Methods for Assessing Technology and Market Readiness for Clean Commercial Transportation

October 2022
Acknowledgments

This report will be updated on a periodic basis in support of the publication of the California Air Resources Board’s Appendix D: Long-Term Heavy-Duty Investment Strategy. A previous version of this report was published in March 2022.

No part of this document may be reproduced or transmitted in any form or by any means—electronic, mechanical, photocopying, recording, or otherwise—without prior written permission by CALSTART. Requests for permission or further information should be addressed to CALSTART, 48 S. Chester Ave, Pasadena, CA 91106 or Publications@CALSTART.org.

All rights reserved.
# Table of Contents

Acknowledgments ......................................................................................................................... ii  
List of Acronyms ........................................................................................................................ iv  
List of Figures and Tables ............................................................................................................... v  
Figures ...................................................................................................................................... v  
Tables ....................................................................................................................................... v  
Executive Summary ....................................................................................................................... 1  
I. Introduction .................................................................................................................................. 3  
II. Technology Status ...................................................................................................................... 5  
   Technology Readiness Level Scoring Methodology ........................................................... 7  
   Technology Status Snapshots ............................................................................................... 8  
III. Market Readiness .................................................................................................................... 11  
   Market Readiness Scoring Methodology ........................................................................... 11  
   Market Readiness Snapshots ............................................................................................... 13  
IV. Impact of Technology and Market Assessments ................................................................ 17  
   Incentives .............................................................................................................................. 17  
   Regulations ........................................................................................................................... 19  
References .................................................................................................................................... 21  
Appendix A: Technology Readiness Scoring Rubric ................................................................. 22  
Appendix B: Market Readiness Scoring Rubric ......................................................................... 23
## List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACF</td>
<td>Advanced Clean Fleets</td>
</tr>
<tr>
<td>ACT</td>
<td>Advanced Clean Trucks</td>
</tr>
<tr>
<td>CARB</td>
<td>California Air Resources Board</td>
</tr>
<tr>
<td>CEC</td>
<td>California Energy Commission</td>
</tr>
<tr>
<td>CORE</td>
<td>Clean Off-Road Equipment Voucher Incentive Project</td>
</tr>
<tr>
<td>EnergIIZE</td>
<td>Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles</td>
</tr>
<tr>
<td>HDIS</td>
<td>Appendix D: Long-Term Heavy-Duty Investment Strategy</td>
</tr>
<tr>
<td>HVIP</td>
<td>Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project</td>
</tr>
<tr>
<td>ICT</td>
<td>Innovative Clean Transit</td>
</tr>
<tr>
<td>MHD</td>
<td>Medium- and Heavy-Duty</td>
</tr>
<tr>
<td>LCFS</td>
<td>Low Carbon Fuel Standard</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
</tr>
<tr>
<td>ZE</td>
<td>Zero-Emission</td>
</tr>
</tbody>
</table>
List of Figures and Tables

Figures

Figure 1. Technology Status Snapshot Example: On-Road Fuel Cell Electric (CARB, 2022)
Figure 2. Technology Status Snapshot Example: Off-Road Battery-Electric: Cargo Handling Equipment (CARB, 2022)
Figure 3. Market Readiness Snapshot Example: On-Road Battery-Electric (CARB, 2022)
Figure 4. Market Readiness Snapshot Example: Off-Road Battery-Electric (CARB, 2022)

Tables

Table A-1: Technology Readiness Level Scoring Rubric
Table B-1: Market Readiness Scoring Rubric – Production Capacity, Service Network, and TCO Cost Parity
Table B-2: Market Readiness Scoring Rubric – Duty Cycle Capability and Infrastructure
Executive Summary

CALSTART and the California Air Resources Board (CARB) conduct yearly assessments to analyze the technology status and market progress of zero-emission (ZE) medium- and heavy-duty (MHD) vehicle 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 and market readiness snapshots. These snapshots are key to the development and direction of successful incentive policy and regulation. CARB utilizes the insights derived from these snapshot updates each year to calibrate and inform MHD vehicle and equipment 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 (HDIS).

