

White Paper

Methods for Assessing Technology and Market Readiness for Clean Commercial Transportation

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Acknowledgments

This report will be updated on a periodic basis in support of the publication of the California Air Resources Board's (CARB's) Appendix D: Long-Term Heavy-Duty Investment Strategy.

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List of Acronyms

ACF	Advanced Clean Fleets
ACT	Advanced Clean Trucks
CARB	California Air Resources Board
CEC	California Energy Commission
CORE	Clean Off-Road Equipment Voucher Incentive Project
EnergIIZE	Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles
FCEV	Fuel Cell Electric Vehicle
HD	Heavy-Duty
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
ICT	Innovative Clean Transit
MD	Medium-Duty
MHDV	Medium- and Heavy-Duty Vehicle
MRI	Market Readiness Indicator
OEM	Original Equipment Manufacturer
RHETTA	Research Hub for Electric Technologies in Truck Applications
TCO	Total Cost of Ownership
TRL	Technology Readiness Level
TSS	Technology Status Snapshot
V2G	Vehicle-to-Grid



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Executive Summary

CALSTART and the California Air Resources Board (CARB) conduct yearly assessments to analyze the technology status and market progress of zero-emission medium- and heavy-duty vehicle (MHDV) and equipment technologies. This document aims to build an understanding of the methods and process used to create and update these assessments, known as **Technology Status Snapshots (TSSs)** and **Market Readiness Indicators (MRIs)**. TSSs and MRIs are key to the development and direction of successful incentive policy and regulation. CARB utilizes the insights derived from these explorations each year to calibrate and inform MHDV funding recommendations. The approaches detailed in this report are enacted, reviewed, and modified (if necessary) by CALSTART and CARB every year prior to the publication of CARB's Appendix D: Long-Term Heavy-Duty Investment Strategy.

In combination, TSSs and MRIs depict a comprehensive view of clean commercial vehicle and equipment platform performance and readiness for the marketplace:

- **TSSs assess the maturity level of a particular technology, determining a platform's viability primarily from its technological performance.** CALSTART and CARB use Technology Readiness Levels (TRLs) to score six categories that currently include applications for both on-road and off-road platforms for battery-electric vehicles and equipment, fuel cell electric vehicles and equipment, and hybrid electric vehicles and equipment. Within these six categories, platforms receive individual TRL scores measured on a scale from 1 to 9, with 1 being platforms with scientific evidence for potential innovation and 9 being a commercially available application. TRL scores are then visualized in TSS charts that are published in CARB's Appendix D: Long-Term Heavy-Duty Investment Strategy each year.
- **MRIs act as a check list of market attributes that describe a platform's viability for success with respect to production or economic factors that could impede development or adoption.** A technology likely has market viability when it attains all four MRI categories: current market scale, investment scale, in-service applicability, and economic viability. If a technology has yet to attain all four attributes, then the technology still requires assistance from incentives or further technological development to succeed.

The ultimate purpose of these technical assessments and market explorations is to provide valuable context for agencies that can influence vehicle and equipment markets through incentives or regulations. Incentive programs have used TSS and MRI assessments to support funding and clean vehicle and equipment deployment goals. TSSs and MRIs help to ensure that the requirements for production and/or adoption mandates align with both technologically

mature and market-ready vehicle and equipment applications, setting up manufacturers and fleets for success. Example assessments are included in this paper to illustrate the methods and process but are not intended as a full summary of all sectors, applications, and technologies.



I. Introduction

To help track the status and progress of the emerging market for cleaner-than-diesel medium- and heavy-duty vehicle (MHDV) and equipment technologies, CALSTART and the California Air Resources Board (CARB) conduct technology and market readiness assessments on a yearly basis. This document aims to build an understanding of the methods and process used to create and update these assessments. The State of California's goals to improve air quality are directly tied to fostering and supporting a self-sustained market for zero-emission and zero-emission enabling vehicles and equipment. Several technology and market-based hurdles currently hinder this market development—to help accelerate the viability of clean MHDVs, CARB has implemented ambitious market and regulatory actions that are guided by rigorous analysis and exploration of market and technology factors. Such analyses and exploration of the market progress and technology status of MHDVs are vital to the development and direction of incentive policy and regulation. These yearly assessments—which use indicators known as Technology Status Snapshots (TSSs) and Market Readiness Indicators (MRIs)—help ensure that vehicle and equipment technology platforms receive appropriate CARB funding.

