding Plan for Clean Transportation Incentives.

To estimate funding needed in the near-term, staff considered the following factors:

- The increase in the relevant technology populations between the baseline modeling and the scenarios;
- The capital cost of the cleaner vehicle or equipment;
- Anticipated technology availability in the next five years; and
- Existing incentive program structure and amount funded per vehicle or piece of equipment.

These costs consist of capital costs of vehicles or equipment unique to each mobile source type. Based on the amount of technology needed that is outlined in the scenarios and the current amount funded by CARB programs for these types of projects, Table 4 shows the estimated incentive funding that would be needed to achieve the technology trajectories over the next five years.

Table 4 - Funding Needed through 2025

Category	Technology Type	Funding per Vehicle or Piece of Equipment (in 2020)	Incremental Statewide 2025 Population*	Total Funding
On-Road LDV	ZE	$2,000 - $7,000	1,011,199	$2 Billion - $7 Billion
On-Road MDV	ZE	$80,000	0**	$0
On-Road HDV	ZE	$150,000 - $300,000	46,905**	$7 Billion - $14 Billion
Construction Equipment	Tier 4	$60,000 - $325,000	783	$47 Million - $254.5 Million
Transport Refrigeration Units	ZE Truck	$50,000	7,503	$375 Million
	ZE Trailer	$60,000	41,648	$2.5 Billion
Commercial Harbor Craft	Tier 4	$1,000,000	2,749	$2.7 Billion
	Plug-in Hybrid	$1,000,000	N/A – Pilot / Demonstration Projects	
	Diesel-Electric	$3,000,000	N/A – Pilot / Demonstration Projects	
	ZE	$2,500,000 - $3,000,000	N/A – Pilot / Demonstration Projects	
Cargo Handling Equipment	ZE	$175,000 - $500,000	315	$55 Million - $158 Million
Agricultural Equipment	Tier 4	$70,000 - $90,000	6,257	$440 Million - $565 Million
	ZE	$25,000 - $45,000	N/A – Pilot / Demonstration Projects	
Ground Support Equipment	ZE	$100,000	996	$100 Million
Forklifts	ZE	$15,000 - $200,000	6,631	$100 Million - $1.3 Billion
			Total	$15.4 Billion - $29.2 Billion
			Total (Annualized over 5 years)	$3.1 Billion - $5.8 Billion

*The difference in population between the baseline and MSS Scenario trajectories
**The difference in population between the baseline and MSS Scenario trajectories from accelerated turnover

While CARB anticipates that incentives will be needed for some types of mobile sources for many years, it is uncertain at what levels. To estimate the cost to align the State's mobile source fleet with the levels of cleaner technologies shown in later years of the 2020 MSS scenarios, staff considered the following factors:

- The total population for the relevant technology in the 2020 Strategy scenarios; and

- The capital cost of the cleaner vehicle or equipment

These costs consist of capital costs of vehicles or equipment unique to each mobile source type. Fueling and/or charging infrastructure costs are not considered here as these items are the subject of other reports being developed through collaboration between CARB and other State agencies. Further, potential fuel costs savings that are likely to occur with zero-emission technologies are not reflected below.

Based on the amount of technology needed that is outlined above, Table 5 shows the approximate costs in 2020 dollars for each vehicle or equipment category, and the population of the relevant fleet in each target year from the 2020 MSS scenario.

Table 5 - Expected Cost of Transition

Category	Technology Type	Capital Cost of Vehicle or Equipment (in 2020)	Statewide Population Based on MSS Scenario	
			2037	2045
On-Road LDV	ZE	\$30,000 - \$60,000	13,944,426	23,101,069
On-Road MDV	ZE	\$200,000	90,422	241,157
On-Road HDV	ZE	\$350,000 - \$1,000,000	288,460	512,472
Construction Equipment	Tier 4	\$25,000 - \$2,900,000	5,526	3,165
	Tier 5	TBD	N/A	N/A
Small Off-Road Engines	ZE Lawn & Garden	\$560	17,907,557	20,983,762
Transport Refrigeration Units	ZE (Truck)	\$50,000	9,077	10,306
	ZE (Trailer)	\$100,000-\$150,000	248,429	282,066
Commercial Harbor Craft	Tier 4	\$700,000	87	0
	Tier 5	TBD	7,678	7,736
	ZE	\$5,500,000	67	79
Cargo Handling Equipment	ZE	\$500,000 - \$1,500,000	7,737	9,786
Agricultural Equipment	Tier 4f	\$143,700	36,126*	40,304*
	Tier 5	TBD	N/A	N/A
	ZE	\$85,000	N/A	N/A
Ground Support Equipment	ZE	\$250,000	11,456	12,009
Forklifts	ZE	\$60,000 - \$500,000	73,325	75,818

*San Joaquin Valley population

In addition to the above categories, achieving the scenario trajectories for sources primarily regulated at the federal and international level will require significant investment from both public and private entities. While we do not estimate here the total cost to transition to the levels of cleaner technology shown in the scenarios, Table 6 shows the approximate current costs for the needed equipment for locomotives and ocean-going vessels. Significant federal incentive funding could result in emissions reductions from these sources, but it will likely be a combination of public and private investments that will achieve the transition in these sectors.

Table 6 - Sources Primarily Regulated at the Federal and International Level

Category	Technology Type	Capital Cost of Equipment or Engine (in 2020)
Locomotives	Tier 4	$3,000,000
	Tier 5	$4,000,000
	ZE	$8,000,000 - $15,000,000
Locomotive (Switcher)	Tier 4	$2,000,000
	Tier 5	$3,000,000
	ZE	$3,000,000 - $7,000,000
Ocean-Going Vessels	Tier 3	$9,400,000
	Shore Power	$15,000,000
	Capture	$5,000,000

CARB and our partners at the federal, State, and local levels have a long history of supporting the transition to clean technologies through funding at many different stages of technology development and deployment; this will continue into the future as we push for the unprecedented numbers of clean combustion and zero-emission vehicles that are needed to meet ambient air quality standards, near-term risk reduction goals, and climate targets. Private entities in California, including industry and members of the public, are known for their innovation and willingness to invest funds into cleaner technologies, and we look forward to continuing to work with the private sector going forward as we work towards complementary goals.

Chapter 5 - 2020 Mobile Source Strategy Scenario Concepts

In California, on-road and off-road mobile sources are the largest contributor to NOx and GHG emissions. In 2017, direct emissions from mobile sources were responsible for 80 percent of statewide NOx (Figure 8) and 40 percent of statewide GHG (Figure 9) emissions when excluding emissions from the production of fuels that power them.

Figure 8 - 2017 Statewide NOx Emissions by Sector

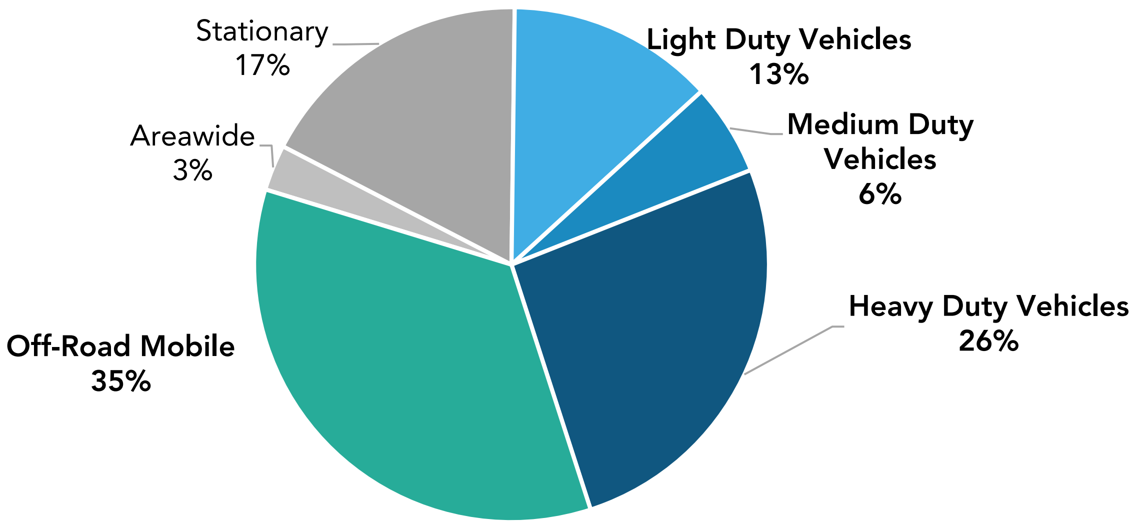
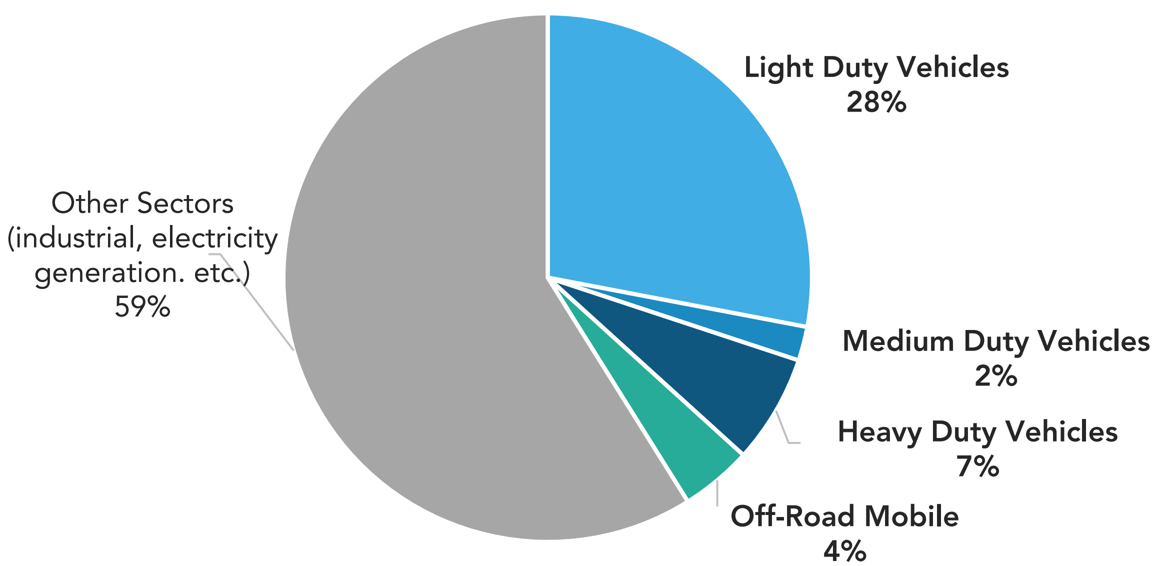


Figure 9 - 2017 Statewide GHG Emissions by Sector



As outlined earlier in the document, while significant progress has been made in reducing mobile source emissions in California, substantial additional emissions reductions from today's levels are required to meet air quality standards and California's climate goals. The 2020 MSS presents a top-down scenario modeling approach that defines the technology mixes needed to achieve these emissions reduction targets. These scenarios are also reflective of the scale of technology transformation that needs to happen within California's mobile source sector. While the scenarios define the technology mixes, they do not necessarily pinpoint the strategies and policy tools that will be used to achieve them. Such a level of transformation requires multiple policy tools as no one tool will achieve all of our goals. Potential policy tools could include, but are not limited to, the following:

- Manufacturer requirements to foster clean technology production and sales;
- In-use requirements to accelerate penetration of newer technology;
- Incentive programs to promote and accelerate the use of advanced clean technologies;
- Zero-emission vehicle fueling and charging infrastructure planning and development;
- Regional land use and transportation planning to enable more transit and mobility options, and to encourage less VMT for mobility needs;
- Transportation pricing to permanently signal to users the mobility options that are more sustainable;
- Enhanced enforcement strategies; and
- Outreach and education to bridge the knowledge gap and increase consumer acceptance of advanced vehicle technologies.

The scenarios developed for the 2020 MSS would require major changes to mobile source sectors, particularly a transformation to zero-emission technologies wherever feasible, and near zero-emission technologies with the cleanest, lowest-carbon fuels everywhere else.

Scenario Modeling Tools

Vision for Clean Air

CARB's Vision for Clean Air Framework, first released in 2012, was developed to enhance CARB's ability to conduct transportation policy, multi-pollutant analyses to inform air quality and climate planning. It allows for the evaluation of technology, energy, and transportation system policy evaluations across multiple sectors and pollutants. In support of the 2016 Strategy, CARB released the updated and expanded Vision 2.1. For the 2020 MSS, staff are using the same modeling framework, but with updated light-duty vehicle (LDV) population and emission rates from EMFAC2017, [68] updated vehicle activity from California's metropolitan planning organizations (MPOs), and refined technology adoption forecasts. Refined technology adoption rates for zero-emission vehicles were updated based on the preliminary ZEV market projection analysis presented in the July 30, 2020 EMFAC 202x workshop.[69] Scenario assumptions for the light-duty vehicle sector are described later in this chapter.

Mobile Emissions Toolkit for Analysis (META)

META was developed to facilitate the updates included in the 2020 MSS. It uses the most current emissions inventory data as the basic framework and incorporates major strategies to reduce criteria and GHG emissions, to present what-if scenarios of technology mix, fuel consumption, and emissions for the on-road heavy-duty and off-road sectors. The META tool provides the explicit technical details and spells out strategy assumptions of the scenario analyses. Most importantly, it provides transparency for the 2020 MSS development. Scenarios visualized through the META tool are used to understand how different combinations of concepts will transform the technology mix of the future vehicle fleet and associated emissions.

The on-road medium- and heavy-duty scenarios in META used population and emission outputs from EMFAC2017 with vehicle activities from MPO travel demand models. This version of EMFAC is used for SIP and transportation conformity purposes. EMFAC2017 incorporated emissions reductions from regulations that had been officially adopted before the end of 2017. The emission benefits of regulations adopted between now and then, such as ACT, are modeled off-line within the META tool. EMFAC2017 outputs served as a baseline for populations and tailpipe emissions, broken down by EMFAC categories. This tool applies the scenario assumptions outlined later in this chapter to the baseline, and then calculates scenario technology population mixes, emissions, and fuel consumption for the 2020 MSS. META on-road allows for scenario selection (for heavy-duty only) and output type, including pollutant and fuel type. There are also options to model what-if scenarios with different combinations of cleaner combustion application scope and ZEV phase-in schedules. This provides an opportunity for end users to compare results with 2020 MSS scenarios.

META-Offroad allows users to visualize the 2020 MSS scenario results and view assumptions for each off-road sector. In the main page, users may select outputs such as population, fuel use, NOx, PM2.5, and carbon dioxide (CO2) emissions, for each off-road sector under baseline or the relevant 2020 MSS scenario. Outputs are provided for the South Coast Air Basin, the San Joaquin Valley, and statewide domains. Baseline emissions for each off-road sector in META are based on the most

[68] California Air Resources Board (CARB) (2017). EMFAC2017 Web Database (v1.0.2) (https://arb.ca.gov/emfac/2017)
[69] https://ww2.arb.ca.gov/sites/default/files/2020-07/EMFAC202x_2nd_Workshop_07302020_ADA.pdf

recent inventory results. The "Assumptions" tab under the Off-road META tool provides a summary of the data sources, inventory status, current rule concepts, and 2020 MSS scenario details for each sector. The "Inputs" tab provides the detailed data behind each scenario.

On-Road Light-Duty Vehicles

Baseline and Existing Policies

In California, the light-duty vehicle (LDV) sector contributes a sizeable proportion of current NOx and GHG emissions. LDVs are defined as vehicles with a gross vehicle weight rating (GVWR) less than or equal to 8,500 lbs. As shown in Figure 8 above, LDVs contribute 13 percent of the total NOx emissions statewide in 2017. In the South Coast Air Basin specifically, LDVs comprised 18 percent of the 2017 NOx emissions inventory. This represents a smaller proportion of the inventory than in prior years as a result of the aggressive LDV regulations and incentives in effect. Future emission baseline projections are shown later in this section.

As shown in Figure 9 above, light-duty vehicles comprise 28 percent of the GHG emissions in California, or about 70 percent of the direct emissions from vehicles or equipment. The indirect or upstream emissions from fuel production (for all transportation modes) are 7 percent for refineries, 4.1 percent for oil/gas extraction, 0.9 percent for pipelines, and 0.7 percent for agriculture fuel production.[70] When coupled with the direct emissions from all transportation sources, the total GHG emissions from mobile sources and their fuel production represent more than 50 percent of the total statewide GHG inventory. The LDV portion of the upstream fuel emissions depend on the emission characteristics of producing gasoline, as opposed to diesel or other petroleum products, at refineries.

The sizable emission contribution of the light-duty vehicle sector is the primary reason that numerous existing policies have been adopted by CARB to control future year emissions, as shown in the next section. Taking into account currently adopted regulations and major CARB programs, emission inventory projections for the light-duty sector are provided below in Table 7.[71] Emission projections for future years provide a critical glimpse into whether current policies are sufficient for achieving emission targets, or if additional actions are necessary.

[70] CARB GHG emissions inventory: https://ww2.arb.ca.gov/ghg-inventory-data

[71] To be consistent with SIP planning inventory, emissions in Table 1 are estimated based VMT provided by MPOs as custom VMT inputs to EMFAC2017. As a result, the GHG emissions for light-duty vehicles in 2017 is lower than the official GHG inventory

Table 7 - Baseline NOx and GHG Emission Projections for LDVs

NOx Statewide	2017	2031	2037
Tailpipe, tons per day (tpd)	184.1	46.7	38.5
% Change from 2017	-	-75%	-79%

GHG Statewide*	2017	2030	2045
Vehicle, MMT CO2e/yr	98.8	68.9	61.8
% Change (vehicle) from 2017	-	-30%	-37%
WTW**, MMT CO2e/yr	118.5	83.7	74.8
% Change (WTW) from 2017	-	-29%	-37%

*Excludes biogenic sources

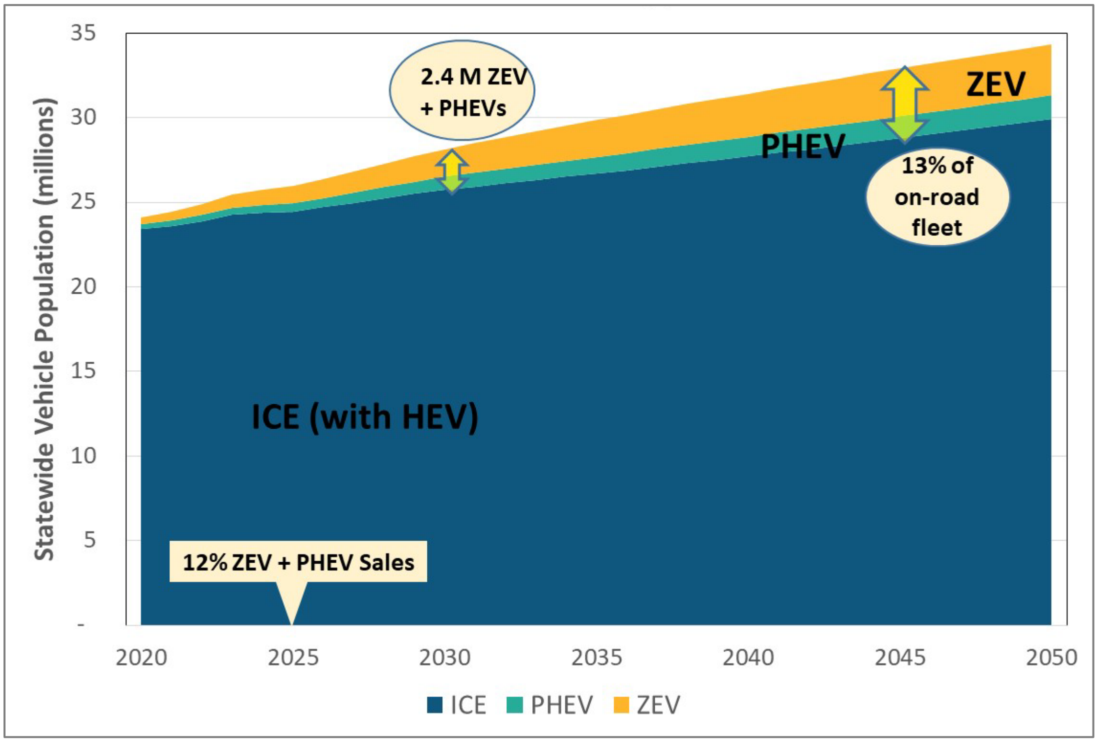
**WTW = Well-to-wheel emissions, including upstream fuel production and delivery

The table for statewide GHG emissions includes both vehicle emissions, and an inclusion of upstream fuel production emissions – this is known as "well-to-wheel" (WTW) when included with vehicle emissions. The analysis accounts for lower fuel lifecyle carbon content (both electricity and gasoline) over time. CARB staff estimated emissions from producing gasoline in 2020 and 2030, accounting for the anticipated lower carbon-intensity ethanol fuel blends in reformulated gasoline (E10 fuel) due to the 2018 Low Carbon Fuel Standard (LCFS) amendments. Emissions from producing electricity accounts for California's power generation mix under the Senate Bill 100[72] renewable requirements (a 60 percent renewable portfolio standard by 2030) and the phase-out of coal generation. These assumptions consider the unique conditions in California and show that driving an electric vehicle produces significantly lower emissions than a conventional gasoline vehicle.

Because of current programs, Table 7 shows that LDV emissions are projected to decline significantly in the next several decades. However, this is still not sufficient to achieve future emission targets. For additional context, Figure 10 below shows the baseline projection of electric vehicles in the on-road fleet. This shows the State is likely to achieve the Governor's target of 1.5 million zero-emission vehicles (including PHEVs) by 2025, as directed in Executive Order B-16-12 which guides State agencies to take actions to support the commercialization of ZEVs and launch the path to the 2050 climate targets, while providing air quality co-benefits. Figure 10, however, also shows that current programs across State agencies will only achieve approximately half of the 5 million ZEVs and PHEVs by 2030 directed in the Governor's Executive Order B-48-18, signed in 2018 (noted as 2.4 million in the figure). This 5 million goal represents the path necessary for the 2030 SB 32 climate statutory requirements.

[72] De Léon, Chapter 312, Statutes of 2018

Figure 10 - Baseline Statewide LDV Technology Projections for the On-Road Fleet



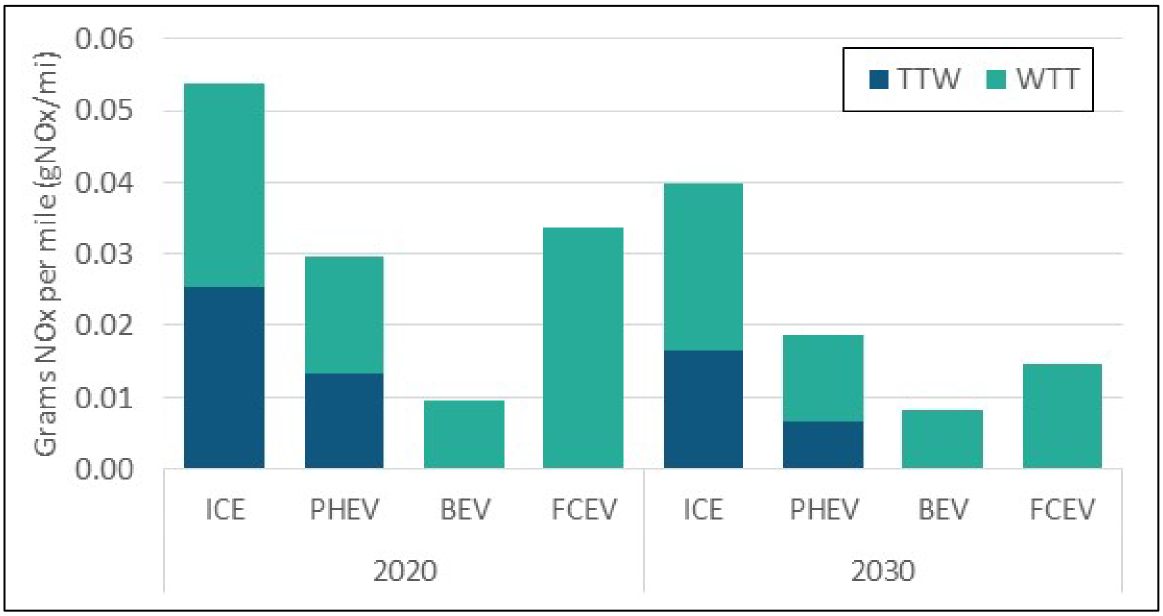
CARB staff have quantified the marginal difference in emissions between driving a mile with a new gasoline conventional vehicle compared to varying electric drive vehicles, coupled with California specific upstream fuel facility emission factors. [73] The figures below show the emissions per mile for a gasoline vehicle (ICE) compared to a PHEV, BEV, and FCEV in California. The data displays both the tailpipe emissions ("tank-to-wheel" or TTW) and upstream emissions associated with producing and delivering the fuel to the vehicles ("well-to-tank" or WTT). Combined, this is called a well-to-wheel emissions analysis comparing varying powertrain types. The analysis compares new passenger vehicles in two different years to account for improved vehicle fuel efficiency and fuel carbon content (electricity, hydrogen and gasoline) over time based on current vehicle and fuel regulations. The PHEVs are assumed to have a percent eVMT of 48 percent in 2020 and 70 percent in 2030. As noted earlier, staff estimated emissions from vehicles using the most current CARB on-road vehicle inventory using EMFAC2017.

The results are presented below for NOx and GHG emissions assuming a passenger car classification. The accompanying model includes further results for light-duty

[73] California Air Resources Board (CARB) (2019). Staff Report: Initial Statement of Reasons. Public Hearing to Consider Electric Vehicle Supply Equipment (EVSE) Standards. Release Date: May 7, 2019. (https://ww3.arb.ca.gov/regact/2019/evse2019/isor.pdf)

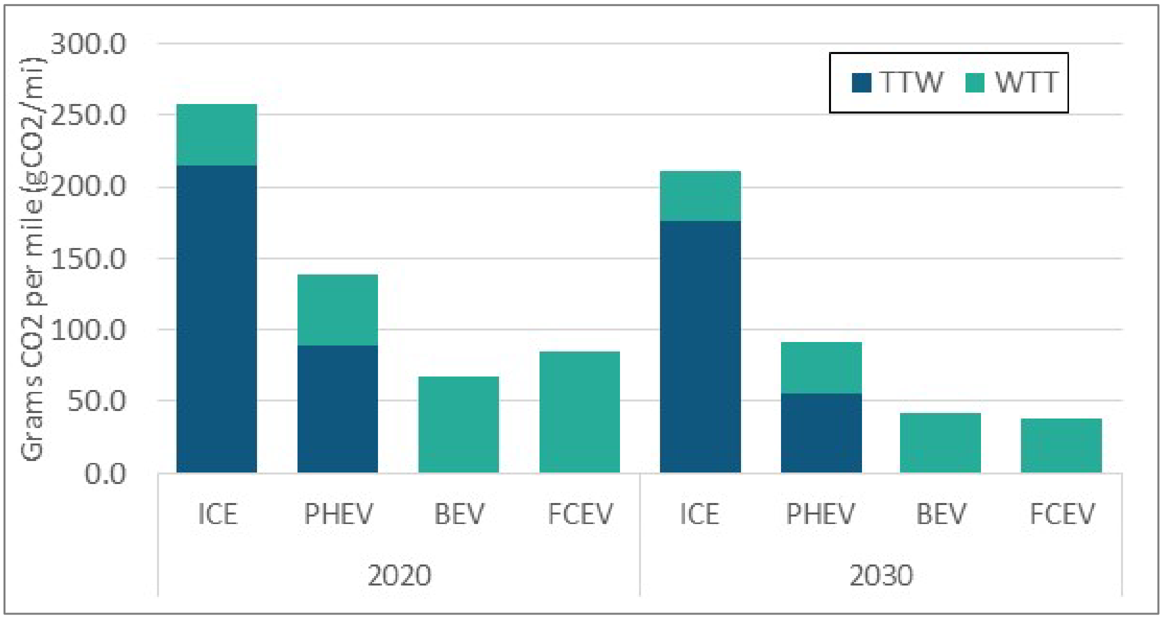
trucks.[74] Figure 11 shows that CARB staff project the WTW NOx emissions for the BEV to be 82 percent lower in 2020 compared to a conventional vehicle, and slightly decreasing to 80 percent lower in 2030. Figure 12 shows that CARB staff project well-to-wheel GHG emissions from a new BEV to be about 74 percent lower than a new gasoline vehicle in 2020, and increases to 80 percent lower in 2030. This trend highlights that BEVs have much lower emissions, and that for GHG emissions the difference is growing over time as emissions from producing electricity are expected to become lower.

Figure 11 - NOx Emission Factors for Four Vehicle Technology Types in a Passenger Car (grams of NOx/mile)



[74] California Air Resources Board (CARB) Vision program model results for well-to-wheel emission factor comparison, https://ww2.arb.ca.gov/resources/documents/vision-scenario-planning

Figure 12 - GHG Emission Factors for Four Vehicle Technology Types in a Passenger Car (grams of CO2e/mile)



Current LDV policies – Vehicle regulations

CARB has been regulating light-duty vehicles for over 50 years. Some policies in place are described below. As discussed earlier, CARB adopted a set of regulations to control emissions from passenger vehicles, collectively called Advanced Clean Cars (ACC). This California program combined the control of smog-causing pollutants and GHG emissions into a single coordinated package of regulations: LEV III Criteria, LEV III GHG, and a technology-forcing mandate for ZEVs.

When CARB adopted ACC in 2012, the Board committed to conducting a comprehensive midterm review of three elements of the program: 1) the ZEV regulation, 2) the 1 milligram per mile particulate matter standard, and 3) the light-duty vehicle GHG standards for 2022 and later model years. Staff's review was conducted at the same time as a similar U.S. EPA and NHTSA midterm evaluation of the federal light-duty vehicle greenhouse gas and fuel economy standards for 2022 through 2025 model years at the national level. CARB concluded the following for its midterm review at its March 2017 hearing:

- Adopted GHG standards remain appropriate for 2022 through 2025 model years;
- Continue with existing technology-forcing ZEV requirements to develop the market;
- Direct staff to immediately begin rule development for 2026 and subsequent model years;

- Continue and expand complementary policies to help support an expanding ZEV market; and
- The particulate matter standard is feasible but further action is needed to ensure robust control.

On April 13, 2018, however, the Trump Administration took a significant step toward dismantling the harmonized national program for reducing light-duty vehicle greenhouse gas emissions when it issued a revised final determination that the federal GHG and fuel economy standards for model year 2022 through 2025 vehicles were no longer appropriate, revoking the previous administration's determination that the standards were appropriate.[75] Over the course of the next year and a half, the Trump Administration revoked California's Clean Air Act waiver for its GHG and ZEV light-duty standards, issued a regulation that those standards are preempted by the Energy Policy and Conservation Act (EPCA), and significantly relaxed the federal light-duty vehicle GHG and fuel economy standards.[76] CARB has challenged these actions, and the litigation is pending.[77] Additionally, CARB recently finalized a voluntary agreement with five automakers to adhere to more aggressive emission reductions on a contractual basis than required by the relaxed federal standards.

Current LDV policies – ZEV market support

As described in CARB's Senate Bill 498[78] report,[79] California has a suite of regulatory, incentive, and supporting programs that accelerate the adoption of ZEVs (light-duty but also medium- and heavy-duty vehicles). The regulatory programs help ensure that vehicles are manufactured and supplied to the market (e.g., the ACC ZEV regulation) or procured for a certain usage (e.g., HD vehicle fleet requirements). Incentive programs help spur demand for these vehicles by encouraging consumers and fleet operators to purchase or lease ZEVs by offsetting some of the additional upfront costs of ZEVs compared to conventional vehicles (e.g., purchase rebates through the Clean Vehicle Rebate Project) or by developing and testing new technologies through demonstrations and pilots (e.g., the Advanced Technology Demonstration Project). The supporting programs also play a critical role in facilitating ZEV market

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[75] 83 Fed. Reg. 16,077 (Apr. 13, 2018).

[76] *See* Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks, 83 Fed. Reg. 42,986 (Aug. 24, 2018); SAFE Vehicles Rule Part One: One National Program, 84 Fed. Reg. 51,310 (Sept. 27, 2019); SAFE Vehicles Rule for Model Years 2021-2016 Passenger Cars and Light Trucks, 85 Fed. Reg. 24,174 (Apr. 30, 2020).

[77] *See California v. Wheeler, et al.* United States Court of Appeals, District of Columbia Circuit, Case No. 19-1239, consolidated under No. 19-1230 along with Nos. 19-1241, 19-1242, 19-1243, 19-1245, 19-1246, and 19-1249; *California v. Wheeler, et al.*, United States Court of Appeals, District of Columbia Circuit, Case No. 20-1167, consolidated with Nos. 20-1145, 20-1168, 20-1169, 20-1173, 20-1174, 20-1176, and 20-1177.

[78] Skinner, Chapter 628, Statutes of 2017

[79] California Air Resources Board (CARB) (2020). Assessment of CARB's Zero-Emission Vehicle Programs Per Senate Bill 498. July 2020. (https://ww3.arb.ca.gov/programs/zev/SB-498-Report-072320.pdf)

growth by providing ZEV fuels and refueling infrastructure (e.g., the LCFS and the Clean Transportation Program), building ZEV awareness, and sharing best practices among different jurisdictions through collaboration. These three types of programs work together to accelerate the ZEV market by fostering supply and demand across all phases of ZEV technology commercialization and market development.

