Port of LONG BEACH
THE GREEN PORT

THE PORT OF LOS ANGELES

2021 UPDATE: FEASIBILITY ASSESSMENT for DRAYAGE TRUCKS

February 2023

SAN PEDRO BAY PORTS
CLEAN AIR ACTION PLAN

PAGE INTENTIONALLY LEFT BLANK

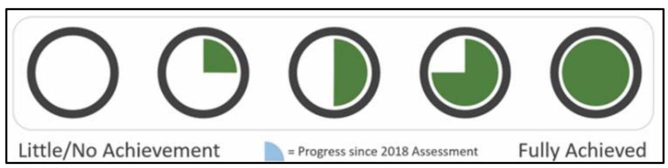
SAN PEDRO BAY PORTS
CLEAN AIR ACTION PLAN

Important Notes: 2021 Feasibility Assessment for Drayage Trucks

The San Pedro Bay Ports Clean Air Action Plan (CAAP) 2017 Update established the need to prepare feasibility assessments to evaluate the status of technology and supporting infrastructure that will be required to achieve the various CAAP strategies. This 2021 Feasibility Assessment for Drayage Trucks follows on and updates the initial Assessment performed in 2018. As with the 2018 version, this 2021 Assessment is intended to evaluate the current state of zero-emission (ZE) and low-emission (LE)[1] fuel-technology platforms suitable for drayage-capable Class 8 trucks – including infrastructure readiness to fuel and service them. The Assessment's overarching objective is to characterize feasibility for near-term (2021 to 2024), large-scale deployments of drayage trucks using such platforms.

This Assessment provides a snapshot about which ZE and/or LE Class 8 platforms are feasible today – or will likely be feasible by 2024 – for widespread deployment in drayage at the San Pedro Bay Ports (SPBP or Ports) complex. Please refer to the "Framework for Clean Air Action Plan Feasibility Assessments" document[2] for the overall process and intent as laid forth in the CAAP. This Assessment is not meant to be a policy document, nor to inventory emission reductions that could be realized through the use of ZE and/or LE drayage trucks, nor to characterize the associated health benefits. It is not meant to establish timelines for meeting various CAAP goals, or forecast commercialization (especially beyond 2024).

Using the same basic methodology as the inaugural 2018 report, this 2021 Assessment uses tables to summarize ratings about the relative degree to which various Class 8 truck fuel-technology platforms are deemed to be "feasible" today. This is done for four key feasibility parameters: Commercial Availability, Operational Feasibility, Infrastructure Availability, and Economic Workability. A different rating system is used to gauge Technical Viability. For each main feasibility parameter and the individual criteria that define it, these tables show "pie wedge" ratings in quarter increments. As the above figure shows, ratings range from "little/no achievement" for a given feasibility criteria, to "fully achieved" today. Note that the rating system for this 2021 Assessment has been updated to include blue wedges, which highlight changes (improvements) in feasibility ratings (if any) *since the 2018 Assessment*.



The use of pie ratings is not meant to represent precise percentages of achievement for a given feasibility criteria. Rather, these ratings summarize the relative degrees of progress towards full or near-full achievement.

This Assessment does not include end user monetary incentives when calculating feasibility for every parameter. Incentive sums fluctuate, have uncertain long-term availability, and are not necessarily available to all end users. Thus, certain costs calculations presented in this Assessment were based on non-incentivized totals.

This Assessment was prepared over many months based on significant outreach, research, and stakeholder feedback. The final document – as well as any public comments received – will be reported to the respective Boards of Harbor Commissioners and posted at www.cleanairactionplan.org. The Ports intend to continue preparing updated drayage truck feasibility assessments at least every three years. This will be done more frequently if warranted by new, relevant information. For example, the ports may decide to annually update portions of this Assessment if new ZE and/or LE technologies become commercially available from Class 8 truck OEMs, and/or if there is a breakthrough development with charging/fueling infrastructure.

---

[1] "Low Emission (LE)" was referred to as "Near-Zero Emission (NZE)" in the 2018 Assessment; the definitions are essentially the same as used in these CAAP Drayage Truck Assessments. See the "Definitions" call-out box on page 12 and footnote 3.

[2] San Pedro Bay Ports, "Framework for Developing Feasibility Assessments", November 2017, please see https://www.cleanairactionplan.org/2017-clean-air-action-plan-update and select this report from various downloadable documents.

Authorship and Uses

This report was prepared by a consulting team consisting of individuals from Tetra Tech and its subcontractor, Gladstein, Neandross & Associates (GNA). Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply endorsement, recommendation, and/or favoring by the Ports or the report authors.

Acknowledgements

Front cover photos: Top left: Kenworth-Toyota project's zero-emission hydrogen-powered fuel cell electric Kenworth T680s, fueling at Shell hydrogen station (photo/permission from Kenworth and Port of Los Angeles); top right: near-zero-emission natural gas trucks (photo/permission from Port of Long Beach). bottom left: two Freightliner (Daimler) eCascadia zero-emission battery-electric trucks in drayage service (photo/permission from Daimler); bottom right: Volvo zero-emission battery-electric truck (photo/permission from Volvo).

Rear cover photo: Photo from the San Pedro Bay Ports.

The following Tetra Tech team members wrote, edited and/or contributed to preparation of this report:

Report Contributor; Project Role	Organization/Affiliation
Patrick Couch; Principal Investigator	Gladstein, Neandross & Associates (Subcontractor)
Jonathan (Jon) Leonard; Lead Author/Editor	
Eleanor Johnstone, Nocona Sanders, Tiara Brown; Research and Content	
Roger Lueras, Graphics Content Support	
Eddy Huang, Ph.D.; Program Manager/Report Oversight	Tetra Tech (Prime Contractor)
Charng-Ching Lin, Ph.D.; Technical Oversight	

Individuals from many organizations provided important inputs for this report, and/or generally assisted to gather information. These organizations included, but were not limited to, the Port of Long Beach, the Port of Los Angeles, the California Air Resources Board, the California Energy Commission, the South Coast Air Quality Management District, Southern California Edison, the Los Angeles Department of Water & Power, and representatives from many heavy-duty vehicle OEMs.

In addition to staff from the Port of Long Beach and the Port of Los Angeles, the following individuals served as peer reviewers for this report. In this role, they provided edits/comments/augmentations that the authors incorporated into the report.

Names of Peer Reviewers	Organization/Affiliation
Lauren Dunlap, Ray Gorski and Renee Moilanen	Starcrest Consulting Group, LLC
Kenneth Kelly	National Renewable Energy Laboratory

The authors gratefully acknowledge all the valued inputs from the contributing individuals and peer reviewers.

List of Terms

ACRONYM	DEFINITION
ACF	Advanced Clean Fleet (regulation)
ACT	Advanced Clean Truck (regulation)
BAT	Broadly applicable truck
BE	Battery electric
BET / BEV	Battery-electric truck / battery-electric vehicle
CAAP	Clean Air Action Plan
CARB	California Air Resources Board
CEC	California Energy Commission
CNG	Compressed natural gas
CO_2	Carbon dioxide
$CO2_e$	Carbon dioxide equivalents
CWI	Cummins Westport Inc.
DEF	Diesel exhaust fluid
DGE	Diesel gallons equivalent
EER	Energy economy ratio
EPA	(U.S.) Environmental Protection Agency
EVSE	Electric vehicle supply equipment
FC	Fuel cell
g/bhp-hr	Grams per brake horsepower-hour
g/hr	Grams per hour
gCO2e/MJ	Grams of carbon dioxide equivalent per mega Joule
g/mi	Grams per mile
GHGs	Greenhouse gases
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (model)
GW	Gigawatt
GWh	Gigawatt hour
HDE	Heavy-duty engine
HDV	Heavy-duty vehicle
KW	kilowatt
KWh	kilowatt hour
LADWP	Los Angeles Department of Water & Power
LCFS	Low Carbon Fuel Standard
LCNG	Liquefied-compressed natural gas
LE	Low emission (see Definitions box in Section 1.2)
LMC	Licensed motor carrier
LNG	Liquefied natural gas
MT	Metric ton
MWh	Megawatt hour
NAAQS	National Ambient Air Quality Standard
NACFE	North American Council for Freight Efficiency
NG	Natural gas
NOx	Oxides of nitrogen
NPV	Net present value
NZE	Near-zero emission
OEM	Original equipment manufacturer
OLNS	Optional Low NOx Standard
O&M	Operation and maintenance
PM	Particulate matter
$PM_{2.5}$	Fine PM (diameter equal to or smaller than 2.5 micrometers)
South Coast AQMD	South Coast Air Quality Management District
SCAB	South Coast Air Basin
SCE	Southern California Edison
SCR	Selective catalytic reduction
TCO	Total cost of ownership
TOU	Time of Use
ZE	Zero emission

Table of Contents

List of Tables

List of Figures

Executive Summary

Scope and Objective of 2021 Feasibility Assessment

Per requirements established under the San Pedro Bay Ports 2017 Clean Air Action Plan (CAAP), this report provides the 2021 Feasibility Assessment for Drayage Trucks ("2021 Assessment" or "this Assessment"). It characterizes the overall feasibility of zero-emission (**ZE**) and low-emission (**LE**)[3] Class 8 trucks of various leading fuel-technology platforms to perform drayage service at the San Pedro Bay Ports (SPBP or Ports). This 2021 Assessment builds upon and updates the inaugural "2018 Assessment," including its "2020 Addendum." While the timeline for this Assessment is roughly 2021 through 2023 ("by 2024"), all commercialization and technology status evaluations (including any projections) are made as of late 2021.

