Appendix D:

Long-Term Heavy-Duty Investment Strategy

Including Fiscal Year 2020-21 Three-Year Recommendations

For Low Carbon Transportation Investments

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Table of Contents

Introduction 5
History of the Heavy-Duty Investment Strategy 8
Updates for FY 2020-21 10
State Air Quality Goals and the Role of Incentives 12
Supporting Commercialization of Advanced Technologies 17
The CARB Portfolio of Funding for Heavy-Duty Investments 19
Low Carbon Transportation and AQIP Specific Investment Strategy 22
Beachhead Strategy 25
Zero-Emission Beachhead 30
Combustion Beachhead 33
Efficiencies Beachhead 36
Technology Status Updates 41
Battery Electric Vehicles Technology Status Snapshot 43
Fuel Cell Electric Vehicles Technology Status Snapshot 51
Hybrid Electric Vehicles Technology Status Snapshot 56
Combustion Technology Status Snapshot 62
Efficiencies Technology Status Snapshot 68
Market Readiness Indicators 74
MRI Components 75
Ongoing Issues Affecting Market Transformation 77
Infrastructure Case Studies from Low Carbon Transportation Demonstration and Pilot Projects 79
Component Cost Analysis 84
Supply Chain 85
Other Issues 85
Metrics of Success for Low Carbon Transportation 89
Creating Healthy Communities 90
Growing the Green Economy 91
Supporting Technology Evolution 92
Priorities for Low Carbon Transportation Investments 96
Low Carbon Transportation Three-Year Investment Recommendations 99
Conclusion 103
Additional Information on Sources of Incentive Funding 106

Table of Figures

Figure 1: Commercialization Path: Stages and Sources of Public Investment 17
Figure 2: Funding Succession 20
Figure 3: The Beachhead Strategy 26
Figure 4: The Zero-Emission Beachhead 33
Figure 5: The Combustion Beachhead 36
Figure 6: The Efficiencies Beachhead 39
Figure 7: On-Road Battery Electric Vehicles Technology Status Snapshot 44
Figure 8: Off-Road Battery Electric Vehicle Technology Status Snapshot 46
Figure 9: On-Road Fuel Cell Electric Vehicles Technology Status Snapshot 52
Figure 10: Off-Road Fuel Cell Electric Vehicles Technology Status Snapshot 54
Figure 11: On-Road Hybrid Electric Vehicles Technology Status Snapshot 58
Figure 12: Off-Road Hybrid Electric Vehicles Technology Status Snapshot 60
Figure 13: On-Road Combustion Technology Status Snapshot 65
Figure 14: Off-Road Combustion Technology Status Snapshot 67
Figure 15: On-Road Efficiencies Technology Status Snapshot 70
Figure 16: Off-Road Efficiencies Technology Status Snapshot 72

Introduction

Reducing air pollution and greenhouse gas emissions from the transportation sector continue to be longstanding goals for protecting public health and the environment in California. The State has made significant headway in this effort and 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. 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.

Transforming the transportation sector to protect California's public health and environment requires a combination of aggressive policies, targeted regulations, and incentives.

To have the best chance of reducing the impacts of climate change and meeting air quality standards, California must lead the way by developing necessary zero-emission technologies and low-carbon fuels now.

The types of incentives deployed need to be carefully prioritized between investing in technologies that are just coming to market and are capable of achieving immediate emissions reductions, and providing support to emerging advanced technologies that help to meet all of California's goals. To have the best chance of reducing the impacts of climate change and meeting air quality standards, California must lead the way by developing necessary zero-emission technologies and supporting low-carbon fuel use now.

The State is driving this transformation while working in conjunction with other agencies at the local, state, and federal levels to maintain progress toward our climate and clean air goals. The California Air Resources Board (CARB) continues its history of building a broad suite of regulatory actions (from the Advanced Clean Truck 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. The

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

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

need for private sector investments and engagement is tremendous, and continuing to drive technology advancement through these phases is critical to meeting the State's goals.

State incentives can help spark private sector investment and create partnerships necessary to support the transformation of the heavy-duty and off-road sectors. Demonstration and pilot projects funded through Low Carbon Transportation or the Air Quality Improvement Program (AQIP) typically require a one-to-one match for incentive funds. To date, CARB has funded over $350 million towards heavy-duty demonstration and pilot projects, matched with nearly $320 million from other sources of funding. CARB is currently working with the California Energy Commission (CEC) on releasing a joint solicitation for a port drayage pilot project, with CARB providing incentive funding for vehicles, and the CEC providing funding for infrastructure. CARB also coordinates funding with the public utilities on the medium- and heavy-duty infrastructure in accordance with SB 350. In 2010, there were four manufacturers participating in CARB's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). Today there are over 30 manufacturers participating in HVIP, representing over 100 vehicle models. HVIP's $530 million in incentive funding has leveraged $2.2 billion in private and other public funding over the past ten years, or more than $4 for every $1 invested in HVIP.

There continues to be a critical need to focus investments on both funding commercially available vehicles and equipment as well as maintaining the innovation pipeline necessary for meeting the State's ultimate vision of a zero-emission economy.

There continues to be a critical need to focus investments on funding commercially available vehicles and equipment as well as maintaining the innovation pipeline necessary for meeting the State's ultimate vision of a zero-emission economy. There are currently an array of local, state, and federal sources of funding to invest in this transformation, but there continues to be a need for more to support both the next generation of technologies for cleaner vehicles and equipment, and accelerating the turnover of the legacy vehicle fleet. Investments are also needed to support the greenhouse gas (GHG) reductions targets defined in Assembly Bill (AB) 32, (Nunez, Chapter 488, Statutes of 2006), in the subsequent Senate Bill (SB) 32 (Pavley, Chapter 249, Statutes of 2016), as well as in executive orders calling for 100 percent of medium-and heavy-duty vehicles in the State to be zero-emission by 2045 where feasible; 100 percent of drayage trucks to be zero-emission by 2035; 100 percent of off-road vehicles and equipment where feasible to be zero-emission by 2035[1]; and statewide carbon neutrality by 2045.[2] CARB has built and continues to maintain a portfolio of funding programs designed to keep the momentum of advancing

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

[2] Executive Order B-55-18. https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf

technology and accelerating fleet turnover. The programs that support the acceleration of fleet turnover are necessary to meet criteria pollutant emission reduction goals set by the Federal government, and also ensure the continued flow of Federal transportation dollars to California. The programs in CARB's portfolio emphasize deploying advanced technologies in disadvantaged communities across the state to ensure that all Californians share the air quality, public health, and economic benefits that come with investments in a green economy.

A cornerstone principle for Low Carbon Transportation funding is to support rapid, continuous innovation by investing in technology applications with the potential to move quickly through the commercialization stages.

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 to identify 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. Graduation of technologies through investment programs is based on advanced technology market assessments, the beachhead concept, the current state of funding, and an understanding of the barriers to commercialization advanced technologies face. The concept of beachheads, which prioritizes funding to technologies and applications that can most easily be self-sustaining and have strong potential to transfer and spread to broader applications, provides a roadmap for State funds that can be focused more strategically. This strategy outlines the actions to support the transformation needed to meet the State's air quality, greenhouse gas reduction, and petroleum dependency reduction goals and mandates.

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, graduating and progressing until they reach a financially sustainable market and are robust enough to be required through regulation.

The Heavy-Duty Investment Strategy provides insight into how CARB plans to invest its Low Carbon Transportation and AQIP funding on a combination of transformational technologies for heavy-duty vehicles, off-road equipment, and fueling infrastructure. Within this document, there is a discussion on the overall CARB 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 investments across zero-emission capable technologies, the cleanest combustion technologies, and efficiency 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.

History of the Heavy-Duty Investment Strategy

This document was originally developed as a companion document to the Fiscal Year (FY) 2017-18 Funding Plan. The document, titled The Three-Year Investment Strategy for Heavy-Duty Vehicles and Off-Road Equipment from Low Carbon Transportation Investments and AQIP, was solely focused on prioritizing heavy-duty projects based on a series of criteria and 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. 25), a guiding principle that has since expanded into a larger discussion on advanced technology vehicles and policy strategy. Paired with the beachhead strategy, the technology status snapshots allowed CARB to infer progress of technology along the commercialization path. These tools have allowed CARB to forecast priority funding areas and minimum investment levels to continue advancement of priority segments.

While the Heavy-Duty Investment Strategy was initially developed independent of any mandate or requirement, the governor subsequently signed into law SB 1403 (Lara, Chapter 370, Statutes of 2018), which required CARB to develop the Heavy-Duty Investment Strategy and Three-Year Recommendations for Low Carbon Transportation Investments. In addition, SB 1403 directed CARB to produce annually a three-year investment strategy for Low Carbon Transportation and AQIP investments beginning with FY 2019-20. Per SB 1403, the Heavy-Duty Investment Strategy is 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, and describe CARB's portfolio of investments.

SB 1403 also requires that no less than 20 percent of funding from the Greenhouse Gas Reduction Fund be used to support early commercial deployment of existing zero- and near zero-emission heavy-duty truck technology. For the purposes of the funding plan, CARB is expanding the definition of near-zero eligibility to include

engines meeting the new optional standard of 0.01 g/bhp-hr NOx standard when paired with in-state renewable fuels. In addition, near zero-emission technologies include ePTOs and vehicles that pair zero-emission technology with a range extending cleaner combustion engine operating on in-state renewable fuel and that operate in zero-emission mode for a portion of the vehicle's duty cycle.

SB 1403 also requires that the Heavy-Duty Investment Strategy include a report on the State's school bus fleet. This report, developed in consultation with the CEC, is to provide information related to milestones 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. CARB and CEC continue to collaborate on school bus incentives, including the report required by SB 1403. That report is included as Appendix E of the Funding Plan.

Recognizing the need for effective statewide action, CARB continues to coordinate with other state agencies, including the CEC, California Public Utilities Commission (CPUC), Employment Training Panel (ETP), and air districts. One recent example is the CPUC's ruling this year ordering California's largest Investor-Owned Utilities to modify their Electric Tariff Rule 18, allowing public charging for medium- and heavy-duty vehicles and off-road equipment in areas served by those utilities.

Updates for FY 2020-21

For the 2020-21 fiscal year, the Heavy-Duty Investment Strategy will include updated technology status snapshots, more detailed metrics of success, market readiness indicators, infrastructure assessment case studies, updated beachheads – shown in a new format – and an updated 3-year priorities table. Over the last 12 months, CARB has engaged stakeholders on these topics, holding four public work group meetings, conducting one-on-one meetings, and releasing drafts of document components to stakeholders for comment.

This year's public workgroup process helped produce a list of quantifiable metrics of success. Infographics summarizing metrics for the Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP) in the areas of public health, technology evolution, and the green economy, are found on page 89.

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State Air Quality Goals and the Role of Incentives

As discussed in the introduction to the FY 2020-21 Funding Plan, there are many drivers that affect CARB investments. Many policies and documents were – and continue to be – developed to support goals outlined in the executive orders mentioned above.

Statutory Drivers

Climate change goals set in AB 32 and the subsequent SB 32, and air quality mandates set in the Federal Clean Air Act are among the key drivers guiding this strategy.
SB 1204 (Lara, Chapter 524, Statutes of 2014) creates the California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program, which is intended to help accelerate the introduction of the next generation of cleaner heavy-duty vehicles and engines with a priority on projects that benefit disadvantaged communities. Among other requirements, SB 1204 directs CARB to develop an annual framework and plan to guide these investments.
SB 350 (De León, Chapter 547, Statutes of 2015) calls for improving access to clean transportation options (such as cleaner transit bus fleets, passenger trains, and ferries) for low-income residents, including those in disadvantaged communities.
AB 739 (Chau, Chapter 639, Statutes of 2017) requires that 15 percent of specified medium- and heavy-duty vehicle purchases by State agencies must be ZEVs by 2025; increasing to 30 percent beginning in 2030.
AB 1550 (Gomez, Chapter 369, Statutes of 2016) establishes disadvantaged community, low-income community, and low-income household targets for the State's Cap-and-Trade auction proceeds investments.

In addition to Senate Bill 1403 which requires the annual publication of this Strategy, this document also supports clean air goals set forth in several Executive Orders, Senate and Assembly bills, the Federal Clean Air Act, as well as state planning documents and mandates for other state agencies.

New Governor's Executive Orders

The State has been guided for a number of years by a series of executive orders. These include the following:

- Achieving carbon neutrality as soon as possible, and no later than 2045; and achieving and maintaining net negative emissions thereafter as directed in the Governor's Executive Order B-55-18.

- Reducing GHG emissions to 1990 levels by 2020 as required by AB 32 (Núñez, Chapter 488, Statutes of 2006) and to 40 percent below 1990 levels by 2030 as required by SB 32 (Pavley, Chapter 249, Statutes of 2016).

- Reducing petroleum use in vehicles by 50 percent by 2030, one of the pillars of the State's climate change strategies for reducing GHG emissions, and reducing

GHG emissions from the transportation sector to 80 percent below 1990 levels by 2050 as directed in the Governor's Executive Order B-16-2012.

- Deploying 1.5 million ZEVs by 2025 and deploying at least 5 million ZEVs by 2030 as directed in Executive Order B-48-18.

Most recently, Executive Order N-79-20 requires that, by 2035, all new cars and passenger trucks sold in California be ZEVs. In addition, the Governor's order set a goal to transition all drayage trucks to zero-emission by 2035, all off-road equipment to zero-emission where feasible by 2035, and the remainder of medium- and heavy-duty vehicles to zero-emission where feasible by 2045.

One additional law passed this year provides additional guidance on publicly funded infrastructure. AB 841 (Ting, Chapter 372, Statutes of 2020) mandates that all electric vehicle charging infrastructure and equipment located on the customer side of the electric meter that is funded or authorized, in whole or in part by CARB, the Energy Commission, or the Public Utilities Commission shall be installed by a contractor holding "the appropriate license classification as determined by the Contractors' State License Board." Additionally, at least one electrician on each crew, at any given time, must hold an Electric Vehicle Infrastructure Training Program (EVITP) certification; and for projects with at least one charging port supplying 25 kW or more, at least 25% of the electricians on the crew must hold an EVITP certification. These new requirements apply to any work performed on or after January 1, 2022 for projects decided or entering contract or agreement with any public agency on or after January 1, 2021.

CARB Guiding Documents

As discussed in the introduction to the FY 2020-21 Funding Plan, there are many drivers that affect CARB investments. These include 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 identifies 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 Strategy noted that heavy-duty trucks more than 8,500 pounds[3] were the fastest growing transportation sector in the United States, and are responsible

[3] 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 Gross Vehicle Weight Rating (GVWR).

for about 33 percent of the total statewide nitrogen oxide (NOx) emissions and approximately 25 percent of the total statewide diesel particulate matter (PM) emissions, and are a significant source of GHG emissions. Emissions from off-road diesel sources that are primarily federally-regulated, such as oceangoing vessels and locomotives, are also expected to increase.[4] 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 that achieve reductions in NOx and PM2.5 emissions using measures outlined in the Mobile Source Strategy. CARB is currently developing the 2020 Mobile Source Strategy, which will take an integrated planning approach to identifying the level of transition to cleaner mobile source technologies needed to achieve all of California's targets.

- 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 and the cleanest combustion technologies paired with renewable fuel use everywhere else.[5] 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.

CARB's 2016 Mobile Source Strategy and the California Sustainable Freight Strategy reference a combination of proposed regulations and incentives designed to help shift California from a reliance on petroleum-fueled heavy-duty vehicles and off-road equipment to zero-emission, hybrid, and the cleanest combustion vehicles and fuels.[6] Together, these approaches are designed to bring about progressively cleaner in-use fleet emission levels.

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[4] CARB. Mobile Source Strategy. May 2016. https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf

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

[6] CARB. Mobile Source Strategy. May 2016. https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf

While incentives are designed to help accelerate technology advancement and market penetration, they also function as a way to reward early adopters of these technologies. As the cleaner technologies become commercially available, costs continue to fall and market adoption increases. 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.

Incentives also play a helping role in meeting the State's air quality and climate change objectives. They provide a means of supporting the State's SIP commitments, which are guided by the federal NAAQS for PM and ozone, as well as aggressive State goals related to reducing GHG emissions, zero-emission vehicle deployment, and carbon neutrality. Each of the programs within the CARB portfolio has its own set of statutory requirements that define the primary driver of investment, guidelines, and implementation directives. It is necessary for CARB to ensure those statutory requirements are met while leveraging all programs to meet all of the State's goals.

BNSF RAILROAD PARTNERSHIP BRINGS ZERO-EMISSION FREIGHT MOBILITY

The Burlington Northern Santa Fe (BNSF) Railway is the largest freight railroad network in North America, shipping more than 10 million freight carloads in 2019 alone. CARB and BNSF have entered a $45 million public-private partnership ($22.6 million from CARB) to develop and test zero-emission technologies that will enable freight to be loaded onto rail and shipped long-distance, aided by electric drive at all points, by 2021. These investments will improve air quality and protect the health of some of California's most disadvantaged and vulnerable communities, who are more likely to live along freight corridors.

As part of the project, Wabtec (formerly GE Transportation) will develop an all battery-electric locomotive to validate the technology's operational benefits and growth potential in the freight rail industry. This locomotive will initially be paired with diesel locomotives that will reduce a freight train's total fuel consumption by at least 10 to 15 percent.

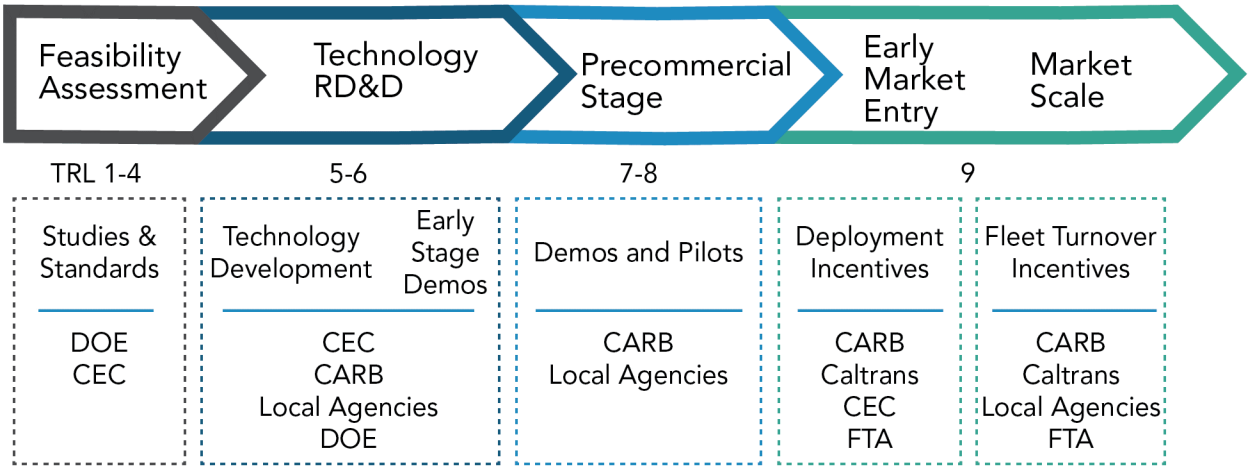
When the trains pull into two California freight yards (Stockton and San Bernardino Intermodal Facilities), their freight will be met by a hybrid-electric gantry crane that may reduce emissions by up to 70 percent. In San Bernardino, BNSF is also testing an all-electric sideloader. Once freight has been unloaded, it may be delivered to distribution centers by an all-electric truck. BNSF has partnered with BYD and SH&H, a local drayage truck operator, to demonstrate a BYD truck.

Incentives also can be used to help further the deployment of advanced technologies in disadvantaged communities that experience environmental and health inequities from air pollution. CARB targets its investments to help purchase cleaner vehicles and equipment, with a focus on advancing zero-emission technologies within and directly surrounding high cumulatively burdened communities.

Supporting Commercialization of Advanced Technologies

Just as there are a variety of regulations affecting heavy-duty vehicles and off-road equipment, there are a variety of incentives at the local, state, and federal levels that support technology advancement at the demonstration, pilot, and commercial deployment stages, or across all technology readiness levels (TRL).[7] Figure 1 shows the commercialization path for technologies and the public agencies that provide key incentives across this path.

Figure 1: Commercialization Path: Stages and Sources of Public Investment



As Figure 1 shows, California, working in partnership with many local and Federal agencies, invest 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. It also signals the importance California places on the development and deployment of these advanced technologies, attracting innovators, private investment, and green businesses to the State.

All CARB investment programs focus on funding starting from the demonstration phase forward, following through the programmatic categories shown above. Utilizing

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

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. Demonstrations feed the innovation pipeline and are necessary to ensure the availability of technologies needed to meet our 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 is not standardized and is focused on smaller batches of vehicles. Higher levels of incentives per vehicle are needed to help entrepreneurs cover the costs of 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. 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 improvements, 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. As a technology gains user acceptance and proves to be reliable and dependable, and manufacturers shift to manufacturing it as their preferred technology, incentive opportunities can shift to programs focused on legacy fleet turnover.

One important factor to consider when discussing lower-volume and higher-volume production is that the metrics separating these phases could vary greatly, depending on the type of equipment under discussion. Some types of off-road equipment have very low total populations in the State, and a commercialization phase that the industry considers higher-volume production could still have relatively low sales volumes or "built to order" production methods.

As sales grow and economies of scale are achieved, incentive funding levels and vehicle eligibility requirements can be adjusted. This ensures maximum incentive efficiency by better targeting incentive funding to motivate user decisions. In this higher-volume commercialization phase, while per vehicle incentives are decreasing, total sales are increasing, and therefore total incentive funding commitments increase.

CARB also provides financing assistance to help small businesses affected by regulations (such as the Truck and Bus Regulation) to purchase the cleanest vehicles that meet State requirements. The Truck Loan Assistance Program has been providing financing opportunities to small businesses who fall below conventional lending criteria and are unable to qualify for traditional financing for cleaner trucks.

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 well into the future, if we are 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 sustainability where incentives can 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.

The CARB Portfolio of Funding for Heavy-Duty Investments

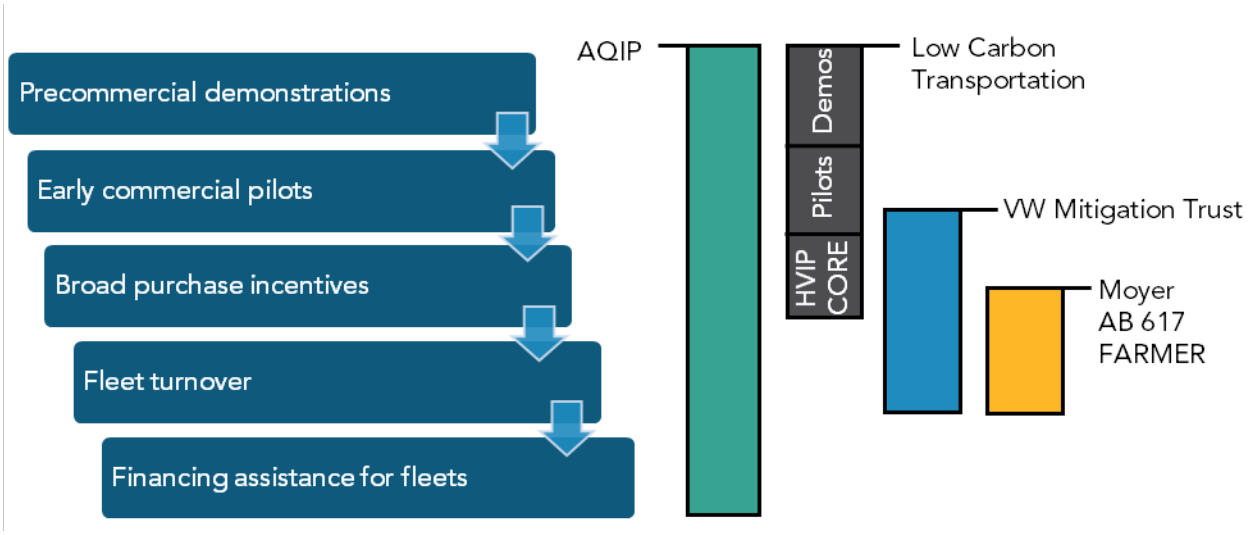
California has a long history of taking action against air pollution and making investments in emerging technology, and CARB has been investing in clean vehicles for over two decades. Over the last several years, as public health crises became more critical and the looming threat of climate change grew, California dedicated increasing financial resources to reducing 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 106), with markedly different but complementary statutory goals. CARB's portfolio places emphasis on technology advancement, the deployment of zero-emission heavy-duty vehicles, and turning over the legacy fleet.