The State also has a number of electric vehicle charging infrastructure programs. The Clean Transportation Program, administered by the California Energy Commission (CEC), provides funding to support PEV infrastructure through various grant solicitations. Additionally, CEC manages the California Electric Vehicle Infrastructure Project (CALeVIP) to provide streamlined incentives for electric vehicle charging infrastructure, and through 2019, CEC has allocated $71 million for charger rebates. The California Public Utilities Commission (CPUC) authorizes investor-owned electric utilities to undertake transportation electrification activities. In 2016, the CPUC approved charging infrastructure pilot programs for three large investor-owned utilities – Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric – to install charging stations for a combined budget of up to $197 million.[80] In 2018, the CPUC approved additional investor-owned utility projects to deploy charging infrastructure pursuant to Senate Bill 350.[81] To date, CPUC has approved over $780 million for transportation electrification programs under SB 350.[82] Finally, Volkswagen, through its subsidiary Electrify America, has agreed to invest $800 million over a 10-year period for ZEV infrastructure, education, and access in California as part of a settlement with CARB. Electrify America will invest $200 million in four installments over the next 10 years.[83]

The State also has a few important programs to support the rollout of hydrogen fueling infrastructure for LDVs. CARB's LCFS Hydrogen Refueling Infrastructure credit provision has initiated the development of nine stations. Additionally, as part of the Assembly Bill 8[84] program aimed at establishing at least 100 stations (45 existing stations are open, with retail service today), the CEC released its latest Grant Funding Opportunity 19-602 to solicit applications to co-fund new hydrogen fueling stations, with awards expected to be announced soon. To facilitate opening of new hydrogen fueling stations, CARB staff assists LDV manufacturers and retail station operators by conducting independent testing to verify compliance with SAE fueling protocols. These are necessary steps to move California's hydrogen fueling and fuel cell electric

[80] California Public Utility Commission, 2019. Summary of CPUC Actions to Support Zero-Emission Vehicle Adoption. https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442459998
[81] De León, Chapter 547, Statutes of 2015
[82] California Public Utility Commission, Approved SB350 Projects. Accessed July 27, 2020: https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442457944
[83] Volkswagen Group of America, 2017. California ZEV Investment Plan: Cycle 1. https://www.electrifyamerica.com/our-plan
[84] Perea, Chapter 401, Statutes of 2013

vehicle (FCEV) industries out of the current early adopter phase and into the broader mass-market.

Scenario Analysis

Targets

As noted earlier, the State has a number of emission reduction targets that apply either to all sectors in the economy, or to the transportation sector as a whole (all mobile sources, including on-road and off-road sectors). Given the size of the contribution from light-duty vehicles to the 2017 emissions inventory, this sub-sector will need to make strong contributions toward regional and Statewide emission targets. Therefore, for the purposes of creating a reference for these light-duty scenarios, the results are compared to an equal-share reduction of the broader targets. This includes a 62 percent NOx reduction in 2037 below the baseline 2037 NOx projections, citing preliminary estimates of the needed NOx reductions to meet the 70 ppb 8-hour ozone standard.[85] For GHG emissions, with an uncertainty of whether natural and working lands will not provide increased carbon sinks over time, this analysis assumes mobile sources will need to achieve zero carbon emissions by 2045 on a full well-to-wheel basis. CARB will be comprehensively evaluating strategies to achieve carbon neutrality through the next Climate Change Scoping Plan process, including renewable fuel supply constraints and unique challenges in varying sectors.

In principle, to achieve full carbon neutrality by 2045 with direct vehicle and fuel production emissions from the LDV sector, the entire on-road LDV fleet needs to be either some form of an electric vehicle using renewable electricity/hydrogen or an internal combustion engine using sustainable biofuels. When considering the additional constraint of dramatically reducing the criteria emissions from the vehicles themselves, separate from the upstream fuel production, the necessity for ZEVs becomes even stronger.

The scenario described below is aggressive, as there are certain limitations that inhibit fully achieving carbon neutrality with direct vehicle and fuel production emissions. These limitations include the pace at which new ZEV sales can grow, the scrappage of legacy gasoline vehicles, and biomass supply limitations and competition from other sectors, among other factors. There are many combinations of strategies that can help to achieve these air quality and 2045 GHG LDV equal-share emission targets, so the challenge is to identify the combination with the greatest chances for success, knowing that every individual strategy will need to be extremely aggressive. The following list describes key scenario considerations and assumptions that were considered.

[85] https://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2016-air-quality-management-plan/final-2016-aqmp/final2016aqmp.pdf?sfvrsn=15

Framework for Scenario Development

The strategies and scenarios described below do not reflect a market feasibility analysis, but rather were identified as strategies that are technically possible but most likely only under optimal policy and market conditions. The technology and fuel assumptions reflect staff's current understanding of the vehicle and fuel technologies that have been developed and are already entering the market. Staff then make assumptions about their future potential market growth.

Advanced vehicle technology and efficiency improvement form the foundation for the scenarios. Given the large incremental improvement in emissions per vehicle from electrification, the scenarios focus on aggressively moving to all-electric technologies, coupled with increases in conventional vehicle improvements. These strategies were assumed to have a correlation related to automaker investments – much of the industry will focus investments on electrification, but conventional vehicles will see a scaling up of existing efficiency strategies, such as hybrid powertrains (as compared to widespread investments in new innovations for conventional engine technology). Battery-electric vehicles were the dominant technology selected for the scenarios, but fuel cell electric vehicles are assumed to continue their growth in the market and are included in the scenarios.

Further, the scenarios rely solely on new light-duty vehicle sales as the mechanism to change the fleet's technology mix and did not assume any retrofit or accelerated scrappage policies. Finally, new mobility trends, namely ride-hailing services with high-mileage vehicles and connected, autonomous vehicles, create opportunities to substantially increase electric vehicle miles traveled (eVMT) by the fleet as a subset of vehicles are more intensively used and thus retired more quickly.

The fuel supply sector will need to transition to nearly all renewable sources to achieve the equal-share emission targets. However, partly because there are limits to renewable sources depending on the fuel type, the results shown here do not quite achieve the "equal share" targets used in this analysis. These scenarios will be revisited as CARB develops the renewable fuel assessments for the next Climate Change Scoping Plan. Transportation electricity will leverage the same grid supply mix that is changing economy-wide in response to State statutes for an aggressive renewable portfolio standard. Hydrogen was assumed to transition to all renewable sources, though there is currently no statute requiring these high levels. To offset remaining liquid fuel usage in the light-duty fleet, the 2016 Strategy had assumed that renewable "drop-in" gasoline would emerge on the market by 2020. However, a review of fuel technology advancements and new expected fuels shows that renewable gasoline is not being seriously developed for California markets. This, coupled with the ongoing supply constraint of low carbon biofuels anticipated to be primarily used in heavier mobile sources, led to the assumption that biofuels beyond ethanol in E10 would not be used in these LDV scenarios.

Reducing vehicle miles traveled, while maintaining mobility needs, is also an essential strategy for achieving long-term emission and sustainability goals. These scenarios leveraged the same aggressive assumptions used in the 2016 MSS analysis, pushing towards a 25 percent reduction in light-duty fleet VMT below 2005 levels by 2035. This target remains extremely aggressive and would require implementing the suite of strategies outlined in CARB's 2018 Progress Report on Sustainable Communities Implementation.[86] In addition to providing congestion mitigation and improved community mobility, VMT reduction also reduces fuel demand, and therefore can alleviate advanced fuel supply constraints (e.g. biofuels, build out of solar and wind, etc.).

Scenario Input Assumptions

Multiple scenarios were created to evaluate the impacts of varying the pace of ZEV sales, with a particular focus on either 2035 or 2040 as dates at which conventional vehicle sales could end. In the scenarios, PHEV sales were included, but at a declining ratio to ZEV sales and also assuming greater all-electric driving range[87] than exhibited by PHEVs in the market today. The primary scenario selected assumed conventional vehicle sales end in 2035, with ZEV and PHEV sales reaching 100 percent by that date. Several specific technology and fuel assumptions are listed below, many of which would require new policy actions.

- The relative ratio of combined ZEV and PHEV sales start at 75 percent ZEV/25 percent PHEV in 2030 scaling to 90 percent/10 percent in 2045 (see Figure 13). The rationale for this assumption reflects a projection that as pure ZEV technology advances, PHEV costs will be relatively higher than BEVs given the complexity of two powertrains (combustion engines and electric systems), and this cost differential will affect market demand. Additionally, to achieve the emission targets, pure ZEV technology will need to be prioritized.
- The relative ratio of combined BEV and FCEV sales start at 90 percent BEV/10 percent FCEV in 2030 scaling to 75 percent/25 percent by 2045 (see Figure 13). The rationale for this assumption reflects increasing FCEV adoption as hydrogen fueling infrastructure expands and a subset of the vehicle market that will still require frequent fast refueling, particularly in larger vehicle classes.
- PHEV eVMT is fixed at 70 percent (or about52 miles of all-electric range) for passenger cars and 50 percent (or about28 miles of all-electric range) for light trucks for all years after 2030. Although technology will continue to improve beyond 2030, these values were kept constant in future years given that the technology will need to be used on a larger number of larger vehicle platforms

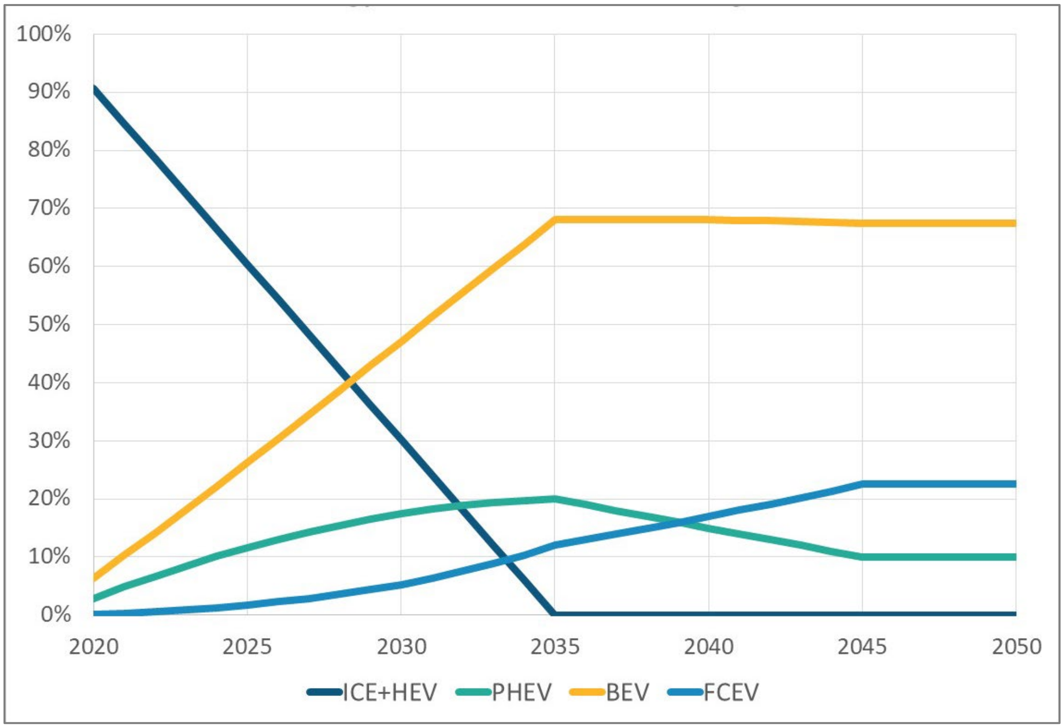
[86] A report which evaluated the first ten years of the Sustainable Communities Strategies program, as required by Senate Bill 150 (Allen, Chapter 646, Statutes of 2017)
[87] Modeled as a larger "percent eVMT" which represents the proportion of a PHEV's annual driving that is solely from the electric drive system.

as the market grows. The scenarios assume the technology improvements will be needed to maintain the eVMT performance on heavier vehicles, some of which will require towing capability.

- New gasoline-only vehicles, including hybrids (non-plugged vehicles), are assumed to have reduced GHG emissions by 2.0 percent per year from 2026 to 2035. This assumption reflects an investment by the automotive industry in ongoing conventional vehicle improvements while focusing most investments on ZEVs, and likely would require a regulatory change to California's vehicle standards.
- BEV and FCEV new vehicle efficiency is assumed to improve at 0.5 percent per year from 2026 to 2045. This assumption reflects greater emphasis on cost reduction of components and systems rather than on further improvements to efficiency.
- NOx emission factors do not change for new vehicles in any of the vehicle classes. This assumption reflects the need for vehicles to remain clean and to prevent a backslide on emission certification levels as a result of the increasing fraction of ZEVs. To accomplish this, light-duty vehicle regulations will need to change to protect against backsliding. The effect would be that as ZEV sales increase, the total light-duty new vehicle fleet average for NOx emissions will decline. It is possible to additionally assume conventional vehicle NOx emission levels will decline, in addition to ZEV sales. CARB staff are considering this as a regulatory option in addition to regulatory provisions to protect against emission certification backsliding.
- By 2045, approximately 90 percent of electricity and all hydrogen is assumed to be from renewable sources. Per SB 100, electricity must be 60 percent renewable by 2030 (when coupled with nuclear and large hydro, the grid is likely to be higher than 60 percent of zero carbon sources by 2030); the statute further requires 100 percent zero carbon on the grid retail sales by 2045.[88] It is assumed 100% electrolytic hydrogen will utilize growing curtailed renewable electricity as utilities procure more zero GHG generation to meet the Renewable Portfolio Standard (RPS).
- For remaining liquid fuel demand in 2045, all scenarios assume E10 ethanol blend in gasoline as the fuel.

[88] SB 100 requires that 100 percent of retails sales of electricity come from RPS-eligible and zero-carbon resources by 2045. SB 100 does not define zero-carbon resources. An interagency effort is underway to evaluate potential paths to achieving the 2045 goal, and this process evaluates electricity generation technologies that could be eligible zero-carbon resources and will model potential resource mix scenarios for 2045. Refer to https://www.energy.ca.gov/sb100 for more information about this process. SB 100 allows for a small amount of electricity generated by natural gas in 2045 which could be replaced by renewably sourced bio-methane, but this scenario did not assume bio-methane was available for electricity production.

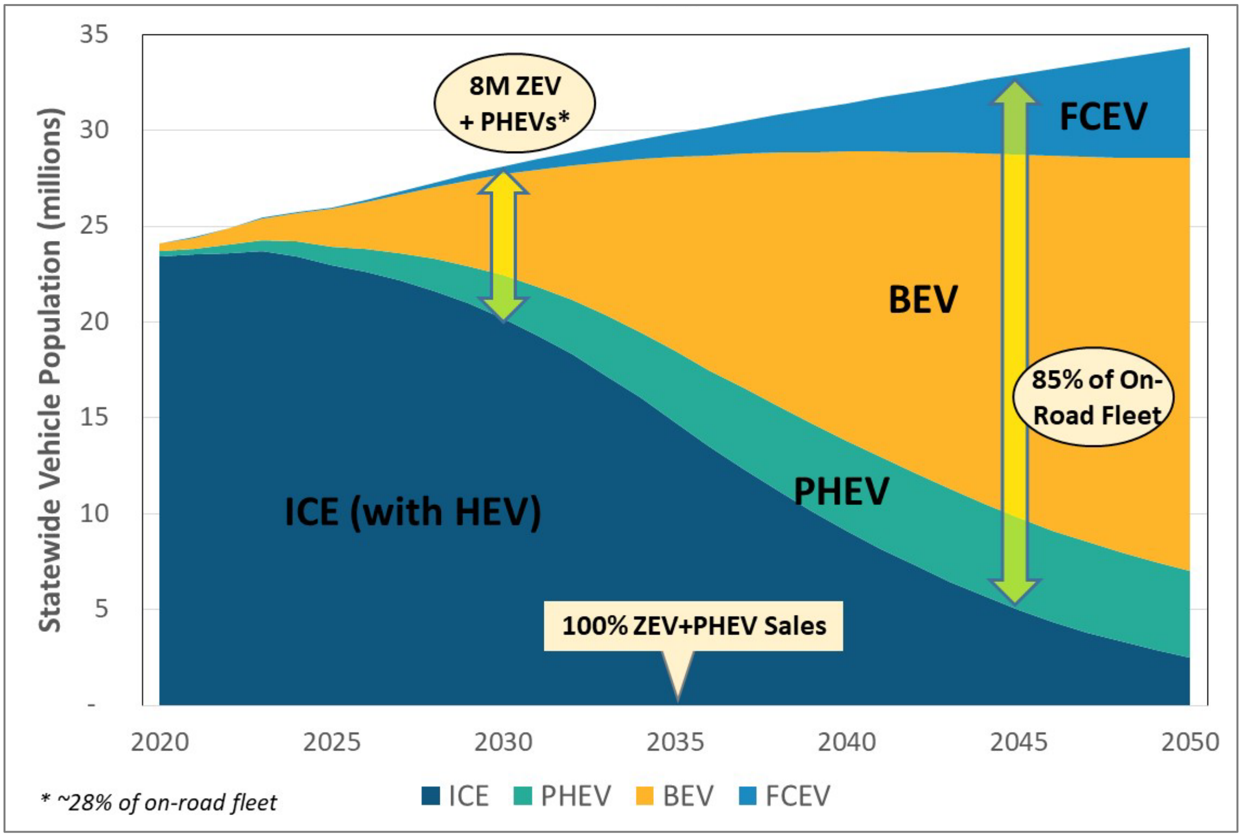
Figure 13 - LDV Sales Fractions by Technology Type



Scenario Results and Trends

In the primary scenario where new sales of ZEVs and PHEVs reach 100 percent in 2035, the on-road fleet still includes 15 percent conventional or hybrid vehicles in 2045, as shown in Figure 14. In 2045, 16 percent of total VMT is from conventional vehicles or PHEVs not using electricity. Given the aggressive nature of sales before 2035, up to 8 million ZEVs and PHEVs would be in the fleet by 2030, well above the Governor's second ZEV target. This reflects the more aggressive climate target being evaluated here compared to when Governor Brown established the 5 million ZEV target.

Figure 14 – Statewide LDV Technology Penetration in the On-Road Fleet



Under this fleet composition, combined with the fuel mix changes and VMT reduction assumptions, the primary scenario generates a 16 percent reduction in NOx emissions in 2031 and a 41 percent reduction in 2037 relative to baseline projections of tailpipe emissions Statewide for each of those years. GHG emissions in 2045 are 87 percent lower than 2020 levels.

Figure 15 - Statewide LDV NOx Emissions (Tailpipe)

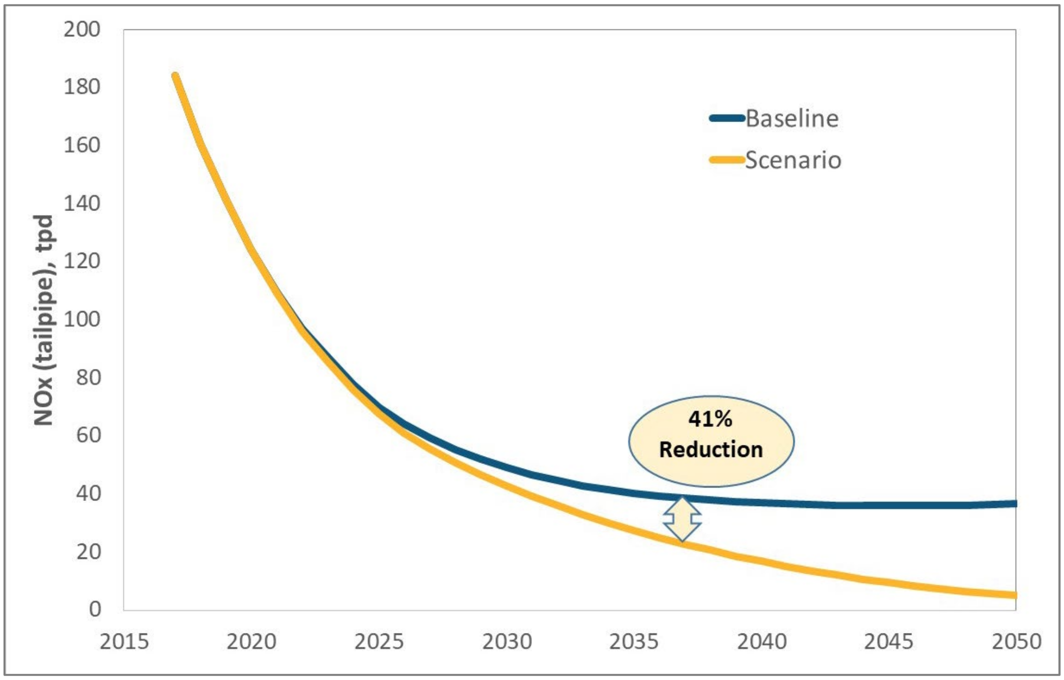


Figure 16 – Statewide LDV GHG Emissions (Well-to-Wheel)

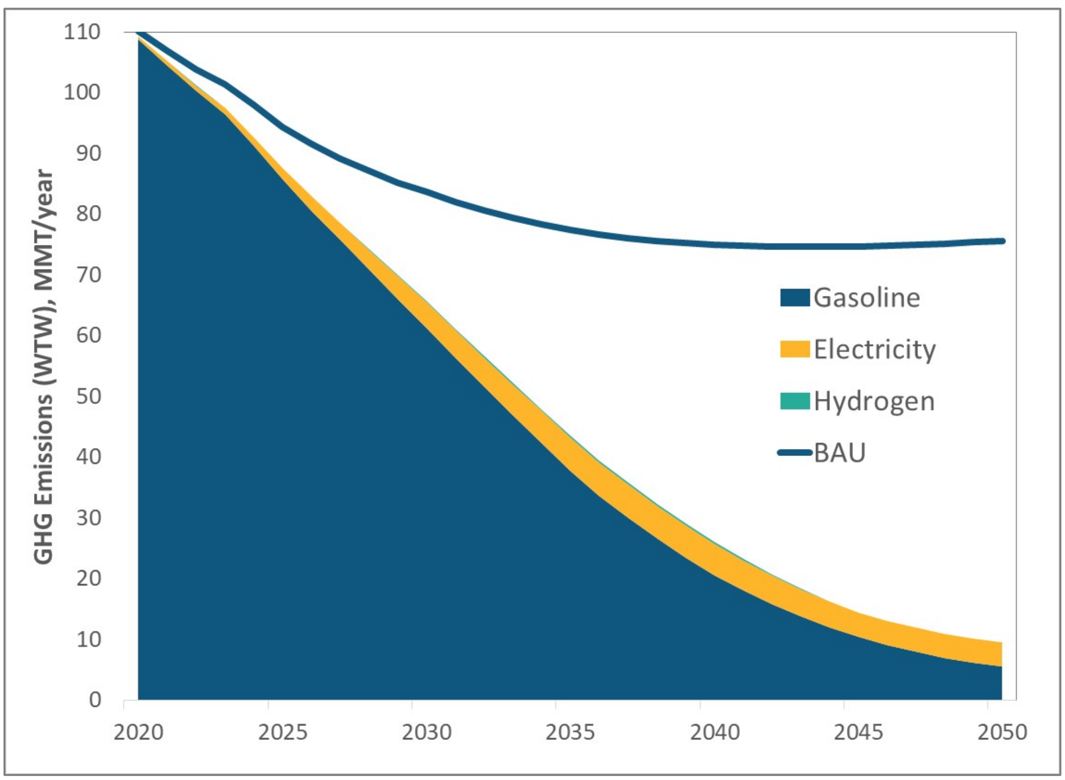
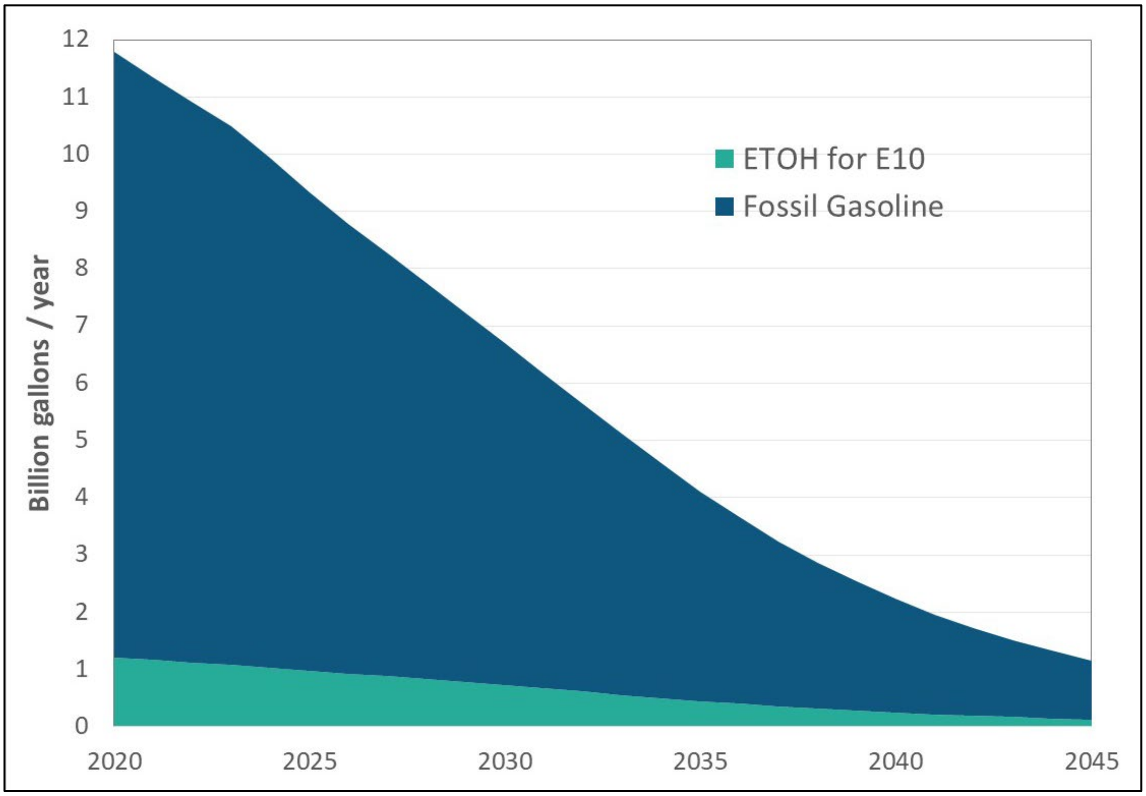


Figure 17 shows the total liquid fuel usage for the light-duty fleet over time. Although a relatively small portion of the on-road fleet in 2045, combustion vehicles would still consume 1.2 billion gallons of liquid fuel in 2045 – only 30 percent of which would be used by PHEVs – and contribute roughly three quarters of the fleet's GHG emissions (see Figure 16). Therefore, the quantity of liquid fuel demand that remains in 2045 has an oversized influence on achieving the light-duty equal share emission targets. Separately, GHG emissions from electricity usage in vehicles would not be zero due to some remaining fossil natural gas usage for electricity generation but will be a small impact.

Figure 17 - LDV Liquid Fuel Demand (fossil gasoline, ethanol for E10)



Discussion of Results

The light-duty vehicle scenarios reveal that even with extremely aggressive electrification, coupled with aggressive VMT reductions and fuel decarbonization,[89] the sector still cannot achieve its "equal share" of the reductions for NOx and GHG emissions in 2037 and 2045 respectively assumed for this analysis.[90] The emission reductions are sizeable, however, with a 41 percent reduction in 2037 of tailpipe NOx

[89] Fuel decarbonization refers to a group of strategies, including SB 100 electric grid requirements, liquid fuel carbon reductions through the Low Carbon Fuel Standard (LCFS), and other actions.
[90] As noted earlier, the "equal share" target for GHG emissions in this analysis is carbon neutrality for the light-duty sector by 2045.

emissions below the 2037 baseline, and an 87 percent reduction of well-to-wheel GHG emission reductions in 2045 below 2020 levels.

The earliest possible date by which staff believe conventional vehicle sales possibly could end is 2035, and although automotive battery technology costs are rapidly declining, achieving this sales trajectory still faces broader market challenges of insufficient ZEV fueling infrastructure, electric drive manufacturing scale-up constraints, battery and fuel cell raw material supply constraints and uncertainty in consumer demand, particularly with lower income households. The next few years will be very telling in terms of new electric vehicle models entering the market, and consumers seeing wider choices and fuel infrastructure advancements.

The scenarios also reveal that while the State needs to push as hard as possible on electrification, CARB also needs to continue taking action to reduce NOx and GHG emissions from new conventional vehicles. A sizeable fraction of the on-road fleet in the later years will still use combustion engines, so new emission standards in model years 2026 to 2035 will have important benefits. For NOx emissions, this includes the need to strongly consider "anti-back-sliding" actions on conventional vehicles in the light-duty fleet average standards as ZEV sales scale up (as simulated in these scenarios), and possibly going further to require the fleet average standard to be lower, thus requiring conventional vehicles to get cleaner (not simulated in this scenario). For GHG emissions, an additional reason to consider new conventional vehicle GHG emission reductions (as simulated in this scenario with efficiency improvement assumptions) is the cumulative climate change mitigation for the years before electrification becomes dominant. This is noted because the difference in the 2045 annual GHG emission results from the scenario, with and without the conventional vehicle GHG improvements is small. But cumulative GHG emissions over time for these conventional vehicles will not be trivial.

Further reductions from conventional vehicles would be possible with select actions not evaluated in these scenarios. For example, to further control NOx emissions, targeted policies (e.g. regulation changes) could focus on cold start emissions. For GHG emissions, advanced biofuels could be used, but were not considered here given the limitations on biomass supply.

Anticipated Regulatory Actions

Advanced Clean Cars II

The ACC regulations are responsible for setting criteria pollutant and GHG emission standards for light-duty and medium-duty vehicles and establishing a ZEV mandate (although CARB's authority for the GHG and ZEV regulations has been preempted by federal action in the SAFE Rules - which California is contesting). ACC II is currently in development to strengthen these standards beyond model year 2025, and the regulatory proposal is anticipated for Board consideration in late 2021. Staff provided an informational Board update in May 2020, outlining staff's preliminary thoughts on real-world emission reduction measures for combustion vehicles, cold-start emission reductions, improved emission control for plug-in hybrid vehicles, new medium-duty requirements, as well as potential changes to ZEV credits and new ZEV consumer protections like vehicle warranty, durability, and battery state-of-health monitoring requirements to ensure emission benefits from ZEVs.

Clean Miles Standard

Senate Bill 1014,[91] the Clean Miles Standard and Incentive Program, requires CARB to develop and the CPUC to implement a GHG reduction program for transportation network companies (TNC) such as Uber and Lyft. SB 1014 directs CARB to adopt GHG per-passenger-mile reduction and percent eVMT targets for TNCs by January 1, 2021. Staff anticipates achieving GHG goals through increased use of ZEVs and increased pooling, as well as use of transit and micro mobility modes of transportation facilitated by the TNCs. The program will begin in 2023 and increase in stringency through 2030. The Clean Miles Standard regulatory proposal is currently being developed; staff provided an informational Board update in January 2020 and the regulation is scheduled for Board consideration in late 2020 or early 2021. The Standardized Regulatory Impact Assessment has been made public, and the program expects to achieve at least 0.25 MMT CO_2e/year of GHG emission reductions in 2030.

Sensitivity scenarios

In addition to the main scenario presented in this chapter, staff have evaluated a number of additional scenarios to gain an understanding of how certain assumptions influence the emissions results. This is important given that the main scenario does not yet achieve the light-duty equal share emission targets noted earlier. The first sensitivity scenario explored how influential the ZEV sales target was on the results of the main scenario. The sensitivity scenario explored a delayed date of 2040 for the end of conventional vehicle sales. As noted earlier, staff will revisit these scenarios as part of the 2022 Climate Change Scoping Plan, and the fuel supply assumptions may change, affecting the emission results.

Scenario with conventional vehicle sales ending in 2040 instead of 2035

- +4 MMT/yr GHG emissions in 2045 compared to the 2035 scenario (83 percent reduction instead of 87 percent below 2020 baseline emissions)
- +3.5 tpd additional NOx emissions in 2037 Statewide compared to the 2035 scenario (32 percent reduction instead of 41 percent below 2037 baseline emissions)

[91] Skinner, Chapter 369, Statutes of 2018

- 1.6 billion gallons liquid fuel demand (instead of 1.2 billion gallons in the 2035 scenario)

Scenario with aggressive growth in ride hailing vehicles

- Assumes growth in high-mileage ride hailing services, including driverless automated ride-hailing in later years
- Slightly lower vehicle population for same mobility needs as vehicle age requirements force older vehicles out of the ride hailing fleets
- Overall increase in light-duty VMT as increased "deadhead miles" over compensate for increased pooling assumptions in the scenario. In 2045, the ride-hailing scenario results in 944 million miles per day statewide compared to 905 million miles in the main scenario,
- Increased deadhead VMT over compensates for slightly higher fraction of the fleet as electric, creating a small increase in the sector's GHG emissions. In 2045, well-to-wheel GHG emissions rise by +0.5 MMT/yr. However, had electrification not been prioritized on the ride-hailing vehicles in this scenario, the rise in GHG emissions would have been larger.