The report that follows emphasizes identifying and summarizing progress towards "feasibility" that the leading Class 8 ZE and/or LE truck platforms have made since the 2018 Assessment (including its 2020 addendum) was released. Five core ZE or LE fuel-technology platforms were initially screened for this Assessment:

1. **ZE** Battery electric
2. **ZE** Hydrogen fuel cell electric
3. **LE** Advanced diesel internal combustion engine (ICE)
4. **LE** Advanced natural gas or propane ICE
5. **LE** Hybrid-electric (electric drive hybridized with an ICE using any fuel; may include plug-in capability to provide partial ZE range)

NOTE: The Ports currently anticipate that future drayage truck feasibility assessments *will no longer evaluate fuel-technology platforms that use any type of combustion technology*. However, the Ports acknowledge that recent regulatory actions by the California Air Resources Board – especially adoption of the Advanced Clean Trucks Regulation (ACT) – <u>may</u> result in OEMs commercializing plug-in hybrid-electric Class 8 trucks that include combustion engines and can operate in <u>zero-emissions mode</u> for a prescribed portion of the daily driving range. The Ports will therefore determine on an as-needed basis if future Assessments (or updates) should evaluate the feasibility of such CARB-defined "near-zero-emission" (NZE) technology, for potential commercialization and broad deployment.

Feasibility continues to be broadly defined as the ability of a ZE or LE drayage truck platform (as defined further on page 3, "Definitions") to provide similar (or better) overall performance and achievement compared to today's baseline diesel ICE drayage truck, when used for all types of drayage service at the San Pedro Bay Ports. The following five key parameters have been collectively applied to assess overall feasibility.

- Commercial Availability
- Technical Viability
- Operational Feasibility
- Availability of Infrastructure and Fuel
- Economic Workability (Key Economic Considerations and Issues)

All five of these parameters interact to collectively define feasibility. However, two feasibility parameters – Commercial Availability and Technical Viability – were used to *initially screen* the five core ZE and LE fuel-technology platforms. Any fuel-technology platforms shown to currently meet (or approach meeting) basic considerations for these two parameters were then further assessed, by applying the three remaining feasibility parameters (Operational Feasibility, Availability of Infrastructure and Fuel, and Economic Workability).

Results and findings of this <u>2021 Feasibility Assessment for Drayage Trucks</u> – including key updates since 2018 – are summarized below. As in 2018, these latest findings *represent a snapshot in time*; they are not intended to preclude or discourage expanded development, demonstration or deployment of ZE and/or LE fuel-technology platforms that have not yet reached sufficient technological and commercial maturity to be deemed feasible. In particular, Class 8 truck OEMs (with their technology partners and fuel providers) are demonstrating ZE hydrogen fuel cell trucks in increasing numbers; the Ports are closely monitoring progress.

---

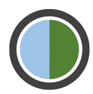
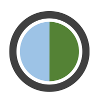
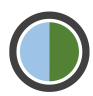
[3]This 2021 Assessment uses the term "LE" (low-emission), whereas the 2018 Assessment used the term "NZE" (near-zero-emission). This change for the 2021 Assessment was necessary because CARB adopted a new definition of "NZE" in 2020. Please see the "Definitions" call-out box (Section 1, page 12). As noted, the term "LE" is applied for this 2021 Assessment identically to how "NZE" was applied for the 2018 Assessment.

Summary of Findings for Commercial Availability

NOTE: the inputs and data for analyses in this Assessment – including truck price estimates -- were collected in mid-2021. Subsequently, substantial price increases occurred due to COVID-related supply chain constraints, which contributed to unusually high inflation affecting all financial sectors. High inflation has impacted pricing on baseline diesel drayage trucks (and fuel), as well as ZE/LE trucks and the energy they consume. Similarly, subsequent supply chain disruptions have resulted in limited manufacturing slots and extended delivery times for all types of new heavy-duty vehicles (HDVs). It remains to be seen how long these impacts will persist, and whether 2021 will prove to be an anomalous year. Notwithstanding the supply chain issues that dominated HDV markets at this report's publishing, it appears that hundreds (if not thousands) of ZE and/or LE Class 8 tractors could potentially be manufactured and available for port drayage by the late-2022 / early-2023 timeframe.

As of late-2021: one **ZE** fuel-technology platform (battery-electric) and one **LE** fuel-technology platform (natural gas ICE) are sold by original equipment manufacturers (OEMs) in commercially available Class 8 trucks that can be used in drayage. The table below summarizes Commercial Availability findings for each of the five core fuel-technology platforms, in terms of relative achievement (quarter "pie" increments) for key criteria and base considerations. For each commercialization criterion (the first column), **blue** pie wedges specifically indicate progress made (if any) since the 2018 Assessment. The table is followed by a summary of findings in narrative form, for each of the five core fuel-technology platforms.

Summary of ratings by key criteria: 2021 Commercial Availability

Commercialization Criteria	Base Considerations	Assessment of Criteria Achievement in 2021 by Leading ZE and LE Fuel-Technology Drayage Truck Platforms				
		ZE Battery-Electric	ZE Fuel Cell	LE Hybrid Electric	LE NG ICE	LE Diesel ICE
Production and Sales with Major OEM Involvement	Production and CARB certification by either a major Class 8 truck OEM, or by a proven technology provider that has partnered with the major OEM.					
Proven Network/Capabilities for Sales, Support and Warranty	Demonstrated existing (or near-term planned) network of sufficient dealerships to sell, service, warranty and provide parts for all commercially deployed drayage trucks.					
Sufficient Means and Timeline for Production	Demonstrated capability to manufacture sufficient numbers of Class 8 trucks (suitable for drayage) within timeline to meet existing or expected demand.					
Existence of Current and/or Near-Term Equipment Orders	Demonstrated backlog of orders, or credible expression of interest from prospective customers to submit near-term orders.					

Legend: Commercial Availability (2021)

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

Source of Ratings: based on OEM survey responses, OEM product information, various government sources, and consultant's industry knowledge.

ZE Battery-Electric – This fuel-technology platform essentially meets all key criteria for commercial availability. As the **blue** pie wedges indicate, ZE battery-electric trucks have progressed significantly for overall commercial maturity and viability since 2018. As of late-2021, seven heavy-duty truck OEMs have announced initiation of small-scale manufacturing and sales for early commercial Class 8 ZE battery-electric trucks; these initially sold trucks will be restricted to short-haul drayage applications. Seven OEMs launching battery-electric Class 8 truck models by 2022 represents a major increase from the 2018 Assessment. Additional OEMs have indicated their intent to make and sell battery-electric trucks by or before 2024 (e.g., Tesla's announced plans). High capital costs are a key barrier to expand manufacturing and use; today's Class 8 battery-electric trucks are likely to be priced at least three times higher than baseline diesel trucks. Notably, key incentive programs – especially California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) – are providing funds that specifically target battery-electric trucks for drayage. This helps fleets achieve an attractive return on investment (discussed under the Economic Workability section).

Notwithstanding these significant commitments and announcements by multiple OEMs, commercialization at scale (hundreds or more units) has not yet been achieved. To date, OEMs have completed demonstration projects for limited numbers of Class 8 battery-electric trucks (tens of units). These have essentially involved *pre-commercial* battery-electric truck platforms. A key finding is that OEMs need additional demonstration time – with greater numbers of trucks using improved, more-robust technology – to progress into viable *early commercial* products. To meet this need, OEMs have been working to design and incorporate an array of improvements that can enhance overall commercial viability for their next-generation trucks. These improvements will be tested on hundreds of units, in close coordination with Class 8 trucking fleets and other key stakeholders. This is essential to help OEMs and their fleet customers fully understand operational parameters for Class 8 battery-electric trucks such as range, charging time, electric-drive performance, battery life, safety procedures, residual value, total cost of ownership, and buildout requirements for charging infrastructure. Through this methodical process – which must be given sufficient time to play out – all parties can determine if ZE battery-electric trucks will be able to provide one-to-one (or close) commercial replacements for diesel ICE trucks, which currently perform about 95 percent of container movements at the San Pedro Bay Ports.

