Appendix D

Heavy-Duty Investment Strategy

including Fiscal Year 2019-20 Three-Year Recommendations
for Low Carbon Transportation Investments

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Introduction

Achieving California's climate, clean air, and community protection goals will require an ongoing transformation of the transportation sector — in both the light-duty and heavy-duty sector — to the use of zero-emission technologies wherever feasible and near zero-emission technologies with the cleanest, lowest-carbon fuels everywhere else. This transformation will utilize advanced technologies and fuels, while supporting progress towards creating the jobs of the future and achieving and maintaining healthy and sustainable communities for all Californians. This transformation requires a combination of aggressive policies, targeted regulations, and incentives. Incentives need to be carefully prioritized between investing in technologies that achieve immediate emissions reductions, and providing support to emerging advanced technologies that are necessary to meet our long-term goals. These long-term goals require immediate action. The existential threat of climate change is not a crisis of the future, but of the present. To reduce the impacts of climate change and meet air quality standards, California must exhibit leadership by developing necessary zero-emission technologies and low-carbon fuels now.

The State is committed to driving this type of transformation and works in partnership with other agencies at the local, state, and federal level to maintain progress toward our climate and clean air goals. The California Air Resources Board (CARB) continues to build a broad suite of regulatory actions (from the diesel truck and bus rule, to the innovative clean transit regulation, to ships at berth) and a comprehensive incentive portfolio that supports technologies from the pre-commercial phase all of the way through to fleet turnover. It is mission-critical to continue to drive technology advancement through these efforts in order to meet our goals — and the need for private sector investments and engagement is enormous.

State incentives can catalyze private sector investment and create the partnerships necessary to support the transformation of the heavy-duty and off-road sectors. There are local, state, and federal sources of funding to invest in this transformation, but more is needed to support both the next generation of technologies for cleaner vehicles and equipment, and accelerating the turnover of the legacy vehicle fleet. For example, the South Coast Air Quality Management District (AQMD), as part of their 2016 Air Quality Management Plan, estimated a need for financial incentives of nearly $1 billion per year through 2031.[1] In the San Joaquin Valley, the air district's fine particulate matter (PM2.5) attainment strategy highlights a need for $5 billion in incentives by 2025.[2] Investments are also needed to meet the greenhouse gas (GHG) reductions targets defined in Assembly Bill (AB) 32, (Nunez, Chapter 488, Statutes of

[1] South Coast Air Quality Management District: 2016 Air Quality Management Plan, March 2017; http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2016-air-quality-management-plan/final-2016-aqmp/final2016aqmp.pdf

[2] San Joaquin Valley Air Pollution Control District: 2018 Plan for the 1997, 2006, and 2012 PM2.5 Standards, November 15, 2018. https://www.valleyair.org/pmplans/documents/2018/pm-plan-adopted/2018-Plan-for-the-1997-2006-and-2012-PM2.5-Standards.pdf

2006) and then subsequently in Senate Bill (SB) 32 (Pavley, Chapter 249, Statutes of 2016), as well as executive orders calling for the deployment of 5 million zero-emission vehicles by 2030[3] and statewide carbon neutrality by 2045.[4] CARB maintains a portfolio of funding programs that keep the momentum of advancing technology from demonstration to commercialization in order to meet State air quality, petroleum dependency, and greenhouse gas reduction goals. CARB's portfolio also includes programs to support the acceleration of fleet turnover, which are necessary to meet air quality goals. The programs in CARB's portfolio place emphasis on deploying advanced technologies in disadvantaged communities across the state to ensure that all Californians see the air quality, public health, and economic benefits that come with investments in a green economy.

It is critical to focus investments on both immediate air quality benefits and the innovation pipeline to meet the State's long-term vision of a zero-emission economy. As the number of incentive programs for heavy-duty vehicles and off-road equipment continues to grow, it is critical to identify how the agency's investments address the emission reductions needed to meet National Ambient Air Quality Standards (NAAQS). Dedicated support is needed to drive the heavy-duty and off-road sectors to zero-emission and meet the longer term greenhouse gas reduction goals.

In contrast to the rest of CARB's incentive portfolio, the Low Carbon Transportation Investments are meant to jump-start the transformation process and provide a down payment on the overall funding needed to reach the State's long-term goals.

This year's Heavy-Duty Investment Strategy expands on CARB's principles of investment—support advanced technologies across the commercialization path—while generally describing boundaries of each of the CARB incentive programs. This document begins to identify parameters of how technologies move through each of the programs — graduating from one to the other, ultimately leading to a financially sustainable market and technologies that are robust enough to require through regulation. Graduation of technologies through investment programs is based on advanced technology market assessments, the beachhead concept, 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 to be focused more strategically. This strategy outlines actions to support the transformation needed to meet the State's air quality; greenhouse gas reductions; and petroleum dependency goals and mandates.

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[3] Executive Order B-48-18. https://www.ca.gov/archive/gov39/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/index.html

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

The Heavy-Duty Investment Strategy provides insight into how CARB will invest its Low Carbon Transportation funding on a combination of transformational technologies for heavy-duty vehicles, off-road equipment, and fueling infrastructure with a focus on moving technologies through the commercialization process and meeting emerging market demand. There will be a more detailed discussion of the investments needed to support rapid, continuous innovation by investing in technology applications with the potential to move quickly through the stages of commercialization. This is a cornerstone investment principle for Low Carbon Transportation funding.

Beachheads are technological footholds that have strong potential to transfer and spread to broader applications.

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 Air Quality Improvement Program (AQIP), was exclusive to the funds included in the annual Funding Plan. The FY 2017-18 Strategy established the foundational concept of beachheads (see p. 17), a primary guiding principle that has since expanded into a global discussion on advanced technology vehicles and policy strategy. Paired with the beachhead strategy, the document was informed by technology status snapshots that allowed CARB to make inferences on the progress of technology along the commercialization path. These tools allowed CARB to forecast priority funding areas and minimum investment levels to continue advancement of priority segments.

In FY 2018-19, staff revisited the Heavy-Duty Three-Year Strategy to update the document's assumptions to reflect movement on technology readiness, changes in policy, and forecast a new three years of funding need.

Updates for FY 2019-20

While the Heavy-Duty Investment Strategy was initially developed independent of mandate, in 2018, the governor signed into law SB 1403 (Lara, Chapter 370, Statutes of 2018), which requires CARB to develop the Heavy-Duty Investment Strategy and Three-Year Recommendations for Low Carbon Transportation Investments. Among other things, SB 1403 directed CARB to produce annually a three-year investment strategy for Low Carbon Transportation and AQIP investments beginning in FY 2019-20. Per SB 1403, the Heavy-Duty Investment Strategy should describe the role of public investments in supporting the demonstration and deployment of advanced technologies, provide an assessment of available funding and the investment needed, and provide a description of CARB's portfolio of investments.

SB 1403 also requires that no less than 20 percent of funding 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, in consultation with the California Energy Commission, has defined near zero-emission as vehicles that have a duty-cycle that include zero-emission operation, including ePTOs and hybrids with an all-electric range. Currently, ePTOs represent a technological improvement that support the pathway towards zero-emission technologies. In the immediate term ePTOs are considered a near zero-emission vehicle, however, as the technology evolves, CARB may modify the definition of near zero-emission to include only those technologies that achieve a specified all-electric range. This definition is consistent with SB 1403, which requires that near zero-emission vehicles reduce greenhouse gas emissions and improve air quality when compared to conventional or fully commercialized alternatives. Focusing on vehicles that include zero-emission operations as part of its duty-cycle ensures that funding is available for those technologies that will create a pathway to zero-emissions. The goal to move towards zero-emission technology is consistent with the goals set forth in legislation and executive orders—for example SB 1275 sets a goal of deploying 1 million ZEVs by 2023, and Executive Orders B-16-2012 and B-48-18 set ZEV deployment goals of 1.5 million by 2025 and 5 million by 2030 respectively. This definition ensures that program investments fund projects that assist the state in reaching its climate goals beyond 2020, consistent with SB 1403.

The bill also requires that the Heavy-Duty Investment Strategy contain a report on the State’s school bus fleet. This report, developed in consultation with the California Energy Commission (CEC), is to include 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 Appendix E of the Funding Plan.

Responding to stakeholder needs, new legislation, and need for added detail, the Strategy has been more thoroughly updated and expanded this year. Primary updates include:

- A more comprehensive discussion on the investment strategy that drives decisions for CARB incentive programs;
- Metrics to help identify when technologies are ready to graduate through CARB incentive programs;
- Updates to the technology status snapshots;
- A new three-year funding priorities table;
- Enhanced consideration of off-road technologies and updated beachheads; and
- A more expansive exploration of the various barriers facing the advancement and adoption of advanced technology heavy-duty vehicles.

Over the last 12 months, CARB has engaged stakeholders on these topics, holding three public workgroups, conducting one-on-one meetings, and releasing a draft of the technology assessments to stakeholders for comment. Additionally, responding to stakeholder concerns and board direction, staff held a focused full-day workgroup with a broad stakeholder group in late 2018. The Heavy-Duty Advanced Technology Implementation Workgroup was purposed with identifying, understanding, and proposing potential solutions to the large number of barriers facing fleets deploying advanced technology heavy-duty vehicles. A summary of the workgroup and its outcomes can be found on page 62.

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. This Strategy is developed in consultation with the CEC. More information on CARB's coordination efforts is included on page 71.

State Air Quality Goals and the Role of Incentives

As discussed in the introduction to the FY 2019-20 Funding Plan, there are many drivers that affect CARB investments. From climate change goals set in AB 32 and the subsequent SB 32, to air quality goals set in the Federal Clean Air Act, many documents and policies have been developed to support achieving these goals. Executive Order B-55-18, commits the State to economy-wide carbon neutrality by 2045. 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 zero-emission vehicles (ZEVs) by 2025 and 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

SUPPORTING AIR QUALITY GOALS
INCENTIVES AND THE SIP

Implementation of CARB's current control program and new regulatory measures account for the majority of emissions reductions in the 2016 State Implementation Plan Strategy and are critical to drive technology development and deployment of the cleanest technologies. However, the scope and timing of the emissions reductions needed to meet ozone standards in the South Coast and PM2.5 standards in the San Joaquin Valley require early actions to enhance the penetration of cleaner technologies through incentive programs and other funding mechanisms. These early actions are also needed to meet the State's commitments for heavy-duty trucks and off-road equipment in the South Coast and San Joaquin Valley.

targets for the State's Cap-and-Trade auction proceeds investments. Two other primary drivers 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, the statewide precursor to each Air District's State Implementation Plan (SIP), notes that heavy-duty trucks over 8,500 pounds[5] are currently the fastest growing transportation sector in the United States, and are responsible for about 33 percent of total statewide nitrogen oxides (NOx) emissions, approximately 25 percent of total statewide diesel particulate matter (PM) emissions, and are a significant source of GHG emissions. Emissions from off-road diesel sources that are not subject to California regulation, such as ocean-going vessels and locomotives are also expected to increase.[6] Early investments that accelerate deployment of zero- and near zero-emission 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 technology. Additionally, vehicles and equipment replaced via CARB's scrap and replace programs have a large impact on each district's individual SIP commitment.

- 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 near zero-emission technologies paired with renewable fuel use everywhere else.[7] The solution will require technology innovation including development and deployment of zero- and near zero-emission trucks, locomotives, cargo handling equipment, TRUs and ships; 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 include 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- and near zero-emission vehicles and fuels.[8] Together, these approaches are designed to achieve progressively cleaner in-use fleet emission levels.

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[5] For 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).

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

[7] California Sustainable Freight Action Plan, July 2016. http://www.dot.ca.gov/casustainablefreight/theplan.html

[8] https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf

While incentives are designed to help accelerate technology advancement and market penetration, they are also intended to reward early adopters of these technologies. As the cleaner technologies become commercially available, costs continue to fall and market adoption increases. Incentives help bring more of the vehicle and equipment fleets into compliance ahead 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 near-term and long-term objectives. They are a critical part of the State's SIP commitments and are guided by the Federal NAAQS for PM and ozone, as well as aggressive State goals related to reducing greenhouse gas 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 necessary for CARB to ensure those statutory requirements are met while leveraging all programs to meet our near- and long-term goals.

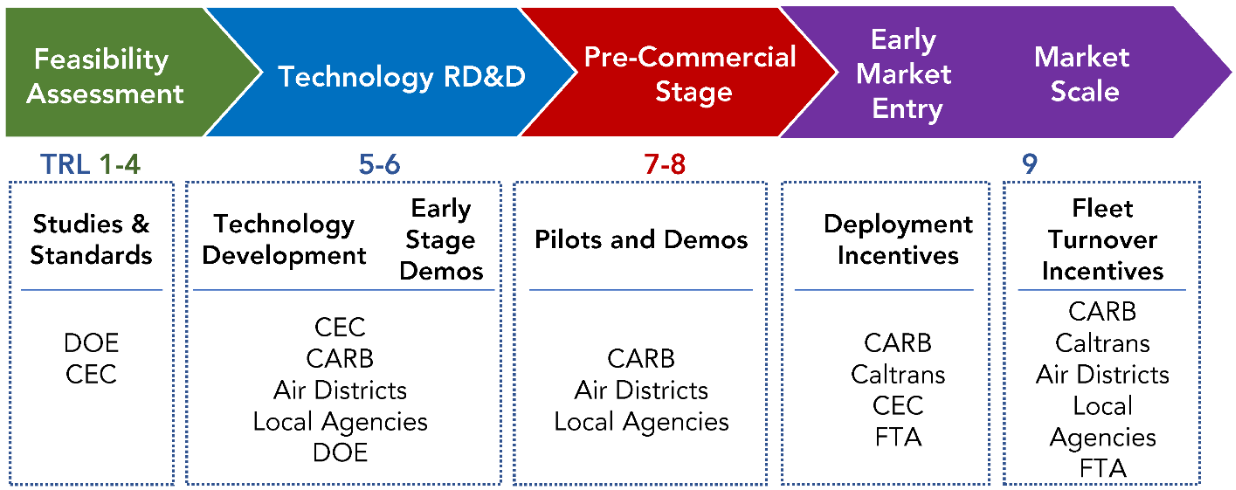
Incentives can also be used to promote the deployment of advanced technologies in disadvantaged communities that experience environmental and health inequities from air pollution. CARB focus investments to help purchase cleaner vehicles and equipment, with a focus on advancing zero emission technologies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

Investment Strategy

Just as there is a range of regulations affecting heavy-duty vehicles and off-road equipment, there are incentives at the local, state, and federal levels that support technology advancement at the demonstration, pilot, and commercial deployment stages, or across all technology readiness levels (TRL).[9] Figure 1 shows the evolution of technology and the public agencies that provide key incentives across this evolution.

[9] https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html, October 28, 2012

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



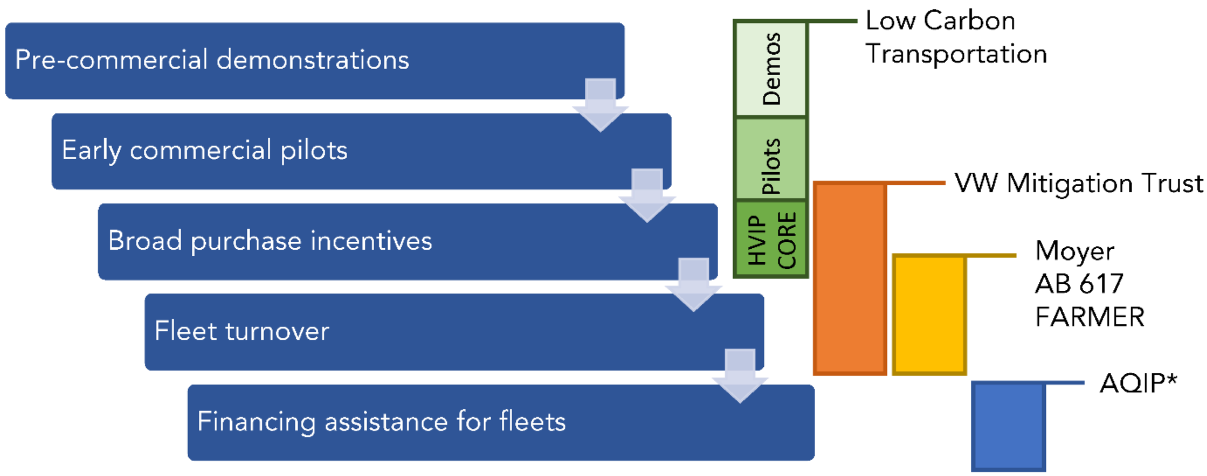
As Figure 1 shows, California, through many state agencies, invests public funds across the entire evolution of technology. This approach is critical because it provides the opportunity to invest not only in the commercial technologies that help meet important near-term goals, but also ensures continual development, demonstration, and deployment of technologies that are necessary to meet the State's long-term goals. 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. CARB has programs in its incentive portfolio that span from pre-commercial demonstration, pilot, early commercial, and commercial phases of technology and market development. Figure 2, shows how CARB's incentive programs work in series, with some overlap between programs. There is a natural progression of support for technologies starting in the pre-commercial demonstration phase all of the way through to financing assistance for small-business truckers who are unable to qualify for conventional financing for cleaner trucks. This year, CARB is laying the groundwork to develop metrics to identify when a vehicle and

FLEDGING TECHNOLOGY
HVIP BRIDGES THE GAP

HVIP is the last stage of Low Carbon Transportation investments, serving technologies in late stages of technology development that are beginning to enter the market. This incentive project bridges the gap between technology transformation and market transformation, allowing fledging technology applications to build volume, establish their markets, and then move beyond the intensive investments made by Low Carbon Transportation. With HVIP's role as a bridge, it will be the first incentive project to be evaluated for graduation protocol.

technology application is ready to graduate from one funding program into another better suited for its stage on the commercialization path. Understanding technology progression through incentive programs and establishing the criteria to determine when an application graduates is of broad importance, but most immediately pertains to CARB's on-road voucher project, the Clean Truck and Bus Voucher Incentive Project (HVIP). HVIP lies in the "broad purchase inventive" category and staff has found it necessary to realign limited funding to best meet its program objectives. Determining when technologies graduate from any funding program necessitates establishing criteria that serve as reliable indicators. HVIP, in this year's Funding Plan, has listed some — such as growing production volumes, achieving cost-effectiveness, integrating into original equipment manufacturer (OEM) manufacturing lines, or the technology simply not developing further — and staff aim to work with stakeholders in the coming year to determine best practices for technology graduation.

Figure 2: Funding Succession



*Statutorily, AQIP funding can be used to support technologies through the whole commercialization pathway. But AQIP is the only program that is able to offer financing assistance to fleets to purchase cleaner vehicles. As the effective date of SB 1 approaches and the need for financing assistance increases, CARB has focused AQIP dollars towards this area, allowing other programs within the portfolio to fund the earlier stages of the commercialization path.

