Appendix D:
Long-Term Heavy-Duty Investment Strategy

Including Fiscal Year 2021-22 Three-Year Recommendations
for Low Carbon Transportation Investments

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Executive Summary

The California Air Resources Board's (CARB) Long-Term Heavy-Duty Investment Strategy serves as a roadmap for transforming the heavy-duty transportation sector and achieving the State's zero-emission vehicles goals. It outlines priorities for investing State Low Carbon Transportation and Air Quality Improvement Program (AQIP) funds into heavy-duty vehicle and off-road equipment projects. Each year, CARB updates and refines its priorities for the targeted technologies and project categories that merit funding investments to help the State reach its climate and air quality goals. The levels of funding identified represent a critical down payment toward meeting the funding need for advanced technology heavy-duty vehicles and off-road equipment, but do not meet the entire amount needed to achieve the State's goals (see Table 1 below).

Continued progress will depend on a commitment to the ongoing transformation of the transportation sector to the use of zero-emission technologies wherever feasible, and the most advanced, cleanest combustion technologies with the lowest-carbon fuels everywhere else.

Reducing air pollution and greenhouse gas (GHG) emissions from the transportation sector continue to be longstanding goals for protecting public health and the environment, and California is making significant headway in this effort. Continued progress will depend on a commitment to the ongoing transformation of the transportation sector to support Governor Newsom's Executive Order N-79-20, establishing low-carbon commercial vehicle adoption targets.

Organization of the Strategy

Within this document, there is a discussion on the overall CARB incentive funding portfolio and the critical role that Low Carbon Transportation and AQIP play in maintaining and increasing adoption of zero-emission technology. This document also details a strategy for investing these funds, which includes continued support for previous Low Carbon Transportation and AQIP investments; focusing those investment across zero-emission capable technologies; and utilizing the beachhead strategy to map out a path that focuses on the technology applications that will lead to the most rapid transformation.

In addition to identifying priority focus areas and recommended levels of incentive funding, the Strategy identifies a number of ways to measure progress. Traditional metrics, such as investments in disadvantaged communities and reduction in criteria and toxic pollutants and GHG emissions are already being utilized. More targeted metrics that address technology advancement, increases in suppliers and supply chain diversity, potential to impact key market segments, and reductions in system costs will be needed to help show that investments are resulting in measurable progress.

One of the primary organizing concepts for the Heavy-Duty Investment Strategy is targeting Low Carbon Transportation and AQIP investments around strategic "beachheads" – particular applications of a technology that have the strong potential to transfer and spread to broader applications. From these initial first-success applications, next-generation vehicle applications can further expand through the extension of these technologies to adjacent markets through the leveraging and adoption of similar powertrains; growth of supply chain volumes for common components; expansion of fueling infrastructure; and confidence in performance and business cases.

CARB monitors the status of key technologies by means of an annual high-level technology snapshot review to assess the generalized status and progress of key technologies. The goal of these analyses is to provide directional guidance on where important platforms are in terms of technology readiness for the market. These high-level assessments, or technology snapshots, were originally built off of the technology assessments conducted by CARB staff in previous years, and are broadly guided by the general framework of Technology Readiness Levels (TRLs). These snapshots cover the current status of battery electric, fuel cell electric, hybrid, and combustion technologies. CARB recognizes that technology status represents only part of the commercialization story, and that a number of other metrics need to be assessed to also evaluate market readiness.

Market readiness, or market transformation, comprises the second key step towards the overall transformation of the heavy-duty sector. While the technology status snapshots provide an assessment of the level of advancement for emerging technologies, this can make for an incomplete picture. There are additional market and economic factors that can hold back what would otherwise be a technologically-advanced platform, and keep it from progressing into the marketplace.

A number of other implementation variables can also affect how readily market transformation takes place, any one of which can have an impact on progress towards successful commercialization. These issues are in addition to those associated with assessing technology status progress and success in continuing to grow and expand upon the beachhead pathways, and include issues such as infrastructure, workforce training, the needs of small fleets, total cost of ownership (TCO), and supply chain management.

Finally, in addition to identifying potential barriers and other issues impacting the overall transformation of the heavy-duty sector, this Strategy identifies priorities for investments for the next three years. Sustained progress in implementing these priorities and recommendations will help California continue its role as a national clean vehicle technology leader by achieving a transformation of the heavy-duty and off-road sectors.

Table 1: Recommendations for Low Carbon Transportation Investment Priorities

	FY 2022-23	FY 2023-24	FY 2024-25
Demos	$50-$90 Million Focus: ZE Ag-Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Rail, ZE/Hybrid Marine	$50-$90 Million Focus: ZE Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Regional Rail, ZE Marine	$50-$90 Million Focus: ZE Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Regional Rail, ZE Marine
Pilots	$200-$325 Million Focus: ZE Long Haul Trucks, Strategic Range Extenders, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ZE Facilities/ Communities/ Corridors	$200-$325 Million Focus: Strategic Range Extenders, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE Switcher Rail, ZE/Hybrid Marine, ZE Facilities/ Communities/ Corridors	$200-$325 Million Focus: Strategic Range Extenders, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE Switcher Rail, ZE/Hybrid Marine, ZE Facilities/ Communities/ Corridors
Commercial	$490-$680 Million Focus: ZE Drayage and Regional Heavy-Duty Delivery, ZE Delivery, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs, ZE Small Fleets, ZE School Bus	$605-$995 Million Focus: ZE Drayage, ZE Long Haul Trucks, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs	$915-$1,385 Million Focus: ZE Drayage, ZE Long Haul Trucks, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs
Total Funding	$740-$1,095 Million*	$855-$1,410 Million*	$1,165-$1,800 Million*

*The vehicle and equipment types listed in the table above are a prioritized selection of the project types that CARB would invest in, given sufficient available funds. These focus areas are identified following the strategy laid out in this document and take into consideration a wide number of factors. This is not an exhaustive list of technologies or applications that Low Carbon Transportation would fund and indeed funding numbers are inclusive of a much broader set of vehicle and equipment investments CARB hopes to make.

Introduction and Background

California is making significant headway in its effort to reduce air pollution and GHG emissions from the transportation sector, and protecting public health and the environment. The Governor has made a commitment to the ongoing transformation of the transportation sector to the use of zero-emission technologies wherever feasible, per Executive Order N-79-20.

This transformation will require the use of advanced technologies and fuels, while at the same time supporting progress towards creating the jobs of the future and achieving and maintaining healthy and sustainable communities for all Californians. It will also require a combination of aggressive policies, targeted regulations, and strategic investments.

This Heavy-Duty Investment Strategy begins to identify the general parameters of how technologies move through the incentive programs in the Low Carbon Transportation portfolio before reaching a financially sustainable market.

The Heavy-Duty Investment Strategy serves as a roadmap showing how California Air Resources Board (CARB) plans to invest its Low Carbon Transportation and Air Quality Improvement Program (AQIP) funding on a combination of transformational technologies for heavy-duty vehicles and off-road equipment. Within this document, there is a discussion on the overall CARB incentive funding portfolio and the critical role that Low Carbon Transportation and AQIP play in maintaining and increasing adoption of zero-emission technology. This document also details a strategy for investing these funds, which includes continued support for previous Low Carbon Transportation and AQIP investments; focusing those investment across zero-emission capable technologies; and utilizing the beachhead strategy[1] to map out a path that focuses on the technology applications that will lead to the most rapid transformation.

The types of incentives deployed need to be carefully prioritized between 1) investing in technologies that are just coming to market and are capable of achieving immediate emissions reductions, and 2) providing support to emerging advanced technologies. To have the best chance of reducing the impacts of climate change and meeting air quality standards, California must lead the way by fostering the development of zero-emission technologies and supporting low-carbon fuel use now. CARB is working

[1] For additional information on the Beachhead Strategy and its applications, see https://calstart.org/beachhead-model-background

closely with other agencies to support a sector-wide low-carbon HD vehicle and off-road technology transition, such as through its efforts with the California Energy Commission (CEC) to support the deployment of necessary zero-emission infrastructure. CARB also continues its history of building a broad suite of regulatory actions (from the Advanced Clean Truck (ACT) Rule, to the Innovative Clean Transit regulation, to ships at berth) alongside a comprehensive incentive portfolio that supports technologies from the pre-commercial phase all of the way through turnover of the legacy fleet (see Figure 2).

The need for private sector investments and engagement through all phases of technology advancement is clear.

State incentives can help spark private sector investment and create partnerships necessary to support the transformation of the heavy-duty and on-road and off-road sectors.

State incentives can help spark private sector investment and create partnerships necessary to support the transformation of the heavy-duty and off-road sectors.

This year's Heavy-Duty Investment Strategy expands on CARB's principles of investment—supporting targeted advanced technologies across the commercialization path—while generally describing the framework of each of the CARB incentive programs. This document begins by identifying the general parameters of how technologies move through each of the programs—graduating and progressing from one program to the next, ultimately leading to a financially sustainable market where technologies are robust enough to no longer need public investment.

History of the Long-Term Heavy-Duty Investment Strategy

The first iteration of the Heavy-Duty Investment Strategy—which was developed as a companion document to the Fiscal Year (FY) 2017-18 Funding Plan and independent of any mandate or requirement—solely focused on prioritizing heavy-duty projects based on a series of criteria. It also provided a three-year funding projection of the level of investment needed to stay the course with Low Carbon Transportation and AQIP funding. The initial Strategy established the foundational concept of beachheads (see p. 23), a guiding principle that has since expanded into a larger discussion on advanced technology vehicles and policy strategy. Paired with the beachhead

Focusing investments on both funding commercially available vehicles and equipment and maintaining the innovation pipeline is critical to meet the State's ultimate vision of a zero-emission economy.

strategy, the technology status snapshots allowed CARB to infer progress of technology along the commercialization path.

The governor subsequently signed into law Senate Bill (SB) 1403 (Lara, Chapter 370, Statutes of 2018), which resulted in the following actions:

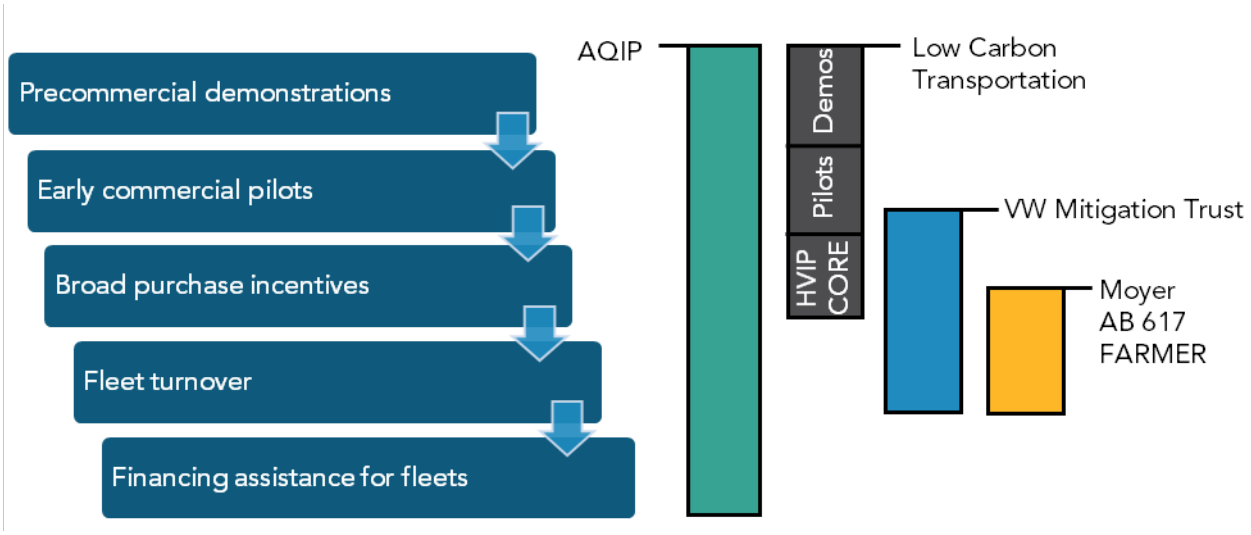
- Required CARB to develop the Heavy-Duty Investment Strategy and Three-Year Recommendations for Low Carbon Transportation Investments.
- Directed CARB to produce annually a three-year investment strategy for Low Carbon Transportation and AQIP investments beginning with FY 2019-20 intended to:
    - Describe the role of public investments in supporting the demonstration and deployment of advanced heavy-duty and off-road technologies;
    - Provide an assessment of the investment needed from Low Carbon Transportation and AQIP funds;
    - Describe CARB's portfolio of investment; and
    - Include a report on the State's school bus fleet in consultation with the CEC, providing information related to milestone achieved by the State's school bus incentive programs and the projected need for funding taking into consideration the State's school bus inventory, turnover, and useful life (Appendix E of the Funding Plan).

The CARB Portfolio of Funding for Heavy-Duty Investments

California continues to dedicate increasing levels of financial resources to reduce criteria and climate pollutant emissions from the transportation sector. The State allocates billions of dollars annually to a multitude of programs (such as those listed in the section Sources of Funding on page 75), with different but complementary goals. CARB's portfolio places an emphasis on technology advancement, the deployment of zero-emission heavy-duty vehicles, and turning over the legacy fleet. These efforts to incentivize new technologies complement CARB's regulatory efforts that ensure these technologies are deployed in strategic and impactful ways that support the State's climate and low-carbon transportation goals.

Figure 1 below shows how CARB's incentive and investment programs work together. There is a natural progression of support for technologies starting in the precommercial demonstration phase all the way through to financing assistance for small businesses who are unable to qualify for conventional financing for cleaner trucks. It should be expected that technologies will eventually "graduate" or progress to the next program in the funding succession or away from incentives completely as they become more established in the market. This is not to say that CARB does not continue to support or invest in these technologies, but rather that the technology has matured and achieved a high enough level of commercialization and acceptance in the market to warrant a graduation from the technology advancement incentives. After graduating from a particular program, the technology will often continue to see support from other programs within CARB's (and other partner agencies') broader portfolio where emission reductions can be directly counted for meeting federal ambient air quality standards, or the technology will reach the point where it no longer requires incentives.

Figure 1: Funding Succession



CARB will continue to increase coordination of its overall investment strategy across the broader portfolio of incentive programs, both within the agency and with other local, state, and federal partners. State and air district programs complement CARB's work with infrastructure, fuels, vehicle, and other project elements. Infrastructure investment by the CEC and utilities, as a key example, are critical to supporting zero-emission trucks, buses, and off-road equipment.

With multiple goals guiding State action on clean heavy-duty vehicles and equipment, maintaining multiple programs with different but complementary objectives is necessary. At CARB this means a portfolio of programs designed for transition and transformation that emphasizes community protection and investment in disadvantaged and low-income communities.

The Low Carbon Transportation projects focus on rapidly advancing technology to meet California's long-term climate, air quality, community protection, petroleum reduction, and zero-emission vehicle deployment goals. These projects fund advanced technologies in their early stages—starting with demonstration and pilot projects and continue through the early stages of commercialization. These projects focus on deployment of early-commercial technologies on a first-come, first-served basis and do not require scrappage.

As a technology reaches market scale, other programs within CARB's portfolio such as Moyer, the Volkswagen (VW) Mitigation Trust, Community Air Protection Program (CAPP), and Funding Agricultural Replacement Measure for Emission Reductions (FARMER) are more appropriate funding sources. These programs focus on achieving cost-effective reductions of criteria pollutants while improving the environments of disadvantaged residents through DAC (disadvantaged community) targets. They tend to focus on turning over the existing fleet at an accelerated pace, and often require additional measures, such as scrappage, or funding through a competitive process. Scrappage programs provide greater certainty of environmental improvement because an older, polluting vehicle must be taken off the road as a condition for funding a clean replacement.

As technologies become required with the adoption of new performance-based standards, projects such as those within AQIP also play a role in ensuring that fleets are able to comply with future regulations and offer financing assistance for clean trucks to small businesses. Statutorily AQIP is able to fund technologies across a wide segment of the commercialization path—previously AQIP dollars have been used to fund demonstration and pilot projects as well as broad purchase incentives, fleet turnover, and financing assistance. As new priorities arise, CARB expects to continue to utilize the broad flexibility of the AQIP program.

This document serves as a way to better understand how CARB's investment programs interact with one another, as well as a way to determine when a technology

is successful enough to progress to the next program in the funding succession, or away from incentives entirely. Many of the criteria that could be considered for this type of analysis are included as part of the programmatic metrics, and some technologies are clearly ready to graduate to scrap and replace programs, which focus on supporting commercially available technologies.

Low Carbon Transportation and AQIP Specific Investment Strategy

Each year, CARB continues to refine and target its strategy for accelerating the development and market introduction of the technologies needed to achieve the State's climate and air quality goals. The State's ongoing investment of Low Carbon Transportation and AQIP funds continue to make this possible, and this Strategy serves as a roadmap for how to approach accelerating targeted technology improvement through:

- Continuing to invest Low Carbon Transportation and AQIP dollars across the commercialization pathway for various technologies, building on previous investment. This includes supporting technologies through the demonstration, pilot, and commercial phases.
- Focusing investments on the technology pathways necessary to meet the State's climate and criteria pollutant emission goals. The two technology pathways identified are Zero-Emission (organized around battery electric, fuel cell electric, and hybrid electric technologies) and Combustion (engine and powertrain improvements).
- Focusing investments around the expansion of "beachhead" markets—early successful vehicle applications where the pathway technologies can best establish initial market acceptance, and then seed additional follow-on market applications. The beachheads are discussed further on page 23.

This approach has proven successful to date: in the five years since the first Heavy-Duty Investment Strategy was published, growth in the industry has accelerated, including a continued increase in HVIP voucher requests and measurable improvements in the capability of technology displayed in demonstration and pilot projects. The numbers of available platforms and participating industrial providers in HVIP are increasing, including global original equipment manufacturers (OEMs) and innovative new manufacturers.

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State Air Quality Goals and the Role of Incentives

As discussed in the introduction to the FY 2021-22 Funding Plan, there are many statutory drivers and executive orders that inform CARB's Heavy-Duty Investment Strategy and support the State's goals, as summarized in Table 2.

Table 2: California Climate Goals: Statutory Drivers and Executive Orders

Policy Title	Year	Summary
Federal Air Quality Act of 1967	1967	Allow California the ability to set its own more stringent air quality standards.
Assembly Bill 32	2006	Reduce GHG emissions to 1990 levels by 2020 (Núñez, Chapter 488, Statutes of 2006).
Executive Order B-16-2012	2012	Reduce petroleum use in vehicles by 50 percent by 2030 and reduce GHG emissions from the transportation sector to 80 percent below 1990 levels by 2050.
Senate Bill 1204	2014	Help accelerate the introduction of the next generation of cleaner heavy-duty vehicles and engines with creation of the California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program; prioritize projects that benefit disadvantaged communities; direct CARB to develop an annual framework and plan to guide these investments (Lara, Chapter 524, Statutes of 2014).
Senate Bill 350	2015	Improve access to clean transportation options (such as cleaner transit bus fleets, passenger trains, and ferries) for low-income residents, including those in disadvantaged communities (De León, Chapter 547, Statutes of 2015).
Senate Bill 32	2016	Reduce GHG emissions to 40 percent below 1990 levels by 2030 (Pavley, Chapter 249, Statutes of 2016).
Assembly Bill 1550	2016	Establish disadvantaged community, low-income community, and low-income household targets for the State's Cap-and-Trade auction proceeds investments (Gomez, Chapter 369, Statutes of 2016).

Policy Title	Year	Summary
Senate Bill 1403	2018	CARB must develop the Heavy-Duty Investment Strategy and Three-Year Recommendations for Low Carbon Transportation and AQIP (Lara, Chapter 370, Statutes of 2018).
Executive Order B-48-18	2018	Deploy 1.5 million ZEVs by 2025 and at least 5 million ZEVs by 2030.
Executive Order B-55-18	2018	Achieve carbon neutrality as soon as possible, and no later than 2045; achieve and maintain net negative emissions thereafter.
Executive Order N-79-20	2020	All new cars and passenger trucks sold in California must be ZEVs by 2025, all drayage trucks to transition to zero-emission by 2035, all off-road equipment to zero-emission where feasible by 2035, and the remainder of MHD vehicles to zero-emission where feasible by 2045.
Senate Bill 44	2021	Allows California to identify medium- and heavy-duty vehicle segments that can more quickly reduce motor vehicle emissions, consistent with the Heavy-Duty Investment Strategy.

CARB Guiding Documents

In addition to the legislation noted above, there are several other CARB documents that affect CARB investments. These include the California State Implementation Plans (SIPs), the 2017 Climate Change Scoping Plan, the 2016 ZEV Action Plan, the Cap-and-Trade Auction Proceeds Investment Plan, the California Sustainable Communities and Climate Protection Act 2018 Progress Report, and the SB 350 Low-Income Barriers Study, Part B: Overcoming Barriers to Clean Transportation Access to Low-Income Residents. Two additional drivers that provide a key focus with specific strategies relevant to the heavy-duty and off-road sectors are the Mobile Source Strategy and the California Sustainable Freight Action Plan.

- **The Mobile Source Strategy** is the State's integrated plan that identified the level of transition to cleaner mobile source technologies needed to achieve California's many air quality, climate, and community risk reduction goals. The 2016 Mobile Source Strategy noted that heavy-duty trucks with a gross vehicle

weight rating (GVWR) of more than 8,500 pounds[2] were the fastest growing transportation sector in the United States, and are responsible for about 33 percent of the total statewide NOx emissions and approximately 25 percent of the total statewide diesel particulate matter (PM) emissions, and are a significant source of GHG emissions. The proposed 2020 Mobile Source Strategy takes an integrated planning approach to identifying the level of transition to cleaner mobile source technologies needed to achieve California's many targets through 2050.[3] Early investments that accelerate deployment of zero-emission, hybrid, and the cleanest combustion technologies in the heavy-duty and off-road sectors are essential, and have already started to play a vital role in transitioning heavy-duty vehicles and off-road equipment to cleaner technologies. Vehicles and equipment that are replaced via CARB's scrap-and-replace programs can have a significant impact on each district's individual State Implementation Plan (SIP) commitment. Additionally, the State Strategy for the State Implementation Plan, or State SIP Strategy, includes federally enforceable commitments to achieve reductions in NOx, reactive organic gases, and PM2.5 emissions using measures conceptualized in the Mobile Source Strategy.

- **The California Sustainable Freight Action Plan** is designed to integrate investments, policies, and programs across several State agencies to help realize a singular vision for California's freight transport system. To meet the State's 80 percent GHG emission reduction target by 2050, freight will need to be moved more efficiently, with zero-emission technologies wherever possible, and hybrid or the cleanest combustion technologies paired with renewable fuel use everywhere else.[4] The solution will require technology innovation, including development and deployment of zero-emission, as well as hybrid and the cleanest combustion trucks, locomotives, cargo handling equipment, transport refrigeration units (TRUs), and ships. It will also require lower-emission aircraft, parallel development of the necessary supporting fueling infrastructure, and logistical/operational efficiency improvements.