This list of needs to address during second-generation OEM demonstrations underscores how each of the five feasibility parameters are interlinked. Improved commercial viability must be achieved in concert with proving (at scale) that battery-electric trucks can achieve basic requirements within the <u>other four feasibility parameters</u>, as further discussed below.

Multiple Class 8 truck OEMs are now initiating efforts to implement larger-scale demonstrations, in conjunction with the Ports and key government agencies. Over the next 24 months, these new demonstrations will provide important venues for OEMs and their fleet customers to further test, validate and improve Class 8 ZE trucks in drayage service. This process to enhance commercial readiness and overall viability must precede larger-scale commercial launches (*hundreds to thousands of units* per OEM for U.S. markets), which appear plausible beginning in the 2024 timeframe.

LE Natural Gas ICE – Five heavy-duty truck OEMs offer LE trucks fueled by natural gas as fully commercial products (all powered by the Cummins Westport 12-liter ISX12N engine). This represents a <u>modest decrease</u> from the 2018 Assessment (from six OEMs down to five). Since mid-2019, Class 8 LE natural gas trucks have demonstrated sufficient feasibility and user acceptance to be deemed commercially viable for drayage service at the Ports. Notably, trucks powered by LE natural gas ICE technology are essentially variations of baseline diesel ICE trucks. By contrast, ZE battery-electric (and hydrogen fuel cell trucks, see below) entail revolutionary changes to manufacture and operate.

NOTE: As noted above, the Ports currently do not anticipate that future drayage truck feasibility assessments will evaluate fuel-technology platforms that include combustion technology. This includes *conventional* heavy-duty natural gas ICE trucks, regardless of the emissions certification levels they achieve. However, it is possible that OEMs will develop and commercialize truck architectures with plug-in electric drive systems that are hybridized with low-emission natural gas engines and can *achieve a prescribed amount of all-electric range*. Regardless of the ICE fuel type, the Ports will be ready to assess these types of Class 8 truck architectures for feasibility, if and when they emerge as pre- or early commercial products that can meet all relevant CARB requirements.

The following summarizes the other three core types of fuel-technology platforms that are not yet deemed to meet the basic criteria for "Commercial Availability."

ZE Hydrogen Fuel Cell – Multiple OEMs are developing and demonstrating Class 8 ZE fuel cell trucks, with the stated intent to fully commercialize by or before 2024. However, none are sold commercially at this time, and this fuel-technology platform does not yet achieve key criteria for Commercial Availability (unchanged from the 2018 Assessment). Clearly though, OEM interest in commercializing hydrogen fuel cell trucks has accelerated since 2018. OEM announcements to make and sell early commercial Class 8 hydrogen fuel cell truck models (and the expected timelines) include Nikola Motor's "TRE FCEV" (beginning in 2023), Kenworth's T680 using Toyota's fuel cell engine (by 2024), Hino's "XLA" also using Toyota fuel cell technology (date to be determined), and Navistar's RH Series powered by GM's fuel cell technology (by 2024). Additional efforts to develop and commercialize Class 8 hydrogen fuel cell trucks for North American markets (within five or fewer years) are underway by Hyundai and Daimler/Volvo. Hyzon is developing an aftermarket approach to commercialize Class 8 fuel cell tractors in 2022 that have been converted from Freightliner Cascadia diesel tractors.

LE Hybrid-Electric and Advanced Diesel ICE – No Class 8 truck OEMs commercially offer models with LE hybrid-electric or low-NOx diesel platforms. This is unchanged from the 2018 Assessment. However, CARB's recent adoption of two key regulations (Advanced Clean Trucks and Low-NOx Omnibus) appear to provide impetus for OEMs to design, build and sell Class 8 trucks with plug-in hybrid-electric and/or low-NOx diesel ICE architectures, beginning with 2024 models. Potentially, future feasibility assessments (or updates) will need to revisit these two fuel-technology platforms for emerging commercialization potential (and overall feasibility), provided they remain allowable options for drayage service under CARB's evolving regulations.

Summary of Findings for Technical Viability

In combination with Commercial Availability, Technical Viability was the second parameter used to screen the five core fuel-technology platforms for overall feasibility. To gauge this, Technology Readiness Level (TRL) ratings (based on a U.S. Department of Energy protocol) were assigned to each platform (late-2021 status). The table below summarizes assigned TRL ratings for late-2021. "Educated prognoses" are also provided for how those TRL ratings may change by (or before) 2024.

Summary of findings for 2021 Technical Viability using TRL ratings

TRL	Relative Stage of Development	Late-2021 TRLs for Leading Fuel-Technology Platforms (Drayage)	~2024: Educated Prognoses (by or before)	Comments / Basis for 2024 Educated Prognosis
TRL 9	**Systems Operations**	**LE NG ICE (TRL 9)**	**LE NG ICE (TRL 9)** **ZE Battery (TRL 8 to 9)**	**ZE Battery Electric:** strong ongoing OEM progress gained through government-funded demos at growing scale will raise this platform to TRL 8 to 9* (*short-haul drayage applications)
TRL 8	**Systems Conditioning**	**ZE Battery (TRL 7 to 8)**	**ZE Fuel Cell (TRL 8)**	**ZE Fuel Cell:** OEM technical progress will accelerate as optimized fuel cell/battery architectures emerge; on-board hydrogen storage continues to improve on cost and performance
TRL 7		**ZE Fuel Cell (TRL 7)**	**LE Diesel ICE (TRL 6 to 7, or higher?)**	**LE Plug-in Hybrid (not shown):** OEM interest is hard to gauge, but plug-in architecture enables valued "zero-emission mile" capability
TRL 6	**Technology Demonstration**	**LE Diesel ICE (TRL 5 to 6)**		
TRL 5	**Technology Development**			**LE Diesel ICE:** could "**leapfrog**" to TRL 8 or 9, but only if suitable diesel engine(s) get certified to 0.02 g/bhp-hr NOx (or other CARB OLNS)
TRL 4				

Source: TRL methodology adapted from U.S. DOE, "Technology Readiness Assessment Guide, Table 1: Technology Readiness Levels, September 2011 (see footnote). TRL ratings estimated based on input from 1) OEM surveys, 2) various technical reports, 3) demonstration activities, and 4) meetings with and/or inputs from CARB and South Coast AQMD technical staff.

TRL 8 is the stage at which a given platform becomes near-final or final, and has adequately exhibited technical viability through test and demonstration. **TRL 9** constitutes the highest rating; this is the stage at which fuel technical viability has been achieved and definitively documented. The following summarizes this 2021 Assessment's findings about Technical Viability, as of late-2021:

- Class 8 **ZE** battery-electric drayage trucks are currently at **TRL 7 to TRL 8** (systems conditioning for early commercialization). Strong progress through multiple major OEM development and demonstration projects has moved Class 8 battery-electric trucks up a full TRL rank since the 2018 Assessment. Class 8 battery-electric trucks are entering the threshold of early commercialization for short-haul and/or lighter-weight[4] drayage applications. However, larger-scale early commercial truck deployments (now being initiated) are essential next steps for OEMs, fleets and other stakeholders. These are necessary to identify and address ongoing technology challenges, and advance the technology for capability to perform successfully across the full range of drayage duty cycles. If this gets accomplished, Class 8 battery-electric trucks are expected to reach TRL 8 to 9 by 2024. Note that the TRL rating of 9 is specifically estimated for short-haul and/or lighter-weight drayage applications.

- Class 8 **ZE** hydrogen fuel cell trucks have now reached **TRL 7.** Multiple Class 8 OEMs (traditional and start-up) are making good technological progress through focused pre-commercial demonstrations. This has helped move them up more than a full TRL rank since the 2018 Assessment. If this OEM work continues at the current (or faster) pace, Class 8 hydrogen fuel cell trucks are expected to reach TRL 8 by 2024.

- Class 8 **LE** natural gas trucks are rated at **TRL 9** today. These fully commercial products have reached full technical maturity and viability (as documented by the Ports in a May 2020 Addendum to the 2018 Assessment).

- No other ZE or LE fuel-technology platform currently achieves a TRL rating at or above the **6-to-7** range. Notably, the pace of technological development for LE hybrid-electric and/or LE diesel ICE may quicken, as OEMs seek pathways to comply with CARB's latest technology-forcing regulations, by or before the 2024 model year.

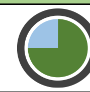
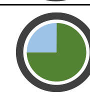
Screening methodology for further assessment: Per the methodology described in this Assessment, the only fuel-technology platforms further characterized for overall feasibility were those found (as of late-2021) to achieve both screening parameters (Commercial Availability and Technical Viability). Consequently, only Class 8 **ZE** battery-electric and **LE** natural gas ICE platforms were further assessed by applying detailed criteria within the three remaining parameters (Operational Feasibility, Infrastructure Availability, and Economic Workability).