<u>**The Commercialization Path**</u>

All CARB investment programs focus on funding from the demonstration phase onward, following the programmatic categories shown above. Following this structure, it is vital to understand what CARB views as demonstration, pilot, and commercial.

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 long-term goals. Low Carbon Transportation is the only substantial source of CARB funding for this critical stage.

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 are 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. CARB recognizes the importance of this stage of commercialization and dedicates significant investments through Low Carbon Transportation.

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 the technology gains user-acceptance, proves to be reliable and dependable, and manufacturers shift to it being the preferred technology they are manufacturing, incentive opportunities can shift to programs that are focused on legacy fleet turn-over, such as the Carl Moyer Program (Moyer), the Funding Agricultural Replacement Measures for Emissions Reductions (FARMER), or Community Air Protection Program (CAPP) Funds, where scrap is typically a requirement.

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) purchase cleaner vehicles. The

Truck Loan Assistance Program, a program within AQIP, provides financing opportunities to small-business truckers 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, to ensure that market successes are solidified and continue to make progress towards 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 called for in SB 1275 (De León, Chapter 530, Statutes of 2014). 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 action against air pollution and 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 had 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 87), though the goals of each are markedly different. CARB's portfolio places emphasis on technology advancement, the deployment of zero-emission heavy-duty vehicles, and turning over the legacy fleet. The programs in CARB's portfolio summarized in this section and discussed in greater detail on page 87.

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 tends to have a focus on pre-commercial demonstrations, early commercial pilots, and some broad purchase incentives, as well as statewide programs for fleet turn over. Air district funds are usually used on scrap and replace projects prioritized on a cost-effective basis to meet SIP requirements. This division in funding is necessary—the State is better 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 — as shown in Figure 3. A description of the funding programs in CARB's portfolio can be found on page 87.

Figure 3: CARB Funding Program by Technology Status

TRL 5-6 7-8 9

Early Stage Demos	Demos and Pilots	Deployment Incentives	Fleet Turnover Incentives	Financing Assistance
Low Carbon Transportation (Demonstrations) AQIP*	Low Carbon Transportation (Demos and Pilots) AQIP*	Low Carbon Transportation (HVIP, CORE) VW Mitigation CAPP	VW Mitigation Moyer CAPP FARMER	AQIP*

*Statutorily, AQIP can support technologies throughout the commercialization path, but it is the only CARB program that can provide financing assistance. As the need for truck loan assistance programs have increased with SB 1, CARB has dedicated AQIP funding towards financing assistance.

With multiple goals guiding State action on clean heavy-duty vehicles, maintaining multiple programs with different objectives is necessary. At CARB, this means a portfolio of programs tasked with technology development, deployment, and market transformation that emphasizes community protection and investment in disadvantaged communities. To ensure that programs within the portfolio work in harmony, staff has reviewed how technologies move among these programs or when they leave the programs entirely. This is important for a number of reasons, not the least of which is conserving limited fiscal resources.

Coordination is not just imperative to increase ease of use for participants, but to guarantee that, together, all of the State's funding programs work effectively to meet the State's goals.

CARB's funding programs were designed to support advanced technologies through the commercialization process while simultaneously supporting California's near- and long-term air quality and climate goals. The Low Carbon Transportation projects focus on ensuring that the advanced technology will be commercially available at the scale needed to meet California's long-term climate, air quality, community protection, and petroleum dependency goals. These projects fund advanced technologies in their early stages — starting with demonstration and pilot projects to validate duty cycle and technological readiness 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 a technology reaches market scale, other programs within CARB's portfolio such as Moyer, the Volkswagen (VW) Mitigation Trust, CAPP, FARMER, and AQIP are more appropriate funding sources. These programs focus on achieving near-term 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. These programs often require additional measures, such scrappage, or funding through a competitive process considering 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 mandated through standards, projects such as those within AQIP also play a role in ensuring that fleets are able to comply with upcoming 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. However, AQIP is unique as the only program in CARB's portfolio that is able to fund a financing assistance program. Because of this and the increased demand that has been placed on the Truck Loan Assistance Program as the effective date of SB 1 nears, 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.

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.

This document is beginning to pave 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. The concept of technology graduation has come to the forefront this year as staff assesses technology progress and the most effective use of limited funding to commercialize technology. 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 can only fund commercial equipment.

Technology Pathways

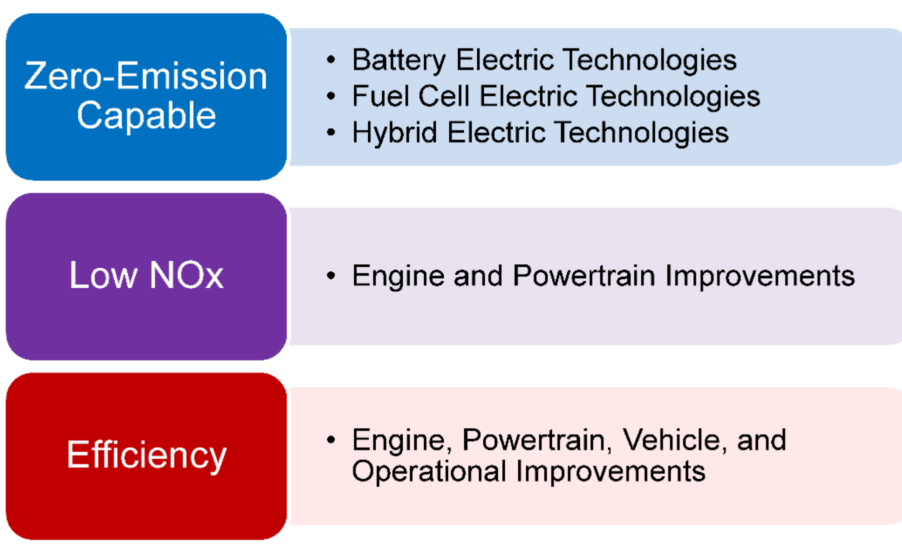
For the past two years, CARB has followed a refined and targeted strategy to accelerate the development and market introduction of technologies that are critical to achieving the State's near term and longer-term climate and air quality goals. The remainder of the report addresses CARB's investment strategy for the Low Carbon Transportation Program.

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

1. Continue to invest Low Carbon Transportation dollars across the commercialization path for various technologies, building on our previous investments. This includes supporting technologies through the demonstration, pilot, and commercial phases.

2. Focus investments on the three critical technology pathways necessary to meet the State's long-term climate and criteria emission goals. The three — often interlinked — critical technology pathways identified are Zero-Emission (organized around battery electric, fuel cell electric and hybrid electric technologies); Low NOx (engines and powertrains); and Efficiencies (engine and powertrain, full vehicle and system operations) (see Figure 4).

Figure 4: Pathways to Near-Term and Long-Term Goals



3. Target investments around the expansion of "beachhead" markets – early successful vehicle applications where the pathway technologies can best establish initial market acceptance, and then from there seed additional adjacent market applications. The beachheads are discussed in the following section.

This strategy has shown success to date as seen in the significant growth in vehicle voucher requests and the improvement of technology capability displayed in demonstration and pilot stage projects. A greater variety of platforms are becoming available and a broader cross section of industrial providers are becoming involved, including global OEMs as well as innovative new manufacturers.

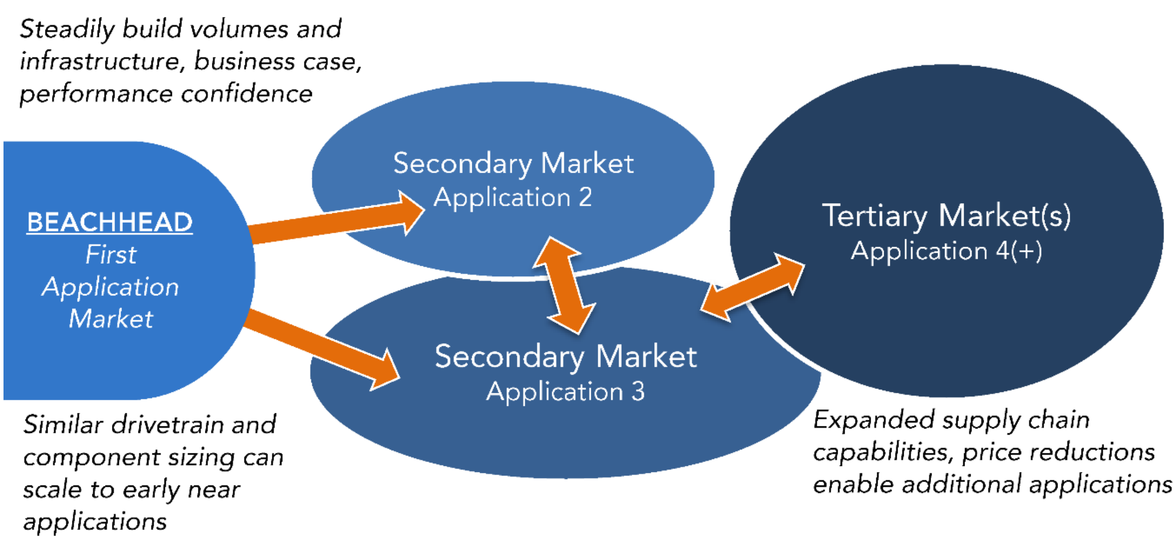
Beachhead Strategy

Since 2017, CARB has followed an increasingly successful strategy for technology commercialization based on targeting its investments on strategic "beachhead", or first-success, applications and on the pathways for additional application markets that extend from them.

With 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 for scaling the technology to larger or smaller application sizes.

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 this foothold, the beachhead process then can grow in impact by the extension of technologies to adjacent markets through the leveraging and adoption of similar powertrains, the growth of supply chain volumes for common components, expansion of fueling infrastructure and confidence in performance and business case grows. With 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 for scaling the technology to larger or smaller application sizes. Figure 5 depicts the Beachhead Process.

Figure 5: Beachhead Process



The term "beachhead" derives originally from military usage and is often connected to the successful Allied landing 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.*"[10]

The commercial definition of beachhead is "a secure initial position that has been gained and can be used for further advancement; foothold."

This concept has helped CARB target and focus most funding 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 U.S., Europe, Asia, India, and South America.

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.

The beachhead strategy, shaped around the three core technology pathways, now defines CARB's approach to driving faster technology commercialization. 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 assist in moving into larger markets or other applications.[11]

Beachhead Strategy Updates 2019

Three main beachheads — one each for the three technology pathways identified earlier — and their resulting progress stages have been developed and adopted and are now being followed to define CARB investments. These three beachheads and

[10] *Random House Unabridged Dictionary, Random House, Inc. 2018*
[11] *http://timberry.bplans.com/the-power-of-beachhead-strategy.html*

pathways — Zero-Emission; Low NOx; and Efficiencies — are not mutually exclusive as some of the efficiency technologies can be overlaid on any one of these beachheads to maximize reductions (i.e. connected-automated vehicles, automated guided vehicles, stop-start systems, etc.).

These beachheads define and guide CARB's investment strategy. However, 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 work group and other industry and stakeholder interactions has solicited comments and feedback on these beachheads in 2019 to identify areas where there may be additional leverage supporting deployment expansion or areas of technology success. Additionally, staff took the opportunity to give renewed focus to the off-road sector. With a rapidly-developing segment poised for further CARB investments, staff desired to further highlight where on-road and off-road points of connection might be for certain technologies, identifying where technology transfer might assist faster off-road technology adoption.

This 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 staff'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 updated for 2019 to include some refinements to its process.

This review assessed opportunities for shared or common components as well as evaluated industry observations about how some common points of shared infrastructure investments, such as ports or distribution centers, could be leveraged to support or enable adoption of products across multiple applications.

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

During this review process, staff determined that a separate beachhead for off-road equipment outside of industrial lifts was not necessary, but did see several specific areas where technology transfer was occurring and supporting new capabilities in off-road applications in the zero-emission beachhead and pathways. In addition to the interconnections in the beachhead model itself, staff also performed a deeper analysis of how advanced technology can successfully transfer and grow in the off-road space. Previous versions of the Heavy-Duty Investment Strategy touched on off-road equipment and how those categories influenced technological advancement for on-road, but didn't fully capture the development staff has seen for off-road advanced technology. Several signals, such as the large oversubscription to the 2016-2017 Advanced Technology Off-Road Demonstration Solicitation, information regarding several large OEM's growing activity in near zero and zero-emission off-road equipment, and examples of new technology currently being tested and proven in other countries all illustrate growing progress towards commercialized advanced technology off-road equipment that should be acknowledged in this strategy document.

Several interconnections have been identified in the off-road sector, and these connections were found between on- and off-road equipment in construction and agricultural equipment and between these segments and cargo handling equipment. The connections and technology transfer occur via opportunities for common components and powertrain systems. This technology transfer is beginning to be seen very clearly in the commercial harbor craft[12], or near-shore vessel, sector, which can include ferries, excursion vessels, crew and supply vessels, and barges. Mostly in Europe but also in North America, powertrain components that have been transferred from or are common with heavy-duty on-road systems are being used to power or provide capabilities for such marine vessels. Examples of this include propulsion systems from Siemens, ABB, The Volvo Group, and BAE Systems. A hybrid electric excursion vessel on the San Francisco Bay, the Enhydra, traces its powertrain directly to the components used by BAE Systems to power 60-foot articulated hybrid electric transit buses.

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 demand for fuel could justify large scale, on-site fuel production which can help reduce the cost of hydrogen fuel. One example that could test this assumption is the Toyota Tri-Gen facility at the Port of Long Beach, now under construction. Once operational it can provide sufficient quantities of hydrogen for multiple applications, including several fuel cell drayage trucks Toyota and Kenworth are developing in a separate CARB-funded pilot project (funded by the Zero- and Near Zero-Emission Freight Facility — ZANZEFF — project). The Zero Emission Cargo Transportation II project supported by CEC, SCAQMD and U.S. Department of Energy (DOE) is also providing funding for fuel cell drayage trucks and further infrastructure to expand upon the Toyota Tri-Gen facility.

[12] https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft

In addition to the benefits of shared infrastructure, there are several other factors that make captive fleets and single sites hosting multiple operations a supportive location for the growth of advanced technology, including off-road equipment. Because there is such a wide variety of off-road equipment used at these sites, investing in the site itself to prove out the initial beachhead technology makes that site more likely to expand and adopt advanced technology for other co-located equipment types. Additional possible site-specific benefits, such as labor training, maintenance expertise, and the opportunity to become familiar with advanced technology in a confined environment, all increase the potential of captive fleet operators to be exposed to and adopt advanced technology for other equipment types. In short, captive fleet sites are not only strong targets for the beachhead technologies to gain their initial foothold, but the additional benefits of testing out that technology make that site a perfect place to expand into the secondary and tertiary markets as well.

The Efficiencies Beachhead and Pathways have also been updated to more clearly align technologies by use profiles for ease of readability and to better reflect the diverse technologies in these segments.

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, which 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.

Zero-Emission Beachhead and Pathways

The most powerful beachhead process to date has been built around the zero-emission pathway. It is centered around 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 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 of several other applications, some in early production now or in stages of development heading toward early production capability over the next three to five years:

- Battery electric shuttle and school buses

- Battery electric delivery vehicles
- Battery electric yard hostlers
- Battery electric, fuel cell electric, and plug-in hybrid (sometimes operating as range extender systems) drayage trucks
- 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 assisted by hybrid, start-stop, and idle reduction technologies (from efficiency pathway)
- Steadily increasing vehicle volumes and availability of infrastructure, knowledge of the business case, and consumer confidence in performance
- Expanded capabilities, including price reductions in energy storage/components enabling medium- and heavy-duty applications (some of this energy storage is transferring directly from light-duty passenger car production)

While extended range applications are being developed that use an engine generator or small fuel cell to augment the range and performance of battery electric heavy-duty vehicles, the rapid 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. Tesla has announced it could reach ranges of 300-500 miles on some routes. At the same time, fuel cell development is highlighting a strong potential in applications needing long distance or longer operating times, such as the long-haul segment along corridors between fueling locations. While the source of the electrical power comes from different sources (batteries, fuel cells or engine generators), it is important to note the core powertrain architectures are highly similar.

There is a parallel off-road zero-emission beachhead that is cross-supporting this expansion: the Forklift/Industrial Lift Beachhead. 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 of-road equipment. Such systems are in the demonstration phases. The knowledge base and core technology is enabling, if not in all cases directly leading to, additional applications, such as:

- Battery electric and fuel cell electric Ground Support Equipment (GSE)
- Battery electric, fuel cell electric and Extended Operations (XO) Electric Cargo Handling Equipment (CHE)

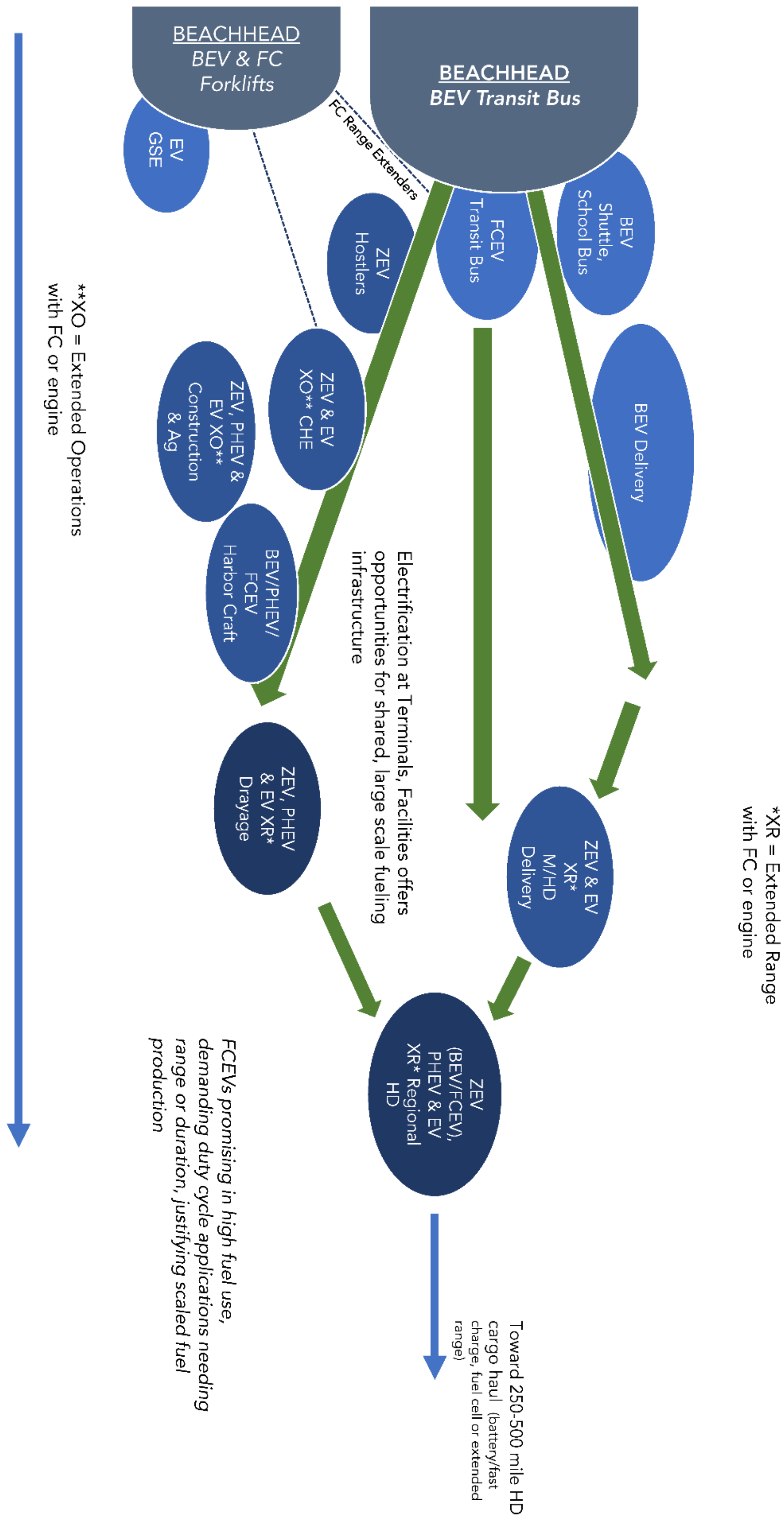
- Battery electric and fuel cell electric TRUs

As important, though, is the technology transfer of heavy-duty components between the on-road sector and segments of the off-road sector. This 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.