TSSs and MRIs each describe distinct maturity levels in the commercialization process for clean vehicle and equipment applications. TSSs track the reliability and progress of separate vehicle and equipment applications from the early-market testing and demonstration phase through to the market readiness stage. This process sets a specific numerical score, known as a Technology Readiness Level (TRL), to each application in order to track technology commercialization progress. MRIs provide a more complete picture of an application's market readiness status within a complex market. Market readiness can be assessed by considering four major MRIs: current market scale, projected investment scale, in-service applicability, and economic viability.

Creating standardized, numerical assessments for technology readiness and standardized categories for market readiness provides consistent scorecards of technology viability to enable effective incentive programs and regulatory action. This report aims to break down CARB and CALSTART's methodologies for determining TRL scores and visualizing the results in TSS charts (Section II); describe the four MRI categories and how each indicates a platform's market readiness (Section III); and highlight examples of both incentive programs and regulations that have been supported by these technology and market readiness assessments (Section IV). Appendix A provides a copy of the TRL Scoring Rubric utilized by CALSTART and CARB's internal team of subject matter experts during the TRL scoring process.



II. Technology Status Snapshots (TSSs)

A clean commercial technology's path to commercialization can be understood first and foremost by a TSS. The goal of these TSS assessments for MHDV applications is to determine a platform's viability primarily from its technological performance. As such, TSSs provide directional guidance, but not precise measurements, on a technology's readiness for commercialization. TSSs for MHDVs illustrate overall technology progress, lending insight to the type of additional development or funding that could further support and accelerate the market for each application. TSSs assist in determining appropriate research, development, or deployment investments to further encourage vehicle and equipment adoption or to help certain technologies or platforms that face more difficult adoption barriers by providing point-in-time evaluations. CARB therefore utilizes these TSS assessments to ensure the continued effectiveness of its policies and investments as described in Appendix D: Long-Term Heavy-Duty Investment Strategy.¹

To quantitatively assess a vehicle or equipment's TSS, CALSTART and CARB use TRLs, a type of measurement system to determine the maturity level of a particular technology that was first pioneered by NASA. CALSTART and CARB have adapted NASA's general methodology by applying this scoring process to an entire MHDV platform, rather than a single component or technology system. CALSTART and CARB use TRLs to score six categories, though these categories have changed over time. These categories currently include vehicle and equipment applications for both on-road and off-road platforms:

- On-road battery-electric
- On-road fuel cell electric
- On-road hybrid electric
- Off-road battery-electric
- Off-road fuel cell electric
- Off-road hybrid electric

Within these six categories are vehicles and equipment that receive individual TRL scores. For example, the on-road battery-electric category currently includes the following platforms:

- Heavy-duty (HD) delivery
- Medium-duty (MD) delivery (cargo van)
- Drayage tractors (short range)
- Shuttle bus
- School bus
- Transit bus
- Refuse haulers
- MD delivery (MD straight truck)
- Autonomous vehicle applications (various platforms)

¹ The Fiscal Year [2021-22 Appendix D: Long-Term Heavy-Duty Investment Strategy](https://ww2.arb.ca.gov/sites/default/files/2021-10/fy21-22_fundingplan_appendix_d.pdf) can be found at https://ww2.arb.ca.gov/sites/default/files/2021-10/fy21-22_fundingplan_appendix_d.pdf

TRLs are measured on a scale from 1 to 9, with 1 defined as platforms with scientific evidence for potential innovation and 9 defined as a fully commercially available application. The definitions and general technology level of each TRL score is detailed in Appendix A: TRL Scoring Rubric. This scoring rubric is provided to industry experts to conduct the yearly TRL scoring assessments. The approach detailed below is enacted, reviewed, and modified (if necessary) by CALSTART and CARB every year prior to the publication of the Long-Term Heavy-Duty Investment Strategy. These scores do not incorporate or address market placement.