Summary of Findings for Operational Feasibility

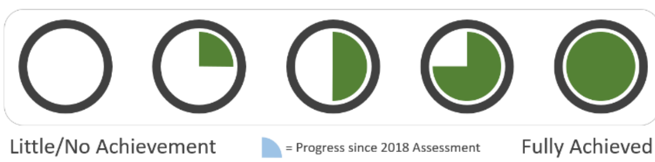
The table below summarizes Operational Feasibility for **ZE** battery-electric and **LE** natural gas ICE trucks according to their relative achievement of key criteria and base considerations. For each parameter/criterion, **blue** pie wedges specifically indicate progress made (if any) since the 2018 Assessment. The table is followed by a summary of findings in narrative form for both fuel-technology platforms.

[4] "Lighter-weight" in this context refers to Class 8 trucks with typical payloads be below the 82,000 Gross Combined Weight (GCW). Please see Section 7.6.5 for additional discussion about this parameter of truck weight.

Summary of ratings by key criteria: 2021 Operational Feasibility

Operational Feasibility Criteria/Parameter	Base Considerations for Drayage Platforms to Achieve Operational Feasibility	Achievement of Criteria in 2021 for Commercially Available Drayage Truck Platforms	
		ZE Battery-Electric	LE NG ICE
Basic Performance	Demonstrated capability to meet drayage company needs for basic performance parameters including power, torque, gradeability, operation of accessories, etc.		
Range	Demonstrated capability to achieve per-shift and daily range requirements found in San Pedro Bay Ports drayage.		
Speed and Frequency of Fueling/Charging	Demonstrated capability to meet drayage company needs for speed and frequency to refuel / recharge such that revenue operation is not significantly reduced relative to diesel baseline.		
Driver Comfort, Safety, and Fueling Logistics	Proven ability to satisfy typical drayage trucking company's needs for comfort, safety and refueling procedures (for the operator).		
Availability of Replacement Parts and Support for Maintenance/Training	Verifiable existence of and timely access (equivalent to baseline diesel) to all replacement parts needed to conduct scheduled and unscheduled maintenance procedures.		
	Verifiable existence of maintenance procedure guidelines and manuals, including OEM-provided training courses upon purchase and deployment of new trucks.		

Legend: Operational Feasibility (2021)



Source: Based on Drayage Truck Operator Survey responses, footnoted studies, OEM product information, and consultant's industry knowledge.

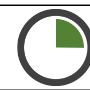
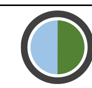
ZE Battery-Electric – Class 8 truck OEMs (with their technology partners) have made significant progress since 2018 to improve pre-production ZE Class 8 truck platforms. These improvements have led to better operational feasibility for fleet customers, including drayage operators. As of late-2021, it appears that the early commercial battery-electric trucks entering into series production (at small volume) in 2022 and 2023 will be capable of meeting basic performance requirements for *short-range* drayage operations (roughly up to 225 miles between charges). They are likely to generally outperform diesel trucks with respect to power, torque, and gradeability. However, range, weight, and recharging time remain barriers that currently limit applicability of these trucks. In particular, this Assessment finds that the incremental weight of current-technology Class 8 battery-electric trucks could be a significant barrier to wider adoption in drayage applications. Also – prior to larger-scale use – OEMs need additional field testing to address remaining safety issues associated with heavy-duty battery-electric vehicles (BEVs). This process is well underway in conjunction with adopting fleets and third-party maintenance providers. Still, trucking fleets have limited experience to date with high-voltage battery packs used in heavy-duty BEVs. All parties need additional real-world use to understand and manage potential hazards, such as shock and thermal events. Other safety issues have occurred with pre-commercial battery-electric trucks, such as sudden loss of power. Fortunately, OEMs are working hard with fleets and other partners to resolve such issues for their next-generation commercial heavy-duty BEVs.

LE Natural Gas ICE – Class 8 trucks powered by natural gas ICE technology achieve full "operational feasibility" for LMCs performing drayage at the Ports. This was demonstrated at the Ports and documented in a May 2020 Addendum to the inaugural 2018 Assessment. LE natural gas ICE trucks continue to offer the only alternative technology (ZE or LE) that can achieve the daily range requirements and fueling intervals expected by drayage operators. The additional fueling time they require relative to diesel trucks is inconsequential with respect to overall daily operations. Driver comfort, safety, and access to parts/service are essentially equivalent to diesel trucks. Fueling procedures are straightforward and do not pose barriers to wider adoption.

Summary of Findings for Infrastructure Availability

For any Class 8 truck platform (ZE or LE) that does not use diesel fuel for its energy source, gaining access to affordable and convenient fueling infrastructure has been (and continues to be) a significant barrier to wider-scale adoption. The table below summarizes Infrastructure Availability by relative achievement of key criteria and base considerations. For each parameter/criterion, **blue** pie wedges specifically indicate progress made (if any) since the 2018 Assessment. The table is followed by a summary of findings in narrative form for both fuel-technology platforms.

Summary of ratings by key criteria: 2021 Infrastructure Availability

Infrastructure Criteria/Parameter	Base Considerations for Assessing Infrastructure Availability	Achievement of Criteria for Remaining Drayage Truck Platforms	
		ZE Battery-Electric	LE NG ICE
Dwell Time at Station	Fueling/Charging can be accommodated within typical work breaks, lunches, and other downtime compatible with trucking company schedules and operational needs.		
Station Location and Footprint	Fleets have existing onsite access to fueling infrastructure, or can be fueled/charged conveniently and affordably off site, at public or private stations. New infrastructure can be installed without extensive redesign, reconfiguration or operational disruptions and sufficient electrical or natural gas capacity exists at site.		
Infrastructure Buildout	Infrastructure can be constructed at a pace consistent with fleet adoption and able to meet fleet fueling/charging requirements by the end of the assessment period.		
Existence of/Compatibility with Standards	A sufficient body of codes and standards exist from appropriate organizations that enables safe and effective refueling/recharging. The refueling/recharging station technology has already been installed at other trucking companies in the U.S., with sufficient time to assess performance and safety.		

Legend: **Infrastructure Availability** **(2021)**

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

Source: based on preliminary OEM survey responses, OEM product information, various government sources, and Tetra Tech team's industry knowledge.

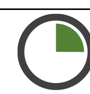
ZE Battery-Electric – The key advancement for battery-electric charging infrastructure since the 2018 Assessment has been emergence of the Combined Charging Standard (CCS) as the leading charging standard in the heavy-duty vehicle space, although CCS has some remaining challenges to resolve. This and other advancements have improved the "Existence of / Compatibility with Standards" parameter in the table above, reflected by the ¼ "pie" increase. While codes and standards for electric charging infrastructure are normalizing, local authorities may still impose additional permitting requirements due to relative unfamiliarity with the technology. This could create significant barriers to infrastructure development. These issues will ultimately be addressed as local authorities and infrastructure developers gain experience, but early infrastructure projects will require more time to permit than those that follow later, which may slow the pace of near-term infrastructure development initiatives. The sub-parameters of "Station Location and Footprint" and "Infrastructure Buildout" have not significantly changed since the 2018 Assessment, although important efforts are underway by both utilities and charging technology providers. Significant uncertainty remains about how rapidly new charging stations and subsequent EV charging loads will be deployed, and the timelines for the utilities to develop long-term infrastructure plans for a fully electrified port system. Specific knowledge gaps that slow the pace for locating and building stations include drayage truck battery capacities and charging rates; truck charging times and locations; charging equipment interface standards and exceptions; and timelines for scaled-up EV deployments. The scope of an infrastructure build-out to charge a fully electrified drayage fleet is substantial. This situation is dynamic, and some companies are working hard to prove-out the business model of rapidly building public charging stations that can serve Class 8 battery-electric trucks in Southern California. However, it remains uncertain if there will be sufficient will and/or investment to build-out the full extent of the charging infrastructure needed to serve the drayage fleet. Given these current uncertainties and challenges, it appears highly unlikely (if not impossible) that a full-scale charging infrastructure for drayage trucks could be built and operational by 2024.

LE Natural Gas ICE – Drayage trucks powered by natural gas ICE technology are farthest along the path of "infrastructure availability," with nearly 74 fueling stations within approximately 100 miles of the Ports. It is expected that substantial unused CNG and LNG dispensing capacity is available to support initial growth as needed for an expanding natural gas drayage fleet. Several natural gas fuel station operators have communicated strong willingness and readiness to construct fueling stations at pace with deployment of LE natural gas drayage trucks. Based on this business model, it is reasonable to assume that by 2024, sufficient natural gas station deployments could occur to support a majority of the drayage truck fleet. As noted above, subsequent feasibility assessments (i.e., beyond this 2021 Assessment) may not require or perform in-depth analysis of conventional heavy-duty natural gas ICE trucks and the associated fueling infrastructure.