Figure 6 illustrates the Zero-Emission Beachhead and Pathways.

Figure 6: Zero-Emission Beachhead and Pathways



Low NOx Beachhead and Pathways

Low NOx engines are those engines which have been certified to any of the optional low NOx engine certifications established by CARB. However, the main focus of this beachhead and its pathways are those engines meeting the most stringent certification level of 0.02 grams per brake horsepower-hour (g/bhp-hr) NOx. Further, because of the differences between how engines operate based on their fuel combustion dynamics, two main pathways have been identified for low NOx engines: a spark ignition pathway and a compression ignition pathway.

The spark ignition pathway offered the first successes with attaining low NOx certification levels (0.02 g/bhp-hr NOx, or 90 percent below EPA'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:

- Low NOx shuttle and school buses
- Low NOx medium duty work trucks and related applications
- Low NOx class 8 regional tractors and drayage trucks

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

- Low NOx class 8 long haul/corridor tractors
- Low NOx port and rail support equipment
- Using low NOx engines as range extender power plants for class 8 extended range electric regional tractors

Spark ignited low NOx 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.

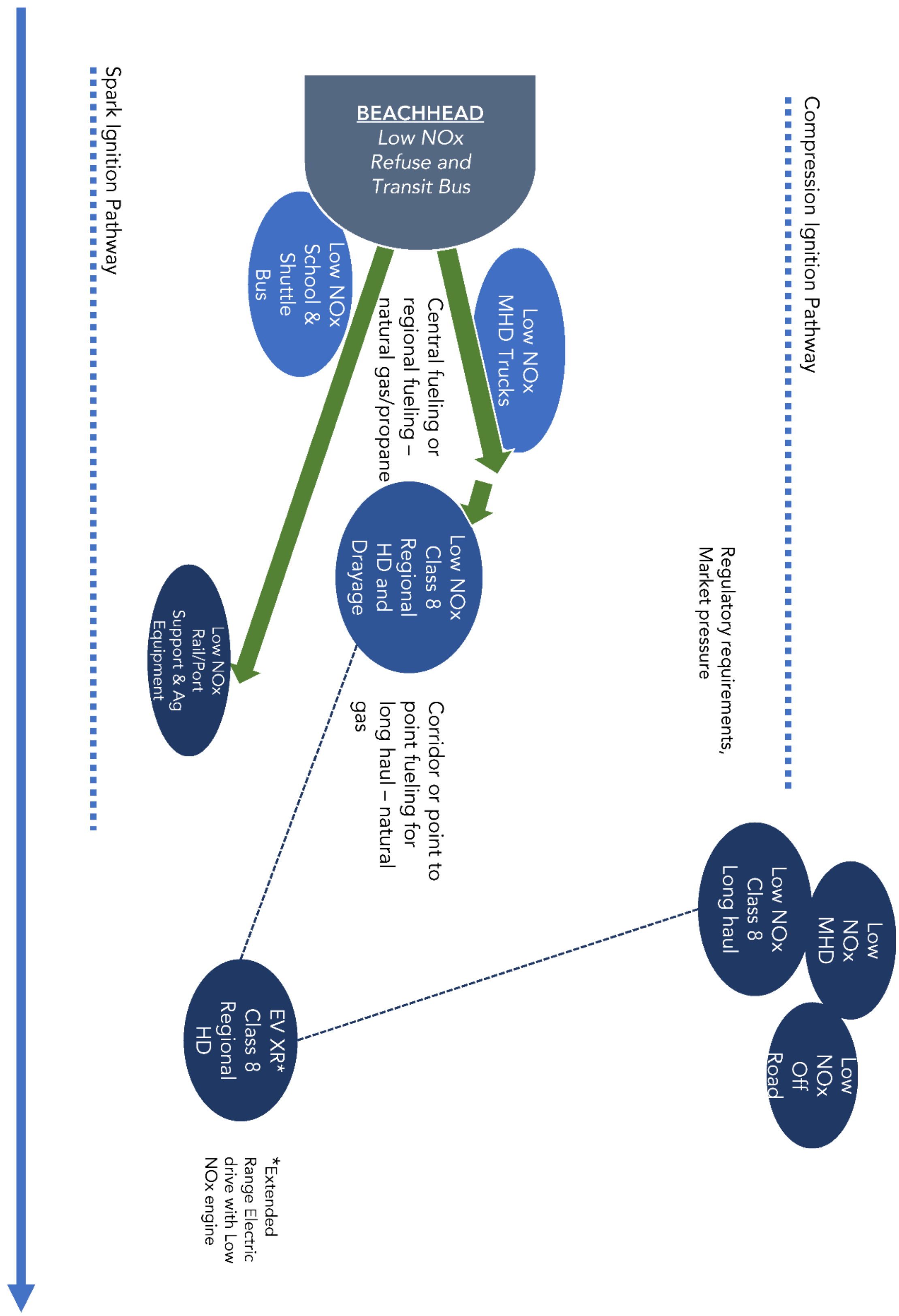
The compression ignition pathway involves very different engine and after-treatment strategies than the spark ignited pathway and is on a different timeline for potential introduction. Customer and market pressure have provided some impetus to drive development of a low NOx product from compression ignited technology. However, it may require consistent regulation to cause the industry to produce a product, given concerns over fuel efficiency loses that could result from reaching lower emission levels. The Achates Power opposed piston engine has already validated in testing the potential to reach low NOx levels with an increase in efficiency over conventional engines.

The most likely beachhead for a low NOx compression ignition engine is the Class 8 long haul application, as this represents highest volumes and the potential for less complicated control strategies than for engines used in lower speed work and vocational truck applications. Once established, the control and engine strategies could then be augmented to support applications such as:

- Low NOx medium-duty engines
- Low NOx off-road engines (CHE, construction, agriculture)

Similarly, a low NOx compression ignited engine could also be used as a power plant for an extended range electric regional class 8 tractor. Figure 7 illustrates the updated Low NOx Beachhead and Pathways.

Figure 7: Low NOx Beachhead and Pathways



Efficiencies Beachhead and Pathways

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, emission and petroleum reduction goals, the efficiencies beachhead focuses on two primary pathways, operational energy efficiency — energy efficiency gained through the more efficient operations of groups of vehicles in a system — and powertrain efficiency, the more efficient operation of an integrated engine, transmission, differential, hybrid components and other supporting systems to power a vehicle. Figure 8 shows this landscape and the technology growth from two generalized beachheads: controlled ecosystems and vocational truck and bus powertrain hybridization. For ease of visualization, these two beachhead pathways have been split into two parallel graphics.

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" (ITS – intelligent transportation systems), 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 geofencing

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

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

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:

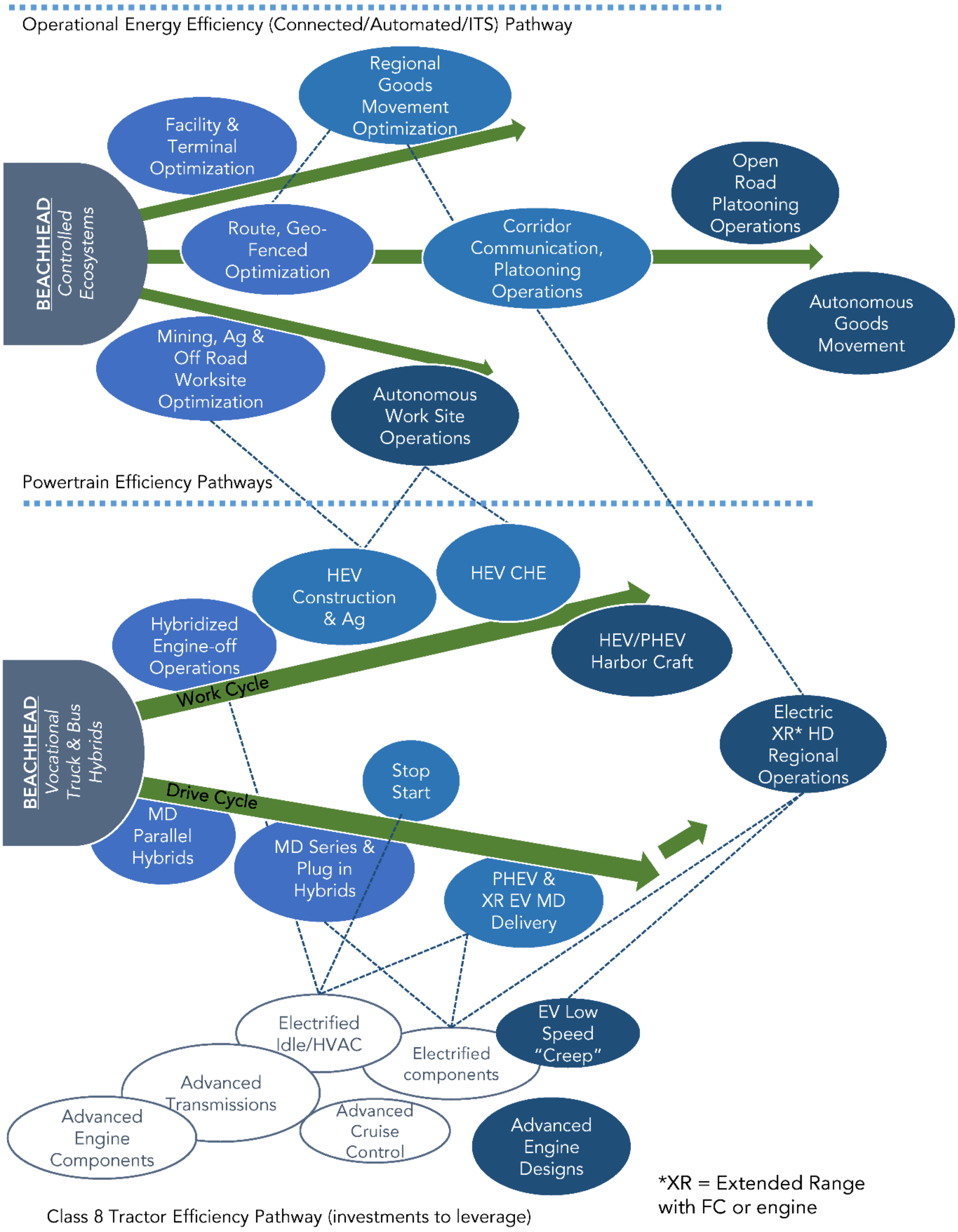
- Start-stop systems to shut off engines at every stop in a drive cycle
- Plug-in hybrid and extended range electric medium-duty delivery
- Plug-in hybrid and extended range electric heavy-duty regional operations

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 dotted lines on the charts. Significant federal and engine maker investments 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. 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 the increased component volumes as they are implemented in Class 8 applications. This 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 8: Efficiencies Beachhead and Pathways



*XR = Extended Range with FC or engine

Using the beachhead strategy, staff 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.

Using the beachhead strategy, staff have 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.

Technology Status Updates

To maintain the effectiveness of the investment strategy and to track progress against goals, it is important to monitor the status of the key pathway technologies. With its grantees and with input from industry stakeholders, CARB conducted a 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 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 staff to adjust investment recommendations to help further expand market and technology success or to further assist technologies moving more slowly or facing additional barriers.

CARB HEAVY-DUTY VEHICLE CLASSIFICATIONS USED

For 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. Indeed, CARB incentives for commercial vehicles can be used from weight classes starting above 8,500 pounds Gross Vehicle Weight Rating (GVWR). This document will refer to medium-duty and heavy-duty applications but will attempt as often as possible to refer back to the CARB weight designation system where they are applicable. This consists of Light Heavy-Duty — LHD (>14,000 pounds - 19,500 pounds GVWR); Medium Heavy-Duty — MHD (>19,500 pounds - 33,000 pounds GVWR) and Heavy Heavy-Duty — HHD (>33,000 pounds GVWR). These weight class initials will be listed next to platforms being tracked to aid in understanding.

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 and the potential market penetration of the application.

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 (in conjunction with staff from other agencies and industry) over previous years,[13] the updates are based on reviews of additional or updated data and information from literature, public

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

information sources, private conversations with technology providers, and field data where available.

With the end goal of broader market acceptance, the strategy takes a layered approach: beginning first with vehicle technology readiness, and then building on that to understand other 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.

In tracking this progress it is important to keep in mind the goals of the Low Carbon Transportation projects as laid out and planned for in this document. Fundamentally, Low Carbon Transportation is tasked with GHG reductions through strategic investments in technologies that provide GHG and other co-benefits. With the end goal of broader market acceptance, the strategy takes a layered approach: beginning first with vehicle technology readiness, and then building on that to understand other 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.

As a result, the assessments evaluate technology readiness, not market readiness per se. Market readiness is driven by a variety of factors that can vary and are complicated by location and application and are not as readily quantifiable. A product may be fully technically ready for commercial introduction, but issues around infrastructure timing, knowledge of business case, training, and other issues can slow introductions. While only some of these are within the scope of the Low Carbon Transportation investments discussed in this document, all of them are important. See the section, On-Going Issues Impacting Market Transformation on page 62, for information on these barriers. These status updates focus on the readiness of the technology generally, and then highlight those barriers or other considerations that may slow adoption.

These technology status "snap-shots" are also unique in their design. They are broadly guided by the general framework of Technology Readiness Levels, or TRLs.[14] However, the approach used in these assessments is an adaptation of the TRL process that is applied not to a component but to a full vehicle platform. Therefore, the technology readiness portrayed is not intended to be absolute, but rather directional to provide information on where pathway technologies generally reside, and what supporting tools or funding could then benefit them. For 2019-20, the technology status snap-shots have also been refined from previous years in several ways. The

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

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 platform that contributes to the 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 platform from a vertically-integrated global OEM would be weighted more heavily than a platform 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 smaller manufacturers already in commercial production.

These assessments are an important first step but tell only part of the commercialization story. Some specific applications for a platform may present market implementation challenges. Therefore, a platform shown as technically ready for early commercial introduction (roughly corresponding to TRL 9) may not necessarily have the ability to perform every possible role in which its class of vehicle might be used.

As previously noted, these assessments are an important first step but tell only part of the commercialization story. Some specific applications for a platform may present market implementation challenges. Therefore, a platform shown as technically ready for early commercial introduction (roughly corresponding to TRL 9) may not necessarily have the ability to perform every possible role in which its class of vehicle might be used. For example, a Class 8 natural gas-powered tractor may not readily serve all long-haul truck roles. Issues of fuel availability, adequate fuel storage tanks, and sufficient power may limit its use to some sub-set of Class 8 routes and duty cycles. Similarly, a battery electric transit bus today may not meet every possible transit district route or operational need for multiple back-to-back shifts. Nonetheless, each of these platforms has achieved technical readiness for commercial production and can address a meaningful portion of that application's needs.

As technologies reach these late stages of technology transformation, staff should consider 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.

As technologies reach these late stages of technology transformation, staff consider 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. Moving forward, staff would like to explore these concepts further, including understanding when technologies "graduate" from technology development under Low Carbon Transportation.

In the technology status charts that follow, the x-axis represents 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 y-axis shows generally the potential market penetration for that technology, with technologies that have a very small potential market near the bottom, and those with a larger potential market near the top. An arrow next to a technology platform shows directional changes in commercialization status since the last update. Given this is the third year of tracking, the platform names represent their positions in the 2017-18 assessments. Each arrow shows progress tracked in each succeeding year.

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 has been added to the charts below. The 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 graduation to more appropriate or alternative incentive strategies.

Technology Status Snap-Shot UPDATE: Battery Electric Vehicles

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 year across most of the platforms assessed. This progress is most pronounced in the platforms that make up the first-success applications identified in the "beachhead" strategy for the zero-emission strategy. Figure 9 depicts the progress made across several BEV platforms.

The full-size transit bus application (HHD weight classes) remains an important first success application as every major North American manufacturer and several new manufacturers have products available for purchase. Importantly, this is not isolated to North America but is a global phenomenon which can be seen also in Europe, China, and India, with growth also in South America. There are now twelve electric bus makers with more than 25 models available in the U.S. and more than 1,650 ZEV buses have been deployed or ordered as of Fall 2018. The dominant percentage of these are BEVs, with just over half of these buses in California. As staff will note in barriers, as the deployments grow and bus numbers per site increase bus operators are facing issues with the time needed to install infrastructure, adequate local charging capacity in some cases, and growing pains with best charging system designs. This is a key important topic to address and around which to develop solutions.

A key secondary application after BEV transit buses is BEV delivery (MHD weight classes). This sector is also seeing progress in both its overall technical readiness and the first large volume purchase entering the market. The largest single BEV commercial vehicle order outside of China took place when FedEx Express this year placed an order for 1,000 Chanje Class 5 electric delivery vans. Additional large orders are anticipated.

TECH EXAMPLE

ELECTRIC DRIVETRAIN TRANSFERABILITY

The Volvo Group is a global, vertically-integrated manufacturer of trucks, buses, construction equipment, and marine powertrains. This diversity of vehicles and equipment has helped the company respond to the growing market and environmental demand for electric-drive technology by leveraging its core electric-drive powertrain across many product categories. Its heavy-duty electric powertrain (electric motors, transmission, energy storage, and power electronics) was initially developed for its electric transit buses. Volvo then adapted this same architecture for multiple other vehicle platforms and applications that have similar needs for power and torque. To date Volvo has adapted both the 185 kW and 370 kW variants of this powertrain for use in a larger 60-foot transit bus, its Class 8 distribution truck tractors, refuse trucks, off-road automated dump trucks, and even in near-shore marine powertrains via its Penta division. This capability enables Volvo to learn from different applications and improve the performance of its electric drivetrain by using one underlying architecture to serve multiple vehicle platforms and use applications. As a global manufacturer, this gives Volvo an advantage in transferring this technology to products they offer worldwide. The company will demonstrate a North American version of this powertrain in trucks deployed in the Volvo LIGHTS (Low Impact Green Heavy Transport Solutions) project, partially funded by CARB.