Figure 2 below shows how CARB's incentive 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" 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 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.

CARB continues to work on incorporating a series of Market Readiness Indicators (MRIs) that can help gauge a particular technology's entrance into the market and the associated challenges. These indicators focus on four areas: market acceptance, technology status, barriers to adoption, and economic status. An expanded discussion of market readiness indicators is included on page 74.

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 investments by the CEC and utilities, as a key example, are critical to supporting zero-emission trucks, buses, and freight equipment.

Figure 2: Funding Succession



Funding appropriated to CARB by the legislature is programmed in two ways: as statewide projects implemented by CARB, or as regional projects implemented by the air districts. The statewide projects administered by CARB focus on precommercial demonstrations, early commercial pilots, and some broad purchase incentives, as well as programs for fleet turnover, in response to legislation, stakeholder input, and Board direction. Air district funds are usually used for scrap-and-replace projects prioritized on a cost-effective basis to meet SIP requirements. This division in funding is necessary—the State is equipped to provide the large-scale investments needed to send a market signal and move the needle in terms of advancing technologies in a way that smaller, locally-focused investments simply cannot match. Air districts are better positioned to address regional and community scale air quality challenges in a way that meet the unique needs of their region and incorporate community input. Some of the larger air districts also have local funds that are generated through local fees. These dollars are invested across a similar spread of projects — pre-commercial demonstrations all the way through to fleet turn-over. At the same time, the State's

programs continue to recognize the need to prioritize funding in impacted communities.

With multiple goals guiding State action on clean heavy-duty vehicles, maintaining multiple programs with different, but complementary objectives is necessary. At CARB, this means a portfolio of programs tasked with transition and transformation that emphasizes community protection and investment in disadvantaged communities. To ensure that programs within the portfolio work in harmony, CARB has reviewed how technologies fit within these programs, how they transition to different financial support mechanisms depending on where they are in commercialization, and when they transition away from needing public investment. This is important for a number of reasons, not the least of which is conserving limited fiscal resources.

The Low Carbon Transportation projects focus on rapidly advancing technology to meet California's long-term climate, air quality, community protection, and petroleum reduction goals. These projects fund advanced technologies in their early stages — starting with demonstration and pilot projects to validate duty cycle and technological readiness while working through operational challenges, and continuing through the early stages of commercialization and market entry to help build economies of scale and increase fleet confidence in the technology. The Low Carbon Transportation projects focused on deployment of early-commercial technologies are streamlined to operate on a first-come, first-served basis and do not require scrappage.

As technology gains user acceptance and proves to be reliable and dependable, and manufacturers shift to it as their preferred technology, incentive opportunities can shift to programs focused on legacy fleet turnover, such as the Carl Moyer Program and others.

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 Measures for Emission Reductions (FARMER) are more appropriate funding sources. These programs focus on achieving cost-effective reductions of criteria pollutants. To achieve these air quality goals and because these programs support advanced technologies that have obtained a higher degree of market acceptance, they are focused on turning over the existing fleet at an accelerated pace. These programs often require additional measures, such as scrappage, or funding through a competitive process considering the cost-effectiveness of a technology. These measures are not only in place to ensure that CARB achieves the maximum emission reduction possible, but also to ensure that the reductions can be credited towards meeting federal ambient air quality standard and SIP goals.

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, financing assistance. In the last few funding cycles, because of the unique nature of AQIP and the increased demand that has been placed on the Truck Loan Assistance Program, CARB has strategically focused AQIP dollars on financing assistance programs and allowed other programs within the incentive portfolio to cover earlier stages of the commercialization path. As new priorities arise, CARB expects to continue to utilize the broad flexibility of the AQIP program.

Considering the distinct goals of each of the funding programs outlined above, it becomes even more important to protect the integrity of CARB's technology advancement programming as a unique and fundamental piece of the State's strategy. It is also necessary to maintain a strong focus on each of the goals of the programs with the portfolio and understand where they fit within the technology commercialization pathway, and ensure that technologies move appropriately through funding programs.

In the higher-volume commercialization phase, while per-vehicle incentives are decreasing, total sales are increasing, and therefore total incentive funding commitments increase.

This document paves the way to a better understanding of how CARB's investment programs interact with one another and when a technology is clearly successful enough to graduate to the next program in the funding succession or away from incentives completely. Many of the criteria that could be considered for this type of analysis are part of the metrics of success 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

Since the first Heavy Duty Investment Strategy was published in 2017, CARB has continued to refine and target its strategy for accelerating the development and market introduction of technologies that are crucial to achieving the State's climate and air quality goals. The remainder of this report focuses on addressing CARB's investment strategy for the Low Carbon Transportation Program.

This roadmap is a strategic approach to accelerate targeted technology improvement:

1. Continuing to invest Low Carbon Transportation dollars across the commercialization pathway for various technologies, building on previous

investments. This includes supporting technologies through the demonstration, pilot, and commercial phases.

2. Focusing investments on the three technology pathways necessary to meet the State's climate and criteria emission goals. The three often interlinked technology pathways identified are Zero-Emission Capable (organized around battery electric, fuel cell electric, and hybrid electric technologies); Combustion (engine and powertrain improvements); and Efficiency (engine and powertrain, full vehicle, and system operations).

3. 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 on page 25.

This approach has proven successful to date. In the four years since the first Heavy-Duty Investment Strategy was published, growth in the industry has accelerated, including a 189% 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 are increasing, including global original equipment manufacturers (OEMs) and innovative new manufacturers.

REFUSE TRUCKS: A PROMISING APPLICATION FOR ZERO-EMISSION TECHNOLOGY

Refuse trucks are a relatively new but promising application for zero-emission technologies. These trucks are typically Class 6-8 vehicles that can be adapted from existing zero-emission formats by adding vocation-specific features, such as lifting and compacting mechanisms. Refuse trucks are ideal for electrification because they operate on intra-city fixed routes at low speeds, return to depots to charge, and recover much of the energy lost during their frequent stops through regenerative braking. A 2018 CARB study indicates that zero-emission refuse trucks may operate up to seven times more efficiently than diesel-powered equivalent vehicles.

The benefits of zero-emission powertrains also extend to residential neighborhoods where refuse trucks travel. Extensive stopping and idling times produce dangerous street-level air pollutants and ongoing noise disturbances that harm community health. Zero-emission refuse trucks significantly reduce both on-road pollutant emissions and noise.

CALSTART's Zero-Emission Vehicle Inventory currently lists seven commercially available refuse truck models available in North and South America and in Europe, where markets are emerging rapidly. The Cities of Los Angeles and New York, representing two of the largest U.S. municipal fleets, have committed to purchasing only zero-emission fleet vehicles by 2035. Other large cities and nations around the world have announced bans on the sale and operations of diesel vehicles in the next 15-20 years. These developments promise a strong policy outlook for the refuse industry.

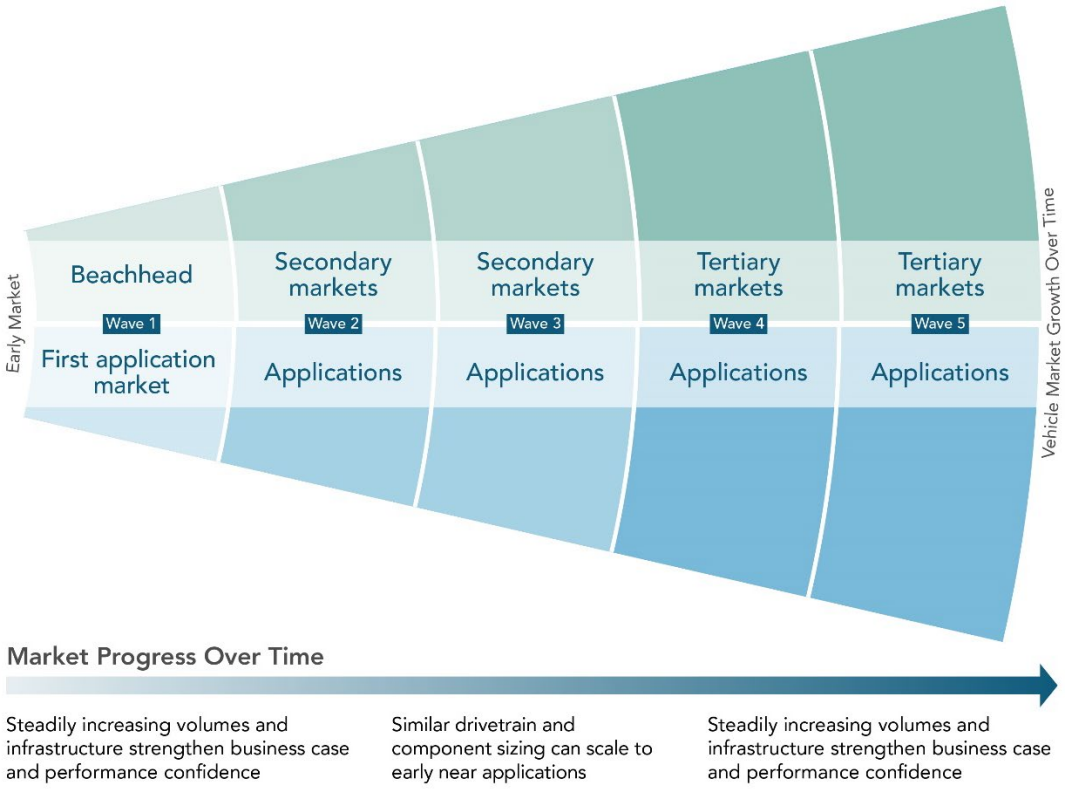
Beachhead Strategy

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. 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 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 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.

Figure 3: The Beachhead Strategy



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."[8]

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 medium- and heavy-duty 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.

[8] *Random House Unabridged Dictionary*. Random House, Inc. 2018.

The beachhead strategy, shaped around the three core technology pathways, 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.[9]

The beachhead strategy defines CARB's approach to driving faster technology commercialization. The strategy is also being adopted by other regions of the world as a framework for accelerating technology transformation. Evidence is being seen in bus applications in Europe, Asia, India, and South America.

Beachhead Strategy Updates 2020

There are three main beachheads—Zero-Emission; Combustion; and Efficiencies. These beachheads are not mutually exclusive, as some of the efficiency technologies (e.g., connected-automated vehicles, automated guided vehicles, stop-start systems) can be overlaid on any one of these beachheads to maximize reductions.

The following sections and graphics illustrate the beachhead strategies for sequenced expansion of the three 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.

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, 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.

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

This 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 2020 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 Efficiencies Beachhead is updated to more clearly align technologies by use profiles for ease of readability and to better reflect the diverse technologies in these segments. 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.

VOLVO: LOW IMPACT GREEN HEAVY TRANSPORT IN SOUTHERN CALIFORNIA

The Volvo LIGHTS (Low Impact Green Heavy Transport Solutions) pilot program is providing a glimpse of a zero-emission vehicle economy. The effort brings together vehicle manufacturers, operators, and technicians; charging station manufacturers, installers, and service providers; and utilities, ports, and warehouses.

The project is placing up to 23 all-electric, class 8 trucks into service in Los Angeles and the Inland Empire along with an additional 29 all-electric off-road vehicles, such as forklifts and work trucks. Volvo LIGHTS will test new technologies in real-world situations, providing valuable lessons about best practices for vehicle and infrastructure operations.

The $90 million public-private partnership was selected in 2018 to receive half of its funding from CARB as a demonstration project, with Volvo contributing nearly $37 million and the remainder from other project partners.

The project will produce lasting physical investments that will benefit other projects as well. Associated off-road ZEV technologies will continue to operate at regional freight facilities. Warehouse operators have installed solar panels to ensure that any electric trucks that charge use the cleanest power available. The partnership will install 58 public and private chargers, which far exceeds the charging needs of the 23 class 8 Volvo trucks alone.

Zero-Emission Beachhead

The most powerful beachhead process to date has been built around the zero-emission pathway. 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. The fuel cell electric bus utilizes the same essential electric power train as does a battery electric bus, which itself was built on the early success of hybrid architectures in the transit bus market, which over time began to expand the use of core electric drive components.

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 applications including:

- Battery electric shuttle and school buses;
- Battery electric delivery vehicles;
- Battery electric yard hostlers;
- 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 medium- and heavy-duty 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 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 price have continued to push the limits of where such systems are needed. From early battery-only ranges of 80-100 miles, major manufacturers are now signaling 120 miles, 170 miles, and up to 250 miles of range for a Class 8 tractor hauling cargo in regional freight applications. Similarly, fuel cell electric powertrains are emerging as a potential market entrant for heavy weight, duration and longer distance applications by 2023.

ZERO-EMISSION BUSES: COST-EFFECTIVE SUCCESS IN SAN JOAQUIN VALLEY

San Joaquin Regional Transit District was one of the earliest adopters of zero-emission transit buses in the nation. SJRTD purchased two 35-foot Proterra all-electric buses in 2013 and has continued to expand its all-electric fleet. Stockton, within the SJRTD, was the first city in the world to feature an all-electric bus rapid transit route, established in 2017. This route was designed to serve disadvantaged communities, expanding economic access through reliable and fast transit while cutting tailpipe emissions in some of the nation's most polluted communities.

SJRTD has direct experience with improvements to all-electric vehicle technologies. The table below shows the cost of each vehicle purchase, decreasing while battery capacity and range increase. ***Over time, SJRTD's all-electric transit bus fleet has increased performance while becoming less expensive.***

Year Built	Number of Buses	Size (Feet)	Battery Size (kWh)	Cost Efficiency of Range ($/kWh)	Cost ($)
2012	2	35	74	$14,865	1,100,000
2016	10	40	105	$8,324 - $10,324	874,000 – 1,084,000
2018	5	40	440	$2,107	927,000

This mirrors the trend of battery production costs falling and efficiency increasing since the 2010s. Cost-effective performance and familiarity with technologies will help operators spread clean transit across the state. RTD's newest vehicles combine the affordability of lower purchase costs and a large battery capacity that allows for longer operating ranges that can charge overnight, reducing costly on-route demand charges and making electric buses more affordable to own and operate.

Fuel cell trucks are being developed by major manufacturers, including Hyundai, Toyota-Hino and Volvo-Daimler (via a new joint venture). While the source of electrical power comes from different sources (batteries, fuel cells, or engine generators), it is important to note that ZEV core powertrain architectures are similar.

Off-road zero-emission technologies cross-support the expansion of drivetrain technologies and 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. The knowledge base and core technology enables, if not in all cases directly leads to, additional applications, such as:

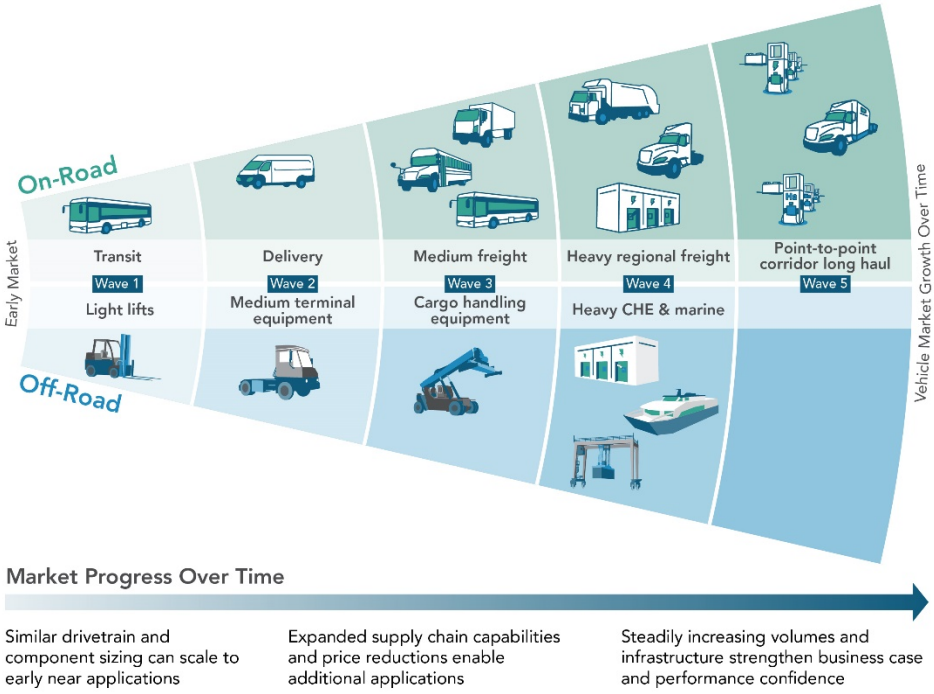
- Battery electric and fuel cell electric ground support equipment (GSE);
- Battery electric, fuel cell electric, and extended operations electric cargo handling equipment (CHE);
- Battery electric, fuel cell electric, and extended operations marine harbor applications; and
- Battery electric and fuel 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. The success of this strategy has been extremely valuable as a framework for planning the introduction timelines of medium- and heavy-duty 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 hybrid or plug-in hybrid and zero-emission trucks is expected due in no small part to the 2020 passage of the Advanced Clean Truck (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. The beachhead model predicts that the earliest successful zero-emission vehicle applications will take place in delivery van, medium-duty truck, and medium-duty shuttle bus markets.

These successes will enable heavier truck applications by reducing costs and establishing robust supply chains.

Figure 4: The Zero-Emission Beachhead



Combustion Beachhead

The combustion beachhead serves as an umbrella for all technologies that utilize the cleanest available forms of combustion. The focus of this beachhead and its pathways since 2016 has been on those engines that met a certification level of 0.02 grams per brake horsepower-hour (g/bhp-hr) NOx. The adoption of the Heavy-Duty Engine and Vehicle Omnibus regulation this year has now 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. With this in mind, staff will be re-evaluating the need for a combustion beachhead in next year's update to the Heavy-Duty Investment Strategy.

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 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 medium- and heavy-duty applications, such as:

- The cleanest combustion shuttle and school buses;
- The cleanest combustion medium-duty work trucks and related applications; and
- The cleanest combustion Class 8 regional tractors and drayage trucks.

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

- The cleanest combustion port and rail support equipment; and
- Using the cleanest 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 this year, it will require heavy-duty engines to 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. U.S. EPA was also working on setting lower NOx standards, via its Cleaner Trucks Initiative, but has delayed announcing its proposed regulations.

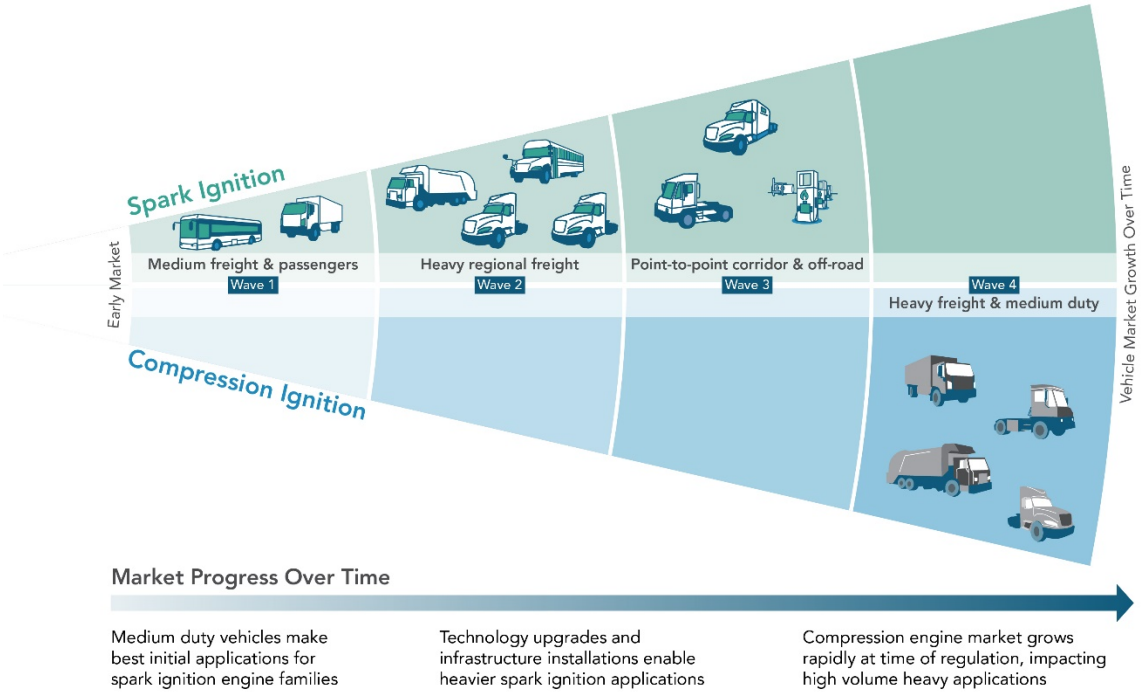
Once regulations are in place that require all diesel engines to operate at the strictest NOx emissions levels, the anticipated market for the cleanest combustion compression engines is expected to expand rapidly and in diverse applications. New technological approaches may also be available to support the transition to the cleanest combustion

compression engines; the Achates Power opposed piston engine has already validated in testing the potential to reach the 0.02 NOx standard with an increase in efficiency over conventional 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 regulation. Therefore, once 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 combustion off-road, new land-based 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 combustion compression ignited 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 and Pathways, with the line entering Wave 3 indicating a market bifurcation caused by diesel engine regulations. The market initially favors spark ignition applications, but regulations later create momentum for compression engine applications. The use of renewable natural gas or propane, and the price benefits of that use augmented by the LCFS, could change or influence the eventual market split on these technologies.

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.

Figure 5: The Combustion Beachhead



Efficiencies Beachhead

Efficiencies represent a large arena for technology improvement and include a range of potential technologies. These include powertrain efficiencies, vehicle efficiencies, and operational efficiencies. For purposes of strategic clarity and to best align with California's climate change, emission, and petroleum reduction goals, the efficiencies beachhead focuses on two primary pathways: (1) operational energy efficiency, which is energy efficiency gained through the more efficient operations of groups of vehicles and equipment in a system and (2) powertrain efficiency, which is the more efficient operation of an integrated engine, transmission, differential, hybrid components, and other supporting systems to power a vehicle. Figure 6 shows this landscape and the technology growth from two generalized beachheads and a supporting pathway: (1) controlled ecosystems, (2) vocational truck and bus powertrain hybridization, and (3) technological advancements that support efficiency advancements.