In combination, the technology status and market readiness snapshots depict a comprehensive view of clean commercial vehicle and equipment platform performance and readiness for the marketplace:

- Technology status snapshots assess the maturity level of a particular technology, determining viability primarily from technological performance. CALSTART and CARB use technology readiness levels (TRLs) to score four categories that currently include applications for both on-road and off-road platforms for battery-electric vehicles and equipment and fuel cell electric vehicles and equipment. Within these four categories, platforms receive individual TRL scores measured on a scale from one to nine, with nine being a commercially mature application. TRL scores are then visualized as graphics that are published in CARB’s HDIS each year.

- Market readiness snapshots help describe a platform’s viability for success with respect to market or economic factors that could impede development or adoption. Technology platforms that have reached a TRL greater than eight are evaluated against the following six market readiness indicators: production capacity, service network, total cost of ownership cost parity (with and without incentives), duty cycle capability, and infrastructure. Platforms receive a score of 0%, 25%, 50%, 75%, or 100%, which are then visualized as graphics in the HDIS.
The ultimate purpose of these technology and market snapshots is to provide valuable context for agencies that can influence vehicle and equipment markets through incentives or regulations. Incentive programs have used technical and market assessments to support funding and clean vehicle and equipment deployment goals. This approach helps 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.
1. Introduction

To help track the status and progress of the emerging market for clean medium- and heavy-duty (MHD) vehicle 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, which are included each year in CARB’s Appendix D: Long-Term Heavy-Duty Investment Strategy (HDIS).¹ The State of California’s goals to improve air quality are directly tied to fostering and supporting a self-sustained market for zero-emission (ZE) and ZE-enabling vehicles and equipment. Several technology and market-based hurdles currently hinder this market development. To help accelerate the viability of clean MHD vehicles and equipment, 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 MHD vehicles and equipment are vital to the development and direction of incentive policy and regulation. These yearly assessments, known as technology status and market readiness updates, or “snapshots,” help ensure that vehicle and equipment technology platforms receive appropriate CARB funding.

These assessments each describe distinct maturity levels in the commercialization process for clean vehicle and equipment applications. Technology status snapshots 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. Market readiness snapshots provide a more complete picture of an application’s commercialization status within a complex market. Market readiness can be assessed by considering six major indicators: production capacity, service network, total cost of ownership (TCO) cost parity (with and without incentives), duty cycle capability, and infrastructure.

¹ The Fiscal Year 2022-23 HDIS can be found in CARB’s Low Carbon Transportation Investments and Air Quality Improvement Program (Clean Transportation Incentives) Funding Plan at https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program/low-1.
Creating standardized, numerical assessments for technology and market readiness provides consistent viability scorecards 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 snapshots (Section II); describe the six market readiness categories and how each indicates a platform’s viability for success (Section III); and highlight examples of both incentive programs and regulations that have been supported by these assessments (Section IV). Appendix A: TRL Scoring Rubric provides a copy of the rubric utilized by CALSTART and CARB’s internal team of subject matter experts during the TRL scoring process. Finally, Appendix B: Market Readiness Scoring Rubric provides tables detailing the scoring criteria for each market readiness indicator.
II. Technology Status

A clean commercial technology’s path to commercialization can be understood first and foremost by a technology status snapshot. The goal of these technical assessments for MHD vehicle and equipment applications is to determine a platform’s viability primarily from its technological performance. As such, technology status snapshots provide directional guidance, but not precise measurements, on a technology’s readiness for commercialization. Status updates for MHD vehicles and equipment 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. They 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 assessments to ensure the continued effectiveness of its policies and investments as described in the HDIS.

To quantitatively assess a vehicle or equipment’s technology status, 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 MHD vehicle or equipment platform, rather than a single component or technology system. CALSTART and CARB use TRLs to score four categories, though these categories have changed over time. These categories currently include vehicle and equipment applications for both on-road and off-road:

- On-road battery-electric
- On-road fuel cell electric
- Off-road battery-electric
- Off-road fuel cell electric
Within these four 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 long haul
- Heavy-duty urban/regional/drayage
- Medium-duty truck
- Step van
- Shuttle bus
- School bus
- Transit bus
- Coach bus
- Cargo van
- Refuse truck
- Work truck

TRLs are measured on a scale from one to nine, with one defined as platforms with scientific evidence for potential innovation and nine 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, which include review of additional or updated data and information from literature, public information sources, conversations with technology providers, and field data where available. The approach detailed below is enacted, reviewed, and modified (if necessary) by CALSTART and CARB every year prior to the publication of the HDIS. These scores do not incorporate or address market placement.
Technology Status Snapshots

Graphics depicting TRL scores are developed and published in CARB’s HDIS for each of the four categories listed above. Each graphic contains the following elements, which may have changed over time in previous iterations of the HDIS. Current examples from the Fiscal Year 2022-23 HDIS are shown below (Figure 1 and Figure 2).