This overall application platform has seen a significant addition of vehicle models in early production (Fuso eCanter[15]) or in development and announced as heading to production in the near term (Freightliner eM2[16]). Overall this category ranges from later pilot stage to early commercial stage, with the weighted placement of this application moving into higher readiness but still being late pilot stage.

Steady technology progress also continues to be made in Class 7 and 8 (HHD) short haul drayage and regional haul trucks, which are both moving into the pilot stage of development. Most major truck OEMs are now actively involved in developing products and are involved in CARB-funded projects around freight facilities. Additionally, several smaller powertrain providers that had been supporting such vehicles have been acquired or invested in by larger Tier 1 truck industry suppliers (Tier 1 companies are manufacturers who sell directly to the OEMs[17]), increasing the smaller firms' viability. Progress also has been made in refuse trucks (HHD) and there is clear technology transfer from bus and other truck platforms to this segment. 2021 remains a common early market production timeline for these products[18] and they are prime candidates for pilot stage deployment and validation.

At least eight school bus products are either commercially available or

TECH EXAMPLE

ON-ROAD SYSTEMS TRANSFER TO HEAVY CARGO LIFTS

Southern California-based forklift manufacturer **Wiggins Lift** has leveraged its expertise in the engineering of material-handling equipment to develop the first commercially available, fully electric, large-capacity fork lift: the aptly named Yard eBull. The heavy lift product line has a capacity to lift from 30,000 to 70,000 pounds. The eBull is powered by a battery and electrification system supplied by Southern California truck manufacturer XOS Trucks.

The electric model is designed to yield several advantages over its diesel counterpart, including reduced fuel costs, reduced maintenance time, and increased workplace efficiency. These enhancements in efficiency should provide a lower lifetime cost than the vehicle's diesel counterparts, despite a higher purchase price, while eliminating emissions-related health impacts for port workers.

Utilizing CARB funding, the Port of Stockton has purchased 18 Yard eBulls. The first Yard eBull units will be delivered to the Port of Stockton by August 2019, with the remainder of the order delivered by March 2020.

[15] https://www.mitsubishi-fuso.com/content/fuso/en/truck/ecanter/lp.html; https://media.daimler.com/marsMediaSite/en/instance/ko/Daimler-starts-production-of-FUSO-eCanter-in-Europe--the-worlds-first-series-all-electric-light-duty-truck.xhtml?oid=23599698

[16] https://www.thedrive.com/news/25626/daimler-delivers-first-freightliner-em2-commercial-electric-truck-to-penske

[17] https://smallbusiness.chron.com/tier-1-company-21998.html

[18] https://www.greenbiz.com/article/big-truck-makers-are-starting-take-electric-trucks-seriously

announced as coming to market. Public agencies have signaled tremendous interest in this application and funding is becoming available not just in California but across the U.S. It is important to note that the range of technology readiness is still fairly broad between those already producing and selling vehicles, such as Lion, and others who are still validating their powertrains. Manufacturers are rapidly working to scale their still low manufacturing capacity for these vehicles.

On the off-road side, one platform not tracked in previous years and added this year is battery electric ferries. There is global use of this technology, in particular in Northern Europe. First units are being ordered into North America.[19] In many cases these vessels use powertrain systems built up from on-road components. While hybrid versions are more prevalent, they share common components with the battery versions.

The technology status held steady for most applications. Class I and II electric forklifts are ubiquitous. In general, BEV ground support equipment at airports is available today as a commercially available option.

Yard hostlers (known by several names, including yard trucks, yard goats and terminal tractors) are simplified Class 8 tractors (HHD) are designed to move trailers within and between warehouse facilities, intermodal sites, port terminals, or cargo yards. They remain a category on the cusp of late pilot and early commercial market deployments with several manufacturers providing or announcing products. While some port operations remain concerned with their unique duty cycle and high utilization, that is an issue of infrastructure suitability and work rules, not technical readiness. While those are important issues for implementation, they do not change the technology readiness status of the platform.

In this year's assessment, staff separates heavy lift equipment from other cargo handling equipment and top picks. BEV cargo handling equipment such as top picks, which are used to lift or pick up containers usually at port or multi-modal facilities, are making progress but remain at the demonstration phase. However, heavy lifts are making faster progress based on a few platforms moving past pilot to early production. Part of this is based on the ability to transfer powertrain technology from on-road applications.

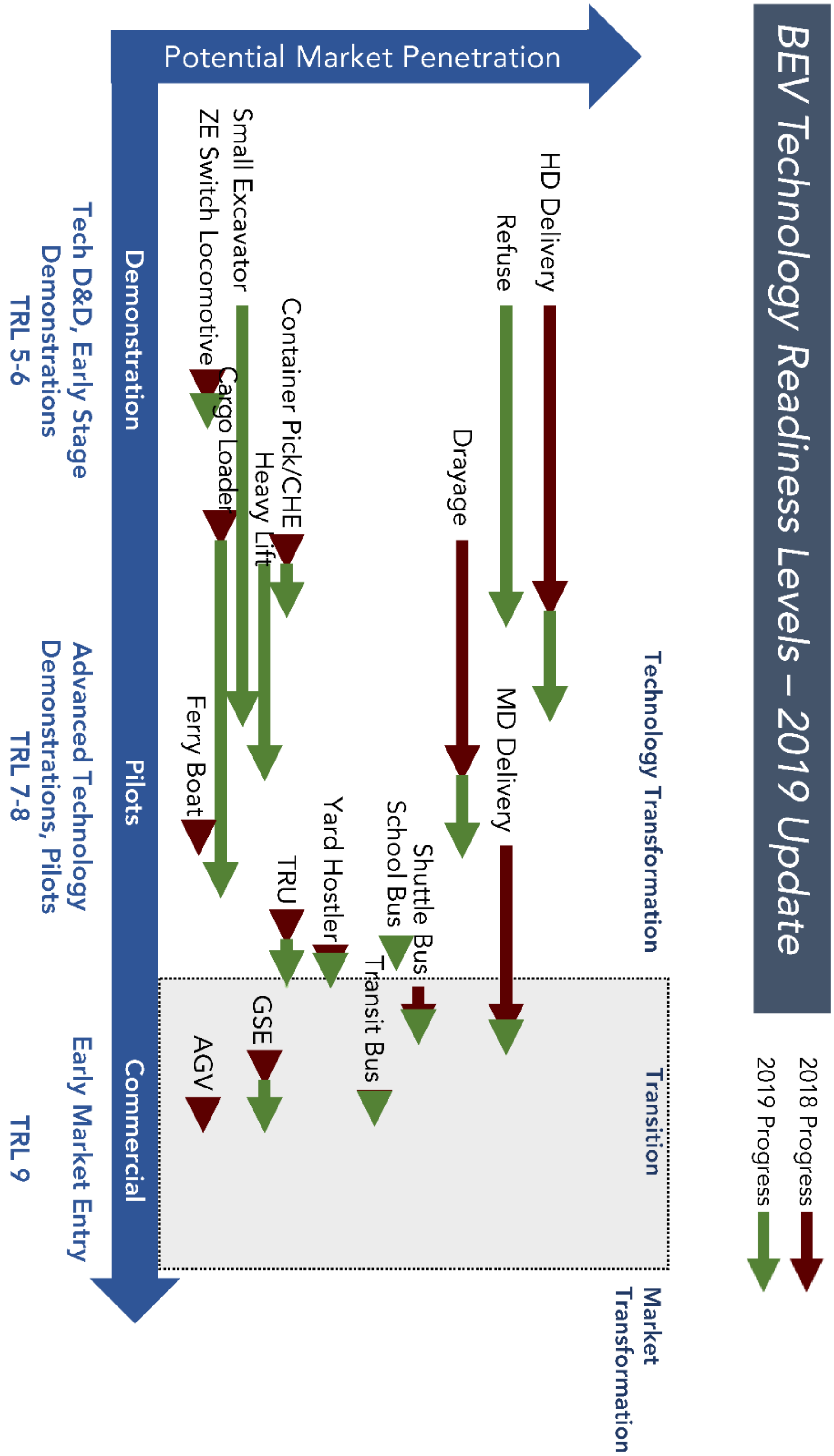
Battery electric transport refrigeration units (TRUs) are designed to function the same as units powered by small engines but they instead get their power from stored energy in batteries. Partly due to impending regulations requiring zero-emission TRU operation in California, several manufacturers are developing fully battery electric units and fielding them for pilot evaluations. Most battery electric designs have the capability to also plug in to shore power, such as at a loading dock, to operate the units as well as charge their batteries. Some TRUs now in production also have the capability of extending their daily operation by accepting power from truck

[19] https://www.goodnet.org/articles/canada-adding-two-fullyelectric-ferries-to-its-fleet

body-mounted solar panels. In addition to battery electric TRU designs, there are also other technologies emerging to allow zero-emission TRU operation without batteries. Such units instead harness the cooling power of cryogenic gases and pneumatic power generation.

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

Figure 9: Technology Status Update – Battery Electric



Key: Off-road shown in red
AGV = automated guided vehicle
GSE = ground support equipment
CHE = cargo handling equipment
TRU = transport refrigeration unit
ZE = zero emission

Source: Based on CARB technology assessments, industry research, interviews with manufacturers, project data and status and other studies and publications.

Key Barriers to BEV Adoption

As can be seen from the charts, 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. A more in-depth discussion of on-going issues impacting market transformation can be found in the next section of this document. As an overview for BEVs, these barriers include:

- Infrastructure has emerged as the current largest issue, requiring increased attention as fleets transition from a handful of vehicles to larger deployments. Based on field examples and comments made at several forums and meetings, fleets are facing several realities including: the long lead time needed to plan, site, and install chargers; the need to increase electrical capacity at their facility; space claim for vehicle charging sites; the cost of the installations themselves; lack of understanding of utility rates and demand charges; and insufficient standardization of physical interface or communication standards. The California Public Utilities Commission SB 350 rate case outcomes for the state's major investor owned utilities will allow investor owned utilities to provide significant assistance with infrastructure costs and to modify their rate structures; this assistance is just now being seen in the market in mid-2019 as the utilities scale up to respond. HVIP has developed a direct connection to utilities to ensure better lead times by connecting fleets to utilities at the time of vehicle order. Additional detail on the work to address infrastructure issues is found in the On-Going Issues Impacting Commercialization section.
- High incremental cost of the vehicles remains a barrier in the general sense, though California has enacted several effective programs to address costs in the form of the HVIP purchase vouchers, Moyer, and VW funding as well as separate funding from air districts. Assuming sufficient funding is allocated to these programs, the State has strategies to address this barrier. Fleets do face high sales taxes and registration fees based on the incremental cost of BEVs. While incremental costs are higher than conventional vehicles due to low production volume, energy storage, and electric powertrain costs, there are signs of improvement as energy storage costs are steadily reducing and MHDV manufacturers are starting to see those reductions. Beachhead markets are also starting to expand core component supplies which will help reduce costs over time.
- Limited vendor and product selection and the accompanying service and support network remains an issue but is improving. Workforce training efforts for maintenance technicians and infrastructure installation personnel could benefit from greater coordination and funding. These limitations should improve in the next few years as pilot programs complete and additional manufacturers enter production. 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.

- Potential payload impacts from the size and weight of the battery electric components are no longer as much of a concern because of legislation passed in 2018 which grants a 2,000-pound weight exemption to zero and near zero-emission commercial vehicles. However, energy storage sometimes displaces passenger or freight capacity and OEMs face increasing demand for longer ranges, necessitating additional energy storage. Weight may remain a concern until energy density improves further.
- Range or time of operations before refueling, while limited, 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 as high as 300- and up to 500-miles of reported range. However, longer-range BEVs require larger and heavier batteries, with some vehicles exceeding state axle weight limitations.
- There still exists a lack of understanding of the business case and best deployment applications. The beachhead strategy has assisted in defining where technology will provide capability and business case. 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). Early transit bus deployments are yielding payback periods as short as 3-5 years relative to conventional technologies, not including infrastructure costs.[20] Given that infrastructure is a long-term investment not tied to any specific vehicle model, this can be a reasonable approach. In California, there is significant funding coming available for infrastructure costs. However, even with infrastructure included, CARB staff has calculated a favorable TCO over conventional technologies, when incentives and Low Carbon Fuel Standard (LCFS) credits are factored in.[21]

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 delivery and service vehicles, shuttle buses and school buses. Heavier vehicle applications such as drayage and regional delivery trucks are now in pilot stage and refuse is entering demonstration phase with several manufacturers. In the off-road sectors BEV technology is in the commercial stage for industrial lifts and GSE. Port equipment is in the late pilot to early commercial stage for yard hostlers/terminal tractors and 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. TRUs are in pilot to early commercial stages. In the marine sector, electrification of ferry boats and other harbor

[20] https://ww3.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf

[21] https://ww3.arb.ca.gov/msprog/ict/meeting/mt170626/170626_wg_pres.pdf

craft are proving themselves in European and U.S. demonstrations and can use technology transferrable from on-road. All these applications are important areas for investment funding to advance.

Technology Status Snap-Shot UPDATE: Fuel Cell Electric Vehicles

Fuel cell electric vehicle (FCEV) technology has seen a solid and growing re-emergence at the late demonstration/early pilot phase for heavy-trucks and continues to expand in forklifts as a successful early commercial product. Demonstration activity in heavier lift and cargo handling equipment continues. Figure 10 provides an overview of the technology status of FCEVs.

There are expanding opportunities to leverage fuel cell systems from one application and use it in others. The fuel cell systems from industrial lift-scale devices (hydrogen fuel cell forklifts are commercially available in Class I, II, and III lift capacities) are under consideration as range extender power plants for on-road vehicles. As an existing product, they can tap an established supply chain and existing early production volumes. Similarly, fuel cell power plants developed for the passenger car market are expanding into heavy-duty demonstrations serving as full propulsion units in on-road drayage truck applications, with the expanded Toyota and Kenworth demonstrations as the prime example.

In the on-road market, fuel cell transit buses continue to make progress and are in the late pilot to early commercial stage. There are now several fully certified commercial FCEV bus products offered in North America, and the first fuel cell buses received HVIP purchase vouchers this past year. This segment, just on the

TECH EXAMPLE
COMMON POWERTRAINS LINK BATTERY AND FUEL CELL ELECTRIC VEHICLES

Nikola Motors is accelerating the commercialization of both pure battery electric and fuel cell electric powertrains to deploy two options for zero-emission trucks. Nikola's trucks share an electric drivetrain and differ only in whether the power comes exclusively from a battery or predominantly from the hydrogen fuel cell, coupled with the battery as a hybrid. The hydrogen-powered trucks are more suited for long-range and/or quick turn operations, as they are lighter than their battery electric counterparts for comparable range and faster to refuel. The battery electric versions are highly efficient and ideal for urban and last-mile delivery duty cycles. The battery electric trucks will be offered with various battery size configurations. The Nikola Two day cab and Tre cab-over are expected to be commercially available starting in late 2022.

TECH EXAMPLE

CENTRALIZED HYDROGEN FUEL PRODUCTION, FUELING POTENTIAL

The world's first 100 percent renewable power plant with an integrated hydrogen fueling station is expected to begin service in 2020 at the Port of Long Beach.

Toyota's Tri-Gen facility is a mega-watt sized carbonate fuel cell power generator that produces outputs in the form of heat, electricity, and hydrogen, using renewable methane from agricultural waste as its feedstock. The chemical converter will produce 2.3 megawatts of electricity and up to an estimated 1.2 tons of hydrogen per day, which could meet the needs of up to 1,500 zero-emission vehicles.

The project provides onsite clean electricity for port operations and produces clean hydrogen fuel available for port servicing vehicles and equipment.

Demonstrating this capability, Toyota and **Kenworth** will use a separate CARB grant to build 10 hydrogen fuel cell electric-powered Class 8 drayage trucks in a parallel project, which will then fuel at the facility.

The project serves as an industry-leading example of two critical advancements: the potential of strategically located large-scale fuel production and infrastructure sites to serve multiple stakeholders and applications; and the potential for state and regional agencies to cooperate and pool funding to speed effective deployments.

This multi-stakeholder project yields potential for future funding collaborations between other government agencies with aligned climate, air quality, and energy goals.

cusp of commercialization, would still benefit from a focused pilot to help with hydrogen infrastructure scaling and to further increase fuel cell component volumes.

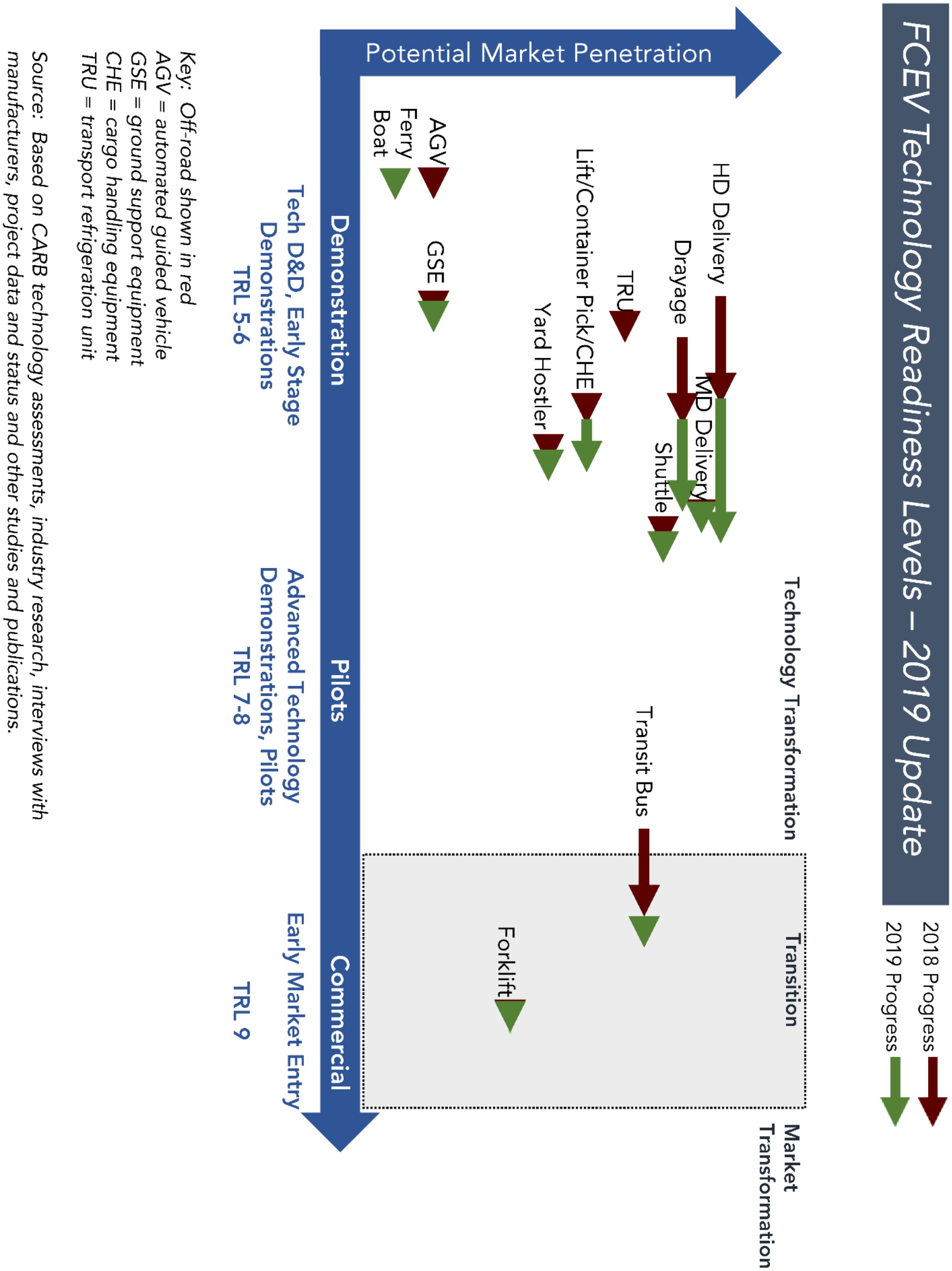
One of the reasons behind a growing interest in fuel cell electrification is the potential for providing sufficient energy for long range, heavy weight duty cycles, or those work cycles requiring continuous operation or multiple-shift operation where recharging may not be an option. Such operations can make use of centralized, high throughput fueling stations which 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.