Reducing VMT in California

Today's California is shaped by historic patterns in transportation and housing. While we have grown to be the fifth largest economy in the world, Californians, in search of an affordable place to live, and with insufficient transportation options, are too often left with little choice but to spend significant time and money commuting long distances. Where we put transportation and housing also imposes and often reinforces long-standing racial and economic injustices by placing a disproportionate burden on low-income Californians, who end up paying the highest proportion of their wages for housing and transportation. It is imperative that California make further progress at the intersections of housing, transportation, and land use policy to meet critical air quality and climate goals, and to improve quality of life for every Californian. As a part of the 2020 Mobile Source Strategy, the following sections explain the important role VMT plays and how we can begin to take action.

The need to curb growth in VMT and reduce auto dependence

Growing dependence on cars for travel threatens the environment, our ability to achieve California's air quality and climate goals, and quality of life for many Californians, especially the most vulnerable. However, electric vehicles alone cannot solve these problems. The 2016 Mobile Source Strategy and the 2017 Climate Change Scoping Plan emphasize the critical role VMT reductions play in 2031 attainment of the 75 ppb 8-hour ozone standard and meeting California's 2030 climate goals. This update to the Mobile Source Strategy builds on the same ambitious, exploratory scenario from these previous plans, which assumed that regional transportation plan/sustainable communities strategies (RTPs/SCSs) prepared by metropolitan planning organizations (MPOs) under Senate Bill 375[92] are successfully implemented statewide, and that light-duty VMT is reduced by an additional 15 percent by 2050.

Unfortunately, as discussed in CARB's 2018 Progress Report to the Legislature on SB 375 implementation, that we are not yet on track to meet the GHG emissions reductions expected under SB 375; in fact, emissions from passenger vehicles are increasing because per capita VMT growth is outpacing technology gains. Thus, a first critical step to meeting our goals is to get on track to reduce emissions and VMT to improve air quality and quality of life.

Looking to the future, as we plan for the 2037 attainment of the 70 ppb ozone standard and 2045 carbon neutrality goals, even deeper VMT reductions will be needed to achieve the necessary emission reductions. As shown in Figure 14 above, over time, CARB projects the vehicle fleet will substantially transition to battery-electric and non-ICE fuel sources. A key takeaway from this chart is that while

[92] Steinberg, Chapter 728, Statutes of 2008

electric vehicles will substantially reduce on-road light-duty mobile source emissions, the transition will not happen quickly enough. Therefore, additional per capita VMT reductions will be necessary to bring the light-duty transportation sector within striking distance of carbon neutrality by 2045, and attainment of the 70 ppb 8-hour ozone standard in 2037.

In addition to meeting air quality and climate goals, there are several other important reasons to curb the growth in VMT. Growth in VMT, where it involves or incentivizes land conversion due to the need for more roadways, impedes California's ability to store carbon and maintain resilient ecosystems and the life-sustaining resources they provide, including clean air and water, food, and fiber. When natural and agricultural lands are lost to more intensive uses, the soil and biomass carbon on the land is often degraded or lost. On average, approximately 50,000 acres of farmland and rangeland are lost per year; of that, 21,000 acres per year are lost to urbanization.[93] Therefore, reducing VMT has direct benefits for California lands by preventing urbanization, thereby protecting the land's potential to sequester carbon, reduce land-based GHG emissions, and increase the capacity for California to withstand inevitable climate impacts. If we are to depend on California lands for food and fiber, carbon sequestration and storage, and climate resiliency, it is important that rates of conversion diminish. Directing new growth to existing communities without displacing current residents can prevent the conversion of natural and working lands, and the associated impacts to climate, water, and air, while fostering compact development that reduces VMT.

Notably, many of the same policy responses to address transportation injustices and systematic racism in land use and transportation planning can simultaneously make communities stronger and more resilient, while reducing VMT impacts. These include affordable housing, safe, reliable transit, a range of affordable mobility options, and access to quality public education, medical care, and jobs all within the same community.

Therefore, reducing per capita VMT is necessary to ensure that the transportation sector can become zero-emission as quickly as possible, while improving the quality of life and protecting the environment and public health.

Changes and additional work by all levels of government are necessary

New structural opportunities are underway for State agencies to collaborate on reducing light-duty VMT and, simultaneously, advancing crucial climate, health, housing, equity, and conservation goals. For example, CARB, the California Transportation Commission (CTC), and the Department of Housing and Community Development now hold bi-annual joint meetings to inform and initiate appropriate

[93] California Department of Conservation. Division of Land Resource Protections Farmland Mapping and Monitoring Program. https://www.conservation.ca.gov/dlrp/fmmp

actions that help better align State transportation, housing, and air quality programs and policies.[94] Governor Newsom's Executive Order N-19-19, among other things, directs the California State Transportation Agency (CalSTA) to leverage the State's $5 billion transportation funding portfolio in a manner to help achieve the goals in the 2017 Climate Change Scoping Plan. CalSTA is currently developing an action plan to better align transportation investment priorities with state climate goals in response to Executive Order N-19-19. In addition, Senate Bill 743[95] went into effect statewide on July 1, 2020. SB 743 fundamentally changed the way public agencies view the consequences of their decision-making, away from impacts on driving and instead, to the impacts of driving on the environment. These important structural and philosophical shifts provide opportunities for improved collaboration, and more informed and aligned decision-making across State, regional, and local agencies. Additional steps that will be needed to secure the baseline level of GHG emissions reductions assumed from RTP/SCSs under SB 375, and to implement these productive changes to reduce per capita VMT even further, are discussed below.

Secure and sustain emissions reductions from SB 375

SCSs are not being implemented, VMT per capita is increasing instead of decreasing, and the State is not on track to achieve the light-duty transportation-related GHG emissions reductions envisioned under SB 375.[96] Transportation and land use projects are not required to be consistent with an SCS to receive local government approval. Measures that could help make regional plans more useful for decision-making and promote SCS implementation include:

- *Update the SB 375 targets and metric to better align with current planning assumptions and sustain emissions reductions:* SB 375 intends to align planning for housing, land use, transportation, and GHG emissions reductions; however, several issues impede its success. SB 375's planning horizon extends only to 2035, which no longer aligns with the 20-year planning horizons for most regional plans that currently extend to 2040 and beyond. Allowing CARB to set SB 375 targets that cover the entire long-range planning period would require MPOs to plan for sustained emissions reductions beyond 2035, but this would require legislative amendments to SB 375. In addition, in its next update to the SB 375 targets, CARB could update the SB 375 targets and target metric to better align with the latest planning assumptions and other changes since the 2017 Climate Change Scoping Plan that ultimately would give stakeholders a clearer picture of how an RTP/SCS that meets those targets conforms to State climate goals. Aligning an RTP/SCS with the updated Climate Change Scoping

[94] Gov. Code § 14516.
[95] Steinberg, Chapter 386, Statutes of 2013
[96] CARB. 2018. *2018 PROGRESS REPORT: California's Sustainable Communities and Climate Protection Act*. Available: https://ww2.arb.ca.gov/sites/default/files/2018-11/Final2018Report_SB150_112618_02_Report.pdf

Plan could also create a more reliable and streamlined pathway to environmental compliance for projects that are included in an RTP/SCS.

- *Clarify what it means for a project to be "consistent with" the RTP/SCS to promote SCS implementation and secure emissions reductions*. Few jurisdictions are implementing RTP/SCSs as envisioned such that the State is not on track to meet current SB 375 targets or related regional air quality attainment requirements under the federal CAA in certain regions. A shared interagency framework of relevant criteria for evaluating projects that are "consistent with" SCSs approved by CARB is needed both to help prioritize state investments to support key actions and projects that align with these criteria, and find means to improve consistency between SCSs and local plans and projects. Ultimately, a shift toward implementation of SCSs that reduce per capita VMT is necessary to achieve the on-the-ground outcomes of sustainable communities and attainment of air quality standards.
- *Pilot regional and local partnerships to implement VMT reduction measures:* Many local and regional governments are responding to interconnected priority issues such as increasing housing, expanding freight sectors, and other changes in land use and transportation systems that require varying solutions based on the local context and State requirements. Over the years, many local and regional governments have also adopted and implemented rules to support sustainable communities and VMT reduction. CARB and other State agencies could partner with air districts to develop and share best practices on how to design and implement local rules and policies to meet local transportation, land use, and housing needs while meeting State climate goals. For example, CARB could write model transportation control measures (TCMs) for nonattainment districts to use as models when adopting versions tailored to local circumstances and preferences.
- *Emphasize the importance of conservation, restoration, and management of natural and working lands in SCSs*. While cities and counties across California have developed local and county climate action plans to reduce GHG emissions and increase climate resilience, few capture the potential VMT and GHG reduction benefits from conserving, restoring, and managing natural working lands. Research is available on the demonstrated effect of land conservation on VMT, and the State is expanding efforts to understand the relationship and synergies of taking an integrated cross-sector approach. Identifying priority conservation areas within SCSs will be as important as identifying priority development areas.

Develop a VMT/GHG mitigation bank to assist with SB 743 implementation under the California Environmental Quality Act

SB 743 means public agencies will no longer identify localized traffic congestion as a significant impact on the environment under the California Environmental Quality Act

(CEQA), and will focus on comprehensive travel impacts instead. The Governor's Office of Planning and Research and Caltrans both recognize VMT as a useful measure of the impact that driving and auto dependence have on our environment. The SB 743 amendments to CEQA present opportunities to streamline and lower the costs for infill development projects in low-VMT areas, and identify and mitigate the environmental impacts from VMT where they occur. Capacity-increasing projects on the State Highway System where Caltrans is the lead agency (or when Caltrans designates another entity as the lead agency) will also be evaluated based on the project's propensity to induce additional VMT. CEQA requires impacts to be mitigated to the extent feasible. Developers of projects benefit from the ability to mitigate GHG emissions, criteria air pollutants, and VMT with the same mitigation measures. The following project types could be considered for the VMT/GHG mitigation bank portfolio, which would also yield air quality benefits in proportion:

- *Clean mobility projects*: Conduct and expand community transportation needs assessments to create an ongoing source of community-led, feasible, equitable, quantifiable VMT/GHG mitigation projects to fill unmet mobility needs. CARB-funded grant programs that could be leveraged to solicit and fund more place-based clean mobility projects include:
    - The new Sustainable Transportation Equity Project: CARB allocated $19.5 million to fund clean transportation solutions through a community-based approach to identify and address the unique mobility needs of a given community.
    - The Clean Mobility Options Voucher Pilot currently provides over $28 million to low-income and disadvantaged communities for car sharing, bike sharing, and other clean mobility projects, including funding for community transportation needs assessments
- *Land conservation easements*: Examine natural and working lands conservation and protection as a source of VMT and GHG mitigation with additional carbon sequestration benefits. Integrating land and transportation strategies can have synergistic effects and help the State further reduce both criteria pollutant and GHG emissions by protecting land-based carbon while providing simultaneous reductions in emissions from transportation. Protecting lands at risk of development through conservation easements or local and regional planning policies that extinguish or transfer development rights avoid increases in VMT, GHG, and criteria pollutants from high-VMT development. The Strategic Growth Council's Sustainable Agriculture Land Conservation Program funded through California Climate Investments could be leveraged for this purpose. Management practices on natural and working lands can provide additional GHG sequestration benefits and mitigation value.

Align with the goals of the California Integrated Travel Project and integrate State incentives and rebates where feasible

The California Integrated Travel Project (Cal ITP) is a contactless integrated fare payment system that allows for seamless fare payment and collection across transit agencies and mobility service providers. It does not require a unique card, app, ticket, or account for each service, increasing the accessibility and usability of diverse transportation options, especially for California's most impacted communities. It simplifies the payment process, provides real-time data services for trip planning, and offers a unique eligibility verification system for unbanked individuals, thereby making it easier to use transit and leading to greater transit usage. CARB is exploring the potential to eventually link its clean transportation and mobility incentives and rebates, including Low Carbon Transportation Program equity projects, to individuals' ITP accounts, integrate the ITP platform into CARB's incentive programs, tie it to subsidies for low-income residents to lower transportation costs, and support equity goals.

Form Public-Private Partnerships between transit providers and mobility service providers

Transit ridership was already falling before the pandemic, but COVID-19 has decimated transit ridership and transit agency farebox revenue, which has forced service reductions. Loss of transit service impacts historically disadvantaged, low-income, and low-mobility groups the most. Early COVID-19 travel survey data indicates an aversion to shared services due to safety concerns, and shifts in preferences toward single-occupancy vehicles.[97] Transit services and mobility providers need each other right now. State, regional, and local agencies can facilitate public-private partnerships (PPPs) between mobility/micro-mobility service providers and transit service providers, and promote equity, by offering incentives and subsidies to low-income and low-mobility individuals to access mobility services through Cal ITP, as described above. In addition, CARB is designing its Clean Miles Standard regulation to reduce VMT by incentivizing reductions in miles driven without a passenger (i.e., dead heading), increased pooled trips in cleaner fleets operated by TNCs, and trips that link with transit and other micro-mobility services.

Explore Non-regressive Transportation Pricing and Demand Management Structures to Reduce Growth in Single-Occupancy Vehicle Travel

This concept would involve applying a regional transportation system pricing program in conjunction with requirements to use the resulting revenue to invest in alternatives to driving alone, such as public transit, carpool, bike, or walk, and/or to encourage traveling at different times of the day. A regional pricing program could implement a suite of regional and locally-focused pricing strategies for use of certain lanes, driving in certain areas, parking in prime locations, curbside management, driving at peak

[97] Circella study (in progress) https://postcovid19mobility.ucdavis.edu/

times, and/or utilizing non-pooled ride-hailing services. Revenue generated from the program could be used to either encourage the use of specified existing clean transportation options, or to provide additional clean transportation options, with a particular focus on ensuring low-income residents have affordable access to jobs and other key destinations. Some examples include, but are not limited to: reducing the cost of transit via transit passes, providing rebates for e-bikes, providing lower-cost or reserved parking spaces for carpools, moving towards per-mile car insurance pricing options, and providing traveler incentives to encourage travel at times when roads are less congested. Legislation would be needed to authorize certain pricing strategies more broadly. If pricing were broadly authorized, CARB could write a model TCM for congestion pricing for nonattainment area districts which could then adopt versions tailored to local circumstances and preferences. Pricing could potentially be considered as a reasonably available control measure in the future, which could be required as a part of attainment SIPs to address air quality in areas in nonattainment for ozone and PM10.

On-Road Medium- and Heavy-Duty Vehicles

In California, medium and heavy-duty vehicles are defined as vehicles with gross vehicle weight rating (GVWR) greater than 8,500 lbs. Emissions from on-road medium and heavy-duty vehicles are major contributors to poor air quality in California. In particular, these vehicles produce emissions in amounts highly disproportionate to the total population of these vehicles, accounting for only 6 percent of the on-road vehicle population, but 72 percent of NOx emissions. The problem is complicated by the large numnober of heavy-duty vehicles, like long-haul trucks, registered in other states that travel on California's highways and roads, while bringing goods and commerce into and out of our state. For more than a decade, CARB has been working closely with the U.S. EPA, engine and vehicle manufacturers, and other interested parties to address this issue and reduce heavy-duty vehicle emissions in California.

The on-road medium-duty vehicle (MDV) sector includes gasoline and diesel-fueled vehicles with GVWR greater than 8,500 lbs. and less than or equal to 14,001 lbs. This sector contributes approximately 7 percent of statewide mobile source NOx emissions and 5 percent of statewide mobile source GHG emissions. Examples include heavy-duty pick-up trucks and walk-in vans. MDVs currently have a suite of requirements for controlling GHG and criteria pollutant emissions. These include criteria pollutant control through the LEV III standards that are part of the ACC program and GHG emission control through Phase 1 GHG standards for medium- and heavy-duty engines and vehicles starting in 2014. In June 2020, CARB's Board adopted California's pioneering Advanced Clean Trucks (ACT) regulation,[98] which pushes zero-emission technology penetration with sales requirements for medium- and heavy-duty truck manufacturers.

The on-road heavy-duty (HD) sector consists of vehicles that have GVWR greater than 14,000 lbs. and are responsible for 33 percent of statewide mobile source NOx and 16 percent of statewide mobile source GHG emissions. This sector is unique from light- or medium-duty on-road sectors because close to half of VMT from the on-road heavy-duty sector is contributed by vehicles sold outside of California, or so called federal-certified vehicles. These federal-certified vehicles fall into two categories: 1) vehicles that were first sold out-of-state and then registered as used vehicles in California, and 2) vehicles that are sold out-of-state and continue to be registered outside of California. In the absence of federal regulation or a fleet rule, a California standard or mandated sales requirement will only impact vehicles that are sold in California but not those that are originally sold outside of California and are the brought into the state as used vehicles.

[98] CARB (2019). Proposed Advanced Clean Trucks Regulation https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks

CARB has made significant strides in reducing both criteria and greenhouse gas pollutants from HD vehicles through technology-forcing regulations. CARB's Truck and Bus Regulation requires all fleets, registered in- and out-of-state, that operate in California to meet stricter NOx standards and have a diesel particulate filter (DPF) by 2023 (i.e. 2010-certified technology).[99] Also, the aforementioned Phase 1 greenhouse gas regulations for heavy-duty trucks and engines, as well as CARB's Tractor-Trailer Greenhouse Gas (TTGHG) Regulation, have resulted in fuel efficiency improvements for the HD sector.[100]

CARB's newly adopted regulations on zero-emission trucks and buses will contribute to achieving both the State's criteria pollutant and GHG reduction goals. The ICT regulation was adopted in December 2018 and requires all public transit agencies to gradually transition to a 100 percent zero-emission bus (ZEB) (either battery-electric or fuel cell) fleet.[101] In addition, as mentioned previously, CARB adopted the ACT regulation in 2020, which requires the sale of heavy-duty ZEVs. To reduce NOx emissions from new on-road HD engines and ensure these emissions reductions are maintained as engines and vehicles are operated, CARB also adopted the Heavy-Duty Omnibus Regulation in 2020. This regulation includes certification of all combustion vehicles to a stricter standard on the Federal Test Procedure (FTP) cycle and a certification standard on a new low load cycle for 2024 and subsequent model year. Taken together, these requirements ensure lower NOx emissions over a more comprehensive range of vehicle operation. Additionally, this regulation includes in-use performance requirements such as more stringent in-use performance standards, lengthened engine useful life, warranty and durability requirements. Besides, in past few years, CARB adopted multiple regulations, which aimed at improving in-use performance including the Heavy-Duty Vehicle Inspection Program (HDVIP) and the Periodic Smoke Inspection Program (PSIP) amendments starting in 2019,[102] and HD Warranty Phase 1 starting in 2022.[103]

As noted in the 2017 Climate Change Scoping Plan,[104] as well as 2016 Mobile Source Strategy, meeting our climate and air quality goals requires sustainable passenger and freight transportation powered by zero-emission technologies everywhere feasible,

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[99] CARB (2019). Truck and Bus Regulation Compliance Requirement Overview. https://ww3.arb.ca.gov/msprog/onrdiesel/documents/fsregsum.pdf

[100] CARB (2018). Proposed California Greenhouse Gas Emissions Standards for Medium- And Heavy-Duty Engines and Vehicles (Phase 2) And Proposed Amendments To The Tractor-Trailer GHG Regulation. https://ww2.arb.ca.gov/rulemaking/2018/phase-2-and-tractor-trailer-amendments-regulation

[101] CARB (2018). Proposed Innovative Clean Transit Regulation, a Replacement of the Fleet Rule for Transit Agencies. https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit

[102] https://ww2.arb.ca.gov/our-work/programs/heavy-duty-diesel-inspection-periodic-smoke-inspection-program/hdvip-psip

[103] https://ww2.arb.ca.gov/rulemaking/2018/hd-warranty-2018

[104] https://ww2.arb.ca.gov/sites/default/files/classic//cc/scopingplan/scoping_plan_2017.pdf

and cleaner combustion with renewable fuels everywhere else. To start on that path, CARB has conducted comprehensive technology and infrastructure assessments for the on-road heavy-duty sector as part of the annual Funding Plan for Clean Transportation Incentives for Low Carbon Transportation Investments and the Air Quality Improvement Program (see Long-Term Heavy-Duty Investment Strategy),[105] as well as the ACT regulation.[106] According to these documents, significant progress has been made in the readiness of zero-emission technology for on-road heavy-duty vehicles. Note that technology readiness generally assesses a technology's technical ability to reliably perform in a majority of its typical duty cycles. It can be described as a continuum, progressing from early research and development, through low-volume demonstration and pilot phases, to full technical readiness where it might be considered commercialized. Technically-ready technologies may still face other barriers to market transformation. There have been thousands of successful deployments of battery-electric and fuel cell heavy-duty vehicles that operate locally (i.e. return-to-base operation), including zero-emission transit buses and large-scale purchases of electric delivery vans and trucks. Additionally, drayage and regional-haul applications and refuse trucks are in the demonstration phase with some now commercially available, as shown on HVIP eligibility list.[107]

Heavy-duty ZEVs market and their applications are expanding. According to CALSTART's Zero-Emission Technology Inventory (ZETI) tool,[108,109] currently there are close to 100 different models of zero-emission vans, trucks and buses that are already commercially available from approximately 26 manufacturers globally. The ZETI tool also estimates that by 2023, the number of vehicle models available will grow to more than 200 models from approximately 49 manufacturers based on industry input and market analysis. Note that commercial availability is defined as availability for immediate production based on placed orders. Of the models announced to be available in 2023, 67 of them are planned to be on medium-duty vehicle platforms, and 19 of them will be deployed on heavy-duty platforms. These heavy-duty vehicles will potentially have all-electric ranges from 75 miles (e.g., Volvo VNR Electric) all the way up to 500 to 650 miles (e.g., Nikola Two FC and Tesla Semi) which makes them

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[105] CARB (2019). Fiscal Year 2019-20 Funding Plan on Clean Transportation Incentives - Appendix D: Heavy-Duty Investment Strategy. https://ww2.arb.ca.gov/sites/default/files/2019-09/fy1920fundingplan-appd.pdf

[106] CARB (2019). Staff Report: Initial Statement of Reasons. Public Hearing to Consider the Proposed Advanced Clean Trucks Regulation. Appendix E: Zero-Emission Truck Market Assessment. https://ww3.arb.ca.gov/regact/2019/act2019/appe.pdf

[107] CARB (2020). HVIP Eligible Vehicle Catalog (web link: https://www.californiahvip.org/how-to-participate/#Eligible-Vehicle-Catalog).

[108] CALSTART is a nonprofit organization working nationally and internationally with businesses and governments to develop clean, efficient transportation solutions.

[109] CALSTART (2020): Drive to Zero's Zero-emission Technology Inventory (ZETI) Tool Version 5.5. https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

suitable for long-haul operation. There are also a number of models that are suitable for drayage trucks such as BYD 8TT model, Peterbilt 520EV/579EV, Mercedes Benz eActros, and Freightliner eCascadia Battery Electric Truck. These are just some examples of the zero-emission technologies that are already or planned to be commercially available in the next 2 to 3 years.

Also in collaboration with the CALSTART, CARB developed a "beachhead" strategy that targets investments on beachhead or first success analysis, identifying the segments of the commercial vehicle market where zero-emission and near clean combustion technology is most likely to succeed first and transfer that success to other applications for different technology pathways. This analysis considered several key identifying factors such as technology readiness, duty cycle and use, industrial activity and capacity, and user economics. For every technology pathway (e.g. zero emissions), this process starts with one beachhead application and then the success of that first application transfers or spreads to additional applications through, for example, adoption of similar drive trains or expansion of fueling infrastructure. For the zero-emission pathway, the first on-road beachhead application was battery-electric transit buses, which served as a "launch point" for shuttle vans, package and delivery vans and trucks, terminal tractors, class 8 drayage trucks, and regional distribution (freight) trucks. In a similar effort, the Institute of Transportation Studies at the University of California, Davis published a report titled "Zero-Emission Medium- and Heavy-Duty Truck Technology, Markets, and Policy Assessments for California"[110] that assesses zero-emission medium- and heavy-duty vehicle technologies, their associated costs, as well as their projected market share. Several heavy-duty ZEV applications, such as battery-electric transit buses, yard trucks, and city delivery trucks, are already economically favorable despite higher purchase prices. Thanks largely to lower operational costs, the total cost of ownership for these vehicles is often less than their conventionally-fueled counterparts. Similar ZEVs using fuel cells are also attractive assuming a hydrogen cost of five dollars per kilogram.

Despite substantial progress made in technology development, there still remain significant barriers to zero-emission transition for the on-road heavy-duty sector, which are outlined in more detail in CARB's Funding Plan for Clean Transportation Incentives for Low Carbon Transportation Investments and the Air Quality Improvement Program.[111] For example, the biggest challenge identified for heavy-duty battery-electric technology is infrastructure availability and cost, which is key for scaling up from a small number of vehicles to larger deployments. CARB staff recognizes that the approaches and design of a HD vehicle infrastructure system will differ from the infrastructure network for LD vehicles, and may require sector or fleet-specific approaches.

[110] https://escholarship.org/uc/item/7n68r0q8
[111] https://ww2.arb.ca.gov/sites/default/files/2019-09/fy1920fundingplan.pdf

Transition to zero-emission technologies calls for actions and collaboration by multiple agencies. CARB is working collaboratively with other California State agencies to ensure these efforts are well aligned, bring the state into compliance with federal air quality standards, and reduce GHG emissions from mobile sources. Currently, the CEC is developing the Infrastructure Development Strategy with charging infrastructure assessments in response to Assembly Bill 2127.[112] This bill requires a statewide assessment of the electric vehicle charging infrastructure needed to support the levels of electric vehicle adoption required for the state to meet its goals of putting at least 5 million zero-emission vehicles on California roads by 2030 and of reducing emissions of greenhouse gases to 40 percent below 1990 levels by 2030.

As part of their analysis for AB 2127, CEC is collaborating with Lawrence Berkeley National Laboratory (LBNL) to determine the number, locations, and types of charger deployments for MDV and HD electric vehicle infrastructure ("HEVI-Pro") in California in 2030. HEVI-Pro aims to develop regional charging infrastructure needs for public, shared-private, and private charging, where charging is selected from suitable power levels from overnight charging (<50 kW) to public fast charging (multi-MW), for the range of medium and heavy-duty vehicle applications envisioned in California's transition to ZEVs. The preliminary findings show that 134,000 battery electric MDV and HD vehicles deployed statewide in 2030 would require approximately 67,000 of 50 kW chargers and 11,000 of 350 kW chargers to complete their trips.[113] CEC plans on releasing the first projections in conjunction with the 2020 Integrated Energy Policy Report, likely in late 2020.

The Transportation Electrification Framework, released by the CPUC in February 2020, directs future investor-owned utility (IOU) investments and programs and ensures these investments are in accord with key State goals and policies. Since 2016, the CPUC authorized IOUs to direct over a billion dollars of funds to transportation electrification infrastructure. Additionally, California Governor's Office of Business and Economic Development (GO-Biz) has been developing Zero-Emission Medium- and Heavy-Duty Vehicle Deployment and Market Acceleration Strategy (Big ZEV Strategy) as part of their ZEV Market Development Framework. This report will identify State actions and areas where more can be done to overcome barriers to achieve market success and scale.

In addition to infrastructure, the high upfront capital cost relative to conventional ICE vehicles is another challenge. Today and for the near future, battery-electric and fuel cell electric trucks and buses are expected have higher upfront costs when compared

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[112] Ting, Chapter 365, Statutes of 2018 (web link: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB2127)

[113] Preliminary findings from the first scenario of the Medium and Heavy-Duty Electric Vehicle Infrastructure Projections (HEVI-Pro) Tool illustrates the wide variation in the on-road vehicle duties and the potential for gigawatt-scale daytime and evening charging requirements. Credit: Lawrence Berkeley National Laboratory: https://efiling.energy.ca.gov/getdocument.aspx?tn=234209

to their diesel or gasoline counterparts. This is due to a combination of low volume production and more expensive components, including batteries and fuel cell systems. The incremental upfront cost difference between ZEV and ICE vehicles is expected to decline over time. As with any new technology, there could also be additional upfront costs associated with ZEV deployment, such as professional services for site assessment and infrastructure buildout and planning, additional procurement processes, as well as operator and technician training. As described in detail within the ACT staff report,[114] while BEVs cost more than conventional combustion vehicles initially due to their large upfront investments, they often pay back over time due to their lower operating costs resulting in a favorable total cost of ownership. Financing the vehicles and infrastructure can spread out the payments to be offset with ongoing reductions in operating costs. Additionally, incentive programs for vehicles or infrastructure may allow fleets to lower or eliminate these higher upfront costs. Educating fleets about the lifecycle costs and payback opportunities will be an important part of accelerating the ZEV market.

Mobile Source Strategy Scenarios

Medium-Duty Vehicles

Starting with MDVs (8,501 – 14,000 lbs. GVWR), CARB is developing strategies for reducing criteria pollutants and GHG emissions from this sector, some of which may overlap with light-duty vehicle strategies, and some of which have overlap with heavy-duty vehicle strategies. Looking towards the future with the 2020 MSS scenarios, an important concept for MDV includes zero-emission transformation starting in 2024. One critical piece of this transition is CARB's ACT regulation mentioned earlier. Besides, CARB is developing an Advanced Clean Fleet rule to accelerate the number of medium and heavy-duty ZEV purchases to achieve a full transition to zero-emission vehicles in California as soon as possible. Other concepts include enhanced LEV IV regulations through ACC II and continued energy efficiency improvements and GHG emission reduction through Phase 3 GHG standards, which is a continuation of the Phase 2 GHG standards.[115]

Driven by California's mid-century climate goals as well as governor's executive order N-79-20, staff proposed a scenario to fully transform the medium-duty vehicle sector to zero-emission technologies. Built upon the recently adopted ACT regulation, this scenario further extends the ZEV phase-in schedule and assumes 100 percent of model year 2035 and newer MDVs being sold in California to be zero-emission. As

[114] CARB (2019). Staff Report: Initial Statement of Reasons. Public Hearing to Consider the Proposed Advanced Clean Trucks Regulation. https://ww3.arb.ca.gov/regact/2019/act2019/isor.pdf

[115] CARB (2018). Proposed California Greenhouse Gas Emissions Standards for Medium- And Heavy-Duty Engines and Vehicles (Phase 2) And Proposed Amendments To The Tractor-Trailer GHG Regulation. https://ww2.arb.ca.gov/rulemaking/2018/phase-2-and-tractor-trailer-amendments-regulation

mentioned above, achieving this level of ZEVs will require multiple concepts and tools in addition to CARB's currently adopted rules.

Figure 18 shows the technology for medium-duty vehicle population under this 2020 MSS scenario, which results in approximately 580,000 zero-emission MDVs driving on California roadways by 2045. As shown in Figure 21, the scenario will also translate to statewide NOx reductions of 0.25 tpd and 1.11 tpd in 2031 and 2037, respectively. This scale of fleet transformation will result in a fuel saving of about 0.15 billion gallons of diesel per year and 0.26 billion gallons of gasoline per year in 2045 (Figure 19), which translates to a WTW GHG reductions of approximately 4.0 million metric tons (MMT) per year (Figure 20). Also by 2050, the WTW GHG emissions from MDVs will be 85 percent below the 2020 baseline. The WTW analysis presented in this document is only for informational purposes and the assumptions (e.g., renewable and bio-fuel mix) are further described in Appendix A.