For the purposes of this strategy and the operational efficiencies pathway, a key market launch point upon which to focus will be from controlled ecosystem locations. A site with a controlled ecosystem is characterized by limited access where advanced systems to control, increase, and optimize the energy efficiency of vehicle and equipment operations can first be staged. Such locations reduce risk for early deployments because they have limited or no interaction with general purpose vehicles. Increased efficiency can be accomplished with connected vehicle, "smart" (intelligent transportation system [ITS]), and automated technology solutions.

The first applications of success seen to date have been in mining and agricultural markets. There is now an expansion of these applications to other controlled ecosystems, including:

- Off-road work sites (including construction).
- Ports, facilities, and terminals.
- Fleet routing and geo-fencing.

From these capabilities, additional extensions, deployment, and inter-vehicle connections of the technology can allow for:

- Regional goods movement optimization.
- Corridor communications and "platooning" (close-following truck convoys with electronic control assistance).
- Full open road truck platooning and automated truck operations.

On a parallel track is the powertrain efficiency pathway, and its beachhead, vocational truck and bus hybridization. Many of these hybrid systems have been early enablers of the zero-emission pathway by supporting electric drive components and energy storage development. However, they will also remain important drivers of urban and regional efficiency on their own via several energy storage approaches: hybrid electric, hybrid hydraulic, and hybrid pneumatic, as examples. Powertrain efficiencies can be further augmented by leveraging the investments already being made by others, particularly at the federal level, in Class 8 tractor and trailer efficiencies.

The initial applications of this beachhead have been in transit bus and delivery applications. The technology capabilities in the on-road markets have been advanced via:

- Parallel systems, which primarily boost or augment conventional engine power to the wheels.
- Plug-in systems, which provide additional hybrid energy for greater efficiency or power needs.
- Series systems, which use the conventional engine as a power generator only.

Building on these capabilities, hybrid systems have extended to the work site for:

- Engine-off operations of tools and equipment at on-road work sites.
- More efficient operation of off-road equipment in construction and cargo handling equipment applications.

Additional control schemes and system cost reductions are already enabling additional capabilities to be demonstrated, including:

- Start-stop systems to shut off engines at every stop in a drive cycle.
- Plug-in hybrid and extended range electric medium-duty delivery.
- Plug-in hybrid and extended range electric heavy-duty regional operations.

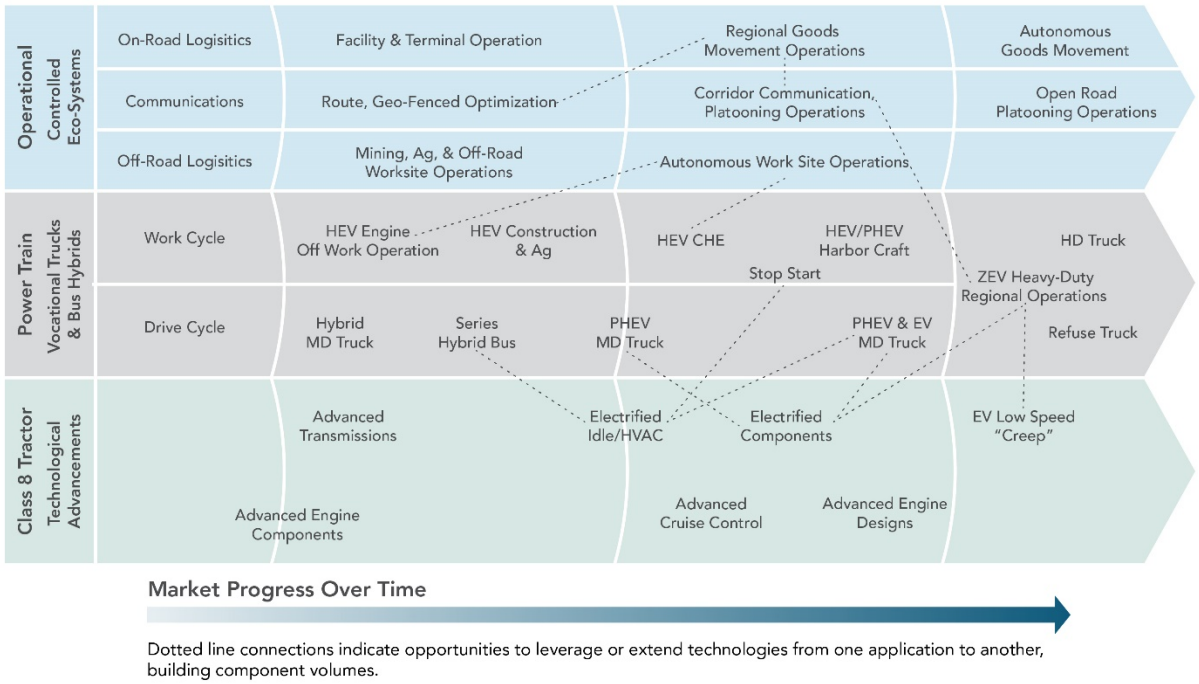
Worth noting are the multiple cross connections between efficiency pathways, including connection to the separate long haul (Class 8 tractor) pathway. These

connections are noted via the dotted lines on the charts. Significant federal and engine maker investments, such as via the Department of Energy's SuperTruck program, have been made in waste heat recovery, turbo-compounding, automated manual transmissions, and other systems which can provide a rich platform to leverage for increased efficiency. Because of this targeted and robust federal funding, no additional State investment is necessary in these systems. Advanced engine architectures and powertrains are exceptions to this strategy. They are not currently receiving any or adequate federal funding and can benefit from State investments.

Targeted leverage points to benefit hybrid electric systems include technology packages used to deliver overnight idle reduction and augment engine efficiency, and include electrically driven heating, ventilation, and air conditioning (HVAC) and electrified pumps and compressors. Uses for these systems may actually emerge first in work and vocational truck systems (such as utility lift trucks and other work site vocations), but they will benefit from increased component volumes as they are implemented in Class 8 applications. This process of early applications leading to expanded component volumes can also help enable start-stop technologies.

Operational energy efficiency technology will reduce energy demands of electric and hybrid powertrains, extending their ranges; their electronic control systems will provide easier implementation for greater automation.

Figure 6: The Efficiencies Beachhead



Dotted line connections indicate opportunities to leverage or extend technologies from one application to another, building component volumes.

Using the beachhead strategy, CARB has prioritized most funding around applications that have strong potential to transfer and spread to broader applications. This involves identifying key places in the market where technology can be successful and then serve as a launch pad for additional market segment deployments. Important considerations are the ability of the technology or its core components to transfer to other applications, or scale to other weight classes in an application. 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 improved affordability.

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Technology Status Updates

Maintaining the effectiveness of the investment strategy and tracking progress against our goals calls for monitoring the status of the key technologies. 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 identified above, 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 general stages on the path to commercialization.

With input from stakeholders, CARB conducts an annual high-level technology snapshot review to assess the generalized status and progress of the key pathway technologies and representative platforms using the technology. The goal is to provide directional guidance on where platforms are in 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[10] (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.

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:

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

beginning first with vehicle technology readiness, and then building on that to understand other barriers 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.[11] 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 chart location of each platform listed is not representative of any one specific product or vehicle, but is an aggregated average status based on the multiple platforms and manufacturers and the different stages at which each may be. Each individual vehicle model that contributes to the platform average is also provided a weighting, based on the type of manufacturer and numbers of units 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 assessments are displayed as the general weighted-average status of known platforms. This may mean a technology could be shown in the pilot stage, even when there may be products from some manufacturers already in commercial production.

As technologies reach these late stages of technology transformation, CARB considers if technological barriers are still the technology's greatest concern, or if other market factors are the primary barrier—and whether or not Low Carbon Transportation is the appropriate incentive program to address those barriers.

In the technology status charts that follow, there are several updates and refinements for this year. The x-axis continues to represent how far the technology has advanced toward readiness for production, with those in the early demonstration stages shown on the left. Those that are closer to being commercially available are shown on the right. The weighted average for the status of each platform is now shown by a diamond 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

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

median point of status: meaning, half the models have lower status scores, and half above. This can inform where general industry capabilities lie.

For this year, on-road platforms have been separated from off-road platforms. Off-road platforms are now displayed on their own charts, by technology. 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.

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.

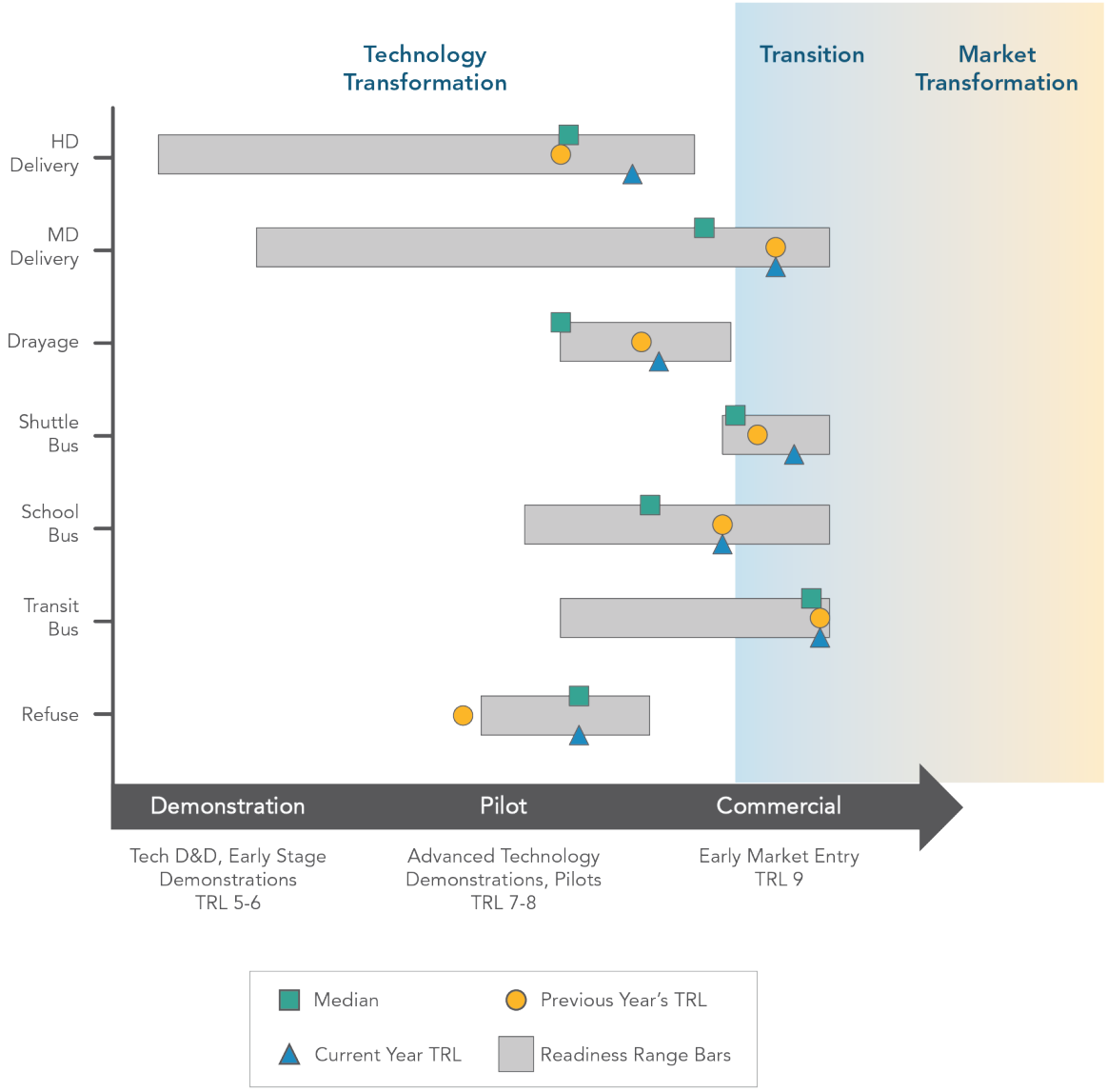
To aid in future assessments of technologies achieving technology transformation and moving into market transition, a demarcation (grey box) around TRL 8-9 is placed to identify applications that are transitioning from technology transformation — the primary goal of this program — to market penetration. 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 Readiness Indicators section on page 74 for further discussion.

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 7 and 8 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 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 but is a global phenomenon that is strongest in China but can also be seen in Europe, India and South America. There are now 12 electric bus makers with more than 25 models available in the United States. Last year more than 2,255 ZEV buses were deployed or ordered across the U.S.[12]; that number should climb to more than 2,500 by fall 2020. The dominant percentage of these are BEVs, with just under 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.

[12] https://calstart.org/zeroing-in-on-zebs-2019/


Technology Transformation
Transition
Market Transformation
HD Delivery
MD Delivery
Drayage
Shuttle Bus
School Bus
Transit Bus
Refuse
Demonstration
Pilot
Commercial
Tech D&D, Early Stage Demonstrations TRL 5-6
Advanced Technology Demonstrations, Pilots TRL 7-8
Early Market Entry TRL 9
Median
Previous Year's TRL
Current Year TRL
Readiness Range Bars

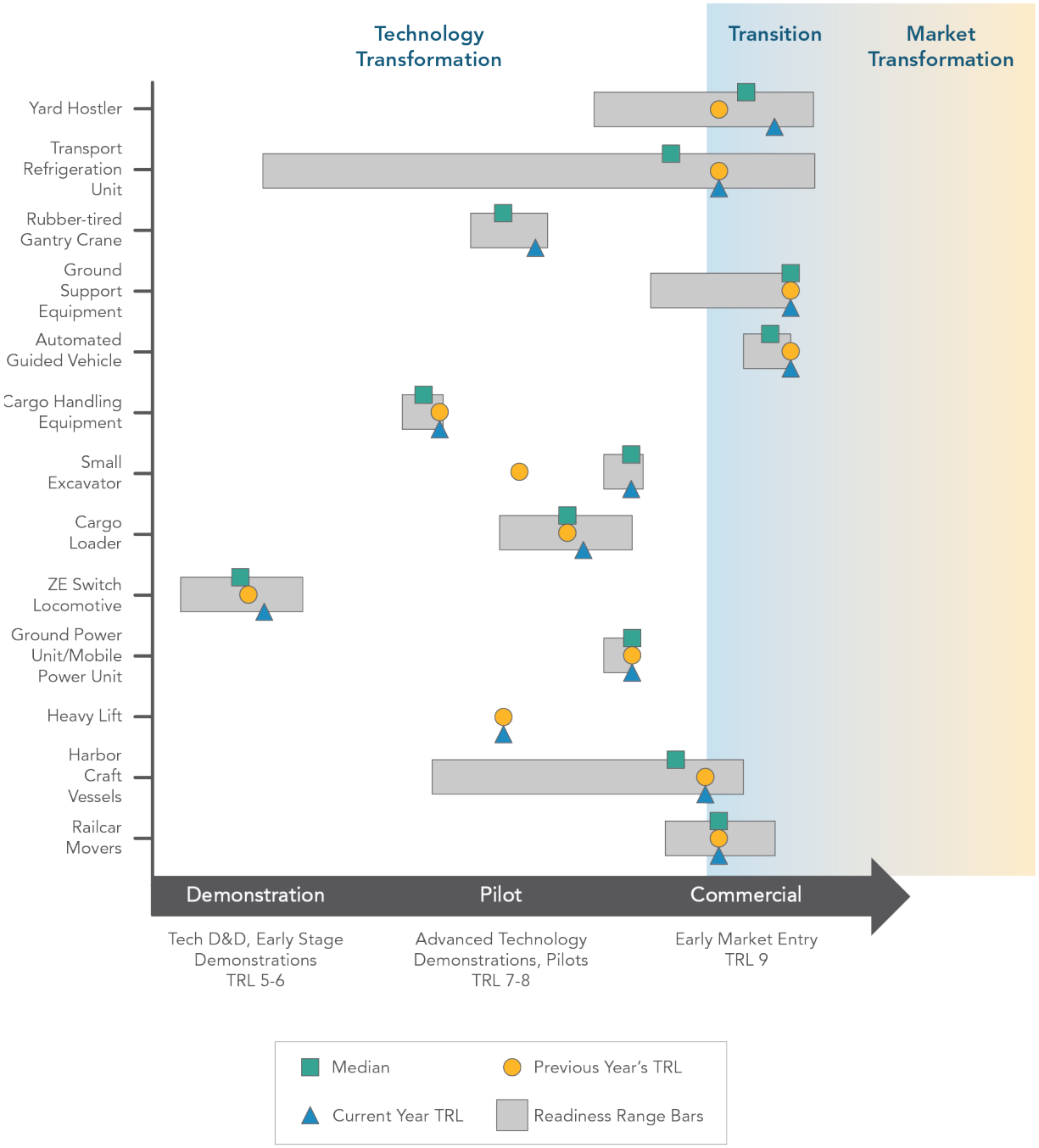
The next growth application emerging strongly after BEV transit buses is BEV delivery (medium-duty weight classes), which continues to make strong progress towards commercial launch. This sector made progress in overall technical readiness, as well as in the growth of the number of manufacturers developing products and in strong fleet purchase commitments. This application platform continues to see a significant addition of vehicle models in early production, such as the Daimler eSprinter,[13] as well as major products announced for production, such as the Ford All Electric Transit, available in 2022.[14] This category ranges from delivery vans to larger delivery and service trucks, such as the Freightliner eM2, expected in 2022[15], and the Peterbilt 220EV, available for order in fall 2020[16]. While there is a wide range of technical readiness across the manufacturers, the platform's overall weighted average is near first production. Based on data collected in the on-line Zero Emission Technology Inventory[17], this medium-duty delivery segment will show the most growth in available products by 2023.[18]

Heavy-duty delivery platforms continued to make strong year-over-year technology readiness progress with all major manufacturers and several new innovators in active product development stages. These applications are characterized by Class 7 and 8 heavy-heavy-duty drayage and regional haul trucks, and while the range of tech readiness is wide, their overall platform weighted averages indicate a late pilot/early commercial stage of technology readiness. Several large OEMs are close to production: Volvo has announced its electric VNR truck will enter limited first production by the end of 2020[19] while Kenworth plans early production of its T680E electric tractors to start in late 2020 and ramp up in 2021.[20] Meritor is providing powertrain components for this truck partly provided from its acquisition of California company Transpower. There is clear technology transfer from bus and other truck platforms to this segment.

Refuse truck platforms also made progress based on this year's assessment, with their category's weighted average solidly in pilot stage and some companies offering early commercial products. While there are not as many manufacturers active on this platform as in heavy-duty (HD) delivery, additional companies have entered the

[13] https://www.drivingelectric.com/mercedes-benz/sprinter; Daimler announces pricing for eSprinter, now in productinproduction in Dusseldorf.
[14] https://media.ford.com/content/fordmedia/fna/us/en/news/2020/03/03/ford-to-offer-all-electric-transit.html
[15] https://www.ttnews.com/articles/schneider-test-freightliner-ecascadia
[16] https://www.peterbilt.com/about/news-events/news-releases/peterbilt-model-220ev-now-available-customer-orders
[17] https://globaldrivetozero.org/tools/zero-emission-technology-inventory/
[18] https://globaldrivetozero.org/tools/zeti-analytics/
[19] https://www.fleetowner.com/running-green/blue-fleets/article/21704267/volvos-first-electric-vnr-ready-for-the-road
[20] https://www.truckinginfo.com/351104/meritor-announces-deal-to-supply-paccar-with-electric-powertrain-components

Figure 8: Off-Road Battery Electric Vehicle Technology Status Snapshot



segment. For example, the Lion Electric Company leveraged its Lion8 Class 8 electric chassis to offer an electric refuse truck variant[21].

[21] https://cleantechnica.com/2020/07/13/lion-electric-boivin-evolution-start-selling-electric-garbage-truck/

All major school bus providers have announced an electric school bus product is available or in development. While the range of technology readiness is still relatively broad between those already producing and selling vehicles, such as Lion, and others who are still validating their powertrains, the ability to manufacture at scale is rapidly being developed.

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 offer eligible equipment in the program, which also includes battery-electric forklifts, railcar movers, airport ground power units and mobile power units.

While not yet in early production, zero emission small excavators also continued to make strong technical progress toward full readiness. Volvo Construction Equipment announced plans to demonstrate their excavators in a project funded by the South Coast Air Quality Management District[22]. Other manufacturers are developing similar products, including JCB and Komatsu.

Europe continues to be a hotbed for electrified maritime applications, including fully battery electric ferries, tugs and support craft, but more powertrain providers are exploring North American applications. The technology is at a relatively high level of readiness and is promising for breakout.

Rubber Tired Gantries (RTGs) have been electrified for many years using electricity provided by cable reel. However, progress is being made now on units using battery electric designs moving toward the pilot stage. Battery-powered locomotives are also making progress, but remain at an earlier stage of technical development.

These platforms can benefit from demonstration and pilot funding assistance to help them transition to upgraded system designs and early market stage deployments.

Key Barriers to BEV Adoption

As can be seen from the charts on page 44, several BEV platforms have moved into the transition phase between technology and market transformation. This shows important progress, but there are still key issues to address in order to expand the market. In overview, these barriers include the following:

[22] https://www.rermag.com/news-analysis/rer-the-environment/article/21129682/volvo-ce-awarded-2-million-grant-to-test-its-electric-construction-machines-in-california

Continued barriers to wider Battery Electric Vehicle adoption include infrastructure, high incremental cost, limited vendor and product selection, range, the business case, and TCO / payback period.

- Infrastructure is increasingly viewed as the top barrier to address, and multiple agencies have already begun to address it. The CPUC approved public utilities' plans for $750 million in funding for medium- and heavy-duty charging infrastructure, and the CEC is addressing this as part of their annual Clean Transportation Incentives Plan. . As vehicle manufacturers begin to bring product to the market, fleets are realizing they must concurrently plan for infrastructure as they spec and procure their vehicles. Depending on the individual utility, there can be long lead times in order to plan, site, and install necessary capacity upgrades and chargers; address different use of space for vehicle charging sites at their depots; and plan for the cost of the installation itself. Utilities are still early in the process of explaining utility rate structures to fleets and what that means for fuel cost. The major Investor Owned Utilities (IOUs), and several municipal utilities, do now offer a range of programs, often referred to generally as "make-ready" programs, to pay for some if not most of these costs. These programs, part of the California Public Utilities Commission SB 350 rate case decisions, also set new charging rate levels more tailored to commercial fleet customers. HVIP has developed a growing array of tools to assist fleets in this planning and funding process which can be accessed at https://www.californiahvip.org/infrastructure/#readiness-tips.

- Total cost of ownership for zero-emission vehicles is already starting to come in lower than for comparable combustion vehicles across a range of vehicle segments. However, the incremental cost of the vehicles at the point of sale can still be higher than for the comparable combustion vehicle.

TOTAL COST OF OWNERSHIP: HOW LCFS REDUCES OPERATION COSTS

Incentive programs can positively impact the total cost of ownership (TCO) of clean vehicle projects at many stages along the life of a vehicle. Though HVIP customarily draws attention for making the purchase of an alternative fuel vehicle easier and more affordable, other programs make operating it less expensive, thereby reducing a vehicle's TCO on an ongoing basis.

The California Low Carbon Fuel Standard (LCFS) is a state regulation that rewards suppliers of clean fuels, such as electricity and hydrogen, with credits that can be used to invest in charging and fueling infrastructure and to reduce the price of the fuels sold. In some cases, vehicle operators can accrue credit directly by operating qualifying zero-emission vehicles. Credits are valuable because they can be sold to suppliers of dirtier fuels to meet their LCFS compliance obligations.