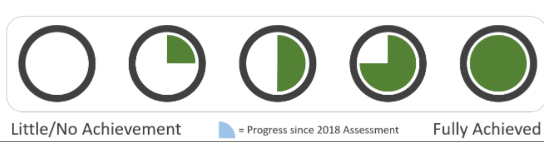
Summary of Findings for Economic Workability

As first noted in the 2018 Assessment, the drayage truck sector is generally a low-margin, low-asset base sector. Fuel-technology platforms are needed that can provide total cost of ownership (TCO) similar to, or better than, baseline diesel ICE trucks. The table below summarizes Economic Workability by relative achievement of key criteria and base considerations. For each parameter/criterion, **blue** pie wedges specifically indicate progress made (if any) since the 2018 Assessment. The table is followed by a summary of findings in narrative form for both Class 8 truck fuel-technology platforms that have been determined to be commercially available and technically viable for drayage.

Summary of ratings by key criteria: 2021 Economic Workability

Economic-Related Criteria/Issue	Base Considerations for Assessing General Economic Workability	Achievement of Criteria in 2021 (Commercially Available Truck Platforms)	
		ZE Battery-Electric	LE NG ICE
Incremental Vehicle Cost	The upfront capital cost for the new technology is affordable to end users, compared to the diesel baseline.		
Fuel and Other Operational Costs	The cost of fuel/energy for the new technology is affordable, on an energy-equivalent basis (taking into account vehicle efficiency). Demand charges/TOU charges (if any) are understood and affordable. Net operational costs help provide an overall attractive cost of ownership.		
Infrastructure Capital and Operational Costs	Infrastructure-related capital and operational costs (if any) are affordable for end users.		
Potential Economic or Workforce Impacts to Make Transition	There are no known major negative economic and/or workforce impacts that could potentially result from transitioning to the new equipment.		
Existence and Sustainability of Financing to Improve Cost of Ownership	Financing mechanisms, including incentives, are in place to help end users with incremental vehicle costs and/or new infrastructure-related costs, and are likely remain available over the next several years.		

Legend: Economic Workability (2021)



Source: based on preliminary OEM survey responses, OEM product information, various government sources, and Tetra Tech team's industry knowledge.

Note: It is recognized that widescale transitioning to ZE battery-electric and/or LE natural gas drayage trucks will entail workforce-related impacts and costs on adopting fleets. Those are likely to be manifested in the form of additional investments in infrastructure and in workforce training to operate and/or maintain these emerging vehicle platforms, and/or new types of charging/fueling infrastructure. However, such investments may ultimately result in positive economic impacts as additional capital is spent in the region. Currently, insufficient information exists to assess and quantify exact workforce impacts (economically positive and negative) that will be associated with such transition(s). Moreover, a full economic analysis of potential workforce impacts is outside the scope of this Assessment.

ZE Battery-Electric – The purchase price of a Class 8 battery-electric truck is roughly two-to-three times greater than a comparable new diesel truck. This higher incremental cost can be offset by lower fuel (energy) and maintenance costs; in the case of battery-electric trucks, cost of ownership is dependent on the fleet's realized cost for electricity. Electricity costs are dependent on numerous factors, and substantial cost differences can exist based on the charging strategy implemented at a particular location. These differences lead to a broad range of ownership costs for battery-electric trucks. They may be comparable to diesel, or they may be substantially greater, based solely on the utility rate available to the fleet. Additional cost uncertainty exists for maintenance costs. While maintenance on battery-electric trucks may be reduced, any associated cost savings are currently highly speculative; this is likely to remain the case until ongoing demonstrations provide more-robust data (on the latest OEM models) to refine estimates.

Incentives currently available to battery-electric trucks can dramatically alter their cost of ownership relative to diesel trucks. Purchase incentives combined with credits through California's Low Carbon Fuel Standard program can reduce cost of ownership down to 25 to 40 percent of diesel trucks. Unfortunately, the long-term availability of these incentives is not guaranteed. Additionally, there are insufficient funds in current funding programs to provide incentives for more than a small fraction of the total drayage fleet.

Notably, as the above table shows by lack of **blue** wedges, the 2021 Assessment finds *no changes in the "pie ratings*" relative to the 2018 Assessment across any of the Economic Workability parameters. This is largely because the purchase price of battery-electric trucks remained relatively constant, although range increases were realized. Note that this economic picture represents a snapshot for late-2021. It is reasonable to expect that improvements in these various parameters for Economic Workability will be realized over the next few years, given that multiple OEMs have announced near-term commercial roll-outs for Class 8 battery-electric trucks, starting in 2022.

LE Natural Gas ICE – As with battery-electric trucks, the 2021 Assessment finds *no changes in the "pie ratings*" for natural gas trucks relative to the 2018 Assessment, across any of the Economic Workability parameters (i.e., the above table lacks **blue** wedges). New Class 8 natural trucks have higher incremental purchase prices relative to baseline diesel trucks (about 40 to 50 percent), although their cost of ownership (12-year vehicle lifetime) is similar to diesel trucks. Cost of ownership and payback time are driven primarily by lower costs of natural gas fuel (on an energy-equivalent basis) compared to diesel (the "fuel price spread"). Today's typical fuel price spread between diesel and CNG provides the necessary fuel cost savings to recover the higher incremental purchase price. However, cost of ownership is sensitive to this price spread, and actual cost savings could change significantly if the price spread collapses or expands.

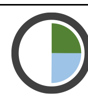
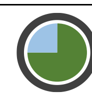
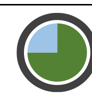
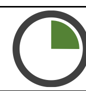
For natural gas trucks, infrastructure costs are generally covered by the assumed fuel prices. However, fleets that choose to construct their own fueling stations may ultimately realize lower fuel prices and a return on investment relative to public access stations. Maintenance and support for privately owned stations are available through service contracts to third parties, or may be taken on by the station owner.

Because the majority of drayage truck operators are assumed to rely on third parties to perform significant repairs that might require specialized maintenance facilities and tools, it is assumed that dealer networks and repair facilities will make the required investments (or have already made those investments) to service trucks.

Similar to the case with battery-electric trucks – albeit to a lesser extent – incentives remain important and uncertain determinants for the TCO of Class 8 natural gas trucks. Significantly, in 2019 (after the 2018 Assessment) CARB removed natural gas HDVs as eligible options to receive funding under HVIP. This eliminated an important source of funding to help fleets "buy down" the incremental cost of heavy-duty natural gas trucks. Today, other incentive programs and opportunities exist for Class 8 natural gas trucks; however, they are more difficult to access and long-term availability is not guaranteed.

Conclusions: 2021 Feasibility Across All Five Parameters

The table below summarizes the relative degree to which both leading fuel-technology platforms achieve the five key feasibility parameters (late-2021); this is specific to drayage service at the San Pedro Bay Ports. It is important to stress that these achievement ratings for each individual feasibility parameter are based on analysis of multiple criteria within that parameter. To be successful in wide drayage use at the Ports, these fuel-technology platforms must achieve each criterion. Thus, overall achievement ratings for the five feasibility parameters in the table below reflect the lowest criterion score for that parameter.

Feasibility Parameter / Criteria	Overall Achievement* of Criteria in 2021 (Commercially Available / Technically Viable Truck Platforms)	
	ZE Battery-Electric	LE NG ICE
Commercial Availability		
Technical Viability	TRL 7 to 8 (moving to 9) (for short-range drayage)	TRL 9
Operational Feasibility		
Infrastructure Availability		
Economic Workability		

Legend: Achievement of Each Noted Parameter / Criteria **(2021)**

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

*These ratings for overall achievement of each five feasibility parameter are based on the analysis of several criteria within that parameter. Because each criterion is important for the success of a given fuel-technology platform in drayage, the overall achievement ratings are based on the lowest criterion score for each feasibility parameter.

Looking Forward

The San Pedro Bay Ports remain committed to the 2017 CAAP goal to achieve a 100-percent ZE drayage fleet by 2035, while also ensuring that the San Pedro Bay Ports remain economically competitive and maintain their nation-leading market positions. Under the best of circumstances, transitioning to an all-ZE drayage fleet is necessarily a gradual and iterative process. As has been corroborated by the Port's two feasibility assessments for drayage trucks (in 2018 and now this 2021 version), moving the large San Pedro Bay Ports drayage fleet to zero emissions entails five complex, inter-related feasibility parameters.