Figure 18 – Statewide Medium-Duty Sector Vehicle Population

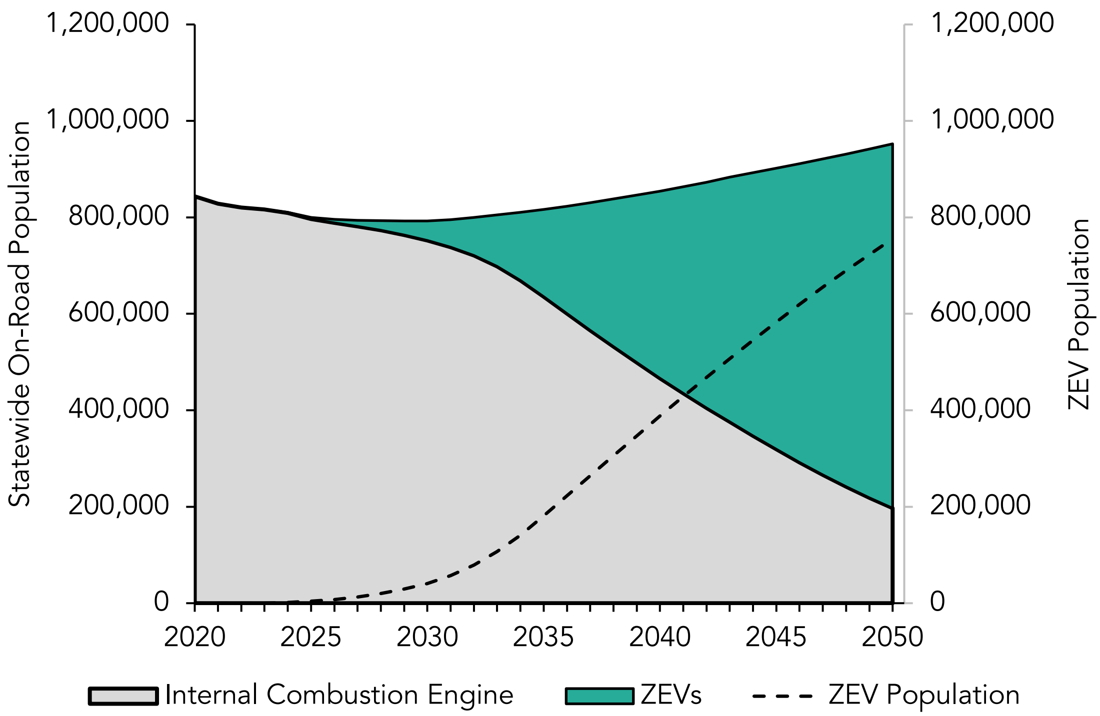


Figure 19 - Statewide Fuel Consumption by Medium-Duty Vehicles

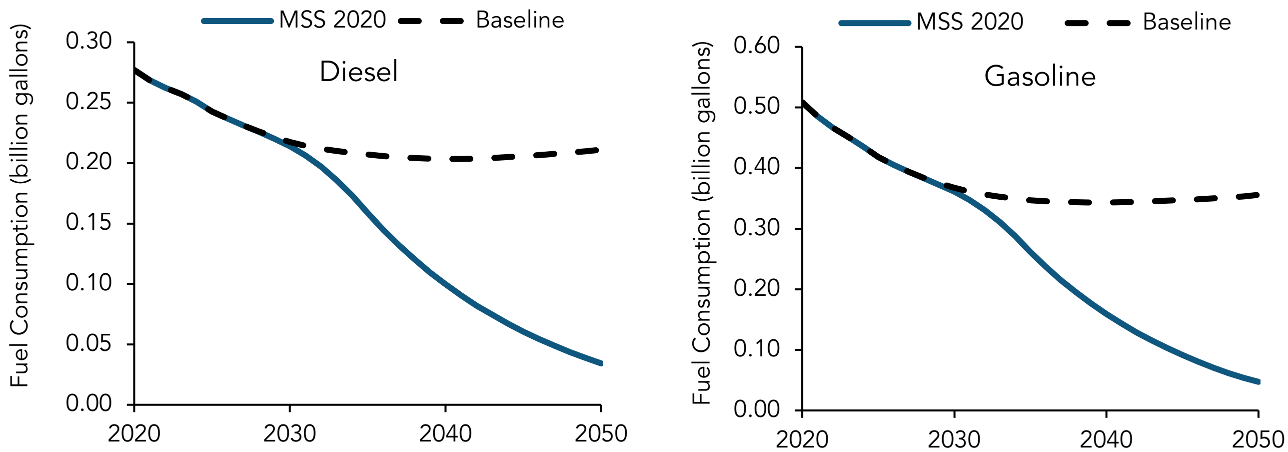


Figure 20 - Statewide Well-to-Wheel GHG Emissions from Medium-Duty Vehicles

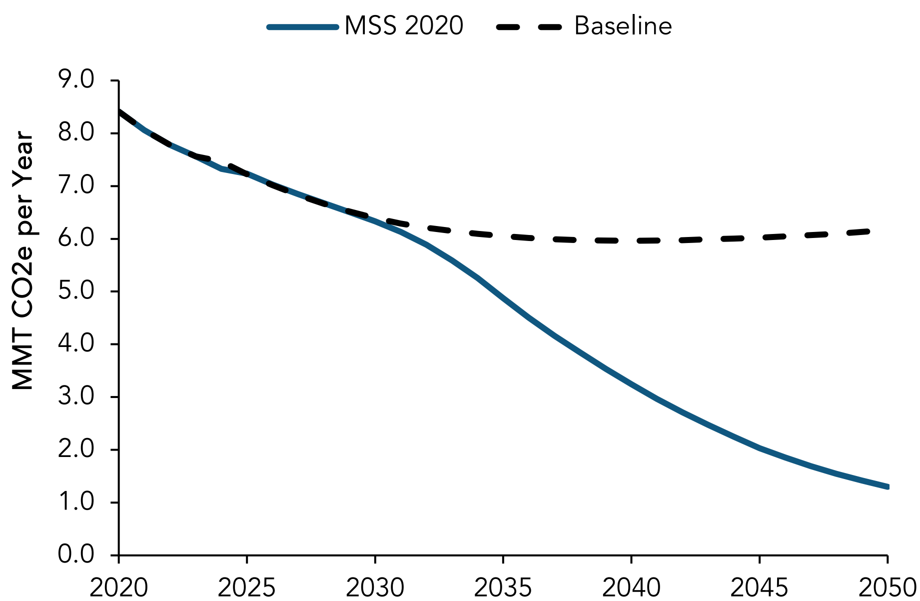
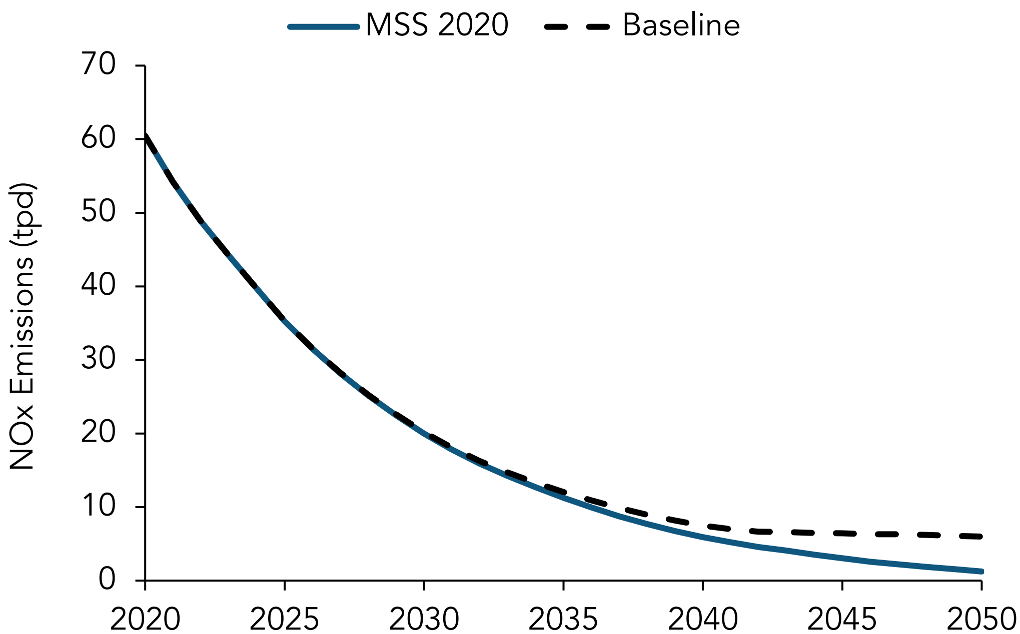


Figure 21 - Statewide NOx Emissions from Medium-Duty Vehicles



Heavy-Duty Vehicles

Moving on to HD vehicles (above 14,000 lbs. GVWR), the 2020 MSS charts the course for the HD sector in the future through a range of concepts, the most important of which is the transition to ZEVs. An ambitious ZEV phase-in for newer vehicles and accelerated turnover of older and high emitting vehicles to ZEV ensures that this sector meets both near- and mid-term air quality goals, while simultaneously achieving long-term climate goals. Currently, there are HD ZEVs on the market that meet both local and regional trucking needs. Many of CARB's incentive programs, such as the Low Carbon Transportation Investments and the Air Quality Improvement Program, have supported introduction of HD ZEV technology. The recently adopted ACT regulation requires manufactures to produce and sell ZEVs starting from 2024 and the potential advanced clean fleet rule will ensure the purchase and deployment of ZEVs across the fleet.

In addition to ZEVs, cleaner and more efficient ICE technology will also be essential for meeting air quality targets, especially in applications where ZEVs may not yet be capable of serving all duty cycles. As mentioned previously, one example of CARB's effort towards cleaner ICE technology is the Heavy-Duty Omnibus Regulation.

Another critical piece of CARB's HD concepts includes the Heavy-Duty Inspection and Maintenance (HD I/M) program, which will ensure that the engines and after-treatment systems of heavy-duty vehicles are well-maintained throughout their lifetime. The

HD I/M program will require all heavy-duty vehicles operating in California have properly functioning emissions controls systems. This program will be implemented beginning in 2023/2024. On August 12, 2020, CARB staff conducted public workshops to discuss draft concepts for California's future HD I/M program.[116]

OBD systems are going play a critical role in implementation of the HD I/M program. Beginning with the 2022 model year, OBD requirements include Real Emissions Assessment Logging (REAL) requirements for the collection and on-board storage of NOx and CO2 emission data, but there are currently no requirements to report REAL data to CARB. The opportunity exists to make better use of the REAL data, potentially via regular reporting requirements. OBD requirements also need to evolve to account for the much lower emission standards included in the Heavy-Duty Omnibus Regulation.

Considering the above mentioned regulatory activities, staff developed a scenario that strives for zero-emission transformation consistent with governor's Executive Order N-79-20, while emphasizing cleaner combustion technologies for ICE vehicles, utilization of renewable fuels, continued fuel efficiency improvements, as well as enhanced in-use performance. Taking into account those HD truck market segments that are suitable for transitioning to ZEVs in the near-term and implementation of the ACT regulation to accelerate ZEV sales, the major assumptions for the phase-in of HD vehicles includes:

- Delivery and drayage fleets are assumed to have 100 percent ZEV sales starting with model year 2024;
- Vehicle categories with low annual mileage or return-to-base operation, which have similar duty cycle to transit buses, assumed ZEV phase-in that matches the ICT[117] regulation phase-in schedule;
- Other vocational and tractor vehicle categories are assumed to follow the ZEV sales schedule as required by the ACT rule for Class 4-8 and Class 7-8 tractors until model year 2030, after which ZEV sales assumptions ramp up to 100 percent sales in 2035;
- All California registered fleets, whether California certified or not, assumed to follow the same ZEV phase-in schedule. As noted above, there are HD vehicles that were originally sold out-of-state and then registered in California as used vehicles. This assumption ensures that California fleets (not just those first sold in California) reflect the ambitious ZEV phase-in schedule; and

[116] https://ww2.arb.ca.gov/our-work/programs/heavy-duty-inspection-and-maintenance-program

[117] CARB (2018). Proposed Innovative Clean Transit Regulation, a Replacement of the Fleet Rule for Transit Agencies. (https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit)

- For model years 2035 and newer, 100 percent ZEV sales assumed for all vehicle categories.

The remainder of model year 2024 and newer heavy-duty vehicles are cleaned up by more stringent engine standards, either through California's Heavy-Duty Omnibus Regulation for vehicles only first sold (or certified) in California, or through the future federal Cleaner Trucks Initiative[118] for all heavy-duty vehicles operating in California.

While ZEV phase-in and cleaner technologies for ICE vehicles will reduce NOx emissions significantly, meeting CARB's air quality targets in 2031 and 2037 requires additional reductions through accelerated scrappage of older and high-emitting vehicles and replacement with zero-emission technologies before the end of vehicles useful lifetime. With Omnibus and ZEV requirements applying to post-2024 model year vehicles, older pre-2024 model year vehicles will contribute disproportionately to overall NOx emissions. According to the 2016 State SIP Strategy,[119] there is a need for an additional 11 tpd of NOx reductions in the South Coast Air Basin by 2031 to meet the 2015 ozone standards of 75 ppb. To achieve the needed 11 tpd NOx reductions, staff determined that approximately, 31,000 heavy-duty model year 2023 and older vehicles would need to be turned over before their end of lifetime. At the statewide level, this translates to approximately 94,000 heavy-duty vehicles that would need to be scrapped and replaced with zero-emission technologies. Note that this scenario does not specify the exact mechanism of accelerated turnover, but rather defines the number of vehicles that are needed to meet air quality goals. It is also worth noting that turnover through a future regulation is currently limited by "useful life" provisions of the Road Repair and Accountability Act of 2017 (SB1). According to SB 1, should a future in-use regulations be adopted, trucks will not be required to turnover until they have reached 13 years from the model year the engine and emission control systems are certified or until they reach 800,000 vehicle miles traveled (but no longer than 18 years from the model year the engine and emission control systems are certified for use), whichever is later.[120]

Figure 22 shows the technology mix resulting from the heavy-duty scenario developed as part of the 2020 MSS. The scenario results in approximately 830,000 heavy-duty ZEVs in 2045. This equates to about 1.9 billion gallons per year in diesel fuel savings (Figure 23), 0.2 billion gallons per year in gasoline fuel savings, and WTW GHG emissions reductions of 23 MMT per year (Figure 24). Also by 2050, the WTW GHG emissions from HDVs will be 53 percent below the 2020 baseline. As shown in Figure 25, the scenario also provides statewide NOx reductions of 121 tpd and 181 tpd in

[118] https://www.epa.gov/regulations-emissions-vehicles-and-engines/cleaner-trucks-initiative
[119] https://ww2.arb.ca.gov/resources/documents/2016-state-strategy-state-implementation-plan-federal-ozone-and-pm25-standards
[120] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1

2031 and 2037, respectively, which are equivalent to 57 and 80 percent reduction below the current baseline.

Collectively, the 2020 MSS scenarios call for deployment of approximately 1.4 million medium- and heavy-duty ZEVs in California by 2045. This transition to ZEVs will results in a fuel savings of 2.1 billion gallons of diesel and 0.46 billion gallons of gasoline. By 2050, the WTW GHG emissions from MDV and HDVs will be 60 percent below the 2020 baseline (assumptions in Appendix A).

Staff has also exercised an alternative concept, which applies cleaner ICE vehicles, instead of ZEVs to achieve NOx reductions needed to meet the 2031 and 2037 South Coast Ozone SIP targets. Under this alternative concept, ZEV phase-in schedule follows the mandated requirement by the ACT rule. In this scenario, trucks replaced through the accelerated turnover will be cleaner ICE (i.e., certified to a 0.02 grams per brake horsepower-hour standard) instead of ZEV. While this alternative scenario achieve the same level of NOx reductions in 2031 and 2037, compared to the MSS scenario, it will result in a much higher number of cleaner ICE engines in 2045 and almost additional 1.4 billion diesel gallons equivalent of fuel being consumed in 2045. This emphasizes that in the absence of aggressive ZEV penetration, there is a need for significant efficiency improvement in heavy-duty trucks powered by ICE to reduce their fuel consumption and GHG emissions.

Figure 22 – Statewide Heavy-Duty Population by Technology Type

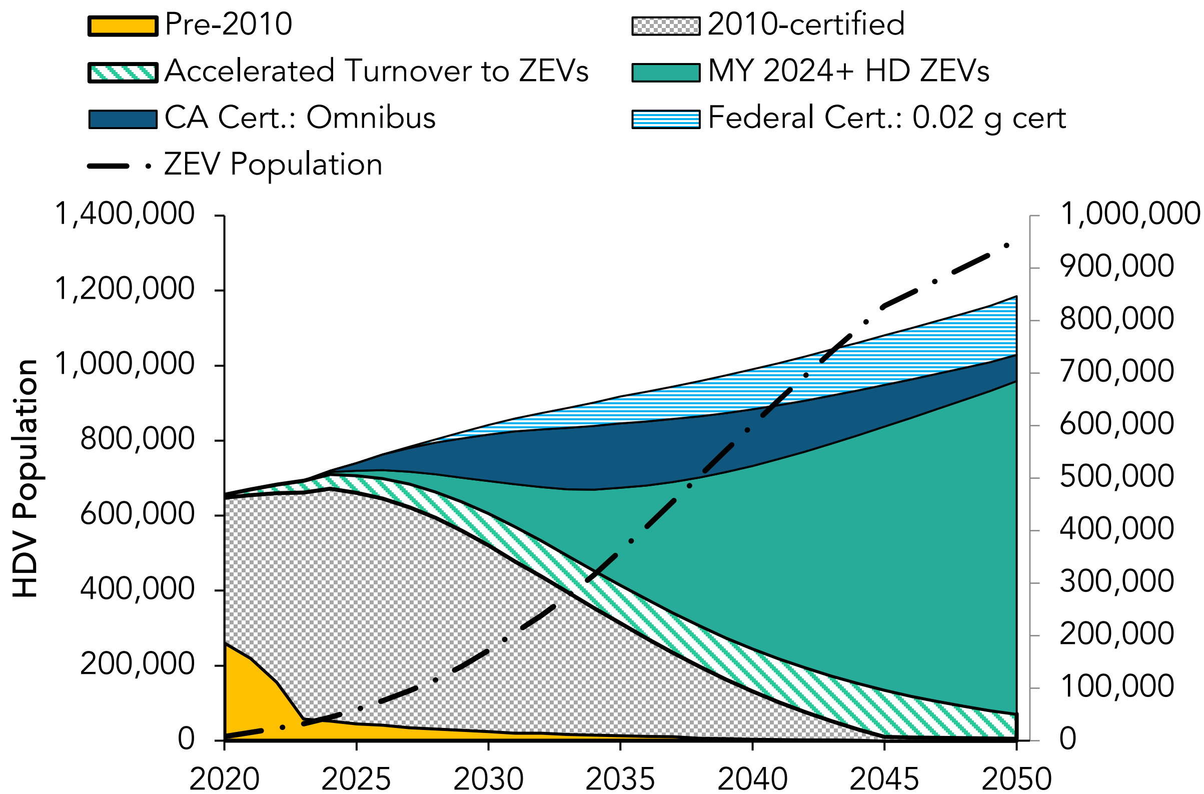


Figure 23 - Statewide Fuel Consumption by Heavy-Duty Vehicles

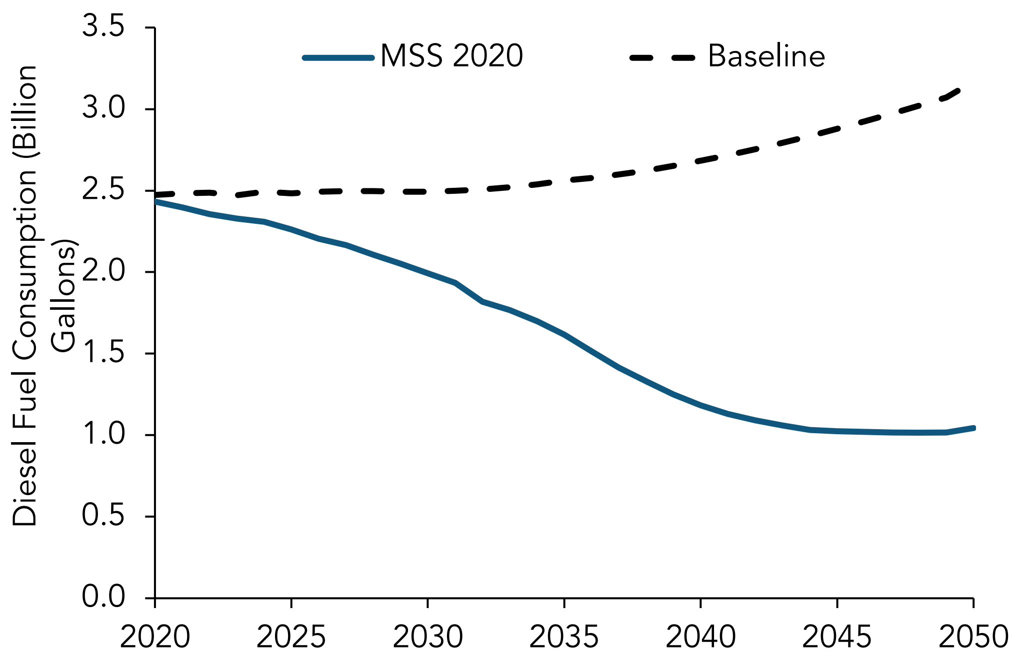


Figure 24 - Statewide Well-To-Wheel GHG Emissions from Heavy-Duty Vehicles

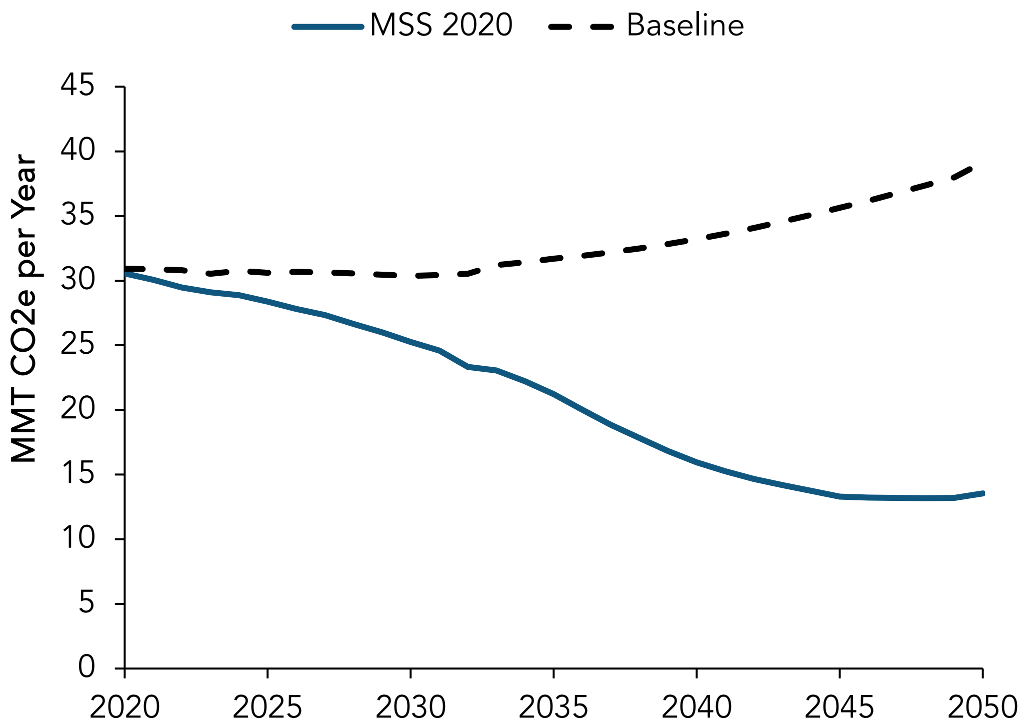
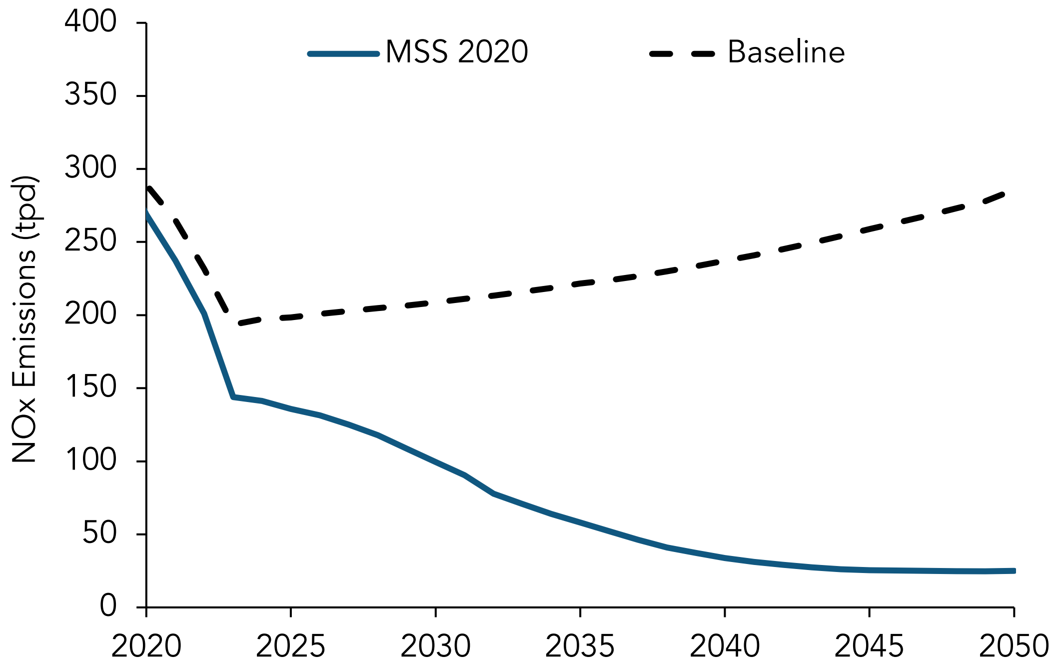


Figure 25 - Statewide NOx Emissions from Heavy-Duty Vehicles

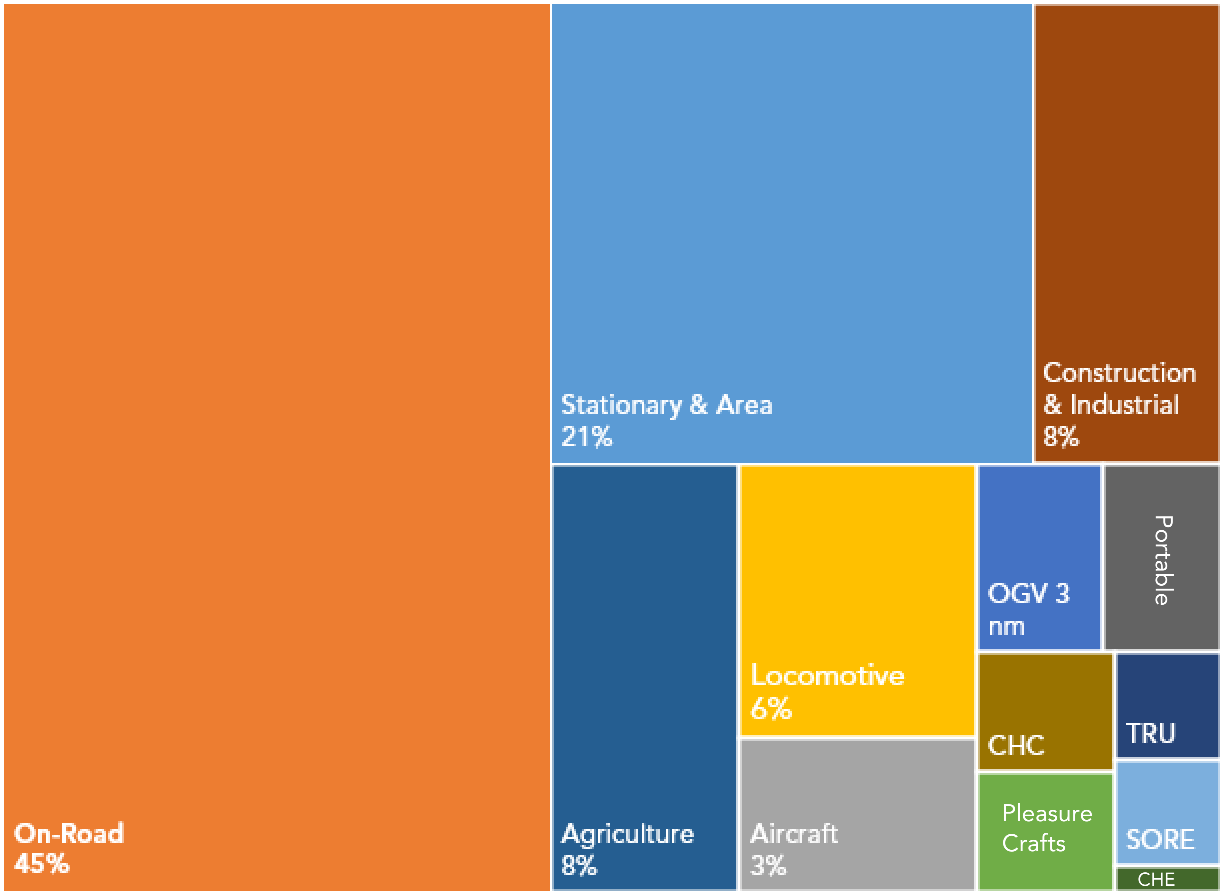


Off-Road Vehicles and Equipment

Off-road equipment covers a wide range of sectors including locomotives, ocean-going vessels, commercial harbor craft, pleasure craft, portable generators, agricultural equipment, construction, mining, oil drilling, lawn and garden, aircrafts, recreational watercraft and many other industries. Off-road engines are significant sources of air pollutants such as NOx, reactive organic gases (ROG), and PM. Figure 26 shows statewide NOx emissions by sector in 2017.[121] Off-road equipment contributes about 35 percent of total statewide NOx emissions in 2017. As the regulations for off-road equipment tend to follow those for on-road vehicles by a few years, the relative contribution of emissions from off-road equipment is expected to continue to grow, absent additional controls. By 2022, off-road equipment will replace on-road vehicles as the largest source of NOx emissions at the statewide level. In addition, off-road equipment consumed 1.5 billion gallons of diesel and more than 400 million gallons of gasoline in 2017 and contributes to about 4 percent of the GHG emissions statewide. Without further progress in improving internal engine efficiency or transitioning to electrification, off-road diesel and gasoline consumption is expected to increase to 2.1 billion and 580 million gallons per year, respectively,[122] by 2045.

[121] CEPAM: California 2019 ozone sip baseline emission projection - version 1.01 planning inventory tool
[122] OFFROAD2017 – ORION, https://www.arb.ca.gov/orion/

Figure 26 - 2017 Statewide NOx Emissions by Sector[123]



The mobile source scenarios and concepts to reduce air pollutants and GHG emissions in the off-road sector are developed based on the following guiding principles:

- *Push for zero-emission technologies wherever feasible*: Commercial deployment of zero-emission technologies is still at an early stage for some off-road sectors due to barriers in technology and cost. CARB is working closely to identify those off-road sectors with the most potential for near-term transitions to zero-emissions.
- *Introduction of cleaner combustion technology*: Where electrification is not currently feasible, introduce more stringent emission standards such as Tier 5 to reduce emissions from new internal combustion engines, and OBD standards to ensure emissions from those engines continue to meet expected levels throughout their entire service lives.
- *Accelerated turnover*: Early turnover of older equipment to cleanest available technologies including Tier 4 or 5 engines, hybridization, and retrofit engines

[123] OGV 3 nm includes OGV emissions occurring within 3 nautical miles of the California coastline.

with after-treatment technologies such as DPF and selective catalytic reduction (SCR).

- *Renewable fuel:* Use renewable fuels where electrification is not available to reduce GHG emissions.

Given the diversity of equipment and duty cycles that comprises the off-road sector, each sector includes a more detailed description of the specific strategies. Table 8 provides a short summary of the conceptual strategies for each off-road sector.

Table 8 - Summary of Conceptual Off-Road Strategies

Sector	Summary of Strategy
▪ Locomotives	• Significantly accelerate the turnover of all locomotives operating in California to Tier 4 or cleaner • Adopt Tier 5 locomotive standards with U.S. EPA • Accelerate the adoption of zero-emissions locomotives and infrastructure • Replace the oldest switchers at railyards near communities with Tier 4 or cleaner by 2030
▪ Ocean-Going Vessels	• Increase at-berth requirements for auxiliary engines and boilers, while moving towards vessels visits with Tier 3 engines • Adopt Tier 4 marine standards with U.S. EPA and IMO • Work towards zero-emission OGV demonstrations
▪ Construction, Mining, Industrial	• Accelerate turnover and require remaining Tier 0 through Tier 2 engines be turned over by 2033 • Develop Tier 5 standards, including efficiency and hybridization requirements to reduce GHG emissions, as well as first ever requirements for OBD for off-road engines
▪ Agriculture	• Continue incentive programs, aiming for replacement of all Tier 0 to Tier 2 tractors used over 200 hours annually by 2024 in the San Joaquin Valley • With continued Incentives, target remaining Tier 0 through Tier 2 equipment and remaining Tier 0 through Tier 2 tractors with more than 100 to 200 annual hours of operation • Develop Tier 5 standards, including efficiency and hybridization requirements to reduce GHG emissions
▪ Commercial Harbor Craft	• Increase applicability of Tier 4 marine standards for commercial harbor craft to apply to all vessel types, require DPFs and develop Tier 5 marine standards • Require new and in-use excursion vessels to be plug-in hybrid, new tugboats diesel-electric, and 20 percent of all ferries to be zero-emission by 2030

Sector	Summary of Strategy
▪ Cargo Handling Equipment ▪ Airport Ground Support ▪ Small Off-Road Engines ▪ Transport Refrigeration Units ▪ Forklifts ▪ Spark Ignited Marine Engines	• Accelerate adoption of full zero-emission operation, with 100 percent zero-emission saturation by mid 2030s • Where exceptions apply to a zero-emission mandate, cleaner emissions standards and hybrid electric units would apply
▪ Aircraft	• Improvement in the current Air Traffic Operation (ATO) as well as transitioning to zero-emission technologies such as zero-emission APUs

Off-Road Federal and International Sources

Locomotives

A locomotive is a self-propelled vehicle used to push or pull trains; the combination of one or more locomotives and the attached freight or passenger railcars forms a train. Higher horsepower line-haul locomotives and lower horsepower switcher locomotives operate in California. A typical freight and passenger locomotive in the United States is powered by a diesel engine that drives an electrical generator or alternator. Locomotives and the railway system are an essential part of California's freight and passenger movement network, but also significant contributors to diesel PM, NOx and GHG emissions in California. These emissions often occur in or near densely populated areas and neighborhoods, exposing nearby residents to harmful levels of diesel PM and ground-level ozone.

In the past, CARB has developed and implemented a number of measures to understand and reduce locomotive and railyard emissions, including studies, enforceable agreements, and funding of clean technology. More recently, CARB has been working closely with the railroad industries to develop more representative and up-to-date emission inventories and to identify emission control strategies. CARB's locomotive emission inventory covers four main sectors: Class I line-haul locomotives, Class III (short-line) locomotives, Class I switch locomotives (switchers), and passenger locomotives. Class I railroads, which are defined as those operations that gross over $450 million per year,[124] carry the most freight and are responsible for about 80 percent of NOx and 79 percent of PM produced by all locomotives in California.[125] Union Pacific Railroad (UP) and BNSF Railway (BSNF) are the two Class I freight railroads operating in California. Class III railroads move goods regionally, have lower revenues, and generally have older locomotives, but much lower overall emissions

[124] Association of American Railroads, Rail Statistics of Class 1 Freight Railroads https://www.aar.org/Documents/Railroad-Statistics.pdf, accessed December 12, 2016.
[125] CARB locomotive emission inventories, https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road

simply due to their lower population and usage of locomotives. Switcher locomotives move railcars and sections of trains in and around railyards (but should not be confused with rubber-tired railcar movers, smaller off-road vehicles than move individual railcars in yards, but are not considered switchers). CARB released updated line-haul and short-line emissions inventories in 2017 and is currently developing a new line-haul and switcher inventory based on the 1998 Memoranda of Understanding (MOU) reporting data[126] from the railroads.