TRL Scoring Methodology

1. Determining a TRL score begins with the internal CALSTART and CARB team, which consists of subject matter experts with expertise in at least one vehicle or equipment segment. This team develops a comprehensive list of vehicles and equipment for consideration that fall within a particular TRL platform.
2. Members of the internal CALSTART and CARB team assess and record each vehicle or equipment's capabilities and development progress. Factors such as economic or market challenges are not weighted in TRL scoring, as these characteristics contribute instead to market readiness.
3. Once the individual vehicle and equipment assessments are compiled, internal industry experts score the technologies according to the scoring rubric (Appendix A). Each industry expert scores all technologies as applicable to individual expertise. A discussion is then held to rectify any large discrepancies in the scoring.
4. Once each score has been vetted by industry experts, the impact each vehicle and/or equipment has on the entire TRL platform is weighted according to two factors: the Parent Company Market Penetration Multiplier, which gives a higher weighting to platforms from companies who have larger market penetration, and the Production Commitment Capacity Multiplier, which gives a higher weighting to vehicles and equipment with firm commitments to higher volume production. These weighted factors are preferable to a simple average—early-stage vehicles and equipment do not define the entire status of a platform. Further, vehicles and equipment that have not made as much commercialization progress still impact the overall status of a platform. For instance, a model from a vertically integrated global original equipment manufacturer (OEM) receives more weight than a model from a start-up manufacturer. This approach enables a more realistic assessment of a platform's technical and commercial readiness. TRLs are therefore displayed as the general aggregated score of known and weighted scores within a platform. In doing so, this approach may result in a platform receiving a TRL of 7 or 8 (i.e., entering the pilot stage) while some models from certain manufacturers in the platform may already be in commercial production. Minimum and maximum range of scores are also noted.
5. Once the TRL score for each platform is determined, the results are visualized in TSS charts, which are described below.

TSS Charts

TSS charts are provided in CARB's Long-Term Heavy-Duty Investment Strategy for each of the six categories listed above. Each chart contains the elements listed below. These elements may have changed over time in previous iterations of the strategy.

- The x-axis follows the TRL scores from 5 to 9 and into market readiness (commercially ready) beyond 9. Platforms in the early demonstration stages are shown on the left, and those closer to commercial readiness are shown on the right.
 - It should be noted that the x-axis begins at TRL 5, rather than TRL 1, as any platform receiving a TRL score of 1 – 4 would not be ready for demonstration projects.
- The weighted average for the status of each platform is shown by a square shape, while its status in the previous year is represented by a circle, showing any progress.
- The range of where different models under development fall in readiness within a platform category is shown with range bars indicating the highest and lowest positions. A green box shows the median point of status: half the models have lower status scores, and half above. This can inform where general industry capabilities lie.
- The y-axis shows the relative potential market volume size for that technology, with technologies that have a relatively small market size near the bottom and those with a larger market size near the top.