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[2] For the purposes of this document, this investment strategy refers throughout to heavy-duty vehicles. However, that designation is meant in the broader sense of commercial vehicle ranges and applications. CARB incentives for commercial vehicles can be used from weight classes starting above 8,500 pounds GVWR.

[3] CARB. 2020 Mobile Source Strategy. https://ww2.arb.ca.gov/resources/documents/2020-mobile-source-strategy

[4] California Sustainable Freight Action Plan. July 2016. https://ww2.arb.ca.gov/sites/default/files/2019-10/CSFAP_FINAL_07272016.pdf

CARB's Mobile Source Strategy and the California Sustainable Freight Strategy reference a combination of proposed regulations, investments, and incentives, and will help move California towards its goal of transitioning 100% of the medium- and heavy-duty vehicle fleet to zero-emission by 2045 everywhere feasible. Together these approaches are designed to bring about progressively cleaner in-use fleet emission levels.

While incentives are designed to help accelerate technology advancement and market penetration, they also function to reward early adopters of these technologies. As the cleaner technologies become commercially available, costs continue to fall and market adoption increases. Incentives support early adopters to lead commercialization efforts and prove new technologies, but they are also important to expanding access to clean vehicles and equipment. CARB is exploring incentive designs that will equitably expand access to fleet operators beyond early adopters as market commercialization of clean technologies continues.

Industry Examples
The Innovative Clean Transit Regulation Charts a Path to Zero-Emission Transit

CARB's Innovative Clean Transit (ICT) regulation requires all transit agencies to fully transition to zero-emission fleets by 2040—large transit agencies were required to submit Rollout Plans outlining this shift. A recent CALSTART report[i] analyzed 22 of these Rollout Plans, finding that the state's zero-emission transit bus marketplace will be technologically diverse.

- Reporting transit agencies plan to deploy both fuel cell electric buses (FCEB) and battery electric buses (BEB) to make up their zero-emission fleets. One agency will exclusively deploy FCEBs; four agencies have opted for entirely BEB fleets; and every other responding agency anticipates a mix of technologies. More than half of responding agencies plan to purchase FCEBs, and two additional agencies will consider both FCEBs and BEBs in their undeclared acquisitions.
- Cutaway buses, which account for about 10 percent of all planned bus purchases by reporting agencies, are much more likely to be fueled by hydrogen than standard long-body buses. Transit agencies expect to purchase 339 cutaway BEBs and 297 cutaway FCEBs. This ratio creates a cutaway FCEB market share of 47 percent—a stark contrast to the entire declared zero-emission bus market by 2040, which is expected to consist of 15 percent FCEBs.

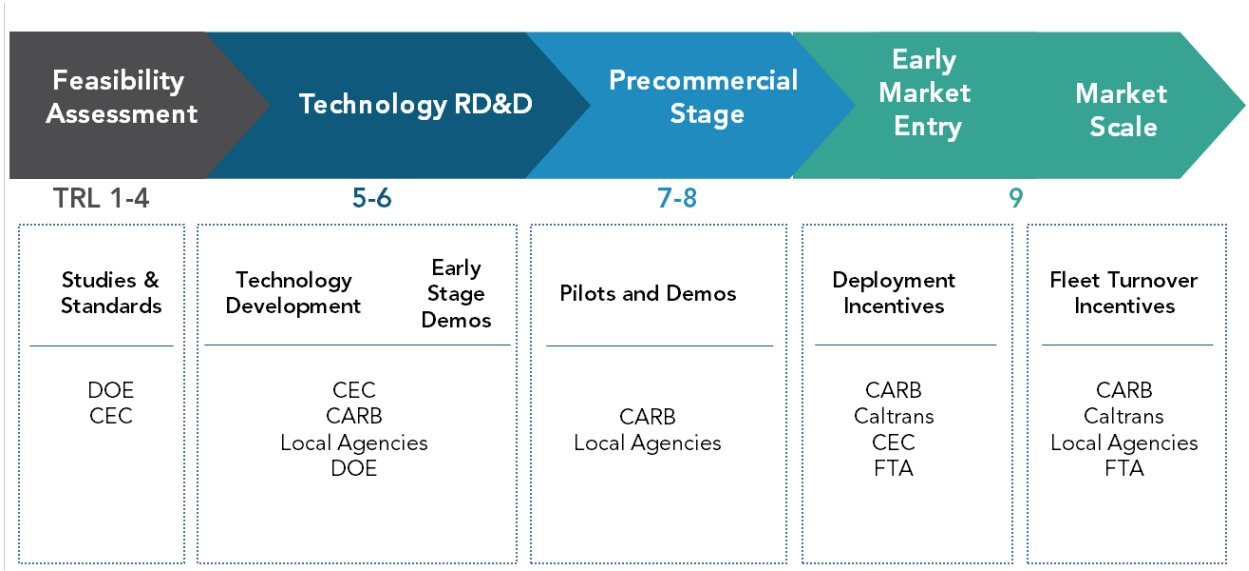
[i] Paddon, et al. California Transit Agencies Chart a Course to Zero-Emissions. June 2021. https://calstart.org/california-transit-agencies-chart-a-course-to-zero-emissions-a-review-of-proposed-zeb-pathways-under-the-innovative-clean-transit-regulation/

Incentives help to bring more of the vehicle and equipment fleets into compliance in advance of a potential regulation. Planned regulations also help provide a higher level of certainty to fleet owners who may be hesitant about upgrading their equipment and help to increase acceptance of the new technologies. Incentives and planned regulations both send a market signal and spur private investments in the development and commercialization of advanced technologies.

Supporting Commercialization of Advanced Technologies

Incentives at the local, state, and federal levels support heavy-duty vehicle and off-road equipment technology advancement at the demonstration, pilot, and commercial deployment stages, or across all TRLs.[5] Figure 2 shows the commercialization path for technologies and the public agencies that provide key incentives across this path.

Figure 2: Commercialization Path: Stages and Sources of Public Investment



As Figure 2 shows, California, working in partnership with many local and federal agencies, invests public funds across the entire technology commercialization path. This approach is critical because it provides the opportunity to invest not only in the commercial technologies, but also ensures continual development, demonstration, and piloting of technologies that are necessary to meet the many State goals and federal mandates.

All CARB investment programs focus on funding starting from the demonstration phase forward, following through the programmatic categories shown above. Utilizing this structure, it is important to understand how CARB defines demonstration, pilot, and commercial phases.

In the demonstration phase, manufacturers are typically focused on producing single vehicle prototypes or small volume vehicle demonstration and testing projects. These investments are crucial because they can accelerate the pace of commercializing advanced technology vehicles and equipment by spurring private investment and

[5] NASA. Technology Readiness Level. October 28, 2012. https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html.

demonstrating that the technology is capable of meeting the specific user needs. Demonstration projects feed the innovation pipeline and are necessary to ensure the availability of technologies needed to meet the State's goals.

In the pilot phase, projects are typically focused on larger scale deployments where issues around manufacturing design, user acceptance, and support can be assessed. During this phase, per-vehicle incentives remain relatively high because engineering designs are still evolving, and manufacturing techniques are not at full volume or capacity, instead focusing on smaller batches of vehicles. Higher levels of incentives per vehicle are needed to help entrepreneurs and early manufacturers cover the costs of this low volume technology development. Pilots are also critical in solving other barriers, such as infrastructure limitations, user acceptance, and building a business case.

In the commercialization phase, incentives are provided to encourage user adoption of advanced technologies that may be available at a higher price due to advanced technology. The commercialization phase can be broadly separated into lower-volume and higher-volume production phases. In the lower-volume commercialization phase, sales volumes generally start out low but grow over time as user acceptance increases and manufacturing costs decrease with engineering improvement, supply chain competition, and economies of scale. Incentive projects that focus on early commercial deployment tend to support fleet expansion within progressive fleets that are interested in "testing the waters" of advanced technology. In higher-volume production, incentives can help support the transition of the technology to wide-scale adoption. In either phase, it should be noted that incentives are available for vehicles achieving a CARB Executive Order for commercial operation.

The continued deployment of incentives helps to accelerate the movement of the market in the direction of financial stability. For the heavy-duty on-road and off-road sectors, incentives will need to keep increasing over the next three years, and possibly well into the future for some applications, to ensure that market successes are solidified and continue to make progress toward reaching State goals. However, the ultimate goal for each technology application is to reach a point of financial stability or incremental cost where incentives can eventually be phased out entirely. As markets continue to grow CARB staff will work with technology providers, researchers, and others to establish early markers of financial stability or commercial viability.

Programmatic Metrics for Low Carbon Transportation

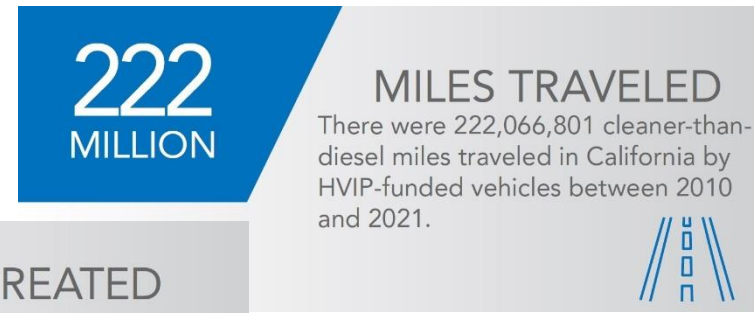
The Long-Term Heavy-Duty Investment Strategy serves a framework for prioritizing available heavy-duty incentives and investments appropriated to the Low Carbon Transportation Investments program, and these investments play a key role in advancing emerging clean vehicles technologies to help meet the State's 2030 goals and beyond. Although this framework applies to all of the incentive programs in CARB's larger portfolio, this section will focus specifically on Low Carbon Transportation Incentives and will cover the requirements mandated by SB 1403.

In addition to identifying priority focus areas and recommended levels of incentive funding, this document also includes metrics to help assess the performance of Low Carbon Transportation projects toward meeting their goals. These include targeted metrics that address technology advancement, increases in suppliers and supply chain diversity, potential to impact key market segments, and reductions in system costs. CARB has identified three broad categories that define success for these programs with some overlap between the three: (1) Creating Healthy Communities, (2) Growing the Green Economy, and (3) Supporting Technology Evolution.

Metrics are summarized into three categories: Creating Healthy Communities, Building the Green Economy, and Supporting Technology Evolution.

CARB will continue to work with stakeholders to develop, quantify, and implement metrics to communicate the full range of benefits accruing from Low Carbon Transportation Investments.

For this year's strategy, CARB has continued to work with stakeholders for input on metrics, including holding three public work group meetings and evaluating the available data needed to quantify suggested metrics. HVIP was closed to new voucher requests from November 2019 to June 2021, but program metrics have been updated where possible. As additional project data becomes available from CARB's demonstration and pilot projects, the metrics will be further refined and expanded in future years.



This will help to address the California State Auditor's recommendation that CARB collect data and use existing date to measure and report on program metrics.

Creating Healthy Communities

An essential part of CARB's mission is to protect the health of Californians from the harmful effects of air pollution—particularly for priority populations that are disproportionately impacted. Projects should aim to reduce the health impacts of transportation and improve the sustainability of communities.

Current metrics:

Vehicle telematics show where emissions reductions are occurring, including in disadvantaged communities that are identified in CalEnviroScreen. Telematics also provide data on vehicle mileage. HVIP gathers telematics data quarterly on an aggregate and vehicle-level basis from participating OEMs for HVIP-funded vehicles.

Other public health metrics CARB considered include health risk assessments and exposure studies. Health risk assessments, while a direct measurement of health, would not capture impacts from many existing demonstration and pilot deployments, which are definitionally limited in size. Exposure studies for vehicle operators, while likely valuable in demonstrating near-source exposure improvements, are outside of the scope of Low Carbon Transportation data collection.

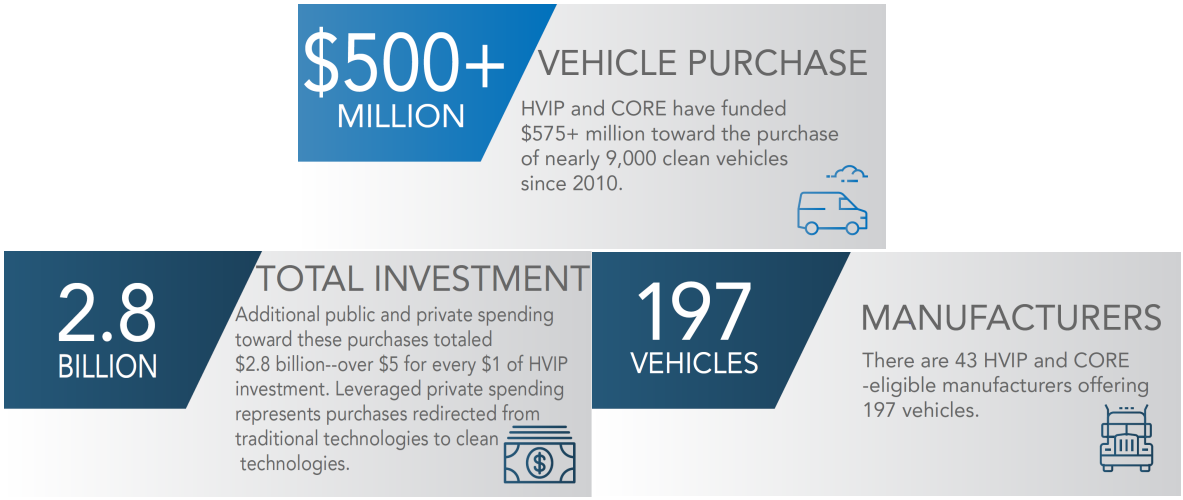
Growing the Green Economy

CARB's investments are intended to create downstream economic benefits where possible. The presence of consistent funding for clean technology projects helps to attract clean tech manufacturing to California, bringing high-quality jobs and supporting a nascent and valuable industry. More information on supply chains is provided on page 59.
Current metrics:

- CARB knows how incentive dollars are being leveraged with private investment and complementary public spending to support the commercial viability of advanced technology, i.e. by tracking the total purchase price and co-funding on HVIP-funded vehicles.
- CARB has qualitative information on the expanding supply chains for advanced technology components. CARB also monitors the number of manufacturers

choosing California as a home for manufacturing. Of the 30 current HVIP-eligible manufacturers, 8 have California manufacturing locations and another 5 have other California-based administrative or operational locations.

New metric this year:
Quantifying HVIP-eligible vehicle models, showing that model availability is widespread across manufacturers and ready to meet fleet demand.



Supporting Technology Evolution

Currently available technologies will not be sufficient to meet CARB's long-term air quality and climate change goals. Therefore, investments should spur the development, improvement, and commercialization of advanced technologies for the future. Technology evolution continues to be a direct goal or ancillary outcome for Low Carbon Transportation investments, as well as a number of CARB's other incentive programs.

In the future, this section of the Strategy could be further expanded to describe metrics that are applicable to a wider array of programs. This will continue to be important as CARB develops the concept of technology graduation, which will be directly related to the pathway and progress of technology evolution. Defining and quantifying metrics that signal when technologies graduate, or move on to other incentive programs or can stand on their own will require an empirical approach to monitoring technology evolution. Further information on technology graduation can be found on page 37.

Current metrics:

- CARB can quantify how investments in commercially available technology are accelerating consumer acceptance, and anecdotal evidence suggests manufacturers' production costs are dropping.
- CARB is also collecting observations that technologies from one application are being transferred to and used in others—a phenomenon being accelerated by CARB investments and a direct validation of CARB's beachhead theory of technology transfer, as further discussed on page 23.

Potential Future Metrics:

- While supplier sourcing data is generally proprietary, and information on volume or where OEMs are sourcing components will likely not be available, some information is being gathered on key component cost and could be a useful metric to show how CARB investments are helping improve the market supply chain.
- Survey data could be valuable for discovering attitudes and perceptions of new vehicle technology and provide valuable feedback from first deployers. HVIP is expected to collect more survey data in the future that could be of use. Stakeholders have also shared, that one of the best indicators of satisfaction is when a fleet that participated in a demonstration or pilot project continues to express interest in or procure additional advanced technology vehicles.

While current criteria for monitoring success provide some feedback on the effectiveness of CARB investments, there are additional benefits that are not yet reflected. CARB will continue to work with stakeholders to solicit, develop, refine, and implement additional metrics that better communicate the full range of benefits accruing from Low Carbon Transportation investments, considering the program's unique position in CARB's investment portfolio.

Industry Examples
Creating Jobs with Clean Commercial Vehicles

Zero-emission vehicles represent a clear growth industry. According to a 2021 CALSTART study on ZEVs and associated job growth,[i] California has developed such a prosperous home-grown industry that the State likely has the highest total number of "green" vehicle technology companies in the United States, including light-duty vehicles, medium- and heavy-duty vehicles, and off-road applications.

Results from this study indicate about 70,000 ZEV jobs have been created in California, spanning over 360 unique companies (many of which are thriving small businesses) in at least 419 different locations. These new employment opportunities—working directly to manufacture ZEVs and their componentry, support ZEV infrastructure, and research new technologies—illustrate electrified transportation's capacity to support California's and the U.S. economy.

Current light-duty ZEV models have already demonstrated their tremendous potential to support the domestic economy. Two of the top three vehicle models in 2021's American-Made Index[ii] are entirely American-made passenger ZEVs that generate both job opportunities and air quality benefits for American citizens.

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[i] CALSTART. California ZEV Job's Study. January 2021. https://calstart.org/wp-content/uploads/2021/02/CA-ZEV-Jobs-Study-Final-0203.pdf

[ii] 2021 Cars.com American-Made Index. June 2021. https://www.cars.com/articles/2021-cars-com-american-made-index-which-cars-are-the-most-american-437020/

Beachhead Strategy

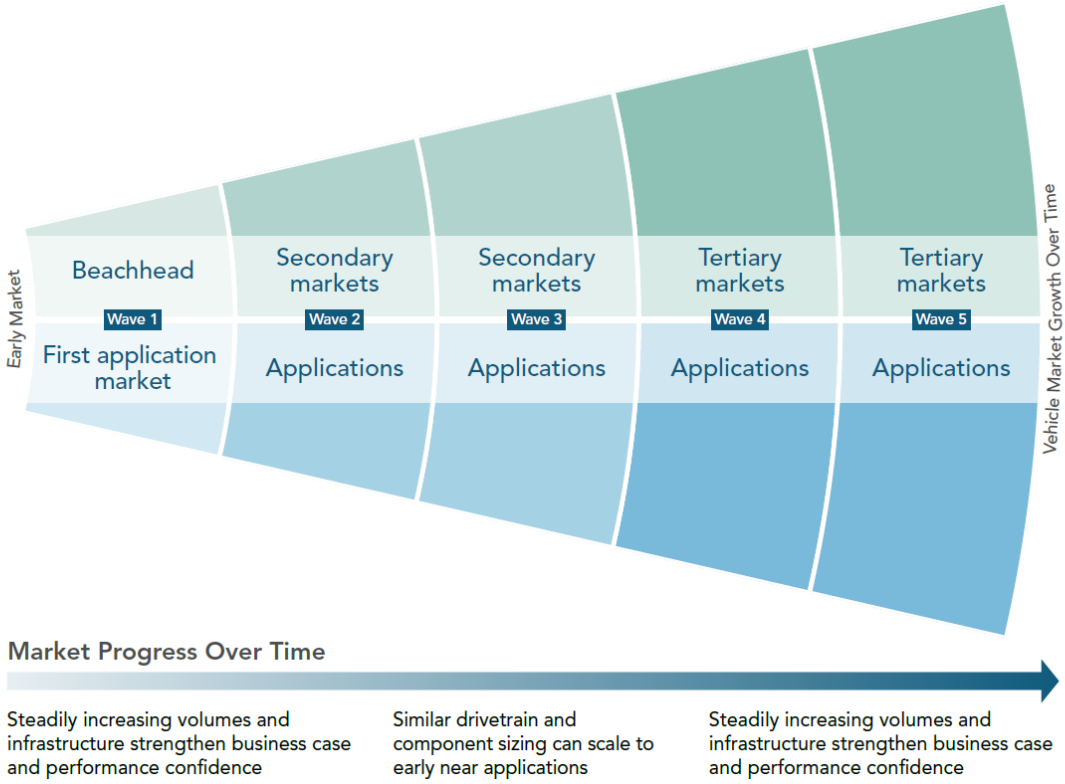
In 2017, CARB developed a visual representation of its focused strategy for technology commercialization based on targeting its investments on strategic "beachheads," or first -success, applications—and on the pathways for additional markets or work applications that extend from them.[6] These beachheads are built around applications that can best make early use of one of the pathway technologies based on duty cycle, business case, industrial capacity, and performance. From these initial first-success applications, next -generation vehicle applications can expand by extending the technologies to adjacent markets through the leveraging and adoption of similar powertrains; growth of supply chain volumes for common components; expansion of fueling infrastructure; and confidence in performance and business cases.

The beachheads are built around initial first-success applications that can best make early use of one of the pathway technologies based on duty cycle, business case, industrial capacity, and performance. Next-generation vehicle applications can then expand by leveraging similar powertrains, growth of supply chain volumes for common components, and expansion of fueling infrastructure.

With market growth, eventual price reductions based on volume production can expand the technology to additional larger, but more price sensitive, markets, and also make use of opportunities to scale the technology to larger or smaller application sizes. Figure 3 below depicts the generic beachhead process, highlighting initial applications, and suggesting the places where there is likely to be a transfer and extension of the technology to additional vehicle applications and subsequent markets. As the supply chain expands for core components and costs improve, multiple applications of increasingly larger market volumes can be supported, driving steadily larger market penetration.

[6] The term "beachhead" derives originally from military usage and is often connected to the successful Allied amphibious vehicle landings in Normandy during World War II, which started with holding a small strip of beach and expanded to a continent. The commercial definition of beachhead is "a secure initial position that has been gained and can be used for further advancement; foothold." Random House Unabridged Dictionary. Random House, Inc. 2018.

Figure 3: The Beachhead Strategy



The beachhead concept has helped CARB target and focus Low Carbon Transportation and AQIP investments around applications that have strong potential to transfer and spread to broader applications. An additional consideration is the ability of the beachhead and its follow-on applications to build the expansion of a common supply chain that can provide similar components for powertrains and systems that can reduce cost over time. This in turn helps to build greater production volumes, leading to continued affordability.

This strategy is also being reviewed and adopted by other regions of the world as a useful framework for accelerating technology transformation in MHD vehicles. As additional geographic regions adopt similar technologies on a common timeline, it helps to grow a global supply chain and spurs investments. Evidence of this is being seen in the zero-emission bus application in the United States, Europe, Asia, India, and South America. The Global Commercial Vehicle Drive to Zero ("Drive to Zero") campaign uses the beachhead model as a foundational principle to drive strategic zero-emission commercial vehicle proliferation and expansion. Drive to Zero, and by association the beachhead model, has been adopted by the Clean Energy Ministerial's Electric Vehicle Initiative and has been formally recognized by nine national governments, including Canada, Chile, China, Finland, Germany, Japan, the Netherlands, Norway, and Sweden.