- The x-axis follows the TRL scores from five to nine and into market readiness (i.e., commercially ready) beyond nine. 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 five, rather than one, as any platform receiving a TRL score of one through four would not be ready for demonstration projects. For the purposes of the HDIS, applications are characterized in terms of three general stages on the path to commercialization: demonstration, pilot, and commercial.
- The weighted status of each platform is shown by a triangle 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. This can inform where general industry capabilities lie.

---

2 For matters of formatting and legibility, the off-road battery-electric chart was split into three separate graphics in the Fiscal Year 2022-23 HDIS, grouped by application type.
Technology Readiness Level Scoring Methodology

- 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.

- 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.

- 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 calibrate results and rectify any large discrepancies in the scoring.

- Once each score has been vetted by industry experts, the impact each vehicle and/or equipment model has on the entire TRL platform is weighted based on a manufacturer multiplier, which gives a higher weighting to platforms from companies that have larger market penetration and demonstrated ability to ramp up 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 overall technical and commercial readiness. TRLs are therefore displayed as the general aggregated score of assessed and weighted scores within a platform. In doing so, this approach may result in a platform receiving a score of seven or eight (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.

- Once the TRL score for each platform is determined, the results are visualized in graphics, which are described below.
Figure 1. Technology Status Snapshot Example: On-Road Fuel Cell Electric (CARB, 2022)
When a platform begins to reach a TRL of eight, it enters the “Readiness Gradient Area.” This area is denoted as a gradient shaded area on the technology status snapshot graphic 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 for market readiness and will most likely require more nuanced or tailored incentive strategies to further deepen adoption in the industry.
III. Market Readiness

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. Similar to technology status snapshots, which constitute a comprehensive TRL numerical score, market readiness snapshots provide a score for a vehicle or equipment’s attainment of certain market attributes. A technology likely has market viability when it attains a high score in all six overarching market readiness categories, as determined by internal subject matter experts at CARB and CALSTART: production capacity, service network, TCO cost parity (with and without incentives), duty cycle capability, and infrastructure. If a technology has yet to attain high scores in all six categories, then the technology still requires assistance from incentives or other market development mechanisms to succeed. CARB utilizes the insights derived from market readiness snapshots completed by the internal team to calibrate and inform MHD vehicle and equipment funding recommendations.

Market Readiness Scoring Methodology

Similar to the TRL methodology, determining a market readiness 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 identifies vehicle and equipment platforms that have scored an eight or above with respect to technology readiness (i.e., entered the commercial “Readiness Gradient Area”) to be assessed for market readiness.

Members of the internal CALSTART and CARB team assess and record each vehicle or equipment segment’s market readiness on a scale of 0% to 100%, in 25% increments, for each of the six indicators described in detail below. Scores are assessed according to the scoring rubric, which is found in Appendix B: Market Readiness Scoring Rubric.

Production Capacity

This category estimates the current manufacturing capacity of an on- or off-road technology segment, where 0% represents production limited to pilot/demonstration vehicles, while 100% represents the case where multiple OEMs have begun serial production at relatively high volumes and are positioned to meet the entirety of current diesel market demand in the next one to five years.
Service Network

Service network measures the existence and accessibility of a workforce for maintenance and repair of the ZE vehicles and equipment. A score of 0% corresponds to the case where no service network is available through the OEM, dealer, or independently in California. A score of 100% corresponds to the case where a developed service network exists that is geographically distributed to serve demand; there are no wait times significant enough to inhibit uptime of the vehicles and equipment.