Figure 1. TSS Chart Example – On-Road Battery-Electric

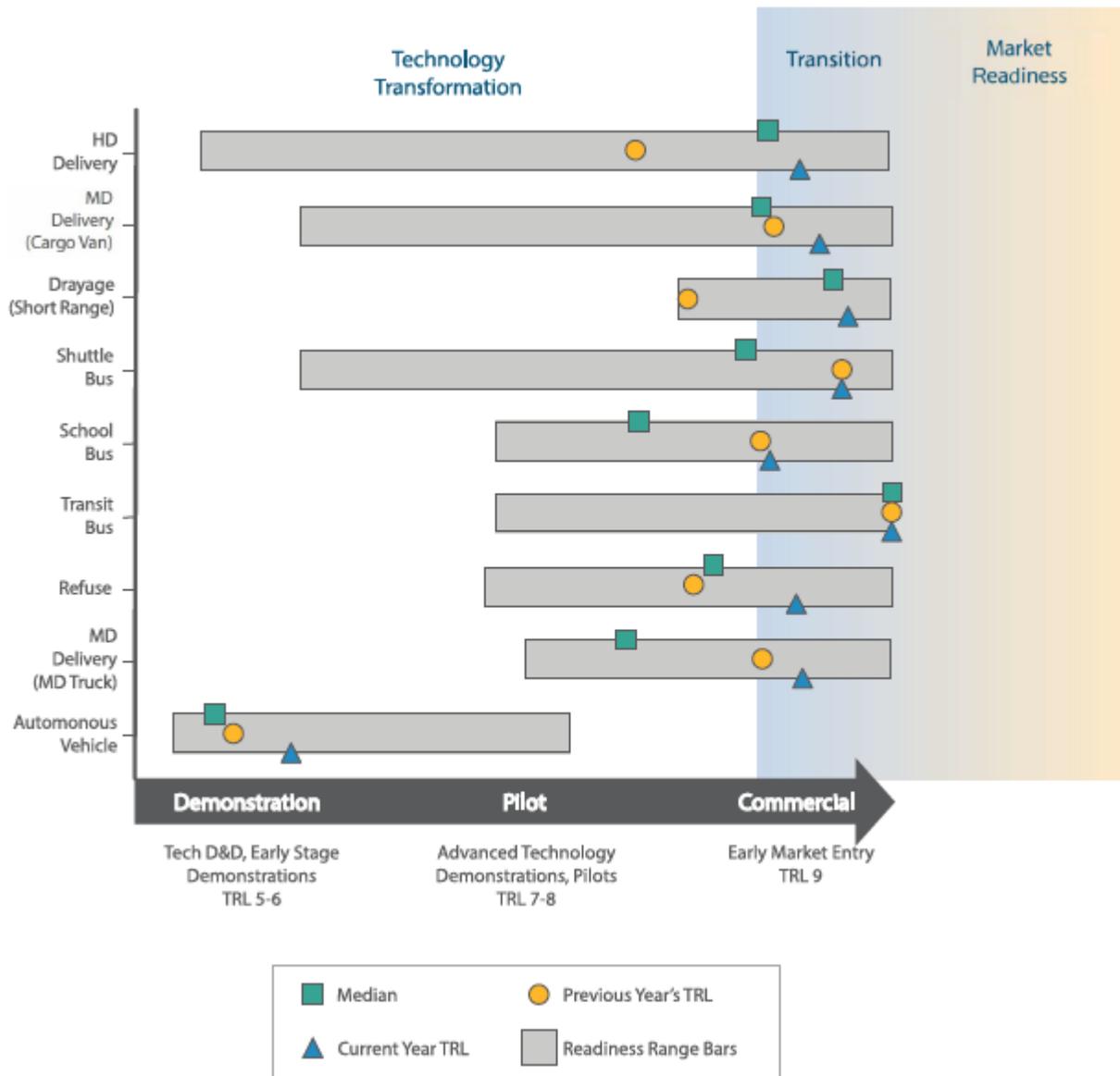
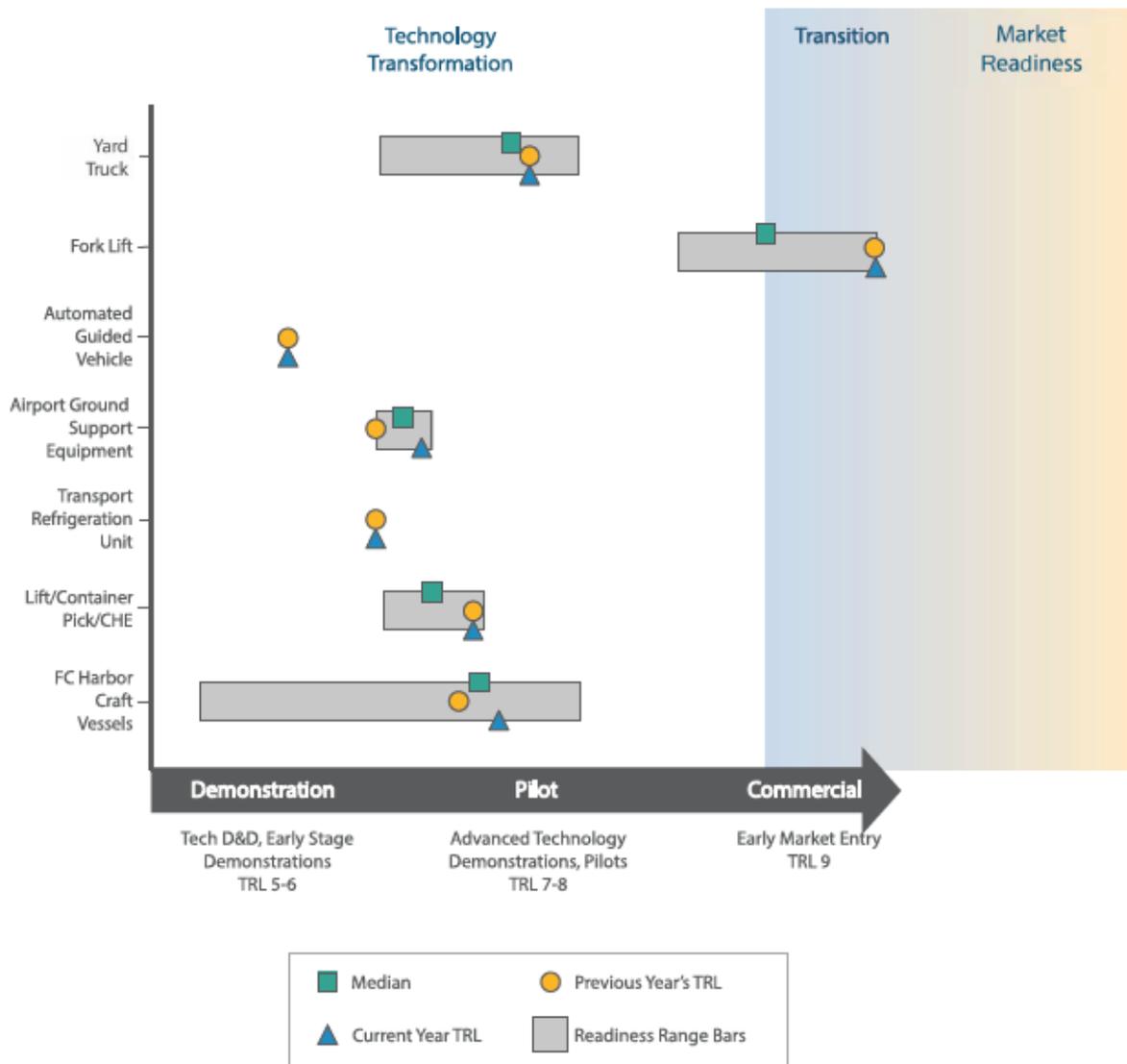