CARB has estimated that all-electric transit buses can generate enough credits to reduce fuel costs to $7,000 annually, saving more than 50 percent on electricity costs and more than 70 percent on annual diesel costs. A hypothetical example using CALSTART's TCO Calculator for a medium-duty all-electric truck shows improved payback period from five years to four.

- California has enacted several effective programs to address costs in the form of the HVIP and CORE purchase vouchers, Moyer, and VW funding, as well as separate funding from air districts. However, significantly reduced Cap and Trade auction proceeds are limiting the funding for CARB incentive projects including HVIP. Fleets also face higher sales taxes and registration fees based on the incremental cost of BEVs. Incremental costs are driven by low production volume and high energy storage and electric powertrain costs. However, energy storage costs are steadily declining and medium- and heavy-duty vehicle manufacturers are starting to see those reductions.

- Limited vendor and product selection, along with the accompanying service and support network, is an issue but is improving. While workforce training efforts for maintenance technicians and infrastructure installation personnel could benefit from greater coordination and funding, AB 841 will help to make additional training available. Product selection is expanding in the primary and secondary beachhead markets. Major OEMs and their dealer networks are starting to enter the market. Some established fleet service providers have entered into agreements to provide maintenance support to smaller company products.

- Legislation passed in 2018 allows a 2,000-pound weight exemption to zero- and near zero-emission commercial vehicles, so weight is not a limiting factor for road use. However, added system weight can displace passenger or freight capacity in some applications.

- Range or time of operations before refueling is steadily improving. Energy storage capacity, and therefore longer range, continues to expand as price drops. Class 8 ranges of 150-250 miles are being announced, with some ranges reported to be as high as 300 and up to 500 miles. As battery prices continue to fall, extended-range vehicles are becoming a more cost-effective option.

- Fleets are still learning the business case and best deployment applications of BEVs. The beachhead strategy has helped to define where technology can provide the best first capability and pay backs. Increasing demonstration, pilot, and commercial deployments are providing data to validate the fuel and maintenance savings associated with BEVs and the associated total cost of ownership (TCO). To assist fleets, the HVIP program has developed a TCO calculator to helps fleets best assess the fit for their operation. It can be found at: https://www.californiahvip.org/resources/#ownership-cost-estimator.

- California offers significant funding to off-set infrastructure costs. Even with infrastructure included, CARB has calculated a favorable TCO over conventional

technologies when incentives and LCFS credits are factored in.[23] LCFS credits can be assessed in the HVIP TCO tool.[24]

BEV Opportunities over the Next Three Years

In on-road applications, BEV technology is steadily expanding in the early beachhead market of transit buses, and emerging in medium-duty delivery and service vehicles, shuttle buses, and school buses. The refuse truck market is entering the pilot phase with several manufacturers. Other heavier vehicle applications such as drayage and regional delivery trucks are now in the later pilot stage, with four major OEMs taking reservations for zero-emission class 8 trucks that will be going into commercial production in 2021.

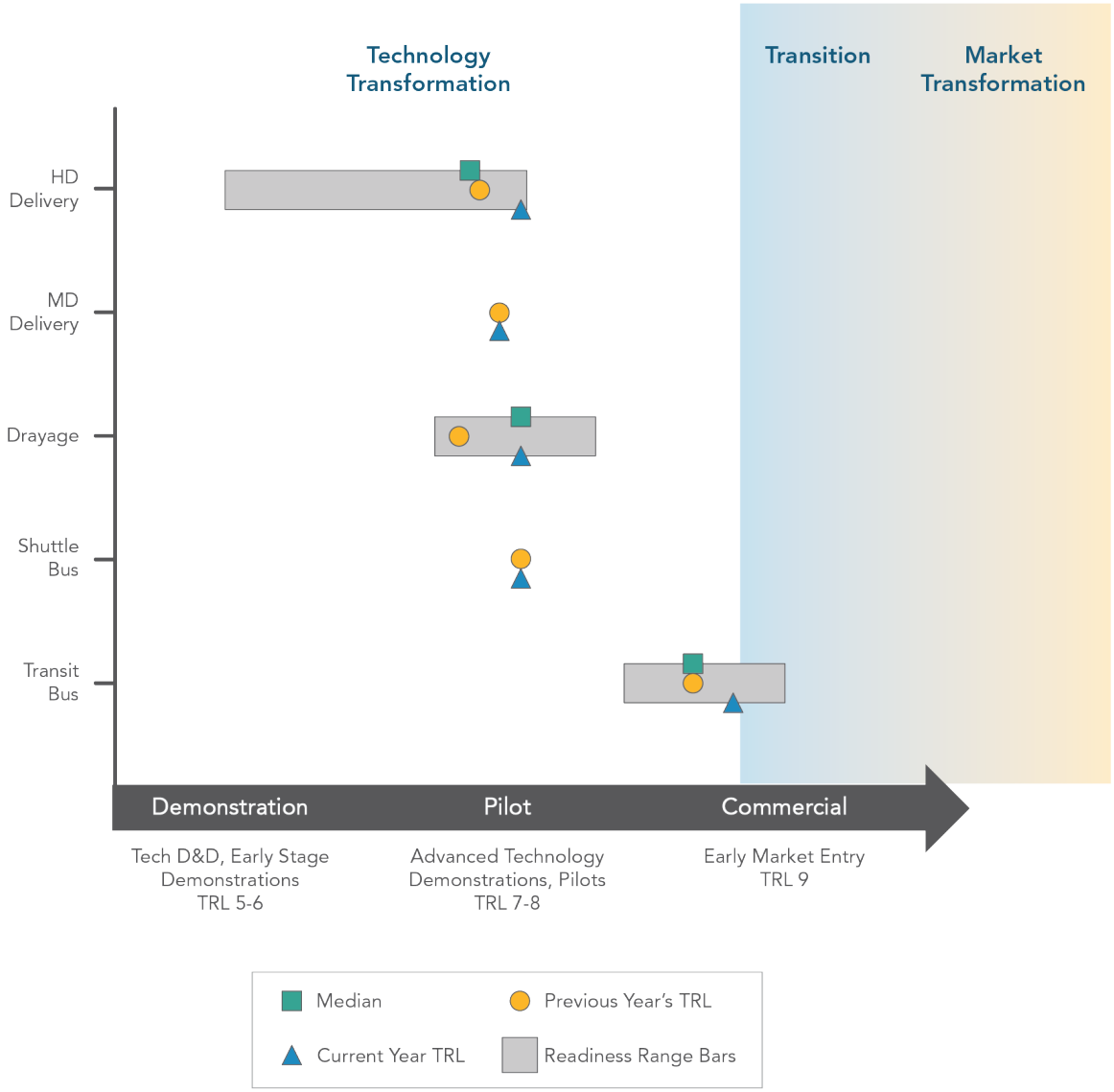
In the off-road sectors, BEV technology is in the commercial stage for industrial lifts and GSE and early production for terminal tractors and TRUs. Mini excavators are in the pilot stage. Port equipment is in the demonstration stage for heavy-duty cargo handling equipment such as top picks. Forklifts capable of lifting more than 10 tons show promise to progress faster, partly due to the ready transfer of powertrains and energy storage from BEV truck platforms. In electrification of the marine sector, ferry boats and other harbor craft are in early production and proving themselves in European applications, and in the U.S. are in demonstration phases. They have shown the ability to use powertrain technology transferable from the on-road sector.

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 9 and 10 provide an overview of the technology status of FCEVs.

[23] CARB. 5th Innovative Clean Transit Workgroup Meeting. June 26, 2017. https://ww3.arb.ca.gov/msprog/ict/meeting/mt170626/170626_wg_pres.pdf
[24] https://www.californiahvip.org/tco/

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



There are expanding opportunities to leverage fuel cell systems from one application to use in others. Fuel cell power plants developed for the passenger car market are expanding into heavy-duty demonstrations and pilots in on-road drayage and logistics truck applications. Hyundai in 2020 is delivering the first 50 of an eventual 1,600 fuel cell-powered Xcient heavy-duty logistics tractors to Switzerland[25]. Additional signs of industry momentum include the announcement of the world's two biggest truck

[25] https://www.hyundai.com/au/en/hyundai-info/news/2020/07/worlds-first-fuel-cell-heavy-duty-truck-xcient-fuel-cell

makers, Daimler and Volvo, agreeing to form a joint venture for the production of fuel cell powertrains for commercial vehicles.[26]

A key note from this year's snapshot highlights a clear trend in where best to focus FCEV market applications. While lighter-weight medium-duty platforms did not show progress, heavy-duty applications such as transit buses and heavy-duty drayage/regional delivery showed strong year-over-year progress. The first early commercial stage FCEV transit buses have entered service in California, while the average for the platform is late pilot/early commercial. Heavy-duty delivery and drayage platforms average squarely in the pilot stage of technology readiness.

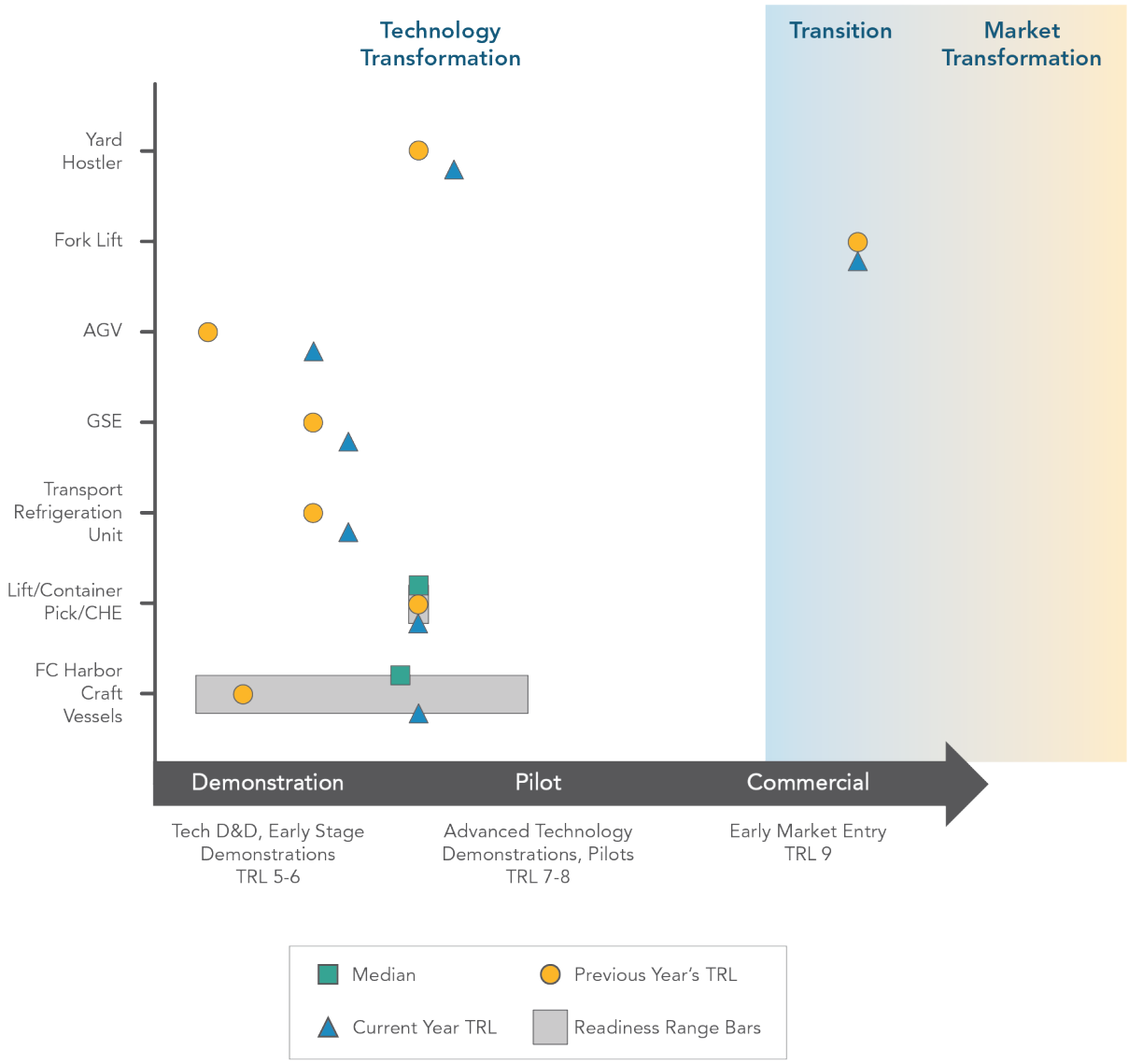
As mentioned, one of the reasons behind a growing interest in fuel cell electrification is the potential for providing sufficient energy for long range, heavy weight duty cycles, or those work cycles requiring continuous operation or multiple-shift operation where time for recharging may not be an option. 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, and drayage trucks, as well as other regional applications.

FCEVs and BEVs are highly complementary technologies. Both make use of the same core powertrain components (electric motors, power electronics, and energy storage) and jointly benefit from increased supply chain volumes. Battery electric capacity continues to increase, allowing steadily greater range,[27] but while there is no absolute point of separation, there may be an emerging crossover point where the fuel cell becomes the preferred option for weight and refueling considerations.

Several manufacturers are exploring both battery electric and fuel cell electric versions of their trucks. The battery electric versions would serve more urban and regional applications, while the fuel cell version would serve longer haul applications. Although

[26] https://www.volvogroup.com/en-en/news/2020/apr/news-3640568.html
[27] Ferris, Robert. Tesla's new semi -truck has a 500 mile range. CNBC. November 17, 2017. https://www.cnbc.com/2017/11/16/tesla-semi-truck-has-a-500-mile-range-ceo-elon-musk-reveals.html

Figure 10: Off-Road Fuel Cell Electric Vehicles Technology Status Snapshot



the balance between these technologies is not yet clear, this is an active area of exploration and research. Much depends on the ability to significantly reduce the cost of hydrogen fuel production and delivery.

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.

Key Barriers to FCEV Adoption

As shown in the charts, only a couple FCEV platforms have moved into the transition phase between technology and market transformation. Additional technology progress is required, as well as progress addressing barriers to market success. As an overview for FCEVs, these barriers continue to include the following:

- Final cost of hydrogen delivered to the pump: Hydrogen prices remain very high relative to current diesel prices. This issue remains a critical issue for hydrogen and must be targeted aggressively for progress to be made. Projects are underway to explore multi-benefit hydrogen production facilities, co-located with fueling infrastructure, which could help reduce hydrogen cost. This allows hydrogen to be used on site and eliminates currently high distribution costs. The use of renewable feedstocks in California incented by LCFS credits can help reduce hydrogen cost.

- Significant infrastructure costs and a lack of easily accessible infrastructure: A focus on developing on-site, high capacity production facilities at locations of high fuel throughput, connected by corridors to similar sites, is emerging as one potential option. Such sites also could provide local hydrogen fuel to nearby refueling sites for other users. California continues to invest in hydrogen infrastructure, but these sites are almost exclusively focused on light-duty passenger cars and only rarely support medium- and heavy-duty vehicle access.[28]

- High incremental vehicle cost due to fuel cell stack, balance of plant, and hydrogen tank costs: While costs have been steadily decreasing with improved engineering and product integration, they have not reduced quite as fast as have battery electric costs. California has enacted several effective programs to address costs in the form of the HVIP and CORE purchase vouchers, Moyer, and separate funding from air districts. Assuming sufficient funding is allocated to these programs, the State has strategies to address this barrier.

- Unknowns about the life cycle of the fuel cell and time before replacement: Fuel cell transit bus performance data shows that fuel cell vehicles can attain long service lives that match the service intervals of a standard diesel-powered transit bus.[29]

[28] CEC & CARB, Joint Agency Staff Report on Assembly Bill 8: 2019 Annual Assessment of Time and Cost Needed To Attain 100 Hydrogen Refueling Stations in California; December 2019. https://ww2.energy.ca.gov/2019publications/CEC-600-2019-039/CEC-600-2019-039.pdf

[29] CARB. AC Transit's Fuel Cell Program Breaks 25,000 Hour Operating Record. July 12, 2017. https://ww2.arb.ca.gov/news/ac-transits-fuel-cell-program-breaks-25000-hour-operating-record

- Understanding of the business case outside forklifts and best deployment applications: The fuel cell transit bus business case is beginning to provide good data from early pilot and commercial deployments. In most cases the hydrogen fuel cost is the biggest constraint, followed by vehicle and infrastructure costs.

- Limited vendor and product selection and the accompanying service and support network: The fuel cell manufacturer market has a strong base of providers; the vehicle producer segment is slowly expanding and starting to grow outside a solid base in forklifts as well as an increasingly solid base in transit buses. In the truck sector, production is envisioned to be 2022 or later.

FCEV Opportunities over the Next Three Years

In on-road applications, FCEV transit buses still straddle late pilot and early commercial stages. Additional pilot stage funding would still be useful, particularly to scale regional/facility infrastructure and on-site fuel production. Fuel cell heavy-duty trucks are now in the mid-pilot stage of commercialization and show growing capabilities. This remains an important investment opportunity for State funds. Fuel cell technology is ready to demonstrate in other on- and off-road applications, including cargo handling equipment and harbor craft, where shared fuel production and infrastructure can be developed and supported.

Fuel production and fueling facilities should be a focus of regional, state, and federal fuels funding. CARB fuel cell vehicle funding can help to leverage other sources of funding for hydrogen infrastructure and fuel production. The agency is committed to finding other such project partnership opportunities that can help build a larger scale, site-based hydrogen production capacity, combined with on-site and regional fueling sites matched with multiple medium-duty fuel cell vehicle applications to use it.

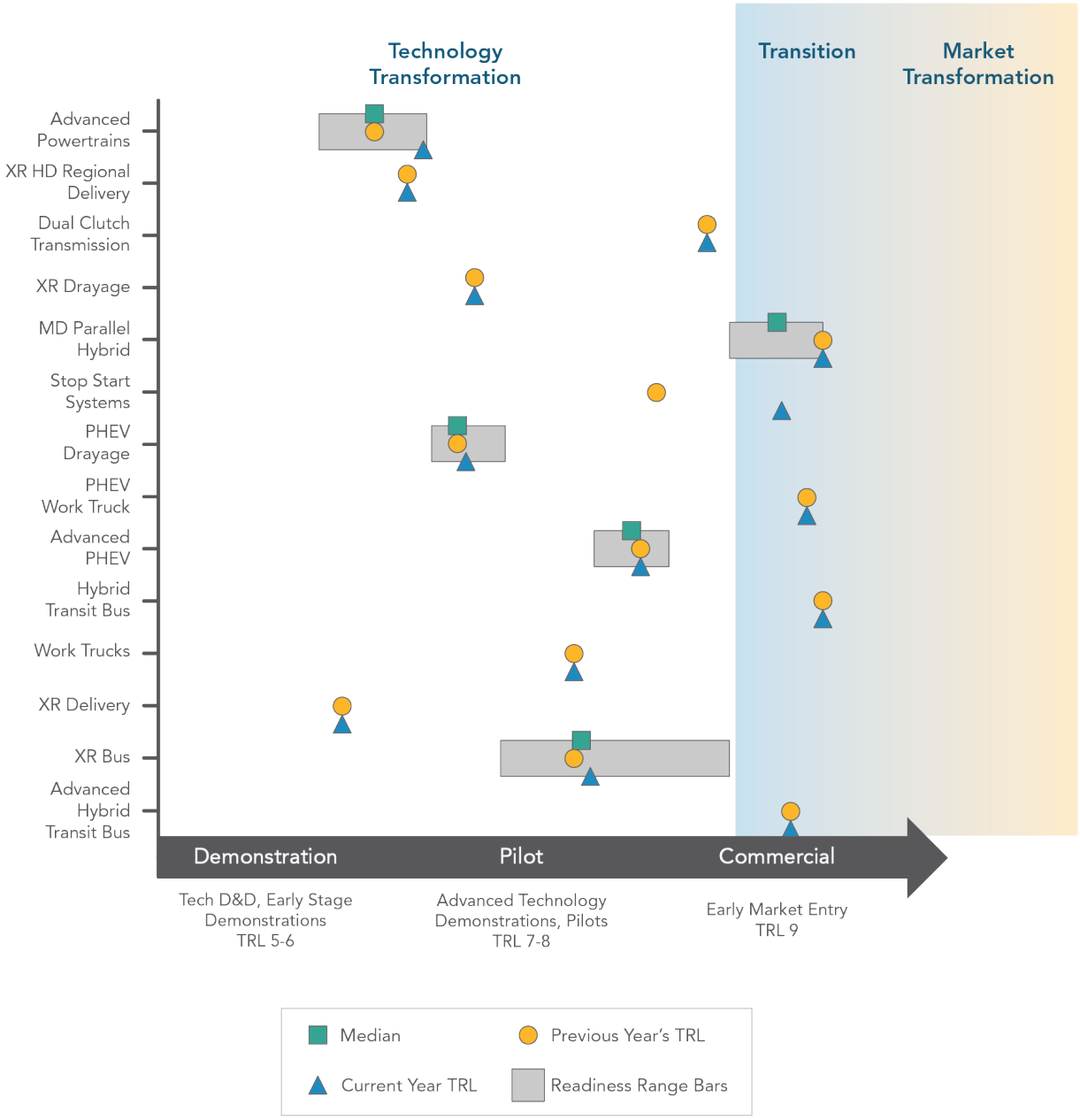
Hybrid Electric Vehicles Technology Status Snapshot

Hybrid electric systems share many subcomponents with battery electric and fuel cell electric systems. While truck hybridization has not expanded greatly recently as manufacturers have focused on fully electric systems, there continues to be progress in hybrid bus technology which remains a strong and fully commercial segment. 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. Through its acquisition of AxleTech, Allison Transmission[30] has recently announced a capability to extend its hybrid bus operation to 10-miles of zero emission driving. These augmented systems are currently at lower volume but build off existing hybrid products and can be considered early commercial stage.

[30] https://www.greencarcongress.com/2020/08/20200828-allison.html

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 11 and 12 depict the progress of the hybrid electric vehicles along the commercialization path.

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



Hybrid systems for trucks are available commercially from several qualified vehicle modifiers, sometimes referred to as up-fitters, in medium-duty delivery and service applications. These systems are relatively low in volume but are considered just beyond early commercial.

Hybrid systems to allow engine off operations at work sites, rather than primarily propulsion, have been in low volume production for years, providing the ability to shut

off idling engines while operating tools, lifts and compressors (electric power take-off). These systems potentially could also be used to power TRUs, as well as to provide ambulance and first responder power, which demonstration funding could help expand.

Start-stop hybrid systems that allow an engine to turn off at stop lights and traffic delays, or during idle operation, are becoming increasingly available in medium-duty vehicles and are offered in heavy-heavy-duty transit, yard hostler/terminal tractor and refuse trucks, and some medium-duty truck applications.