TCO Cost Parity (With and Without Incentives)

Cost parity is a measure of the difference between ZE TCO and diesel or gasoline TCO. TCO analysis is based on CARB’s draft Advanced Clean Fleets (ACF) TCO analysis and makes all the same assumptions. Two cases are presented: one in which Low Carbon Fuel Standard (LCFS) credits are the only form of incentive included in the platform’s TCO, and another where both LCFS credits and current Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)/Clean Off-Road Equipment Voucher Incentive Project (CORE) incentives are included. All TCOs are projected to 2025. For both TCO categories, a score of 0% corresponds to the case where the ZE TCO is greater than 30% higher than diesel TCO. A score of 100% corresponds to the case where the ZE TCO is at or below cost parity with diesel.

Duty Cycle Applicability

Duty cycle applicability measures how well a given technology platform can meet the range of duty cycles required of it. For on-road vehicles, a score of 0% represents the case where range, payload capacity, and power of ZE models are not sufficient to meet the majority of duty cycle requirements, while a score of 100% means that ZE models can meet all known requirements. For off-road technologies, a 100% score corresponds to the case where power, lift capacity, and operating time of ZE models are sufficient to meet duty cycle requirements.

Infrastructure

This category measures the extent to which charging or refueling infrastructure is available and easy to install for a given on- or off-road vehicle platform. A score of 0% represents the case where the appropriate charging or refueling infrastructure is completely unavailable commercially or in pilot/demonstration projects. A score of 100%, on the other hand, represents the case where charging or refueling equipment is completely available.

---

3 For more information on CARB’s “Draft Advanced Clean Fleets Total Cost of Ownership Discussion Document,” visit https://www2.arb.ca.gov/sites/default/files/2021-08/210909costdoc_ADA.pdf.
to customers who want it with no significant barriers (e.g., high cost, difficult and long permitting process, difficult utility connection/coordination, or high utility rates).

Once industry experts have scored each segment against the six categories above, a discussion is then held to calibrate results and rectify any large discrepancies in the scoring. Upon determination of the final market readiness scores for each segment, the results are visualized in market readiness snapshots, which are described below.

**Market Readiness Snapshots**

For the first time in the FY 2022-23 HDIS, these snapshots are provided for all technologies that have achieved a TRL of eight or greater. Each chart (Figure 3 and Figure 4) contains the following elements:

- Technology segments are listed along the left side with market readiness indicator categories across the top.
- The score for each market readiness indicator is shown as a circle, or pie shape, that is shaded to represent 0%, 25%, 50%, 75%, or 100%.
**Figure 3. Market Readiness Snapshot Example: On-Road Battery-Electric (CARB, 2022)**

<table>
<thead>
<tr>
<th></th>
<th>Production Capacity</th>
<th>Service Network</th>
<th>TCO Cost Parity</th>
<th>TCO Cost Parity with Incentives</th>
<th>Duty Cycle Capability</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD Long Haul</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HD Urban/Regional/Drayage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step Van</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargo Van</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refuse Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shuttle Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coach Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**

- 0%
- 25%
- 50%
- 75%
- 100%
Figure 4. Market Readiness Snapshot Example: Off-Road Battery-Electric (CARB, 2022)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Production Capacity</th>
<th>Service Network</th>
<th>TCO Cost Parity</th>
<th>TCO Cost Parity with Incentives</th>
<th>Duty Cycle Capability</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yard Truck</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>RTG Crane</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>Forklift (Light)</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>Forklift (Heavy)</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>Excavator (Light)</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>Compact Track Loader/</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>Skid Steer</td>
<td><img src="#" alt="Yellow" /></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airport GSE (Light)</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>Switcher Locomotive</td>
<td><img src="#" alt="Yellow" /></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railcar Mover</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>TRU</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
<tr>
<td>GPU/MPU</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
</tr>
</tbody>
</table>

**Legend**

- **0%**
- **25%**
- **50%**
- **75%**
- **100%**
**Infrastructure Installation Inhibits Market Readiness**

ZE vehicles and equipment require charging or refueling infrastructure, and these installation costs have proved to be a consistent barrier to market readiness in many 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 ZE vehicles and equipment 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, prolonged timelines, and sometimes exorbitant “make-ready” costs.