According to the latest MOU data, in 2018, Tier 4 line-hauls account for only 4 percent of total line-haul energy use in the South Coast Air Basin, which suggests that rail companies are not purchasing new Tier 4 locomotives, instead relying on older tier locomotives that are being remanufactured and used for the next few decades.[127] In the absence of federal action to address harmful emissions from locomotives and railyards, CARB is developing a regulation[128] to reduce criteria pollutants, toxic air contaminants, and GHG emissions for locomotive in-use, idling, and maintenance activities. This regulation include actions originally presented to CARB's Board in March 2018, as well as new concepts to further reduce locomotive and railyard emissions. This regulation could be implemented at the State and/or air district level, and provide an opportunity for the railroads to further reduce emissions from rail operations and address long-standing environmental justice concerns voiced by communities near railyards. Regulation concepts for locomotives include:

- Establish a locomotive emissions reduction spending account (conceptually this is an account where railroads get paid when bringing in older, dirtier tiers, and can use the account funds to purchase newer locomotives);
- Adopt an in-use useful life limit;
- Adopt U.S. EPA 30 minute idling limit.

As discussed earlier, in 2017, CARB also petitioned U.S. EPA to exercise its authority[129] to adopt more stringent emission standards for locomotives to help states meet federal air quality standards and climate goals, and address issues affecting public health and welfare.[130] CARB has recommended the NOx and PM emission factor for Tier 5 locomotives to be set at 0.2 grams per brake horsepower-hour (g/bhp-hr) and 0.01 g/bhp-hr, respectively. Tier 5 locomotives also offer 25 percent energy efficiency improvement over the current technology (i.e., Tier 4).

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[126] Summary data can be found at: https://ww2.arb.ca.gov/1998-mou-summay-data-archive
[127] More details can be found at: https://ww2.arb.ca.gov/sites/default/files/2020-09/CARBlocoinvwebinar2020.pdf
[128] https://www.aqmd.gov/docs/default-source/planning/fbmsm-docs/railworkshop_11-20-19_english.pdf?sfvrsn=6
[129] 42 U.S.C. § 7547(a)(5). Nonroad engines and vehicles
[130] Petition for rulemaking: seeking the amendment of the locomotive emission standards, https://ww2.arb.ca.gov/resources/documents/petition-rulemaking-seeking-amendment-locomotive-emission-standards, April 2017

CARB is also participating in demonstration projects with the rail industry on battery electric locomotives, with delivery and testing possible near the beginning of 2021. These efforts may offer additional emission reduction options and in the near future, but are not yet reflected in the criteria emission reduction strategies, pending a successful demonstration.

Mobile Source Strategy Scenario

While CARB continues to work closely with stakeholders including rail companies, environmental groups, and communities on expanding the concepts to reduce emissions from locomotives and railyards, staff has also laid out more ambitious and longer-term strategies that are needed to achieve California's near- and mid-term air quality and longer-term climate goals. These strategies aim for a complete phase out of Tier 0 through Tier 2 line-hauls by 2030, coupled with a significant penetration of Tier 4 locomotives, as well as Tier 5 and zero-emissions locomotives once they are available. Following this strategy, almost 90 percent of all line-hauls will become Tier 4 or Tier 5 by 2031. Additionally, the strategy assumes locomotives that are remanufactured twice or more will be prohibited from California operations. The scenario assumes that beginning in 2023, all pre-Tier 0, Tier 0, and Tier 0+ switchers will be replaced with Tier 3 and Tier 4 locomotives by 2030.

Based on the assumptions described above, Figure 27 shows projected NOx emissions by Tier group in the South Coast Air Basin for line-haul locomotives. The dashed line shows the updated baseline emissions. The new baseline is higher than the emissions estimated previously in the 2016 State SIP Strategy. As shown, the scenario will result in almost 12 tpd of NOx reduction in 2031. This reduction is equivalent to 2 tpd of NOx emissions below the emissions estimated in the South Coast 2016 Air Quality Management Plan, which is needed to meet the NOx reduction commitment from mobile sources in 2031.

Figure 27 - South Coast Air Basin NOx Emissions from Locomotives: MSS Scenario

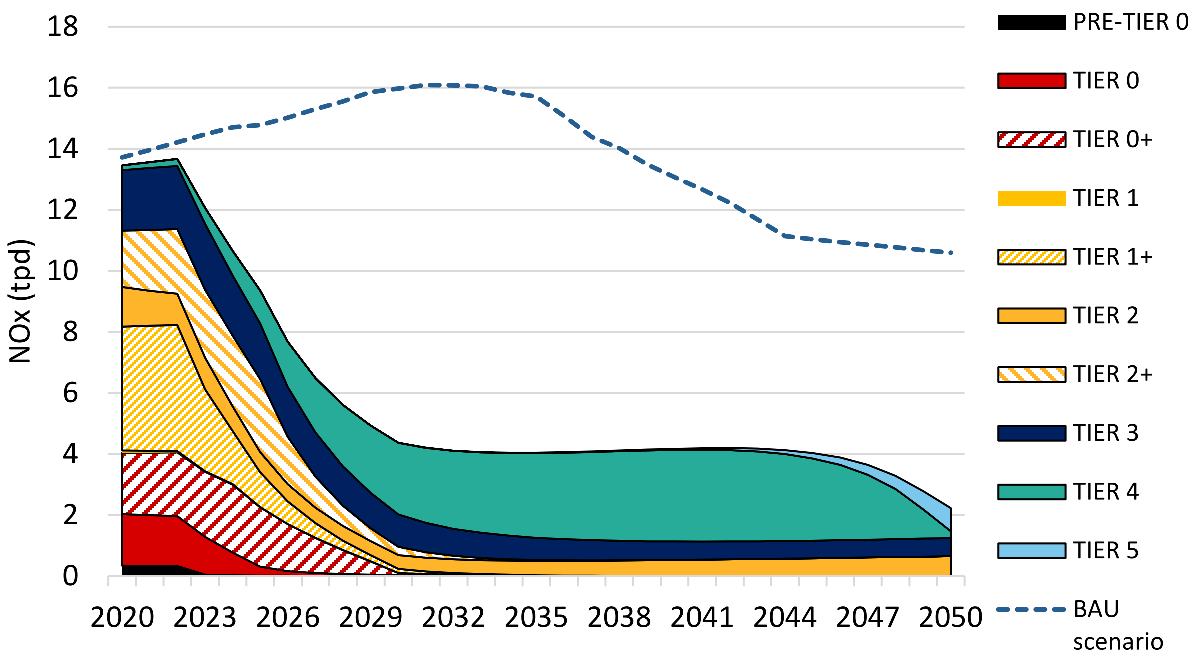
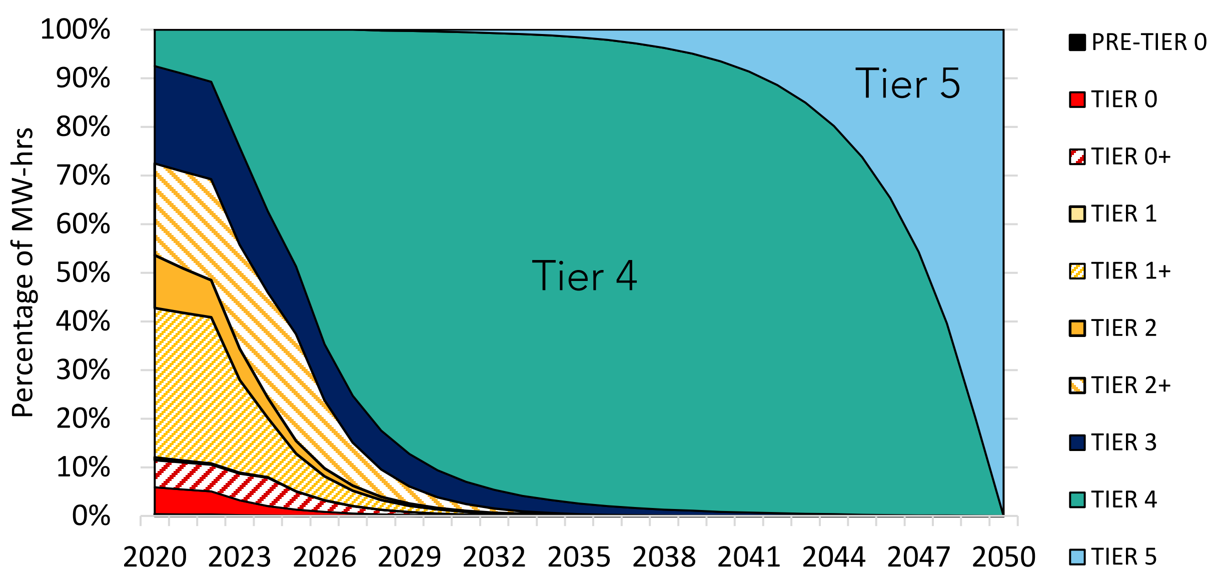


Figure 28 shows the relative energy use by different locomotive Tier groups assuming the technology penetration shown in Figure 27. As described earlier, following the 2020 MSS scenario, Tier 4 and 5 locomotives will make up over 90 percent of the total line-haul activities in 2031.

Figure 28 - South Coast Air Basin Locomotive Energy Use: MSS Scenario



Ocean-Going Vessels

Ocean-Going Vessels (OGV) are large vessels designed for deep water navigation, defined as commercial vessels greater than or equal to 400 feet in length, with a carrying capacity of 10,000 gross tons or more, or propelled by a diesel marine compression ignition engine with a displacement of greater than or equal to 30 liters per cylinder. OGVs include large cargo vessels such as container vessels, tankers, bulk carriers, and car carriers (or "ro-ro" vessels), as well as passenger cruise vessels. These vessels transport containerized cargo; bulk items such as vehicles, cement, and coke; liquids such as oil and petrochemicals; and passengers. OGVs are an important part of California's trade economy, but are also a significant source of GHG emissions, criteria pollutants, and toxic air contaminants especially in areas near ports and marine terminals.

The International Maritime Organization (IMO), under Annex VI ("Regulations for the Prevention of Air Pollution from Ships"), specifies new marine engine NOx standards and sets fuel sulfur limits. CARB has the authority to regulate emissions from auxiliary engines on vessels docked at California ports. CARB set the first OGV At-Berth Regulation in 2007 with compliance requirements that began in 2014.[131] The At-Berth Regulation requires container ships, cruise vessels and refrigerated cargo vessels to turn off their auxiliary engines and utilize shore power for a certain percent of time while at berth. The rule is limited to fleets of vessels making 25 or more visits (five or more for passenger ships) that operate in six California ports: Los Angeles, Long Beach, Oakland, San Diego, San Francisco, and Hueneme. This regulation will result in an 80 percent NOx emission reduction from auxiliary engines from applicable vessel types by 2020.

In August 2020, CARB expanded the At Berth Regulation to cover new vessel types (such as roll-on/roll-off vehicle carriers and tankers), small fleets, new ports and terminals, and increase the usage of shore power. The action will continue to reduce vessel emissions at berth from auxiliary engines, and reduce toxic pollutant exposure in disadvantaged communities near the ports.

Mobile Source Strategy Scenario

While the recent actions target at berth auxiliary engine emissions, emissions from main engines and auxiliary engines during transit, anchorage, and maneuvering must also be addressed in order to achieve NOx reductions needed to meet California's near- and mid-term air quality goals. Currently, very few vessels with Tier 3 main engines visit California ports, even though the Tier 3 engine standard applied to new marine engines beginning in 2016. Tier 2 vessels emit three times higher NOx than

[131] https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation

Tier 3 vessels; thus, phasing out of older Tier vessels is key to reducing criteria and toxics emissions from OGVs. Under this scenario staff assumed:

1. *Incentivizing vessels visits from cleaner OGVs:* Starting in 2023, replace all Tier 0, Tier 1, and Tier 2 vessel visits in California with visits being made by Tier 3 or cleaner vessels by 2031.
2. *Cleaner marine standards:* While marine Tier 3 is considerably cleaner than Tier 2, the Tier 3 NOx standard is still 5 to 10 times higher than the standards for other diesel equipment sectors, and does not include a PM standard. CARB will work with U.S. EPA, U.S. Coast Guard, and other partners to urge IMO to adopt more stringent Tier 4 marine standard by 2028, and establish efficiency requirements for existing vessels. In the 2020 MSS scenario, Tier 4 NOx and PM emission factors are set at 1 g/kw-hr and 0.1 g/kw-hr, respectively.

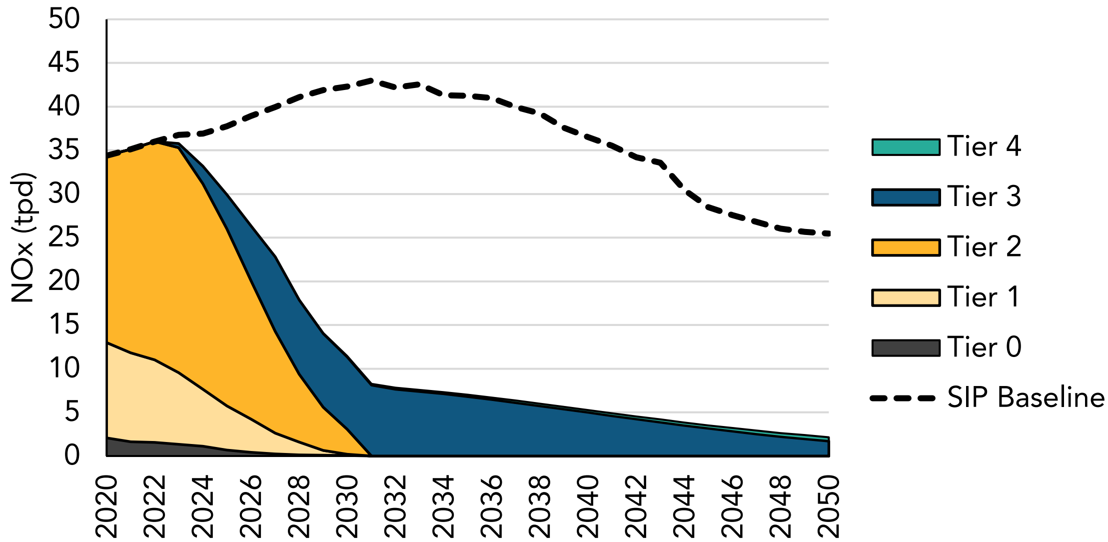
Figure 29 shows the OGV NOx emission projection in the South Coast Air Basin under the MSS scenario. The emissions here include all OGV modes and cover up to 100 nautical miles of operation off the coast of California. The dashed line shows baseline emissions from main and auxiliary engines. The 2020 MSS scenario can reduce NOx emissions by 35 tpd in South Coast by 2031, still short of the target of 38 tpd reduction as identified in the 2016 MSS[132] which relied on earlier Tier 4 engine adoption.

Several major shipping companies are working towards zero-emission vessels. For example, Maersk, the world's largest container shipper, aims to be carbon neutral by 2050 and to have carbon neutral vessels commercially available by 2030.[133] Biofuels, renewable hydrogen and other hydrogen-derived fuels such as ammonia, methanol, batteries and fuel cells are being considered as potential fuel choices for zero-emission vessels. As the zero-emission technologies for marine vessels are still at an early stage and technological feasibility needs to be proven, CARB did not incorporate these strategies in the current 2020 MSS scenario. CARB will consider these strategies in future updates to the MSS as more information becomes available.

[132] Under further deployment of cleaner technologies

[133] https://www.maersk.com/news/articles/2019/06/26/towards-a-zero-carbon-future

Figure 29 - South Coast NOx Emissions from All OGV Modes: MSS Scenario



Aircraft

Currently, CARB's official emissions inventory[134] has emissions data for five different aircraft categories that contribute significantly to NOx emissions; these are piston aircraft (civil), agricultural aircraft (crop dusting), jet aircraft (military), jet aircraft (commercial), and jet aircraft (civil). The jet aircraft (commercial) contribute to about 90 percent of NOx emissions from aircraft in California, whereas jet aircraft (military) and jet aircraft (civil) each contribute about 4.5 percent of NOx. Together, the piston aircraft (civil) and agricultural aircraft (crop dusting) produce less than 1 percent of NOx emissions. As significant progress has been made to reduce NOx emissions from on-road, off-road, and area sources in recent years, the NOx emissions from aircraft are becoming increasingly important. For the South Coast Air Basin, about 16.2 tpd of NOx emissions comes from the aircraft in 2020; and by 2031, NOx emissions from the aircraft will increase to about 20.5 tpd by 2031.

The International Civil Aviation Organization (ICAO) is a United Nations intergovernmental body responsible for worldwide planning, implementation, and coordination of civil Aviation & Emissions. The Committee on Aviation Environmental Protection (CAEP) within ICAO is taking a critical role in formulating emission standards and recommended practices. These are the basis of Federal Aviation Administration's aircraft engine performance certification standards, established through U.S. EPA regulations. Historically, U.S. EPA has adopted the aircraft emission standards proposed by ICAO for harmonization with global airline industry.

[134] CEPAM: California 2019 ozone sip baseline emission projection - version 1.01 planning inventory tool

The first NOx standard, adopted in 1981, applied to engines starting in 1986. The standard established a ceiling on NOx emissions at 100 g/kN at rated engine thrust for engine pressure ratio (EPR) of 30. Table 9 shows the progression of NOx emission standards at 30 EPR and Figure 30 shows the comparison between different NOx standards at various EPRs.

Table 9 - Aircraft engine emission standards relevant to NOx

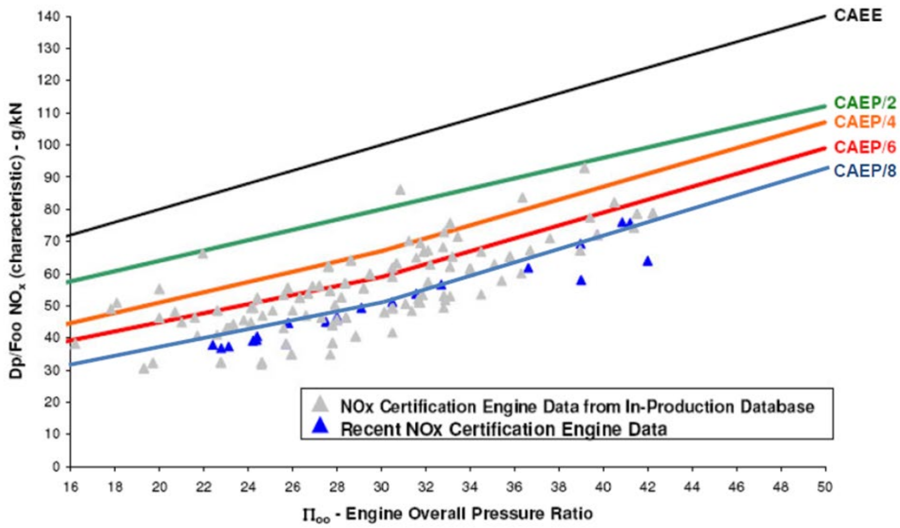
Regulation	Adoption year	NOx @ EPR 30	% NOx below CAEP/1	Newly certified engine
CAEP/1	1981	100 g/kN	0%	1986
CAEP/2	1993	80 g/kN	20%	1996
CAEP/4	1999	67 g/kN	33%	2003
CAEP/6	2005	59 g/kN	41%	2007
CAEP/8	2011	50 g/kN	50%	2013
CAEP/10*	2017	NA	NA	2020

* Note: Focusing on fuel efficiency and CO2 reduction

Recently, U.S. EPA has proposed GHG emission standards for certain classes of engines used by certain civil subsonic jet airplanes (those with a maximum takeoff mass greater than 5,700 kilograms), as well as larger subsonic propeller-driven airplanes (those powered by turboprop engines with a maximum takeoff mass greater than 8,618 kilograms). These proposed standards are equivalent to the Airplane CO2 Emission Standards adopted by the ICAO in 2017 and would apply to both new type designs (new type design airplanes) and in-production airplanes.[135] As described by U.S. EPA, the proposed standard is technology-following. Although there are a variety of aircraft and engine technologies under development which show tremendous promise in reducing GHG emissions, the standard will not require a technology response from manufacturers. Furthermore, U.S. EPA did not consider other advanced technology under development by the industry (i.e., hybrid and zero-emission technology). CARB urges U.S. EPA to strengthen the proposed standard in terms of stringency, applicability, and time.

[135] U.S EPA, Draft Airplane Greenhouse Gas Standards Technical Support Document (TSD) July 2020, EPA-420-D-20-004

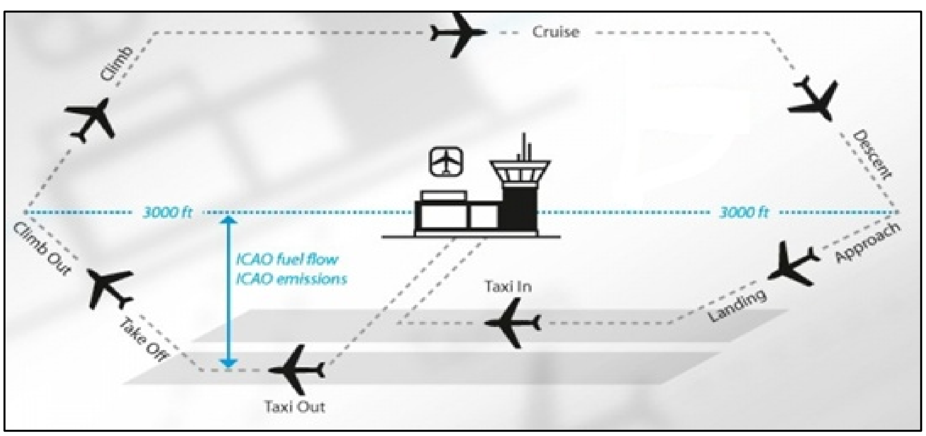
Figure 30 - Comparison of CAEP NOx standards and engine NOx emissions[136]



<u>Landing and Take-off (LTO) Cycle</u>

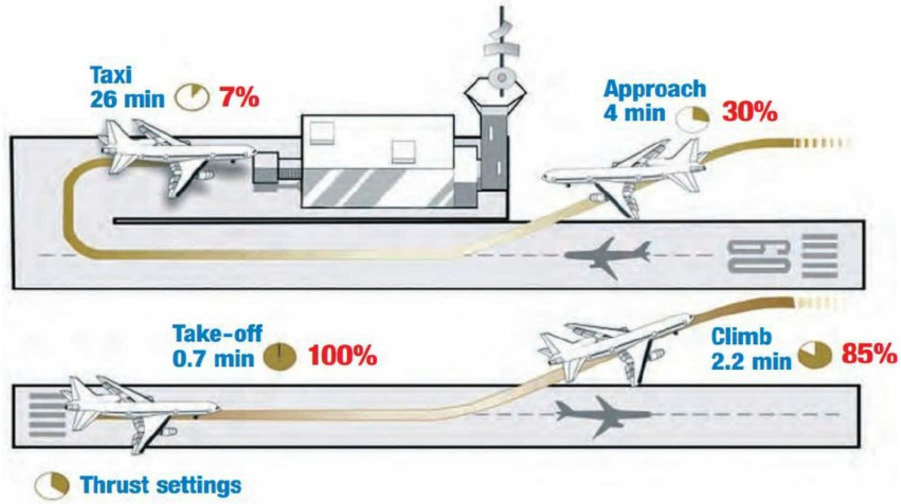
The CAEP is responsible for setting emission measurement procedures and standards. These standards and procedures are based on a standardized landing and take-off (LTO) cycle developed to address ground-level air quality issues. The LTO cycle is comprised of six modes; namely, taxi-out, take-off, climb-out, approach, landing, and taxi-in modes (Figure 31 and Figure 32); climb, cruise, and descent operation for aircraft above 3,000 feet are not included in the LTO cycle.

Figure 31- Typical aircraft flight path including the LTO cycle[137]



[136] Jahangir, Ebad. *ICAO Technology Goals Process for Aviation Environmental Protection.* May 12, 2010. http://www.icao.int/Meetings/EnvironmentalColloquium/Documents/2010-Colloquium/3_Jahangir_Icao.pdf
[137] Advanced Emission Model. "European Organisation for the Safety of Air Navigation." 2015. https://www.eurocontrol.int/services/advanced-emission-model-aem.

Figure 32- Duration and Thrust Settings within each Segment of the LTO Cycle



Mobile Source Strategy Scenario

Under the 2020 MSS, staff proposed a scenario focusing on four strategies:
(1) improving the current air traffic operation, (2) transitioning toward zero-emission auxiliary power unit (APU), (3) accelerating the turnover of old aircraft, and
(4) technology advancement for future aircraft. The following provides additional details for each strategy:

Improve the Current Air Traffic Operation (ATO) during LTO cycle

a) *De-Rated Take Off:* Aircraft are designed to take off safely without full thrust. By not applying full thrust during take-off, aircraft would consume less fuel and indirectly reduce NOx emissions as well as the level of noise. According to a study conducted by MIT in 2005,[138] each 1 percent of derate can approximately reduce NOx emissions by 0.7 percent below 3000 feet while increasing the fuel burn (and hence CO2) by 0.6 percent.

b) *Reduce Power during Taxiing:* Most commercial aircraft are equipped with two to four engines. Aircraft engines, even at idle or minimal power settings, are used to taxi the aircraft while on the ground. Because of this, taxi-in, idle and even taxi-out can be completed with one or more of those engines not operating. If an engine can be shut down during the taxi-in until the aircraft is in an advanced stage of the taxi-out for takeoff, then such a procedure has the potential to reduce fuel burn and criteria emissions such as NOx.[139]

c) *Improved Taxi Time:* Prolonged taxi time for aircraft causes unnecessary waste of fuel and an increase in emissions. By minimizing the taxi time when the aircraft is

[138] King, M., Waitz, I., 2005. Assessment of the Effects of Operational Procedures and Derated Thrust on American Airlines B777 Emissions from London's Heathrow and Gatwick Airports. Partner, Cambridge, MA.
[139] Sustainable Aviation, Aircraft on the Ground CO2 Reduction Programme, UK's Airport Operators Association

taxi-in or taxi-out, less fuel will be consumed leading to less NOx emissions. Such a control measure would require real-time optimization of air traffic with constant feedback from all associated airports.

Reduce the Usage for Auxiliary Power Unit

The typical aircraft APU is a small turbine engine that starts the aircraft main engines and powers the electrical systems on the aircraft when the main engines are off. By switching to the on-board rechargeable batteries as the power supply, it would reduce the usage of the gas turbine APU and hence the NOx emissions.

Accelerated Turnover

Similar to other off-road mobile source categories, replacing old aircraft that are powered by the CAEP/1 to CAEP/4 engines with the newer engines (CAEP/8 or newer) can reduce NOx emissions and improve safety, as well as fuel efficiency.

Technology Advancement

The NOx formation correlates with the high temperature and pressure during the combustion process. With innovative research and advanced optimization of engine design, it has been demonstrated that NOx emissions can be further reduced beyond the CAEP/8 standards. For example, under the FAA's Continuous Lower Energy, Emissions, and Noise Phase II (CLEEN II) Program, FAA awarded five-year agreements to Aurora Flight Sciences, Boeing, Collins Aerospace, Delta Tech Ops/MDS Coating Technologies, General Electric, Honeywell, Pratt & Whitney, and Rolls-Royce to accelerate the development of new aircraft and engine technologies. The goal of the program is to achieve 70 percent NOx and 40 percent fuel burn reduction below the CAEP/8 standards. In 2016, GE's Twin Annular Premixing Swirler (TAPS) II combustor matured under CLEEN I and entered into service as part of CFM International's TAPS Leading Edge Aviation Propulsion (LEAP) engine, currently onboard Airbus 320neo, Boeing 737 MAX, and COMAC C919 aircraft. Under CLEEN I, GE engine emissions tests of TAPS II had results that were more than 60 percent below the 2004 ICAO CAEP NOX standards. The FAA anticipates that more of these technologies could go into service in the next several years.[140]

With all of these technology advancements in mind, for the 2020 MSS, staff developed a scenario assuming a phase-in requirement for improving ATO efficiency starting in 2023. Staff assumed that by 2030:

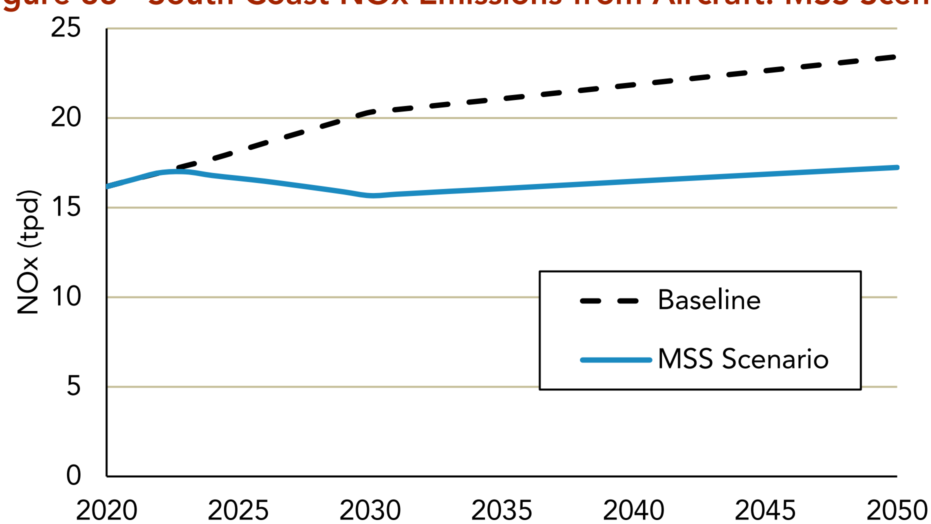
- 90 percent of take offs in California will be 25 percent de-rated (95 percent of take offs by 2050);
- 90 percent of aircrafts will have single engine taxiing (95 percent by 2050);
- 40 percent reduction in taxi time (50 percent by 2050);
- 40 percent reduction in APU usage (95 percent by 2050)

[140] https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/

With these assumptions, Figure 33 presents the resultant NOx emissions reductions for the South Coast Air Basin. Without any control, the NOx emissions would increase from 16.2 tpd in 2020 to about 20.5 tpd by 2031. However, with improved air traffic operation, and reduced APU usage, NOx emissions will be reduced by 4.7 tpd and 5.2 tpd in 2031 and 2037 respectively. Please note that these estimates do not account for further deployment of cleaner technologies and accelerated turnover of older aircrafts.

It is noteworthy to also mention that as a result of the COVID-19 pandemic, the domestic and worldwide air traffic volume has declined significantly. It is estimated that almost 62 percent of the worldwide passenger jets are grounded since the COVID-19 pandemic. To save the cost of fuel, most airlines are operating newer aircraft that are most fuel-efficient. Therefore, the airline industry is already accelerating the turnover of the older aircraft based on sound business solutions. Moreover, the COVID-19 pandemic has forced all business sectors and government agencies to reduce travel by encouraging more online meetings. Such new business practice is likely to continue after the COVID-19 pandemic is over. Consequently, future air travel would grow at a much slower rate when compared to the growth rate before the COVID-19 pandemic, which in turn would help to reduce NOx emissions.

Figure 33 - South Coast NOx Emissions from Aircraft: MSS Scenario



Off-Road Sectors: Zero-Emission

Cargo Handling Equipment

Cargo handling equipment (CHE) includes any motorized vehicles used to handle cargo or perform routine maintenance activities at California's ports and intermodal rail yards. CHE includes yard tractors, rubber-tired gantry (RTG) cranes, container handlers, forklifts, etc. CHE can be a significant source of diesel PM emissions in communities near the ports and intermodal rail facilities.

CARB initially adopted the CHE regulation on December 8, 2005, and it became effective on December 31, 2006. This regulation was fully implemented by the end of 2017 and has resulted in reductions of diesel PM and NOx at ports and intermodal rail yards throughout California. CARB staff are currently assessing the availability and performance of zero-emission and hybrid technologies to reduce emissions from a fleet predominantly powered by internal combustion engines and evaluating additional solutions that may include efficiency improvements.

Mobile Source Strategy Scenario

As part of the 2020 MSS, CARB staff has developed a scenario where CHE will start transitioning to full electric in 2026, with over 90 percent penetration of electric equipment by 2036. This assumption about aggressive electrification is supported by the fact that currently some electric RTG cranes, electric forklifts, and electric yard tractors are already commercially available. Other technologies are in early production or demonstration phases. Figure 34 shows the technology mix as a result of this scenario. As shown, the zero-emission CHE population share will reach 90 percent by 2036. Figure 35 shows statewide NOx emission from CHE. Statewide NOx emission reductions from CHE in 2031 and 2037 will be 1.1 tpd and 1.5 tpd, respectively. Under this scenario, CHE electrification will reduce diesel fuel use by 115 million gallons in 2045.