There is also an emerging clearer sense of the highly complementary nature of battery electric and fuel cell electric platforms and their uses. Both can make use of the same core powertrain components (electric motors, power electronics, and energy storage) and jointly benefit from increased supply chain volumes. While battery electric capacity is increasing and therefore greater range is becoming increasingly possible, with Tesla signaling ranges to 500 miles[22], there may be a cross-over point where the fuel cell becomes the preferred option for weight and refueling considerations. Indeed, Nikola Motor Company this year unveiled both battery electric and fuel cell electric versions of their trucks, with the battery electric versions aimed more at urban and regional applications, and the fuel cell version aimed at long haul applications. While 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.

The development of other fuel cell electric trucks, specialty equipment, and shuttle buses is underway at the demonstration phase. Multiple medium- and heavy-duty demonstration projects are underway in the United States. It is worth noting the potential also for fuel cell use in other off-road applications including heavy cargo handling equipment and the marine sector. CARB is funding a demonstration of a fuel cell electric top pick from Hyster at the Port of Long Beach. In San Francisco Bay, a promising demonstration of a fuel cell powered ferry boat could lead to other applications such as harbor support and work vessels. Such applications could make use of centralized fuel production and fueling infrastructure, such as at port sites.

[22] https://www.cnbc.com/2017/11/16/tesla-semi-truck-has-a-500-mile-range-ceo-elon-musk-reveals.html

Figure 10: Technology Status Update – Fuel Cell Electric



Key Barriers to FCEV Adoption

As can be seen from the charts, only a couple of 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. A more in-depth discussion of on-going issues impacting market transformation can be found in the next section of this document. As an overview for FCEVs, these barriers include:

- Final cost of hydrogen delivered to the pump: Hydrogen prices are very high relative to current diesel prices. This remains one of the core issues 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 Low Carbon Fuel Standard (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 facility at locations of high fuel throughput, connected by corridors to similar sites, is emerging as one potential option. Such sites could also provide local hydrogen fuel to close-by 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 rarely support medium- and heavy-duty vehicle access.
- High incremental cost of the vehicles due to fuel cell stack, balance of plant, and hydrogen tank costs: Costs are slowly dropping with improved engineering and product integration though not quite as fast as battery electric costs are dropping. California has enacted several effective programs to address costs in the form of the HVIP 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: Recent fuel cell transit bus performance data shows that fuel cell vehicles can attain long service lives that match service intervals of a standard diesel-powered transit bus.[23]
- 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 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

[23] https://ww2.arb.ca.gov/news/ac-transits-fuel-cell-program-breaks-25000-hour-operating-record

grow outside a solid base in forklifts, a growing suite of transit bus providers and an emerging list of potential truck manufacturers. In trucks, production is envisioned to be 2022 or later.

FCEV Opportunities over the Next Three Years

In on-road applications, FCEV technology is still straddling pilot and early commercial stages for transit buses and could benefit from additional pilot stage funding, particularly to assist with building out and understanding facility infrastructure and on-site fuel production. Fuel cell heavy-duty trucks are in the early to mid-pilot stage of commercialization and show growing capabilities. This remains an important investment opportunity for state funds. Similarly, 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 cost remains a prime barrier to scaling and investments in technologies and processes for large scale on-site production and fueling facilities should be a focus of regional, state, and federal fuels funding. CARB fuel cell vehicle funding has been used to leverage other agency funding of 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 MHD fuel cell vehicle applications to use it.

Technology Status Snap-Shot UPDATE: Hybrid Electric Vehicles

Hybrid electric systems share many sub-components with battery electric and fuel cell electric systems, so improvements in the core technologies generally benefit all variants. Over the past year there has been a noticeable expansion of capabilities in hybrid buses, which remain a strong and fully commercial segment of the transit bus market. Particularly in series-hybrid systems, manufacturers have added increased energy storage and the capacity to operate in extended zero-emission mode, activated via geo-fencing to protect sensitive areas or populations. These augmented systems build on the fully commercial bus design but are currently at lower volume and would be considered late pilot or early commercial stage. Additionally, all auxiliary systems (such as air conditioning, heating, steering) are being electrified to enable zero-emission operations. This variant allows buses to meet all extended range or hours of operation needs a transit operation might have while still providing meaningful emission reductions. Development and deployment of electrified auxiliary systems for hybrids is helping to increase volumes and reduce costs for the systems, which are also used by fully-electric vehicles. A California electric powertrain company, EDI, was also acquired this past year by engine manufacturer Cummins as part of its strategy to bring BEV and hybrid electric vehicle (HEV) technologies to market in heavy weight class applications including delivery trucks (MHD), transit buses (HHD) and regional heavy haul trucks (HHD). Figure 11 depicts the progress of the hybrid electric vehicles along the commercialization path.

Hybrid systems are also available commercially from one major truck maker and several qualified vehicle modifiers, sometimes referred to as up-fitters, in medium-duty delivery and service applications (MHD). These systems are in low volume but would be considered just beyond early commercial.

Hybrid systems are already in production that provide work power and engine idle reduction at work sites (electric power take-off). These systems potentially could also be used to power TRUs as well as provide ambulance and first responder power, which could be a focus of demonstration funding to extend the value of those commercial systems.

Start-stop hybrid systems that allow an engine to turn off at stop lights, traffic delays or during idle operation are becoming increasingly available in medium-duty vehicles; they are becoming very prevalent in pick-up and sport utility platforms. Start-stop systems are offered in transit, yard hostler/terminal tractors and refuse trucks (HHD) and some medium duty truck applications (MHD). The importance of this development is both in the immediate fuel and maintenance savings and in building out a high-volume supply chain for components. Additionally, the proliferation of electrified accessories familiarizes service technicians with systems they will also encounter on fully-electrified vehicles.

TECH EXAMPLE

TRANSIT BUS POWERTRAINS ADAPTABLE TO MARINE PLATFORMS

BAE Systems is one of the world's largest technology companies that serves multiple industries. BAE is currently utilizing its multi-industry expertise to expand the application of electric bus powertrains. The company has adapted and transferred its bus powertrains to light rail, trucking, and marine applications.

As an example, BAE Systems powertrains from 60-foot articulated transit buses are being used as the power and propulsion system for an electric-hybrid passenger vessel now in regular service in the San Francisco Bay. Red and White Fleet's Enhydra electric hybrid passenger vessel operates with less noise and emissions, and operates at a higher efficiency, than its sister ships with conventional propulsion.

Enhydra serves as one example of how this hybrid system can be used in multiple applications, greatly leveraging the initial engineering designs and expanding the applications that together can increase supply chain volumes.

This same system can function either as the lone power source or as the HybriGen Assist system that provides electric power to larger vessels.

BAE Systems has leveraged its market influence and the flexibility of its electric propulsion systems to expand into additional markets and provide more emissions- and fuel-reduction propulsion solutions.

HEV drayage and heavy regional delivery truck applications (HHD), including plug-in hybrid electric (PHEV) and extended range series-electric designs, are in the demonstration or early pilot stage. The rapid emergence of BEV technology and stringent emission certification testing has slowed some HEV development, though HEV architectures are the backbone of FCEVs.

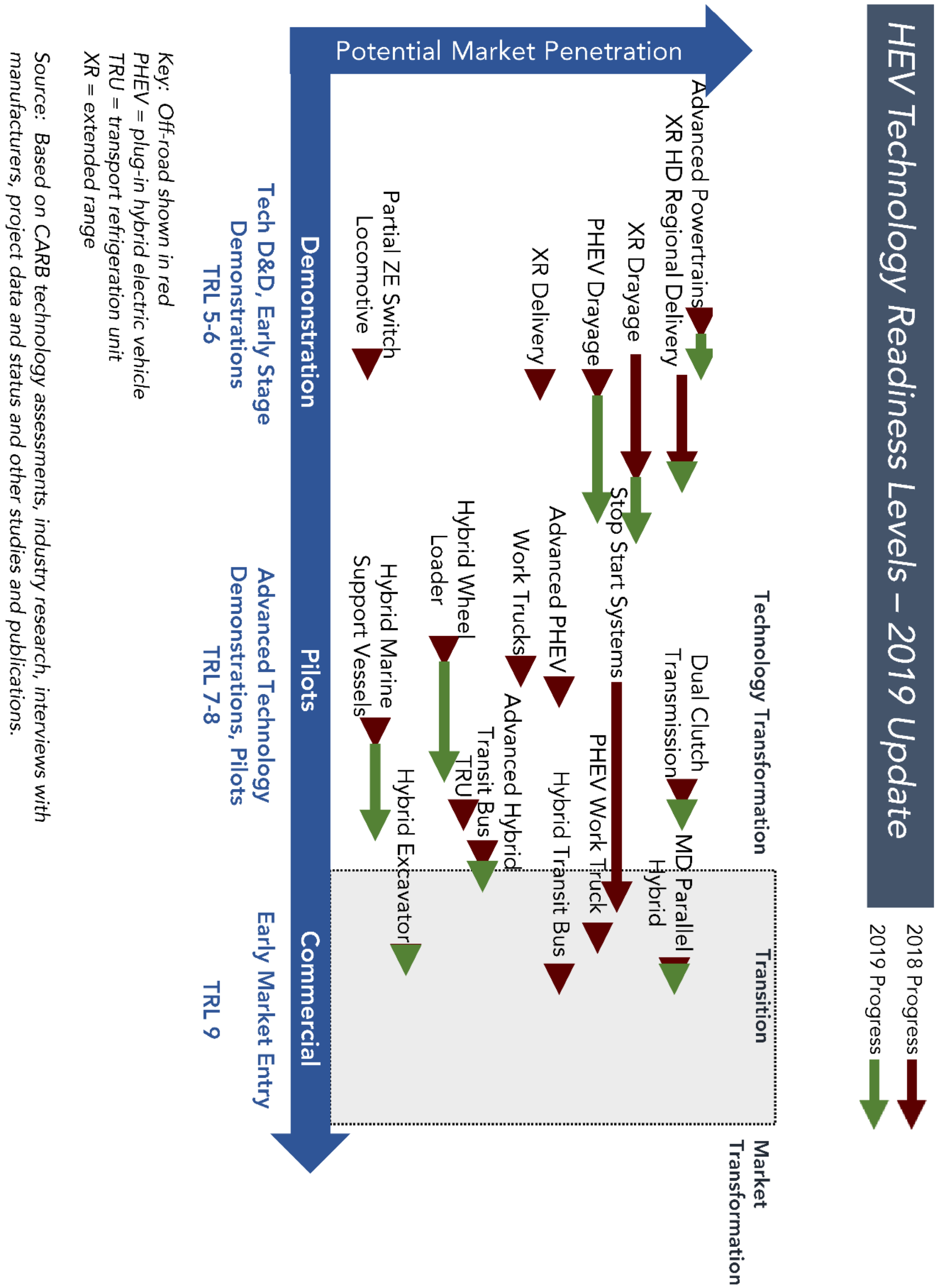
The off-road segment is increasingly promising for the use of HEV technology as these applications often require high power demands, long operational capability, and are remote from electric or hydrogen refueling options. Additional factors such as the cheaper cost of HEV technology and the chassis packaging requirements for many off-road applications play a role in making hybridization a desirable option. HEV technology has the potential to meet the needs of these rigorous off-road applications and many stakeholders, including manufacturers and end-users, have expressed interest in developing and utilizing this technology.

In terms of specific platforms, hybrid excavators range from the pilot stage to early commercial stage. Hybrid wheel loaders are in the demonstration or advanced demonstration stage moving to pilot. Both products are commonly used for construction purposes. Wheel loaders also have goods movement/freight uses. Both wheel loaders and excavators, as well as other hybrid construction and agricultural equipment, are freight-enabling applications because of the common supply chain for components. Hybrid cargo handling equipment has been developed, mostly in Europe, and some is entering the very early market.

Marine vessels, particularly harbor craft but not only limited to that segment, is a rapidly emerging sector for hybridization. Several 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 use in Europe and in demonstration and pilot stages in the U.S. These vessels have been developed using components in some case taken directly from transit hybrid systems and are excellent examples of the potential for direct technology transfer. The systems can provide direct propulsion power, 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. CARB is currently funding a hybrid tug boat as part of the ZANZEFF program.

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.

Figure 11: Technology Status Update – Hybrid Electric



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. A more in-depth discussion of on-going issues impacting market transformation can be found in the next section of this document. As an overview for HEVs, these barriers include:

- The incremental cost of the vehicles: While it has been dropping steadily the last few years, cost is still higher because of energy storage and control system integration. 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 fuel price increases may help hybrids.
- 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 result in missing incentive funding opportunities. Complications are greater for marine applications, which face challenging EPA and Coast Guard certification processes.
- OBD integration, and the optimization of hybrid operations with emissions control systems creates additional costs passed on to the customer.
- Limited vendor and product selection reduces options.
- Infrastructure is a barrier for plug-in hybrids but not conventional designs.

HEV Opportunities over the Next Three Years

As electrification moves into heavier weight classes, more demanding duty cycles, and longer periods of operations, hybrid technologies remain an extremely relevant solution. This is particularly true of 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 not either available or convenient. These applications can benefit from demonstration and pilot funding as well as purchase incentive funding where they are 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 stands to expand capabilities for goods movement.

Extended range architectures for medium- and heavy-duty transit and delivery applications could also benefit from demonstration and pilot focus to ensure options are developed to cover needs across the entire market. Hybrid harbor craft represent a technology already in use in Europe that could have much wider application in the U.S. and pilot and incentive funding could assist. The ability to power TRUs and provide work site engine-off operation, as well as some drive cycle engine-off operations, needs expansion as these systems can bring NOx reduction benefits as well.

<u>Technology Status Snap-Shot UPDATE: Low NOx</u>

Now fully developed, the natural gas low NOx (certified to 0.02 g/bhp-hr NOx) Cummins Westport 11.9-liter engine is now in mass production and beyond the early commercial stage. The low NOx version has effectively replaced the version certified to the less stringent U.S. EPA 2010 standards. Importantly, it is available as a factory-installed option from all truck makers. This engine brings low NOx technology to drayage, regional delivery, and many long-haul applications (HHD) where natural gas fuel is available.

As has been noted, several other gaseous fuel engines (natural gas and propane) certified to one of the optional low NOx levels are also in full commercial production for transit buses (HHD), medium-duty on-road trucks, and school buses (MHD). These include 6.8- and 8-liter propane, and 8.9-liter and 6.7-liter natural gas engines. This technology is a success story as its status has moved through the stages of the commercialization process tracked here. Figure 12 depicts the progress made by Low NOx engines over the past two years. The natural gas 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.

In Europe, 13-liter natural gas engines employing compression ignition technology are available but are not currently being built for the U.S. market and do not meet any of the low NOx standards.

U.S. EPA has launched its Cleaner Trucks Initiative with a stated goal of updating the federal NOx emission standards to further reduce NOx emissions from heavy-duty engines. This initiative, complementary to California's proposed rulemaking to mandate (a to-be-determined) 0.0x g/bhp-hr by 2023 is putting additional pressure on diesel engine makers to look at strategies for reducing NOx. The Manufacturers of Emission Controls Association has published a report that finds that engine makers can achieve ultra-low NOx emissions while still meeting 2027 greenhouse gas regulations. One company working to exceed this in timing and capability is Achates Power, whose high-efficiency, low NOx engine is in development and heading for demonstration, with help from CARB funds. Both 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 greenhouse gas standards today.