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 (EnerGIIZE) Commercial Vehicles**, a first-of-its-kind infrastructure incentive program launched by the California Energy Commission (CEC), is helping advance electric charging, as well as hydrogen refueling infrastructure, for MHD vehicles 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, technology status and market readiness snapshots 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 and market assessments 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 these snapshots.

Incentives

Both technology status and market readiness snapshots provide CARB with critical information to make sound decisions for incentive program planning according to technological maturity. Technology status snapshots 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 (U.S. Government Accountability Office, 2020). TRL scores help identify which vehicles and equipment would benefit from programs to further technological development: during the 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 (Federal Highway Administration, n.d.). A standardized methodology to arrive at a platform’s technology maturity, and now market readiness as well, 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 technical and market 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

Funded by CARB and managed by CALSTART, HVIP provides point-of-sale incentives for eligible ZE and near-ZE vehicles in California. To date, the program has administered hundreds of millions of dollars to accelerate the adoption of thousands of alternative fuel MHD vehicles. 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 is a streamlined voucher incentive program funded by CARB and managed by CALSTART that encourages California freight, construction, agriculture, lawn and garden, and harbor-craft equipment users to purchase or lease currently commercialized ZE off-road equipment. This program helps offset the higher cost of ZE technology with a point-of-sale discount; there is no scrappage requirement, and additional funding is available for equipment deployed in disadvantaged communities.°

Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles

EnergIIZE Commercial Vehicles accelerates the deployment of infrastructure needed to fuel ZE trucks, buses, and off-road equipment. This project helps 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 works with companies and public agencies to implement clean battery-electric and hydrogen vehicle technologies, benefitting communities most impacted by transportation-related pollution.°

° Learn more about HVIP at https://californiahvip.org/about/.

° Learn more about CORE at https://californiacore.org/.

° Learn more about EnergIIZE Commercial Vehicles at https://energiize.org/.
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. These snapshots 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 reduction goals.

Innovative Clean Transit Regulation

Adopted in 2018, the Innovative Clean Transit (ICT) regulation requires all public transit agencies to fully transition to 100% ZE bus fleets by 2040. This transition will be gradual, with 100% of new ZE 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 pounds must comply, which includes standard, articulated, over-the-road, double-decker, and cutaway buses.7

Advanced Clean Trucks Regulation

The Advanced Clean Trucks (ACT) regulation aims to help accelerate a large-scale transition of ZE MHD vehicles in weight classes 2b – 8. Manufacturers that certify Class 2b – 8 chassis or complete vehicles with combustion engines are required to sell ZE trucks as an increasing percentage of their annual California sales from 2024 to 2035. By 2035, ZE truck/chassis sales will 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 ZE trucks capable of meeting fleets’ needs.8

---

7 Learn more about the ICT regulation at https://ww2.arb.ca.gov/resources/fact-sheets/innovative-clean-transit-ict-regulation-fact-sheet.

8 Learn more about the ACT regulation at https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks.
Advanced Clean Fleets Regulation

The ACF regulation has been proposed to accelerate the market for both ZE 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 ZE vehicles where feasible and will assist in achieving the Governor’s Executive Order N-79-20 to reach:

- 100% ZE drayage trucks by 2035;
- 100% ZE off-road vehicles and equipment by 2035, where feasible; and
- 100% ZE MHD vehicles by 2045, where feasible.

The proposed draft regulation contains an end to combustion truck sales, requiring 100% ZE MHD vehicle sales by 2040.⁹

---

⁹ Learn more about the proposed ACF regulation at https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets.
References