Figure 34 - Statewide CHE Population: MSS Scenario

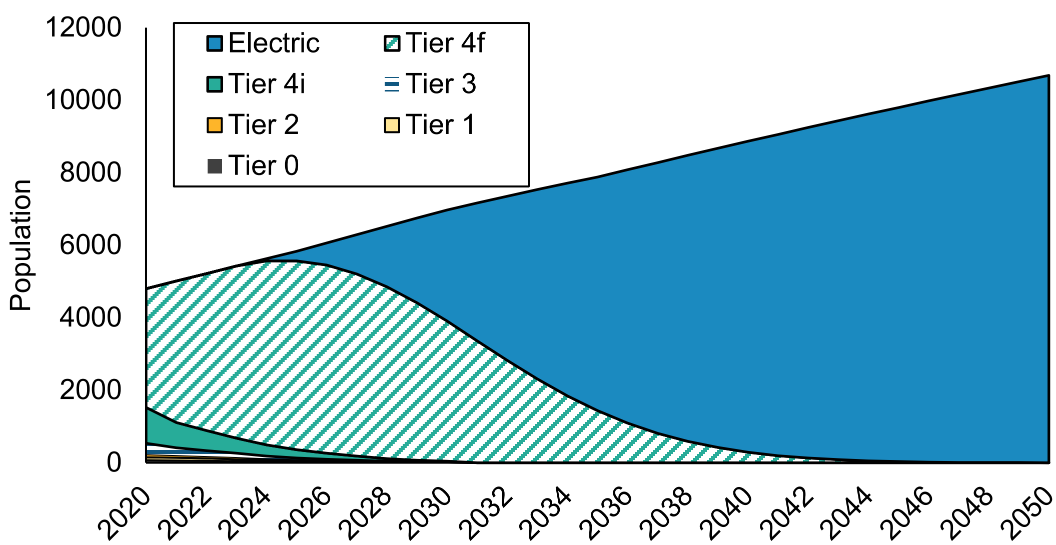
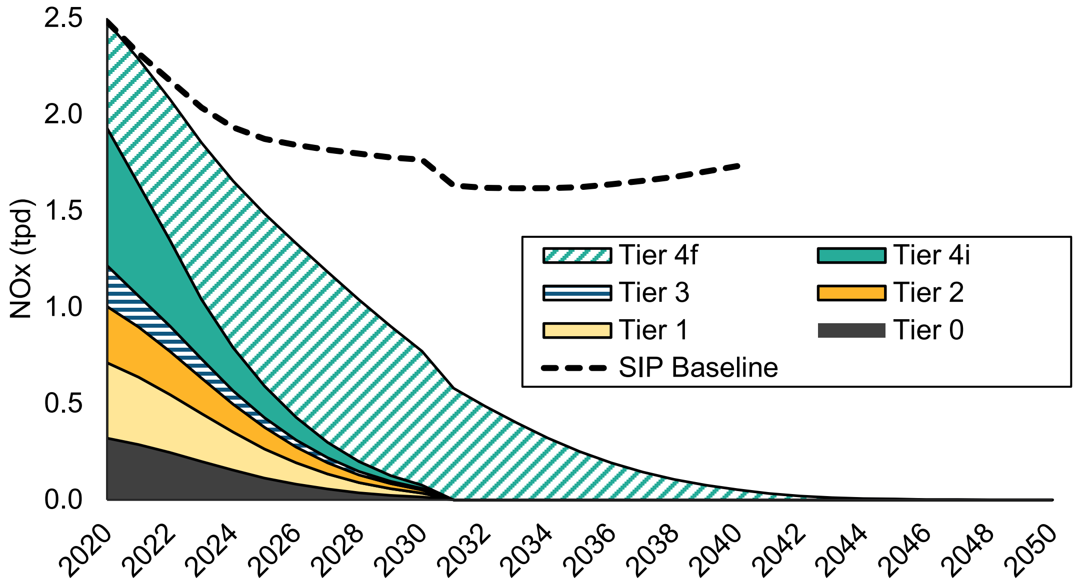


Figure 35 - Statewide CHE NOx Emissions: MSS Scenario



Small Off-Road Engines

Small off-road engines (SORE) are spark-ignition engines rated at or below 19 kilowatts (i.e., 25 horsepower). Engines in this category are primarily used in lawn and garden equipment as well as other outdoor power equipment and specialty vehicles. Currently there are 14 million pieces of gas powered small engines in California, equivalent to the number of light-duty passenger cars[141] driving on California roadways.

SORE are significant contributors to ROG that are ozone precursors. CARB adopted emission standards for SORE in 1990 and was the first agency in the world to control emissions from these engines. While SORE are 40-80 percent cleaner today than they were before CARB's control program began, they are still significantly dirtier than cars. Total smog-forming emissions from SORE exceeded the emissions from passenger cars in California in 2018 and, absent additional regulation, will be more than twice those from California's passenger vehicle fleet by 2031. Currently, nearly 50 percent of the lawn and garden equipment and 70 percent of the light commercial equipment (such as generators, compressors, and pressure washers) are electric, based on the survey by California State University, Fullerton.

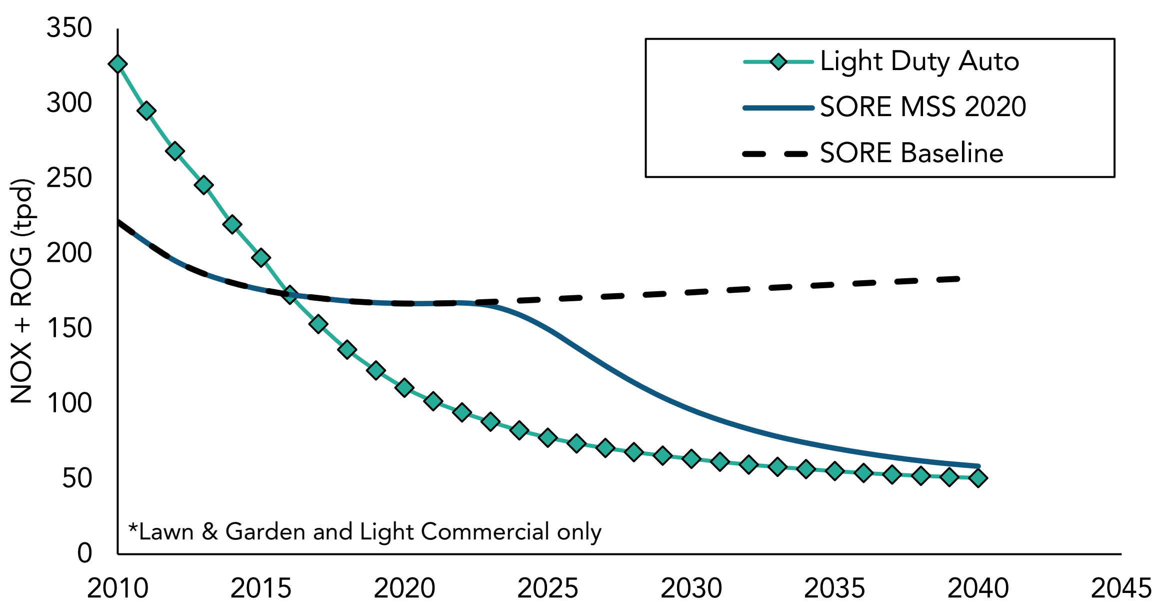
As outlined in the 2016 Mobile Source Strategy, CARB will be proposing amendments to the existing SORE regulation that sets more stringent exhaust and evaporative emissions standards and accelerates the transition of the SORE category from internal combustion engines to zero-emissions. Specifically, staff would propose to tighten exhaust and evaporative emission standards to zero in two steps with standards set to

[141] Referring to LDA category in the EMFAC model

zero for model year 2025.[142] Under the proposal, beginning in model year 2023, lower exhaust and evaporative emission standards, as well as requirements for extended durability, would apply to all new non-preempted engines. For model years 2025 through 2027, production of spark-ignition engines would continue to be allowed through credit averaging, banking and trading provisions. For model years 2028 and beyond, the amendments would require all new production to be zero-emission equipment, except for federal preempted equipment, which accounts for about 11 percent of the population in California.

Considering that staff's current proposal would largely transform SORE to zero-emission technology by 2040, no additional 2020 MSS scenarios were modeled for this sector. Figure 20 shows statewide NOx emission projections from SORE. NOx emission reductions under the 2020 MSS scenario in 2031 and 2037 are 9.9 tpd and 13.9 tpd, respectively. As noted earlier, federal preempted engines account for the majority of remaining emissions after 2031, making up almost 90 percent of the total remaining NOx emissions from SORE by 2040. This again emphasizes the need for federal actions to reduce emissions from preempted equipment. As shown, the current proposal will reduce emissions from SORE in California such that overall emissions becomes similar to the total emissions from California's light-duty passenger vehicle fleet by 2040. Electrification of SORE is estimated to reduce gasoline fuel use by 230 million gallons in 2045.

Figure 36 - Statewide Smog-Forming Emission Projections from SORE



[142] This is the same scenario as the draft proposal presented at CARB's June 2020 workshop to discuss potential changes to CARB's Small Off-Road Engine Exhaust and Evaporative emission regulations. More details can be found at: https://ww2.arb.ca.gov/resources/documents/june-9-2020-sore-workshop-slides

Airport Ground Support Equipment

Airport Ground Support Equipment (GSE) are diesel, gasoline, natural gas and electric equipment used at airports. Common equipment includes aircraft tugs, baggage tugs, passenger stairs, and similar equipment. This category is well suited to electrification due to the equipment generally being captive at one location (allowing for the development of charging infrastructure), and the relatively stable power requirements (compared to large mining or construction equipment). Currently, approximately 34 percent of GSE reported to CARB is electric, with 38 percent being diesel, 17 percent gasoline, and 11 percent being natural gas. This proportion of equipment sales in each fuel type does not appear to have changed significantly in the last decade (based on data reported in the DOORS program), meaning that higher penetration of zero-emission equipment may not occur naturally.

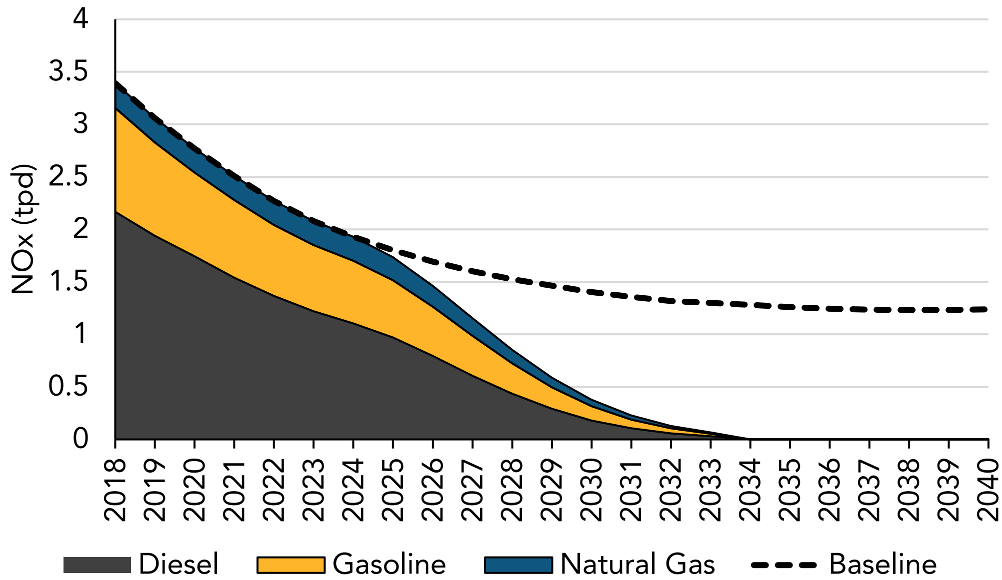
This equipment, although not a relatively large contributor to statewide emissions compared to other categories, is significant source of air pollution and toxic air contaminants to communities located near airports. The use of GSE is clustered and confined to a small area near other sources (such as cars and mass transit to airports, aircraft emissions, and other sources in or near the communities that surround many of the airports in the state). Currently, the diesel portion of this equipment is subject to the In-Use Off-Road Diesel Regulation, which requires these fleets meet approximately a Tier 3 average by 2023.

Mobile Source Strategy Scenario

Under the 2020 MSS, staff assumes full electrification of the remaining diesel, gasoline and LNG equipment, phased in over 10 years from 2025 to 2034. This technology trajectory will require additional electrification infrastructure installed at airports and ground support terminals. As shown in Figure 37, this effort will reduce statewide NOx emissions by about 1 tpd in 2031.

This effort is supported by incentives currently, and may be accomplished with an MOU between the South Coast Air Quality Management District for specific airports in impacted communities.

Figure 37 - Statewide NOx Emissions from GSE: MSS Scenario



Forklifts (Spark Ignition and Diesel)

Forklifts are off-road equipment with a mix of diesel, gasoline, natural gas and electric engines. Forklifts with moderate to low lift capacity are an excellent candidate for full electrification, as they are often captive to facilities, used in urban or industrial areas, and already have electric options available commercially. Larger forklifts may be less suitable to full electrification, due to a mix of available technology and power requirements. A threshold for full electrification will be developed by CARB staff in further developing this strategy, but it is likely to be between 6,000 to 10,000 pound capacity which broadly means full electrification for all forklifts under 50 or 80 horsepower.

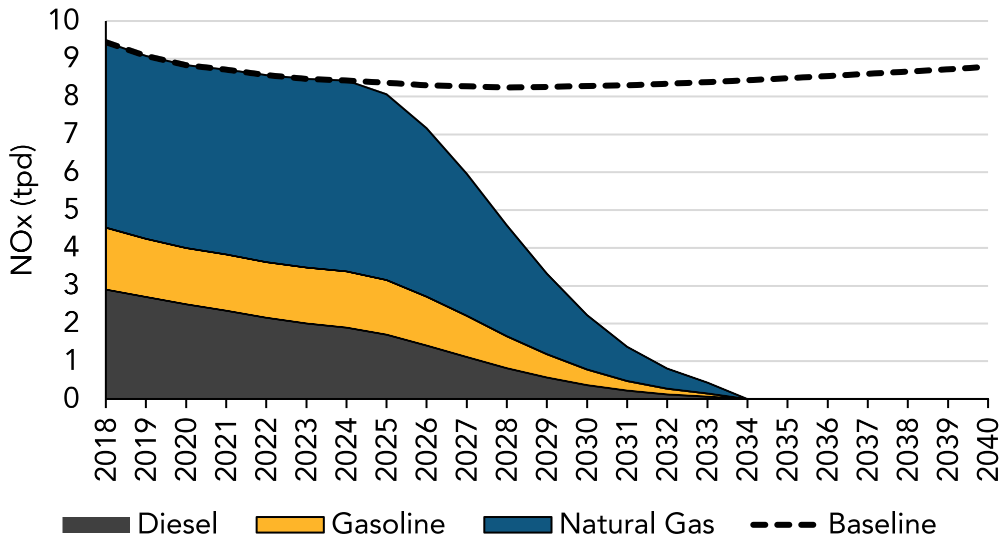
Diesel forklifts over 25 horsepower are currently subject to the In-Use Off-Road Regulation, meeting an increasingly stringent fleet average target with a final target in 2023. Gasoline and CNG forklifts have been subject to the Large Spark Ignition Regulation, and completed their final emissions requirements in 2013.

Mobile Source Strategy Scenario

Under this 2020 MSS scenario, staff developed a scenario where forklifts will transition to zero-emission technology starting in 2025, with a possible measure coming to the Board in 2022. Diesel forklifts would need to be pulled from the In-Use Off-Road

Regulation and included with forklifts from other fuels in this strategy. As shown in Figure 38, this strategy would result in 6.9 tpd of statewide NOx reduction in 2031.[143]

Figure 38 - Statewide NOx Emissions from Forklifts: MSS Scenario



Transport Refrigeration Units

Transport refrigeration units (TRUs) are diesel-powered refrigeration units installed on vehicles such as trucks, trailers, shipping containers, and rail cars. The CARB TRU emissions inventory also includes TRU generator sets (gensets), which are designed to provide electricity to electrically driven refrigeration units (including systems for semi-trailers, vans, and shipping containers). TRUs are responsible for the safe transportation of refrigerated goods, including meats, produce, dairy, and certain medicine and chemical products. TRUs operate in large numbers at distribution centers, food manufacturing facilities, packing houses, and intermodal facilities.

TRUs are a significant source of various pollutants, but are of particular concern due to their PM2.5 emissions at locations and facilities where a large number of TRUs operate simultaneously, concentrating their emissions impact in the surrounding communities. CARB adopted the TRU Airborne Toxic Control Measure (ATCM) on February 26, 2004, with amendments in 2010 and 2011, to reduce diesel PM emissions. This regulation requires TRU diesel engines to meet in-use diesel PM emission standards by the end of the seventh year after manufacture.

Currently, CARB is pursuing regulatory actions to further reduce emissions from this sector. The current regulatory concepts go beyond the current TRU ATCM by

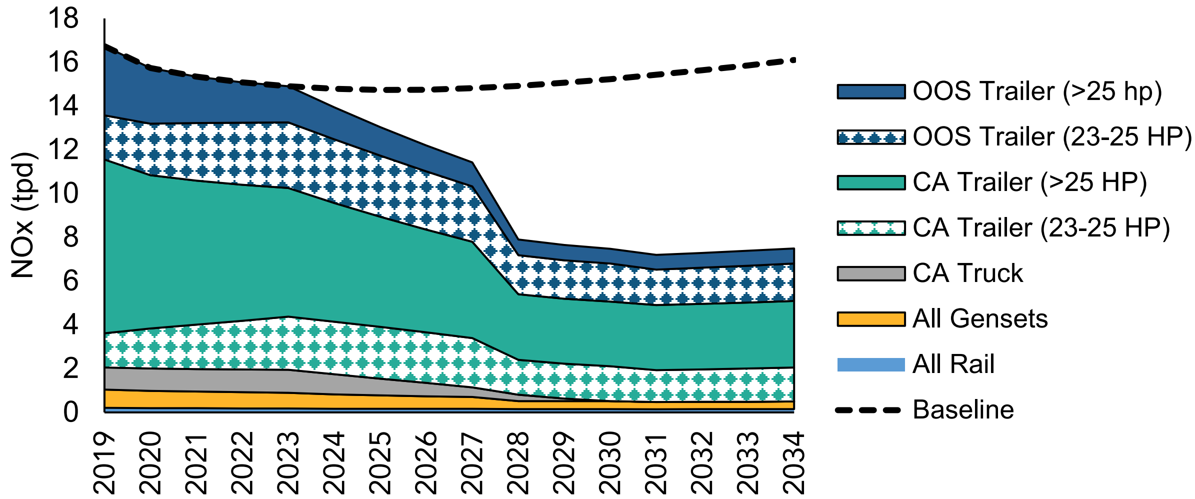
[143] Although this figure shows the reduction from all forklifts, CARB will assess the impact from smaller fleets, rental equipment (due to the infrastructure required for the end user to charge the forklift), and determine if there is a need for an upward limit on forklift capacity due to technology limitations.

transitioning to zero-emission wherever feasible, as well as increasing the earlier penetration of infrastructure that will be needed for those technologies. The current regulatory proposal requires the following:

- Starting December 31, 2023, all truck TRUs must turnover at least 15 percent each year (for 7 years) to full zero-emission technology. All truck TRUs must be full zero-emission by 2029;
- Starting December 31, 2027, all trailer TRUs, domestic shipping container TRUs, and TRU generator sets must use zero-emission operation if parked or stationary for more than 15 minutes at an applicable facility. This requirement is assumed to reduce diesel engine run time, fuel use, and emissions by 40 percent. This is based on a stationary run time equal to 49 percent of overall TRU activity, adding additional time allowance for the first 15 minutes, and stationary time while not at a facility subject to the control measure (unloading at a smaller facility without loading docks); and
- Starting December 31, 2023, newly manufactured diesel engines in trailer TRUs, domestic shipping container TRUs, railcar TRUs, and TRU gensets that operate in California, regardless of horsepower, must meet the U.S. EPA Tier 4 final emission standard for 25-50 hp engines. This requirement applies to all diesel engines in trailer TRUs, domestic shipping container TRUs, railcar TRUs, and TRU gensets starting December 31, 2030. The current emission standards for TRU engines below 25 horsepower are significantly higher than those for over 25 horsepower engines. As a result, many TRU engines are between 23 and 25 horsepower. This measure can reduce PM emissions from these engines by 90 percent, and NOx emissions by 71 percent.

Figure 39 shows TRU emissions under the current staff regulatory concepts, with the dotted line showing the baseline emissions. Under the existing TRU ATCM (baseline), NOx will continue to decrease slightly until 2026, when almost all units will be Tier 4. After 2026, growth will begin to push NOx gradually higher. By 2040, NOx will be only about 20 percent lower than 2010. Under this concept, NOx emissions will be reduced by 50 percent, and PM will be reduced by almost 70 percent by 2031.

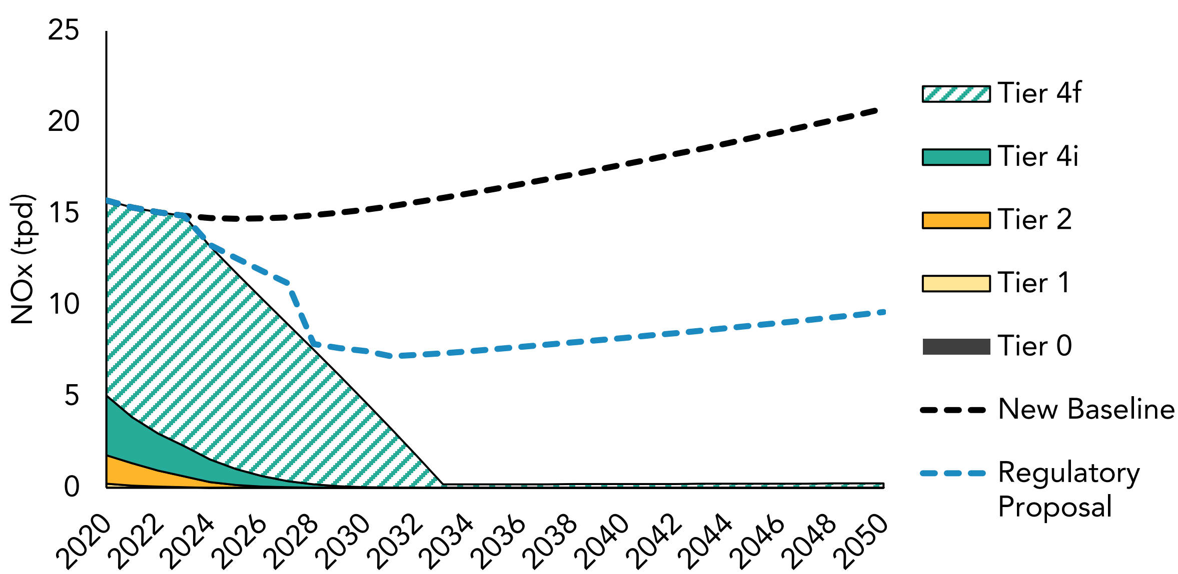
Figure 39 - Statewide NOx Emissions from TRU: Regulatory Proposal



Mobile Source Strategy Scenario

As part of the 2020 MSS, staff developed a rapid electrification scenario for TRUs, featuring the share of zero-emission TRUs increasing from 10 percent in 2024 to 100 percent in 2034. Statewide NOx emissions from TRUs will be reduced by 12 tpd in 2031 under the MSS scenario.

Figure 40 - Statewide NOx Emissions from TRU: MSS Scenario



Recreational Watercraft

Recreational watercraft (RW) is a broad category of marine vessels that includes gasoline powered spark-ignition marine watercraft (SIMW) and engines (SIME) and diesel-powered marine watercraft. A significant ROG source in California is the exhaust and evaporative emissions produced by SIMW and SIME. In 2015, the Board set standards for evaporative emissions from SIMWs, however, the exhaust emissions standards for these watercraft have not been changed since 2009.

Mobile Source Strategy Scenario

Under this 2020 MSS, staff developed a scenario which assumes that starting in 2027, THC+NOx emissions from outboard and personal watercraft will be reduced by 40 and 70 percent below current levels for less than 40 kW and above 40 kW engines respectively.

In addition to these standards changes, which would apply to internal combustion outboard and personal watercraft (PWC) marine engines only, staff believes there to be an opportunity for further significant emission reductions from the electrification of marine engines in certain applications. Specifically, small outboard engines less than 19 kW, which are not typically operated aggressively or for extended periods, could be replaced with electric motors within a ten-year phase-in period. Additionally, 25 percent of existing PWC applications could be powered with electric motors over that same ten-year time period. The inherently lighter mass typical of PWCs is better suited to electric propulsion systems than are other types of marine vessels. Not only would this replacement of internal combustion engines with electric propulsion motors eliminate exhaust emissions, it would also eliminate evaporative emissions, helping to achieve attainment with ambient air quality standards in the South Coast Air Basin and other areas of the State.

Figure 41 provides potential NOx and ROG emissions reductions under this scenario. As shown, the scenario will achieve a total of 2.5 and 9.8 tpd of ROG + NOx emissions in 2031 and 2037, respectively. In addition to criteria emissions benefit, the proposed scenario will result in reductions in gasoline consumption of about 11 million gallons by 2045 (Figure 42).

Figure 41 - Statewide Smog-Forming Emissions from Recreational Watercraft

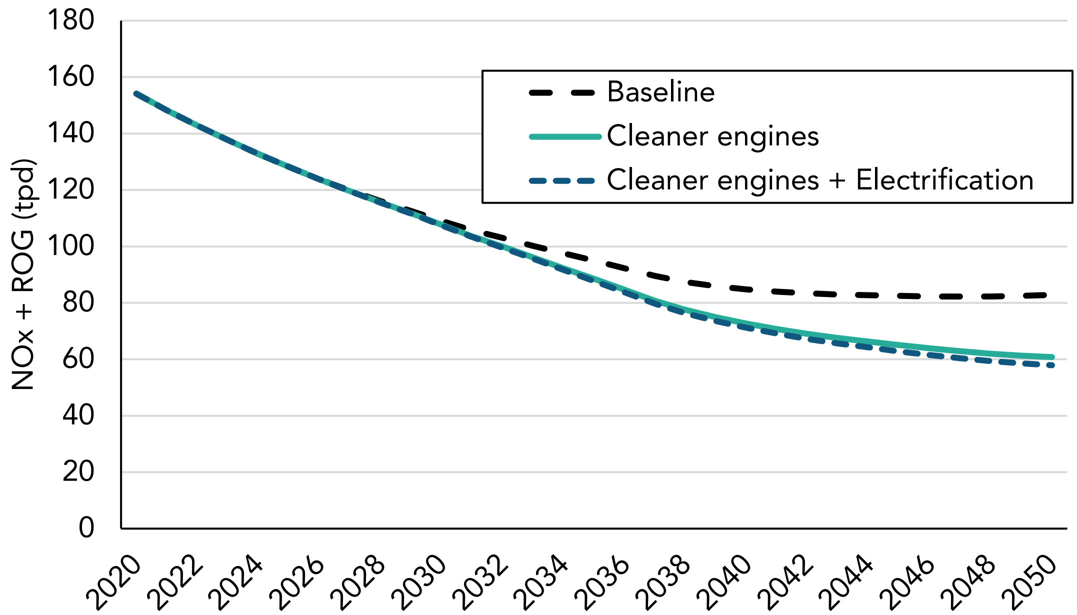
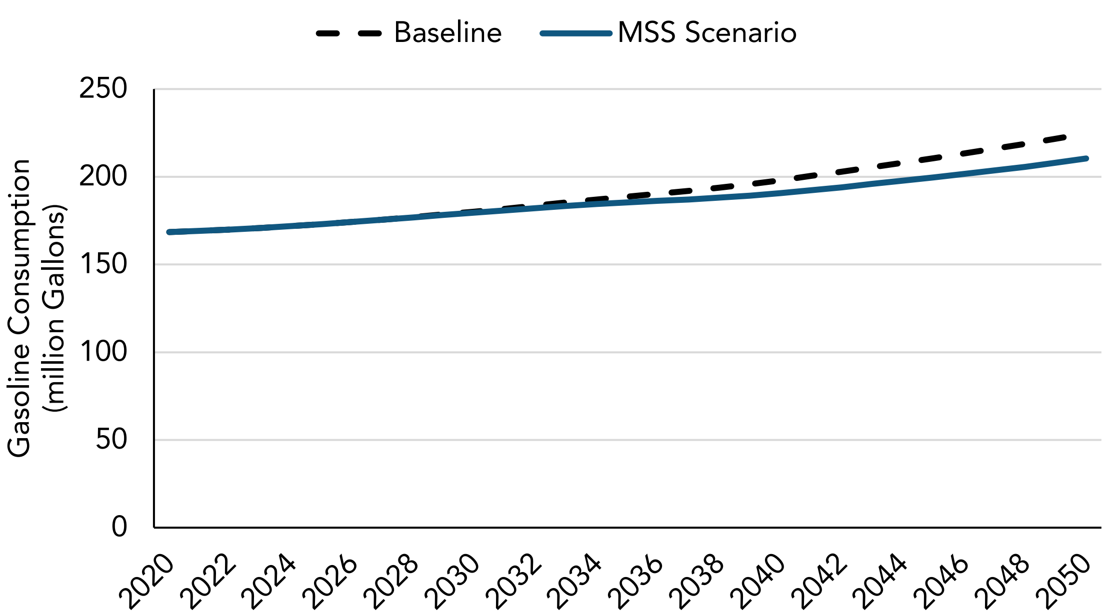


Figure 42 - Statewide Gasoline Fuel Consumption from Recreational Watercraft



Off-Road Sectors: Accelerated Turnover and Zero-Emission

Construction and Earthmoving Equipment (In-Use Off-Road)

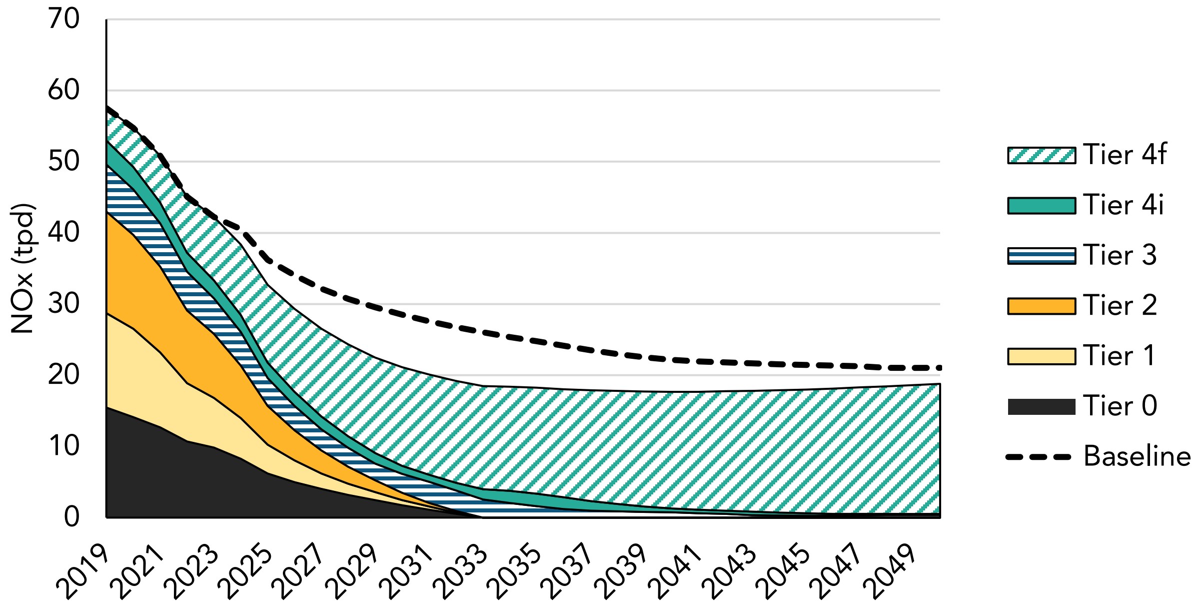
The in-use off-road equipment sector includes equipment used in industries such as construction, mining, industrial, oil drilling, and similar industries, and covers mobile diesel vehicles over 25 horsepower. Common examples are loaders, backhoes, excavators, forklifts, oil rigs, and other off-road equipment.

The diesel equipment in this category is currently subject to CARB's In-Use Off-Road Regulation, passed by the Board in 2008. The existing rule requires that fleets meet an increasingly stringent set of fleet average targets, culminating in 2023 for large fleets (large fleets represent about 73 percent of vehicle ownership). The most stringent fleet average target generally corresponds to roughly a 2012 model year, or a Tier 3 average standard. While this regulation has resulted in significant emissions reductions from the sector, the regulation does allow Tier 0, 1 and 2 equipment to continue operating indefinitely with no activity restrictions (dependent on the mix of other equipment owned by the fleet). For comparison, a single Tier 0 off-road engine in the 100-175 horsepower bin has 80 times higher NOx emissions than a Tier 4 Final off-road engine. By 2031, this Tier 0 equipment will be 32 years old or more, Tier 1 will be 28 to 31 years old, and Tier 2 will be 24 to 27 years old. This equipment, already having provided a long useful life, can continue to operate hundreds or thousands of hours per year with no restrictions under the current rule, with no end date.