The beachhead strategy, shaped around two core technology pathways and overarching efficiency improvements, now defines CARB's approach to driving faster technology commercialization through Clean Transportation investments. The beachhead strategy is about focusing resources on a key area or areas—usually a smaller market segment or product to start—and successfully deploying in that market first, or even dominating that market, to help it move into larger markets or other applications.[7]

Beachhead Strategy Updates 2021

There are two main beachheads—Zero-Emission and Combustion. Previous versions listed a third beachhead—Efficiencies—that has been recategorized because some of the efficiency technologies (e.g., connected-automated vehicles, automated guided vehicles, stop-start systems) can be overlaid on the other two beachheads to maximize reductions. These efficiency improvements and many others are expected to be adopted in U.S. EPA Phase 3 HD GHG standards that will build upon current program design to deliver deeper GHG reductions within the federal fleet.

The Global Commercial Vehicle Drive to Zero ("Drive to Zero") campaign uses the beachhead model as a foundational principle for zero-emission commercial vehicle proliferation. Drive to Zero, and by association the beachhead model, has been adopted by the Clean Energy Ministerial's Electric Vehicle Initiative and has been formally recognized by nine national governments, including Canada, Chile, China, Finland, Germany, Japan, the Netherlands, Norway, and Sweden.

The following sections and graphics illustrate the beachhead strategies for sequenced expansion of technology pathways from successful early applications. Given a dynamic market, timing and stages can change and evolve differently. Therefore, the sequences outlined are not intended to be absolute or guaranteed but do provide a guide and focus for investments. They represent a technical assessment of the reasonable potential to progressively scale and transfer components and capabilities to additional applications and platforms. This assessment comes from interviews with manufacturers and suppliers; assessment of component use and commonality across geographical regions and applications; and evaluations of the transferability potential of these components. Technology transfer is considered both from a historical and technological perspective, accounting for how lighter segments and return-to-base operations have supported early deployments, recognizing transfers and tech

[7] Berry, Tim. Don't Underestimate Beachhead Strategy. Bplans. http://timberry.bplans.com/the-power-of-beachhead-strategy.html

adoptions in medium waves, and predicting how manufacturers and fleets will logically incorporate transferable technologies into new applications.

In recognition of the dynamic nature of markets and technology, they remain "works in progress" and are updated and modified as needed to adapt to changing conditions. CARB staff, via workgroup and other industry and stakeholder interactions, initially solicited comments and feedback on these beachheads in 2019 to identify areas where there may be additional leverage to support expanded deployment or areas of technology success. Additionally, this year CARB took the opportunity to give renewed focus to the off-road sector. With a rapidly developing segment poised for further CARB investments, staff wanted to highlight where the on-road and off-road points of connection might be for certain technologies, identifying where technology transfer might assist faster off-road technology adoption.

This year's review aimed to identify any off-road-specific beachhead technology applications; understand how components and control systems can be shared among different types of off-road equipment and with heavy-duty on-road vehicles; and depict the results of CARB's analysis using the beachhead model. In addition, staff sought to identify the unique opportunities and challenges of deploying advanced technology in off-road applications, and to assess the potential impact of such opportunities and challenges. From this review, the beachhead strategy has been refined for 2021 through continued stakeholder engagement and monitoring of vehicle and technology markets and developments.

This year, the beachhead process was also refined and updated to more clearly visually group those applications that can potentially make use of shared infrastructure, such as yard hostlers, cargo handling equipment, marine harbor craft, and drayage trucks. Such applications can have common points of operation, such as marine terminals, and can build upon existing infrastructure investments, such as those already being made in electrical capacity for gantry cranes and shore power, or hydrogen investments for trucks or lifts. In the case of hydrogen, such opportunities for higher-volume fuel demand could justify large-scale, on-site fuel production which can help reduce the cost of hydrogen fuel.

Staff have explored these goals through several public mechanisms. Staff reached out to stakeholders with specific insight into the off-road sector and held three work groups to elicit feedback from interested stakeholders. Staff also held one-on-one meetings with several stakeholders with relevant expertise, such as technology providers, OEMs, end-use operators, and facility owners.

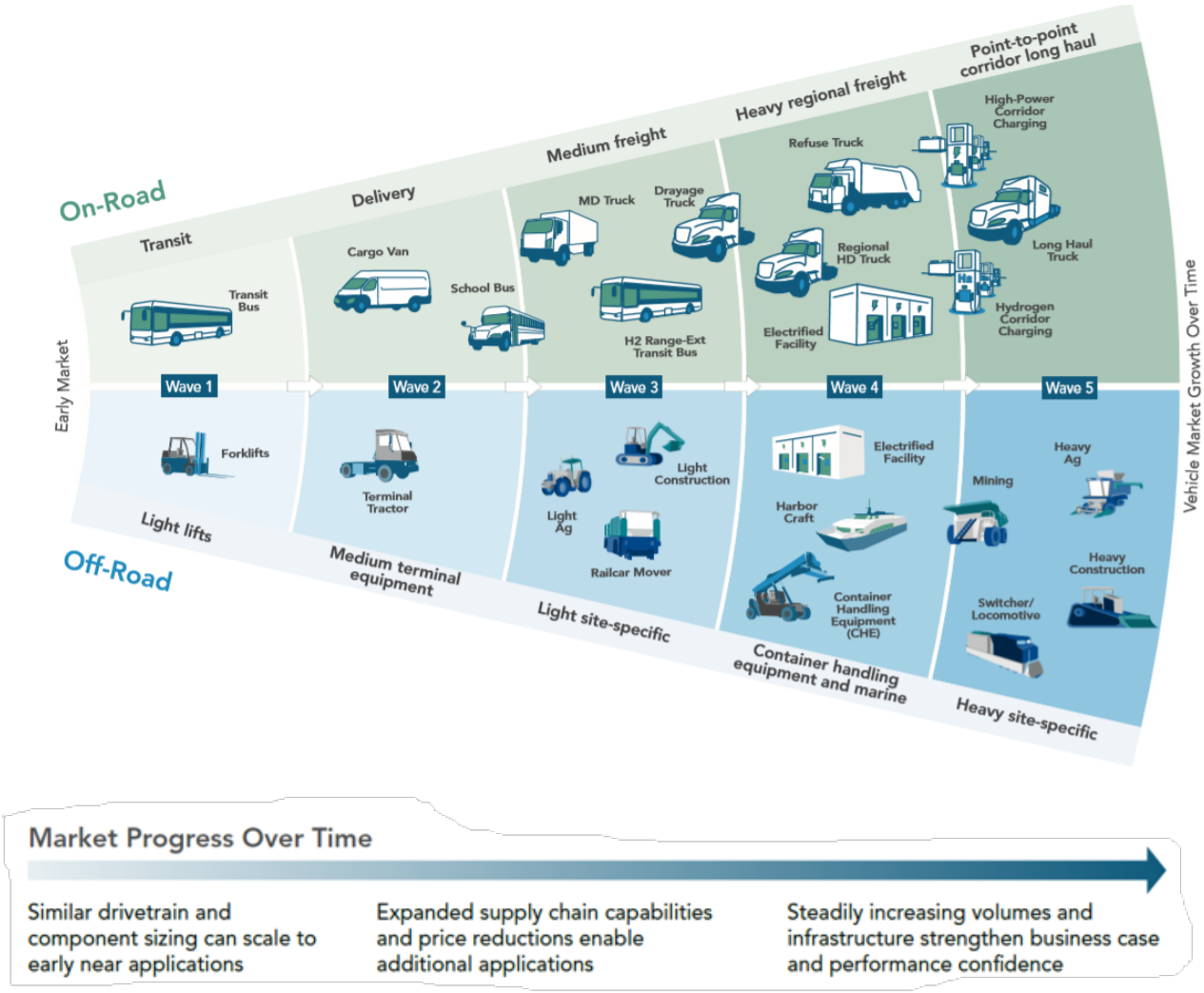
Finally, all pathways have been graphically updated to more clearly convey the stages of transformation and expanded application and market growth. The Combustion Beachhead has been updated to demonstrate a potentially significant impact that regulations on diesel engine emissions could have on the cleanest combustion engine

market and to clearly identify the market applicability of all available clean combustion technologies. The Zero-Emission Beachhead now reflects additional off-road technology pathways that are responsive to inquiries made during public review sessions. These beachhead graphics visualize technological pathways to successive vehicle applications and market expansion but are not meant to indicate a specific timeframe or place along the technological continuum that would correspond to "where the market is now."

Zero-Emission Beachhead

The most powerful beachhead process to date has been built around the zero-emission pathway, as illustrated in Figure 4. It is centered on the first-success application of the zero-emission transit bus and how that core market, while relatively small in initial volume, forms the basis for a successful first marketplace and a stepping stone for additional uses of the core component technologies and architectures. An FCEB utilizes many of the same powertrain components as a BEB, which itself was built on the early success of hybrid architectures in the transit bus market. Over time, transit buses began to expand the use of some of these core electric drive components into other bus applications and to expand to truck and van applications. As the technology matures and business cases improve, opening opportunities for manufacturers to meet growing demand, core electric drive components will continue to expand from smaller or reliably return-to-base applications to more diverse, rigorous duty cycles.

Figure 4: The Zero-Emission Beachhead



The development of these core components have had even broader applicability than initially expected, and have now served as the launch point for the development and deployment of several other secondary market applications including:

- Battery electric shuttle and school buses;
- Battery electric delivery vehicles;
- Battery electric yard hostlers;
- Battery electric off-road work trucks designed for site-specific functions (in agricultural, construction, rail, and mining operations);
- Battery electric refuse trucks;
- Battery electric, fuel cell electric, and plug-in hybrid (sometimes operating as range extender systems) drayage trucks; and
- Battery electric, fuel cell electric, and plug-in hybrid (and range extender) regional heavy-haul trucks.

This expansion to other applications is due to:

- Common powertrains and components (motors, power electronics, energy storage) that can be transferred to other applications with similar power and torque needs, or scaled up or down to suit other applications;
- Supply chain expansion partially assisted by hybrid, start-stop, and idle reduction technologies;
- Steadily increasing vehicle volumes and availability of infrastructure, knowledge of the business case, and consumer confidence in performance; and
- Expanded capabilities, including price reductions in energy storage/components enabling MHD applications (with some of this energy storage transferring directly from light-duty passenger car production).

Extended range applications are still being developed that use an engine or fuel cell generator to augment the range and performance of battery electric heavy-duty vehicle. However, the steady and steep improvement in battery capacity and steady reductions in battery price have continued to push the limits of where such systems are needed. From early battery-only ranges of 80-100 miles on a single charge, major manufacturers are now regularly signaling 200 miles, with several manufacturer indicating ranges exceeding 300 miles and a few models anticipated to exceed 600 miles on a single charge.[8] Similarly, fuel cell electric powertrains are emerging as a potential market entrant for heavy weight, duration, and longer distance applications by 2023, with early commercial deployments operating successfully in on-road and off-road applications.

Fuel cell trucks are being developed by an increasing number of major manufacturers and partnerships including Hyzon, Hyundai, Hino (Toyota), Kenworth (Toyota), Navistar (GM), Nikola, and Volvo-Daimler. While the source of electrical power comes from different sources (batteries, fuel cells, or engine generators), it is important to note that ZEV core components and systems are similar.

[8] CALSTART. ZETI Analytics. https://globaldrivetozero.org/tools/zeti-analytics/

Industry Examples
Manufacturing Backs Commercial Hydrogen and FCEV Production

Automakers and hydrogen suppliers have announced substantial support and investments in FCEV technology, production, and supporting fueling and infrastructure. These partnerships have generated sufficient interest and capital that lead to McKinsey's estimation that FCEVs are currently a $1 billion industry that should rise to $20 billion by the end of the decade. In the past year alone:

- Navistar and GM will combine their respective truck bodies and fuel cell technologies to develop a commercial-production HD FCEV for launch in 2024.
- Hyzon, a spin-off company that upfits its hydrogen fuel cell technologies into commercially available glider vehicles, anticipates producing 40,000 FCEVs by 2025, including applications.
- Daimler and Volvo have formed a joint venture to undertake commercial HD FCEV production by 2025 and to harmonize FCEV policies.
- Toyota has developed partnerships to demonstrate and bring to production its fuel cell technologies in drayage trucks with Kenworth and Hino—the latter has separately partnered with start-up Xos to develop long-haul FCEV models.

Though industry is scaling up to deliver on FCEVs' potential, continued public investments will drive new innovations to further reduce fuel cell costs. Notably, CARB and the CEC have jointly and partially funded the NorCal Drayage Project,[i] which will support the deployment of 30 Hyundai XCIENT Class 8 FCE trucks in northern California and establish a high capacity and high throughput liquid hydrogen fueling station to support more than 50 trucks and back-to-back fueling, with the expectation of completing a single 60-kg fill in less than 15 minutes.

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[i] CARB. Attachment 2 – Project Executive Summary. March 2021. https://ww2.arb.ca.gov/sites/default/files/2021-03/fy1920zedrayageappsummary.pdf

Off-road zero-emission technologies leverage the expansion of drivetrain technologies, operating times and distances. Industrial lifts have been an important market for zero-emission technologies such as battery electric and fuel cell electric systems. Fuel cell systems from the industrial lift application are becoming an asset for extended range and extended operation capabilities in on-road trucks and heavy-duty

off-road equipment. Such systems are in the demonstration phases.[9] The knowledge base and core technology enables, if not in all cases directly leads to, additional applications, such as:

- Battery electric and fuel cell electric ground support equipment (GSE);
- Battery electric and fuel cell electric sight-specific agricultural, rail, and construction applications;
- Battery electric, fuel cell electric, and extended operations electric cargo handling equipment (CHE);
- Battery electric, fuel cell electric, and extended operations marine harbor applications; and
- Battery electric and fuel cell electric TRUs.

As important, though, is the technology transfer of heavy-duty components between the on-road sector and segments of the off-road sector. Technology transfer between sectors has been illustrated in zero-emission bus components now being used in marine applications (hybrid, battery, and fuel cell) but is also found in common powertrain components that can be used in construction, agricultural, and cargo-handling equipment. Examples here include wheel loaders and heavy lifts.

[9] For additional information on zero-emission off-road technologies and market progress, see https://calstart.org/zero-emission-off-road-technology-and-market-update

Industry Examples
Flexible Designs for Zero-Emission Applications

Technology transfer of heavy-duty components between on-road, off-road, and marine sectors is one of the foundational elements of CARB's beachhead strategy. Several companies have recently undertaken new endeavors to facilitate and advance this transfer, developing a robust ZECV market.

In January 2021, Komatsu announced plans to develop a battery-electric middle class hydraulic excavator.[i] This vehicle design marks the first application of this electric drivetrain designed for on-road buses in battery-electric off-road and construction equipment. Implementing these battery systems, which were originally utilized in vehicles such as electric school buses, coach buses, delivery vans, and low-floor cutaway shuttle buses, within first-of-its-kind construction equipment demonstrates the flexibility and continual growth of zero-emission capabilities.

Also in early 2021, Cummins announced the development of North America's first commercial zero-emissions ferry,[ii] which will be powered by Cummins' 360kW fuel cell. This project, which will act as the flagship for a planned fuel-cell powered fleet to transport commuters in the bay of San Francisco, is partially funded by a $3 million grant from CARB (administered by the Bay Area Air Quality Management District) that comes from the California Climate Investments initiative.

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[i] Komatsu. Joint PoC verification tests to start for electrification of small and medium-sized hydraulic excavators. January 2021. https://www.komatsu.jp/en/newsroom/2021/20210126

[ii] Cummins. Cummins Fuel Cells Powering North America's First Commercial Zero Emissions Ferry. February 2021. https://www.cummins.com/news/2021/02/09/cummins-fuel-cells-powering-north-americas-first-commercial-zero-emissions-ferry

The success of this strategy has been extremely valuable as a framework for planning the introduction timelines of HD electrification. Rather than expecting market launches randomly, there is a clear and sequenced cadence to the growth of zero-emission capabilities. Utilities, cities, fleets, and government agencies can better plan the phased timing of infrastructure deployments, supporting policies, incentives, and development of funding and use regulations based on this steady expansion and progression.

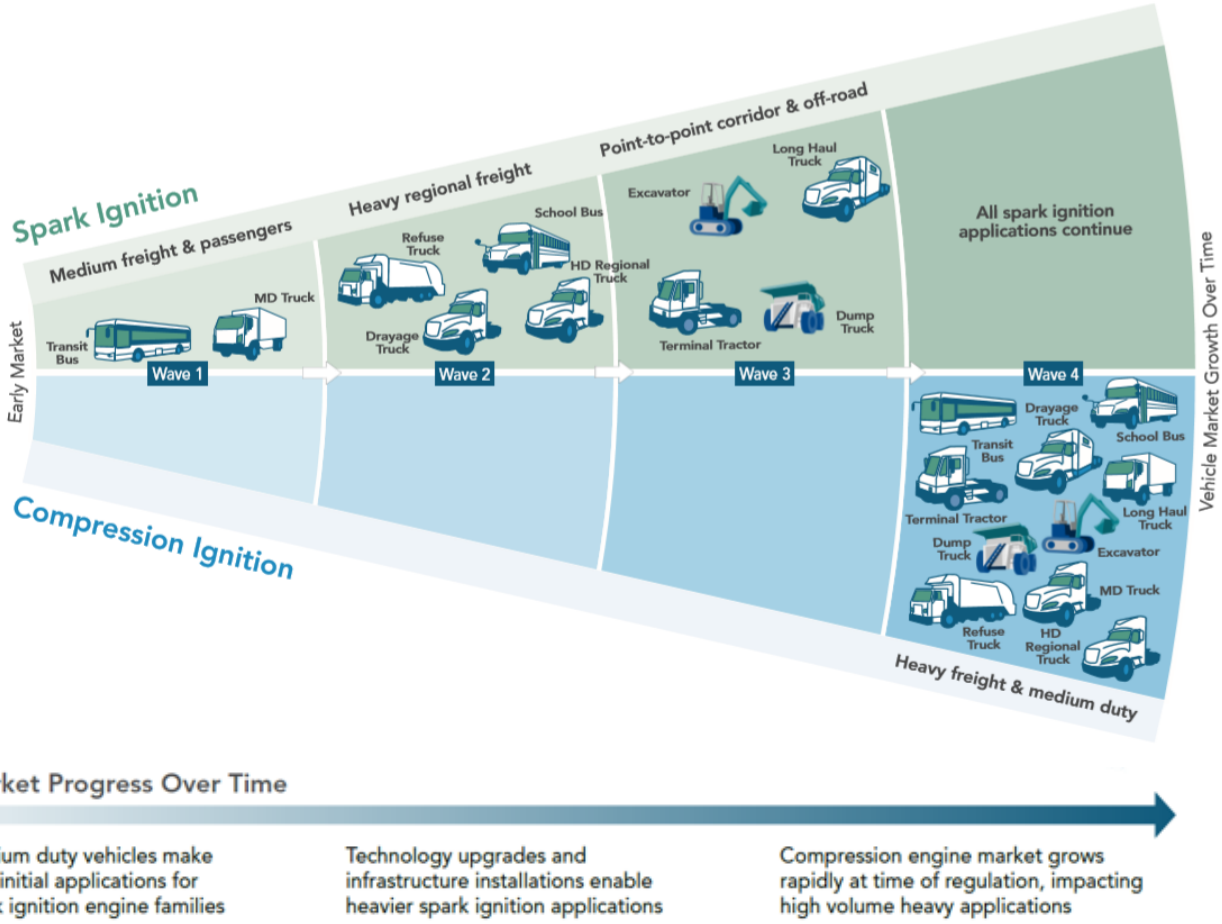
Rapid growth in plug-in hybrid and zero-emission trucks is expected due in no small part to the 2020 passage of CARB's ACT rule. The new regulation will require large manufacturers to sell qualifying zero-emission vehicles as a percentage of their total

vehicle sales starting in 2024. Additionally, 15 states accounting for more than 30 percent of the U.S. commercial vehicle market signed a 2020 memorandum of understanding to accelerate the adoption of zero -emission commercial vehicles aligned with ACT market penetration goals. New Jersey is now attempting to adopt a proposed ACT regulation, and New York passed legislation to adopt Governor Newsom's Executive Order N-79-20 requiring all sales of new passenger cars and trucks in the state be zero-emission by 2035. The beachhead model predicts that the earliest successful zero-emission vehicle applications will take place in transit bus, delivery van, medium-duty truck, and medium-duty school and shuttle bus markets. These successes will enable heavier truck applications by reducing costs and establishing robust supply chains.

Combustion Beachhead

Illustrated in Figure 5 below, the combustion beachhead serves as an umbrella for all applications that utilize the cleanest available forms of combustion. The focus of this beachhead and its pathways since 2016 has been on those engines that might meet a certification level of 0.02 grams per brake g/bhp-hr NOx, which CARB adopted in 2020 under the Heavy-Duty Engine and Vehicle Omnibus regulation. This rule has also set a more stringent optional NOx certification level at 0.01 g/bhp-hr. To the extent that combustion technologies will continue to be utilized, CARB has recognized through the adoption of regulations such as the Omnibus Low NOx Regulation, that those technologies be regulated to the cleanest level possible. It will also be critical that the cleanest combustion technologies be paired with lower carbon fuels wherever possible, which are also incentivized through the Low Carbon Fuel Standard (LCFS). As a result of the recent adoption of new regulations and a statewide focus on zero-emission, CARB will continue to support technologies that provide surplus emission reductions to regulation but will maintain a zero-emission and zero-emission enabling focus for the Low Carbon Transportation investments.

Figure 5: The Combustion Beachhead



Two main pathways have been identified for the cleanest combustion engines, based on the engines' fuel combustion dynamics: a spark ignition pathway and a compression ignition pathway.

The spark ignition pathway offered the first successes with attaining optional NOx certification levels (0.02 g/bhp-hr NOx, or 90 percent below the U.S. Environmental Protection Agency's 2010 standards for diesel engines). This pathway is well established around the natural gas and propane market segments, with its first beachheads in refuse truck and transit bus applications. This was primarily driven by the first engine size commercialized: the 8.9-liter engine.

With follow on engine products in larger (11.9 liter) and smaller displacement sizes, these first beachheads have expanded to other MHD applications, such as:

- 0.02 g/bhp-hr NOx shuttle and school buses;
- 0.02 g/bhp-hr NOx medium-duty work trucks and related applications; and

- 0.02 g/bhp-hr NOx Class 8 regional tractors and drayage trucks.

Additional engineering work and energy storage could lead to other potential application markets, such as:

- Cleanest combustion port and rail support equipment; and
- Clean combustion engines as range extender power plants for Class 8 extended range electric regional tractors.

Spark ignited combustion engines share core components, after-treatment strategies, and fuel systems with each other, and in general with the existing spark ignition engine marketplace. These engines are in the commercial deployment stage.