## Appendix A: Technology Readiness Scoring Rubric

### Table A-1: Technology Readiness Level Scoring Rubric

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

### Table B-1: Market Readiness Scoring Rubric – Production Capacity, Service Network, and TCO Cost Parity

<table>
<thead>
<tr>
<th>MRI Score</th>
<th>Production Capacity</th>
<th>Service Network</th>
<th>TCO Cost Parity&lt;sup&gt;10&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>Production capacity is limited to prototypes or pilot/demonstration vehicles.</td>
<td>No service network&lt;sup&gt;11&lt;/sup&gt; is available through the OEM, dealer, or independently in California.</td>
<td>2025 ZE TCO is greater than 30% higher than diesel TCO.</td>
</tr>
<tr>
<td>25%</td>
<td>Production capacity is limited to small volumes of vehicles currently, although vehicles may be entering serial production soon.</td>
<td>Some service network is trained and available in California, but not widely enough to provide ZE customers certainty that their vehicles will be repaired in a timely fashion. Customers regularly experience significant delays that prevent the full utilization of ZE vehicles and deter them from adopting future ZE vehicles.</td>
<td>2025 ZEV TCO is between 20-30% higher than diesel TCO.</td>
</tr>
<tr>
<td>50%</td>
<td>At least one OEM has begun serial production at relatively high production volumes (above specialized/retrofit manufacturing).&lt;sup&gt;12&lt;/sup&gt;</td>
<td>Some workforce is trained and available in California, but not widely enough to provide ZE customers certainty that their vehicles will be repaired in a timely fashion. Some customers experience significant delays that prevent the full utilization of ZE vehicles and deter them from adopting future ZE vehicles.</td>
<td>2025 ZE TCO is between 10-20% higher than diesel TCO.</td>
</tr>
</tbody>
</table>

<sup>10</sup> TCO Cost Parity includes LCFS only, no incentives; TCO Cost Parity with Incentives includes available funding from HVIP, CORE, etc.

<sup>11</sup> A service network is defined as a system of professionals capable of repairing and/or maintaining ZE vehicles.

<sup>12</sup> This measurement is weighed against market size for each vehicle segment.
<table>
<thead>
<tr>
<th>MRI Score</th>
<th>Production Capacity</th>
<th>Service Network</th>
<th>TCO Cost Parity$^{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>75%</td>
<td>Multiple OEMs have begun serial production at relatively high volumes (above specialized/retrofit manufacturing) and are positioned to meet the entirety of current diesel market demand in the next 5-10 years if demand were to increase.</td>
<td>A well-trained workforce exists and is available but is unevenly distributed geographically within California.</td>
<td>2025 ZE TCO is between 5-10% higher than diesel TCO.</td>
</tr>
<tr>
<td>100%</td>
<td>Multiple OEMs have begun serial production at relatively high volumes (above specialized/retrofit manufacturing) and are positioned to meet the entirety of current diesel market demand in the next one to five years if demand were to increase.</td>
<td>A well-trained workforce exists and is available to all customers who need it regardless of geographic location.</td>
<td>2025 ZE TCO is at or below cost parity with diesel.</td>
</tr>
</tbody>
</table>
**Table B-2: Market Readiness Scoring Rubric – Duty Cycle Capability and Infrastructure**

<table>
<thead>
<tr>
<th>MRI Score</th>
<th>Duty Cycle Capability</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>Range, payload capacity, and power of ZE models are not sufficient to meet the majority of duty cycle requirements.</td>
<td>Appropriate charging/refueling equipment is completely unavailable commercially and in pilot/demonstration projects.</td>
</tr>
<tr>
<td>25%</td>
<td>Only one of range, payload capacity, or power requirements is sufficient.</td>
<td>Appropriate charging/refueling equipment is available in small quantities commercially or in pilot/demonstration projects.</td>
</tr>
<tr>
<td>50%</td>
<td>Two of range, payload capacity, or power requirements is sufficient.</td>
<td>Appropriate charging/refueling equipment is available commercially but has one or more significant barriers(^{13}) which may prevent the installation of charging infrastructure or the adoption of ZE vehicles.</td>
</tr>
<tr>
<td>75%</td>
<td>Range, payload capacity, and power are sufficient to meet the majority of duty cycle requirements.</td>
<td>Appropriate charging/refueling equipment is available commercially, but has one or more significant barriers that are on track to be overcome and do not necessarily prevent installation of charging infrastructure or adoption of ZE vehicles.</td>
</tr>
<tr>
<td>100%</td>
<td>Range, payload capacity, and power are sufficient to meet all known duty cycle requirements.</td>
<td>Charging/refueling equipment is completely available to all customers who want it with no significant barriers.</td>
</tr>
</tbody>
</table>

\(^{13}\) Significant barriers include high cost, difficult and long permitting process, difficult utility connection/coordination, and high utility rates.