Fortunately, this 2021 Assessment demonstrates that important changes have occurred since 2018 regarding the commercial and technological maturity of Class 8 trucks using **ZE** fuel-technology platforms. Relatedly, over the last two years CARB has adopted its Advanced Clean Truck (ACT) regulation that helps address the "supply side" for ZE Class 8 trucks, while also initiating a proposed Advanced Clean Fleet (ACF) regulation that addresses the corresponding "demand side." Finally, to help OEMs build ZE trucks and fleets to purchase them, state and local agencies have joined with the Ports to implement new incentive programs that specifically target deployment of Class 8 ZE trucks performing drayage at the San Pedro Bay Ports.

It is these factors together that have resulted in nearly all major "traditional" Class 8 truck OEMs – and numerous "relative newcomer" OEMs – announcing plans to sell early commercial ZE battery-electric trucks (BETs) beginning in 2022. It appears plausible that within two-to-three years, multiple OEMs will annually produce *hundreds or thousands* of commercially viable Class 8 BETs. The Ports' 2017 CAAP goal of a 100-percent ZE drayage fleet by 2035 will stimulate demand in these early years from SPBP drayage fleets to purchase and deploy these ZE trucks. Initially, the BETS produced by OEMs and deployed by fleets serving the Ports will be limited to short-haul drayage routes (up to about 250 miles between charging events).

Meanwhile, multiple Class 8 OEMs – in many cases the same ones now entering into early commercialization for battery-electric trucks – are making steady progress to advance the technological and commercial maturity of ZE hydrogen fuel cell trucks. There is strong synergy here: fuel cell trucks are essentially specialized versions of BETs, but they provide OEMs with ability to deliver longer (diesel-like) driving ranges. ZE hydrogen fuel cell trucks are earlier in their development compared to ZE battery-electric trucks and are expected to achieve feasibility (across all five parameters) for San Pedro Bay Ports drayage service after ZE battery-electric trucks. It must be emphasized that for both ZE drayage truck architectures, charging/fueling infrastructure logistics and costs remain key challenges. All stakeholders (OEMs, fleets, infrastructure providers, the Ports, and government officials) have a role in addressing and resolving key remaining challenges to enable wide-scale use.

Putting all these factors together – especially considering the CAAP's end goal and CARB's ACT/ACF regulatory actions – the Ports will likely focus the next feasibility assessment for drayage trucks on these two ZE fuel-technology platforms. It is acknowledged that OEMs may pursue other emerging ZE fuel-technology platforms for drayage trucks, such as plug-in hybrid trucks with capability for partial ZE operation. As needed, the Ports will further assess the feasibility of such platforms, taking into account the best available information about technological, economic, and regulatory landscapes.

1. Introduction

1.1. Background: Clean Air Action Plan and Clean Trucks Program

In 2006, the Port of Los Angeles and the Port of Long Beach jointly adopted the San Pedro Bay Ports Clean Air Action Plan (CAAP). The CAAP presents an overall strategy to systematically reduce emissions from five key goods movement sectors – ships, trucks, trains, cargo-handling equipment and harbor craft, with a 2010 update that added San Pedro Bay-Wide Health Risk Standards. In November 2017, the Ports jointly adopted the 2017 Clean Air Action Plan (CAAP) Update. The CAAP Update further defined and clarified emissions reduction targets, and the strategies that will achieve those reductions. The current CAAP specifies incremental reduction targets for all key pollutants between 2020 and 2050, and outlines fourteen source-specific strategies to achieve these targets Oxides of nitrogen (NOx) is an especially important pollutant to control; it combines with volatile organic compounds (VOCs) in the atmosphere to form ground-level ozone (photochemical smog).

The Clean Truck Program (CTP) is an integral part of the CAAP designed to generate and implement truck-related emission-reduction strategies. Since 2006, the CTP has reduced emissions from harbor ("drayage[5]") trucks by more than 90 percent; this was accomplished three years ahead of schedule. Under the 2017 CAAP Update, the CTP was further refined to continue systematically reducing truck emissions. Specifically, it called for transitioning the San Pedro Bay Ports ("the Ports" or SPBP) drayage fleet to zero-emission or near-zero-emission trucks (see below). The ultimate goal is to achieve zero-emission drayage operations by 2035. Additional details about the overarching CAAP – and specifically how the CTP will phase in cleaner trucks over time – are available on the CAAP website at http://www.cleanairactionplan.org/strategies/trucks/.

1.2. Origin and Framework for CAAP Feasibility Assessments

The 2017 CAAP Update incorporated appropriate checks and balances designed to help ensure that its various control measures are achievable, both technologically and economically. This includes a provision for the Ports to conduct separate "feasibility assessments" for drayage trucks and terminal equipment. Each assessment is intended to evaluate the status of zero-emission (ZE) and low-emission (LE) fuel-technology platforms (see **Definitions** callout box) – including supporting fueling infrastructures – for their feasibility and timeline to replace conventional, higher-emitting diesel-fueled platforms that currently dominate goods movement activities.

For additional information, see the Ports' joint document "Framework for Developing Feasibility Assessments,"[6] available online at http://www.cleanairactionplan.org/documents/feasibility-assessment-framework.pdf/

The ultimate goal of this 2021 Feasibility Assessment for Drayage Trucks (2021 Assessment) is to ascertain which (if any) emerging ZE or LE fuel-technology platforms for Class 8 trucks are now "feasible" (see **Evaluating "Feasibility"** below) – or have good potential by 2024 to become feasible – for replacing baseline diesel trucks performing drayage at the Ports. This 2021 Assessment updates the inaugural version from 2018 ("2018 Assessment"). Because market conditions and technology landscapes can change rapidly, the Ports anticipate preparing an updated drayage truck feasibility assessment (in some form) every three years, or more frequently if warranted by relevant new information. For example, the ports may decide to

[5]CARB's working definition for a "drayage truck" is an on-road heavy-duty (>26,000 lbs GVWR) truck (usually diesel fueled) that transports containers or bulk cargo to and from seaports, intermodal railyards and other locations (e.g., in-land warehouse and distribution facilities). A more formal definition is available in CARB's Drayage Truck Regulation (see https://ww2.arb.ca.gov/our-work/programs/drayage-trucks-seaports-railyards/about).
[6] San Pedro Bay Ports, "Framework for Developing Feasibility Assessments", November 2017, http://www.cleanairactionplan.org/documents/feasibility-assessment-framework.pdf/.

annually update portions of this 2021 Assessment if new ZE and/or LE fuel-technology platforms become commercially

Definitions: Zero-Emission (ZE) and Low-Emission (LE) Truck Types

Per CARB's 2020 Advanced Clean Trucks (ACT) regulation*:

- A zero-emission (ZE) vehicle is powered by "a drivetrain that produces zero exhaust emissions of any criteria pollutant (or precursor pollutant) or greenhouse gas under any possible operational modes or conditions."
- A near-zero-emission (NZE) vehicle is either 1) an on-road plug-in hybrid electric vehicle that achieves all-electric range; or 2) an on-road hybrid electric vehicle that has the capability to charge the battery from an off-vehicle conductive or inductive electric source and achieves all-electric range.

The 2018 Feasibility Assessment for Drayage Trucks – which predated CARB's 2020 adoption of ACT – used "NZE" as a general study category for trucks powered by any (non-ZE) fuel-technology combination that emits NOx at a significantly lower level than the federal 2010 heavy-duty engine emissions standard. This 2018 Feasibility Assessment "NZE" term for the purpose of a study category label, was broader than the CARB regulatory definition of "NZE" in the ACT regulation. After the 2020 CARB regulations were adopted, we understood that the 2018 Feasibility Assessment's "NZE" term was broad enough to include heavy-duty trucks powered by heavy-duty drivetrain technology that could meet: (1) CARB's NZE definition under the 2020 ACT regulation (see above); and (2) CARB's Optional Reduced NOx Standards for Heavy-Duty Vehicles**; and (3) CARB's 2020 Low-NOx Omnibus regulation*** (which takes effect beginning with engine model year 2024). For additional regulatory context most relevant to this 2021 Assessment, please see Section 5.2.4.

To remain consistent with the Ports' original stated intent to conduct feasibility assessments of zero- and lower-emission technologies – and to better facilitate comparisons between the 2018 and 2021 Assessments – this 2021 Assessment maintains the same metrics for categorizing which types of non-ZE trucks warrant assessment. However, the term NZE is no longer used (in this context). It has been replaced with the term Low Emission (LE). This avoids confusion with CARB's NZE definition adopted under ACT, which effectively precludes non-electric drivetrain technologies.

In summary, for purposes of this 2021 Assessment:

1. **ZE** refers to any fuel-technology combination for drayage trucks that meets CARB's ZEV definition under the ACT regulation.
2. **LE** refers to any fuel-technology combination for drayage trucks that *is significantly lower emitting on oxides of nitrogen (NOx) than the federal 2010 emissions standards for on-road heavy-duty engines*.