<u>Mobile Source Strategy Scenario</u>

For the 2020 MSS, staff developed a scenario where the current In-Use Off-Road Regulation will be extended with the goal of full turnover of Tier 0, 1 and 2 engines between 2024 and 2033. This scenario will allow a 10 year phase out of these engines to cleaner Tier 4 final engines. As illustrated in Figure 43, this scenario will result in a statewide NOx emissions reduction of 7.5 tpd by 2031, with 2.4 tpd in South Coast and 1.7 tpd in the San Joaquin Valley. Diesel PM will be reduced in the sector by 47 percent over the same period.

Figure 43 - Statewide NOx Emissions from In-Use Off-Road: MSS Scenario



Agricultural Equipment

California is the nation's leader in agricultural production, producing over 400 different commodities that generate over $40 billion in annual sales and over 400,000 jobs statewide. Agricultural equipment is used in agricultural goods production and supply, and is a significant contributor to California's air quality issues. The San Joaquin Valley contains over 50 percent of the state's agricultural equipment, and diesel agricultural equipment contributed 18 percent of the NOx emissions in the San Joaquin Valley in 2019.[144]

Since 2009, over $400 million dollars in private and public funding have been invested in the San Joaquin Valley to replace older agricultural tractors with newer and cleaner models. Through 2016, the Natural Resources Conservation Service (NRCS) grant program by U.S. Department of Agriculture, in combination with the San Joaquin Valley Air Pollution Control District's program, has provided over $129 million that helped replace over 5,000 Tier 0 and Tier 1 tractors, plus other agricultural equipment. In 2018, CARB developed the Funding Agricultural Replacement Measures for Emission Reductions (FARMER) Program,[145] which facilitates distribution of State funds allocated by the California Legislature to incentivize turnover of agricultural equipment. The 2017-18 fiscal year allocated $108 million for San Joaquin Valley agricultural equipment replacement projects. The 2018-19 fiscal year included

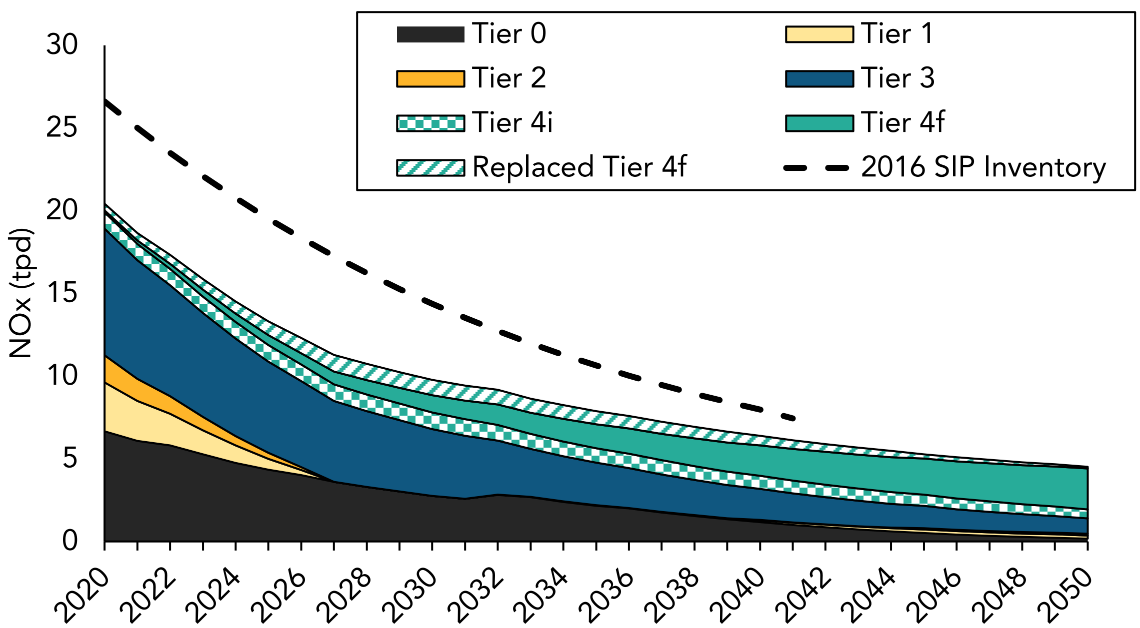
[144] https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php
[145] CARB FARMER Program, https://ww2.arb.ca.gov/our-work/programs/farmer-program

$132 million statewide for the FARMER program, with approximately 80 percent of the funds allocated to the SJV. The current goal for emissions reductions is 11 tpd of NOx from agricultural equipment in the San Joaquin Valley by 2024; this is roughly equivalent to replacing all Tier 0, Tier 1 and Tier 2 tractors that are used over 200 hours per year with Tier 4 engines and equipment.

Mobile Source Strategy Scenario

Under this 2020 MSS, staff developed a scenario that assumed continued incentive funding opportunities in the sector through 2031. Figure 44 shows the NOx emissions from farm tractors in the San Joaquin Valley under the baseline (i.e., 2016 SIP inventory) as well as the proposed MSS scenarios. At the average levels of funding over the past 4 years, continued funding through 2031 could replace Tier 0, 1 and 2 equipment in the remaining categories of equipment such as harvesters, bale wagons, tillers, etc. that are used over 100 hours per year, and the remaining Tier 0, 1 and 2 tractors used from 100 to 200 hours per year, with a total reduction of an additional 4 tpd of NOx in the San Joaquin Valley in 2031.

Figure 44 - San Joaquin Valley NOx Emissions from Farm Tractors



Commercial Harbor Craft

Commercial harbor craft (CHC) include any private, commercial, government, or military marine vessels including, but not limited to ferries, excursion vessels, tugboats (including ocean-going tugboats), towboats, crew and supply vessels, work boats, pilot vessels, barges, dredges, and commercial and charter fishing boats. The majority of CHC have diesel engines, which are significant emitters of PM and NOx. CHC emissions are concentrated near the ports, and pose significant health risks to nearby communities.

CARB's CHC Regulation was adopted in 2007 to reduce toxic and criteria emissions to protect public health. It was then amended in 2010 and will be fully implemented by the end of 2022. CARB is currently developing a new emission inventory and rule concept for CHC. The current regulatory concepts establish expanded and more stringent in-use requirements to cover more vessel categories. The concepts also mandate accelerated deployment of zero-emission and advanced technologies in vessel categories where technology feasibility has been demonstrated. For example, based on regulatory concepts released March 2020:

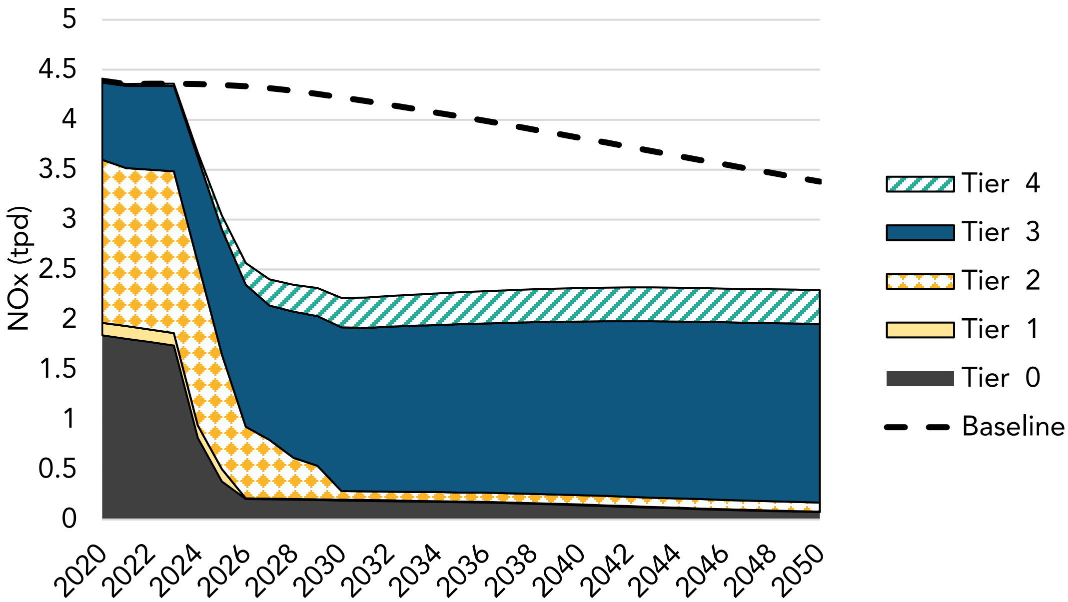
- Starting in 2023, all CHC except for commercial fishing vessels are required to meet the cleanest possible standard and retrofit with DPF based on a compliance schedule. The current regulated CHC categories are ferries, excursion, crew and supply, tug/tow boats, barges, and dredges. The concept will impose in-use requirements on the rest of vessel categories except for commercial fishing vessels, including workboats, pilot vessels, commercial passenger fishing, and all barges over 400 feet in length or otherwise meeting the definition of an ocean-going vessel. The concept also removes the current exemption for engines less than 50 horsepower;
- Starting in 2025, all new tugboats are required to be diesel-electric vessels. Diesel-electric vessels can deliver power to propellers through multiple pathways, such as diesel electro-mechanical propulsion systems, to reduce fuel by eliminating the need to run large main engines when vessel power demand is low (standby or low speed transit modes).[146] Diesel-electric tugboats could achieve about 15 percent fuel efficiency enhancement over their conventional counterparts;
- Starting in 2026, all new excursion vessels are required to be plug-in hybrid vessels that are capable of deriving 30 percent or more of combined propulsion and auxiliary power from a zero-emission tailpipe emission source;
- Starting in 2028, all new and in-use short run ferries are required to be zero-emission.

Figure 45 shows NOx emissions from CHC under the current regulatory concepts.[147] As noted in CARB's March 5, 2020 workshop, emissions under the new baseline emissions inventory are much higher than those estimated previously for the 2016 State SIP Strategy. As a result, the NOx emission reductions from the 2016 SIP

[146] Enhanced Efficiency Diesel-Electric Vessels have been built today in the tugboat sector. By design, the vessels augment mechanical propulsion with auxiliary diesel electric generators using a power take-in (PTI) system to maximize the time diesel engines are operating in their most efficient load range (e.g. typically 80 to 90 percent of maximum rated power).
[147] https://ww2.arb.ca.gov/resources/documents/public-webinar-notice-march-5-2020

baseline under the rule concepts are minimal and therefore more aggressive actions need to be taken in order to achieve the NOx reductions needed to meet the State's air quality goals.

Figure 45 - South Coast NOx Emissions from CHC: Regulatory Proposal

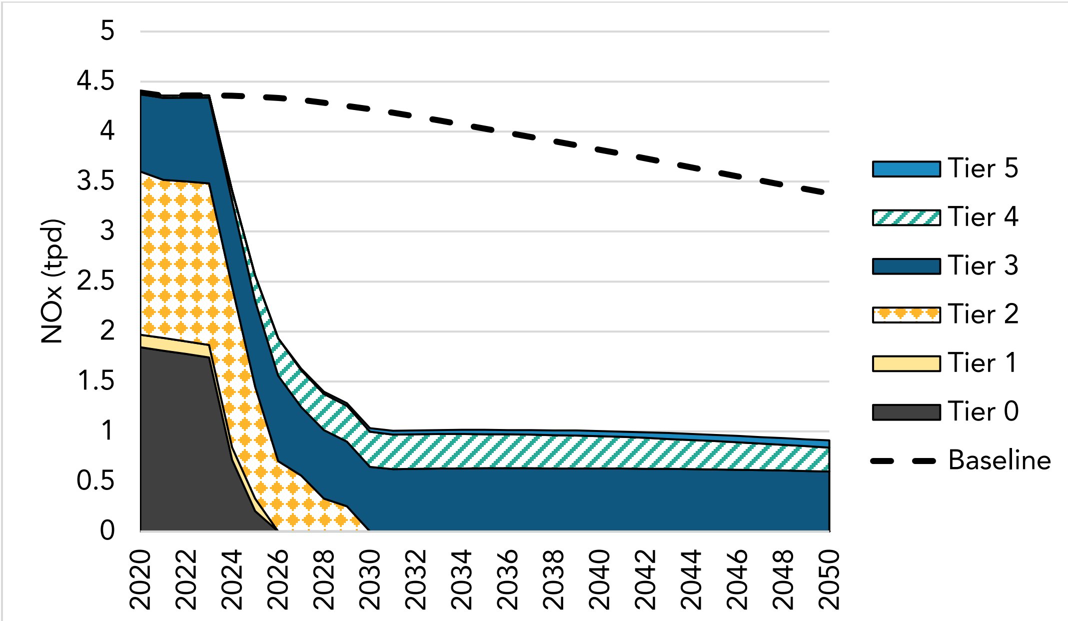


Mobile Source Strategy Scenario

For the 2020 MSS, staff developed a scenario which assumes introduction of Tier 4 and Tier 5 standards with DPF requirements for all CHC in 2024 and 2027, respectively. The scenario also assumes that commercial fishing vessels would no longer be exempted from the emission performance requirements. Current Tier 4 standard only applies to new vessels over 600 kW. This scenario would require Tier 4 engines for all vessel types. Under this scenario, staff assumed a Tier 4 standard which would impose a NOx emission standard of 1.04 g/bhp-hr (three to four times lower than the current Tier 3 levels); and a PM emission standard of 0.027 g/bhp-hr (two to seven times lower than current Tier 3 levels). Also, staff assumed a Tier 5 standard with NOx emissions of 0.20 g/bhp-hr and PM emissions of 0.010 g/bhp-hr. In this scenario, staff assumed that by 2030, all new and in-use excursion vessels would be plug-in hybrid, all new tugboats would be diesel-electric, and 20 percent of all ferries would be zero-emission.

Figure 46 shows NOx emission projections from CHC in the South Coast Air Basin under the 2020 MSS Scenario. As shown, the scenario can achieve over 3 tpd of NOx emissions reduction in 2031, significantly more than is estimated under the current regulatory concept.

Figure 46 - South Coast NOx Emissions from CHC: MSS Scenario

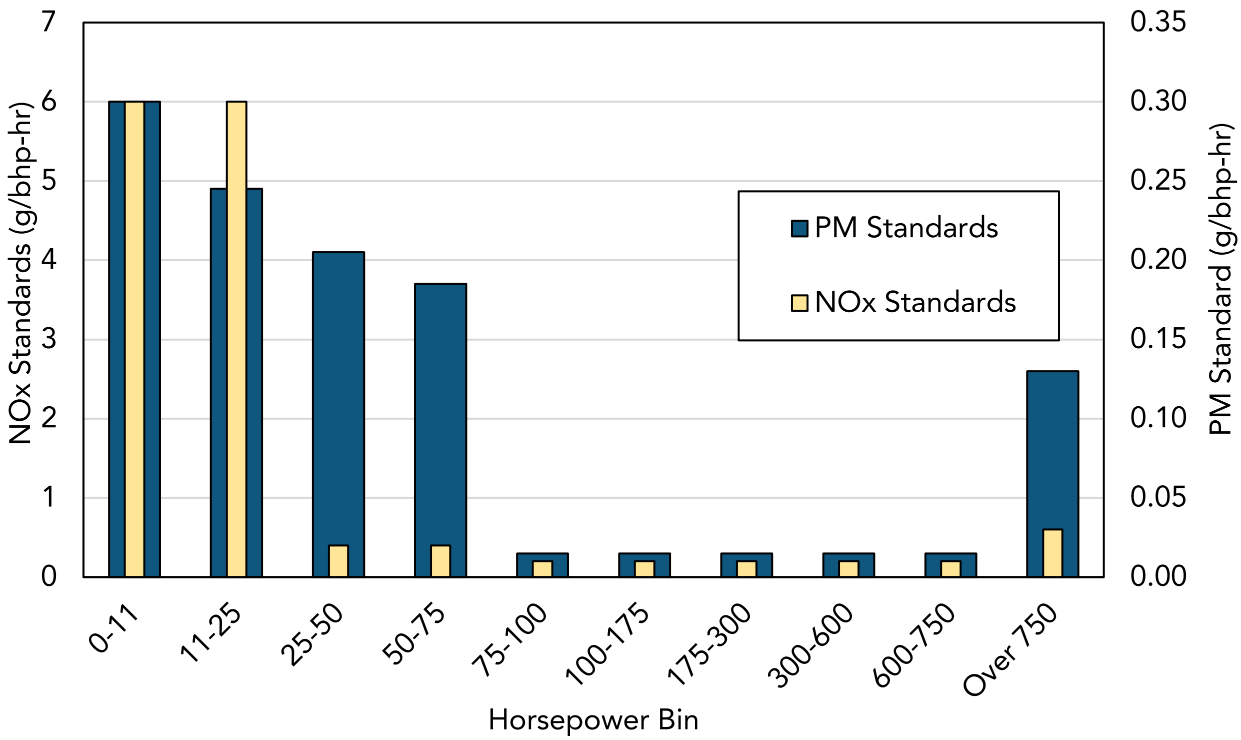


Cleaner and More-Efficient Off-Road Diesel Technology

Cleaner Diesel Technology

The last emissions standards for off-road diesel equipment (Tier 4 Interim and Final standards) were established in May 2004 by U.S. EPA, and took effect starting in 2008 with full implementation in 2015. These standards are shown below in Figure 47. From 75 to 750 horsepower, the standards are approximately equivalent to the 2010 on-road heavy-duty truck emission standards. However, technical challenges in lower and higher horsepower applications created barriers to SCR and DPF requirements, leaving NOx emissions standards in these horsepower bins only slightly below Tier 1 standards in the 50 to 75 horsepower bin, and exactly the same for the 0 to 50 horsepower groups.

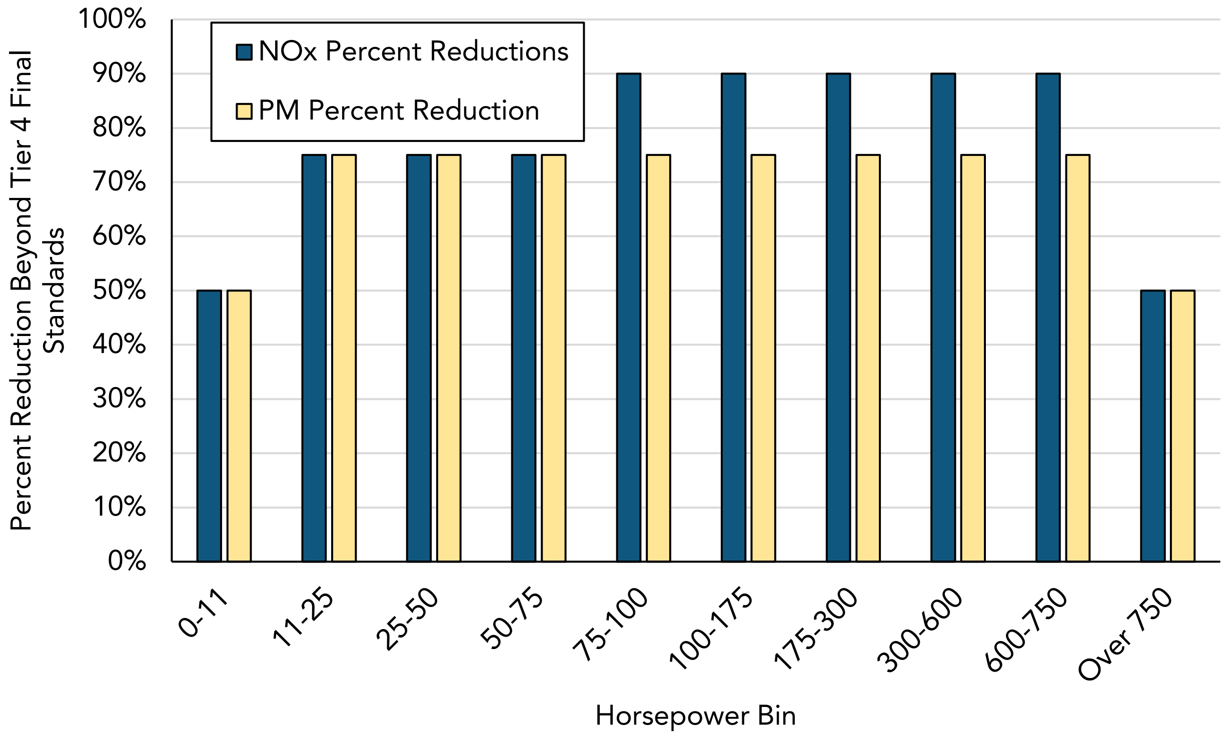
Figure 47 - Tier 4 Final Off-Road Diesel Standards for NOx and PM[148]



Technology demonstrations for SCR and DPF systems in the last 16 years (in particular the last three years) have shown that significant additional reductions are feasible for off-road engines. Again, the 75 to 750 horsepower groups show the greatest potential for reductions with up to 90 percent NOx reductions below Tier 4 Final as potentially feasible. However, under 75 horsepower, there seems to be significant potential for 50 to 75 percent NOx and PM reductions. This would effectively be the first real NOx reduction requirements for equipment under 25 horsepower, and the most significant PM reduction requirements for equipment under 75 horsepower of all off-road engine standards. The reduction beyond the Tier 4 Final standards is shown below in Figure 48, as the percent reduction from the existing standards.

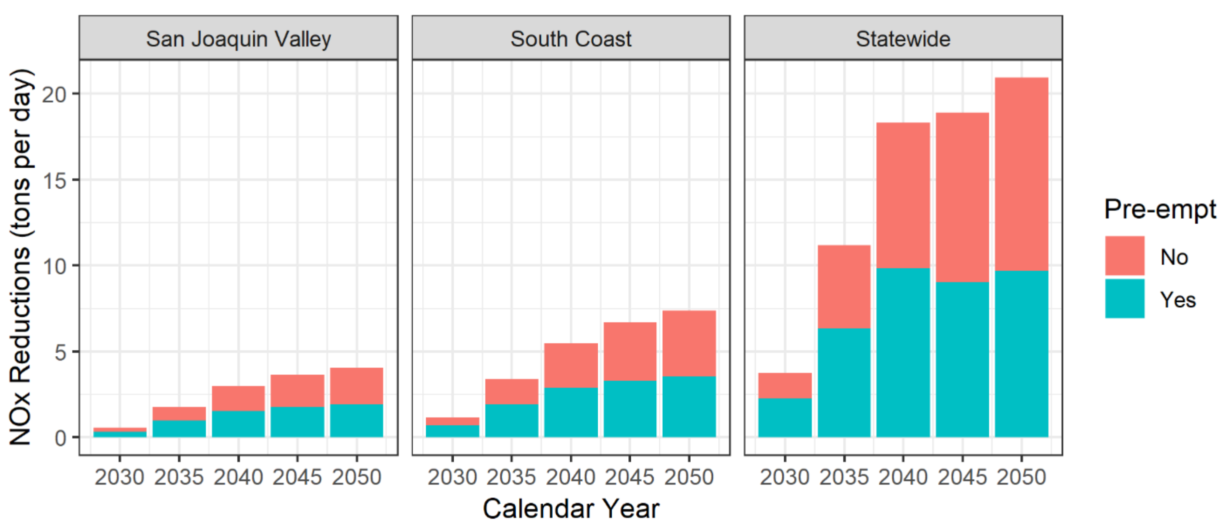
148 The less stringent PM standard for <11 hp engines was effective until 2010. Tier 4 HC and NOx are a combined standard for < 75 hp engines.

Figure 48 - Potential NOx and PM Emission Standard Reductions from Tier V Standards



The Tier 5 standards could be implemented as early as 2028 for non-federally preempt equipment, and possibly in 2030 for preempt equipment. While these standards would improve benefits seen from incentive and regulations that accelerate turnover, they would also have a significant positive impact solely due to natural turnover of equipment as shown below in Figure 49, providing up to 18 tpd NOx benefits statewide in 2040.

Figure 49 - Off-Road NOx Emissions Benefits from Tier 5



On-board diagnostics for Off-road

OBD systems are self-diagnostic systems incorporated into a vehicle's on-board computer. They are comprised mainly of software designed to detect emission-control system malfunctions as they occur. This is done by monitoring virtually every component and system that can cause increases in emissions. The OBD system continuously works in the background during vehicle operation to monitor emission-related components and alerts the vehicle operator of detected malfunctions by illuminating the malfunction indicator light (MIL) on the vehicle's instrument panel. Additionally, the OBD system stores important information, including identification of the faulty component or system and the nature of the fault, which allows for quicker diagnosis and proper repair of the problem by technicians. This helps vehicle owners experience less expensive repairs, and promotes repairs being done correctly the first time. OBD systems have also become the basis for emission inspection programs in California and throughout the nation. For light-duty vehicles, all 2000 and newer model year vehicles are inspected nearly exclusively by accessing the OBD system to verify that no emission-related faults are present. For heavy-duty, research is still ongoing to develop such a program, but it is likely that OBD information will play a vital role in the inspection process.

The first generation of OBD systems intended for light- and medium-duty vehicles with three way catalysts and feedback control (referred to as OBD I) was implemented by CARB in 1988, and required monitoring of only a few of the emission-related components on the vehicle (CARB, 1985). In 1989, CARB adopted regulations requiring a second generation of OBD systems (referred to as OBD II) that standardized the system and addressed the shortcomings of the OBD I requirements. OBD II required all 1996 and newer passenger cars, light-duty trucks, and medium-duty vehicles and engines to be equipped with OBD II systems (CARB, 1989).

In 2004, CARB adopted regulations requiring diagnostic systems for heavy-duty vehicles and engines (i.e., vehicles with a GVWR greater than 14,000 pounds). CARB first adopted the Engine Manufacturer Diagnostic (EMD) regulation, which required manufacturers of heavy-duty engines and vehicles to implement diagnostic systems on all 2007 and subsequent MY on-road heavy-duty engines. The EMD regulations were much less comprehensive than the OBD II regulations and were intended for heavy-duty manufacturers to achieve a minimum level of diagnostic capability (CARB, 2004). In 2005, CARB adopted heavy-duty OBD (HD OBD) requirements for 2010 and subsequent MY heavy-duty engines and vehicles, which phased in with full implementation required for the 2013 MY (CARB, 2005a).

The OBD system is required to monitor components that can cause emission increases and detect a fault when emissions exceed the emission standards by a certain amount. Emission "thresholds" for these faults are typically either a multiple of the exhaust emission standard (e.g., 2.0 times the applicable standard) or an additive value above the standards (e.g., 0.2 g/bhp-hr above the applicable standards).

OBD systems have been instrumental in reducing emissions for on-road light-, medium-, and heavy-duty vehicles and engines, and the opportunity now exists to expand this benefit to off-road equipment and engines. Concurrent with consideration of Tier 5 emission standards, CARB staff would consider proposing initial off-road OBD requirements, including standardized engine control unit communications and interfaces, threshold monitoring, and recording of emissions history information from on-board NOx sensors (as is done for on-road vehicles via the REAL requirements).

Efficiency Improvement

Off-road diesel equipment is becoming an increasingly important contributor to statewide GHG emissions. By 2045, off-road diesel equipment in California will consume approximately 2.1 billion gallons of diesel fuel, which is equivalent to the annual diesel consumption of approximately 490,000 heavy-duty trucks in California. While the recent state and federal regulatory actions such as national Phase 2 greenhouse gas emissions standards for medium and heavy-duty trucks as well as California's ACT regulation will significantly improve the efficiency of the on-road heavy-duty sector, off-road equipment sectors have generally lagged in hybridization and electrification. In part, this is due to technology and infrastructure hurdles, and in part due to the difficulty of creating targets for fuel efficiency in off-road sectors that lack a universal, objective metric such as miles per gallon. Despite these difficulties, there are already numerous commercial hybrid vehicles available in the construction, mining, and industrial equipment sectors. It is notable that these equipment types were produced with no emissions requirements and demonstrate that hybridization technology is viable for many types of off-road equipment and desirable for end users in many applications. Currently, commercial and demonstration off-road hybrid projects show a range of 14 to 60 percent fuel savings over traditional diesel engines, with an average of 25 percent.

Separately, marine and locomotive sectors do not yet have many commercial applications available but have made significant progress in demonstration projects. Marine engines used in auxiliary engines for ocean going vessels, as well as main engines for some commercial harbor craft have shown potential for hydrogen as a fuel source. Locomotives have shown significant progress in demonstration projects including battery-electric assist, with up to 70 percent fuel savings. In terms of electrification, San Bernardino County Transit Authority is planning to begin revenue service with a single fuel cell multiple unit (MU) in early 2020 and other passenger rail operators have been progressive in adopting the cleanest locomotives, and initiated various efforts to transition to ZE locomotives. Additionally, BNSF will demo a battery-electric locomotive (BEL) from Stockton to Barstow in early 2021. Potentially, large percentage of passenger locomotives can be converted to fuel cell or electrified, but the overall fuel consumption of passenger locomotives is much smaller than freight locomotives. BEL increases efficiency by 10 to 15 percent, but stores little energy, so fuel use converted from diesel to electric will be small. Switchers that account for about 10 percent of freight diesel use could also be converted to electric, but it is unlikely any significant portion of freight line-haul locomotives will be converted to electric (connected to the grid). The current cleanest locomotive (Tier 4) does not have efficiency benefits compared to older locomotives. Tier 5 locomotives, if the standards are adopted, are expected to have 10 to 25 percent efficiency improvement. BELs are expected to provide 10 to 15 percent efficiency improvement to the diesel locomotives, but Tier 5 and BEL improvements will not be accumulative. If freight railroads begin using Tier 5 or hybridized locomotives in 2030, 25 percent efficiency improvement could be achieved.

In this 2020 MSS, staff assumed a scenario where there will be a significant efficiency improvement in off-road diesel engines sold in California beginning in 2028, with some early-action incentive-based penetration in 2025. The overall goal would be a 12 percent reduction in GHG emissions by 2030, and a 30 percent reduction by 2040. Penetration rates will vary by category depending on their suitability for hybridization or electrification, as well as the rate of equipment turnover – including natural and accelerated turnover by incentives and/or regulatory actions. Locomotive and marine engine standards could be incorporated with locomotive Tier 5 standards and marine Tier 4 standards, requiring coordination with U.S. EPA and the IMO.

Figure 50 demonstrates the potential fuel saving resulting from such a scenario. As shown, the scenario will reduce GHG emissions by 25 and 26 percent from the baseline in 2040 and 2050, respectively. To model the scenario, staff used the modeling assumptions (e.g., GHG emission benefits and target population of the off-road diesel engine sectors) described in Table 10.

The wide-scale electrification and hybridization transformation will result in a fuel saving of about 0.51 billion gallons of diesel per year in 2045, which translates to a WTW GHG reductions of approximately 5.25 MMT per year (Figure 51). Also by 2050, the WTW GHG emissions from off-road will be 20 percent below the baseline.