The compression ignition pathway involves very different engine and after-treatment strategies than the spark ignited pathway and has been on a different timeline for introduction because of these challenges. Nonetheless, that timeline has been solidified in 2020, at least in California, via regulatory requirements. When CARB approved its Heavy-Duty Omnibus Regulation for adoption last year, it required all heavy-duty engines to initially meet a 0.05 gr/bhp-hr standard by 2024 (75 percent reduction from U.S. Environmental Protection Agency [EPA] 2010 standards) and 0.02 gr/bhp-hr (90 percent reduction from EPA 2010 standards) by 2027. The U.S. EPA is also developing lower NOx standards for on-road HDVs in conjunction with setting GHG and ZEV policies as part of the "Clean Trucks Plan"[10] set forth by President Biden's August 2021 Executive Order that sets rulemaking targets with defined deadlines over the next decade.[11]

Once implementation dates are reached on a suite of new regulations for the cleanest combustion technologies, all applications and market segments will need to make use of compliant engines. The control and engine strategies could then be augmented to support the cleanest combustion technologies for off-road engines.

Once regulations are in place that require all diesel engines to operate at these stricter NOx emissions levels, the anticipated market for these clean combustion compression engines is expected to expand rapidly and in diverse applications. New technological approaches may also be available to further support the transition to clean combustion compression ignition engines; the Achates Power opposed piston engine has already

[10] EPA Regulations for Emissions from Vehicles and Engines Clean Trucks Plan

[11] Executive Order on Strengthening American Leadership in Clean Cars and Trucks | The White House

validated through testing the potential to reach the 0.02 NOx standard with an increase in efficiency over existing spark and compression ignited engines.

Given the on-set of regulations, the beachhead approach is less applicable to the compression ignition engine market. While the most likely beachhead for the cleanest combustion compression ignition engine might have been the Class 8 long haul application, as this represents the highest volumes and the potential for less complicated control strategies, regulations will now require all engines to meet the low-NOx standard of 0.02 gr/bhp-hr. Therefore, once the implementation dates are reached, all applications and market segments will need to make use of compliant engines. Importantly, once established, the control and engine strategies could then be accessed and adapted to support the cleanest land-based, off-road, combustion ignition engine applications such as CHE, construction, industrial, or agriculture. Although not within the three-year timeframe of discussion here, such off-road Tier 5 engine standards could possibly be proposed in 2024, and implemented starting in 2028, with emission reductions ranging from 50 to 90 percent of current Tier 4 standards. Further, future Tier 5 regulatory development would likely consider both efficiency and zero-emission transitional strategy aspects. Similarly, a compression ignited combustion engine could also be used as a power plant for an extended range electric regional Class 8 tractor. Figure 5 illustrates the updated Combustion Beachhead pathways, with the rapid expansion of compression ignition vehicle applications in Wave 4 spurred by the new Low NOx diesel engine regulations.

Technology Status Updates

Monitoring the status of key technologies is imperative to maintain the effectiveness of the investment strategy and track progress against set goals. With input from grantees and from industry stakeholders, CARB conducts an annual high level technology snapshot review to assess the generalized status and progress of the key technologies and representative platforms using the technology. The goal of these analyses is to provide valuable directional guidance on where important platforms are in terms of technology readiness for the market. This approach allows CARB to adjust investment recommendations to help further expand market and technology success or to further assist technologies moving more slowly or facing additional barriers.

As in previous years, for each of the critical pathways and technology categories, staff and CARB's grantee have prepared an updated high-level overview of the technology readiness assessment of the technology as it pertains to heavy--duty vehicles and off-road equipment. Building on the baseline approach established in

FY 2017-18, applications of the technology are characterized in terms of three general stages on the path to commercialization.[12]

> With input from stakeholders, CARB conducts an annual high-level technology snapshot review to assess the generalized status and progress of key pathway technologies and representative platforms using each technology, providing directional guidance on technology readiness for the market.

For consistency and to track progress, these updated assessments build on the assessments presented in the previous Three-Year Heavy-Duty Investment Strategy documents and adjust them for changes in the intervening year. While these assessments were originally built from technology assessments conducted by CARB staff over previous years[13] (in conjunction with staff from other agencies and industry stakeholders), the updates are based on reviews of additional or updated data and information from literature, public information sources, private conversations with technology providers, and field data where available.

[12] For additional information on technology readiness and market commercialization signals, see https://calstart.org/technology-and-market-readiness

[13] CARB. Technology and Fuels Assessment Reports. June 2015 to December 2016. https://www.arb.ca.gov/msprog/tech/report.htm

Industry Examples
Small Companies Support Big Technological Growth

Small businesses have supported and enabled the early MHD ZEV market. Vehicle upfitters and modifiers have created bespoke models that fit the specific needs of early fleet adopters. The ZEV deployments that small businesses have generated have helped to demonstrate the suitability of ZEV technologies, also generating new jobs and economic growth in the process.

Reviewing HVIP vouchers indicates that a few leading small companies have had a potent impact on California's early ZEV market. Companies that have predominantly manufactured buses and shuttles (Greenpower Motor, Motiv Power Systems, and Lion Electric), on-road trucks and vans (Phoenix Motorcars and Lightning Systems), and off-road yard trucks (Orange EV) have combined to manufacture over 560 vehicles for California fleets. This contribution accounts for nearly 30 percent of the total ZEV vouchers issued by the end of May 2021.

As larger fleets and manufacturers enter the marketplace, small business will continue to provide critical support in reaching California's and the nation's clean transportation goals. The U.S. Department of Energy (DOE) recognizes how critical small-business contributions are to the development of clean energy technological solutions—in June 2021, 235 small businesses were awarded $54 million in seed funding for projects ranging from electric vehicle batteries, advanced grid technologies, and more.[i]

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[i] DOE. June 2021. https://www.energy.gov/articles/doe-awards-54-million-235-american-small-businesses-developing-novel-clean-energy-and

In tracking this progress, it is important to keep in mind the goals of the Low Carbon Transportation projects as laid out and planned for in this document.

Fundamentally, Low Carbon Transportation is tasked with GHG reductions through strategic investments in technologies that provide GHG and other co-benefits. With the end goal of broader market acceptance, the strategy takes a layered approach: beginning first with vehicle technology readiness, and then building on that to understand other challenges to market acceptance, such as work site rules, unique duty cycles, and infrastructure costs. Taking these steps to understand the root issues of readiness and barriers greatly assists in formulating more nuanced and effective funding recommendations and priorities, as well as helping to shape regulatory structures.

These technology status "snapshots" are also unique in their design. They are broadly guided by the general framework of Technology Readiness Levels, or TRLs.[14] However, the approach used in these assessments is an adaptation of the TRL process that is applied not to a component but to a full vehicle platform. Therefore, the technology readiness portrayed is not intended to be absolute, but rather directional, to provide information on where pathway technologies generally reside and what supporting tools or funding could then benefit them.

The charted location of each platform or technology listed is not representative of any one specific product or vehicle, but is an aggregated average status based on the multiple platforms, vehicles and manufacturers and the different stages at which each may be. Each individual vehicle model that contributes to the platform/technology average is also provided a weighting, based on the type of manufacturer and numbers of units produced and fielded, where relevant. For example, the status level of a model from a vertically integrated global OEM would be weighted more heavily than a model from a start-up vehicle integrator. This weighting helps provide a realistic assessment of where a platform is in overall progress toward technical and commercial readiness. These platform/technology assessments are displayed as the general weighted average status of known platforms/technologies. This may mean a platform/technology could be shown in the pilot stage, even when there may be products from some manufacturers already in commercial production.

Challenges Affecting Low-Carbon Technology Acceptance

As platforms and technologies reach these late stages of transformation, CARB considers if technological challenges are still the technology's greatest concern, or if other market factors are the primary barrier—and whether Low Carbon Transportation is the appropriate incentive program to address those challenges. Challenges for each vehicle category and its respective platforms will vary, but several challenges transcend categories and are broadly representative of obstacles for new technologies in an established marketplace (including but not limited to):

- Higher Upfront Costs
- Infrastructure Costs and Timing

[14] NASA. Technology Readiness Level. October 28, 2012.
https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

Updates and refinements to last year's plan have been incorporated into the technology status charts that follow:

- The x-axis follows the TRL scores from 5 to 9 then into market transformation beyond 9, with those in the early demonstration stages shown on the left. Those that are closer to being commercially ready are shown on the right.
- The weighted average for the status of each platform is now shown by a square shape, while its status in the previous year is represented by a circle, showing any progress.
- The range of where different models under development fall in readiness within a platform category is now shown with range bars indicating the highest and lowest positions. Where meaningful, a downward arrow point shows the median point of status: meaning, half the models have lower status scores, and half above. This can inform where general industry capabilities lie.
- The y-axis shows the relative potential market volume size for that technology, with technologies that have a relatively small market size near the bottom and those with a larger market size near the top.

To aid in future assessments of technologies achieving technology transformation and moving into market readiness transition, a demarcation (a gradient shaded area) around TRL 8-9 is placed to identify applications that are transitioning from technology transformation to market transformation. As these technologies mature, they should be more carefully examined for market readiness and graduation to more appropriate or alternative incentive strategies. See the Market Transformation section on page 55 for further discussion.

Some of the progress noted is very solid year-over-year and is one signal of the early success of the investment strategy, particularly in areas where pilot and demonstration funding has helped validate vehicle designs.

Battery Electric Vehicles Technology Status Snapshot

Battery electric vehicle (BEV) technologies and key platforms are a critical element of the zero-emission pathway. They have improved continually in technology readiness in the past several years across most of the platforms assessed. This progress is most pronounced in the platforms that make up the first-success applications identified in the zero-emission "beachhead" strategy. Figures 6 and 7 depict the progress made across several on- and off-road BEV platforms.

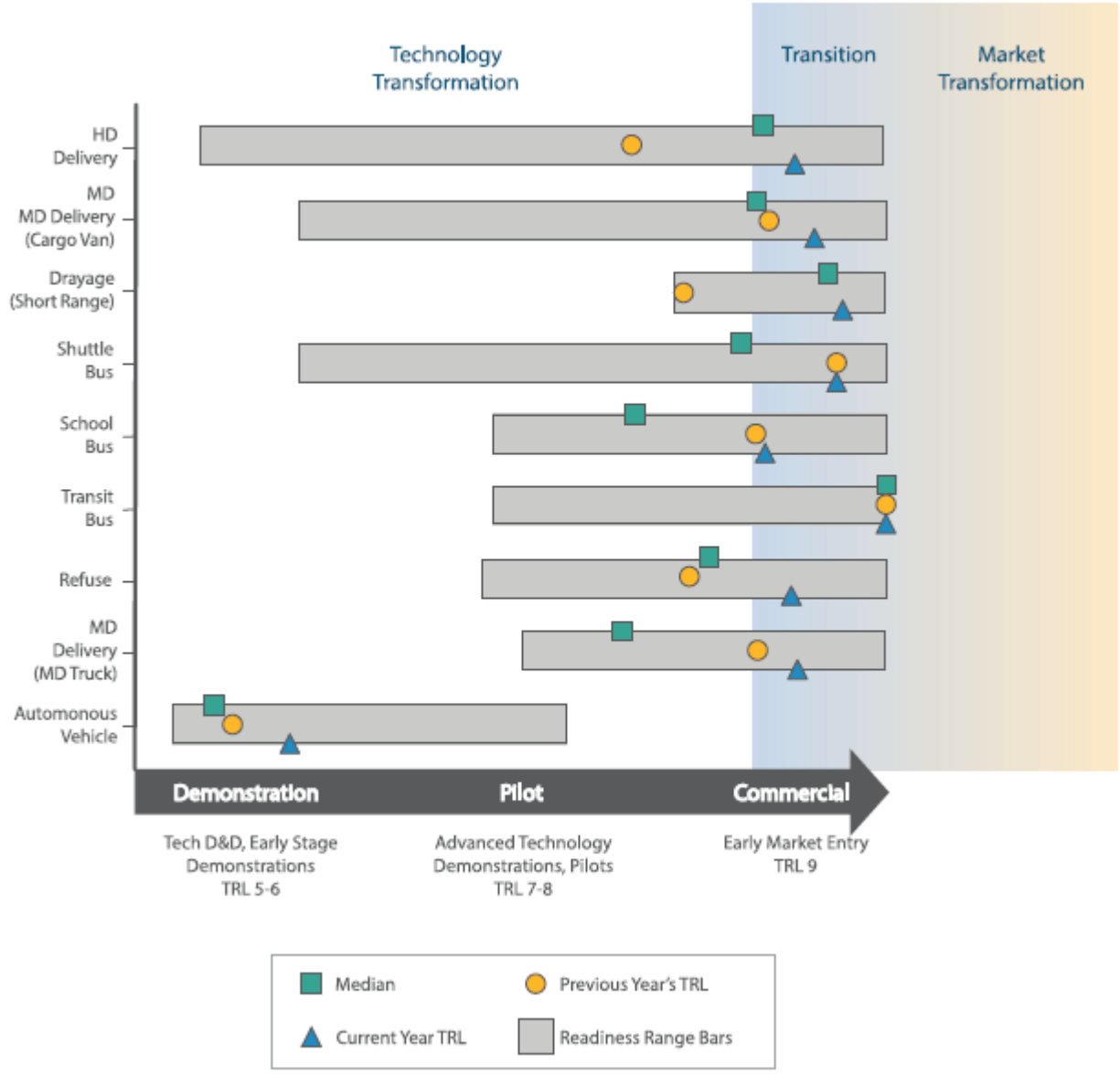
The full-size transit bus application (heavy-duty weight classes) remains an important first success application that is successful and growing. Every major North American bus manufacturer and several new manufacturers have products available for purchase and new players are entering the space. Importantly, this is not isolated to North America; strongest in China, this global phenomenon can also be seen in Europe,

India, and South America. There are now 13 electric bus makers with approximately 30 models available in the United States.[15] Last year more than 2,700 ZE buses were already deployed or ordered across the U.S.[16] The dominant percentage of these are BEVs, with approximately half of these buses in California, in no small part due to supportive incentive structures and the Innovative Clean Transit Regulation. Shuttle buses are also starting to see orders in the hundreds. While California's ZEV transit bus progress is exemplary for the U.S. market, more than 1,000 ZEV transit buses have been deployed in geographically diverse agencies across the nation, indicating that the technology continues to gain traction and advance toward full commercialization.

[15] CALSTART. ZETI. https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

[16] CALSTART. Zeroing in on ZEBs: 2020 Edition. December 2020. https://calstart.org/wp-content/uploads/2021/04/Zeroing_In_on_ZEBs_FINAL.pdf

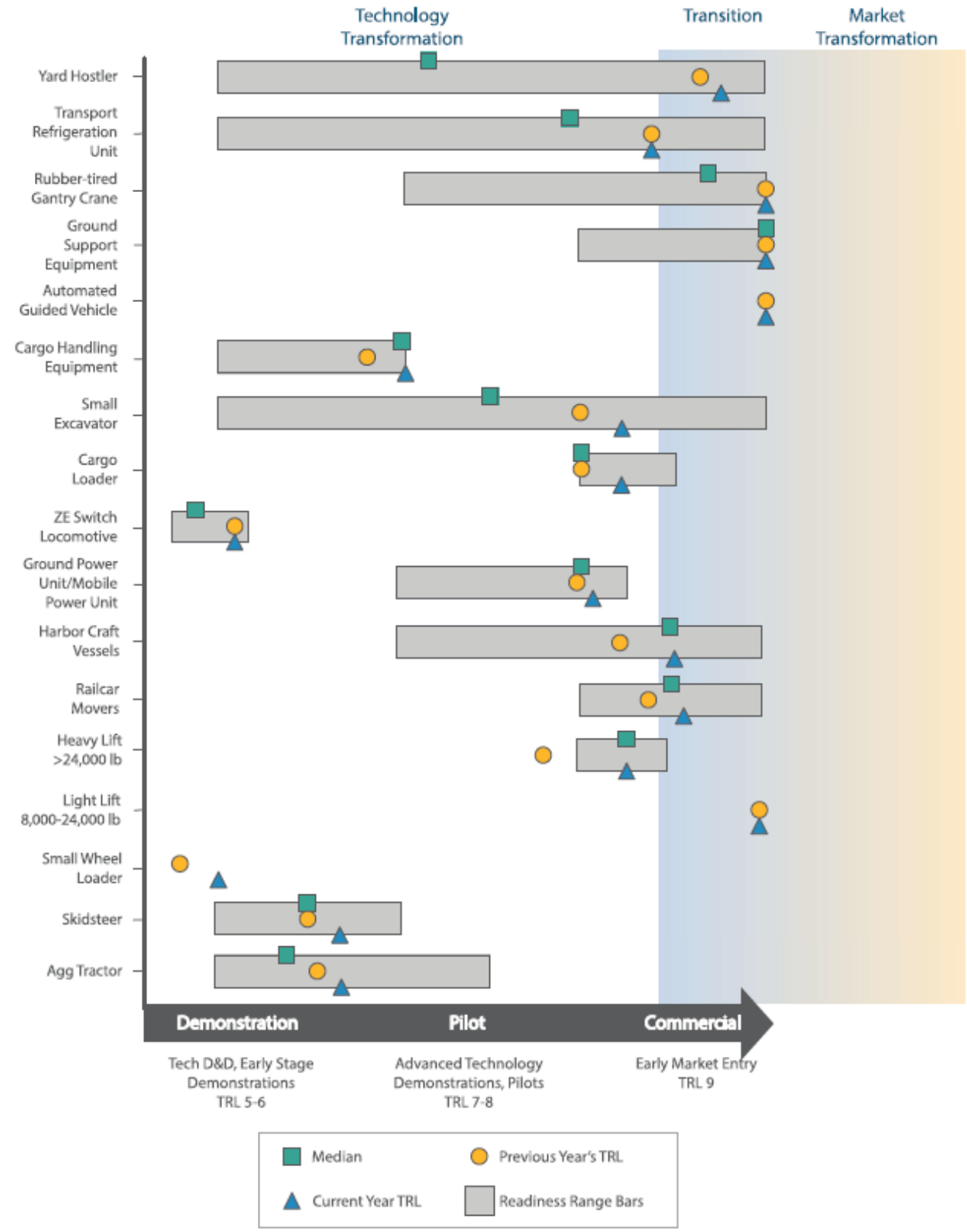
Figure 6: On-Road Battery Electric Vehicles Technology Status Snapshot



Most notably, heavy-duty delivery platforms have had a breakout year—all major manufacturers and several new innovators are now in active sales and product development stages. These applications are characterized by Class 7 and 8 heavy-duty drayage and regional haul trucks, and while the range of technology readiness is wide, their overall platform weighted averages have moved to early commercialization. Several large OEMs are close to production: Kenworth, Peterbilt, and Volvo will deliver trucks by late 2021 or early 2022. When HVIP reopened in June 2021, there were 364 vouchers requested for BEV Class 8 trucks.

Refuse trucks have expanded their market size and technological viability despite having a smaller potential market cap than other BEV applications. School buses and medium-duty delivery trucks and vans have also ventured further into the transition zone and remain a compelling technology moving forward.

Figure 7: Off-Road Battery Electric Vehicle Technology Status Snapshot



In the off-road sector, which is now tracked in a separate stand-alone chart, yard tractors and TRUs stand out for their technical status as early products and for their high demand in the Clean Off-Road Equipment (CORE) incentive project, with funding reserved for 127 and 96 units respectively in CORE as of September 2020. A total of 13 different manufacturers offers eligible equipment in the program, which includes battery-electric forklifts, railcar movers, airport ground power units, and mobile power units. The number of eligible manufacturers and models expected to expand during the next round of CORE funding.

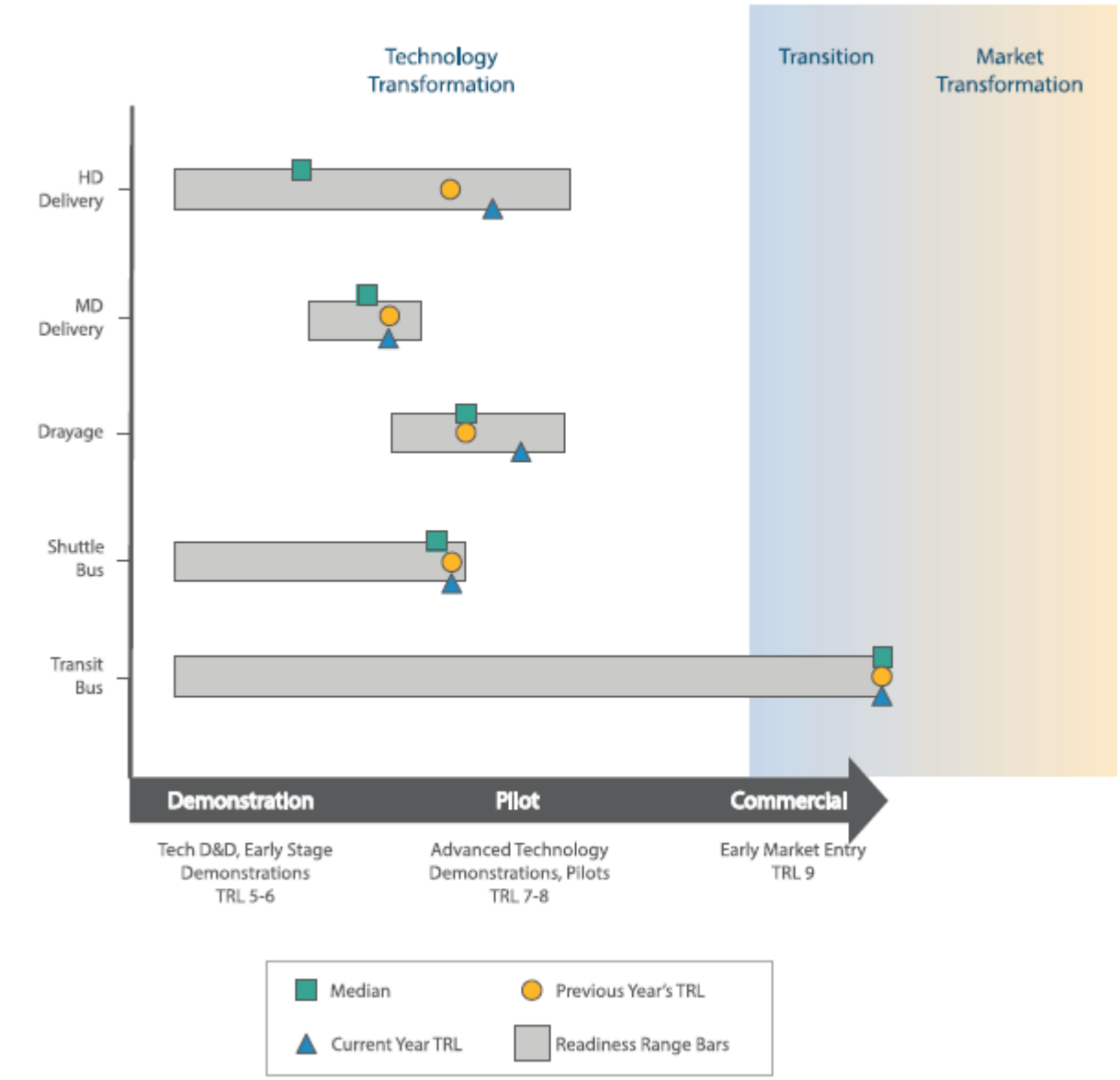
BEV harbor craft vessels and railcar movers have made strides and entered the early market transformation zone in the past year; early commercial BEV harbor craft vessels can even be seen in commercial applications, such as in Niagara Falls where the "Maid of the Mist" ferries and the Gee's Bend ferry in Alabama are entirely electric. Commercial ports around the world, including in Scandinavia, South Korea, and the Port of Istanbul have purchased BEV harbor craft vessels, furthering the case for commercial viability. These technologies require intense charging infrastructure but have proven to be able to replicate aspects of ICE duty cycles and can operate more efficiently under the right circumstances. Though the market for BEV harbor craft is relatively small and bespoke, the early progress in applying new, clean technologies has shown the flexibility and diversity of ZEV drivetrains that may quickly occupy a sizeable share of the smaller harbor craft market.