Figure 2. TSS Chart Example – Off-Road Fuel Cell Electric



The Readiness Gradient

When a platform begins to reach a TRL of 8.5 out of 9, it enters the "Readiness Gradient Area." This area is denoted as a gradient shaded area on the TSS chart and signifies that the technology is beginning to reach a level of maturity where market factors—not just technology factors—will play a major role in its overall viability. When a technology's Current Year TRL enters this gradient, the platform is ready to be assessed by the MRIs for market readiness and will most likely require more nuanced or tailored incentive strategies to further deepen adoption in the industry.



III. Market Readiness Indicators (MRIs)

Market readiness describes the viability of a platform to succeed when addressing production or economic factors that could impede the development or adoption of a platform. Unlike TSSs, which constitute a comprehensive TRL numerical score, MRIs act more as a check list of certain market attributes. A technology likely has market viability when it attains all four overarching MRI categories, as determined by internal subject matter experts at CARB and CALSTART: current market scale, investment scale, in-service applicability, and economic viability. If a technology has yet to attain all four attributes, then the technology still requires assistance from incentives or further technological development to succeed. CARB utilizes the insights derived from MRI explorations completed by the internal team to calibrate and inform MHDV funding recommendations.

Current Market Scale

This category describes the extent to which a technology is adopted in the marketplace. The current market scale of a commercially viable technology, as designated by a high TRL score, is based on the extent of commercial viability and market acceptance. This is marked by several specific signals, such as sales volume. Sales volume is a rather straightforward signal of market acceptance: a commercially viable low- or zero-emission platform has sales that begin to take market share from gasoline- or diesel-powered vehicles and equipment.

- Zero-emission yard trucks and transit buses illustrate how current market scale can indicate market readiness in the off- and on-road HD markets respectively. With support from the California Clean Off-Road Equipment (CORE) program, demand for yard trucks, and therefore sales volumes, are higher than other zero-emission off-road technologies; applications for yard truck sales met CORE's funding limit within the first day of the program's launch, with 92 approved vouchers and a wait list of more than 120 additional yard trucks (Welch, 2020). Zero-emission transit buses have even more significant sales volume; this growth can be attributed to several incentive programs and demonstration projects, including the California's Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP), that supported this early market technology. With statistics that include over 1,371 battery and fuel cell electric transit buses currently deployed, on order, or soon to be on order in California as of September 2021,² zero-emission transit buses have reached a level of technological maturity that can succeed under mandated industry

² CALSTART's [latest edition of the Zeroing in on Zero-Emissions Bus report](https://calstart.org/zeroing-in-on-zebus/) can be found at <https://calstart.org/zeroing-in-on-zebus/>

requirements—the development of the Innovative Clean Transit (ICT) regulation is a result of this success (see Section IV).

Investment Scale

Investment scale describes the commitment level of manufacturers and suppliers to a vehicle and/or technology platform. High cost, limited consumer options, and slow production times are often the result of a small number of manufacturers or suppliers producing equipment or models for new technologies. Therefore, the maturity of a platform is typically signaled by the number and size of manufacturers and suppliers working on the technology. As more manufacturers enter the marketplace, consumer choice and the number of models increases, as well as model capability to perform for different applications. Economies of scale and efficiencies in production processes also kick in as larger OEMs join, resulting in lower prices. Examples of investment scale indicators might include the following:

- The increasing scale of zero-emission school bus production and the number of manufacturers developing all electric school bus models act as a strong signal for this technology's market readiness. Blue Bird, for instance, announced 500 electric-powered school buses delivered or on order—a milestone for this technologically mature platform. By 2021, nine different manufacturers plan to offer 17 distinct school bus models in the North American market, with multiple model options available for each currently commercial school bus type (BusinessWire, 2021; CALSTART, 2020a).
- An increasing number of traditional truck manufacturers are working to bring zero-emission HD delivery and short-range drayage trucks from demonstration to commercialization: for example, Peterbilt's Model 579EV, Volvo's VNR electric, and Daimler's Freightliner eCascadia Class 8 truck have been brought to market and/or are being delivered to customers. GM and Ford are beginning to do the same for MD vans with the BrightDrop EV600 and the Ford E-Transit (GM, 2021; Mihalascu, 2022). In addition, numerous dedicated zero-emission OEMs, like BYD and Lion Electric, are also delivering substantial amounts of HD trucks to customers (Al-Alawi, 2021).