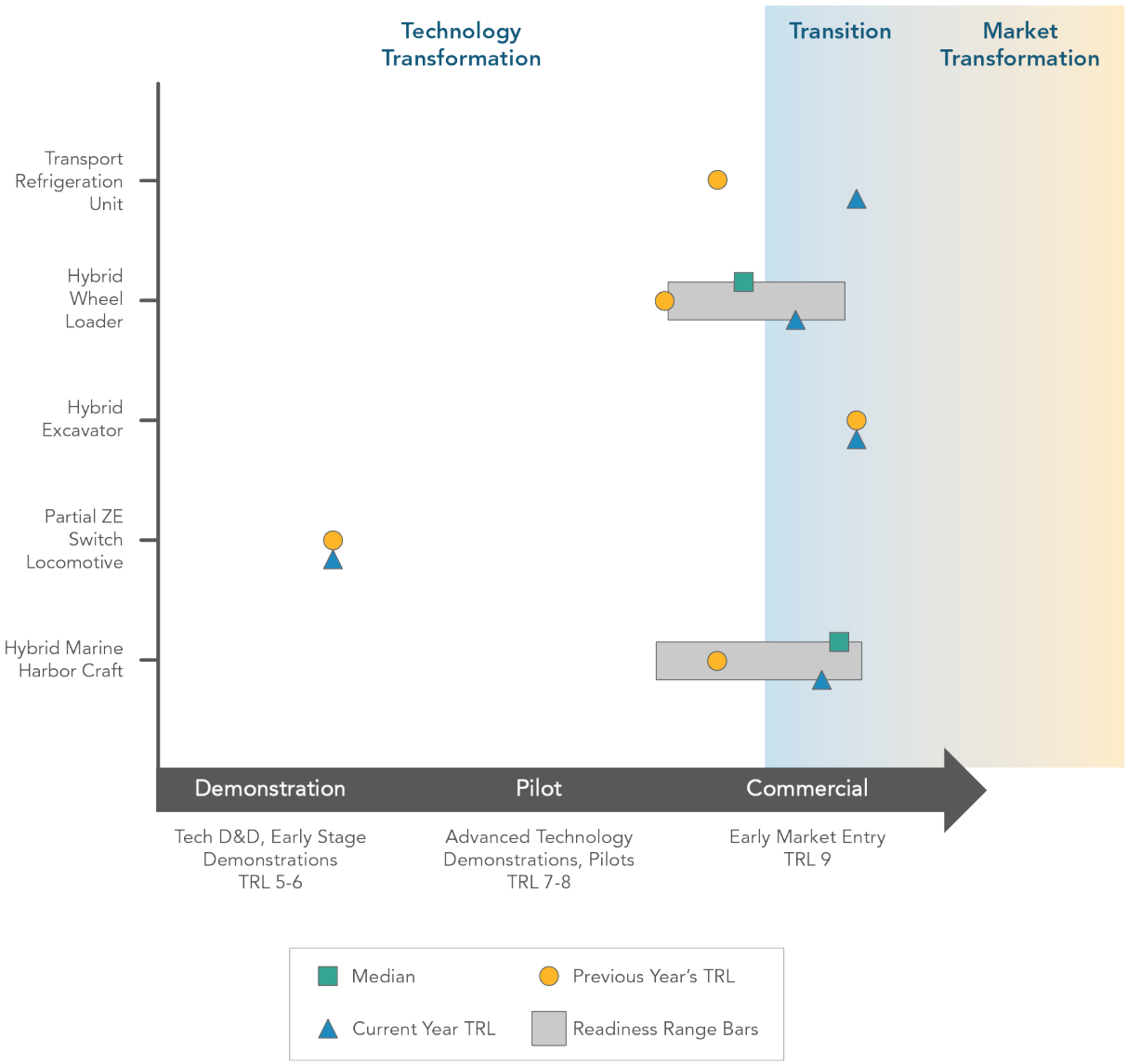
Little progress is being seen in HEV drayage and heavy regional delivery truck applications. Plug-in hybrid electric (PHEV) and extended range series-electric designs remain in the demonstration or early pilot stage. The rapid emergence of BEV technology and stringent emission certification testing has slowed some HEV development even though HEV architectures are the backbone of FCEVs. Emerging test requirements for low emission engines that can meet emission levels in all operating regimes may make future combustion engine-based hybrids more feasible.

Hybrid electric power systems are showing worldwide applications in the maritime sector. Hybrid ferry and support vessels are in early commercial use in Europe and increasingly in pilot and early commercial stages in the U.S.

However, the off-road segment remains extremely promising for the use of HEV technology, as these applications often require high power demands and long operational capability, and are remote from electric or hydrogen refueling options. Additional factors such as cost and the chassis packaging requirements for many off-road applications play a role in making hybridization a desirable option. HEV technology has the capability to meet the needs of these rigorous off-road applications with reduced fuel use and lower carbon emissions, and potentially lower criteria emissions.

Hybrid excavators range from the pilot stage to early commercial stage. Hybrid wheel loaders are in advanced demonstration and pilot stages. Both products are commonly used for construction purposes. Wheel loaders also have goods movement/freight

Figure 12: Off-Road Hybrid Electric Vehicles Technology Status Snapshot



uses. Hybrid construction and agricultural equipment are freight-enabling applications because of the common supply chain for components and similar architectures for powertrains.

Hybrid electric power systems are showing worldwide applications in the maritime sector. Major global manufacturers have powertrains or major developments in this segment, including ABB, Siemens, BAE Systems, and Volvo Penta. Hybrid ferry and support vessels are in early commercial use in Europe and increasingly in pilot and early commercial stages in the United States. The Washington State Ferry system, largest in the U.S., this year committed to transition to fully electric powertrains for its

ferries, including hybrid electric, plug in hybrid electric and battery electric vessels[31]. Hybrid systems can provide direct propulsion power, and/or provide auxiliary or idle power for marine vessels, some as large as cruise ships. Primary applications include tugs, tenders, ferries, and other similar vessels.

Hybrid systems provide fuel savings and potential emission reductions (on a duty or work cycle basis) and also serve as an important pathway for zero-emission technologies. Hybrid electric heavy-duty vehicles help increase the production volume for components like battery packs, electric motors, and control systems by bringing down manufacturing costs and supporting the supply chain to benefit other zero-emission technologies.

Barriers to HEV Adoption

As can be seen from the charts, several HEV platforms have moved into the transition phase between technology and market transformation. Market volumes and adoption success in some of these applications may signal that graduation to funding programs more focused on market transformation may be indicated. In other segments, tech improvement has slowed or stagnated, partly from low fuel prices and growing interest in less complex battery electric systems. As an overview for HEVs, key barriers include the following:

- The incremental cost of the vehicles: While vehicle cost has been dropping steadily the last few years, it is still higher because of energy storage and control system integration, and complexities of conventional engine integration and certification. It is a bigger issue for plug-in hybrids, largely due to higher capacity batteries.

- Lack of understanding of the business case and best deployment applications: Relatively low conventional fuel costs have made recovery of the incremental cost from fuel savings take longer. Recent dramatic fuel price drops have not helped hybrids.

- A lengthy and expensive certification process for hybrid vehicles and equipment: The Innovative Technology Regulation was partially designed to assist hybrid technologies. However, some manufacturers remain concerned about the complexity of meeting emission regulations in systems combining engines and hybrid components, sometimes resulting in missing incentive funding opportunities. Complications are greater for marine applications, which face challenging EPA and Coast Guard certification processes.

- Limited vendor and product selection reduces options.

[31] https://insideevs.com/news/427007/washington-state-ferries-electrified/

- Infrastructure is a barrier for plug-in hybrids but not conventional designs.

HEV Opportunities over the Next Three Years

Hybrid technology looks most promising in the near term in off-road applications and in the maritime sector. As electrification moves into heavier weight classes, more demanding duty cycles, and longer periods of operations, hybrid technologies remain an extremely relevant solution. This will include some cargo handling equipment, construction equipment, and agricultural equipment, where there remains a need for a combustion engine for power or sustained energy and where fuel cell technology is neither available nor convenient. These applications can benefit from demonstration and pilot funding, as well as purchase incentive funding for products already in the market (such as construction equipment). Due to considerable overlap in componentry, duty cycle, and energy demands, construction and agriculture can be considered a freight-enabling application for purposes of commercialization. Demonstration projects for construction equipment stand to expand capabilities for goods movement. Hybrid harbor craft represent a technology already in use in Europe that could have much wider application in the United States, and pilot incentive funding could assist.

Combustion Technology Status Snapshot

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 than currently required under EPA rules for heavy-duty engines and vehicles. The regulation will require 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)[32]. Additional provisions require these levels be met via a testing procedure that better matches real-world operating conditions. The regulation would also allow 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 would be required by CARB's proposed Advanced Clean Trucks (ACT) Regulation. In addition, to incentivize early emission reductions especially in critical areas like the South Coast and San Joaquin Valley, the regulation would provide compliance credit multipliers to manufacturers that certify early to applicable emission standards.

U.S. EPA has been developing lower emission regulations parallel to and in consultation with CARB via its Cleaner Trucks Initiative, with a stated goal of updating the federal NOx emission standards to further reduce NOx emissions from heavy-duty engines. EPA has yet to publicly signal the reduction levels it would seek, and in the summer of 2020 the agency announced it was further delaying release of its Notice of Proposed Rulemaking (NPRM) which had been expected earlier in the year.

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

In 2020 the Manufacturers of Emission Controls Association (MECA) published a white paper highlighting the technical feasibility of diesel engines meeting a 90 percent NOx reduction level by 2027[33]. There has been significant progress in demonstrating the efficacy of the after-treatment systems needed to meet this standard, as noted by MECA. It had in an earlier report found that engine makers can achieve the most stringent NOx emissions standard while still meeting 2027 GHG regulations[34]. Achates Power, whose high-efficiency, combustion engine is nearing demonstration with help from CARB funds, is working to exceed this capability. Modeling and engine dynamometer testing have shown the capability to meet a 90 percent reduction in NOx from EPA 2010 standards while meeting or exceeding 2027 GHG standards today and do so at lower cost than conventional designs[35]. Larger displacement engines for switch locomotives and some marine vessels may also show the potential to exceed Tier 4 emissions.

Meeting lower NOx levels has long been a reality for spark-ignited engines. Medium- and heavy-duty engines such as those powered by natural gas and propane have reached full technology readiness over the past several years and are in regular serial production. The Cummins Westport 11.9-liter engine is a prime example of this class and is now in mass production and beyond the early commercial stage. This cleanest combustion version has effectively replaced the version certified to the less stringent U.S. EPA 2010 standards. It is available as a factory-installed option from all truck makers. This engine brings the cleanest combustion technology to drayage, regional delivery, and many long-haul applications (heavy heavy-duty) along corridors where natural gas fuel is available.

Meeting lower NOx standards has long been a reality for spark-ignited engines. Medium- and heavy-duty engines such as those powered by natural gas and propane have reached full technology readiness over the past several years and are in regular serial production.

Several gaseous fuel engines (natural gas and propane) have certified to the current NOx standards and are now the default models for this class and are in commercial production for transit buses (heavy heavy-duty), medium-duty on-road trucks, and school buses (medium-duty). These include 6.8- and 8-liter propane, and 8.9-liter and 6.7-liter natural gas engines. The engines cited above are now being sold in the United States at volumes of several thousand units per year and are past the early commercial stage.

[33] http://www.meca.org/resources/MECA_2027_Low_NOx_White_Paper_FINAL.pdf
[34] http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf
[35] http://achatespower.com/wp-content/uploads/2020/03/Achates-Power-Cost-Study-White-Paper_March-2020.pdf

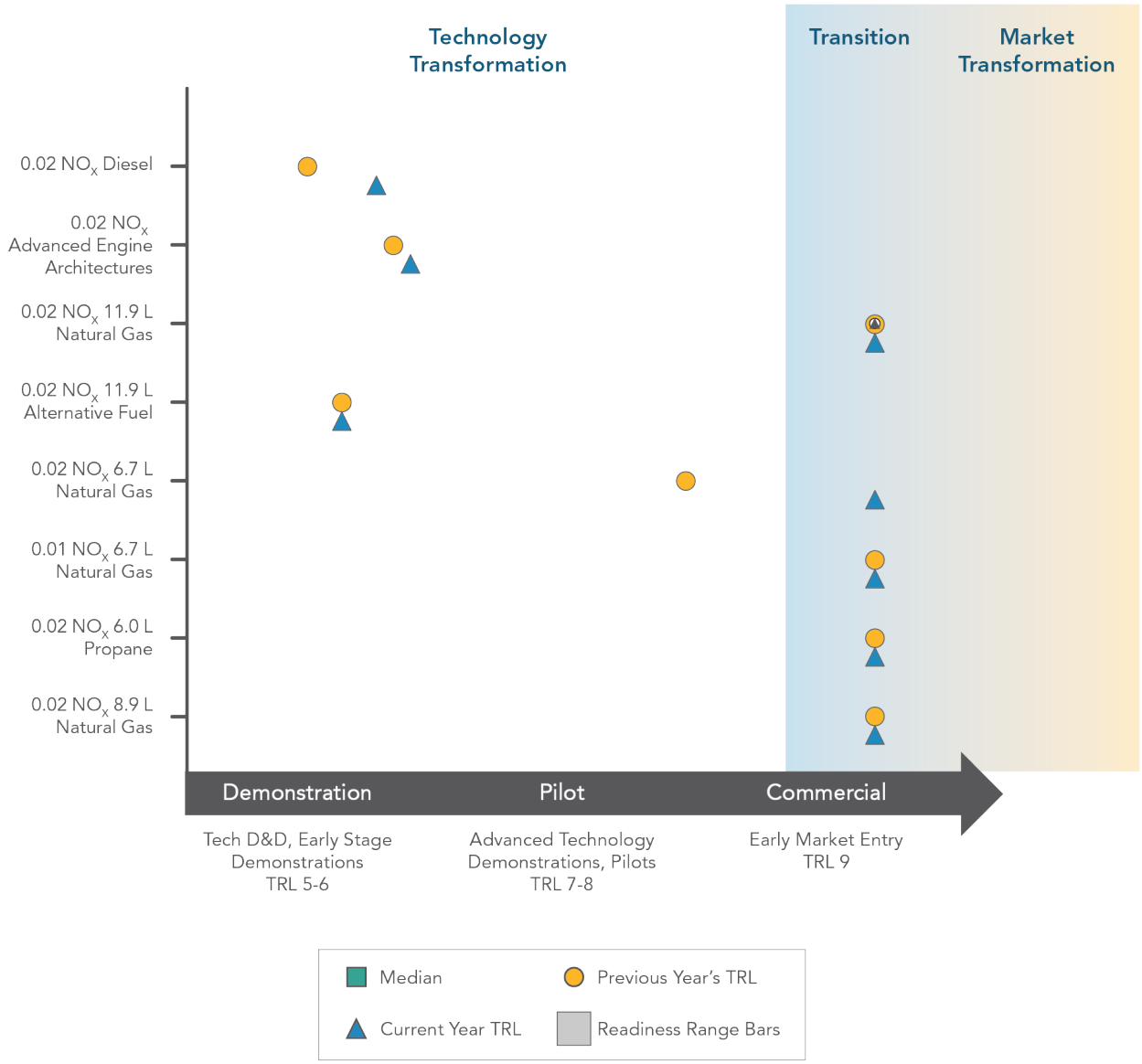
This technology has become a strong story of success as its status has moved through the stages of the commercialization process tracked here. Figures 13 and 14 depict the progress made by the cleanest combustion engines over the past two years.

Expanding the deployment of the cleanest combustion engines into diesel-fueled vehicles and the heaviest on-road engine weight classes is important for technology transfer to off-road equipment. New combustion engines utilizing the cleanest advanced technologies should be paired with renewable fuel use to maximize criteria and climate emission reduction benefits.

Hybrid systems also have the potential, on a duty cycle or work cycle basis, to also greatly reduce NOx emissions assuming the engines and aftertreatment systems are sufficiently integrated with the hybrid components and operation. This would have the further benefit of combining full powertrain efficiency improvements with emissions reductions.

In the marine sector, there are potential retrofit technologies, as well as bonnet systems for reducing NOx, PM, and sulfur oxide emissions. While very different compared to on-road mobile applications, there are opportunities for developed technologies for container ships to transfer to other types of vessels (e.g., tanker vessels) and crossover is possible between other sources like locomotives. Advances in these technologies help the State to meet its climate and air quality goals.

Figure 13: On-Road Combustion Technology Status Snapshot



Barriers to Combustion Adoption

Several of the cleanest combustion platforms are in serial production and squarely in the market transformation phase. Strong core market volumes, growing production, and user acceptance in some of these applications may signal that graduation to funding programs more focused on market transformation is indicated. As an overview for the cleanest combustion engines, despite its mature technology readiness level, these barriers include the following:

- Incremental cost: While moving past the early commercial stage and into higher volume production, the cleanest combustion natural gas (NG) engines and trucks still carry an incremental cost compared to diesel, largely due to fuel tanks. Combustion engines based on propane engines do not carry as high an incremental cost. Advanced engine systems could eliminate additional fuel system costs but may carry higher costs for lower volumes in the early years.

- Fueling infrastructure: More than 20,000 natural gas vehicles currently operate in the State, with an existing expansive network of public and private fueling infrastructure. However, fueling infrastructure availability may be an issue if there is substantial additional turnover from diesel to natural gas and propane vehicles in some regions and route structures.

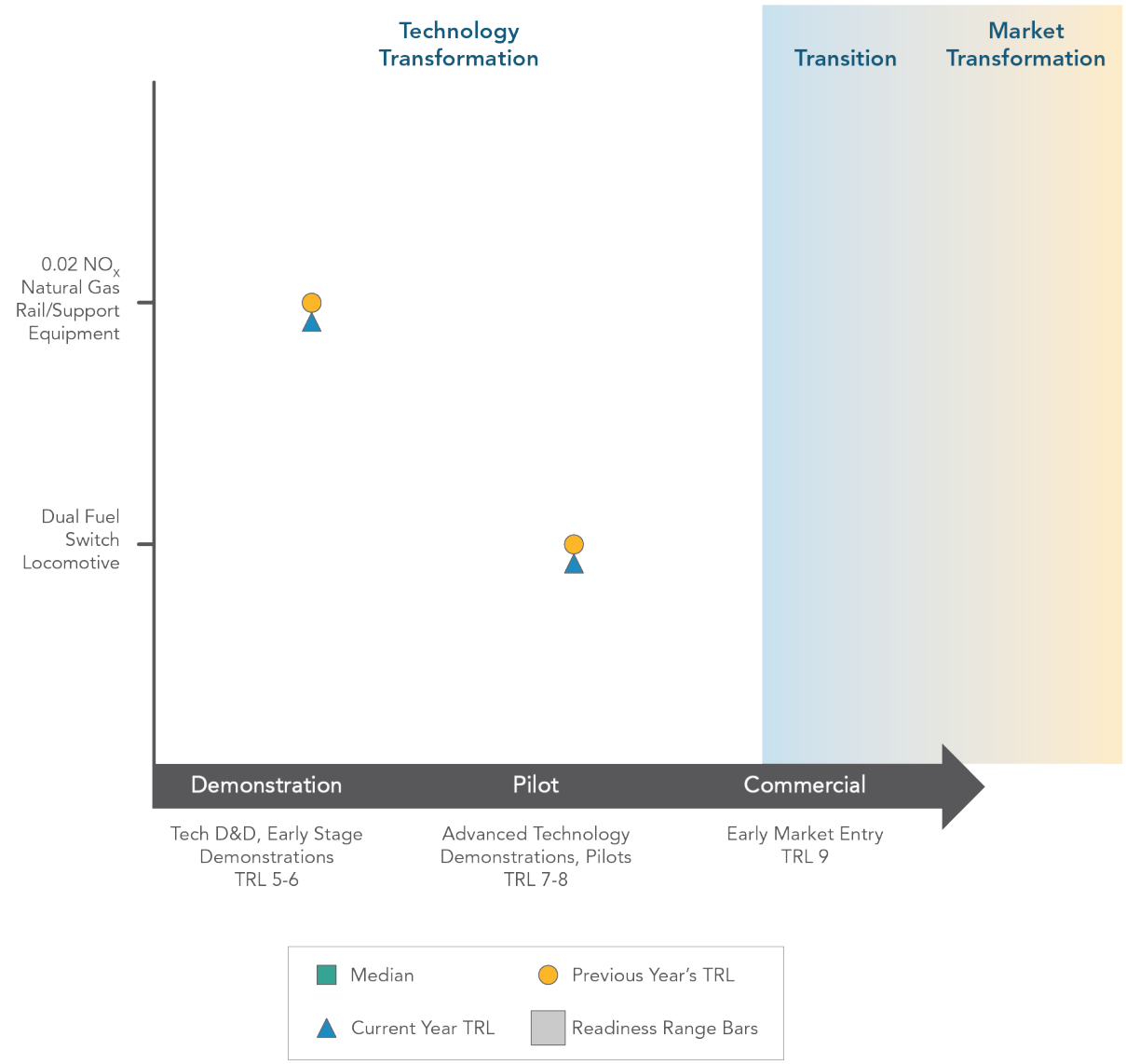
- Reliability concerns: Current generations of NG engine technology are proving to be reliable. Nonetheless, fleets may still remember reliability problems from earlier generations of NG engines. Case studies shared broadly with fleet decision makers could facilitate the transition.

- Limited understanding of payback period: Fleet knowledge of payback periods is often a barrier for alternative fuels. However, even fossil-based natural gas can be cheaper per mile than diesel; renewable natural gas (RNG) even more so. When renewable fuels are used, the Low Carbon Fuel Standard credits can provide a significant price advantage.

- Reduced efficiency: Generally, natural gas and propane engines use spark-ignited engine systems, which are less fuel efficient than compression-ignition engines.

- Limited vendor and product selection: For natural gas this has been mostly addressed, as most truck makers offer a manufacturer-installed version of the engine.

Figure 14: Off-Road Combustion Technology Status Snapshot



Combustion Opportunities over the Next Three Years

Supported by an expansive network of public and private natural gas fueling infrastructure built out over the last 30 years, the cleanest combustion natural gas and propane engines are now technical success stories that are generally beyond early commercial status. They are ready for promotion from technology transformation programs to make use of funding programs specifically designed to support fleet turnover and transformation.

Given regulatory decisions, conventional diesel engines will be required to meet a lower NOx certification level over the next several years. The State has previously invested in technologies to assist this capability. Nonetheless, advanced engine designs that can achieve lower NOx emissions while also increasing efficiency remain a valuable investment (see mention of future Tier 5 emissions standards in the Beachhead Strategies discussion). Achieving lower NOx emissions in off-road equipment remains a technical challenge, and more pilot and demonstration work could be warranted. Validating other innovative NOx reduction strategies involving duty cycle improvements, powertrain efficiencies, and engine-off operations would also help drive innovation. The cleanest combustion engines are also valuable components that should be integrated into series electric and plug-in hybrid designs to further reduce combustion emissions. This work should be focused on areas where zero-emission technologies are significantly further behind on the commercialization path.

Efficiencies in engine / power plant and drivetrain optimization; vehicle efficiency improvements; and operational / worksite efficiencies are the primary focus of the Efficiencies Beachhead, but idle reductions and automated / connected vehicles are also of interest.

Efficiencies Technology Status Snapshot

In the heavy-duty and off-road sectors, efficiency strategies can be grouped roughly into three categories: engine/power plant and drivetrain optimization; vehicle efficiency improvements; and operational/work site efficiency improvements. Figures 15 and 16 illustrate the gains made in these categories of efficiency strategies over the past two years. In the interest of streamlining presentation and review, those powertrain efficiencies mostly enabled through hybridization have been eliminated from this section (please refer to the hybrid electric section for those technologies).

Of those systems remaining in this assessment, work-site idle reduction systems deserve notice. Most of these systems are in early commercial production, with some advanced or extreme function capabilities (such as higher torque or extended time operations) still in the pilot stage. The active reduction of idling from on- and off-road engines during work periods or lulls in intensive activity can be a significant fuel saver.