Several other technologies have come significantly closer to transitioning to early market this year, including cargo loaders, small excavators, and heavy lifts. Small excavators in particular have also secured a niche market for operation in building shells where diesel equivalents could create air quality concerns for workers. Utilizing this niche market, the first BEV mini excavator has reached a score of TRL 9, with others likely joining in the next couple of years.

Fuel Cell Electric Vehicles Technology Status Snapshot

Fuel cell electric vehicle (FCEV) technology has been gaining momentum as a solution for applications with needs for longer range, longer duration, faster fueling or other demanding duty cycles. FCEVs generally are at the late demonstration/early pilot phase for heavy trucks and continue to expand in forklifts as a successful commercial product. Demonstration activity in heavier lift and cargo handling equipment continues. Figures 8 and 9 provide an overview of the technology status of FCEVs.

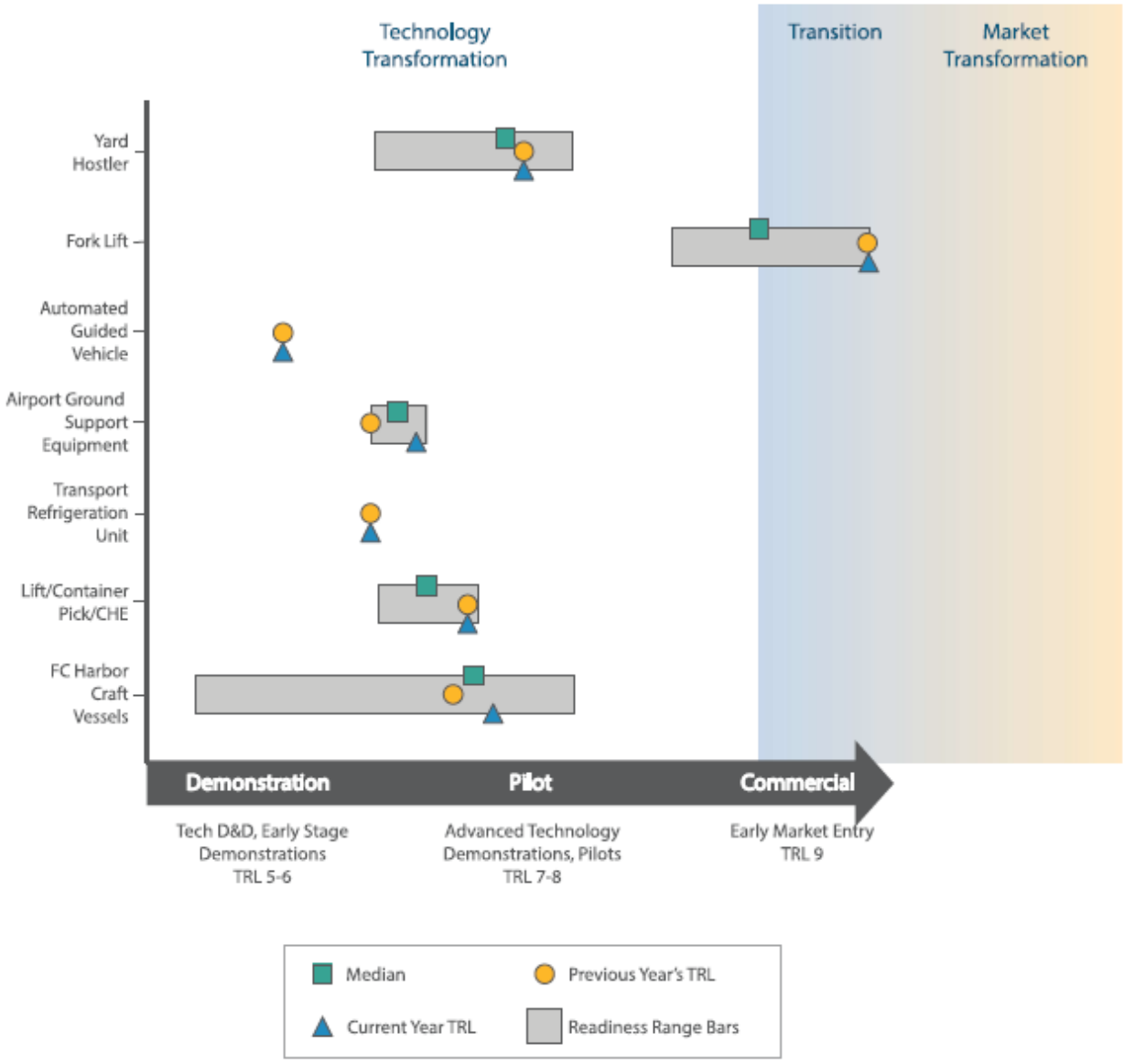
Figure 8: On-Road Fuel Cell Electric Vehicles Technology Status Snapshot



Fuel cell technology has gravitated toward heavier applications in the past several years. HD delivery and drayage are both prime candidates to take advantage of the benefits of fuel cell technology. These vehicles are the drivers of several large pilot projects at domestic ports, supported by global OEMs. The European market has announced plans for large-scale pilot projects in the coming years, creating a strong market signal for fuel cell HDV delivery and drayage manufacturers, though the segment's higher 2021 scoring is slightly limited by the uneven growth that few early manufacturers have.

As mentioned atop the fuel cell section, one of the reasons behind a growing interest in fuel cell electrification is the potential for quickly providing sufficient energy for long range or heavier cargo loads where higher capacity on-board energy storage is needed, or those work cycles requiring continuous operation or multiple-shift operation where time for recharging may not be an option. Such operations can make use of centralized, high throughput fueling stations that can be sited with on-location higher capacity hydrogen production facilities. While still in the prove-out phase, such production sites may allow for much lower cost hydrogen fuel production. Such high volume centralized fueling could serve as a base for a range of applications, such as port equipment, marine vessels, transit buses -and drayage trucks, as well as other regional applications.

Figure 9: Off-Road Fuel Cell Electric Vehicles Technology Status Snapshot



As illustrated in Figure 9 above, the off-road fuel cell vehicle models tracked here sustained minimal movement over the past year. Harbor craft vessels and airport ground support equipment did generate visible advancements, moving to the early pilot phase.

FCEVs have had their most successful break-out application to date with industrial forklifts. This core capability is exploring scaling to higher fuel use and weight applications, including potentially heavy lifts, cargo handling equipment, and the marine sector. Such applications could make strong use of centralized fuel production and fueling infrastructure in locations such as port sites. This is reflective of the

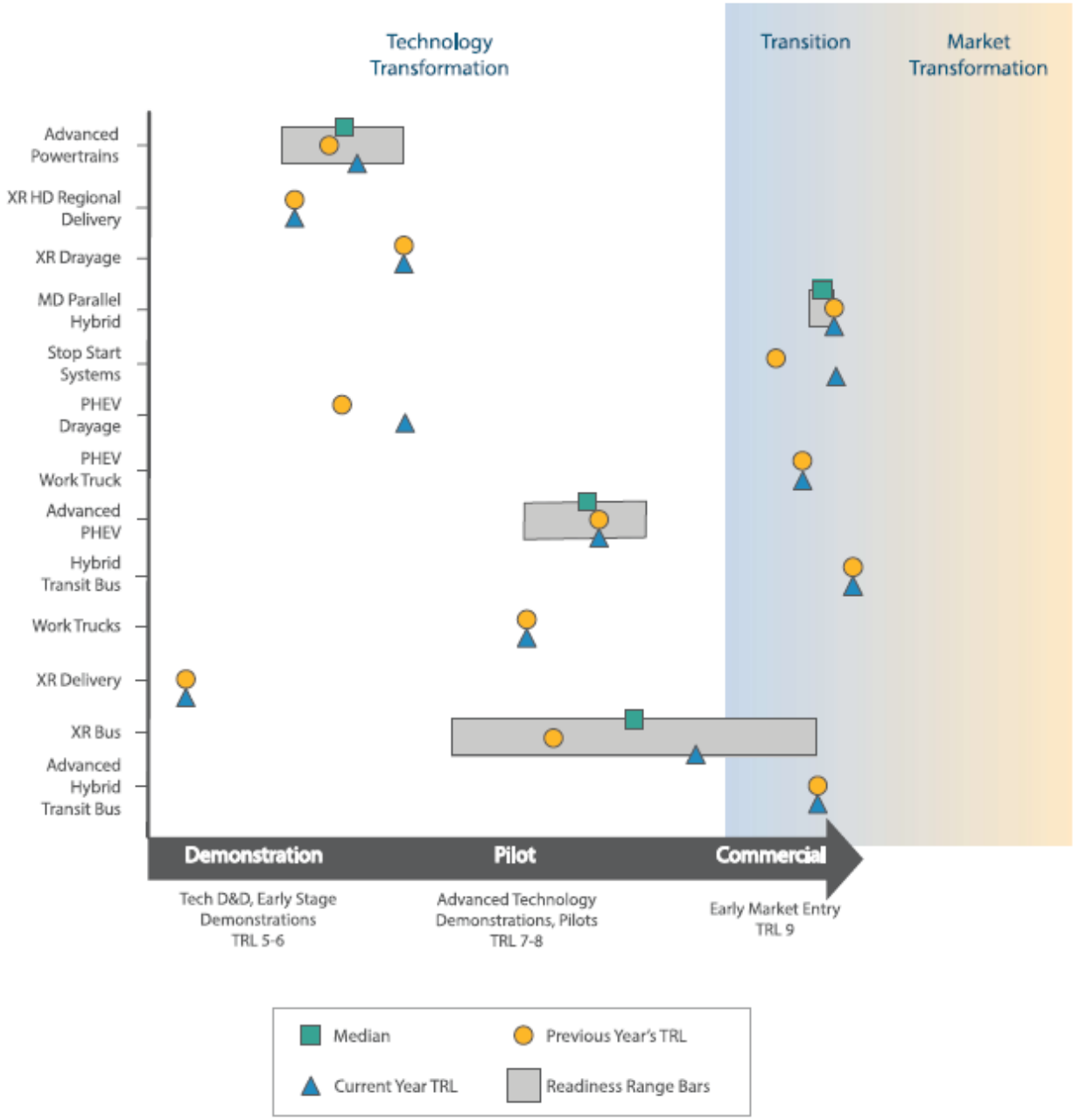
advancement seen in harbor craft vessels, which have seen a small advancement in TRL as new pilot projects scheduled for the next several years are announced. In Paris, a pilot project for commercial fuel cell cargo shipping is set to begin in fall of 2021.[17]

Hybrid Electric Vehicles Technology Status Snapshot

Hybrid electric systems share many subcomponents with battery electric and fuel cell electric systems. Manufacturers have added increased energy storage and the capacity to operate in extended zero-emission- mode with the addition of electrified auxiliary systems (such as air conditioning, heating, steering) to enable zero-emission operations. These augmented systems are currently at lower volume but build off existing hybrid products and can be considered early commercial stage. Development and deployment of electrified auxiliary systems for hybrids is helping to increase volumes and reduce costs for the systems, which can also be used by fully electric vehicles. Figures 10 and 11 depict the progress of the hybrid electric vehicles (HEVs) along the commercialization path.

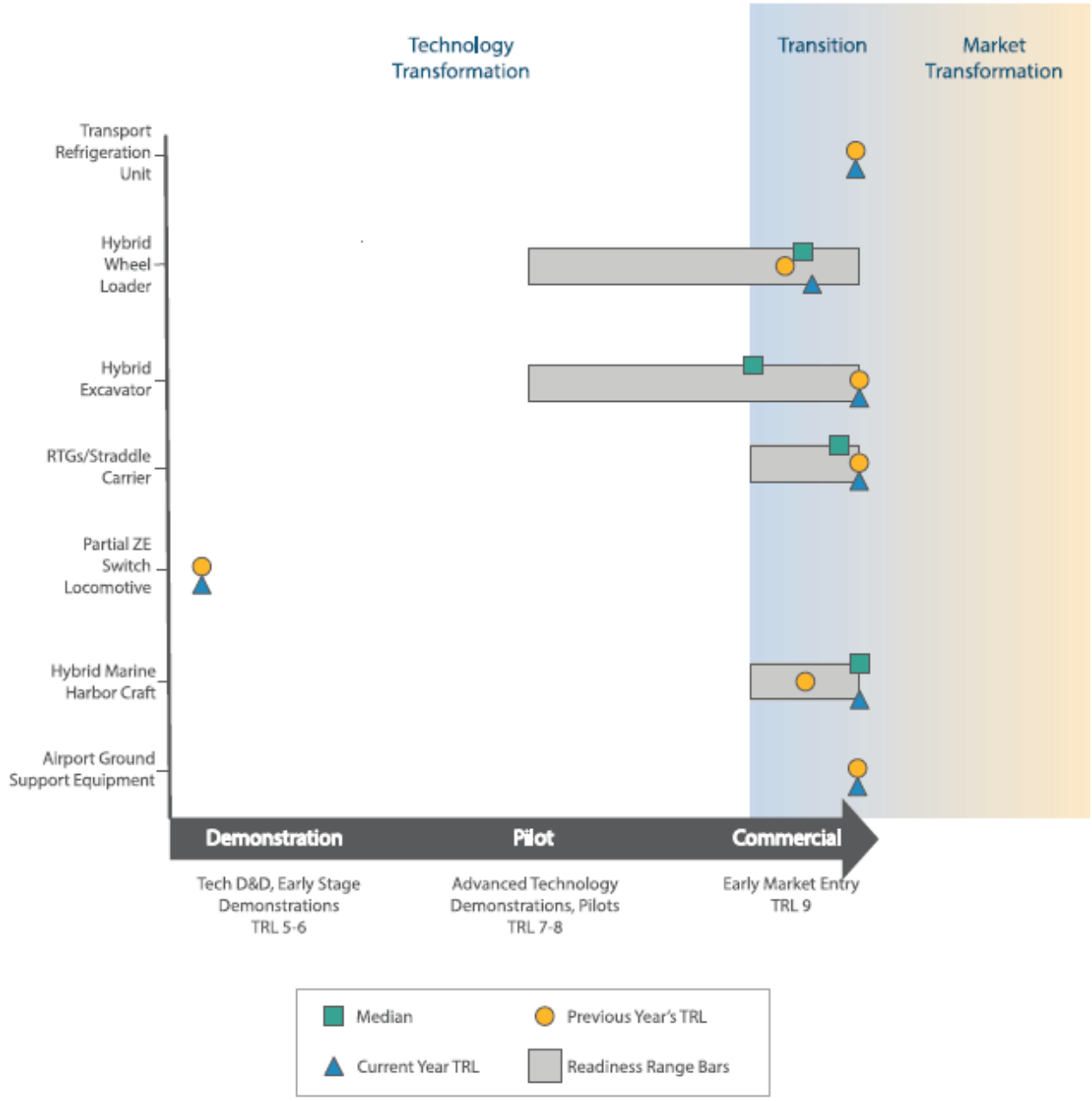
[17] https://flagships.eu/2021/04/07/worlds-first-hydrogen-cargo-vessel-set-for-paris-debut/

Figure 10: On-Road Hybrid Electric Vehicles Technology Status Snapshot



Stop start systems advanced almost fully to TRL 9 this year due to the wide applicability and acceptance of this technology. XR (Extended Range) buses are now nearly considered early market; this is significant movement from its position near late pilot status a year ago. Further, plug-in hybrid electric vehicle (PHEV) drayage is now entering early pilot phase.

Figure 11: Off-Road Hybrid Electric Vehicles Technology Status Snapshot



Hybrid wheel loaders, which are used for construction purposes as well as goods movement and freight uses, showed noticeable growth, and continues to transition through the early market stage, moving closer to TRL 9. Hybrid marine harbor craft also showed improvement over last year's TRL assessment and now is placed in at the early commercial phase.

Combustion Technology Status Snapshot

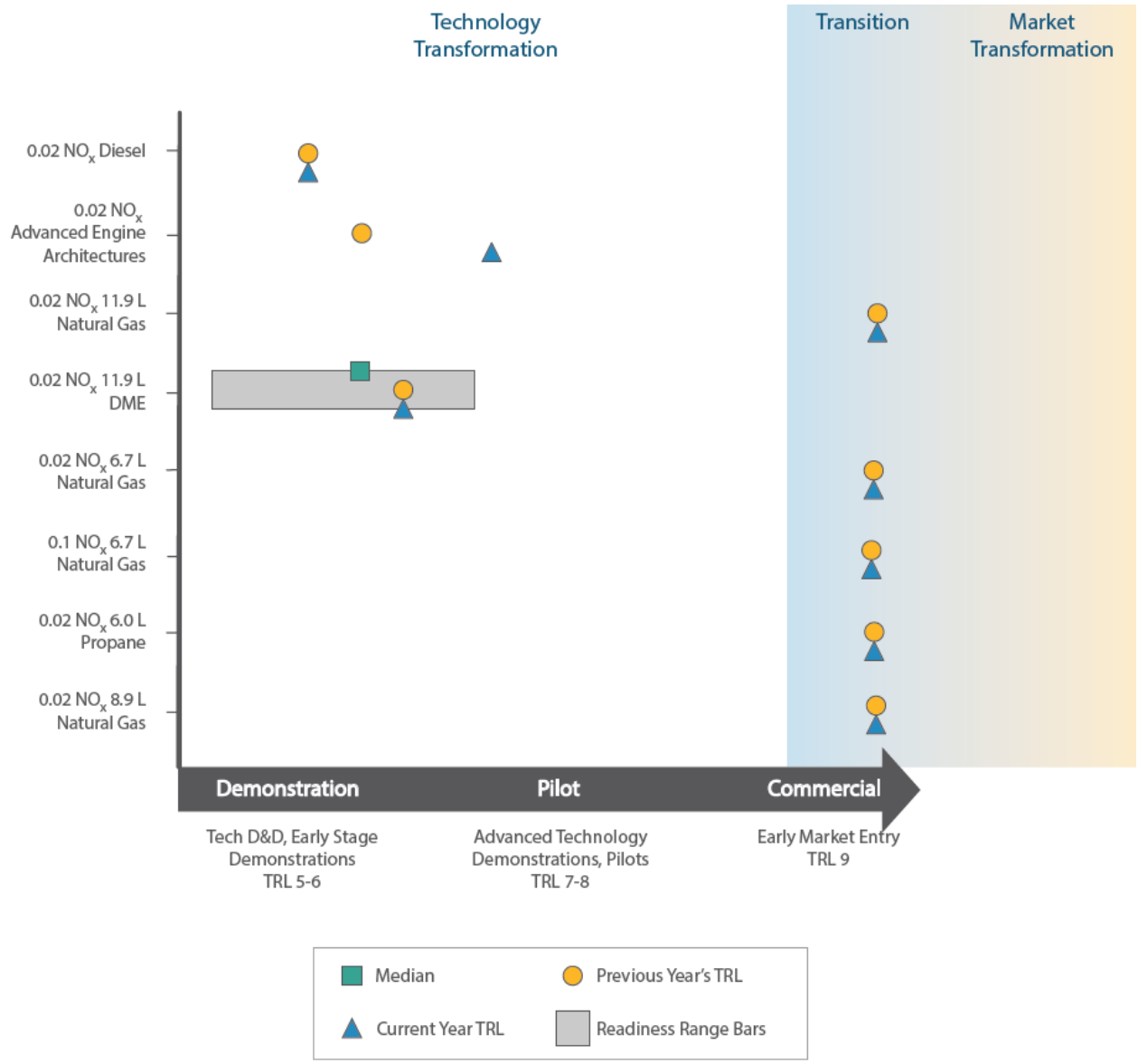
Combustion technology has successfully moved through the stages of the commercialization process - Figures 12 and 13 depict the progress made by the cleanest combustion engines over the past two years. This success, however, is due in large part to regulations aimed at reducing NOx emission levels.

The CARB Board in 2020 approved the Heavy-Duty Omnibus Regulation which, among several provisions, sets a specific timeline for achieving lower NOx emission levels:

- Requires engines to meet levels of 0.05 g/bhp-hr NOx by 2024 and 0.02 g/bhp-hr NOx by 2027 (90 percent reduction from EPA 2010).[18]
- Mandates levels be met via a testing procedure that better matches real-world operating conditions.
- Pending final rule allows manufacturers that produce and certify heavy-duty zero-emission vehicles by 2026 to generate NOx credits in order to incentivize the sales of heavy-duty ZEVs earlier than required by CARB's ACT Regulation.
- Incentivizes early emission reductions especially in critical areas like the South Coast and San Joaquin Valley by providing compliance credit multipliers to manufacturers that certify early to applicable emission standards.