In-Service Applicability

To achieve a self-sustaining market, clean technologies must perform as required by fleet operators and fulfill duty cycles in real-world scenarios. In-service applicability describes a technology's ability to meet range requirements, access refueling/recharging stations, and overcome power or stored energy limitations. An application's ability to overcome these challenges signals how quickly the technology will become commercially viable.

- Small battery-electric excavators exemplify achievement of in-service applicability: with relatively low power requirements and access to charging stations, current models provide high performance. While often initially sought for indoor use to increase workplace safety with reduced emissions and noise, many small battery-electric excavators are now used for

both indoor and outdoor applications. Yard trucks also demonstrate in-service applicability for similar reasons: these specialized off-road vehicles have unique duty cycles that consist of low top speeds, frequent stops and starts, significant idle time waiting for containers to be loaded/unloaded, and heavy loads. Battery sizes available in current models allow most full shifts to be completed on a single charge, and yard trucks rarely stray far from their facilities, negating any range concerns. Additionally, warehouses, cargo yards, and ports where yard trucks tend to work are favorable for infrastructure placement and charging operations.

- Long-haul fuel cell electric vehicles (FCEVs) are also signaling market readiness with a successful demonstration project in Switzerland. A fleet of Hyundai XCIENT fuel cell trucks has met the demands of rigorous duty cycles and exceeded travel of one million kilometers since 2019: lighter weight, faster fueling, available torque, and shared infrastructure in targeted corridor stations have mitigated range concerns (FuelCellWorks, 2021). In California, the Port of Los Angeles and its partners have deployed five new FCEVs and opened two hydrogen fueling stations under the Shore-to-Store project, with plans to include five additional hydrogen-fueled HD trucks, in order to assess the operational and technical feasibility of FCEVs and to expand infrastructure to support hydrogen throughout the region (Kenworth, 2021).
- On the other hand, for long-haul battery-electric trucks to reach a similar level of in-service applicability, significant investments in shared, high-power corridor stations to support long-distance freight movement are still necessary. Though battery-electric trucks have proven their capacity to electrify certain segments of the trucking sector, charging infrastructure will be critical to facilitate higher speeds and longer duty cycles on a large scale (St. John, 2021).

Economic Viability

This category corresponds to a new platform's total cost of ownership (TCO) and affordability when fleets are looking to transition to clean transportation. This affordability is strongly tied to the time required for the payback period of a new zero-emission vehicle or equipment to equal that of a conventionally fueled alternative. A fleet's payback period considers TCO costs such as incremental costs, operating costs (fueling and maintenance), hidden costs such as retraining staff or investing in new facilities, and other factors. The length of this payback period is variable across different platforms but imperative given the importance placed on business case in the MHDV industry. Upfront costs for zero-emission vehicles are typically higher than diesel-powered vehicles, but reduced fueling and maintenance costs over time culminate in a favorable TCO compared to conventional vehicles. Consequently, vehicles with lower purchase prices that are utilized frequently will have shorter payback periods. Typical considerations for economic viability include achievement of TCO parity with the conventional alternative; lower incremental purchase cost compared to the conventional alternative; and lower indirect/replacement/transition costs from changing technology.

- Zero-emission delivery vans and MD trucks signal economic viability: given that these smaller vehicles make short but frequent trips with lighter payloads—and often return to central terminals to charge—they do not require batteries of relatively high weight or power. These factors decrease the incremental cost of batteries and result in greater fuel cost savings compared to conventional delivery vehicles. Smaller batteries and overnight charging can also allow these vehicles to charge without incurring large time-of-use or peak demand charges, which can significantly affect TCO depending on utility service territory.
- Zero-emission school buses' efficient powertrains do not achieve high absolute fuel savings given the limited number of trips and miles driven per day, but manufacturers, operators, and utilities are beginning to roll out vehicle-to-grid (V2G) operations. V2G allows electrified vehicles to communicate and interact with the electric grid to manage charging or send power from the vehicle batteries to the grid. Utilities and school districts may be interested in V2G to manage electric grid demand during peak hours or provide regulating services, improving TCO for these applications. Several school bus manufacturers including BYD, Lion Electric, Bluebird, Navistar IC Bus, and Thomas Built offer models that come equipped with standard or optional V2G capability, allowing the bus to sell electricity to the grid and further reduce operational costs (Lion Electric, 2021; BYD, 2022; Nuvve, 2021; IC Bus, 2021; Thomas Built, 2021). At least fourteen states have school bus V2G demonstrations active or planned.