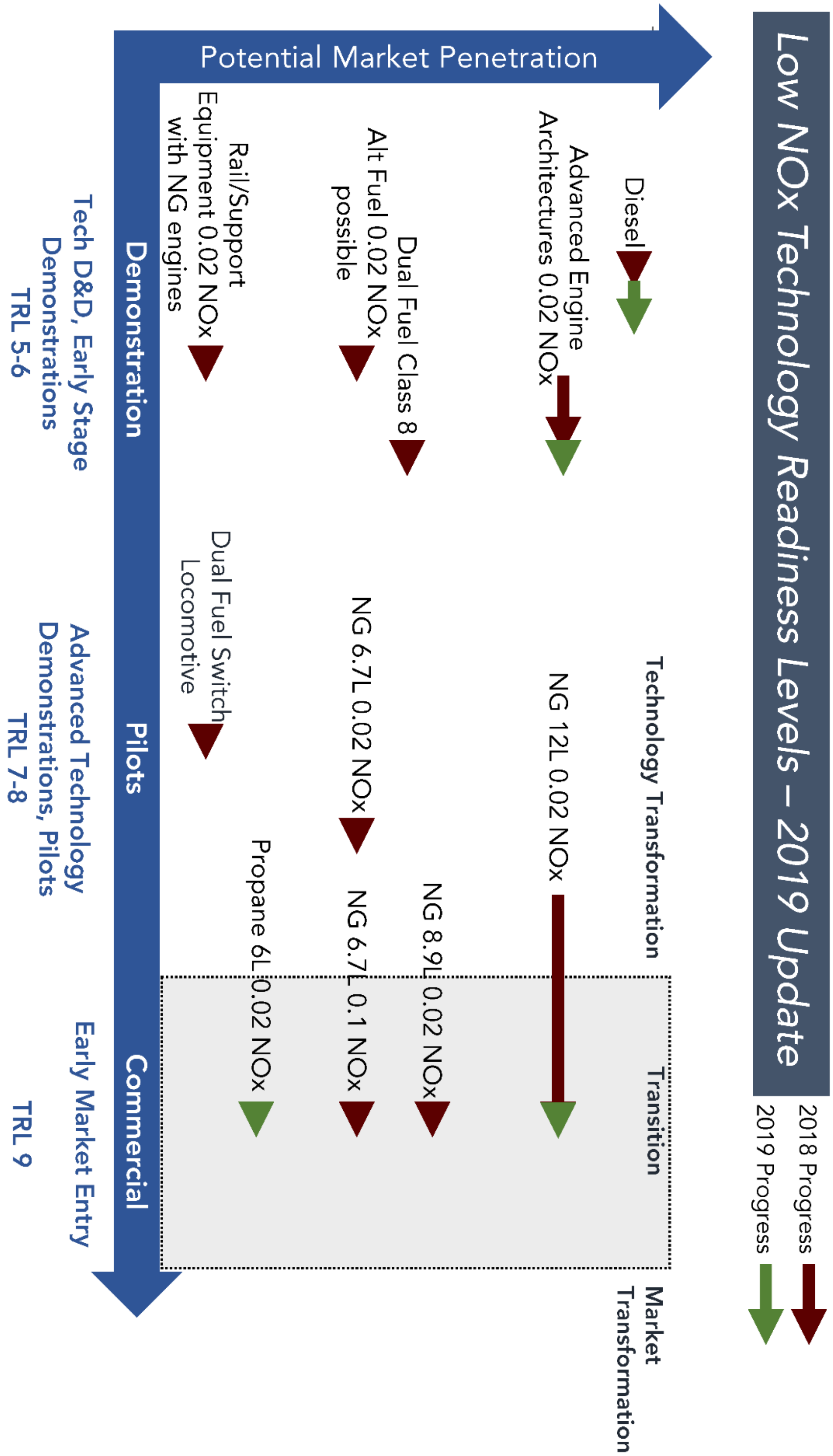
Continued funding is indicated to support this emerging solution and move the technology toward widespread commercialization. Larger displacement engines for switch locomotives and some marine vessels may also show the potential to exceed Tier 4 emissions.

Expanding low NOx engine deployment into diesel-fueled vehicles and the heaviest on-road engine weight classes is important for technology transfer to off-road equipment. New low NOx engine 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 after treatment 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 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 in meeting State climate and air quality goals.

Figure 12: Technology Status Update – Low NOx



Key: Off-road shown in red
Alt fuel = a recognized alternative, low carbon fuel other than NG
Dual fuel = engine capable of operating on diesel and NG/alt fuel
L = liter
NG = natural gas engine, either compressed or liquefied

Source: Based on CARB technology assessments, industry research, interviews with manufacturers, project data and status and other studies and publications.

Barriers to Low NOx Adoption

As can be seen from the charts, several Low NOx platforms have moved into the transition period between technology and market transformation. 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. A more in-depth discussion of on-going issues impacting market transformation can be found in the next section of this document. As an overview for low NOx engines, these barriers include:

- Incremental cost: While moving past the early commercial stage and into higher volume production, low NOx natural gas engines and trucks still carry an incremental cost compared to diesel, largely due to fuel tanks. Low NOx 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 were 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 assist 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. If renewable fuels are used, the Low Carbon Fuel Standard credits could provide a significant price differential.
- 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.

Low NOx 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, low NOx 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 proceedings, conventional diesel engines may 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 low NOx emissions while also increasing efficiency remain a valuable investment. Achieving low 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. Low NOx 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.

Technology Status Snap-Shot UPDATE: Efficiencies

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. Figure 13 illustrates 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 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. Beyond platooning of trucks – the ability of two or more trucks using sensor and control technologies to follow closely to save fuel from better aerodynamics – full automation of vehicles is in validation in several categories, both on and off-road. Of great interest are those technologies allowing much more efficient work sites, therefore reducing energy use and carbon emissions. Volvo Construction Equipment has completed a quarry demonstration in Sweden that showed impressive net fuel and emission reductions per unit of work using automated and electrified work machines.[24] 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.

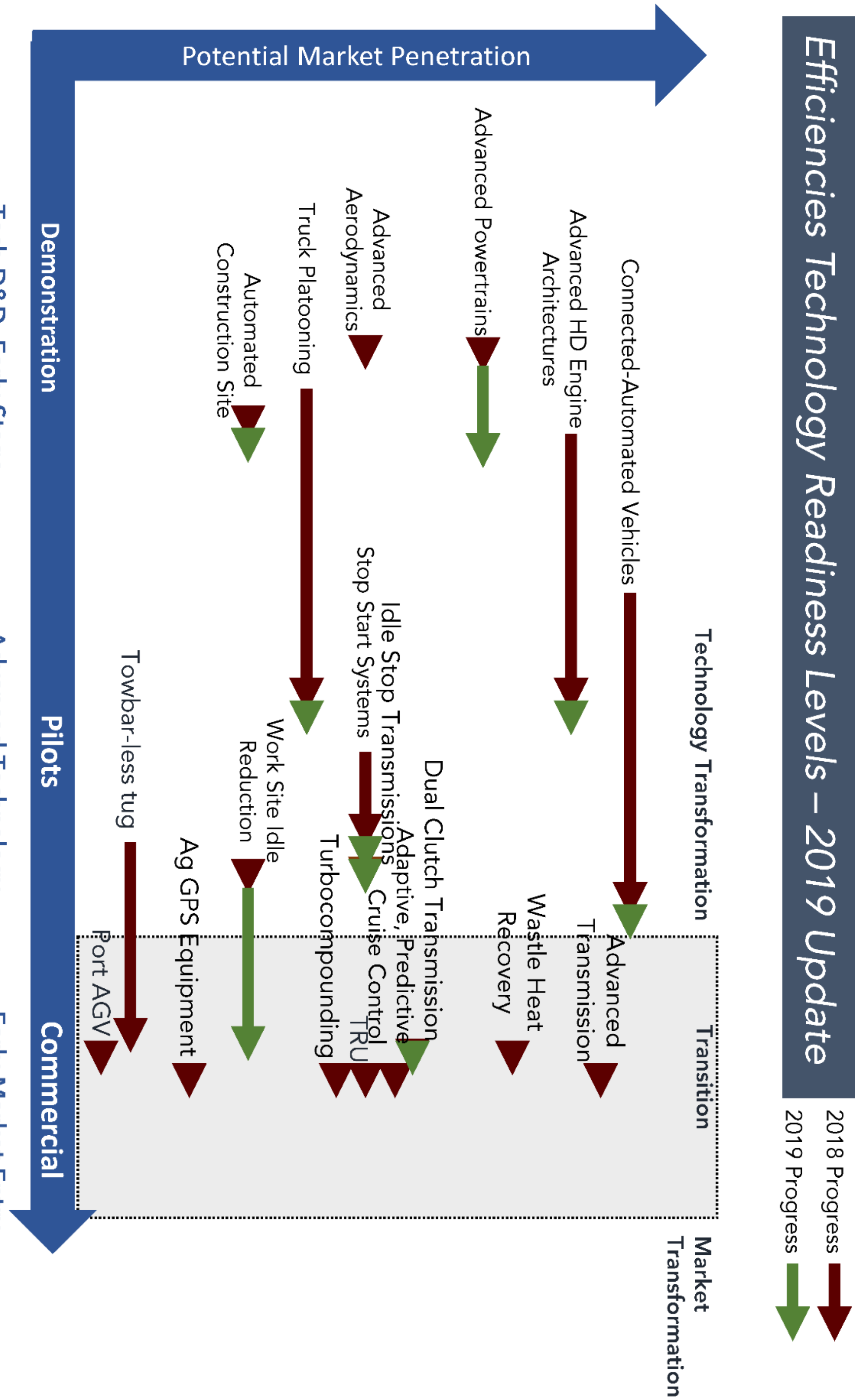
[24] https://www.equipmentworld.com/volvo-electric-site-quarry-test-reduced-emissions-by-95/

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 low NOx, near zero, and zero-emission powertrains can extend the effectiveness of these systems and should be encouraged.

Figure 13: Technology Status Update – Efficiencies



Key: Off-road shown in red
AGV = automated ground vehicle
GPS = geo-positioning satellite
TRU = transport refrigeration unit

Source: Based on CARB technology assessments, industry research, interviews with manufacturers, project data and status and other studies and publications.

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. A more in-depth discussion of on-going issues impacting market transformation can be found in the next section of this document. As an overview for efficiency technologies, these barriers include:

- 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 so are freight-enabling applications because of the similar components and supply chains involved.

Despite DOE and other investments, a technology gap remains for advanced engine development that California funding could help address because of its potential to leap-frog current designs in efficiency. Worksite 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.

Other Emerging Technologies

There are additional applications that represent opportunities, including locomotives and ocean-going vessels, which could entail reducing the operations of auxiliary or secondary engine systems on vessels. Early demonstration projects utilizing zero-emission or near zero-emission 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.

On-Going Issues Impacting Market Transformation

Along the entire path of technology commercialization, the transition from technology transformation — which is the primary focus of Low Carbon Transportation funds — to market transformation, involves many implementation variables which can slow progress. Therefore, in addition to assessing technology status progress and success in growing beachhead pathways, staff have also compiled observations on a number of on-going issues that are or can impact successful commercialization. Many of these issues have been raised in stakeholder and industry discussions in work group sessions and privately.

MAKING PROGRESS
INFRASTRUCTURE FUNDING ALIGNMENT

In 2018, a landmark decision from the CPUC authorized California's three large investor-owned utilities to invest over $600 million in heavy-duty and off-road electrification. Beginning in 2018, Pacific Gas & Electric (PG&E) and Southern California Edison (SCE) began building their first-come, first-served make-ready infrastructure programs with expected program launches in the fall of 2019. Seeing a clear overlap in goals with CARB's first-come, first-served voucher incentive program, HVIP, CARB and HVIP administrator, CALSTART, began working toward integrating the vehicle and infrastructure programs. Starting first with an exploratory pilot with PG&E, CALSTART and CARB are making modifications to the HVIP application process that allow HVIP to automatically notify the utility when a fleet makes a plug-in vehicle order. Infrastructure buildout timelines are proving a growing barrier and utilities have reported receiving late notification of planned ZEV deployments that have caused increased delays in vehicle deployment. It's hoped that this automated back-end connection between HVIP and utilities will expedite projects and ease resource demands on fleets and utilities.

Implementation Workgroup

As CARB uses its Low Carbon Transportation investments to move advanced vehicle technologies forward, CARB learns about the various barriers that delay both technology advancement and economy-wide adoption. Through demonstration and pilot projects, staff gather large amounts of useful data about the operational requirements of equipment, where technologies are best suited, and where additional work is needed. However, staff recognizes that a large share of barriers are experienced — not in the handful of demonstration projects CARB funds — but by fleets around the State that will be the final adopters of advanced technology vehicles, many of whom are already deploying zero-emission and low NOx vehicles through early commercial incentive projects like HVIP.

Stakeholders brought this to the attention of the Board at the hearing to consider the FY 2018-19 Funding Plan in October 2018. Citing mounting concerns from fleets adopting advanced technology vehicles, the Board directed staff to hold a workgroup tasked with soliciting input from stakeholders on the barriers they are observing or predict as well as discuss potential options for how CARB can assist in the relief of those barriers.

Held on December 11, 2018, the Heavy-Duty Advanced Technology Barriers and Incentives Workgroup included: a morning plenary session to discuss common themes; breakout sessions to separately take a deeper dive into low NOx and zero-emission vehicle adoption barriers and solutions; and then an afternoon plenary session where the outcomes of the breakout sessions were discussed and solutions brainstormed. The eight hours of stakeholder collaboration were successful in uncovering barriers and providing an opportunity to propose novel solutions in the broader context of common barriers to advanced technologies.

Throughout the discussions, participants noted that as much as policies and incentives are tailored to technology type, they should also be sensitive to fleet size. The workgroup concluded that a large fleet is generally one with 10 or more vehicles while a small fleet would be a fleet with fewer than 10. Where small and large fleets are specified in the discussion below, they were in the context of this decision.

Purchase Cost

Perhaps the most well-recognized barrier to the deployment of advanced technology vehicles is their higher cost compared to their conventional counterparts. For novel, more complicated, or lower volume vehicles, the incremental cost can be even more exaggerated. The workgroup pointed out that the cost to purchase and deploy an advanced technology vehicle is greater than just the incremental cost. Fleets pay increased sales tax on a more expensive vehicle and face other costs associated with new technologies, such as training and adapting to new maintenance procedures.

The workgroup's observations and suggestions included:

- Ensure that incentives addressing incremental cost are appropriate, which could be accomplished by conducting an evaluation of vehicle and component costs to add granularity to voucher amounts.
- A leasing program that allows fleets to use advanced technology as an operational expense with little upfront capital would reduce or eliminate this barrier. Leasing companies already have access to HVIP but a pilot project could be impactful.
- Reducing the incremental tax burden for advanced technology trucks and buses warrants attention from the State.
- With the goal of commercializing technologies that eventually do not need incentives, and considering the limited resources available to Low Carbon Transportation projects, CARB could consider setting cost reduction targets for OEMs and reducing voucher amounts appropriately.

Infrastructure

Participants noted the high costs of infrastructure as an important barrier — particularly for zero-emission technologies — and the cost of hydrogen and electricity.

Fleets face uncertainty on charging connection standards, which complicates deployment timing and future fleet expansion. Scaling infrastructure raises more problems with available space and the extensive subterranean work required. Once infrastructure is in, fleets in many parts of the state have uncertain electricity costs and fuel cell fleets are forced to absorb very high hydrogen costs. Information on infrastructure costs and updates on CARB's efforts to expand understanding and mitigate barriers for electric and hydrogen fueling infrastructure are further described on page 67.

The workgroup's observations and suggestions included:

- Early infrastructure planning is a straightforward way of reducing costs, preventing delays, and getting ahead of surprises before they derail a project. Staff is already working on ways to interconnect HVIP with utilities to ensure fleets are seeking infrastructure information as early as possible. Other non-monetary opportunities may exist to incentivize program participants to plan early.
- Participants noted the importance of coordination between CARB, the CPUC, and CEC. CARB has been actively engaged with the CPUC and all of the state's largest utilities for several years. Despite the work that CARB and the CPUC have done to reduce the burden of infrastructure costs and develop better electricity rates for the use of electricity as a fuel, energy costs continue to be a concern. Beyond CARB's collaborations, the group would like to see voucher programs provide additional funding for other solutions to electricity costs: specifically energy storage. Energy storage has been an allowable cost in HVIP's infrastructure funding, but staff are proposing to no longer fund infrastructure through HVIP.
- Hydrogen fueling faces numerous cost barriers, including the cost of building a hydrogen fueling station and the currently elevated cost of hydrogen. Data suggests however that at-scale production could dramatically lower the cost of the fuel. Stakeholders suggested projects that would emphasize scale production.
- Some would like to see greater flexibility for infrastructure voucher enhancements. Public fleets suggested that the ability to get funding through voucher programs for joint projects with shared or public infrastructure would reduce overall costs. This consortium option could apply to shared infrastructure and/or vehicles. Allowing fuel system providers to access infrastructure incentives facilitates participation by fleets that do not currently manage their fueling. Stakeholders emphasized that projects similar to the Zero and Near-Zero Emission Freight Facilities project are very helpful in achieving cost-effective deployments. Incentives could be higher for projects that include extra capacity or provide public access.

Information Gap

CARB has been effective in engaging a variety of fleets for participation in incentive projects. However, these early adopters represent a small segment of the whole transportation sector that needs to transition to clean vehicles. CARB, as well as vehicle manufacturers, dealerships, and other stakeholders should continue outreach to educate new fleets on best practices for deploying advanced technology vehicles and make them aware of available incentives.

The workgroup's observations and suggestions included:

- The leading suggestion was that CARB should lead or work with other entities to develop a centralized funding clearinghouse that makes it easier for prospective fleets to learn about advanced technology vehicles, benefits, costs and considerations, available funding programs, and guide them through the application. Participants also suggested that workshops geared toward fleet managers would be helpful.
- In conducting outreach, classic marketing strategies like customer testimonials could instill confidence while a heavy focus on the business case for fuel switching would be effective. To that point, the workgroup suggested a total cost of ownership model that would highlight cost savings, such as not maintaining diesel particulate filters. Providing guidance on how to access incentives or navigate the advanced technology space would be valuable. The HVIP website was suggested as a possible platform for the information and tools.

Service and Support

Beyond deploying vehicles and infrastructure, fleets are tasked with maintaining their vehicles. Advanced technology vehicles present a steep learning curve and fleet managers are finding a dearth of qualified technicians.

The workgroup's observations and suggestions included:

- Stakeholders suggested CARB work with other governmental entities that develop curriculum or fund workforce training programs. Given that some transit agencies have already developed training programs or centers of excellence for battery and fuel cell electric buses, it would be prudent to leverage these in working with community colleges.

Secondary Market

In the trucking space, many companies count on a secondary market to recuperate value from the vehicle. A large portion of the industry counts on these cheaper vehicles for their operations. Fortifying a secondary market lends confidence to new vehicle purchasers and can create new users in the secondary space.

The workgroup's observations and suggestions included:

- Secondary markets are not yet developed for zero-emission trucks, and very early for low NOx trucks. Stakeholders would like some way for residual value to be guaranteed.

- Putting used vehicles in rental fleets serves two purposes: finding a market for used vehicles while also enabling low-risk experience for other operators interested in leasing rather than owning.

Stable Funding and Support

To create the momentum needed to transform the heavy-duty sector, fleets and manufacturers need confidence in the direction and support of government.

The workgroup's observations and suggestions included:

- By far the most important thing, stakeholders said, is that fleets have an assurance that the funding programs they depend on to afford advanced technology vehicles will remain available. Stakeholders noted that the legislature would need to support a multi-year guaranteed appropriation.
- Stakeholders also noted that it would be encouraging if the state had a uniform and defined pathway for heavy-duty transformation coordinated centrally by a State clean transportation "czar."

Reliability and Consumer Confidence

Having some overlap with previous categories, many of which mention consumer confidence as an outcome, addressing reliability and making users more comfortable with new technology is critical to breaking into new market segments that are generally more hesitant.

The workgroup's observations and suggestions included:

- Continuing pilots to deploy larger numbers of advanced technology vehicles is key, stakeholders said. Pilot projects allow fleets low-risk hands-on experience while being able to feed information back to the manufacturer to make an even better next-generation product.
- As mentioned previously, full-service leasing removes most of the risk and gives customers assurance of maintenance and resolution of any problems. An added benefit is there's no need to hire dedicated service technicians.
- The workgroup highlighted that, particularly for battery electric vehicles, electricity reliability is a concern. The workgroup would like to see greater support of resiliency and redundancy tools such as energy storage.