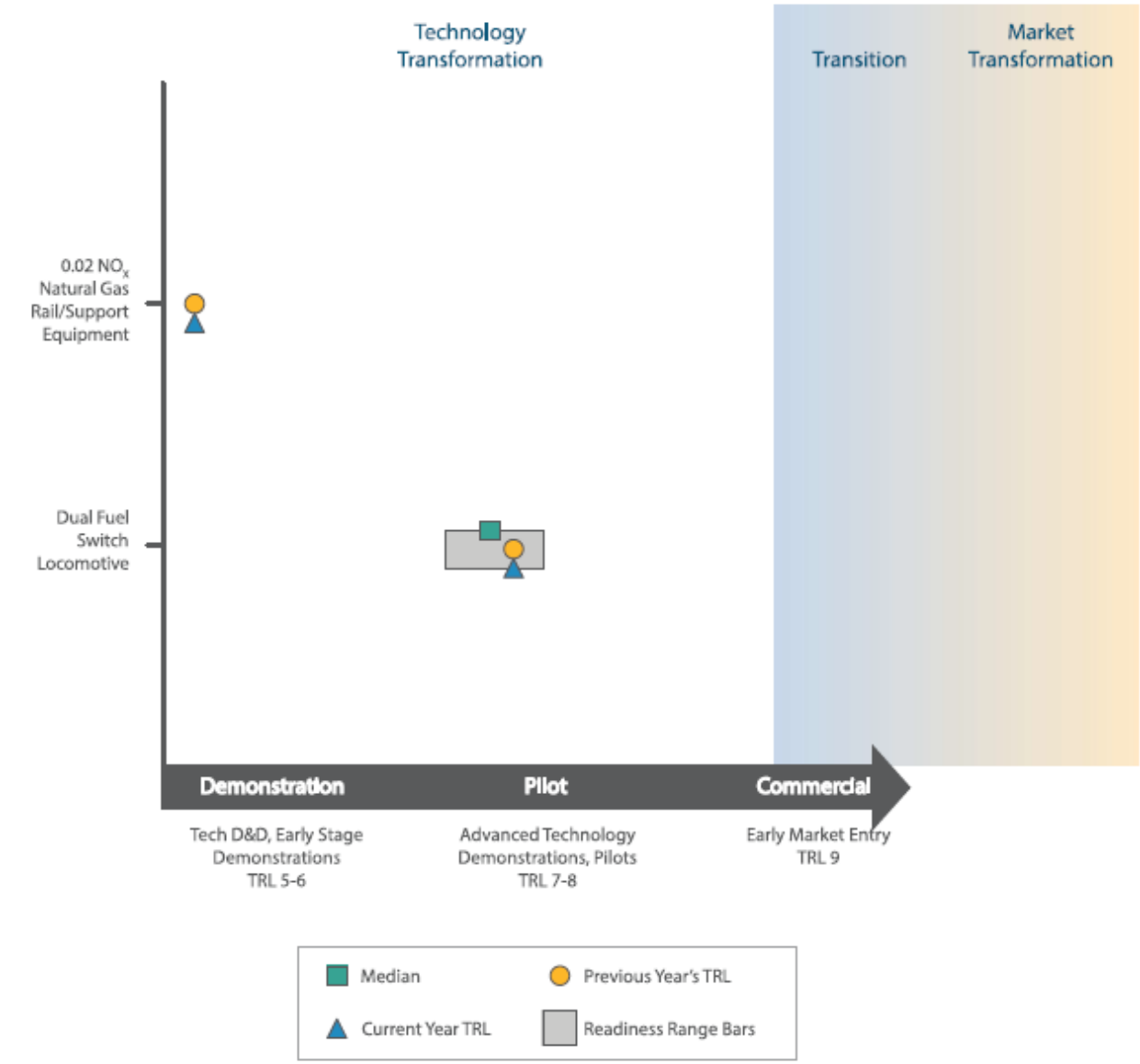
[18] https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox

Figure 12: On-Road Combustion Technology Status Snapshot



This year, growth was seen in the Advanced Engine Architectures platforms. These advancements were spurred by advancing pilot projects and demo projects. The score for DME has moved from early to late Demonstration due to information that was missed last year. The old score was also updated as a correction.

Figure 13: Off-Road Combustion Technology Status Snapshot



As illustrated in Figure 13 above, there were no visible advancements in the off-road combustion snapshots this year. Compression engines capable of meeting additional low-NOx (less than .02g/bhp-hr) off-road applications have been successfully tested and are expected for real-world demonstration testing in the coming years. These engines and their diverse off-road applications will support CARB's anticipated Tier 5 regulations and any forthcoming U.S. EPA off-road criteria and GHG improvement regulations.

Market Transformation

Conducting technology readiness assessments are an important first step in evaluating advanced technologies, but one that describes only part of the commercialization story. As technologies move toward full technical readiness, their commercialization status becomes more dependent on market readiness or market transformation.[19]

While the technology status snapshots provide an assessment of the level of advancement for emerging technologies, this can make for an incomplete picture. Market and economic factors can hold back what would otherwise be a technologically-advanced platform. Market transformation can be viewed through the lens of four main categories: current market scale, projected investment scale, service applicability, and economic feasibility.

- Current market scale describes the extent to which the marketplace has adopted a given technology platform. This category takes a commercially viable technology, as described by the TRL scores, to the logical step of assessing market impacts. Market acceptance may include several specific markers or signals that indicate a technology is more commercially viable. Sales volumes may provide the most direct evaluation of market acceptance—if a low-carbon vehicle platform is selling capably and cutting into the broader gasoline- or diesel-powered market share, the platform can be readily understood as commercially viable. Zero-emission yard trucks and transit buses, for instance, have sold in great volumes compared to other ZEV technologies. Zero-emission transit bus growth stands out as an early market technology that was supported by several incentive programs and demonstration investments, and whose sales volumes have indicated sufficient technological maturity to develop a regulation (Innovative Clean Transit) for this segment. By contrast, ZEV cargo handling equipment applications may be technologically viable, but sales volumes do not indicate a fully mature market for the platform.
- Investment scale conveys how committed manufacturers and suppliers are to technology platforms. If only a few manufacturers or suppliers are producing equipment or models for new technologies, costs will likely be higher, consumer choice will be limited, and production times are likely slower than in markets with large number of commercial manufacturers. For this reason, the number and size of manufacturers is an important signal for the maturity of vehicle platforms. Greater numbers of manufacturers create more consumer choice and vehicle models that can meet a range of applications. Larger OEM participation in the marketplace will help bring prices down due to economies

[19] For additional information on technology readiness and market commercialization signals, see https://calstart.org/technology-and-market-readiness

of scale and efficiencies in production processes. A greater number of zero-emission school bus manufacturers are scaling up production to help advance the technologically-ready segment, and zero-emission regional haul truck manufacturers are progressing through demonstration phases to bring their trucks to commercialization. In marine applications, new platforms are being tested by upfitting zero-emission technologies to existing ferry and tug platforms, but the segment lacks large-scale and OEM investment.

- Service applicability describes how well a technology fits the real-world applications of duty cycles. Newer technologies may have limited ranges, require regular access to refueling stations, and may have power limitations relative to established technologies. Applications that can immediately overcome these challenges will be the most commercially viable, and other applications that must address these before achieving market impact will require longer lead times to commercialization. Small BEV excavators perform well because they don't have large power requirements, often have access to power supplies to recharge, and can operate indoors without creating hazardous pollutants. Long-haul FCEVs are demonstrating that they can meet rigorous duty cycles in a Swiss deployment, where the lighter weight, fast fueling, and available torque has enabled a FCEV fleet to travel over one million kilometers since 2019.[20] This truck fleet can optimize shared infrastructure through targeted corridor stations that refuel FCEVs rapidly. Currently, BEV long-haul trucks can charge relatively quickly at a smaller scale, but shared and high-power corridor charging stations will require significant utility-grade infrastructure investments to enable the large-scale, high-speed charging that will support long-distance applications.
- Economic feasibility pertains to how affordable the new platforms will be for fleets adopting the new technology. This category may include factors such as incremental costs, operating costs (fueling and maintenance), hidden costs such as retraining staff or investing in new facilities, and others. These costs all impact a fleet's payback period, or the period of time that a new low-carbon vehicle project will need to break even with a conventionally-fueled vehicle project. Short payback periods are critical to fleet operators who view vehicles as income-generating investments. ZEV technologies typically cost more to purchase, but may cost less to fuel and maintain, creating an anticipated break-even point where fleet operators will save on the vehicle's TCO. Vehicles that cost less and are driven more will have shorter payback periods relative to gasoline- or diesel-powered operations. ZEV delivery vans and MD trucks have relatively short payback periods due to the smaller size of their batteries (lower

[20] Fuel Cell Works. July 2021. https://fuelcellsworks.com/news/fleet-of-hyundai-xcient-fuel-cell-trucks-surpass1-million-kilometer-benchmark-in-switzerland/

incremental cost) and their high mileage (fuel cost savings). ZE school buses, by comparison, drive relatively few miles and therefore do not achieve high fuel savings. However, bus operators and utilities are experimenting with vehicle-to-grid operations to explore additional revenue streams.

Ongoing Issues Affecting Market Transformation

There are a number of implementation variables that can affect how readily market transformation takes place. Any one of these can have an impact on progress towards successful commercialization. Many of these issues have previously been raised in stakeholder and industry discussions and are mentioned throughout the document. These issues are in addition to those associated with assessing technology status progress and success in continuing to grow and expand upon the beachhead pathways.

Last year's Strategy document focused on several key issues, including infrastructure, component costs, and a few others. For this year's update, the discussion will continue to look at infrastructure (as it is still one of the most frequently cited issues affecting market transformation), workforce training, small fleets, and TCO.

Infrastructure

Under AB 2127, the CEC publishes a biennial Electric Vehicle Charging Infrastructure Assessment, which is meant to address the charging needs of 5 million zero emission vehicles (ZEVs) by 2030.[21] Executive Order N-79-20 later directed the Commission to update this assessment to support expanded ZEV adoption targets. The Assessment finds that a portfolio of charging solutions will be needed to address site-specific real estate and grid constraints. In order to maximize grid integration, energy resilience, and ease of use for site hosts and drivers, charging equipment hardware and software should use common connector and communication standards. The Assessment also outlines the need for continued government support and funding, increased private funding, and a flexible and scalable framework to accommodate the growing charging market. CEC is working on updated infrastructure needs assessments that will integrate up to date fleet data from CARB.

CEC is also preparing to launch a first of its kind infrastructure incentive program—the Medium and Heavy-Duty Block Grant for Zero-Emission Vehicle Infrastructure Incentives - EnergIIZE Commercial Vehicles Project (Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles). EnergIIZE will help to advance electric charging, as well as hydrogen refueling infrastructure for MHD vehicles, by providing

[21] Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment. July 2021. https://www.energy.ca.gov/programs-and-topics/programs/electric-vehicle-charging-infrastructure-assessment-ab-2127.

incentives to buy down the cost of infrastructure. CALSTART, CEC, and CARB will be working together to design and implement this important project. The Governor's 2021–22 budget includes a three-year, $3.9 billion budget for ZEV-related investments for CARB, the Governor's Office of Business and Economic Development (Go-Biz) and the CEC. Of that package, the CEC will administer $1.165 billion towards infrastructure deployment to accelerate charging and hydrogen fueling station deployment and grants to promote instate ZEV and ZEV-related manufacturing, such as infrastructure equipment and ZEV components. The investments will help the markets for ZEVs and infrastructure grow to scale and serve as a foundation for an equitable and sustainable economic recovery by drawing private investments to California and creating jobs in manufacturing, construction, and engineering.

SB 350 requires California's electric utilities to invest in transportation electrification, and a number of programs have been already approved by the California Public Utilities Commission (CPUC). In 2018, the CPUC approved the first five projects from the three large investor-owned utilities. However, these programs are only available in the territories of the utilities providing the programs, and funding is not available through this program for the State's publicly-owned utilities. The CPUC and the utilities are planning and forecasting, as well as developing rate structures for fleets as a way of addressing concerns about grid resiliency and capacity as more fleets transition to ZEVs. Grid integration will also likely be an important component for achieving grid resiliency; multiple agencies are working on a framework for grid integration while the utilities are working on developing pilot programs to address this.

Workforce Training

Besides the critical importance of infrastructure, advancing market transformation will require support from an adequate service network, and achieving this will necessitate a workforce training and development program. A consistent concern among fleets is a shortage of technicians adequately trained to operate and maintain zero-emission fleets, as well as a lack of training programs and curriculum to stock the workforce pipeline. Some early leaders, especially public transit agencies operating zero-emission buses, have developed curricula and established Centers for Excellence. AB 841 also provides training opportunities focused on infrastructure installation. However, significant resources need to be dedicated to train the large workforce that will be needed to support thousands and—eventually—tens of thousands of drayage trucks, vans, cargo handling equipment, yard hostlers, and a wide range of other vehicles and equipment. CARB appreciates and supports the efforts of early adopter fleets to build a foundation of knowledge and has encouraged, through Low Carbon Transportation Demonstration and Pilot projects, the development of new curricula from learnings on new equipment types. A number of Low Carbon Transportation and AQIP-funded projects include workforce training components. The California Energy

Commission is also looking to address the needs of zero-emission vehicle workforce training with the development of the Inclusive, Diverse, Equitable, Accessible, and Local (IDEAL) Zero-Emission Vehicle Workforce Pilot. In addition, CARB is actively coordinating with other State and partner agencies, including the California Employment Training Panel, the California Conservation Corps, community colleges, transit agencies, and public utilities on workforce training and development.

Small Fleets

For FY 2021-22, CARB is proposing an Innovative Small e-Fleets funding set aside through HVIP, which would provide $25 million of pilot funding for incentives geared towards small fleets and independent owner operators of on-road vehicles. Implementing Innovative Small e-Fleets would allow for CARB to pilot a handful of innovative financing mechanisms including, but not limited to: open-ended leases, truck as a service, case management, as well as other mechanisms. Traditionally, small fleets, owner operators, and fleets served by the Truck Loan Assistance Program, have had difficulty transitioning to zero-emission trucks due to the high upfront costs and access to refueling infrastructure. By dedicating this set of HVIP funding to small fleets, an underserved group will get the support they need to transition to zero emission heavy-duty vehicles. CALSTART's Transforming Trucks, Transforming Communities effort also serves as an overarching campaign to reach small fleets, elevate communities, and accelerate the market equitably. These combined efforts to fund and engage with local businesses and community leaders help create a more equitable transition to zero-emission commercial transportation and invest in the health of community residents and success of small fleet operators. An estimated 40 percent of class 7-8 trucks in California are single-vehicle fleets (owner-operator), and there are about 40,000 such vehicles in the state in total, or 160,000 individual owner operators.

Component Cost Analysis

Incentive programs such as HVIP and CORE were created to overcome the most significant barrier to low-carbon vehicle adoption—higher incremental purchase or lease costs relative to gasoline- or diesel-powered equivalent vehicles. Alternative-fuel vehicles in general, and ZEVs in particular, cost more upfront. As clean vehicle segments mature and expand, higher acquisition costs for low-carbon transportation may be expected to decline, but prices depend upon many factors.

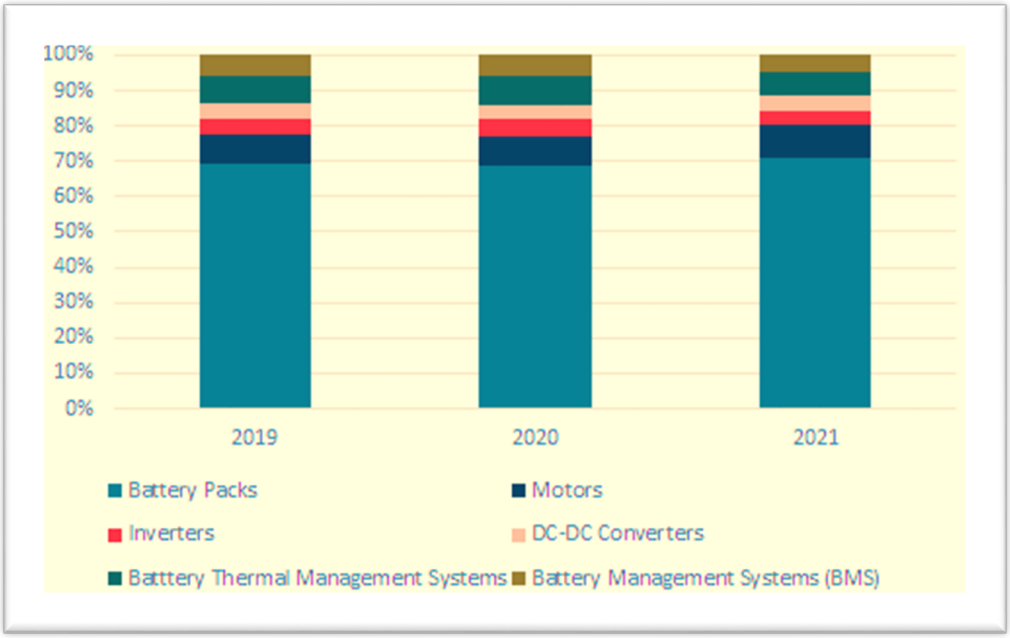
The following discussion on component costs focuses on ZEVs, which have the highest incremental costs of eligible vehicle technologies.[22] Incremental costs for HD ZEVs are largely attributable to the costs of batteries with the components that make up

[22] For additional information on component costs, supply chains, and other factors impacting low-carbon technology costs, see https://calstart.org/zero-emission-component-cost-study

drivetrains having a smaller contribution to overall cost of the vehicle. Each of these components is specific to ZEVs and represents an added cost relative to diesel vehicles. Following the beachhead model of successful component and supply chain integration, the cost to develop, manufacture and integrate these shared components could apply to many vehicle segments and applications.

As Figure 14 shows, batteries consistently account for the majority of average incremental HD ZEV costs, equaling nearly 70 percent in each of the past three years.

Figure 14: Incremental BEV Costs Over Time[23]



Battery Costs

The cost of batteries is a clear driver in incremental cost, and therefore a key factor related to ZEV uptake. HD ZEVs are particularly susceptible to high battery costs for two reasons: the larger vehicles need larger battery packs to meet the on-board energy storage needs of larger vehicles and cargo loads, and the costs of building battery cells and modules into purpose-built and low production volume packs is more expensive relative to light-duty applications.

Global EV battery production has ramped up steeply over the past decade, and improvements in design and production have accordingly reduced the cost for battery cells. Since 2010, global industry average costs for battery packs (light-duty) has fallen by nearly 90 percent, from $1,100 per kilowatt-hour down to $137 per kilowatt-hour

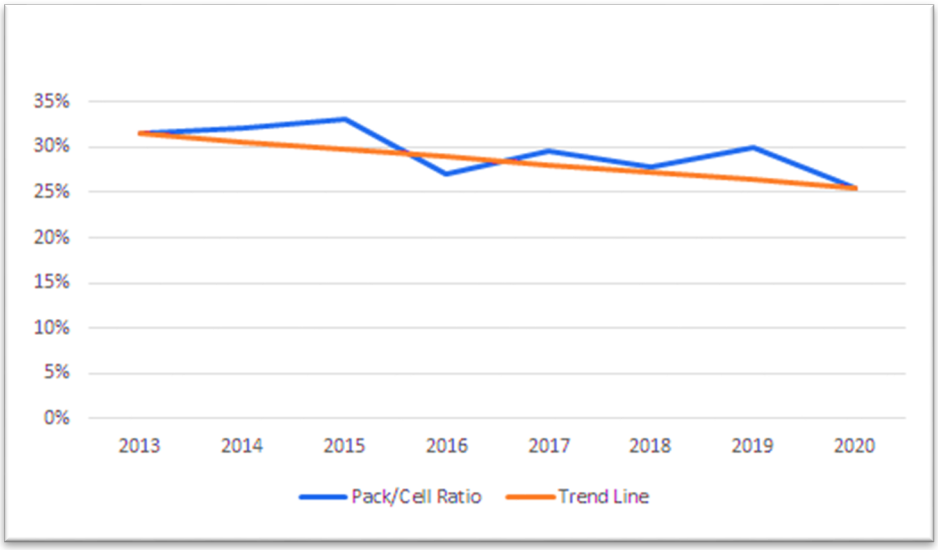
[23] Interact Analysis 2021

(kWh) in 2020 (according to research by Bloomberg New Energy Finance). Such a decline in battery costs presents tremendous potential for the broader electric vehicle industry to increase market share as purchase prices become cost-competitive with gasoline- and diesel-powered vehicles. Global costs are not representative of all markets, however – research by YUNEV indicates the U.S. industry average for light-duty battery cells is higher than the estimated average global battery cell prices. Research by YUNEV also indicates that Battery pack prices for HD vehicles in the U.S. remain higher than global average prices, coming in above $300 per kWh.

Additionally, and in most cases in the United States, the full value of lower battery cell costs is diminished when converting cells into battery packs, which can account for a large percent of the delivered cost of ZEV battery packs. Supplemental costs to transform cells into battery packs is typically higher in the HD applications than for mass-market passenger vehicles. The added costs of battery packs in the HD segment may stem from complex configurations to meet new models and relatively low volumes that do not benefit from mass-market production efficiencies. These complexities, combined with supply chain and production disruptions arising from the 2019 coronavirus outbreak, have restricted HD battery pack cost improvements to zero annually across all battery chemistries in the past three years. Some variability between battery chemistry costs has emerged – for instance, the LFP (Lithium Iron Phosphate) battery chemistry has experienced a cost reduction of 16 percent annually over the past two years. The trend in the overall cost of batteries, however, has been stalled by increasing prices for other prominent chemistries.

Greater production volumes and the proliferation of standardized production models will likely reduce HD battery pack costs. In the light-duty sector, battery pack construction represents a smaller percentage of total battery costs, and the percentage continues to reduce as companies improve their processes and increase production volumes, thereby reducing overall vehicle costs and encouraging consumers to purchase EVs (see Figure 15 below).

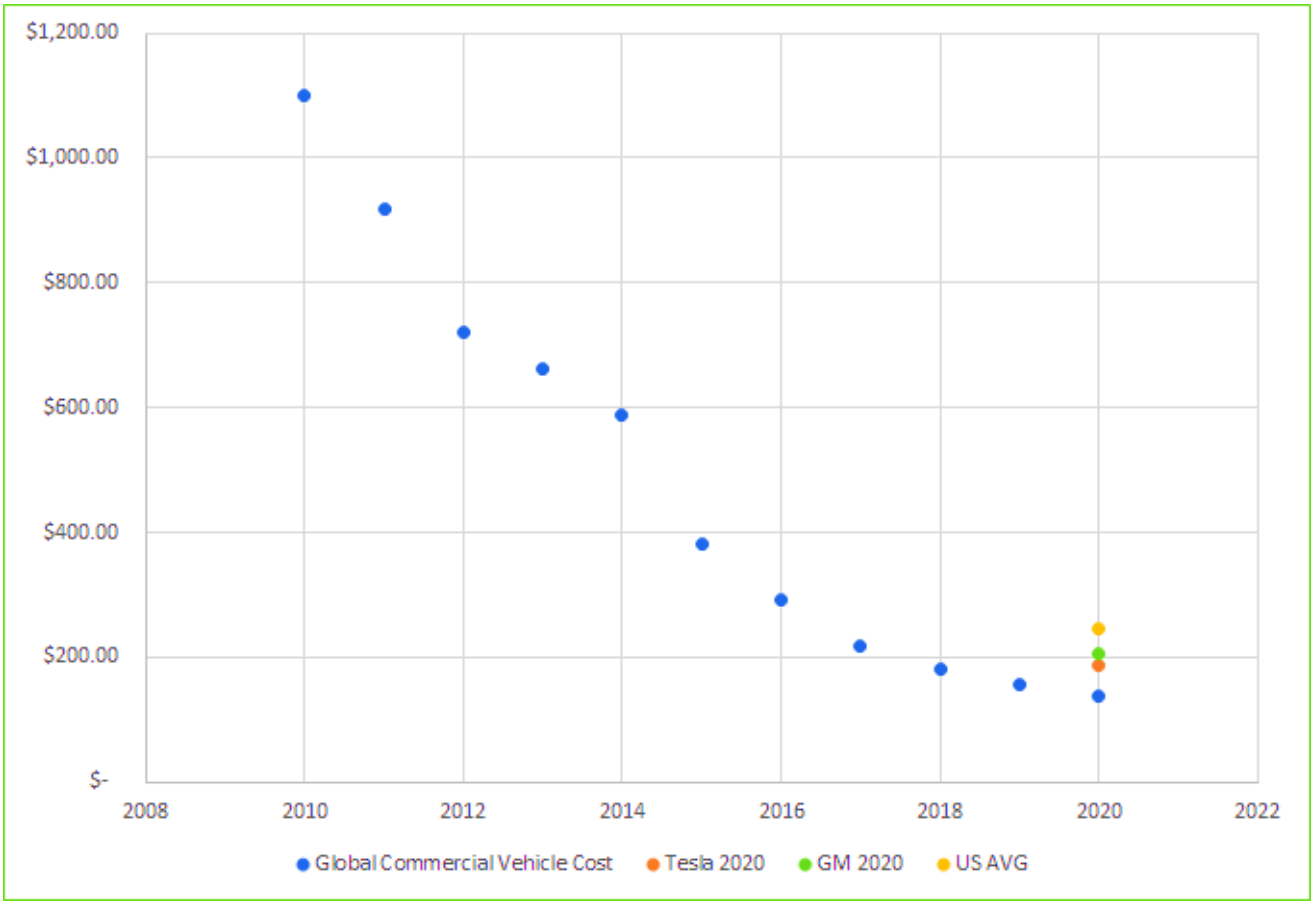
Figure 15: Battery Pack Construction Costs as a Percentage of Total Battery Costs Over Time (Light-Duty) [24]



Some manufacturers have developed a competitive advantage for access to lower-cost battery cells. In the light-duty market, Tesla's estimated average battery packs cost $187 per kilowatt-hour, and GM's estimated average battery packs cost $207 per kilowatt-hour. These companies have achieved their cost reductions through large company-owned battery production facilities or through large-scale purchasing contracts, respectively. Their lower battery costs also reflect the supply chains and investments made in light-duty applications that will benefit HD products. As the higher $246 per kilowatt-hour average industry U.S. battery pack cost indicates, most light-duty firms are not yet able to achieve such cost reductions and may often exceed the industry average. Access to established manufacturing capabilities also creates a challenge for most HD manufacturers as they continue to grow their battery supply chains. Figure 16 below illustrates the relatively high 2020 battery pack costs for Tesla, GM, and the United States on average as compared to the global light-duty commercial vehicle cost. The average global battery cost is lower than the cheapest US batteries, primarily lowered by inexpensive batteries from China.