*https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks
** https://ww2.arb.ca.gov/our-work/programs/optional-reduced-nox-standards
***https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox

available, and/or if there is a breakthrough development with infrastructure.

Evaluating Feasibility

For purposes of this Assessment, "feasibility" refers to the ability of any fuel-technology drayage truck type to provide similar or better performance and achievement across five key parameters, as compared to today's baseline diesel drayage trucks. Specifically, per the Ports' "Framework for Developing Feasibility Assessments," the following five parameters have been applied to collectively assess and evaluate overall feasibility: 1) commercial availability, 2) technical viability, 3) operational feasibility, 4) infrastructure/fuel availability, and 5) economic workability. For each of these parameters, feasibility has been evaluated within the context of *widespread deployment* in all types of drayage trucking at both San Pedro Bay Ports. See Section 4 for additional discussion.

2. Report Overview

2.1. Overall Methodology and Anticipated Outcomes

This 2021 Feasibility Assessment for Drayage Trucks (2021 Assessment) builds upon and updates the inaugural 2018 Assessment (including its Addendum,[7] which the Ports released in May 2020). It characterizes the late-2021 status of ZE and LE fuel-technology platforms that are fully suitable to power Class 8 drayage trucks serving the San Pedro Bay Ports, or at least exhibit clear potential to achieve this by 2024. As with each of the Ports' joint assessments, the fundamental purpose of this 2021 Assessment is to help the Ports continue making sufficient and timely progress to meet CAAP goals.

To prepare this Assessment, the authors reviewed and analyzed available information deemed to be relevant and credible (see further discussion below), while applying feasibility parameters and boundaries as defined by the "Framework" document footnoted above. This was used to derive a near-term feasibility "snapshot" (2021 to 2024) about the ability for emerging ZE and/or LE drayage truck platforms to replace conventional, higher-emission diesel trucks. In cases where emerging platforms currently fall short of this bar, this report summarizes progress being made for them to become feasible, and remaining challenges to overcome before feasibility is likely to be achieved. It is important to note this 2021 snapshot highlights ZE and LE drayage truck platforms that are feasible (or approaching feasibility) *based on available information in late 2021*. However, given the accelerated progress made in 2022 by virtually all Class 8 truck OEMs and their technology partners – combined with key regulatory drivers described in this Assessment – the Ports anticipate that OEM commercialization of ZE drayage trucks by 2024 will likely exceed that which is described in this 2021 report.

With all of this information gathered and assessed, the Ports can best 1) focus attention, resources and support on specific areas that need the most attention, and 2) determine if the CAAP's initial timelines for drayage trucks will need to be adjusted. Examples of specific potential outcomes from this 2021 Feasibility Assessment for Drayage Trucks include the following actions the Ports could take:

- Further develop strategies needed to enable large-scale deployment of ZE drayage trucks (and LE drayage trucks, if still allowed under CARB regulations); these could include expansion of technology demonstrations, funding programs, and infrastructure installation.
- Issue advisories and/or guidance documents to drayage trucking companies, including potential ways to provide additional flexibility while still meeting CAAP deadlines and in compliance with CARB regulations.

2.2. Timeline, Applicability, Scope, and Limitations

The following provides important information about the timeline, scope, and applicability of this Assessment:

Relevant Timeline – This report represents a snapshot in time. It will be updated by late 2024, or sooner if important new information becomes available.[8] Through the public process to engage stakeholders, and by continuing to consult with technical experts, the Ports will continue to refine the scope and content of each feasibility assessment.

Breadth of Application – This report evaluates the feasibility of emerging drayage truck platforms in terms of their potential for *widespread deployment* by all drayage trucking companies and independent owners-operators (IOOs) that legally provide drayage service within the SPBP complex. The Ports recognize that some emerging platforms may be feasible solely in select circumstances (e.g., where unique operational, infrastructure, and/or financial conditions exist), compared to the overall SPBP complex. Such situations are recognized and discussed, particularly as they pertain to potential for broader application.

Assessed Types of Drayage – The SPBP drayage truck fleet is utilized in three basic types of service to move cargo to and from marine terminals: 1) near-dock service (approximately six to eight miles), 2) local/railyard service (eight to 20 miles), and 3)

---

[7] In May 2020, the Ports commissioned an update to the 2018 Drayage Trucks Feasibility Assessment to take into account a significant advancement in technology readiness for one of the evaluated fuel-technology platforms. The 2018 Assessment complete with this May 2020 Addendum can be downloaded at https://cleanairactionplan.org/strategies/trucks/.

[8] San Pedro Bay Ports, "2017 Clean Air Action Plan Update," November 2017, http://www.cleanairactionplan.org/documents/final-2017-clean-air-action-plan-update.pdf.

regional service (20 to 120 miles)[9]. The energy and power needs for a given drayage trip will vary depending on the specific application and duty cycle. For example, near-dock drayage may involve extensive low-speed, low-load driving compared to regional warehouse hauling, while not requiring as much on-board energy storage – even though both may be transporting a twenty-foot container of similar weight. To the extent that it is relevant, this report attempts to account for these differences, and characterize important nuances that impact the overall feasibility of each drayage truck fuel-technology platform. However, it is important to recognize that trucking companies – or licensed motor carriers (LMCs) – in the drayage registry currently do not have special fleets to focus on a specific type of drayage service. In today's system, the same truck may be dispatched to perform near-dock, rail or regional service, each with a very different duty cycle.[10] In the future, the fleet could evolve to become more specialized, e.g., a sub-fleet of ZE trucks could move cargo exclusively on shorter-range and/or lighter-weight routes in communities that are disproportionally impacted by local air pollution.

Assessed Fuel-Technology Platforms – This report uses the same basic parameters and criteria (described further) to assess and compare the following five basic emerging ZE and LE fuel-technology platforms:

6. **ZE** Battery electric (charged while stationary via conductive or inductive infrastructure)
7. **ZE** Hydrogen fuel cell electric (electricity generated onboard by reacting hydrogen and oxygen from air; typically hybridized with a battery pack for peak power and regenerative braking)
8. **LE** Advanced diesel internal combustion engine (ICE)
9. **LE** Advanced natural gas or propane ICE
10. **LE** Hybrid-electric (electric drive hybridized with an ICE (using any fuel); may or may not include plug-in capability)

NOTES: As of late-2021, the five basic architectures noted above (with possible variations) exhibit the best potential to be widely deployed in drayage trucks by or before 2024. However, other fuel-technology platforms are not explicitly excluded from this 2021 Assessment (or subsequent assessments). For example, electric-drive platforms may include some type of "range-extender" technology, such as a ZE battery-electric architecture that uses a smaller battery pack (for reduced weight and/or cost and quicker charging time), augmented by a range-extending fuel cell stack. Another example is an LE hybrid architecture that provides a limited number of "zero-emission miles" (e.g., in and around boundaries of the Ports), but still relies on a low-emission combustion engine. ZE electric-drive trucks powered directly from the grid (via an overhead catenary) have been shown in limited demonstration to be technically viable. However, no Class 8 original equipment manufacturer (OEM) is known to currently be working on this architecture for the U.S. market. Moreover, the required buildout of catenary infrastructure is impracticable within the timeframe of this Assessment.

Uncertainties and Inherent Challenges – Over the last few years, heavy-duty ZE and LE fuel-technology platforms with proven or potential use in drayage trucks have been undergoing rapid development. This presents a dynamic situation in which information from available and acceptable sources can suddenly become outdated. To the extent possible, such factors have been considered in this 2021 Assessment, and reasonable attempts have been made to incorporate emerging developments as they occur. It is possible, albeit unlikely, that one or more fuel-technology truck platforms that *are not yet demonstrated in drayage applications* could emerge as "feasible" within this Assessment's relatively near-term timeframe.

2.3. Selection of Credible Information Sources

To accurately assess feasibility of emerging ZE and LE drayage truck platforms, it is imperative to obtain and apply credible information across all input parameters. The previously described "Framework" document provides guidance for this process by giving specific examples of credible information sources. It notes that such an approach "ensures consistency with previous studies that have already been publicly vetted and reviewed by technical experts."[11]

[9] San Pedro Bay Ports, "Zero/Near-Zero Emissions Drayage Truck Testing & Demonstration Guidelines," July 2016. Distances are one-way trips.

[10] See for example the National Renewable Energy Laboratory's "Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development," October 2016, https://www.nrel.gov/docs/fy16osti/66649.pdf.

[11] San Pedro Bay Ports, "Framework for Developing Feasibility Assessments", November 2017, page 3.