Infrastructure Installation Inhibits Market Readiness

Zero-emission vehicles require charging or refueling infrastructure and the installation cost of this equipment has proved to be a consistent barrier to market readiness in many vehicle applications. Several factors contribute to the persistent nature of this issue. First, infrastructure planning, siting, permitting, and installation approvals often take a significant amount of time, which further delays fleet deployment. Moreover, the cost of infrastructure can add overwhelming expenses to fleets already struggling to purchase zero-emission vehicles with high upfront costs. Fleets have also expressed uncertainty about the process of installing infrastructure and the available avenues of support to complete these projects. Lastly, fleets must also coordinate with utilities in order to ensure enough electricity is available to operate charging stations, meaning an increased number of stakeholders and prolonged timelines.

Understanding this challenge is vital to accelerate market readiness for clean commercial transportation. Using this assessment process to understand market readiness has resulted in the creation of new infrastructure programs and approaches to make the technologically viable electric applications more market-ready:

- [SB 350 Investments](#) aim to mitigate fleets' concerns about grid resiliency, capacity, and integration with programs approved by California Public Utilities Commission to plan, forecast, and develop rate structures with utilities.
- [Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles \(EnergIZE\)](#), a first-of-its-kind infrastructure incentive program launched by the California Energy Commission's (CEC), will help advance electric charging, as well as hydrogen refueling infrastructure for MHDVs, by providing incentives to buy down the cost of infrastructure.
- [Research Hub for Electric Technologies in Truck Applications \(RHETTA\)](#), also a CEC program, will fund advancements in high power charging systems and help to plan, design, and deploy innovative corridor charging strategies for battery-electric trucks.



IV. Impact of Technology and Market Assessments

In combination, TSSs and MRIs depict a holistic outlook on how ready clean commercial transportation vehicle and equipment platforms are to perform and their readiness for the marketplace. The ultimate purpose for these technical assessments and market explorations is to provide valuable context for agencies that have the ability to influence markets through incentives and regulations. Below is a non-exhaustive list of key incentive programs and regulations that make use of TSSs and MRIs.

Incentives

Both TSSs and MRIs provide CARB with the critical information to make sound decisions for incentive program planning according to technology maturity. TSSs serve as input to establish a common language and reference point to facilitate dialogue supported by well-defined measures and methods across organizational disciplines, departments, and business functions (GAO, 2020). TRL scores help identify which vehicles and equipment would benefit from programs to further technological development: during the report development process, next steps to increase a platform's TRL score are typically determined and can be utilized to scope the level of funding and effort required (FHWA, n.d.). And though MRIs are not score-based, discussions held for each category do offer important, general perspective on market readiness of technologies and platforms. A standardized methodology to arrive at a platform's technology maturity therefore helps improve the effectiveness of incentive programs, providing CARB with supporting documentation to affect decision-making. Below are examples of incentive programs in which CARB utilized TSS and MRI assessments to determine which platforms were ready for commercial incentives and capable of achieving clean vehicle and equipment deployment goals.

Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)

Funded by CARB and managed by CALSTART, HVIP provides point-of-sale incentives for eligible zero and near-zero emission vehicles in California. To date, the program has administered hundreds of millions of dollars to accelerate the adoption of thousands of alternative fuel MHDVs. A first-come, first-served project with no scrappage requirement, purchasers that receive HVIP funding pay the total cost of the vehicle less the incentive amount, where trained HVIP-dealers front the incremental cost of the voucher and receive a reimbursement from CALSTART after the vehicle has been deployed.

The Clean Off-Road Equipment Voucher Incentive Project (CORE)

With an initial \$44 million from the Greenhouse Gas Reduction Fund (now spent through), CORE is a streamlined voucher incentive program funded by CARB and managed by CALSTART that encourages California freight equipment users to purchase or lease currently commercialized zero-emission off-road freight equipment. This program helps offset the higher cost of zero-emission technology with a point-of-sale discount; there is no scrappage requirement, and additional funding is available for charging and fueling infrastructure and for equipment deployed in disadvantaged communities. CORE is working towards additional and larger follow-on funding and is moving beyond the freight-sector into the construction, agriculture, lawn and garden, and harbor-craft sectors.

Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles (EnergIIZE)

EnergIIZE accelerates the deployment of infrastructure needed to fuel zero-emission trucks, buses, and off-road equipment. This project will help lower the cost of infrastructure for fleets by using a concierge-like model to help eligible applicants plan and fund the purchase of charging and hydrogen fueling infrastructure. With an initial \$50 million in funding from the CEC, EnergIIZE will work with companies and public agencies to implement clean battery-electric and hydrogen vehicle technologies, benefitting communities most impacted by transportation-related pollution.

Regulations

Technology and market readiness assessments help measure technical maturity with a standard set of benchmarks or terms, in turn providing policymakers with vital information on the progress of key technologies to reduce emissions. This information and insights are therefore critical in identifying the need for climate change policies, regulations, and/or future development of resource needs. TSSs and MRIs provided valuable context to ensure that the requirements for production and/or adoption mandated in the following examples aligned with both technologically mature and market-ready vehicle and equipment applications, setting up OEMs and fleets for success and achievement of emissions goals.

Innovative Clean Transit (ICT) Regulation

Adopted in 2018, the ICT regulation requires all public transit agencies to fully transition to 100% zero-emission bus fleets by 2040. This transition will be gradual, with 100% of new zero-emission bus purchases required beginning in 2029. All transit agencies that own, operate, or lease buses with a gross vehicle weight rating greater than 14,000 lbs. must comply, which includes standard, articulated, over-the-road, double-decker, and cutaway buses.

Advanced Clean Truck (ACT) Regulation

The ACT regulation aims to help accelerate a large-scale transition of zero-emission MHDVs in weight classes 2b to 8. Manufacturers who certify Class 2b-8 chassis or complete vehicles with combustion engines are required to sell zero-emission trucks as an increasing percentage of their annual California sales from 2024 to 2035. By 2035, zero-emission truck/chassis sales would need to

be 55% of Class 2b – 3 truck sales, 75% of Class 4 – 8 straight truck sales, and 40% of truck tractor sales. Fleet owners with 50 or more trucks are also required to report information for their existing fleet operations, which will provide insight on future regulations and requirements for purchasing available zero-emission trucks capable of meeting fleets' needs.

Advanced Clean Fleets (ACF) Regulation

The ACF regulation is being developed to accelerate the market for both zero-emission trucks and buses and is part of a statewide effort to reduce emissions from transportation. Intended to help improve air quality and public health and to meet economy-wide Carbon Neutrality by 2045, among other climate goals, the ACF regulation will require fleets that are well suited for electrification to transition to zero-emission vehicles where feasible and will assist in achieving the Governor's Executive Order N-79-20 to reach:

- 100% zero-emission drayage trucks by 2035;
- 100% zero-emission off-road vehicles and equipment by 2035, where feasible; and
- 100% zero-emission MHDVs by 2045, where feasible.

The proposed draft regulation contains an end to combustion truck sales, requiring 100% zero-emission MHDV sales by 2040.

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Appendix A: TRL Scoring Rubric

Table A-1: TRL Scoring Rubric

TRL Level	General Technology Level	TRL Definition	Example Technology
9	Early Market	Full commercial application; Technology in general availability for users. Manufacturing phase. Successfully operated in uncontrolled commercial environment.	Battery-Electric Bus; FCEV Forklift; Methane Engine 8.9L
8	Large Scale Pilot	Pre-production. First of its kind commercial system. Technology ready to support commercial activity. In limited release assessment numbers. Vehicle succeeds in uncontrolled environment.	Battery-Electric Harbor Craft Vessels; Battery-Electric Mobile Power Unit
7	Early Pilot/Late Demonstration	Demonstration system. Operating in intended environment at pre-commercial scale. Units succeeds in a relevant environment.	FCEV Drayage; FCEV Harbor Craft Vessels
6	Early Demonstration (Advanced Prototype System)	Tested in intended environment at close to expected performance. Limited vehicle builds. Vehicle succeeds in first real world scenarios.	0.02 NOx Diesel Engine; FCEV Automated Guided Vehicle
5	Prototype	Large scale prototypes. Tested in intended environment; tested well enough to validate in real world scenarios.	John Deere Gridcon Autonomous Tractor
4	Technology Development	Small scale (ugly) prototypes. First prototypes built, tested to perform under specific conditions.	Fully Autonomous Long-Haul Trucks
3	Research	Benefits and viability of technology confirmed in lab. (Pre-Prototype)	
2	Research	Early invention stage. Concept and application have been finalized.	
1	Research	Scientific evidence for potential innovation.	