[24] BloombergNEF. December 2020. https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

Figure 16: Battery Cell Costs Over Time by Geography and Select Manufacturers ($/kWh)



Drivetrain Costs

Zero-emission drivetrain components, though not as significant as batteries, add to the incremental costs of HD ZEVs. Descriptions of ZEVs' major incremental cost sources and the components that make up ZEV drivetrains can be found in Table 3.

Table 3: Sources and Descriptions of ZEV Component Costs

Source	Description
Battery pack	A device or container consisting of one or more electrochemical cells, in which chemical energy is converted into electricity and stored and later used as a source of power. This excludes supercapacitors.
Electric Motor	A machine that converts electrical energy into mechanical energy/motion.

Source	Description
Inverter	A machine that converts direct current (DC) into alternating current (AC). In practice, inverters often also include control/intelligent functionality and rectification (AC-DC) for returning energy to the battery during braking.
DC-DC converter	A device that converts a source of DC from one voltage level to another.
Battery thermal management system	A system that regulates temperature level and distribution, typically using systems of cooling heating, insulation, or ventilation, to keep the battery within parameters that are optimal for safety and lifetime.
Battery management system (BMS)	An electronic system that manages the state of the battery to keep it within safe operating parameters, controlling factors such as voltage and charge of each cell.

These drivetrain components have largely been established for several years, and therefore costs have not reduced significantly—based on Interact Analysis' proprietary data set, costs for commercial EV drivetrains have reduced 4 percent annually since 2019. These costs, like battery packs, are attributable to unique HD designs and low production volumes. These costs may also be impacted by supply chain and production disruptions from the 2019 coronavirus outbreak, so it is possible that further and deeper cost reductions will be achieved in the next few years as supply chains recover. Since some of these components could be transferable between platforms, growing HD ZEV demand should support scaled-up production of each component, and with greater production volumes these component costs are likely to decline.

Incremental Costs

While commercial HD battery pack and EV drivetrain prices have not reduced as quickly as in the light-duty segment, market indicators suggest that in the coming years prices will fall more dramatically. Revenue from both batteries and EV drivetrains have more than doubled since 2019, according to market research from Interact Analysis. This expanding revenue stream is indicative of a rapidly growing market and a rapidly increasing demand for these products. Rapid expansion of the market will lead to a higher and more stable demand for batteries, leading HD

> Higher incremental costs will persist for the immediate near-term. In this context, incentives will remain integral to bridge the gap to commercialization for HD ZEVs and to support the growth of and investments in the commercial ZEV sector.

manufacturers to lower costs in the long run by devoting more resources to improving battery and electric drivetrain supply chains. Many leading truck OEMs and parts suppliers are currently developing key supply chains for these crucial components and will ultimately lead the industry into an increasingly competitive and profitable market.

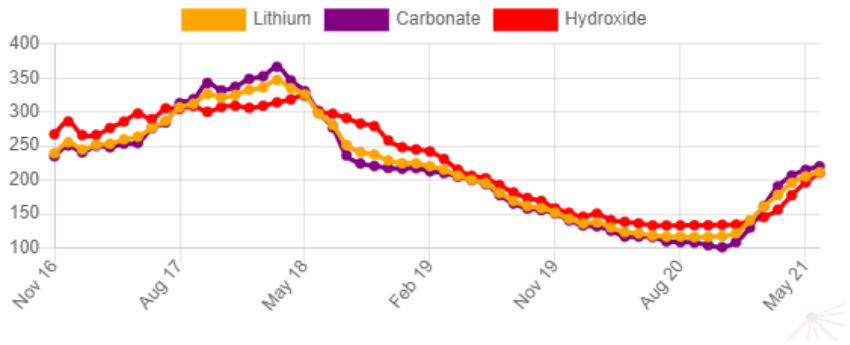
While price reductions are expected on the horizon, the relatively low rate of battery pack and drivetrain cost decline suggest that higher incremental costs will persist for the immediate near-term. In this context, incentives for HD ZEVs seek to bridge the gap to commercialization by targeting incremental cost of zero emission vehicles as compared to conventional vehicles and will remain integral to supporting the growth of and investments in the commercial ZEV sector.

Supply Chains

Securing predictable and reliable supply chains for the raw materials that make up batteries, the single largest driver of high HD ZEV incremental costs, is critical to reducing costs and volatility. The price of batteries is strongly tied to the costs of these raw materials. Figure 17 below illustrates the cost of lithium, carbonate, and hydroxide over the course of November 2016 to May 2021.

The cost of lithium, which is the main component of industry-leading lithium-ion battery configurations, provides a good example of volatility in the marketplace. Lithium is relatively inexpensive and abundant, but mining operations are still securing rights to deposits and scaling up operations to meet rapidly expanding global demand. Though the cost of lithium has fallen in recent years, recently prices have spiked. Battery manufacturers and OEMs without sufficient reserves of lithium and associated raw materials may be exposed to market fluctuations that add costs to the prices of battery cells, which are already high relative to internal-combustion vehicle designs.

Figure 17: Cost of Essential Battery Materials[25]



[25] Benchmark Minerals. Lithium Price Index. https://www.benchmarkminerals.com/

Though EV batteries manufacturers compete in a global marketplace, domestic raw material production may result in less expensive battery packs due to lack of tariffs and shipping costs while also creating new economic opportunities. As of July 2021, the United States has only one large-scale lithium mine that supplies approximately two percent of the world's lithium. The outlook for lithium production is more promising in coming years and may yield a tenfold increase in domestic output by the end of the decade. Mining operations in Nevada are poised to produce $3.9 billion of lithium, and new opportunities in brine ponds such as California's Salton Sea can potentially be used for large-scale lithium extraction in a more environmentally sustainable manner than a conventional mine.[26] Other potentially viable brine ponds can be found in Arkansas, Nevada, and North Dakota. Recent announcements by OEMs to secure domestic lithium supplies indicate that OEM's are working quickly to secure lithium supply for their increasing EV needs.

Lithium and other raw materials used in batteries and drivetrain components are not only vulnerable to price spikes, but also to variations in how they are used in ZEV components. Lithium-ion batteries are currently the dominant industry battery chemistry, and cobalt has been a critical and expensive material that the U.S. DOE describes as the highest material supply chain risk for EVs in the short- and long-term.[27] Even if battery manufacturers and OEMs are able to secure these raw materials, battery designs may shift away from using these and other materials. Battery improvements touting solid-state designs that shift away from lithium-ion or cathodes that reduce or eliminate cobalt use could improve performance and reduce costs, but would also require large-scale investors in those raw materials to quickly alter their commodity investments and production plans.

Similarly, rare earth metals are used in electric motors and impact drivetrain costs. Deposits of these metals are few and typically found in foreign nations, making the market for them competitive and oligarchic, with prices potentially manipulated by a few controlling interests. Investments in rare earth metals may be expensive and necessary, but new designs that reduce or eliminate their use may emerge that render these investments costly and unnecessary. This uncertainty over the sources and incorporation of rare earth metals is emerging in the marketplace, as trade friction with Chinese-controlled rare earth metal suppliers has encouraged automakers to develop new designs that eliminate or reduce the need for rare earth metals.[28]

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[26] The New York Times. May 2021. https://www.nytimes.com/2021/05/06/business/lithium-mining-race.html

[27] Vehicle Technologies Office. April 2021. https://www.energy.gov/eere/vehicles/articles/reducing-reliance-cobalt-lithium-ion-batteries

[28] Reuters. July 2021. https://www.reuters.com/business/autos-transportation/china-frictions-steer-electric-automakers-away-rare-earth-magnets-2021-07-19/

The uncertainty inherent in the evolution of EV batteries may have the greatest impact on OEMs that have incorporated vertical integration into their supply chains. Vertical integration is an impactful way to reduce battery costs per kWh by streamlining supply chains and processes, but also exposes vertically integrated companies to risk if battery designs shift significantly. Along with the large capital investment and increased risk of building the infrastructure, scientific breakthroughs in battery technology may render the current battery technology obsolete. If a new generation of battery is developed that makes lithium-ion batteries obsolete, companies that have invested in vertically integrating their battery component supply chain will have a much harder time pivoting than companies that buy battery cells and assemble them into battery packs.

Recent semiconductor chip shortages have slowed vehicle production across the automotive market. Shortages have mostly impacted high-volume light-duty vehicle manufacturers, though continued supply constraints may create more significant delays in medium- and heavy-duty segments that have already begun to impact truck manufacturers, particularly as demand has increased over the past year.[29] [30] Some automakers have begun to prioritize EV manufacturing with available chips to meet their production commitments.[31]

Priorities for Low Carbon Transportation Investments

Each year, the Long-Term Heavy-Duty Investment Strategy includes an updated assessment of projected funding needs and recommended priority investment areas for Low Carbon Transportation funds. These priorities for investment are shaped by relevant guiding legislation, such as SB 1204 and SB 1403, and also take into account the following:

- Evaluation of the updated technology status and progress made;
- Identification of areas where accelerated progress has been made, and additional funding could further support technologies in reaching the market;
- Identification of areas where progress has been slower, and a targeted approach to eliminating barriers could help to aid further development; and
- Additional sector-specific research, as well as conversations and feedback from industry as part of this Strategy update, including stakeholder input from public work group meetings and one-on-one discussions.

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[29] Wall Street Journal. August 2021. https://www.wsj.com/articles/chip-shortage-curtails-heavy-duty-truck-production-11630661401

[30] Reuters. August 2021. https://www.reuters.com/business/autos-transportation/truckmaker-volvo-profit-just-misses-view-chip-shortage-weighs-2021-07-20/

[31] CNBC. August 2021. https://www.cnbc.com/2021/09/06/vw-ford-daimler-fear-chip-shortage-could-persist-for-some-time.html

It is important to note that the levels of funding recommended do not represent the total funding necessary to support the technologies needed for fleet transformation. Rather, these amounts are guided in part by an assessment of OEM and supplier capacity for producing a meaningful number of demonstration and pilot projects during the three-year investment strategy timeframe. These recommendations are designed to ensure that State funds are focused on the technologies that need to advance in commercialization over the next three years in order to impact 2030 and 2050 outcomes, while also providing benefits today. If additional resources were to become available, the transformation of the heavy-duty and off-road sectors could happen more quickly, and significantly increased funding could help spur manufacturers to increase production capacity, provide additional fleet support, training, and infrastructure.

Keep Expanding Successful Beachheads and Pathways

The beachhead markets continue to show success and have been establishing footholds in other areas. For instance, advances in zero-emission drayage and regional delivery have developed from the progress made with the transit bus beachhead, which continues to experience year-over-year growth. It will continue to be important that the first beachhead market successes noted here be consolidated and further expanded.

Priorities for the on-road sector:

- Supporting local and regional heavy-duty drayage and delivery truck deployments and their associated community health improvements through efforts such as 'Project 800,' which aims to secure 800 drayage truck purchase commitments by the end of 2021.
- Shifting the larger focus from deployments of a few large fleets to helping out a greater number of smaller fleets.
- Continuing to support ZEV transit buses, giving a priority to hydrogen fuel cells, which have the potential to provide longer range operations. This includes helping to develop larger scale infrastructure, service, and component volumes to move these products closer to full market readiness.
- Continuing to support the transformation of school bus fleets to ZEV.

Priorities for the off-road sector:

- Deploying heavier cargo handling equipment.
- Continuing to develop zero-emission and hybrid marine applications.
- Continuing advancements in lighter construction and agricultural applications while supporting the development of heavier applications.
- Innovating and supporting early advances in rail and mining equipment.

Industry Examples
Pacific Ports to Create Demand for Off-Road ZEVs

The Northwest Ports of Seattle, Tacoma, Vancouver, British Columbia, and the combined container operations of The Northwest Seaport Alliance announced new zero-emission targets for seaport-related activities this year.[i] Under the Northwest Ports Clean Air Strategy, the ports will work to: transition equipment, fuels, and infrastructure; support cleaner air for local communities; and help limit global temperature rise to 1.5°C.

With the ports of Los Angeles and Long Beach—the two largest ports in the United States—committed to similar zero-emission targets, the West Coast is now poised to emerge as a corridor of opportunity for zero-emission off-road vehicles. The combined port authority of Seattle-Tacoma is the U.S.' third largest in terms of cargo handling and container volume with a total of 3.7 million twenty-foot equivalent units (TEUs) in 2019,[ii] and Port Metro Vancouver is Canada's largest port at 3.4 million TEUs in 2019.[iii] With Los Angeles and Long Beach's combined 2019 TEUs of 16.9 million, these four ports authorities will likely result in an estimated 37 percent of the U.S. and Canada's total cargo throughput seeking zero-emission technology for handling and movement. This zero-emission shift will produce an inherent increased demand for the sale and manufacture of zero-emission off-road vehicles to achieve emission goals and reduce local health impacts while continuing to facilitate such high levels of port activity.

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[i] Port of Seattle. Northwest Ports of Vancouver, BC, Seattle, and Tacoma Ain to Phase Out Maritime Emissions by 2050. April 2021. https://www.portseattle.org/news/northwest-ports-vancouver-bc-seattle-and-tacoma-aim-phase-out-maritime-emissions-2050

[ii] Bureau of Transportation Statistics. Port Profiles. 2020. https://explore.dot.gov/views/PortProfiles2020/HomeDashboard?%3AisGuestRedirectFromVizp

Target Promising Next Pathway Markets

Subsequent application technologies that are in the development pipeline need to continue to be supported and brought through the development stages to early production. Ensuring that consistent and robust funding is available will ensure that these beachhead technologies keep expanding.

Key pilot stage priorities include:

- Continuing to build out larger zero-emission ecosystems at the facility, corridor, and/or community level.

- Deploying more zero-emission construction and agriculture equipment.
- Supporting development of longer-range goods movement applications.
- Developing strategic range extenders for applications where zero-emission options are not yet feasible.
- Building on zero-emission switcher rail technology advancement.

Focus on and Expand the Innovation Pipeline

Maintaining momentum in the "innovation pipeline" for a number of early stage technologies is going to be necessary for meeting State climate and air quality goals for 2030 and beyond. California companies are among the world leaders in developing advanced component and vehicle solutions, providing tangible economic and job benefits to the State. Leveraging the work and funding of those companies with Low Carbon Transportation demonstration funding can act as a powerful lever.
This year's plan includes a focus on the following technology demonstration areas:

- Advancing longer-haul truck demonstrations.
- Applying zero-emission technologies to construction equipment.
- Advancing zero-emission marine demonstrations.
- Developing longer distance/regional zero-emission rail applications.

Low Carbon Transportation Three-Year Investment Recommendations

The Long-Term Heavy-Duty Investment Strategy includes a set of funding recommendations that function as a snapshot in time, incorporating a rolling three-year funding horizon. This year's update to the Strategy builds on the funding levels identified in the FY 2021-22 report, addresses FY 2022-23 and FY 2023-24, and adds a new third year, FY 2024-25. Based on the updates to the technology status snapshots and the refinements to the beachhead strategies, CARB has reevaluated and updated the projected levels of investment needed to move pathway technologies forward towards meeting State goals over the new three-year funding period.

The recommended levels of funding have been developed around a central core of established priorities, as well as the updated priorities, strategies, and segment opportunities identified in the discussion above. For example, continuing to support hydrogen fuel cell technologies will be important to advancing those vehicle and equipment platforms that have the potential to considerably extend the range of operations for zero-emission technologies. Building on further development of zero-emission ecosystems helps to prove the ability of these technologies to function at the more expansive facility, corridor, or community deployment levels. While many prior demonstrations and pilots have focused on deployments in port environments, newer projects, have also been conducted at railyards and distribution centers. Ongoing demonstrations of zero-emission rail and marine technologies are underway and show great potential for further deployment. While the application of zero-emission technologies in the areas of construction and agriculture has not advanced as rapidly as most on-road applications, they are now starting to be ready for further deployment. And finally, going forward, CARB intends to apply an equity overlay to all of these investments that looks at ways to target funding to small fleets, priority populations, and impacted communities as a means of making progress towards reaching the State's equity goals.

The aggregated results of these funding projections are shown in Table 4. The table summarizes key focus areas and frames the range of investments ideally needed each year over the course of the next three fiscal years. Both low and high funding levels are shown to suggest the range of investment needed to maintain progress. At the lower funding levels, not all of the priorities can be achieved. The higher levels represent aggressive levels of investment sufficient to drive all of the identified priorities, potentially allowing additional applications within a pathway to advance.

These recommendations focus on creating the critical technology capability and product mix needed for transformation, while not fully funding that transformation. As has been highlighted in prior Strategy documents and by way of input from public meetings, the need for incentives geared toward meeting California's GHG and air quality goals continues to exceed the recommended funding levels shown here.

Table 4: Recommendations for Low Carbon Transportation Investment Priorities

	FY 2022-23	FY 2023-24	FY 2024-25
Demos	$50-$90 Million Focus: ZE Ag-Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Rail, ZE/Hybrid Marine	$50-$90 Million Focus: ZE Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Regional Rail, ZE Marine	$50-$90 Million Focus: ZE Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Regional Rail, ZE Marine
Pilots	$200-$325 Million Focus: ZE Long Haul Trucks, Strategic Range Extenders, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ZE Facilities/ Communities/ Corridors	$200-$325 Million Focus: Strategic Range Extenders, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE Switcher Rail, ZE/Hybrid Marine, ZE Facilities/ Communities/ Corridors	$200-$325 Million Focus: Strategic Range Extenders, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE Switcher Rail, ZE/Hybrid Marine, ZE Facilities/ Communities/ Corridors
Commercial	$490-$680 Million Focus: ZE Drayage and Regional Heavy-Duty Delivery, ZE Delivery, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs, ZE Small Fleets, ZE School Bus	$605-$995 Million Focus: ZE Drayage, ZE Long Haul Trucks, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs	$915-$1,385 Million Focus: ZE Drayage, ZE Long Haul Trucks, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs
Total Funding	$740-$1,095 Million*	$855-$1,410 Million*	$1,165-$1,800 Million*

**The vehicle and equipment types listed in the table above are a prioritized selection of the project types that CARB would invest in, given sufficient available funds. These focus areas are identified following the strategy laid out in this document and take into consideration a wide number of factors. This is not an exhaustive list of technologies or applications that Low Carbon Transportation would fund and indeed funding numbers are inclusive of a much broader set of vehicle and equipment investments CARB hopes to make.*

Conclusion

The ongoing transformation of medium- and heavy-duty fleets through the development of clean technologies is not important just for California, but is becoming a priority of global importance. This Heavy-Duty Investment Strategy provides critical guidance for CARB, and also to our partners across California, the United States, and around the world. This document is meant to be a useful reference for both public and private efforts to approach the challenges that California faces—and the kinds of targeted solutions that can achieve desired outcomes.

The past year held unprecedented public health and economic challenges, and CARB's transformation of the heavy-duty sector was not unaffected. The FY 2020-21 State budget included no Low Carbon Transportation funding to help keep this effort on track. Production of new advanced technology vehicles slowed down and even came to a stop at times, as employees were sent home, stopped working, or became sick. Labor shortages and equipment shortages have further complicated the situation, and led to additional slowdowns and congestion for shipments moving through California's ports.

At the same time, lockdowns and teleworking led to an overall reduction in vehicle miles traveled (VMT) early in the pandemic, and reduced congestion for many vehicles moving freight. Even though VMT has now started to return to pre-pandemic levels, traffic patterns have changed, and the associated implications for traffic congestion, public health, and the economy are still being studied.

For the 2021-22 fiscal year, Low Carbon Transportation funding has increased to levels much higher than seen in any prior years. These incentives will help to accelerate the transition to low carbon freight and passenger transportation, supporting the State's targets that all passenger vehicle and truck sales be zero-emission by 2035, and all other vehicles in the heavy-duty fleet transition to zero-emission by 2045 as described in Executive Order N-79-20.

This year's Heavy-Duty Investment Strategy continues to build on CARB's portfolio approach, applying the framework of strategic beachheads to focus and prioritize funding around the technologies and applications with the strongest potential to transfer to broader applications. This approach will continue to provide a strategic focus to support the transformation required for meeting the State's goals.

The funding amounts recommended in this document are focused on the projected need for jump-starting the transformation process over the next three years by moving crucial technologies and applications through the commercialization process and into early beachhead success markets. CARB's Low Carbon Transportation funds serve as a "down payment," and a more complete transformation will require the investment of multiple agencies at the Federal, State, and local level in collaboration with private partners.

CARB and our partners have a long history of supporting the transition to clean technologies through funding many stages of technology development and deployment; this will continue into the new decade as California pushes for the unprecedented numbers of zero-emission, hybrid, and cleanest combustion vehicles that are needed to meet ambient air quality standards, risk reduction goals, and climate targets.

With the end of most COVID-19 related restrictions, California's economy has essentially fully reopened, and is anticipating having one of the best years of economic growth as it emerges from the pandemic.[32] The challenge ahead will mean ensuring that in creating a "new normal" for transportation, the State doesn't fall back on "business as usual."

However, even as the economy recovers, it remains imperative that the State use the funds that are available to achieve the greatest benefit possible for all Californians, including creating healthy communities, supporting technology evolution, and growing the green economy. In this way, California can continue to move forward in a more equitable manner, making steady progress on the transformation of the heavy-duty sector while ensuring that everyone shares in the prosperity and economic growth that comes with it.