There are continuing advancements coming in the connected and automated technology arena. Full automation of vehicles is in validation in several categories, both on- and off-road. TuSimple has achieved the most notice in 2020 as they have partnered with Navistar and committed to offering a fully autonomous Class 8 truck by

2024[36]. Aurora, which has funding from Amazon[37], and Waymo[38], funded by Google, are also making progress with autonomous heavy vehicle demonstrations.

Of great interest are those technologies allowing much more efficient work sites, therefore reducing energy use and carbon emissions. Volvo Construction Equipment's quarry demonstration in Sweden showed impressive net fuel and emission reductions per unit of work using automated and electrified work machines.[39] There are some similar technologies, though not yet as fully integrated, in the agricultural equipment sector. Such projects could show great promise for California work sites.

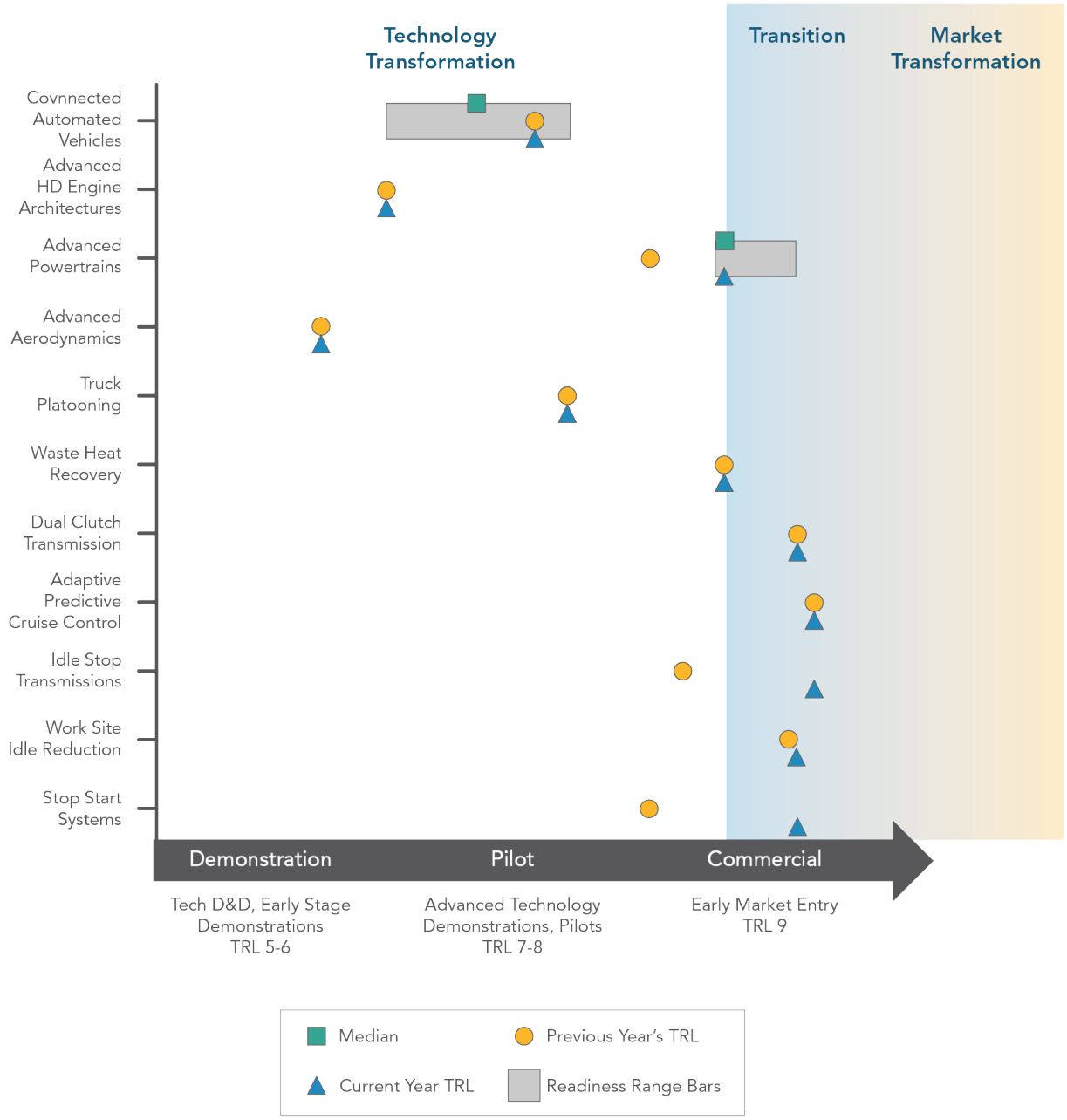
Safety as well as efficiency considerations have led connected and autonomy-pathway technologies to become increasingly commonplace in truck specifications, including adaptive cruise control, collision avoidance, and lane departure warning systems. These systems are enablers of automation and also provide some of the building blocks for region-based vehicle operation, such as geo-fencing for zero-emissions operations.

Towbar-less tugs for aircraft push back are becoming increasingly common and can enable aircraft to not start their engines until towed all the way to the runway, saving fuel and emissions. Zero-emission versions of these tractors are in the demonstration phase and should be funded and encouraged.

Generally, CARB considers connected vehicle technologies as having a "multiplier" effect. While they may not be a large investment category on their own, their inclusion in projects paired with advanced cleanest combustion, hybrid, and zero-emission powertrains can extend the effectiveness of these systems and should be encouraged.

[36] https://news.navistar.com/2020-07-15-Navistar-and-TuSimple-Partner-to-Bring-Autonomous-Trucks-to-Market-Navistar-Invests-in-Autonomous-Trucking-Company
[37] https://www.theverge.com/2020/1/24/21080298/aurora-self-driving-car-announcement-2020-plan-waymo-ford-general-motors
[38] https://venturebeat.com/2020/06/30/waymo-expanding-autonomous-truck-testing-in-american-southwest/
[39] Doyle, Marcia Gruver. Volvo: Electric Site quarry test reduced emissions by 95%. Equipment World. https://www.equipmentworld.com/volvo-electric-site-quarry-test-reduced-emissions-by-95/

Figure 15: On-Road Efficiencies Technology Status Snapshot



Barriers to Adoption of Efficiency Opportunities

As can be seen from the charts, many Efficiency systems have moved into the transition period between technology and market transformation. Most of those applications do not receive Low Carbon Transportation funding directly, as several are subcomponents driven by fuel efficiency regulations. For those that receive Low

Carbon Transportation funding, graduation to funding programs more focused on market transformation, such as Moyer or CAPP, should be assessed. As an overview for efficiency technologies, these barriers include the following:

- The cost added to vehicles, due to expensive components and relatively costly integration, varies greatly by efficiency technology.

- The low cost of diesel fuel creates longer payback times for any efficiency technology.

- Infrastructure may be a potential barrier for connected and automated technologies—the question is how much off-vehicle infrastructure is required.

- Lack of understanding of the business case and best deployment applications are a challenge with most new capabilities.

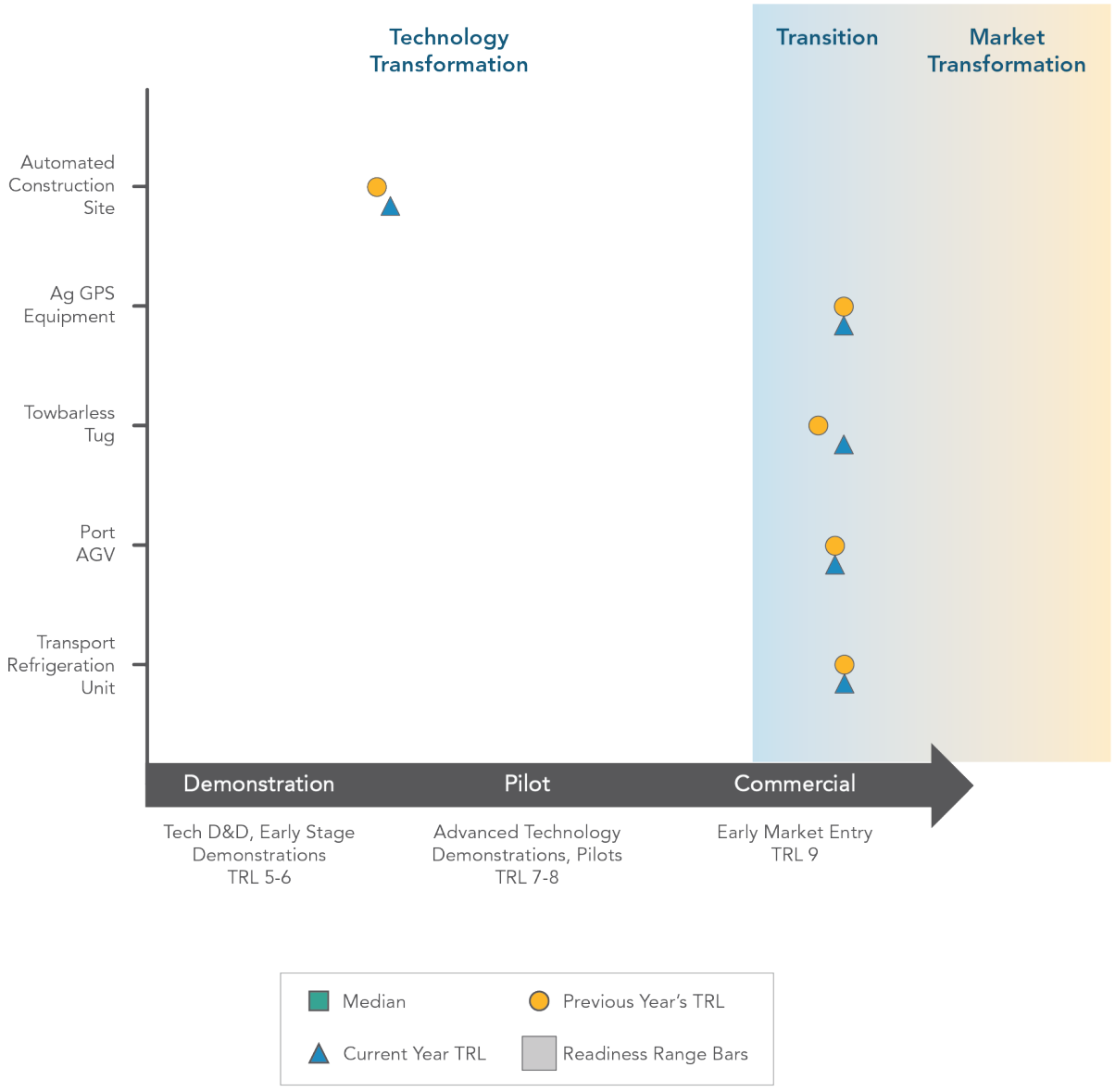
- There is not much familiarity yet with some of the advanced technologies. This issue is steadily being addressed as trucking fleets see the value of specific technologies and add additional connected and semi-autonomous technology to their standard truck fleets.

Efficiency Opportunities over the Next Three Years

Off-road connected and automated work site demonstrations are ripe arenas for investment because of their ability to reduce emissions and increase productivity in otherwise hard to address sectors. Promising applications to expand this technology are ready for demonstration and pilot stage projects. Construction and agricultural sites are promising candidates, and freight-enabling applications, because of the similar components and supply chains involved.

Despite investments from DOE and others, a technology gap remains for advanced engine development that California funding could help address because of its potential to leapfrog current designs in efficiency. Work site and powertrain engine-off technologies can be accelerated to the market via focused pilots or commercial incentives. Combining connected technology with the above strategies, such as geo-fenced powertrain management, provides a highly leveraged strategy to move multiple technologies forward.

Figure 16: Off-Road Efficiencies Technology Status Snapshot



Other Emerging Technologies

There are additional applications that represent opportunities, including locomotives and oceangoing vessels,
athat could entail reducing the operations of auxiliary or secondary engine systems on vessels. Early demonstration projects utilizing zero-emission or the cleanest combustion technologies are underway and should be expanded in the rail sector.

Staff anticipates working with other CARB divisions, other State agencies, and stakeholders to coordinate on funding developments in these areas.

Market Readiness Indicators

Conducting technology readiness assessments is an important first step in evaluating advanced technologies, but one that tells only part of the commercialization story. As technologies move toward full technical readiness (higher average TRL scores by platform), their commercialization status becomes more dependent on their market readiness. Assessing market readiness can be better accomplished by evaluating status against key "Market Readiness Indicators" (MRIs).

Even though a technology may be technically ready for commercial introduction at TRL 9, other issues – such as work site rules, unique duty cycles, the business case, and infrastructure costs – can impact its introduction into the marketplace.

The technology status snapshots analyze the level of advancement for emerging technologies from a technical performance level. However, as production capability begins, this can result in an incomplete picture, because market and economic factors can hold back a technologically-advanced platform. Understanding barriers and issues of readiness helps in formulating nuanced and effective investment recommendations and informs the pace of technology introductions.

This year, CARB worked with industry stakeholders to: 1) develop a list of quantifiable market-viability indicators; 2) assess the importance or weight of each indicator; and 3) review related frameworks for their guidance on approaches. Subsequent efforts in future years will include quantifying these indicators by each funded technology and identifying available supporting data.

CARB has identified Market Readiness Indicators in 4 areas:

- Market acceptance
- Technology performance
- Barriers to adoption
- Economic factors

CARB worked with stakeholders this year to develop a list of quantifiable market-viability indicators, asses their importance or weight, and review related frameworks for guidance on approach.

MRI Components

The purpose of the MRI is to help complete the picture of technology status and market readiness by assessing the market viability of a given technology platform. The MRI core components developed through this process include:

- Market acceptance
- Technology performance
- Barriers to adoption
- Economic factors

Each component of the MRI includes several important assessment criteria. The components and assessment criteria were discussed during Work Group meetings in spring 2020, and 66 participants helped score the relative importance of assessment criteria. The results helped CARB prioritize the most important criteria.

Market acceptance includes the following criteria:

- Having significant volumes in the marketplace
- Participation from large OEMs
- Entering mass production and integrating into OEM manufacturing lines
- Having established reliability, consumer confidence, and acceptance
- Having an established secondary market and parts/service network

Technology performance includes the following criteria:

- Compatible with a significant number of applicable duty cycles
- Operational benefits of new technology compared to conventional technology
- Achieves cost-effective emission reductions
- Provides opportunity for technology transfer to other applications (beachhead)

Barriers to adoption includes the following criteria:

- Supported by adequate infrastructure
- Vehicle and infrastructure technology is standardized and unimpeded by certification or code requirements
- Supported by an adequate service network

Economic factors include the following criteria:

- Achieves TCO parity with conventional alternative
- Has a low incremental purchase cost compared to the conventional choice
- Low indirect/replacement/transition costs from changing technology

Each of the criteria within each of the four indicator categories was referenced to minimize overlap with another indicator, and ensure that each was quantifiable. It was determined early on that each category would not be weighted the same; some indicators would be more impactful to weighting market readiness than others. To address this, indicators are ranked above in the order of their perceived importance to

market success, which was calibrated with stakeholder input. Additional work will need to be conducted to identify a means of quantifying or scoring each of the criteria.

As envisioned, an evaluation of how well a technology platform demonstrates success or progress against each criterion can illustrate its market readiness in that MRI component category. When a technology platform is assessed across all the MRI component categories, market readiness can be more clearly understood and shown in relation to other platforms.

Over the next year, CARB staff will work with industry and other stakeholders to further refine the MRI process and assess those technology platforms for market readiness that have shown high technical readiness and are in the process of transitioning to market introduction and penetration.

Ongoing Issues Affecting Market Transformation

Market transformation can be affected by a number of implementation variables, any one of which can slow progress. CARB has compiled observations on a number of ongoing issues that do or have the potential to affect successful commercialization. Many of these issues have been raised in stakeholder and industry discussions and are discussed throughout the document. These issues are in addition to those associated with assessing technology status progress and success in growing beachhead pathways.

Last year's Strategy document included a detailed discussion of issues related to market transformation that have been raised by stakeholders a number of times over the years. Issues discussed include:

- Infrastructure
- Purchase cost
- Information gap
- Service and support
- Secondary market
- Stable funding and support
- Reliability and consumer confidence, and
- Other strategies

For this year's update, the discussion will provide a more focused analysis, looking closely at several key issues: infrastructure, component costs, and a few other issues.

HYUNDAI DELIVERS ON HYDROGEN IN SWITZERLAND

The Swiss H2 Mobility Association, which consists of 19 major retailers, will partner with Hyundai Hydrogen Mobility (HHM) to operate up to 1,600 HD fuel cell trucks (FCVs) by 2025, supported by as many as 150 fueling stations. Retailers have agreed to lease HHM's trucks on a pay-per-use basis that will pay for mileage, warranty, services, insurance, and access to hydrogen. HHM is installing corridor refueling stations and is contracting with a separate company to provide hydrogen.

Switzerland provides an ideal early market for HD FCVs for two reasons: savings from the LVSA, a heavy-duty vehicle fee, and Swiss geography. The LVSA is an annual fee that the Swiss government assesses for each HD truck transporting goods on Switzerland's roads. The LVSA exempts vehicles that operate entirely on electricity (or electricity derived from hydrogen).

The amount that fleet operators must pay for operating diesel trucks is high enough that several of Switzerland's largest retailers are transitioning to HD FCVs. The subsidies from HD FCVs exemptions under the LVSA provide financial opportunities, and the steep angles of the Alps necessitate a highly efficient freight solution.

HD FCVs serve an immediate need for clean freight. All-electric HD truck performance is improving alongside battery technologies, and the market will differentiate the best zero-emission technologies over time, but FCVs will unquestionably serve a critical role in transitioning to a clean freight sector.

Infrastructure Case Studies from Low Carbon Transportation Demonstration and Pilot Projects

The Long-Term Heavy-Duty Investment Strategy defines the purpose of demonstration and pilot projects in supporting critical emerging technologies through their early commercialization. Low Carbon Transportation demonstration and pilot projects are often among the first of their kind whose trailblazing serves broader State goals by gathering data, understanding outcomes, and communicating learnings.

As projects draw to a close, those with data on completed infrastructure provide an opportunity to:

- Inform CARB efforts and aid coordination activities within and outside the agency
- Expand knowledge base of infrastructure barriers — specifically on the underpinnings of cost, timing, and knowledge gaps — and understand the cost and timing impacts on Low Carbon Transportation investments
- Explain observed phenomenon
- Guide data requirements for upcoming solicitations
- Improve the success of future projects

Because of their experimental nature, some outcomes, particularly costs, aren't likely to be representative of similar current or future deployments. Therefore, CARB sought more qualitative lessons learned from two past projects — both from the FY 2014-15 Zero-Emission Truck & Bus Pilot Commercial Deployment Projects — to highlight their success and support the success of future projects.

The Fuel Cell Electric Bus Commercialization Consortium case study focused on the hydrogen fueling station built at the Orange County Transportation Authority (OCTA) Santa Anna Base. Green On-Road Linen Delivery Project case study focused on charging infrastructure that was constructed in four Central Valley cities. All told, 29 Level 2 electric vehicle supply equipment (EVSE) were installed.

CARB explored several basic questions: How did outcomes compare to expectations? What are the underlying causes of noticed discrepancies? What can be done to avoid revealed problems or recreate observed successes?

Lessons Learned

Demos and pilots are demanding, foster remarkable innovation, build lasting partnerships, and emerge as successes despite — or more likely because of — the challenges they encounter. Four fundamental lessons emerged, summarized below and exemplified in the two case studies that follow. The lessons share some commonalities and in fact enhance each other's effects on outcomes.

Break down project complexity. From the two case studies, CARB found that most potential challenges fell into just a few categories — needs, change, and

communication — that can easily be addressed to manage risk and offer assurance against complexity and unknowns.

Clarify all needs upfront. A recurring theme was the value of casting a wide investigative net while assembling an application to understand all needs from all parties. From knowing the energy needs of a fleet with variable operations to confirming partners' contract provisions (e.g. indemnity or bonding), projects pointed to thorough pre-launch needs assessments as a primary contributor to success. In addition to informing primary and contingency plans, extensive upfront research can expose roadblocks such as utility distribution system upgrades that could add years and millions of dollars. To start, projects should ask questions of team members, such as:

- Of fleets: What are your operational needs? How might your needs change throughout the project? What ZEV expansion plans do you have? What alternatives do you have for sites or deployment frameworks?
- Of vehicle and technology providers: Is your technology suitable and capable of meeting fleet duty cycles under all use circumstances? Are you ready to start and scale production to meet project goals?
- Of utilities: What is the existing capacity at the site(s)? What will need to be done to meet the fleet's needs? How long will upgrades take and what cost will be passed along to the project?
- Of all project partners: What will you need from other partners? Can you accept the contract terms of other partners in addition to those of CARB? Where can you foresee problems emerging and how might the team prevent the problems or mitigate impacts? How would you backfill, should a partner leave?

Plan for change. Thoughtful planning and upfront needs assessments for project objectives reduces possible barriers and establishes a sturdy foundation for the project. But acknowledging that trouble can arise anywhere and at any time, it's important to plan for alternative outcomes. Luckily, like with many of these lessons, performing well on one feeds into performance on another and the needs assessments above can equip the team with better information and more effective tools.

The manner and timing of many challenges are hard to predict but impacts on the project are likely to be similar: skewing budgets or timelines. Using the process in the section above, partners can begin in the early formative stages of a project with a common-sense examination of project elements to identify the most critical tasks and understand parts of the timeline with the most uncertainty. After anticipating likely trouble, projects should explore means of mitigating those impacts through buffers where feasible, built-in flexibility (for example, submitting an application that allows a public agency partner to bid out certain tasks after the grant is awarded), and contingency plans (e.g. plans to change sites, fueling strategy, or project partners).

Prioritize open, broad, and frequent communication. A noticeable theme among the items above is the essentiality of communication. Beginning before an application is submitted, partners should work to understand each other's needs, capacities, readiness, and establish clear roles and responsibilities. From pre-application and through implementation, regular and open communication among all members is strongly associated with achievement, particularly in clearing blind spots, creating and executing contingency plans, and quickly adapting to change. Ease of communication is associated with the team structure, where real or contractual connections between the grantee and all other partners yielded the fastest and most reliable conduits. The grantee should also serve as repository for pre-project analyses, all documentation, and data so that it remains accessible and unaffected by changes to project partners. Centralized and middle-man-free communications reduce uncertainty, expedite work, simplify large project changes, and provide higher quality data.

The case study summaries that follow highlight the challenges and successes that projects faced. While in many ways the challenges are unique to those projects, all solutions to them are encompassed in the lessons above.

Green On-Road Linen Delivery Project

The Green On-Road Linen Delivery Project, managed by San Joaquin Valley Air Pollution Control District (SJVAPCD, grantee), deployed 21 Motiv Power Systems battery-electric Class 6 walk-in vans with supporting infrastructure in AmeriPride fleets. Complicated by nature — sites spanned two utilities and four Central Valley cities — the project overcame additional obstacles to meet its goals and teach us about its success. Already, partners have implemented some of those learnings in successive projects.

Cost and time estimating. Estimating costs and timelines before a project starts is critically important, helping projects to get it as right as possible and learn from what goes wrong. Thorough and well-documented baselines compared against outcomes yield valuable insights. At this project's conclusion, some original estimates needed to be reconstructed. The exercise proved valuable and pointed to some of the estimate assumptions critical to document: EVSE, construction, and utility costs per site; and per site timelines.