Other Strategies

Understanding that financial resources are limited, the State must look for non-monetary strategies to encourage the development and deployment of advanced technology heavy-duty vehicles. Many of these are beyond the scope of Low Carbon Transportation but are worth mentioning. Green zoning programs like those in London, New York, and other large cities have proven effective. Dedicated clean truck lanes at port entrances could provide a significant economic incentive for truckers. Finally, OEMs can play a role to improve the user experience, such as by providing software that gives more operating feedback for drivers and fleet owners.

Fueling Infrastructure

CARB demonstration and pilot incentives reduce the purchase price of vehicles and often do allow for infrastructure costs, but fleets purchasing vehicles that use emerging alternative fuels (e.g. electricity, hydrogen) face a number of barriers — as outlined in the discussion above — with limited options for funding. Further, the impacts of charging increasing numbers of heavy-duty vehicles to the electrical grid need to be considered. In the early years of deployment, assistance with infrastructure costs will be crucial.

The HVIP program began issuing voucher enhancements in 2018 on an ad-hoc basis to provide additional incentive funding to support electric and hydrogen fueling. These enhancements provide critical aid but are only designed to cover the cost of physical infrastructure and do not assist with the costs to upgrade utility service, install equipment, or make site improvements. HVIP faces extreme demand for vehicle vouchers with a limited budget, leading to a waitlist in the summer of 2019. Responding to demand and in recognition of HVIP's mission as a streamlined vehicle incentive program, HVIP has proposed to eliminate the infrastructure voucher enhancement. Other funding is needed to supplement this project change.

California's major utilities are becoming more active in funding infrastructure, with many programs launching this year. However, it is important to note that these programs are only available in the territories of the utilities providing each program and the programs are currently authorized for five years pending further direction from the CPUC.

Until more funding sources for infrastructure are identified, it will be important to increase the efficacy of those available. The State will see the greatest return on its investments by coordinating investment programs and streamlining participation. Over the coming years, a number of actions can be taken to maximize State resources:

- Align vehicle and infrastructure solicitations from other agencies for demonstration or pilot projects,
- Work to make utilities partners for infrastructure in demonstration and pilot projects,
- Interconnect utilities and voucher projects to connect fleets to one after applying to the other,
- Establish protocol for utilities, state agencies, air districts and other first-contact entities to direct interested fleets to the appropriate funding programs, and
- Develop a one-stop-shop portal that allows fleets to access information, apply for funding, and contact program staff. The portal would interconnect programs allowing for simplified coordination and real-time communication.

As infrastructure is a critical barrier to broader fuel-switching, CARB will continue working to develop available resources and build effective connections with other incentive programs to make infrastructure funding more accessible.

Infrastructure Assessment
Infrastructure continues to grow in visibility and is critical to the success of CARB vehicle investments. Staff recognizes that there are large data gaps — especially in quantifying the total magnitude of need for infrastructure to support heavy-duty transformation. In the absence of an economy-wide needs assessment, CARB is interested in leveraging its existing projects to extract lessons-learned and eventually conduct a broader assessment of infrastructure needs for Low Carbon Transportation projects.

In the next year, multiple projects will be concluding and submitting final reports, providing a large array of data points representing a diverse set of equipment: on- and off-road as well as different vehicle sizes and fleet types. This should enable an assessment of demonstration and pilot projects to gather information about hydrogen stations, EVSE, construction, installation, permitting, planning, and utility-side costs. Timelines will also be studied and, for all of these categories, CARB would like to understand differences between planned or forecasted costs and actual costs. Finally, CARB would query projects on the major factors that influence cost or time overruns. Staff would collect the following data points for each site in the selected projects:

- Number and types of EVSE or capacity of hydrogen stations installed
- Numbers of vehicles using infrastructure
- Planned/forecast and actual costs for:
    - EVSE/station equipment
    - Construction and installation
    - Utility-side costs, including cost share with customer
    - Design and planning costs
    - Permitting costs
- Time to complete project, planned and actual
- Major drivers of cost overruns and delays

HVIP Infrastructure Valuation
While the cost of infrastructure is often discussed, there have been few valuations of the magnitude of investment needed statewide. To provide an initial sense of scope, staff have conducted an analysis of the value of infrastructure needed to support commercial vehicles deployed with HVIP incentives (Table 1, below). The analysis was simple. In its 10 years of operation, HVIP has issued 1,777 vouchers[25] for zero-emission (all battery electric) trucks (class 2b-8). While only 461 of those have been delivered so far, staff assume that all of the currently issued vouchers will be paid. Similarly, 819 battery electric and five fuel cell electric transit bus vouchers have been issued (235 and 5 paid, respectively). Using best available data on infrastructure costs, which represents an average of all costs borne by the fleet operator per vehicle — including equipment, installation, and utility costs — CARB estimates that a total buildout of $148 million of infrastructure is necessary to support HVIP-funded zero-emission trucks and buses. These heavy-duty zero-emission vehicle deployments

[25] CALSTART. July 1, 2019.

through HVIP represent a significant portion of heavy-duty ZEVs deployed to date, but only a small fraction of the numbers — and infrastructure investment needed — in the future.

Table 1: HVIP-Associated Infrastructure Valuation

Vehicle (Class)	Tech	# Vouchers Issued	Average Cost per Vehicle for Infrastructure[26]	Estimated Value of Infrastructure needed
Truck (2b-3)	BEV	111	$25,000[27]	$2,775,000
Truck (4-5)		1,278	$25,000[27]	$31,950,000
Truck (6-7)		256	$52,500[28]	$13,440,000
Truck (8)		132	$105,000[29]	$13,860,000
Buses	BEV	819	$105,000[30]	$85,995,000
	FCEV	5	$114,000[31]	$570,000
Total		2,601	Total	$148,590,000

It's worth noting that infrastructure costs aren't always linear and efficiencies can be achieved with sufficient planning and advanced charging strategies. The converse can also be true, with inefficient buildouts or local circuit constraints inflating per-vehicle costs. For hydrogen, preliminary data suggests substantial cost savings with large deployments, possibly being less expensive overall compared to battery electric infrastructure.

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 with California's community colleges will continue to be important.

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[26] Includes charger/equipment, installation, construction, and utility upgrades.

[27] Pacific Gas & Electric. A.17-01-020 Electric Vehicle Infrastructure and Education Senate Bill 350 Transportation Electrification Program Application Prepared Testimony. http://pgera.azurewebsites.net/Regulation/ValidateDocAccess?docID=399564

[28] Class 6-7 trucks are assumed to use the same infrastructure as a class 8 truck but would be able to share the charger with another class 6-7 truck; as a result, their infrastructure costs are half that of a class 8 truck.

[29] CARB. Innovative Clean Transit Rulemaking, Initial Statement of Reasons. Charging needs for class 8 are assumed to be similar to those for transit bus. https://ww3.arb.ca.gov/regact/2018/ict2018/isor.pdf

[30] CARB. Innovative Clean Transit Rulemaking, Initial Statement of Reasons. https://ww3.arb.ca.gov/regact/2018/ict2018/isor.pdf

[31] Preliminary findings from the Fuel Cell Electric Bus Commercialization Consortium Project funded by CARB.

Some national fleet support and maintenance providers have been exploring and developing partnerships to provide the service and support network to new manufacturers or importers of vehicles. 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

As mentioned in the December 2018 workgroup, a growing 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 curriculum and established Centers for Excellence. However, huge 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 curriculum from learnings on new equipment types. Additionally, CARB began working this year with the California ETP, which provides financial and technical resources to develop partnerships, curriculum, 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 can be very resource-intensive and 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 towards greater vehicle repairability. Adding market transparency, consistency, and stability will be a critical step towards 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 Funding Timeline with Approval/Certification Process

The timeline for certification does not align well with the timeline for seeking incentive funding: in the past, available incentive funds have 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. Some of these are statutorily imposed while others are agency policies.

Across programs funded by the state, a common challenge is implementing flexible and compatible programs. Most legislature-appropriated funds come with strict encumbrance and expenditure deadlines that can make it difficult to align programs across agencies. These restrictions are also not well aligned with the manufacturing time needed for new commercial vehicles, especially those with advanced technologies. Adopters of advanced technologies need assurances that funding will be available when they take delivery of a new vehicle. However, vouchers are reserved at the time of order and vehicle build times can stretch out to nearly two years, bringing funds close to their deadlines. This can create even bigger obstacles for demonstration projects which have less predictable and often protracted timelines to build, fully demonstrate, and analyze data from pre-commercial 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 has begun a pilot project to integrate vehicle funding with utility infrastructure readiness programs (See "Infrastructure Alignment" on page 62). The outcomes of this pilot will be used to inform future collaborations with utilities.

Codes and Standards

This remains a category in flux, though there is progress being made. In the past year there has been growing consensus around charging connectors, though there is no universal approach. 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, can likely 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 backing in Europe: that of using the Combined Charging Standard (CCS) connector interface. While not standardized in the U.S., the connector is increasingly being used. That said, at least five different connector types can still be found in the field. CCS could provide inter-operability between light-duty passenger cars and trucks and for standard and high-rate charging speeds. 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 turn-around 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 inter-operability and commonality.

Low Carbon Transportation Investment Priorities

As introduced in the opening of this document and reinforced throughout, CARB has multiple investment programs tasked with specific goals. Low Carbon Transportation carries the unique responsibility of advancing emerging clean vehicle technologies; commercializing priority pathway technology applications to ensure the long-term availability of solutions necessary to meet the State's 2030 goals — and beyond. While the guidance above is applicable broadly to all of CARB's incentive programming, the remainder of this document is focused on Low Carbon Transportation and includes the recommendation elements mandated by SB 1403.

Metrics of Success

To effectively set goals, establish priorities, and assess progress, staff must define what makes a program successful. Across the state, agencies and organizations describe success by a number of measures — some specific, others broad. While certain metrics, like cost-effectiveness, are commonly used to evaluate the effectiveness of programs (and indeed all Low Carbon Transportation projects conduct cost-effectiveness calculations), near-term emissions reductions are not the only way to measure the success of investment programs, from pre-commercial demonstration to financing assistance. The exploration and learnings presented here likely apply to many or all incentive programs under CARB's purview, though this section focuses specifically on metrics for Low Carbon Transportation.

While some near-term measures (i.e., criteria and toxic pollutant and GHG emission reductions, investments in disadvantaged communities) are already being captured, these alone are not adequate to assess progress on technology transformation toward 2030 and 2050 outcomes. More targeted metrics, including 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.

In defining what makes a successful Low Carbon Transportation project, staff identified three broad categories that define success, with some overlap between the three: Creating Healthy Communities; Growing the Green Economy; and Supporting Technology Evolution. Taking the categories established in the first year, CARB has worked with stakeholders and discussed potential metrics— especially using data already being collected — that CARB could use to construct a holistic set of evaluation tools.

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 priority populations that are disproportionately impacted. With transportation being an unavoidable part of our

communities, projects should aim to reduce the health impacts of transportation and increase the sustainability of communities.

Current metrics:

- CARB collects substantial amounts of data to quantify emissions reductions.
- Location information on projects shows where emissions reductions are occurring.

Metrics feasible in the future:

- Zero-emission miles in priority communities could be quantified, providing information on the amount of zero-emission operation happening in priority communities.
- It may be possible to estimate the long-term benefits of launching a new application that eventually displaces all legacy technologies. This could be done by multiplying emissions benefits across the vehicle population expected to turn over in a set amount of time.

In addition to the metrics listed above, several others were discussed during the workgroup process, including health risk assessments and exposure studies. Upon further evaluation, health risk assessments, while a direct measurement of health, are confounded and would not capture impacts from demonstration and pilot deployments, which are meant to make technology available for large-scale deployment in the future. Exposure studies for vehicle operators, while likely valuable in demonstrating near-source exposure improvements, are outside of the scope of LCT data collection.

Growing the Green Economy

CARB's investments should create downstream economic benefits where possible. Consistent funding for clean technology projects tends to attract clean tech manufacturing to California, bringing high-quality jobs and supporting a nascent and valuable industry.

Current metrics:

- CARB knows how incentive dollars are being leveraged with private investment to support the commercial viability of advanced technology.
- CARB has qualitative information on expanding supply chains for advanced technology components. CARB also monitors the number of manufacturers choosing California as a home for manufacturing.

Metrics feasible in the future:

- It is possible to track the number of suppliers for core components and track growth over time. 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.

- However, supplier data is generally sensitive and information on volume or where OEMs are sourcing components will not be available. This will limit staff's ability to understand how OEMs are integrating supply chains or how components are shared among equipment types.

Supporting Technology Evolution

CARB knows that currently available technologies will not be sufficient to meet long-term air quality and climate change goals. Therefore, investments should spur the development, improvement, and commercialization of advanced technologies for the future. While a core goal of Low Carbon Transportation investments, technology evolution is a goal or ancillary outcome for a number of CARB's incentive programs. In the future, this section could be expanded to describe metrics applicable to a wider array of programs. This will be important as CARB explores 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 move on to other incentive programs or can stand on their own will require an empirical approach to monitoring technology evolution.

CALIFORNIA LEADERSHIP: ADVANCED TRUCK AND BUS COMPONENTS

California leads the nation in the number of technology firm locations in seven out of eleven technology categories critical to high efficiency heavy-duty vehicles. The findings come from a recently updated CALSTART component supply chain assessment. While not intended as comprehensive, the review tallied more than 1,500 facilities from more than 600 suppliers, manufacturers and developers across the US related to supplying advanced vehicle componentry for heavy trucks, buses, and off-road vehicles. California has almost half of the alternative fuel company offices in the U.S., and half of the infrastructure companies. In 6 out of 11 categories, California has more than 20% of the U.S. offices. The categories in which California showed more company offices than other regions include:

- Alternative Fuel
- Full Electrification
- Powertrains & Accessories
- Off-Board Infrastructure
- Automation
- Energy Storage
- Connected Systems

The review considered headquarters; offices; production facilities; and research and development facilities. In the remaining 4 categories, California's competitive advantage is still clear, as the state is home to just 2 fewer facilities than the leading state in each category. Data is current as of June 2019.

Current metrics:

- Staff can quantify how investments in commercially available technology are accelerating consumer acceptance and anecdotal evidence suggests dropping production costs for manufacturers.
- Staff are also collecting observations that technologies from one application are being used in others — a phenomenon being accelerated by CARB investments and a direct validation of CARB's beachhead theory of technology transfer.

Metrics feasible in the future:

- Survey data could be valuable for elucidating attitudes and perceptions of new vehicle technology. However, survey data is burdensome to collect and is easily confounded. Additionally, different respondent types (i.e. operator vs. maintenance technician vs. fleet owner) are known to supply different responses. HVIP is expected to collect more survey data in the future and could be of use. Though, as stakeholders have told us, 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 procures more advanced technology vehicles.
- Staff is also collecting observations that investments are accelerating technology transfer from one application to another and improving performance.

Metrics and Moving Forward

While current practices for monitoring success provide some feedback on the effectiveness of CARB investments in terms of emission reductions, there are additional benefits to these programs that aren't yet reflected. Given the long-term nature of return on Low Carbon Transportation investments, determining how to estimate the long-term benefits is key. CARB will continue to work with stakeholders to develop and implement additional metrics that communicate all of the value of Low Carbon Transportation investments.

Priorities for Low Carbon Transportation

The Heavy-Duty Investment Strategy establishes a series of tools to assess needs and guide investment actions. Based on the technology status updates, the progress being made against the beachhead strategy to date, and consideration of barriers, staff have developed updated and refined priorities for the targeted technologies and project categories that could benefit from funding investments to help the State reach its climate and air quality goals. These priorities were assembled based on:

1) Evaluating the updated technology status and progress outlined previously;
2) Identifying areas of accelerated progress where funding could support or accelerate technologies in reaching the market;
3) Identifying areas of slower progress where barriers could be targeted to aid development; and

4) Additional sector research as well as industry conversations and feedback during the assembly of this update, including from Work Group sessions and one-on-one meetings.

The recommended funding levels resulting from these priorities 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 capabilities for producing a meaningful number of demonstration and pilot projects during the three-year investment strategy timeframe. The funding strategy and amounts are designed to ensure State funds are going to the best projects that focus on a targeted and vital portion of what needs to move forward over the next three years to impact 2030 and 2050 outcomes, while still also mindful of providing crucial near-term benefits. If significant additional resources were to become available, the transformation of the heavy-duty and off-road sectors could be expedited and, if that funding were sufficient, it could also spur manufacturers to increase production capacity and provide additional fleet support, training, and infrastructure.

Given the findings from this yearly review, and the successful outcomes being monitored 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. For instance, zero-emission transit continues to experience year-over-year growth, bolstered by new regulations requiring California's public transit agencies to transition to zero-emissions by 2035. However, there are marketplace implementation issues around infrastructure planning and technology scaling considerations that transit operators need assistance to address. This work will also be of direct assistance to goods movement applications — from medium-duty delivery to heavy-duty short drayage and regional distribution. Using commercial stage funding investments, it is crucial that the first beachhead market successes noted in this update be consolidated and further expanded.

> *The funding strategy and amounts are designed to ensure State funds are going to the best projects that focus on a targeted and vital portion of what needs to move forward over the next three years to impact 2030 and 2050 outcomes, while still also mindful of providing crucial near-term benefits.*

This means:

- Building out market success in the zero-emission beachhead markets and supporting the growth of the secondary and other follow-on markets now emerging, especially last mile and medium-duty delivery.

- Adequate funding for HVIP and CORE vouchers is a high priority.
- The secondary markets now showing expanded products includes urban and suburban delivery, school bus, shuttle bus and some specialized service applications for technologies in the zero-emission pathway. Drayage and regional haul tractor applications have been added to the low NOx pathway.

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

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

Target Promising Next Pathway Markets. For the beachhead strategy to be fully successful, the next application technology 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 and left unaddressed 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 State policies demand. Key pilot stage priorities include:

- Building out larger ZE vehicle "ecosystems" in pilot projects that enable and set the template for scaled and fully-integrated infrastructure is growing in importance. The ZANZEFF framework was exceptionally valuable in helping terminals, distribution centers and domiciles build out infrastructure plans for multiple vehicles and needs to be continued if funding permits.
- ZEV transit buses also represent a specific case that could benefit from inclusion in this framework, with a priority to hydrogen fuel cells, to help develop larger scale infrastructure, service, and component volumes and move these products closer to full commercial readiness.

- Zero- and near zero-emission drayage trucks have received significant focus and now show promise to move even faster than originally projected in the beachhead strategy. Ensuring pilot stage funding for multiple projects over the next two to three years will maintain this pace and ensure supply chain growth and competition, as additional OEMs enter the market.
- ZEV yard hostlers, container-handling equipment, and other off-road equipment would benefit from both commercial incentives and additional pilot deployments assisting with infrastructure.
- Near zero- and zero-emission port, construction and agricultural equipment, including wheel loaders, lifts, and heavier cargo handling equipment are 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.
- FCEV medium- and heavy-duty delivery vehicles, particularly in the higher weight classes (MHD and HHD, Classes 6-8).
- Advanced PHEV with extended range in the higher weight classes (MHD and HHD, Classes 5-8).
- Advanced engine architectures for efficiency and low NOx, 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.
- School buses in smaller and less densely populated districts to assess use profiles, develop infrastructure and explore additional benefits such as grid integration.