[32] UCLA Anderson School of Management: California June 2021 Forecast. June 2, 2021. https://www.anderson.ucla.edu/news-and-events/press-releases/ucla-anderson-forecast-remains-optimistic-for-post-covid-19-recovery

Additional Information on Sources of Incentive Funding

CARB manages a broad portfolio of incentive funding programs that collectively help to achieve CARB's goals, as was mentioned earlier in this document. Additional funding is available from other State agencies, air districts, and local agencies that contributes to meeting the State's goals and objectives. While the summary of programs below is by no means an exhaustive list, the programs included are significant because, in most cases, the program goals intersect with related goals here at CARB.

Summary of CARB Funding Programs

Low Carbon Transportation

Cap-and-Trade auction proceeds provide funding for CARB's advanced technology clean transportation incentive programs that reduce GHG emissions, and have enabled an expansion of the types of projects previously funded through AQIP. These investments accelerate the transition to low carbon freight and passenger transportation, supporting the State's climate goals including a mid-term target in 2030 for 40 percent GHG emissions reduction below 1990 levels codified under SB 32, as well as longer-term targets for economy-wide carbon neutrality in 2045 and a GHG reduction of 80 percent below 1990 levels by 2050. These investments also support the State's goal to deploy five million zero emission vehicles by 2030.

The Legislature has appropriated approximately $2.1 billion to CARB for Low Carbon Transportation projects over the past eight budget cycles (FY 2013-14 through FY 2020-21). These appropriations are being used to fund:

- Zero-emission and plug in hybrid passenger vehicles through the Clean Vehicle Rebate Project (CVRP).
- Light-duty vehicle equity projects to increase access to the cleanest vehicles benefiting low-income and disadvantaged communities and for lower income Californians.
- Deployment incentives for clean trucks, buses, and off-road equipment utilizing zero-emission, hybrid, and cleanest combustion technologies.
- Advanced technology demonstration and pilot projects for freight trucks and equipment.

Air Quality Improvement Program

AQIP is a mobile source incentive program that focuses on reducing criteria pollutant and diesel particulate emissions along with concurrent reductions in GHG emissions. CARB's investments that started under AQIP provided the foundation for the Low Carbon Transportation investments that typically make up the vast majority of the proposed Funding Plan. AQIP has provided funding for CVRP, HVIP, and advanced

technology demonstrations since 2009. With the technology advancement objectives now most often covered by Low Carbon Transportation, AQIP has been almost exclusively used for the Truck Loan Assistance Program, which provides financing assistance for small-business fleet owners subject to CARB's In-Use Truck and Bus Regulation. The program is tailored to truck owners that experience challenges obtaining conventional financing. However, as demand for this program changes, AQIP funds may be redirected to other areas of greater need.

Volkswagen Environmental Mitigation Trust

The VW Environmental Mitigation Trust (also referred to as Appendix D of the first Partial Consent Decree in the VW settlement) allocates to California about $423 million to fully mitigate the excess NOx emissions caused by VW's use of illegal software in certain diesel cars. The Consent Decree defines the eligible mitigation actions; most are scrap-and-replace projects for the heavy-duty sector. CARB developed a Beneficiary Mitigation Plan that describes the projects California will fund with its allocation. At least 50 percent of the project funds are expected to provide benefits to areas of the State that are disproportionately affected by air pollution. The first funding installment is currently underway, with additional funding opportunities coming in the next year. More information can be found on the program website: https://ww2.arb.ca.gov/our-work/programs/volkswagen-environmental-mitigation-trust-california.

Community Air Protection Incentives

AB 617 (C. Garcia, Chapter 136, Statutes of 2017) called for the establishment of community air monitoring plans and emissions reduction programs in communities that have continued to suffer from disproportionate levels of air pollution throughout the State. Through an extensive public process, CARB established the CAPP, which includes funding appropriated from the Greenhouse Gas Reduction Fund and programmed through local air districts, to support early actions for emission reductions in communities selected or under consideration for future selection for participation in AB 617. Projects are selected based on community-identified needs. Staff continues to work with stakeholders to develop the mechanisms for funding emission reductions, which can include retrofits or replacements of stationary sources and mobile sources (including heavy-duty vehicles and off-road equipment), as well as measures to address priorities identified in community emissions reduction programs. The Legislature has appropriated $704 million over the last three funding cycles. More information can be found on the program website: https://www.arb.ca.gov/msprog/cap/capfunds.htm.

Funding Agricultural Replacement Measures for the Emission Reductions (FARMER) Program

The 2017 budget bill passed by the Legislature provided funding for a program to reduce emissions from agricultural equipment. CARB developed the FARMER Program in 2018. Additional funding was allocated to FARMER by the Legislature through subsequent budget bills in 2018 and 2019. The FARMER Program encourages early turnover and replacement of older, uncontrolled equipment and provides funding to participants through California's air districts for the following categories:

- Projects eligible under current Carl Moyer Program guidelines, so long as the vehicles and equipment are engaged in agricultural operations (up to 85 percent of the cost).
- Zero-emission agricultural utility terrain vehicles (up to 75 percent of the cost).
- Continuation of the Ag Trade-Up Pilot administered by San Joaquin Valley Air Pollution Control District (APCD) since 2016.
- New or used heavy-duty agricultural trucks (up to 65 percent of the cost) that meets the 2010 emission standard of 0.20 g/bhp-hr NOx.
- Advanced technology demonstration projects in agricultural applications.

FARMER has received $332 million over three budget cycles. More information can be found on the program website: https://ww2.arb.ca.gov/our-work/programs/farmer-program.

Carl Moyer Memorial Air Quality Standards Attainment Program

Moyer began in 1998 as CARB's first incentive program. It has historically been budgeted at $69 million annually, though the program has expanded and is receiving nearly $94 million in FY 2019-20. Moyer provides a source of funding to all 35 air districts in the State. This program complements CARB's regulatory efforts and specifically targets ozone precursors and particulate matter emission reductions. To date, the Moyer program has collectively replaced approximately 68,000 engines and has reduced more than 194,514 tons of smog and 7,156 tons of toxic diesel PM. Popular funded projects include heavy-duty truck replacement (with higher cost-effectiveness limits to encourage the cleanest combustion and zero-emission replacements), repower and replacement of off-road construction and agricultural equipment, as well as marine and locomotive projects. More information can be found on the program website: https://www.arb.ca.gov/msprog/moyer/moyer.htm.

Low Carbon Fuel Standard (LCFS)

The LCFS is designed to decrease the carbon intensity of California's transportation fuel pool and provide an increasing range of low carbon and renewable alternatives, which reduce petroleum dependency and achieve air quality benefits. Providers of low carbon fuels generate LCFS credits that can be sold to entities generating deficits for

providing high carbon fuels. At an average credit price of $199, the estimated value of LCFS credits generated in 2020 was over $4 billion.

LCFS credits provide a significant incentive for promoting supply of a variety of low carbon fuels in different transportation sectors. Besides diesel alternatives like biodiesel and renewable diesel, LCFS also incentivizes the use of low-carbon electricity, hydrogen, renewable natural gas (RNG) and renewable propane in heavy-duty transportation applications such as trucks and transit buses. Starting 2019, LCFS also allows credits for supplying electricity to cargo handling equipment, transport refrigeration units and ocean going vessels at-berth. For biodiesel, renewable diesel, RNG, and renewable propane used as transportation fuel in California, the producer or the importer of the fuel is the default credit generator.

Whereas, for hydrogen and electricity used as transportation fuel the owner of the hydrogen station and charger, respectively, is the default credit generator. The default credit generator for these fuels has an option to designate another entity to participate in the LCFS and generate credits on their behalf. Currently, a variety of entities are participating in the LCFS program including but not limited to fuel producers, station owners, EV charging providers, fleet operators, transit agencies, ports, and terminals. More information can be found on the LCFS program website: https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard.

Proposition 1B - Goods Movement Emission Reduction Program

California voters approved Proposition 1B, the Highway Safety, Traffic Reduction, Air Quality, and Port Security Bond Act of 2006. The program has granted $1 billion in the Good Movement Emission Reduction Program, mostly to heavy-duty truck upgrades, but the program also funded cleaner yard hostlers, locomotives, cargo handling equipment, commercial harbor craft, transport refrigeration units, and shore power for ships at berth. Over 14,450 projects have reduced more than 87,000 tons of NOx and 2,500 tons of PM. In addition, the Proposition 1B School Bus program provided another $196 million for 1,042 school bus replacements and 3,592 school bus retrofits.
Goods Movement:
https://ww2.arb.ca.gov/our-work/programs/proposition-1b-goods-movement-emission-reduction-program
School Bus:
https://ww2.arb.ca.gov/our-work/programs/lower-emission-school-bus-program/proposition-1b-school-bus-account

Diesel Emission Reduction Act

Grant funding for lower emission diesel vehicles is available through the federal Diesel Emission Reduction Act (DERA). DERA Funding is distributed through national competitive grants and through noncompetitive State allocations. Historically, California has chosen to focus its State Program allocations on school bus cleanup.

Although this funding is not guaranteed, it remains an important source of funding for replacing older diesel school buses. Since 2011, San Joaquin Valley APCD has administered over $4 million of California's state allocation of DERA funding to retrofit and replace school buses statewide. North Coast Unified Air Quality Management District (AQMD) started administering the program in October 2019. More information can be found on the program website: https://www.epa.gov/cleandiesel. The collection of funding shown above represents a comprehensive and strategic portfolio designed to accomplish a number of goals in a coordinated approach: carrying technology through phases of development and deployment to meet air quality and climate change goals.

Other Sources of Funding

More than a dozen agencies provide hundreds of millions of dollars of incentive funding annually through a range of funding programs designed to deploy advanced technology heavy-duty vehicles. Coordination is essential, not just to increase ease of use for participants, but also to guarantee that, together, all of the State's funding programs work effectively to meet the State's goals.
As part of the technical assistance and market acceleration work funded by CARB through HVIP, CARB supports a convening of the quarterly "Funders Forum," comprised of MHD funders across several public-sector entities including large state agencies, ports, utilities, and other stakeholders. The goal is to share program updates, identify synergies and barriers, leverage collaborative goals and strategies, and collectively plan for the future of MHD vehicles and infrastructure statewide. While CARB funds the convening effort, it is hosted by a third party, through a contract with the nonprofit CALSTART.

California Energy Commission

Clean Transportation Program

School Bus Replacement Program

The CEC is currently administering a $75 million School Bus Replacement Program. This one-time allocation, part of the California Clean Energy Jobs Act, is the largest single allocation of State funding toward school buses outside of home-to-school funding since 2006. This statewide project will replace some of the oldest public diesel-fueled school buses with zero-emission replacements in disadvantaged communities and school districts in which a majority of students are eligible for free or reduced-price meals. CARB is working closely with the CEC as they administer these funds, by sharing information based on CARB's decades of experience implementing school bus funding. More information can be found on the program website: https://www.energy.ca.gov/programs-and-topics/programs/school-bus-replacement-program.

Electric Program Investment Charge

Another CEC-administered program, the Electric Program Investment Charge (EPIC) Program, supports investments in research of clean energy technologies and strategies to improve the State's electricity systems. The program provides opportunities to support short-lived climate pollutant emission reductions from reduced or avoided fugitive methane emissions stemming from fossil fuel production and distribution via investments such as improved energy efficiency technologies in building, industrial, agricultural and water sectors; demand response; distributed renewable generation; electric vehicle infrastructure; advanced energy storage interconnection systems; and advanced vehicle-grid integration. More information can be found on the program website: https://www.energy.ca.gov/programs-and-topics/programs/electric-program-investment-charge-epic-program.

California State Transportation Agency/California Department of Transportation

The Transit and Intercity Rail Capital Program

The Transit and Intercity Rail Capital Program (TIRCP) was created by SB 862 (Committee on Budget and Fiscal Review, Chapter 36, Statutes of 2014) and modified by SB 9 (Chapter 710, Statutes of 2015) to provide grants from the Greenhouse Gas Reduction Fund to fund transformative capital improvements that will modernize California's intercity, commuter, and urban rail systems, as well as bus and ferry transit systems, to reduce emissions of GHGs by reducing congestion and vehicle miles traveled throughout California while providing benefits to priority populations.[33] The goal of the TIRCP is to achieve the following objectives:

- Reduce GHG emissions.
- Provide benefits by improving transportation accessibility in priority populations
- Expand and improve rail service to increase ridership.
- Integrate the rail service of the State's various rail operations, including integration with the high-speed rail system.
- Improve safety.

TIRCP can provide funding for zero-emission passenger transport, including buses, rail, and ferries. On October 18, 2019, TIRCP opened its most recent call for projects, to begin accepting Cycle 4 2020 project applications. The projects awarded under Cycle 4 were announced on April 21, 2020. Release of the Cycle 5 project guidelines is anticipated in fall of 2021. More information can be found on the program website: https://calsta.ca.gov/subject-areas/transit-intercity-rail-capital-prog.

[33] Priority populations were formerly referred to as disadvantaged communities, low-income communities, and low-income households within a half mile of disadvantaged communities

Low Carbon Transit Operations Program

The Low Carbon Transit Operations Program is one of several programs that are part of the transit, affordable housing, and sustainable communities program established by the California Legislature in 2014 as part of Senate Bill 862. The Low Carbon Transit Operations Program (LCTOP), administered by Caltrans, provides operating and capital assistance for transit agencies to reduce GHG emissions and improve mobility, with an emphasis in serving priority populations. Approved projects in LCTOP support new or expanded bus or rail services, expand intermodal transit facilities, and may include equipment acquisition, fueling, maintenance, and other costs to operate those services or facilities, with each project reducing GHG emissions. More information can be found on the program website: https://dot.ca.gov/programs/rail-and-mass-transportation/low-carbon-transit-operations-program-lctop.

California Transportation Commission

Trade Corridor Enhancement Program

The purpose of the Trade Corridor Enhancement Program is to provide funding for infrastructure improvements on federally designated Trade Corridors of National and Regional Significance, on the Primary Freight Network as identified in California's Freight Mobility Plan, and along other corridors that have a high volume of freight movement. The Trade Corridor Enhancement Program will also support the goals of the National Highway Freight Program, the California Freight Mobility Plan, and the guiding principles in the California Sustainable Freight Action Plan. The focus of the program is on improvements to State roadways, railways, and ports, though the program is also able to support intelligent transportation systems (ITS), as well as shore power and emissions capture and control systems for ships at berth.

California Electric Utilities

California's investor-owned electric utilities, pursuant to SB 350, are required to invest in infrastructure for transportation electrification (TE). Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E) submitted applications in 2017 and 2018 for small-scale pilots and large-scale programs to provide infrastructure to customers deploying plug-in electric vehicles. In 2018, the California Public Utilities Commission (CPUC) approved over $780 million in utility investments, more than $600 million of which is dedicated to non-light-duty vehicles and off-road equipment. Included in the approval are new rate designs for the three utilities designed to lower the cost of electricity as a fuel. The large-scale programs are operated on a first-come, first-served basis and provide utility- and customer-side infrastructure at no cost to eligible customers. Eligible customers may also receive rebates on approved electric vehicle supply equipment.

Pilot projects began in early 2019, and the large-scale projects from PG&E (EV Fleet) and SCE (Charge Ready Transport) launched in the summer of 2019. SDG&E's $107 million large-scale medium- and heavy-duty infrastructure program (Power Your Drive for Fleets) is now open for applications. The programs are accessible to direct customers and customers of most community choice aggregators (CCAs).

Many of California's publicly-owned utilities (such as SMUD, LADWP, and other municipal utilities) also have programs to provide low- or no-cost infrastructure and favorable EV rates. Others can provide infrastructure and support services on an ad hoc basis.

Local Air Districts

Many of California's air districts provide grants to help fund cleaner vehicles. Some of these programs use State funds that are administered at the local level to eligible applicants such as Moyer, CAPP, and others. Some districts have local funds to support programs such as the San Joaquin Valley APCD's waste hauler and tractor replacement; the South Coast AQMD's Advanced Technology Fund and the Mobile Source Air Pollution Reduction Review Committee (MSRC) funding; the Sacramento Metropolitan AQMD's Sacramento Emergency Clean Air and Transportation (SECAT) truck replacement program; and the Bay Area AQMD's Mobile Source Incentive Fund program. More information about these programs is available on each district's website.

U.S. Department of Energy

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) funds transportation solutions that put electric drive vehicles on the road and replace imported petroleum with clean domestic fuels. Through the Vehicle, Bioenergy, and Fuel Cell Technologies Offices, EERE advances the development of next-generation technologies to improve plug-in electric and other alternative-fuel vehicles, improve advanced combustion engine and vehicle efficiency, and produce low-carbon domestic transportation fuels.

The Vehicle Technologies Office (VTO) supports high impact projects that can significantly advance its mission to develop more energy efficient and environmentally friendly transportation technologies that use less petroleum. The VTO is strongly committed to partnerships to help ensure the eventual market acceptance of the technologies being developed. New funding opportunities are announced regularly.

The Bioenergy Technologies Office (BETO) supports groundbreaking bioenergy technologies to produce industrially viable fuels, products, and power using renewable biomass and waste resources. BETO selects research and development projects through open and competitive procurements called Funding Opportunity Announcements (FOA) and encourages collaborative partnerships among industry,

universities, national laboratories, Federal, state, and local governments, and non-government agencies.

The Fuel Cell Technologies Office (FCTO) focuses on applied research, development, and innovation to advance hydrogen and fuel cells for transportation and diverse applications enabling energy security, resiliency, and a strong domestic economy in emerging technologies. The FCTO has helped pave the way to commercialization for fuel cell transit buses, and is involved in demonstrating fuel cell technology with several CARB demonstration projects, such as a fuel cell ferries, delivery vans, and Class 8 drayage trucks.

Other examples of DOE grant funding opportunities in the heavy-duty space, typically administered through the EERE Office, include the Zero-Emission Cargo Transport Demonstration (designed to accelerate the introduction and penetration of electric transportation technologies into the cargo transport sector); Efficient Class 8 Trucks, or SuperTruck initiatives (whose goal is developing Class 8 tractor trailers with 50 percent greater fuel efficiency); and the Clean Cities Program, which partners with cities across the country to reduce the use of petroleum in the transportation sector.

U.S. Department of Agriculture

The U.S. Department of Agriculture's Environmental Quality Incentives Program (EQIP) provides financial and technical assistance to agricultural producers to address natural resource concerns and deliver environmental benefits such as improved water and air quality, conserved ground and surface water, reduced soil erosion and sedimentation, and improved or created wildlife habitat. The National Air Quality Initiative (NAQI) funding pool receives money from EQIP. NAQI is designed to help agricultural producers meet air quality compliance requirements and offer funding opportunities to support practices related to on-farm mobile engines that reduce emissions of NOx, PM, and volatile organic compounds from agricultural sources and help to achieve and maintain the health- and welfare-based National Ambient Air Quality Standards (NAAQS) in California.

Federal Transit Administration

The Federal Transit Administration (FTA) provides funding to transit operators for the purchase of transit vehicles. In addition, the FTA offers specific programs to fund research for and incentivize the purchase of zero-emission or clean combustion transit vehicles.

FTA's Low or No Emission Vehicle Program is a competitive funding program available to states and transit agencies for the purchase or lease of zero-emission or clean combustion transit buses and related equipment, or for leasing, constructing, or rehabilitating facilities in order to support zero-emission or clean combustion transit

buses. The program provides funding to support the wider deployment of advanced propulsion technologies within the nation's transit fleet.

The Low and No Emission Component Assessment Project is available to eligible institutions of higher education to fund testing, evaluation, and analysis of low or no emission (LoNo) components intended for use in LoNo transit buses used to provide public transportation.

The Zero Emission Research Opportunity (ZERO) is a program available to nonprofit organizations to fund research, demonstrations, testing, and evaluation of zero-emission and related technology for public transportation applications.

Federal Aviation Administration

The FAA's Airport Zero Emission Vehicle (ZEV) and Infrastructure Pilot Program allows airports that are eligible for Airport Improvement Program grants to purchase zero-emissions airport vehicles and the infrastructure required to operate them.

The Voluntary Airport Low Emissions (VALE) Program incentivizes airport sponsors by funding the incremental cost of alternative fuel vehicles in place of conventionally powered diesel and gasoline vehicles. The supporting recharging/refueling infrastructure is also eligible for funding.

Acronym List

AB – Assembly Bill

AC – Alternating Current

ACT – Advanced Clean Truck

ARFVTP – Alternative and Renewable Fuel and Vehicle Technology Program

APCD – Air Pollution Control District

AQIP – Air Quality Improvement Program

AQMD – Air Quality Management District

BEB – Battery Electric Bus

BEV – Battery Electric Vehicle

CAPP – Community Air Protection Program

CARB – California Air Resources Board

CCA – Community Choice Aggregator

CEC – California Energy Commission

CHE – Cargo Handling Equipment

CORE – Clean Off-Road Equipment

CPUC – California Public Utilities Commission

CVRP – Clean Vehicle Rebate Project

DC – Direct Current

DERA – Diesel Emission Reduction Act

DME – Dimethyl Ether

DOE – Department of Energy

EERE – Office of Energy Efficiency and Renewable Energy

EPA – Environmental Protection Agency

EPIC – Electric Program Investment Charge

ePTO – Electric Power Take-off System

EQIP – Environmental Quality Incentives Program

FARMER – Funding Agricultural Replacement Measures for Emission Reductions

FCEB – Fuel Cell Electric Bus

FCEV – Fuel Cell Electric Vehicle

FCTO – Fuel Cell Technologies Office

FTA – Federal Transit Administration

FY – Fiscal Year

g/bhp-hr – Grams Per Brake Horsepower-Hour

GHG – Greenhouse Gas

GSE – Ground Support Equipment

GVWR – Gross Vehicle Weight Rating

HEV – Hybrid-Electric Vehicle

HD – Heavy Duty

HVIP – Hybrid and Zero-Emission Voucher Incentive Program

ITS – Intelligent Transportation Systems

LCFS – Low Carbon Fuel Standard

LCTOP – Low Carbon Transit Operation Program

LFP – Lithium Iron Phosphate

LoNo – Low or No Emission Vehicle Program

MHD – Medium Heavy Duty

MSRC – Mobile Source Air Pollution Reduction Review Committee

NAAQS – National Ambient Air Quality Standards

NAQI – National Air Quality Initiative

NOx – Nitrogen Oxides

OEM – Original Engine Manufacturer

PG&E – Pacific Gas & Electric

PHEV – Plug-In Hybrid-Electric Vehicle

PM – Particulate Matter

PM2.5- Fine Particulate Matter

RNG – Renewable Natural Gas

SB – Senate Bill

SCE – Southern California Edison

SDG&E – San Diego Gas & Electric

SECAT – Sacramento Emergency Clean Air and Transportation Program

SIP – State Implementation Plan

TCO – Total Cost of Ownership

TE – Transportation Electrification

TIRCP – Transit and Intercity Rail Capital Program

TRL – Technology Readiness Level

TRU – Transport Refrigeration Unit

VALE – Voluntary Airport Low Emissions Program

VMT – Vehicle Miles Traveled

VTO – Vehicle Technologies Office

VW – Volkswagen

XR – Extended Range

ZE – Zero-Emission

ZERO – Zero Emission Research Opportunity

ZEV – Zero-Emission Vehicle