Accurate estimates are fundamental to project success when limited grant funding is based on them. Projects must clear blind spots early by fully understanding the needs and limitations of all partners. Understanding fleet needs in this project was hindered because the grantee and fleet were not directly contracted, convoluting communication; this was fixed in the current SJVAPCD-led Frito-Lay ZANZEFF Project.

When deploying BEVs, fleet needs must also be communicated to the utility early. Three of the four sites required substantial and unanticipated utility upgrades. The Fresno site was located at the end of a constrained circuit and necessary upgrades

could have taken years or cost millions. Sufficient needs assessments and utility involvement pre-application can reduce delays, costs, and identify major roadblocks.

Reacting to change. Within a year of launching, AmeriPride was bought by Aramark, causing months of uncertainty about fleet commitment and deferral of major infrastructure decisions. Amidst involved PG&E expansions that year, the Camp Fire pulled utility resources from the project and poor weather followed with more construction interruptions.

The experience exemplified that partners may have control over large aspects of a project where infinite challenges can emerge. Knowing this, project teams can instead plan for delay, the likely consequence of all challenges. Where feasible, buffers can buy time and contingency plans allow quick pivots on project partners, fueling strategies, locations, or operations. Strong communication among all partners opens more options and increases agility.

Conclusion

Dedication from project partners and the grantee allowed project agility to navigate sequential formidable challenges to complete the project. Thoughtful ex post analysis and action on these lessons learned allow the project to continue yielding benefits.

Fuel Cell Electric Bus Commercialization Consortium Project

The Fuel Cell Electric Bus Commercialization Consortium (FCEBCC) Project, managed by The Center for Transportation and the Environment (CTE, grantee) deployed 20 fuel cell electric buses including 10 for the Orange County Transportation Authority (OCTA) supported by a new hydrogen station in Santa Ana. Despite challenges constructing the station, the project emerged as a remarkable success and its experiences offer keys to achievement.

Aligning project partners. Contracting deserves extensive pre-application research — dependent on strong communication — to meet timelines and budgets. OCTA, like other large public agencies, requires extensive liability and indemnification provisions, which only became clear to the original hydrogen fueling system provider after the project launched. After several months of unsuccessful negotiation, the original partner left the project, leaving CTE and OCTA to conduct a request for proposals for a new provider.

As a positive outcome, the project used the scope change opportunity to double station storage and dispensing capability with rapid side-by-side refueling comparable to that of natural gas. That made it one of the largest hydrogen fueling stations in the world, completed at equal cost to the original design — validation of the value of scale for hydrogen. However, it came at the cost of a one-year delay to construction start, and additional utility upgrades added months more.

Clearly, all parties should understand each other's contractual requirements before submitting a grant application and projects might require acceptance of terms and conditions for partner eligibility. Because project changes are likely, understanding the needs and restrictions of project partners can inform built-in flexibility, such as including in the application a process for bidding out construction after award.

Communicating with safety and permitting officials. Many of CARB's demos and pilots, being the first of their kind in their respective locations, must educate local authorities and navigate permitting processes not intended for ZEV infrastructure projects. Compared to EV charging, hydrogen fueling faces wider knowledge gaps. To address this, CTE led proactive and continued engagement with safety and permitting authorities, which accelerated permitting and prepared safety personnel. The Santa Ana Fire Marshal participated in the design review of the station and was kept in contact with CTE and the station contractor throughout the project.

Conclusion

While overlooked contract terms caused delay, the station was completed and successfully entered operational status within the original term of the CARB grant agreement. Keen foresight and dedicated communication between the grantee and partners as well as local authorities eased permitting and better prepared safety personnel. The result is one of the largest hydrogen fueling stations in the world and a complement of lessons learned to benefit future projects.

Case Studies Summary

In addition to highlighting project success, the infrastructure case studies effectively distilled great complexity into several takeaways, which reinforce each other's improvements to project outcomes:

- Break down perceived complexity
- Thoroughly assess the needs and limitations of all partners upfront
- Structure buffers and contingency plans for critical project elements
- Make communication a priority that guides team structure

The lessons learned recommend action by grantees, project partners, and fleets for success within and in some ways outside of Low Carbon Transportation projects. However, staff also see areas where CARB could have a role in aiding current and future projects. There may be ways that solicitations or their process could be modified to encourage better upfront needs assessments or contingency planning, for example. CARB could also modify its role in project implementation to facilitate better communication or be more participatory in certain project changes. CARB staff will work with grantees and project partners to explore how CARB can help to implement these lessons and search for others.

Component Cost Analysis

The incremental cost of zero-emission medium- and heavy-duty vehicles still poses a significant barrier to more widespread adoption. For battery-electric vehicles, the incremental cost is largely the result of more expensive component costs. Specifically, the cost of the battery packs alone can represent 80% of the incremental cost of the BEV.

A BEV typically adds the major components of batteries, e-motors, a 2-speed gear box (on some heavier-duty trucks and buses), high-voltage cabling and connectors, an on-board charge controller and a battery cooling system. At the same time, a BEV does not need an engine, transmission, engine cooling system, emissions aftertreatment system, fuel system, or the cost of emissions certification and warranty that would come with a diesel-powered vehicle.

Ongoing issues affecting commercialization include:

- Purchase cost
- Infrastructure
- Information gap
- Service and support
- Secondary market
- Stable funding and support
- Reliability and consumer confidence
- Supply chain
- Workforce training
- Component costs
- Certification
- Codes and Standards

But of all these costs, the battery system dominates. Worldwide lithium-ion battery production continues to grow substantially year after year, along with increasing demand for electric passenger cars and sport utility vehicles (SUVs). As larger and larger battery plants are built and as battery technologies advance, Lithium-Ion battery costs continue to fall.

This cost reduction drives increased demand for the lower cost batteries and suppliers of medium- and heavy-duty BEVs are competing with much larger passenger car/SUV OEMs for those batteries. So, while scale is driving more competitive battery pricing, many of the medium- and heavy-duty BEV OEMs find it difficult to achieve the same economics as their larger OEM counterparts in the passenger car and SUV segments. Nevertheless, scale is helping reduce the cost of battery packs, and this subsequently reduces medium- and heavy-duty EV vehicle cost. Vehicle suppliers are also taking advantage of lower battery costs to increase the capacity of battery systems in vehicles to extend the driving range.

Ongoing improvements to supply chain scale and efficiencies will continue to bring steady and meaningful price reductions for medium- and heavy-duty BEVs; however, dramatic price reductions are not foreseen in the immediate future. In the mid-term (2-3 years), battery cost reductions up to 25% can be reasonably anticipated for some OEMs and vehicle segments.

Supply Chain

One of the outcomes of GGRF investments has been the development and growth of California's clean, advanced transportation technology industry. As more California fleets have taken advantage of the GGRF incentives for clean vehicles, more technology manufacturers and suppliers have established California facilities to meet that demand. This equates to a growing supply chain within California.

CARB has partnered with CALSTART, a grantee administrator of the HVIP and CORE programs, to undertake research to document and evaluate the impact of this supply chain. Initial research conducted in 2018 and 2019 has identified nearly 450 facilities within the state that are involved in the production and distribution of key technologies in the areas of vehicle electrification, aerodynamics, light weighting, automation, and infrastructure. This number has grown significantly since initial research was conducted in 2015.

The next step is to assess the value these firms contribute to the California economy in terms of jobs and output. CALSTART is now utilizing advanced "machine learning" tools to get a better sense of these economic values. Future revisions of this Investment Strategy will include updates to this Supply Chain Study that will include total employment, payroll, and economic output.

Other Issues

Service Centers

Many advanced technology vehicle suppliers do not yet have an adequate network of service centers in California. Access to local service and warranty support is an important commercialization component for prospective fleets. Likewise, a shared network of service centers around California could reduce the cost of support for each supplier. Additionally, building and supporting vocational training programs in partnership with California's community colleges will continue to be important.

Some national fleet support and maintenance providers have been exploring and developing partnerships to provide the service and support a network to new vehicle manufacturers or importers. This structure may signal a new and innovative strategy to address service gap and distance issues, as these providers often have national networks of service and maintenance centers.

Workforce Training

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. Additionally, CARB began working last year with the California Employment Training Panel (ETP), which provides financial and technical resources to develop partnerships, curricula, and training programs. CARB will continue working with ETP to establish partnerships with manufacturers, fleets, and educational institutions to leverage CARB investments for greater workforce development opportunities.

Certification Process

The certification process is often very resource-intensive and can inadvertently act as a barrier to the timely introduction of new technologies. Despite this, the certification process plays a critical role in supporting CARB's efforts to drive greater deployment of zero-emission technology. To that end, CARB adopted the Zero-Emission Powertrain Certification Regulation (ZEPCert) in June 2019, which establishes certification requirements for heavy-duty battery electric and fuel-cell vehicles and the powertrains they use. ZEPCert is intended to bring about greater transparency, consistency, and stability to the market by addressing some of the key concerns associated with the dynamic and evolving nature of the heavy-duty zero-emission industry. Specifically, ZEPCert will help reduce variability in the quality and reliability of heavy-duty electric and fuel cell vehicles, ensure information regarding these vehicles and their powertrains are effectively and consistently communicated to purchasers, and accelerate progress toward greater vehicle reparability. Adding market transparency, consistency, and stability will be a critical step toward broad market adoption of zero-emission technology.

The certification process can also be particularly difficult for hybrid technologies. Even with CARB's new Innovative Technology Regulation, the certification process for hybrids can be very expensive and time consuming, and it can be a barrier to the timely introduction of new technologies.

Aligning the Funding Timeline with the Approval/Certification Process

The timeline for certification does not align well with the timeline for seeking incentive funding: in the past, available incentive funds had already been spent by the time a technology makes it through the yearly certification process.

A number of hurdles exist in aligning different programs, especially those held by separate agencies. Many programs—and the funding pots they use—come with different goals, requirements, timelines, and restrictions. Most Legislature-appropriated funds come with strict encumbrance and expenditure deadlines that can make it difficult to align programs across agencies. While some of these deadlines are statutorily imposed, others are the result of agency policies.

The manufacturing time needed for producing new commercial vehicles, especially those with advanced technologies, can be substantial. The time required for completing the certification process can also be significant, so finding ways to ensure the certification process is completed before funds expire continues to be a key issue. Adopters of advanced technologies have asked for assurances that funding will still be available when they take delivery of a new vehicle. But while incentive vouchers are reserved at the time of order, vehicle build times can stretch out to nearly two years, at which point funds can be close to their deadlines before vouchers are redeemed. This can pose even bigger obstacles for demonstration projects which have less predictable and often even longer timelines to build, fully demonstrate, and analyze data from precommercial vehicles.

CARB began collaborating with the CPUC in 2016 as the agency began implementation of some of its statutory requirements under SB 350. After collaborating on the development of guidance for utilities, as well as the review of utility applications, CARB continued to work with the agency and utilities. CARB is involved in a pilot project to integrate vehicle funding with utility infrastructure readiness programs. The outcomes of this pilot will be used to inform future collaborations with utilities.

Codes and Standards

Over the past few years there has been growing consensus around charging connectors, though there is no universal approach; however, OEMS in North American and Europe are coming closer to agreeing on a single heavy-duty charging standard in each of their respective regions. The level of charging needed for domicile and opportunity charging is also still highly variable and uncertain. While some medium-duty trucks and buses, including most school buses, are likely to be able to use the standardized Level 2 charging interface (J1772), the needed charging rates vary by vehicle and manufacturer, making establishing a standard template for planning infrastructure installation difficult. For the higher-rate charging needed for full-size transit buses and heavy duty vehicles, there is increasing momentum around the approach that has strong support in North America and Europe for the use of the Combined Charging Standard (CCS) connector interface. The CCS connector has two variants, with the CCS1 connector being more common in North America and the CCS2 connector seeing widespread use in Europe. Both the CCS1 and CCS2 connector now have Underwriters Laboratories (UL) certification allowing for widespread use of both connector types in North America. While neither CCS connector is standardized in the United States, the CCS1 connector, also used in passenger cars, has seen higher early use, but the CCS2 connector is being explored. That said, at least five different connector types can still be found in the field. CCS connectors are supported by the same communications protocols between the charging infrastructure and the vehicles, allowing for swap outs of one connector for the other without full replacement of charging infrastructure. Therefore, CCS could provide interoperability between light-duty passenger cars and trucks and for standard

and high-rate charging speeds once one of the CCS connectors dominates the market. Most transit bus makers have also agreed to a common protocol for overhead on-route charging, which is important for some transit operators. There is also a new standard emerging, driven by CCS users, to establish a 1 megawatt and greater charging standard to enable Class 8 truck refueling for longer-distance driving and/or faster turnaround at depots to maintain high vehicle utilization. While setting such codes and standards is not a CARB or State function, California funding could be used to encourage interoperability and commonality.

Metrics of Success for Low Carbon Transportation

One of the main functions of this Long-Term Heavy-Duty Investment Strategy is to serve as a framework for prioritizing available heavy-duty incentives appropriated to the Low Carbon Transportation Investments program in order to meet the specific goals outlined earlier in this document. Low Carbon Transportation investments play a key role in advancing emerging clean vehicle technologies and commercializing the applications needed to ensure long-term solutions to meet the State's 2030 goals and beyond. Although this framework also applies to all of the incentive programs in CARB's larger portfolio, the remainder of this document will focus specifically on Low Carbon Transportation incentives and will cover the requirements mandated by SB 1403.

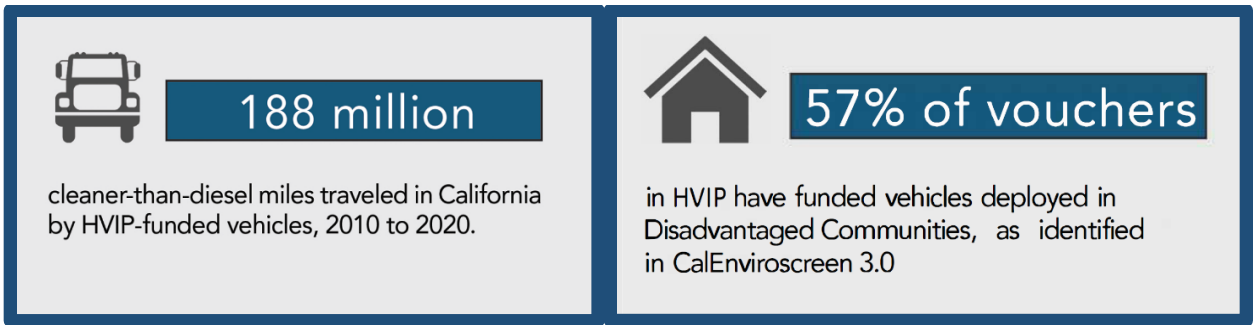
In addition to identifying priority focus areas and recommended levels of incentive funding, this document also identifies ways to quantify progress. Metrics can be used to help assess the performance of Low Carbon Transportation projects toward meeting their goals. While cost-effectiveness is commonly used to evaluate the overall effectiveness of programs (and all Low Carbon Transportation projects do conduct cost-effectiveness calculations), this not the only way to measure the success of program investments, particularly those aimed at longer-term market transformation.

Traditional metrics, such as investments in disadvantaged communities and reductions in criteria and toxic pollutants and GHG emissions, are already being utilized, but these alone are not enough to assess progress overall. More targeted metrics addressing technology advancement, increases in suppliers and supply chain diversity, potential to impact key market segments, and reductions in system costs are also needed to help demonstrate that investments are resulting in measurable progress.

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.

In developing this year's strategy, CARB has continued to work with stakeholders for input on metrics, including holding four public work group meetings and evaluating the available data needed to quantify suggested metrics. As a result of this process, several new metrics are included in this document, specifically using data collected from the HVIP program[40]. As additional project data becomes available from CARB's demonstration and pilot projects, the metrics will be further refined and expanded in future years.

[40] Data shown is current as of July 2020.



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.

Potential future metrics:

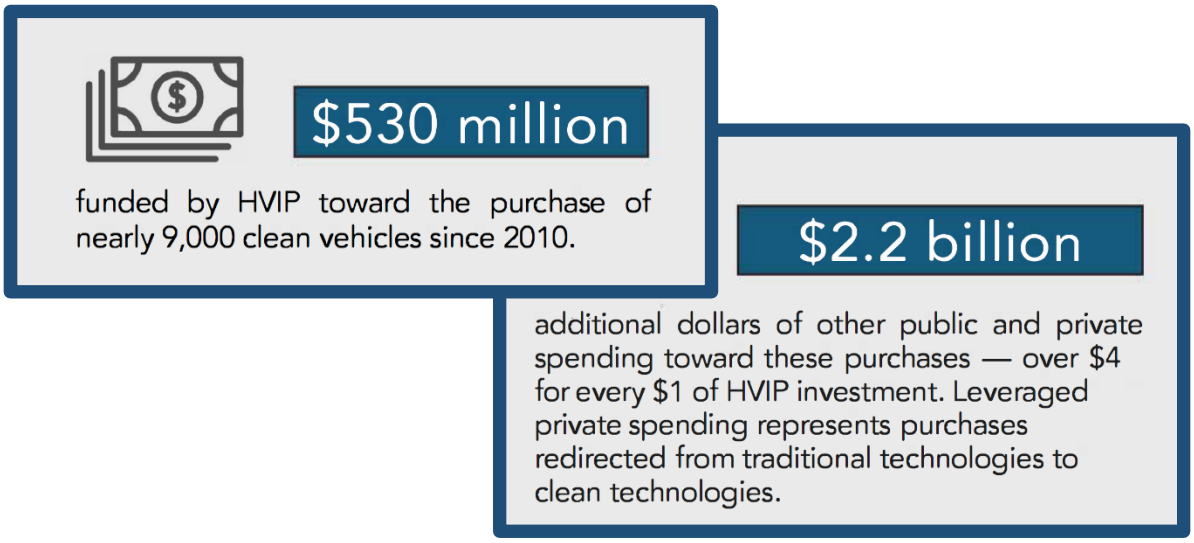
- Emissions benefits could be multiplied across the vehicle population that is expected to turn over in a specified amount of time, in order to estimate the long-term benefits of launching a new application.

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.

Metrics are summarized into three categories: Public Health, Technology Evolution, and Building the Green Economy.

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, in light of the program's unique position in the CARB investment portfolio.

Growing the Green Economy



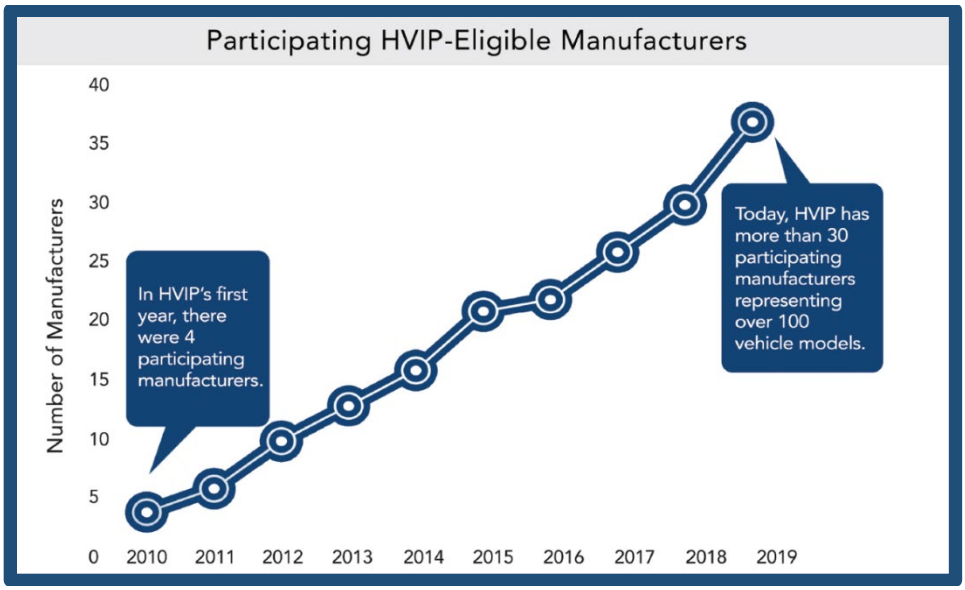
CARB's investments are intended to create downstream economic benefits where possible. The presence of consistent funding for clean technology projects helps to attract clean tech manufacturing to California, bringing high-quality jobs and supporting a nascent and valuable industry. More information on supply chains is provided on page 85.

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 manufacturers, showing how the number of manufacturers has increased over the lifetime of the program (10 years).



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.

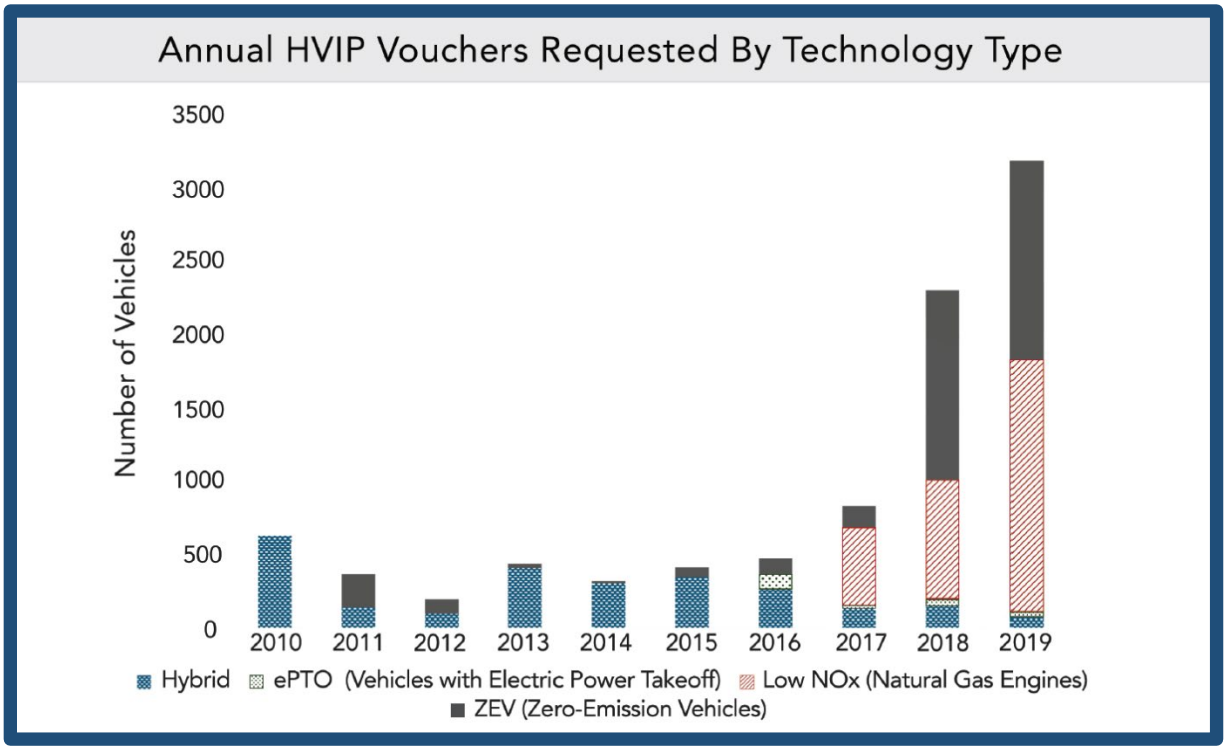
In the future, this section of the Strategy could be further expanded to describe metrics that are applicable to a wider array of programs. This will continue to be important as CARB develops the concept of technology graduation, which will be directly related to the pathway and progress of technology 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 19.