TECH EXAMPLE
LEARNING FROM A FULL FACILITY TRANSFORMATION

Frito-Lay, in conjunction with the San Joaquin Valley Air Pollution Control District (SJVAPCD) and CARB, aims to replace all diesel-powered freight equipment at one of its largest food production, warehouse, and regional distribution facilities by 2021. The "**Frito-Lay Zero and Near-Zero Emission Project**" in Modesto will deploy over 60 zero-emission and near-zero-emission vehicles to showcase freight technology and how it functions at the facility level. Frito-Lay hopes to use lessons from this project to understand the applicability of such technologies in furthering its sustainability goals.
The range of technology included in the project is extensive and includes electric yard hostlers from **BYD**, electric forklifts from **Crown**, electric delivery trucks from **Peterbilt** and semi-tractors, including low NOx, renewable natural gas (RNG) tractors from **Volvo** and zero emission battery electric semi-tractors from **Tesla**. The project includes energy generation and storage; vehicle fueling; and warehouse equipment. For infrastructure, Frito-Lay will utilize a 1-Megawatt photovoltaic array with energy storage and install charging stations with an additional energy system. The project was made possible with a $15 million grant from CARB.

An additional priority will be the inclusion of 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. One of the biggest points of leverage for State funding is in maintaining the momentum of the "innovation pipeline" of targeted, pathway technologies that 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. Driving these core technologies forward is of critical importance to the success of the beachhead strategy. California companies are among the world leaders in developing advanced component and vehicle solutions, which provide tangible economic and job benefits to the state. CARB demonstration funding is a powerful lever when coordinated with the work and funding of private companies and other state and federal agencies. Therefore, while CARB's funding focus is on demonstrations just past or at the prototype phase, staff must work in partnership with other agencies that also provide demonstration stage funding to target technologies and projects driving beachhead success. The strategy remains consistent for this year's plan, and includes these targets:

- Longer range (>250-miles) zero-emission and PHEV electric drive medium- and heavy-duty goods movement vehicles. Range extender designs should focus on using fuel cell or low NOx engines.
- Further improvement of near zero- and zero-emission heavy-duty sector technologies, from advanced engines to advanced near zero- and zero-emissions powertrains. Demonstration platforms could include transit and regional medium- and heavy-duty delivery vehicles.
- Advanced low NOx, high-efficiency engine, and low carbon alternative fuel engine demonstrations have longer-term benefits both on their own and as components of a near zero-emission powertrain design.

The off-road sector is also poised to demonstrate breakthrough technologies in high fuel-use applications. These technologies include zero-emission, near zero-, and low NOx technologies as well as efficiency technologies. Zero-emission capable hybrids are emerging as a promising next step for many off-road applications with the toughest 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. 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 the ability to transfer and scale to goods movement applications.

Low Carbon Transportation Three-Year Investment Recommendations

The Three Year Heavy-Duty Investment Strategy is a living document that encompasses a rolling three-year horizon. Therefore, the funding levels recommended in this updated strategy expand upon the levels identified in the FY 2018-19 report by adding a new third year, FY 2022-23. Based on the updates to the technology status snapshots and the refinements to the beachhead strategies, CARB and its grantee have also re-evaluated the required level of activity to move pathway technologies forward toward 2030 goals over the updated three-year funding period.

The recommended funding is based around core established priorities and the updated priorities, strategies, and segment opportunities identified in the reviews as mentioned above. For instance, the need to scale infrastructure for large volume vehicle deployments is growing as a way to address barriers, but also is showing itself as 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 share and reduce investment costs for common electric infrastructure, at central nodes servicing multiple application types such as freight domiciles also presents opportunities to speed learning and technology adoption.

The recommended funding is based around core continuing priorities and the updated priorities, strategies and segment opportunities identified in the reviews as mentioned above.

From these inputs an updated portfolio of high value and critical path project funding was assembled and compiled into the recommended funding levels. These levels are presented by fiscal year and by stage of technology: Demonstration; Pilot; and Commercial. Highest priorities for State funding are listed in the recommendations table.

These do not represent all of the project types CARB might fund, but a small subset of top priorities staff believe will be most important for continuing to develop and commercialize advanced technologies without stranding our previous investments. Those priorities are 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 towards meeting the funding need for advanced technology heavy-duty vehicles and off-road equipment, but the amounts do not meet the entire need to achieve the State's goals.

CARB and its grantee used multiple approaches to assemble the levels of funding deemed necessary. First, for the Demonstration and Pilot funding levels, a matrix framework of representative projects for the targeted technologies and pathways was compiled, and sizing was based on the funding needed to drive meaningful learnings and results in each application category. These levels were determined considering historical investments in past projects, 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 encourage multi-regional participation. Second, manufacturers, suppliers, and fleets were solicited for feedback from Work Group meetings and private conversations to ascertain most valuable sizing and number of projects and other project needs, such as data collection or infrastructure. Third, past examples of comparable demonstration and pilot projects managed by CARB and other state and regional agencies were also a factor. As a result, infrastructure support for projects is included in the recommended funding levels for demonstration and pilot activities.

This strategy and the funding recommended here are meant to represent a critical part of driving technology transformation. However, this represents just a subset of the larger work and funding required and does not represent the overall funding need for fully transforming the heavy-duty and off-road sectors.

For the commercial stage funding recommendations, market research, OEM, fleet and supplier interviews, and confidential sales projections from manufacturers were used to develop an aggregated expected market demand projection for HVIP. The grantee layered on to this assessment historical data to validate continuity and reality of projections. Industry production capacity and fleet acceptance were factored in, as was research and market data on emerging product offerings, combined with confidential conversations with manufacturers on expected launch dates. This process and the numbers associated with them have been previously discussed with industry at separate HVIP work group meetings. Infrastructure funding is included as part of the commercial incentives for only the first year of the three-year plan presented here. *However, it is not included in the second and third year as the HVIP infrastructure voucher enhancement was intended to provide temporary relief and not to reimburse infrastructure costs indefinitely.*

The aggregated results of this projection activity are summarized in Table 2. It highlights the key priority areas and frames the range of investments ideally needed each year over the three fiscal years. Low and high funding levels are portrayed to suggest the minimum levels needed to maintain progress. At lower funding levels not all of the priorities can be achieved. The higher levels represent aggressive investments able to drive all of the identified priorities and potentially allows additional pathway applications to be advanced.

As has been highlighted in many public meetings, the need for incentives geared towards meeting California’s near- and long-term GHG and air quality goals far exceeds the recommended funding shown here, which is primarily focused on creating the critical technology capability and product mix for transformation, but not fully funding that transformation.

Table 2: Recommendations for Low Carbon Transportation Investment Priorities

THREE-YEAR RECOMMENDATIONS FOR LOW CARBON TRANSPORTATION*			
	FY 2020-21	**FY 2021-22**	**FY 2022-23**
Demos	*$60-$85 Million* Focus: ZE/PHEV Heavy-Duty Regional Delivery, ZE/Hybrid Ag-Construction Equipment, ZE/Hybrid Heavier Cargo Handling Equipment, ZE/Hybrid Marine	*$50-$90 Million* Focus: ZE/PHEV Longer Range Heavy-Duty Goods Movement, ZE/PHEV Ag-Construction Equipment, ZE/Hybrid Heavier Cargo Handling Equipment, ZE/Hybrid Marine	*$50-$90 Million* Focus: ZE Longer Range Heavy-Duty Goods Movement, ZE Construction Equipment, ZE Heavier Cargo Handling Equipment, ZE Rail, ZE/Hybrid Marine
Pilots	*$185-$310 Million* Focus: ZE/PHEV Drayage and Regional Delivery, Advanced Powertrains, ZE/Hybrid Heavier Cargo Handling Equipment, ZE Facilities	*$200-$325 Million* Focus: ZE/PHEV 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 Goods Movement, Advanced Powertrains, ZE Ag-Construction-Heavier Cargo Handling Equipment, ZE/Hybrid Marine, ZE Facilities
Commercial	*$220-$320 Million* Focus: ZE Delivery, ZE Transit, Ground Support Equipment, ZE/Hybrid Heavier Cargo Handling Equipment	*$300-$400 Million* Focus: ZE/PHEV Drayage and Regional Delivery, ZE Delivery, ZE Transit, ZE/Hybrid Heavier Cargo Handling Equipment	*$340-$460 Million* Focus: ZE/PHEV Drayage and Regional Heavy-Duty Delivery, ZE Delivery, ZE Transit, ZE/Hybrid Heavier Cargo Handling Equipment, ZE/Hybrid Marine
Total Funding	**$465-$715 Million***	**$550-$815 Million***	**$590-$875 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.
** The funding amounts listed here represent a critical down payment towards meeting the total funding need and the minimum investment necessary to continue technology advancement, but does not meet the entire need.*

Summary

In California, the magnitude of economy-wide carbon and criteria pollutant reduction necessary to meet State and federal goals is massive — and the transportation sector will be the most challenging. To achieve these reductions, the State needs a new generation of advanced, clean vehicles — and the heavy-duty and off-road sectors are proving promising. However, there are few commercialized zero- and near zero-emission options available today. Tremendous progress is required over the next decade.

Clearly signaled, adequately funded, and multiple-year incentives remain a critical factor for driving the rapid transformation of the transportation sector to zero-emission technologies wherever feasible and near zero-emission technologies with the cleanest, lowest carbon fuels everywhere else. These steady incentives are necessary to carry key applications through the full commercialization path and make necessary technology available. CARB's Low Carbon Transportation funding for vehicles represent a key component of this important approach when applied against the targeted Heavy-Duty Investment Strategy and priorities outlined in this document.

The prospective roadmap updated here builds on CARB's investment portfolio approach by applying the framework of strategic beachheads to help prioritize funding around those technologies and applications that have strong potential to transfer and spread to broader applications. This approach is proving successful based on the assessment update outlined here. It will continue to provide strategic focus to drive actions needed over the next three years to both support the transformation required for the long-term, as well as needed near-term benefits.

Clearly signaled, adequately funded and multiple-year incentives remain a critical factor for driving the rapid transformation of the transportation sector to zero-emission technologies wherever feasible and near zero-emission technologies with the cleanest, lowest carbon fuels everywhere else.

Nonetheless, it must again be noted that the funds recommended here are not the full amount required for transformation. Rather they are focused on jump-starting the transformation process by moving crucial technologies and applications through the commercialization process and into early beachhead success markets. While more funding is becoming available for commercial vehicle purchases, there is a growing gap emerging for critical demonstration and pilot stage technology investments that could stall rapid commercialization. As additional sources of funding for heavy-duty on- and off-road technologies become available, they will ideally be applied against the strategy outlined in this document.

CARB's Low Carbon Transportation funds are a down payment on the overall funding need. The incentives needed to drive complete transformation is quite large; it will require the investments of multiple agencies at the federal, state, and local level contributing funding to this "down payment" to achieve the changeover of technologies in transportation needed to meet the climate and criteria emissions and petroleum reduction goals the State has set.

CARB, and the State more broadly, possess a portfolio of investments and regulatory tools to drive necessary change. All of these levers are necessary to develop and commercialize clean technology and then facilitate the full transformation of the transportation sector. But without clear guidance and a concerted effort, these resources will not be enough.

The development of clean technologies and the transformation of medium- and heavy-duty fleets is becoming a global priority. The Heavy-Duty Investment Strategy is purposed with giving critical guidance not just to CARB, but to our partners in California and around the world. This document is designed to be a useful reference for efforts across public and private sectors to grapple with the challenges we face — and targeted solutions that can be followed to achieve desired outcomes.

This document is designed to be a useful reference for efforts across public and private sectors to grapple with the challenges we face — and targeted solutions that can be followed to achieve desired outcomes.

The Heavy-Duty Investment Strategy confirms a theory of change and presents a roadmap based on a continuum of driving technology development and transfer through to market transformation to achieve State goals for 2030 and beyond. However, implementing these strategies and achieving desired outcomes requires multi-level, expansive, and sustained collaboration. CARB continues to work closely with key players and, with this document as a unifying and cross-sector strategy, staff encourage expanded collaboration in addressing the critical public health and existential challenges faced worldwide.

Sources of Funding

As discussed in this document, CARB operates a substantial portfolio of connected investment programs that work in a concerted manner to achieve CARB goals. More broadly, the State, air districts, and local agencies provide additional funding that contributes to State objectives. A summary of these programs is included here.

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, expanding 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 change strategy pillar of a 50 percent reduction in petroleum use in vehicles by 2030 as well as the State's goal to deploy five million zero-emission vehicles by 2030. Low Carbon Transportation and Fuels investments account for about 91 percent of the funds covered in the FY 2019-20 Funding Plan.

The Legislature has appropriated approximately $1.7 billion to CARB for Low Carbon Transportation projects over the past six budget cycles (FY 2013-14 through FY 2018-19). 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 and buses utilizing zero-emission, hybrid, and low NOx technologies; and advanced technology demonstration and pilot projects for freight trucks and equipment.

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 impacted by air pollution. 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 pollution monitoring and emission reduction programs. Through extensive public process, CARB established the Community Air Protection Program (CAPP), which includes funding, programmed through local air districts, to support early actions for emissions reductions in communities disproportionately impacted by air pollution. Staff continue to work with stakeholders to develop the mechanisms for funding emissions reductions, which can include retrofits or replacements to stationary sources and mobile sources (including heavy-duty vehicles and off-road equipment). CAPP has received $495 million over the last two funding cycles and has been appropriated an additional $245 million in FY 2019-20. Funds are administered through the air districts. More information can be found on the program website: https://www.arb.ca.gov/msprog/cap/capfunds.htm

Funding Agricultural Replacement Measures for Emission Reductions 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. FARMER encourages early turnover and replacement of older, uncontrolled equipment. The FARMER Program 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 75 percent of the cost of a new agricultural zero-emission utility terrain vehicle
- Continuation of the Ag Trade-Up Pilot administered by San Joaquin Valley Air Pollution Control District (APCD) since 2016
- Up to 65 percent of the cost of a new or used heavy-duty agricultural truck that meets the 2010 emission standard of 0.20 g/bhp-hr NOx

FARMER has received $267 million over the last two 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 more than 61,000 engines and has reduced more than 186,000 tons of smog and 6,800 tons of toxic diesel PM. Popular funded projects include heavy-duty truck replacement (with higher cost-effectiveness limits to encourage low NOx 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) allows providers of low carbon intensity alternative fuels to generate LCFS credits that can be sold on the open market. Natural gas and electricity fuel providers have been opting into LCFS as voluntary credit generators since 2011, while hydrogen providers are just starting to generate credits. Compressed natural gas and on-road electricity fuels accounted for 18 percent (over two million metric tons) of the total LCFS credits generated in 2018. At an average 2018 credit price of $160, LCFS is a significant incentive that helps offset fuel and station operation costs, allowing alternative fuel providers to pass those savings on to the customer.
More information can be found on the program website:
https://ww3.arb.ca.gov/regact/2015/lcfs2015/lcfs2015.htm

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. $1 billion in the Good Movement Emission Reduction Program have been granted 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 13,900 projects have reduced over 81,000 tons of NOx and 2,400 tons of PM. In addition, the Proposition 1B School Bus program provided another $200 million just for school bus retrofit and replacement. Though the Proposition 1B School Bus program has finished granting their funds, further rebates for school buses are available through other programs.
Goods Movement: https://www.arb.ca.gov/bonds/gmbond/gmbond.htm
School Bus: https://www.arb.ca.gov/bonds/schoolbus/schoolbus.htm

Air Quality Improvement Program

AQIP is a mobile source incentive program that focuses on reducing criteria pollutant and diesel particulate emissions with concurrent GHG reductions. CARB investments started under AQIP provide the foundation for the Low Carbon Transportation investments that now make up the vast majority of the proposed Funding Plan. AQIP has provided funding for CVRP, HVIP, and advanced technology demonstrations since 2009. With the technology advancement objectives now handled under Low Carbon Transportation, AQIP is almost exclusively used for the Truck Loan Assistance Program, which provides financing assistance for small-business fleet owners subject to ARB's In-Use Truck and Bus Regulation. The program is tailored to truck owners that experience challenges obtaining conventional financing.

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 non-competitive state allocations. Historically, California has chosen to focus its State Program allocations on school bus clean-up. Although this funding is not guaranteed, it remains an important source of funding for replacing older diesel school buses. When these funds are available, they have been administered by the San Joaquin Valley APCD on behalf of CARB for the Lower-Emission School Bus Program and will be administered through the North Coast Unified AQMD beginning 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 synchrony: 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 issue hundreds of millions of dollars annually through dozens of different funding programs to deploy advanced technology heavy-duty vehicles. Coordination is not just imperative to increase ease of use for participants, but 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 the CEC coordinate on their respective investment plans. The CEC administers a key 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 fuel and vehicles to help attain the State's air quality and climate change policies.
More details on the Clean Transportation Program can be found at these locations:
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 investment plan guides the allocation of program funding for transportation solicitations for the upcoming fiscal year. The FY 2019-20 Investment Plan is anticipated to be formally adopted in September 2019. More information on current and previous investment plans can be found at: https://ww2.energy.ca.gov/transportation/arfvtp/investmentplans.html

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 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, and bus and ferry transit systems to reduce emissions of greenhouse gases by reducing congestion and vehicle miles traveled throughout California while providing benefits to priority populations.[32] 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.

[32] Formerly referred to as disadvantaged communities, low-income communities, and low-income households within a ½ mile of disadvantaged communities

- Improve safety.

TIRCP can provide funding for zero-emission passenger transport, including buses, rail, and ferries. On September 20th, 2019, TIRCP will open its next call for projects, to begin accepting Cycle 4 2020 project applications. More information can be found on the program website: https://dot.ca.gov/programs/rail-and-mass-transportation/transit-and-intercity-rail-capital-program

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 by Senate Bill 862. The Low Carbon Transit Operations Program (LCTOP), administered by Caltrans, provides operating and capital assistance for transit agencies to reduce greenhouse gas emission 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 greenhouse gas 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 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 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 bonnet 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). PG&E, SCE, and San Diego Gas & Electric (SDG&E) submitted applications in 2017 and 2018 for small-scale pilots and large-scale programs to provide infrastructure to customers deploying plug-in electric vehicles. In 2018, the 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 and SCE launched in the summer of 2019. In August 2019, the CPUC approved SDG&E's $106 million large-scale medium- and heavy-duty infrastructure program, which is expected to launch in 2020.

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, 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 the districts' websites.

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, 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 ferry, 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 in order 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 or 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 helps 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 and incentivize the purchase of zero- or near zero-emission 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- or near zero-emission transit buses and related equipment, or for leasing, constructing, or rehabilitating facilities in order to support zero- or near zero- emission 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.

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

ACRONYM LIST

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

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