Table 10 - Modeling Parameters for Off-Road Diesel Engine Efficiency Improvement

Sector	Percent fuel savings	Target population of the sector	Penetration Rate Modeled
OGV	▪ 25% on average ▪ Renewable H2 production shows a 99% WTW NOx reduction & 51% reduction with non-renewable method	▪ Hybrid auxiliary engines and boilers → 32% of total fuel consumption ▪ Including car carrier and Roro types also → 35%	▪ Market share increases at 2% annually from 2028
Locomotive	▪ Approx. 25% efficiency improvement	▪ Class I Line-haul, Switcher, Passenger locomotives → 98% of total fuel consumption	▪ Market share increases at 2% annually from 2028
Construction & Mining & Industrial	▪ Approx. 25% on average (up to 70% depending on application type)	▪ 66% of the sector fuel consumption defined by the horsepower range 75 ~ 600hp	▪ Market share increases at 10% annually from 2024 to 2033
Agriculture	▪ Approx. 25% efficiency improvement	▪ 41% of the sector fuel consumption defined by the horsepower range 75 ~ 600hp	▪ Market share increases at 7% annually from 2028
Portable Equipment (PE)	▪ Requires additional demonstrations, but hydrogen has significant potential	-	-
Commercial Harbor Craft (CHC)	▪ Approx. 25% on average	▪ Tug, Ferry, and Excursion populations → 53% of the total sector fuel consumption	▪ Market share increases at 10% annually from 2028 to 2037
Transportation Refrigerator Unit (TRU)	▪ Zero-emission (MSS Scenario)	▪ 100% of the total sector fuel consumption	▪ Market share of E-TRU increases from 10% in 2024 to 100% in 2034
Cargo Handling Equipment (CHE)	▪ Zero-emission (MSS Scenario)	▪ 100% of the total sector fuel consumption	▪ Market share of E-CHE increases from 8% in 2026 to 100% by 2037

Figure 50 – Technology Shifts in Diesel Fuel Use by Sector

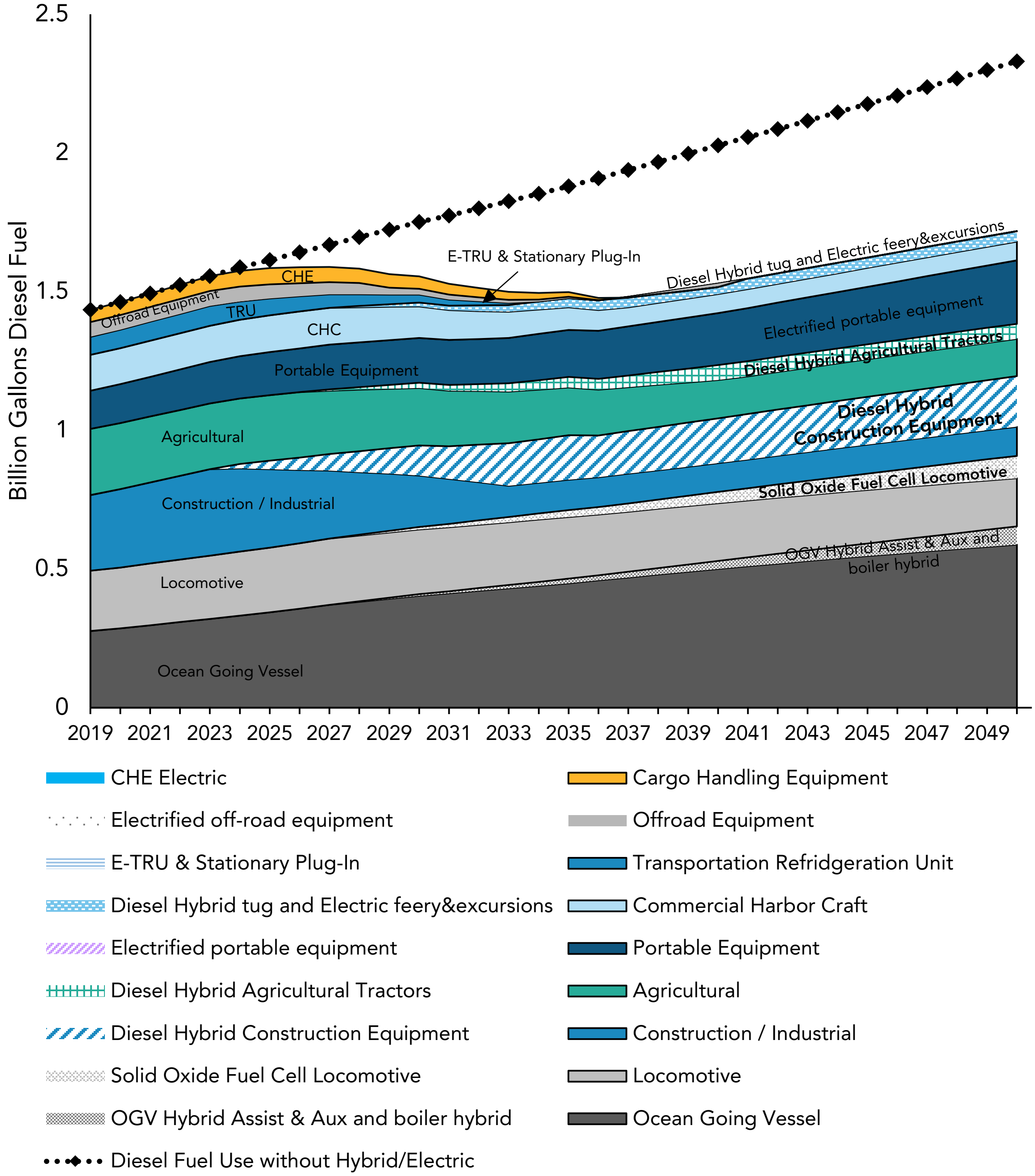
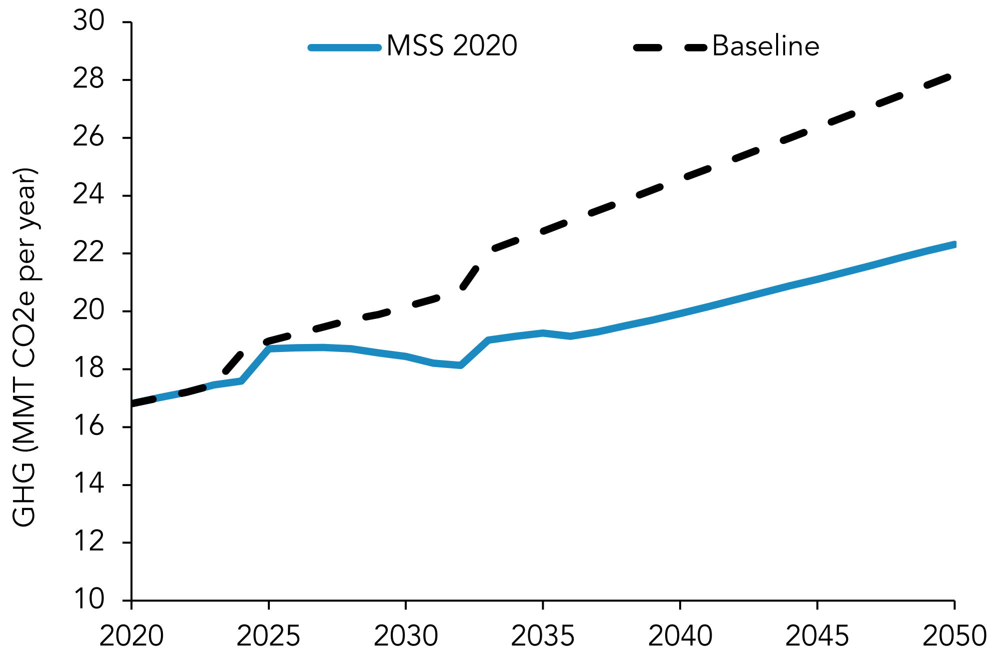


Figure 51 - Statewide Well-to-Wheel GHG Emissions from Off-road Sector



Summary of Mobile Source Scenarios

A summary of statewide fuel use and NOx emissions reductions from the 2020 Mobile Source Strategy scenarios is provided in Table 11. As shown, the scenarios in the 2020 MSS would achieve an overall statewide NOx emissions reduction of 523 and 603 tpd in 2031 and 2037 respectively, which are equivalent to 47 and 56 percent reduction from projected baseline NOx emissions in those years.[149] Also, as a result of these strategies, mobile source NOx emissions in 2031 and 2037 will be 74 and 83 percent below 2017 baseline. The scenarios will also reduce mobile source fuel consumption by 9.5 billion gallons of gasoline and 3.0 billion gallons of diesel equivalent in 2045. This equates to a WTW GHG emissions reduction of approximately 93 MMT CO2e in 2045. In terms of on-road transportation (i.e., on-road light- and heavy-duty vehicles), by 2045, the scenarios would achieve a WTW GHG emissions reductions of approximately 80 percent from the 2020 baseline.

Table 11 - Statewide NOx Emissions Reductions and Fuel Use from the 2020 MSS Scenarios

Category		Scenario Assumptions	Statewide NOx Reduction (tpd)		Statewide Fuel Use Reduction
			2031	2037	2045
On Road	Light-Duty Vehicles	• 70% ZEV + PHEV sales in 2030 • 100% ZEV + PHEV sales in 2035 • 7.9 M ZEV by 2030 • 27.9 M ZEV+PHEV by 2045	4.2	13.8	8.8 B GGE 0.1 B DGE
	VMT	• ~25% reduction in statewide per capita GHG by 2035 relative to 2005			
	Medium-Duty Vehicles	• 100% ZEV sales starting 2035	0.24	0.88	0.15 B DGE 0.26 B GGE
	Heavy-Duty Vehicles	• Reflect HD Omnibus, ACT, and HD I/M starting in 2024, and federal 0.02 g/bhp-hr starting in 2027 • 100% of model year 2035 and newer vehicles registered in California will be ZEV • Accelerated turnover of older trucks	121	181	1.9 B DGE 0.2 B GGE

[149] According to 2016 South Coast AQMP, the preliminary projections, based upon ozone "isopleths" developed for the 2031 emission scenarios indicate that 2037 Basin NOx carrying capacity to meet the 70 ppb standard could be as low as 75 tpd. This is additional 62 percent NOx reduction beyond the projected 2037 baseline and 25 tpd of additional NOx emission reductions between 2031 and 2037.

Category		Scenario Assumptions	Statewide NOx Reduction (tpd) 2031	Statewide NOx Reduction (tpd) 2037	Statewide Fuel Use Reduction 2045
Off Road	Off-Road Efficiency Improvement[150]	• Zero-emissions and hybridization where feasible with the goal of 12 percent reduction in GHG by 2030, and 30 percent by 2040	N/A	N/A	0.54 B DGE
	Off-Road Tier V Standard	• Tier 5 being introduced starting in 2028-2030 • 50 – 90% NOx reduction from current Tier 4f standard	4.7	14.1	N/A
	Rail	• 100% of replaced locomotive will be Tier 4 • Remanufacturing limit • Tier 5 being introduced in 2028	66	60	N/A
	Ocean Going Vessels *(out to 100 nm)*	• 100% of Tier 0/1/2 visits are phased out by 2031 • Tier 3 visits begin in 2025 (begin replacing all Tier 0-2) • Tier 4 visits begin in 2028 (no additional Tier 3 visits)	263	258	N/A
	Construction	• Full turnover of Tier 0/1/2 to Tier 4f by 2033	7.5	5.4	N/A
	SORE	• 100% of new sales will be zero-emission equipment (ZEE) starting 2025	10.5	14.7	0.23 B GGE
	Aircraft	• 25 percent derate during take-off • 40 percent reduction in Taxi time • Single engine taxiing • 40 percent reduction in APU usage	12.5	13.3	N/A
	Transport Refrigeration Units	• Accelerated penetration of electric TRU (from 10% in 2024 to 100% in 2034)	12.2	16.7	0.11 B DGE
	Commercial Harbor Craft	• All vessels (including commercial fishing) being Tier 4/5 by 2031 • Introduction of Plug-in hybrid for excursions and diesel-electric for tugs by 2030	11.6	10.8	0.027 B DGE

[150] Excluding categories such as CHE and TRU that are going to zero-emission in other scenarios. This is done to avoid double counting

Category		Scenario Assumptions	Statewide NOx Reduction (tpd) 2031	Statewide NOx Reduction (tpd) 2037	Statewide Fuel Use Reduction 2045
Off Road	Cargo Handling Equipment	• Begin transition to full electric operation beginning in 2026 (accelerated turnover)	1.1	1.6	0.12 B DGE
	Agriculture	• An incentive based concept consistent with the 2018 SJV SIP	N/A	N/A	NYQ
	Airport Ground Support Equipment	• Full electrification transition from 2024-2034	1.1	1.2	0.035 B DGE
	Forklifts	• Transition to zero-emission technology starting in 2025 with fully electric fleet by 2034	6.9	8.6	0.016 B DGE
	Recreational Watercraft	• New THC + NOx standards of 40 and 70 percent below current levels • Electrification of small outboard and PWC engines	0.6	2.5	0.011 B GGE
Total Statewide Emissions/Fuel Use Reductions			**523**	**602**	**9.5 B GGE** **3.0 B DGE**

DGE: Diesel Gallons Equivalent
GGE: Gasoline Gallons Equivalent

The 2020 MSS scenarios illustrate that even with extremely aggressive electrification, accelerated turnover, coupled with aggressive VMT reductions and fuel decarbonization,[151] the mobile source sector alone cannot become carbon neutral by 2045. This emphasized the importance of CDR strategies such as mechanical and land-based sequestration. This economy-wide approach that includes consideration of CDR is introduced in a recent report by Energy and Environmental Economics (E3). [152] The E3 report provides insights into the types of economy-wide transformation that will be necessary to achieve carbon neutrality by mid-century.

CARB staff will continue to develop the concepts described in Table 11 in order to translate them into measures that will be included in the State SIP Strategy being developed for the 70 ppb 8-hour ozone standard, along with the next Climate Change Scoping Plan, and other CARB planning documents to be released in the coming years.

[151] Fuel decarbonization refers to a group of strategies, including SB 100 electric grid requirements, liquid fuel carbon reductions through the Low Carbon Fuel Standard (LCFS), and other actions.
[152] Achieving Carbon Neutrality in California: PATHWAYS Scenarios Developed for the California Air Resources Board https://ww2.arb.ca.gov/sites/default/files/2020-08/e3_cn_draft_report_aug2020.pdf

Appendix A - Upstream Energy Emission Factors for Scenario Modeling

Background

As part of the Mobile Source Strategy (MSS) both the emissions associated with the operation of the vehicles (i.e. tank-to-wheel emissions, TTW) and upstream energy production (i.e. well-to-tank emissions, WTT) are assessed. Well-to-tank (WTT) emissions include direct emissions resulting from the processes required for producing, refining and delivering energy. In order to estimate WTT emissions, staff developed WTT emission factors for each of the five transportation fuel types in the MSS, including gasoline, diesel, electricity, hydrogen, and compressed natural gas (CNG).

This technical appendix provides an overview of the methods and data used to estimate upstream emission factors. You can find a more detailed description of these methods on the Vision Scenario Planning webpage.[153]

Scope and Boundary

For the purposes of the 2020 Mobile Source strategy, the scope of the upstream emissions analysis is consistent with current emissions inventory methodologies.[154] For greenhouse gas (GHG) emissions, system scope refers to upstream life-cycle phases of fuel production. AB 32 defines statewide GHG emissions as the total annual emissions of greenhouse gases occurring in California, including all emissions of greenhouse gases from the generation of electricity delivered to and consumed in California.[155] For criteria emissions, only in-state emissions are included. Table 12 lists the system scope and the geographic boundary of the WTT emissions covered in the analysis. The system scope for most of the fuel blendstocks include feedstock and fuel production. For electricity, system loss from transmission and electric vehicle charging is also considered.

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[153] CARB, Vision Scenario Planning webpage. Available: https://ww2.arb.ca.gov/resources/documents/vision-scenario-planning
[154] CARB GHG emissions inventory: https://ww2.arb.ca.gov/ghg-inventory-data
[155] Nunez, Chapter 488, Statutes of 2006. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32

Table 12 - System Scope and Geographic Boundary by Fuel Type

Fuel Type	Blendstocks	System Scope	Geographic Boundary
GAS	California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB)	Crude extraction and transportation(tanker truck and ocean-going-vessel), refinery, fuel transportation (heavy-duty trucks), and evaporative losses of fuel marketing	GHG/Criteria Emission: in-state only
	Conventional ETOH	Feedstock and fuel production	GHG/Criteria Emission: in-state only
	Cellulosic ETOH	Feedstock and fuel production	GHG/Criteria Emission: in-state only
DSL	CARBOB-Diesel	Crude extraction and transportation, refinery, fuel transportation, and market loss	GHG/Criteria Emission: in-state only
	Biodiesel (BD)	Feedstock and fuel production	GHG/Criteria Emission: in-state only
	Renewable Diesel (RD)	Feedstock and fuel production	GHG/Criteria Emission: in-state only
ELE	CA-Grid Electricity	Feedstock production (natural gas recovery), power generation, and system loss for transmission (7%) and charging (15%)	GHG: emissions for in-state generation and import Criteria emission: in-state emission only
HYD	Hydrogen via steam methane reforming process (SMR)	Feedstock and fuel production	GHG/Criteria Emission: in-state only
	Renewable Hydrogen (via Electrolysis)	Feedstock and fuel production	GHG/Criteria Emission: in-state only
CNG	Renewable natural gas (RNG) from landfill gas (LFG)	Feedstock and fuel production	GHG/Criteria Emission: in-state only
	RNG from dairy biogas	Feedstock and fuel production	GHG/Criteria Emission: in-state only

Methodology

Upstream WTT emission factors for each fuel type (EF_f^{WTT}) are determined by the mix of blendstocks, the blendstock WTT emission factor, and the in-state production ratio, as follows:

$$EF_f^{WTT} = \sum_b (M_{fb} \times EF_{fb} \times R_{fb}) \text{(Equation 1)}$$

where:

EF_f^{WTT} represents the WTT emission factor for each fuel type (*f*)

M_{fb} is the mix (%) for the blendstock (*b*) in the *f* fuel type

EF_{fb} is the WTT emission factor for the blendstock or fuel pathway (b) in the *f* fuel type

R_{fb} is the in-state production ratio[156] of emissions for the blendstock (b) in the *f* fuel type

Blendstock Mix

Each fuel type is comprised of different blendstocks, and it is these blendstocks that determine the emissions intensity of a given fuel. For example, the blendstocks for diesel fuel consumed in California (e.g. B5, B20…etc.) include fossil ultra-low sulfur diesel (ULSD), biodiesel (BD), and renewable diesel (RD). Blendstock mix (M_{fb}) is critical to formulate the WTT emission factor of a fuel type and may vary given changes in supply and demand.

The following assumptions are used for determining blendstock mix.

Liquid Fuels (DSL and GAS)

- LCFS compliance scenario (low demand and low ZEV with 20% CI reduction)[157] is used for biofuel supply including ethanol, biodiesel, and renewable diesel through 2030. After 2030, BD and RD volumes are assumed to be constant at 500 mm gallon and 1.1 billion gallons annually respectively.
- The supply of cellulosic ethanol (ETOH) after 2030 is held constant at 2030 levels (i.e. 125 mm gallon/yr). The ethanol fraction in California reformulated gasoline (CaRFG) (i.e. E10) is consistent with the LCFS compliance scenario.

[156] Please refer to Table 2 for the emissions scope by fuel type. In most cases only the in-state contribution of a fuel's upstream emissions are counted, with the exception of electricity.
[157] CARB, 2018. 2018 Amendments to the LCFS and ADF Regulations, Illustrative Compliance Scenario Calculator. https://www.arb.ca.gov/fuels/lcfs/2018-0815_illustrative_compliance_scenario_calc.xlsx?_ga=2.155021808.917945968.1597354480-1389483658.1577128071

Electricity (ELE)

- Only grid electricity is considered, while behind-the-meter renewable power for EV chargers is excluded.
- Generation mix (including contracted imports) and unspecified import information is obtained from the 2019 Renewable Energy Solutions (RESOLVE)[158] model outputs for the preliminary scenario run, "46MMT base 20191001 2045", which is constrained by the SB100 target in 2045.[159]

Hydrogen (HYD)

- The renewable hydrogen supply in the BAU scenario is assumed to be fixed at 35% after 2025 based on SB1505.[160]
- The hydrogen supply in the scenario is assumed to be 60% by 2030 and 100% by 2045 according to the proposed SB662.[161]
- It is also assumed 100% electrolytic hydrogen in California will utilize curtailed renewable electricity as utilities procure more zero GHG generation to meet the Renewable Portfolio Standard (RPS).

Compressed Natural Gas (CNG)

- CNG is assumed to be 100% supplied by RNG consistent with the LCFS compliance scenario. The fraction of RNG from dairy biogas is fixed at 24% after 2030, with the remainder from landfill gas (LFG).

Figure 52 below provides the resulting blendstock volumes for the five fuel types in the MSS scenario.

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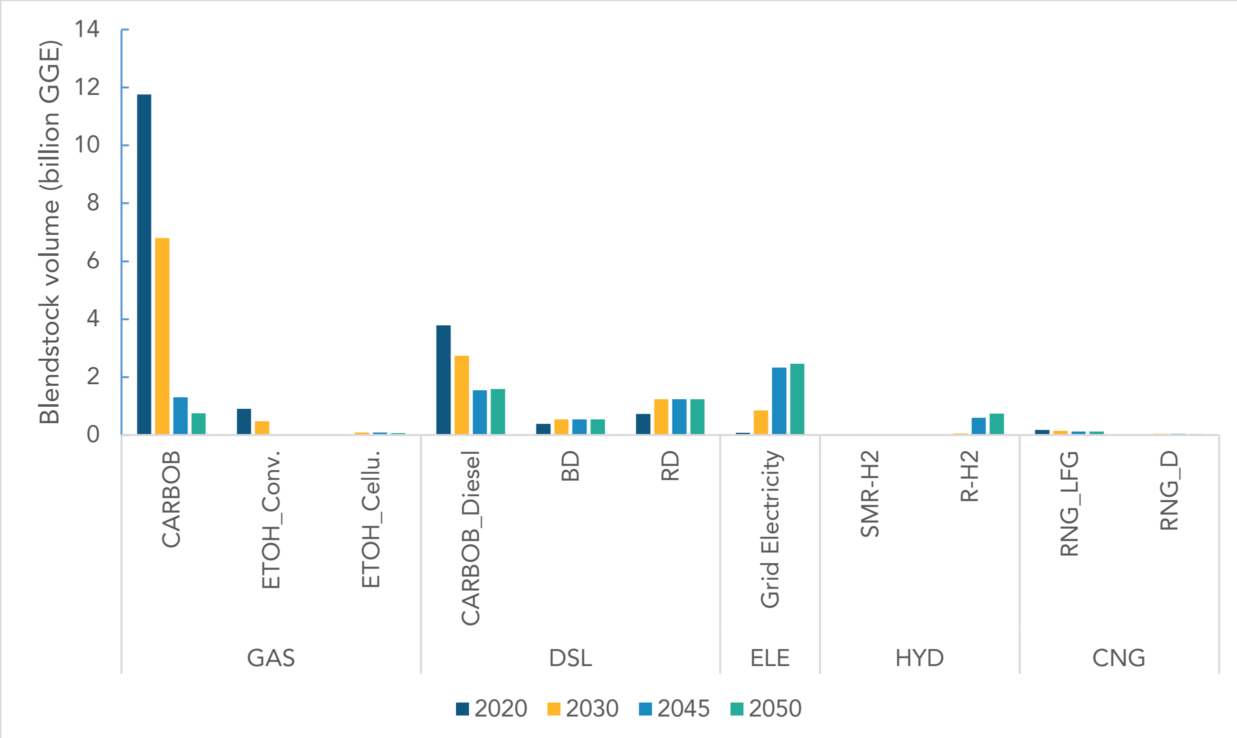
[158] California Public Utilities Commission (CPUC), 2019. RESOLVE Model and Preliminary Results used for 2019 IRP Portfolio Development. https://www.cpuc.ca.gov/General.aspx?id=6442462824

[159] SB 100 requires that 100 percent of retails sales of electricity come from Renewables Portfolio Standard-eligible and zero-carbon resources by 2045. SB 100 does not define zero-carbon resources. An interagency effort is underway to evaluate potential paths to achieving the 2045 goal, and this process evaluates electricity generation technologies that could be eligible zero-carbon resources and will model potential resource mix scenarios for 2045. Refer to https://www.energy.ca.gov/sb100 for more information about this process.

[160] Lowenthal, Chapter 877, Statutes of 2006. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=200520060SB1505

[161] Archuleta, SB-662 Energy: transportation sector: hydrogen.(2019-2020). http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB662

Figure 52 - Blendstock Volume by Fuel Type



In-State Production Ratio

As discussed earlier, AB 32 defines statewide GHG emissions as the total annual GHG emissions in the state, including all GHG emissions from the generation of electricity delivered to and consumed in California.[162] Therefore, a necessary step for estimating WTT emissions is identifying the in-state production ratio for each blendstock.

The in-state production ratio for any given blendstock is calculated by dividing the in-state supply by the fuel demand and blend-mix. For example, while almost finished fuel products consumed in California are blended in-state, the majority of blendstocks or feedstock are produced and imported from other places.

CaRFG is blended by ethanol and CARBOB, with 100 percent of CARBOB refined in-state from mostly imported crude oil, and nearly 87 percent of ethanol coming from outside California.[163]

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[162] Nunez, Chapter 488, Statutes of 2006. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32

[163] CARB, LCFS Dashboard: Share of Liquid Biofuels Produced In-State by Volume 2019. http://ww3.arb.ca.gov/fuels/lcfs/dashboard/figure10_053120.xlsx; CARB, LCFS Dashboard: Major Sources of Crude Supplied to California 2019. http://ww3.arb.ca.gov/fuels/lcfs/dashboard/crude.xlsx

For crude oil, ethanol, and biodiesel the future in-state supply capacity is assumed to be set to 2019 levels, with 2019 capacity data from LCFS reporting data[164,165] and US Energy Information Administration (US EIA).[166,167] For RD, 100 percent in-state supply is assumed.[168] Electricity, when used as a transportation fuel, is assumed to be produced in California, while half of hydrogen demand is assumed to be produced in California starting in 2025.[169] CNG is assumed to be 100 percent RNG, with a majority of RNG produced from landfill gas (LFG) imported through the natural gas pipeline. The remainder, which includes dairy biomethane, is assumed to be produced predominantly (80 percent) in California. Table 13 summarizes the assumptions for blendstocks or fuel pathways applied to all scenarios including BAU.

[164] CARB, LCFS Dashboard: Share of Liquid Biofuels Produced In-State by Volume 2019. http://ww3.arb.ca.gov/fuels/lcfs/dashboard/figure10_053120.xlsx

[165]ibid. footnote 12.

[166] US EIA, 2019. U.S. Fuel Ethanol Plant Production Capacity. https://www.eia.gov/petroleum/ethanolcapacity/index.php

[167] US EIA, 2020. Monthly Biodiesel Production Report. https://www.eia.gov/biofuels/biodiesel/production/

[168] Three refineries in California recently announced their plans for RD production/expansion. https://adi-analytics.com/2020/02/10/regulations-to-drive-u-s-renewable-diesel-capacity-growth-through-2025/
https://www.mercurynews.com/2020/08/08/marathon-refinery-closure-could-signal-big-transition-for-area-refineries/#:~:text=Meanwhile%2C%20Marathon%20is%20exploring%20a,per%2Dday%20renewable%20diesel%20operation.
https://www.mercurynews.com/2020/08/08/marathon-refinery-closure-could-signal-big-transition-for-area-refineries/#:~:text=Meanwhile%2C%20Marathon%20is%20exploring%20a,per%2Dday%20renewable%20diesel%20operation.

[169] Air Liquide, 2019. Air Liquide committed to producing renewable hydrogen for the West Coast mobility market with new liquid hydrogen plant. https://www.airliquide.com/united-states-america/air-liquide-committed-producing-renewable-hydrogen-west-coast-mobility-market.

Table 13 - In-State Production Ratios by Fuel Type and Blendstock

Fuel Type	Blendstocks/ Pathways	Assumptions	Data source
GAS	CARBOB	Import fraction of crude oil fixed at 2019 level (73%) and 100% CARBOB produced in-state	LCFS
	Conventional ETOH	Capped at 2019 level of CA supply from EIA (230 mm gallon/yr)	EIA
	Cellulosic ETOH	Capped at maximum in-state supply from LCFS data (1.4 mm gallon/yr)	LCFS
DSL	CARBOB-Diesel	Import fraction of crude oil fixed at 2019 level (73%) and 100% CARBOB produced in-state	LCFS
	Biodiesel (BD)	Capped at 2019 level of CA supply from EIA (85 mm gallon/yr)	EIA
	Renewable Diesel (RD)	100% RD produced in-state	Industrial News
ELE	CA-Grid Electricity	100% (AB 32 boundary)	AB 32[170]
HYD	Fossil SMR Hydrogen	50% produced in CA. The feedstock, fossil NG, is assumed 10% in-state produced.	Assumption
	Renewable Hydrogen (via Electrolysis)	50% produced via renewable power in CA	Assumption
CNG	RNG (LFG)	10% as in-state produced NG in pipeline	Assumption
	RNG (Dariry biogas)	80% produced in CA	Assumption

WTT EF for each Blendstock

WTT emission factors for each blendstock (EF_{fb}) are synthesized from a variety of sources and studies[171,172] as shown in Table 14 below. In general, the WTT GHG emission factors for each blendstock comes from the LCFS compliance scenario tool, with the exception of CARBOB, electricity, and renewable hydrogen.

Upstream emissions for electricity are determined by generation mix and imports to the grid supplying California from the RESOLVE model. This annual generation mix data is then imported to CAGREET 3.0 to calculate the annual average emission factors, including emissions at power plants, natural gas extraction, processing, and

[170] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32
[171] Sun et al (2019) Criteria Air Pollutant and Greenhouse Gases Emissions from U.S. Refineries Allocated to Refinery Products, Environ. Sci. Technol. 2019, 53, 11, 6556–6569, DOI: 10.1021/acs.est.8b05870
[172] D. L. Jones (2010) Potential Air Emission Impacts of Cellulosic Ethanol Production at Seven Demonstration Refineries in the United States, Journal of the Air & Waste Management Association, 60:9, 1118-1143, DOI: 10.3155/1047-3289.60.9.1118

delivery. Criteria emission factors for electricity generation are developed based on California Emission Inventory Development and Reporting System (CEIDARS), and applied to the total mix of generators located in California.

Hydrogen is assumed to be supplied from two sources, fossil hydrogen through SMR with fossil natural gas and electrolytic hydrogen using renewable power. The WTT GHG emission factor for SMR hydrogen includes emissions from hydrogen production processes and feedstock production (recovery of fossil natural gas). Criteria emission factors for SMR were developed based on CARB's CEIDARS database. Electrolytic hydrogen from renewable power is assumed to have an emission rate of zero.

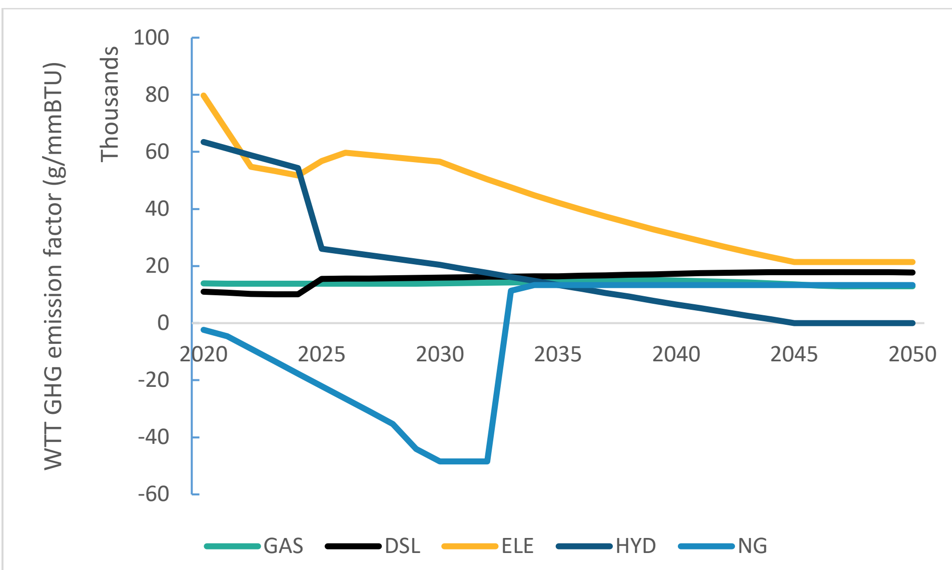
Table 14 - Data Sources for Determining WTT EFs of Blendstocks

Fuel Type	Blendstocks/ Pathways	GHG EFs	Criteria EFs
GAS	CARBOB	*Crude Oil:* Oil Production Greenhouse gas Emissions Estimator (OPGEE) model data[173] *Refinery:* Argonne National Laboratory (ANL) update[174] *T/D:* Emission FACtors model (EMFAC) 2017[175]	*Crude Oil:* CAGREET3.0[176] Refinery: ANL update *T/D and marketing:* California Emission Projections and Analysis Model (CEPAM) database[177]
	Conventional ETOH	Compliance scenarios from LCFS rulemaking documents[178]	*Feedstock*: CAGREET3.0 *Fuel production:* CEIDARS
	Cellulosic ETOH	Compliance scenarios from LCFS rulemaking documents[179]	*Feedstock*: CAGREET3.0 Fuel production: Literature[180]
DSL	CARBOB-Diesel	*Crude Oil:* OPGEE model *Refinery*: ANL update *T/D:* EMFAC	*Crude Oil:* CAGREET3.0 Refinery: ANL update T/D and marketing: CEPAM

[173] CARB, 2019. Calculation of 2019 Crude Average Carbon Intensity Value. https://ww2.arb.ca.gov/sites/default/files/classic//fuels/lcfs/crude-oil/2019_crude_average_ci_value_final.pdf
[174] ibid. footnote 21
[175] CARB, 2017. EMission FACtor (EMFAC). https://arb.ca.gov/emfac/
[176] CARB, 2019. CA-GREET3.0 Model. Available: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet30-corrected.xlsm?_ga=2.247817287.1944131420.1600710547-1389483658.1577128071
[177] CARB, 2018. CEPAM: 2016 SIP - Standard Emission Tool. https://arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php
[178] CARB, 2019. Low Carbon Fuel Standard Amendments 2019. https://ww2.arb.ca.gov/rulemaking/2019/lcfs2019
[179] The CI values for ethanol in the Illustrative Compliance Scenario assumed that eventually all ethanol consumed in California is produced with CCS. For a conservative estimate, we use the CI value without CCS credits as we assume all CCS projects located outside of California.
[180] ibid. footnote 22

Fuel Type	Blendstocks/ Pathways	GHG EFs	Criteria EFs
	Biodiesel (BD)	Compliance scenario from LCFS rulemaking documents	*Feedstock:* CAGREET3.0 *Fuel production:* CAGREET3.0
	Renewable Diesel (RD)	Compliance scenario from LCFS rulemaking documents	*Feedstock*: CAGREET3.0 *Fuel production:* CAGREET3.0
ELE	CA-Grid Electricity	RESOLVE's outputs with CAGREET3.0 EFs	RESOLVE's outputs with EFs developed based on CEIDARS
HYD	Fossil SMR Hydrogen	*Feedstock*: CAGREET3.0 *Fuel production*: CAGREET3.0	*Feedstock*: CAGREET3.0 *Fuel production*: CEIDARS
CNG	RNG (LFG)	LCFS compliance scenario tool	USEPA biogas study[181] (assuming 70% recovery)
	RNG (Dariry biogas)	LCFS compliance scenario tool	USEPA biogas study (assuming 85% recovery)

Figure 53 - WTT GHG EFs by Fuel Type



[181]Williams, R., C. Ely, T. Martynowicz, AND Mike Kosusko. Evaluating the Air Quality, Climate and Economic Impacts of Biogas Management Technologies. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/099, 2016. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100QCXZ.PDF?Dockey=P100QCXZ.PDF