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 25.

New metrics this year:

- The number of HVIP vouchers requested each year by type of advanced technology, which shows HVIP's evolution from primarily hybrid-electric technologies in its early years to primarily battery-electric zero-emission technologies today.



Potential future metrics:

- The number of suppliers for core components and growth over time could be tracked. Increases in the number of component suppliers not only means more industry and more jobs, but demonstrates a growing demand for the advanced technology vehicles being assembled with those components.

Supplier data are generally proprietary, and information on volume or where OEMs are sourcing components will likely not be available. This will limit CARB's ability to understand how OEMs are integrating supply chains or how components are shared among equipment types.

- Survey data could be valuable for discovering attitudes and perceptions of new vehicle technology. However, survey data can be difficult to collect and easy to misinterpret. Additionally, different respondent types (i.e., operator versus maintenance technician versus fleet owner) are known to supply differing responses. HVIP is expected to collect more survey data in the future that could be of use. However, as stakeholders have shared, 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 develop, refine, and implement additional metrics that better communicate the full range of benefits accruing from Low Carbon Transportation investments, in light of the program's unique position in CARB's investment portfolio.

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Priorities for Low Carbon Transportation Investments

The Long-Term Heavy-Duty Investment Strategy includes an assessment of funding needs and recommended investment actions for Low Carbon Transportation investments. CARB has updated and refined priorities for the targeted technologies and project categories that merit funding investments to help the State reach its climate and air quality goals. These priorities were developed starting with the relevant guiding legislation (primarily SB 1204 and SB 1403), and are also based on the following activities:

1. Evaluating the updated technology status and progress as outlined previously.
2. Identifying areas of accelerated progress where funding could further support technologies in reaching the market.
3. Identifying areas of slower progress where a targeted approach to eliminating barriers could aid development.
4. Additional sector research, as well as conversations and feedback from industry during the assembly of this Strategy update, including from work group sessions and one-on-one meetings.

The recommended funding levels do not represent the total funding required for California to support the technologies needed for fleet transformation. These amounts are guided in part by assessments of OEM and supplier capacity for producing a meaningful number of demonstration and pilot projects during the three-year investment strategy time frame. Funding recommendations are designed to ensure that State funds are focused on technologies that need to advance in commercialization over the next three years in order to impact 2030 and 2050 outcomes, while still providing benefits today. If significant additional resources were to become available, the transformation of the heavy-duty and off-road sectors could be expedited, and significantly increased funding could also spur manufacturers to increase production capacity and provide additional fleet support, training, and infrastructure.

Given the findings from this yearly strategy update, and the successful outcomes being reported to date from the strategy, the recommendations continue to stress core themes while adding some technology categories and considerations.

Keep Expanding Successful Beachheads and Pathways. The beachhead markets continue to show success and have been establishing footholds in other applications. For instance, zero-emission drayage and regional delivery is seeing a significant increase in growth, bolstered by new regulations requiring manufacturers to meet a ZEV sales requirement starting in 2024. Advances in these areas have spread from the progress made with the transit bus beachhead, which continues to

> Priorities for future years include expanding beachhead pathways, developing new pathways, and expanding the innovation pipeline.

experience year-over-year growth. However, there are marketplace implementation issues surrounding infrastructure planning as well as technology scaling considerations that truck manufacturers will need assistance to address. This work will also be of direct assistance to goods movement applications—from medium-duty delivery and heavy-duty drayage and regional distribution up to longer range haul. Using commercial stage funding investments, it is crucial that the first beachhead market successes noted in this update be consolidated and further expanded.

This means:

- Building out market success in the zero-emission beachhead markets and supporting the growth of the secondary and additional follow-on markets now emerging, particularly last mile and medium-duty delivery.
- Prioritizing funding for HVIP and CORE vouchers.
- Expanding into serving the secondary markets with products that include urban and suburban delivery, school bus, shuttle bus, and some specialized service applications for technologies in the zero-emission pathway.
- Continuing to support ZEV transit buses, giving a priority to hydrogen fuel cells, and helping to develop larger scale infrastructure, service, and component volumes to move these products closer to full market readiness.
- Funding zero-emission drayage trucks, which have received significant focus and now are moving even faster than originally projected in the beachhead strategy.

Several off-road freight-enabling and zero emission-enabling technologies are also ready for commercial purchase incentives. Examples include:

- BEV yard hostlers, which are similarly used in multiple applications beyond ports and terminals, including warehouse, distribution, and food processing operations. They can help to further expand the off-road beachhead pathway, which helps enable drayage vehicles, and other port and terminal equipment.
- Some construction equipment that meets this commercial market threshold. Due to similar load, power demands, and packaging, these can be freight enabling by driving supporting markets and increasing common component volumes. These sectors share many components and supply chains with ports, goods movement, and GSE.

Target Promising Next Pathway Markets. For the beachhead strategy to be fully successful, the subsequent application technologies in the developmental pipeline must continue to be supported and brought through the development stages to early production. However, State funding for critical next markets and innovation is variable and often insufficient. Left unaddressed, this will slow the pace of beachhead expansion. This could mean technologies needed for follow-on beachhead market growth will not have been demonstrated, validated, and brought through product development quickly enough to maintain the pace of transformation that State policies demand. Key pilot stage priorities include the following:

- Building out larger ZE vehicle "ecosystems" in pilot projects that enable and set the template for scaled and fully integrated infrastructure, which is growing in importance. The ZANZEFF framework was exceptionally valuable in helping terminals, distribution centers, and fleet domiciles build out infrastructure plans for multiple vehicles. Similar efforts need to be continued if funding permits.
- Incorporating hybrid and zero-emission port, construction, and agricultural equipment, including wheel loaders, lifts, and heavier cargo handling equipment, which are now emerging. Added to this category are marine harbor craft, both hybrid and ZEV. Pilot projects can help build component volumes, validate performance in a system of vehicles, and provide improved business case data. Demonstrations may also still be warranted to drive technological development.
- Including FCEV medium- and heavy-duty delivery vehicles, particularly in the higher weight classes (Classes 6-8).
- Bringing in advanced PHEV with extended range in the higher weight classes (Classes 5-8).
- Branching out into advanced engine architectures for efficiency and the cleanest combustion, including technologies such as opposed piston designs and compression ignition alternative fuels, which will be ready for pilot stage expansion during the timeline of this investment strategy.
- Exploring options for school buses in smaller and less densely populated districts to assess use profiles, develop infrastructure and explore additional benefits such as grid integration.
- Including emerging connected and automated technologies with the pilot project priorities noted above. These technologies can provide additive benefits that should be encouraged, particularly in off-road work sites and in on-road sequencing and separating of vehicles. Encouraging their inclusion in pilots can support continual progress.

Focus on and Expand the Innovation Pipeline. Several key targeted pathway technologies need to continue their progression to market over the next several years to enable the State to meet its climate and air quality goals for 2030 and beyond. Maintaining momentum in the "innovation pipeline" for these technologies is necessary for meeting these goals, and serves as an important point of leverage for State funding. This progress is also of critical importance to the success of the beachhead strategy.

California companies are among the world leaders in developing advanced component and vehicle solutions, providing tangible economic and job benefits to the State. Low Carbon Transportation demonstration funding can act as a powerful lever when coordinated with the work and funding of private companies and other state and federal agencies. While much of the funding focus is on demonstrations that are just past or at the prototype phase, there continues to be a need to partner with other agencies that also provide demonstration stage funding to target technologies and

projects that help to drive the success of beachheads. This strategy continues for this year's plan, and includes these targets:

- Funding longer range (>250-mile) zero-emission electric drive medium- and heavy-duty goods movement vehicles.
- Facilitating further improvement of hybrid and zero-emission heavy-duty sector technologies.

The off-road sector is also now in a position to demonstrate breakthrough technologies in high fuel-use applications. These technologies include zero-emission, hybrid and efficiency technologies. Zero-emission capable hybrids are emerging as a promising next step for many off-road applications with some of the most challenging duty cycles. This technology also supports the long-term transition to fully zero-emission for these applications and strengthens the zero-emission supply chain. Marine harbor craft applications are likely to become an important sector using common components from heavy-duty on-road vehicles. Heavier cargo handling equipment such as top handlers and rubber tired gantry cranes are receiving growing interest from OEMs and technology providers looking to develop zero-emission offerings. The construction and agricultural sectors are also important demonstration applications because of their ability to transfer and scale to goods movement applications.

Low Carbon Transportation Three-Year Investment Recommendations

The Three Year Heavy-Duty Investment Strategy provides a snapshot in time, incorporating a rolling three-year funding horizon. This year's updated strategy expands upon the funding levels identified in the FY 2019-20 report, addresses FY 2020-21 and FY 2021-22, and adds a new third year, FY 2023-24. Based on the updates to the technology status snapshots and the refinements to the beachhead strategies, CARB has reevaluated and updated the levels of investment needed to move pathway technologies forward toward State goals over the new three-year funding period.

The recommended funding is based around a central core of established priorities, as well as the updated priorities, strategies, and segment opportunities identified in the reviews mentioned above. For example, the need to scale infrastructure for large volume vehicle deployments is growing as a way to address a key barrier, and is also providing an opportunity for enabling additional deployments in key locations, such as ports and terminals. The suitability of technology transfer into the marine sector for hybrid and ZEV harbor craft has emerged as a higher profile opportunity. The potential to encourage higher-volume, lower-cost hydrogen fuel production, or to

This strategy provides a snapshot in time, incorporating a rolling three-year funding horizon. The recommended funding is based on a central core of established priorities.

share and reduce investment costs for common electric infrastructure, at central nodes that can service multiple application types also presents opportunities to speed learning and technology adoption.

From these inputs, an updated funding portfolio was assembled with recommended funding levels. These levels are presented by fiscal year and by stage of technology: Demonstration, Pilot, and Commercial. The highest priorities for State funding are listed in the recommendations table. These recommendations do not represent all of the project types CARB might potentially fund, but rather, a small subset of the highest priorities staff believe to be the most important for ensuring the continued development and commercialization of these advanced technologies. Those priorities have been developed following the strategy laid out in this document—considering technology transfer, emission reductions needs, and pending regulations, among other factors.

The estimated funding levels are inclusive of a broader set of vehicle and equipment investments that CARB hopes to make. The draft funding amounts represent a critical down payment toward meeting the funding need for advanced technology heavy-duty vehicles and off-road equipment, but the amounts do not meet the entire amount needed to achieve the State's goals.

CARB and its grantee used a multi-pronged approach to assemble the levels of funding listed in the table. First, for the Demonstration and Pilot funding levels, a matrix of representative projects for the targeted technologies and pathways was compiled, with sizing based on the funding needed to provide meaningful results in each application category. These levels were determined by considering historical investments in past projects; the possible number, type, and size of vehicles or equipment that could be included in each project; project duration; and the number of projects per category needed to encourage competition—as well as to encourage multiregional participation.

Second, manufacturers, suppliers, and fleets were solicited for feedback from work group meetings and private conversations to ascertain the most advantageous sizing, number of projects, and other project needs, such as data collection or infrastructure. Staff also reviewed past examples of comparable demonstration and pilot projects managed by CARB and other state and regional agencies. As a result, infrastructure support for projects is included in the recommended funding levels for demonstration and pilot activities.

Market research; interviews with OEMs, fleet, and suppliers; and confidential sales projections from manufacturers were used to develop a projection of market demand for the commercial-stage funding recommendations. The grantee used historical HVIP data to validate the projections. Industry production capacity and fleet acceptance were then factored in, as well as research and market data on emerging product offerings, combined with confidential conversations with manufacturers on expected

launch dates. This process has been previously discussed with stakeholders at HVIP work group meetings.

The aggregated results of these projections are shown in Table 1. The table summarizes the key focus areas and frames the range of investments ideally needed each year over the course of the next three fiscal years. Low and high funding levels are portrayed 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.

The recommendations are primarily focused on creating the critical technology capability and product mix needed for transformation, but not fully funding that transformation. As has been highlighted in prior strategy documents and input from public meetings, the need for incentives geared toward meeting California's GHG and air quality goals far exceeds the recommended funding shown here.

Table 1: Recommendations for Low Carbon Transportation Investment Priorities

THREE-YEAR RECOMMENDATIONS FOR LOW CARBON TRANSPORTATION*			
	FY 2021-22	**FY 2022-23**	**FY 2023-24**
Demos	*$50-$90 Million* Focus: ZE Longer Range HD Goods Movement, ZE Ag-Construction Equipment, ZE/Hybrid Heavier Cargo Handling Equipment, ZE/Hybrid Marine	*$50-$90 Million* Focus: ZE Longer Range HD Goods Movement, ZE Ag-Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Rail, ZE/Hybrid Marine	*$50-$90 Million* Focus: ZE Longer Range HD Goods Movement, ZE Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine
Pilots	*$200-$325 Million* Focus: ZE Drayage and Regional Delivery, Advanced Powertrains, ZE/Hybrid Ag-Construction- Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ZE Facilities	*$200-$325 Million* Focus: ZE Longer Range HD Goods Movement, Advanced Powertrains, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ZE Facilities	*$200-$325 Million* Focus: ZE Longer Range Goods Movement, Advanced Powertrains, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE Rail, ZE/Hybrid Marine, ZE Facilities
Commercial	*$396-$475 Million* Focus: ZE Drayage and Regional Delivery, ZE Delivery, ZE Transit, ZE Heavier Cargo Handling Equipment, ePTOs	*$490-$680 Million* Focus: ZE Drayage and Regional Heavy-Duty Delivery, ZE Delivery, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs	*$605-$995 Million* Focus: ZE Drayage, ZE Regional Heavy-Duty Delivery, ZE Transit, ZE Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ePTOs
Total Funding	**$646-$890 Million***	**$740-$1095 Million***	**$855-$1410 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 development of clean technologies and the transformation of medium- and heavy-duty fleets is becoming a priority of global importance. This Heavy-Duty Investment Strategy provides critical guidance not just to CARB, but to our partners across California, the U.S., and around the world. This document is designed 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.

2020 has proven to be a challenging year for people all across the globe. The COVID-19 pandemic has impacted lives and livelihoods, as well as federal, State, and local budgets. In the advanced technology vehicle and equipment market, manufacturing facilities have slowed or shut down, with corresponding disruptions to supply chains. In many cases, demand for new vehicles and equipment has also slowed.

Not surprisingly, California's 2020 State Budget is considerably different from those enacted in previous years. Funding allocations for clean transportation incentives are reduced, so the funds that are available – and the associated benefits of those funds – are especially critical.

COVID-19 has been shown to pose greater risk to individuals suffering from respiratory illnesses,[1] and air pollution already brings a variety of negative respiratory health impacts.

Compounding these issues is the fact that both COVID-19 and air pollution have a disproportionate impact on disadvantaged communities and people of color.

In the context of increasing focus on climate change, public health, and social equity, we recognize that it is now even more urgent to continue with the State's commitment to its ambitious air quality and climate change goals.

COVID-19 has been shown to pose greater risk to individuals suffering from respiratory illnesses,[41] and air pollution already brings a variety of negative respiratory health impacts. Compounding these issues is the fact that both COVID-19 and air pollution have a disproportionate impact on disadvantaged communities and people of color. As such, CARB will continue to make protecting residents of these communities a priority for our incentive programs.

In the context of increasing focus on climate change, public health, and social equity, CARB recognizes that it is now even more urgent to continue with the State's commitment to its ambitious air quality and climate change goals. Amid the current

[41] Psychosocial Vulnerabilities to Upper Respiratory Infectious Illness: Implications for Susceptibility to Coronavirus Disease 2019 (COVID-19): U.S. National Library of Medicine, National Institutes of Health, July 8, 2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7345443/

series of public health and economic crises, the magnitude of economy-wide carbon and criteria pollutant reduction needed to meet these goals is massive—and accomplishing the corresponding transformation of the transportation sector will continue to be a huge challenge.

An emergent new generation of advanced technology clean vehicles, and innovations in the heavy-duty and off-road sectors, are necessary to achieve the reductions. Although the number of commercialized zero-emission, hybrid, and cleanest combustion options available today is still fairly small, the options are starting to increase rapidly.

Point-of-sale incentives remain critical to facilitating the rapid transformation of the transportation sector to zero-emission technologies wherever feasible, and to hybrid and cleanest combustion technologies with the lowest-carbon fuels everywhere else. These incentives are essential to ensuring that key applications progress in their rates of adoption, while more-advanced technologies will require progressively lower amounts of incentive support as they mature. Also working in tandem with incentives to drive the transformation are a number of new landmark regulations, such as the Advanced Clean Truck Rule and the Heavy-Duty Low NOx Omnibus Regulation, both passed this year, and the Innovative Clean Transit Rule.

CARB's incentives help to accelerate the transition to low carbon freight and passenger transportation, supporting the State's target that all passenger vehicle and truck sales be zero-emission by 2035, all drayage trucks and off-road equipment 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.

CARB's 2016 Mobile Source Strategy[42] was the first integrated planning effort looking specifically at mobile sources to identify complementary policies to reduce emissions in three broad categories of air pollutants – smog-forming emissions, GHG emissions, and particulate matter. In the 2020 Mobile Source Strategy[43], CARB is again taking a multi-pollutant approach to evaluate existing and potential future control programs necessary to achieve California's targets over the next 30 years. The Heavy-Duty Investment Strategy plays a key role in supporting and informing the Mobile Source Strategy.

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.

[42] https://ww2.arb.ca.gov/resources/documents/2016-mobile-source-strategy
[43] https://ww2.arb.ca.gov/resources/documents/2020-mobile-source-strategy

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 investments 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.

This year's State Budget highlights promoting economic recovery as one of its central goals, and providing financial support to businesses to replace legacy engines and equipment is one of many ways to support economic recovery in the transportation sector. CARB's incentive programs will continue to leverage all funding, including any made available through economic recovery packages, to have the greatest impact and potential for emission reductions in disadvantaged and low-income communities and throughout the State.

As the State moves forward and works to revive California from the current economic crisis, it is imperative to 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.

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. What follows is a summary of these programs. While this is by no means an exhaustive list, the programs included here 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 greenhouse gas (GHG) emissions reduction below 1990 levels codified under Senate Bill (SB) 32,[44] 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 seven budget cycles (FY 2013-14 through FY 2019-20). These appropriations are being used to fund:

- Zero-emission and plug-in hybrid passenger vehicles through 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

[44] Pavley, Chapter 249, Statutes of 2016

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 later this year and in the next two years. 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 Community Air Protection (CAP) Program, 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 Moyer Program guidelines, so long as the vehicles and equipment are engaged in agricultural operations (up to 85% of the cost).
- Agricultural zero-emission 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.

FARMER has received $332 million over the last 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

The Low Carbon Fuel Standard (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 $192, the estimated value of LCFS credits generated in 2019 was close to $3 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 14,390 projects have reduced more than 86,000 tons of NOx and 2,400 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. While all Prop 1B funds have been awarded to the local air districts for implementation, the program framework exists to serve as a mechanism to award clean truck funds through newer funding programs.

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 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.

California Energy Commission

Clean Transportation Program

CARB and CEC coordinate throughout the process of developing their respective investment plans. The CEC administers an important criteria pollutant and GHG reduction investment program for the transportation sector—the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP). Funds that are collected from vehicle and vessel registration fees, vehicle identification plates, and vehicle smog fees provide, on average, $100 million per year for projects that will transform California's fuels and vehicles to help attain the State's air quality and climate change goals.
More details on the Clean Transportation Program can be found on these pages of the CEC's website:
https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program
https://www.energy.ca.gov/about/core-responsibility-fact-sheets/transforming-transportation

Each year, the CEC prepares an investment plan for the program to determine funding priorities and opportunities. The plan guides the allocation of program funding for transportation solicitations for the upcoming fiscal year. The 2020-2023 Investment Plan (for FY 2020-21) was formally adopted in August 2020. More information on current and previous investment plans can be found at:
https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/clean-transportation-program-investment.

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 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; demonstration of biomass-to-energy conversion systems; 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.[45] 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.

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

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. More information can be found on the program website: https://calsta.ca.gov/subject-areas/transit-intercity-rail-capital-prog.

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, 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 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 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 initiative (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 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

1. AB – Assembly Bill
2. AGV – automated guided vehicle
3. ARFVTP – Alternative and Renewable Fuel and Vehicle Technology Program
4. APCD – Air Pollution Control District
5. AQIP – Air Quality Improvement Program
6. AQMD – Air Quality Management District
7. BEV – battery electric vehicle
8. Cal/EPA – California Environmental Protection Agency
9. CAPP – Community Air Protection Program
10. CARB – California Air Resources Board
11. CCS – Combined Charging Standard
12. CEC – California Energy Commission
13. CHE – cargo handling equipment
14. CORE – Clean Off-Road Equipment
15. CPUC – California Public Utilities Commission
16. CVRP – Clean Vehicle Rebate Project
17. DERA – Diesel Emission Reduction Act
18. DOE – Department of Energy
19. EERE – Office of Energy Efficiency and Renewable Energy
20. EPIC – Electric Program Investment Charge
21. EQIP – Environmental Quality Incentives Program
22. ETP – Employment Training Panel
23. FARMER – Funding Agricultural Replacement Measures for Emission Reductions
24. FCEV – fuel cell electric vehicle
25. FCTO – Fuel Cell Technologies Office
26. FTA – Federal Transit Administration
27. FY – fiscal year
28. g/bhp-hr – grams per brake horsepower-hour
29. GHG – greenhouse gas
30. GPU – ground power unit
31. GSE – ground support equipment
32. GVWR – gross vehicle weight rating
33. HEV – hybrid-electric vehicle
34. HHD – heavy duty
35. HVAC – heating, ventilation, and air conditioning
36. HVIP – Hybrid and Zero-Emission Voucher Incentive Program
37. ITS – intelligent transportation systems
38. LCFS – Low Carbon Fuel Standard
39. LCTOP – Low Carbon Transit Operation Program
40. LHD – light heavy duty
41. LoNo – Low or No Emission Vehicle Program
42. MHD – medium heavy duty
43. MPU – mobile power unit

44. MSRC – Mobile Source Air Pollution Reduction Review Committee
45. NAAQS – National Ambient Air Quality Standards
46. NAQI – National Air Quality Initiative
47. NOx –nitrogen oxides
48. OEM – original engine manufacturer
49. PG&E – Pacific Gas & Electric
50. PHEV – plug-in hybrid-electric vehicle
51. PM – particulate matter
52. PM2.5- fine particulate matter
53. RNG – renewable natural gas
54. RTG – rubber-tired gantry crane
55. SB – Senate Bill
56. SCE – Southern California Edison
57. SDG&E – San Diego Gas & Electric
58. SECAT – Sacramento Emergency Clean Air and Transportation Program
59. SIP – State Implementation Plan
60. SOx – sulfur oxides
61. TCO – total cost of ownership
62. TE – transportation electrification
63. TIRCP – Transit and Intercity Rail Capital Program
64. TRL – technology readiness level
65. TRU – Transport Refrigeration Unit
66. VALE – Voluntary Airport Low Emissions Program
67. VTO – Vehicle Technologies Office
68. VW – Volkswagen
69. XO – extended operation
70. ZANZEFF – Zero- and Near Zero-Emission Freight Facility
71. ZE – zero-emission
72. ZEPCert – Zero-Emission Powertrain Certification Regulation
73. ZEV – zero-emission vehicle