Following this template, the authors utilized an array of credible and relevant information sources to prepare this 2021 Feasibility Assessment for Drayage Trucks. This includes existing reports prepared by the two Ports under their joint Technology Advancement Program (TAP), as well as outside technical reports by appropriate agencies, which include the U.S. Environmental Protection Agency (EPA), the California Air Resources Board (CARB), the California Energy Commission (CEC), and the South Coast Air Quality Management District (South Coast AQMD). Where appropriate, reports from industry stakeholders – including Class 8 truck original equipment manufacturers (OEMs), fuel providers, licensed motor carriers (LMCs) and other end users and/or their associations – were also utilized. In addition, the authors gathered direct inputs via 1) discussions with CARB, South Coast AQMD and CEC staff; and 2) surveys or telephone interviews conducted with representatives from heavy-duty truck OEMs, technology providers and end users. More details about the specific sources of information that have been utilized are provided throughout this report, including references found in tables, figures and footnotes.

Role of the Ports' Joint Technology Advancement Program (TAP)
The Ports' joint Technology Advancement Program (TAP) facilitates development and demonstration of clean goods movement technologies needed to meet CAAP goals. Since 2007, the TAP has undertaken numerous projects to help develop, test and/or commercialize Class 8 truck platforms that incorporate ZE or NZE architectures. TAP projects have resulted in successful deployments for some pre-commercial or early commercial platforms discussed in this 2021 Assessment. Please see the 2020 TAP Annual Report,* which is currently available online.
***Source:** San Pedro Bay Ports, "2020 Annual Report and 2021 Priorities: Technology Advancement Program," April 2021, https://cleanairactionplan.org/2021/04/14/2018-tap-annual-report-now-availalble-2/.

In the preparation of this report, it was equally important to define boundaries for acceptable information and data sources. Table 1 presents the general types of information sources that were deemed unacceptable as references in the preparation of this report/assessment.

Table 1. General types of unacceptable information/data sources for feasibility assessments

Unacceptable Types of Information/Data Sources for Feasibility Assessments
• Unsourced reports
• Personal accounts or anecdotes (unless provided by individuals verified to be involved in an official capacity with at least one "Information Source" identified in Appendix A: Acceptable Data Sources)
• Policy advocacy documents without verifiable data/sources to support claims
• Material lacking sufficient information to be judged credible, verifiable, and/or relevant by Port CAAP representatives and/or TAP advisors

3. Overview of Existing SPBP Drayage Fleet

3.1. Late-2021 Snapshot by Key Fuel-Technology Types

As of late -2021, approximately 20,000 Class 8 trucks are registered to perform SPBP drayage, although the active drayage fleet on any given day ranges roughly between 9,000 and 13,000 trucks. Figure 1 breaks out all registered drayage trucks by engine model year. Nearly 95 percent are conventional-technology trucks powered by heavy-duty diesel engines. Approximately 6,000 (about one third) of the in-use drayage trucks are equipped with model year 2007 to 2009 engines that predate modern diesel engine control technology for oxides of nitrogen (NOx). NOx reacts with volatile organic compounds (VOCs) in the atmosphere to form ground-level ozone (photochemical smog).

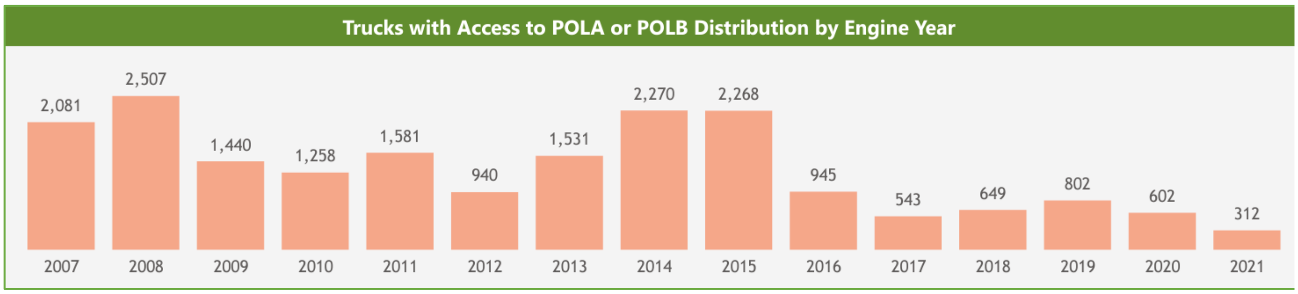


Figure 1. SPBP drayage truck fleet constitution by engine model year (Port of Los Angeles, see text)

In an important new development since the 2018 Assessment, this fleet now includes 29 ZE battery-electric drayage trucks (pre-commercial or early commercial units). Another key change for the SPBP drayage fleet composition since the 2018 Assessment has been the shift towards natural gas ICE trucks that are powered by engines that emit 90 percent less NOx than the cleanest diesel trucks. The net result is that approximately 237 drayage trucks (about 1.2 percent of the registered SPBP fleet) either do not directly emit pollutants, or their engines have been certified to emit at reduced NOx levels of 0.02 g/bhp-hr (90 percent below the current federal and California heavy-duty engine standard).[12] As such, they meet the LE definition used in this Assessment.

Liquefied Natural Gas (LNG) vs. Compressed Natural Gas (CNG): Heavy-duty natural gas vehicles (including Class 8 drayage trucks) operate on either CNG or LNG (see https://www.nrel.gov/docs/fy09osti/42946.pdf for additional details). At the time of the original CAAP, the primary form of on-board fuel storage for heavy-duty natural gas trucks was LNG. However, the heavy-duty vehicle market in recent years has trended away from LNG towards greater use of CNG. Consequently, the analysis that follow in this study are primarily based on CNG Class 8 trucks. Notably, the natural gas used in CNG trucks can come from the pipeline and be compressed at the station site, or it can be delivered as LNG and converted to CNG at "liquefied-compressed natural gas" (LCNG) stations.

In 2018, the vast majority of Class 8 trucks fueled by natural gas in the SPBP drayage fleet were factory-equipped with the 9-liter ISL G engine natural gas engine from Cummins Westport, Inc. (CWI). This engine was somewhat undersized/underpowered for Class 8 drayage applications,[13] compared to typical diesel engines used in Class 8 trucking applications. Consequently, the 9-liter ISL G engine was better suited for vocational and medium duty applications. Heavy-duty trucks with CWI's larger, more-powerful ISX12 G natural gas engine – introduced in 2015 specifically for Class 8 goods movement trucking applications – had not yet penetrated into the SPBP drayage fleet.

[12] U.S. EPA, https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-heavy-duty-highway-engines-and-vehicles.
[13] Cummins Westport International (CWI) indicates that the "natural choice" for its ISL G in trucking was "vocational and medium-duty" applications" rather than Class 8 tractor applications like drayage. CWI recently replaced the ISL G for North American markets with its L9N engine.

By the end of 2018, CWI replaced the ISL G and the ISX12 G with its L9N and ISX12N natural gas engines, respectively. CWI had certified both of these heavy-duty natural gas engines to CARB's lowest-tier Optional Low-NOx Standard (OLNS) of 0.02 grams per brake horsepower-hour (g/bhp-hr), which is 90 percent lower than the most stringent NOx emission standard (federal or California) for heavy-duty engines. This ability of 12-liter LE natural gas engines to deliver "surplus" NOx reductions enabled state and local agencies to offer incentive funds for natural gas trucks that better met the needs of trucking companies engaged in drayage. The net results associated with these market shifts are that 1) nearly 25 percent of the 900 natural gas ICE trucks in the SPBP drayage fleet (late-2021) use an LE architecture, and 2) CWI's 12-liter engine with near-diesel-equivalent range and performance has become the dominant natural gas powerplant for goods movement trucking applications. The significance of CWI's LE 12-liter heavy-duty natural gas engine penetrating into the SPBP drayage fleet is further discussed in subsequent sections, as related to overall feasibility.

3.2. Minimum and Maximum Size of SPBP Drayage Fleet

It is important to characterize the maximum and minimum size requirements of the SPBP drayage fleet when investigating the various feasibility parameters addressed in this Assessment. Several approaches have been used to develop a range for the number of drayage trucks required to operate an efficient drayage fleet. An upper end bound was set based on the number of trucks currently registered in the SPBP Drayage Truck Registry (PDTR). Based on recent historical patterns, this Assessment assumes 19,000 trucks to be the upper-end estimate for the maximum fleet.

Determining the lower bound of the drayage fleet size is more challenging. The drayage fleet undergoes day-to-day and seasonal variations in cargo throughput, as well as longer-term changes in baseline cargo throughput. Consequently, single-day or single-month maximum truck volumes do not necessarily reflect the number of individual trucks required. Additional insight can be gained by reviewing the number of trucks by frequency of container moves. In the 2018 Assessment, the lower bound fleet size was determined based on the sum of frequent (more than five moves per weekday) and semi-frequent trucks (2.5 to 5 moves per weekday). Since 2018, the Ports have revised their definitions of frequent, semi-frequent, and infrequent trucks to be based on the average number of moves per week (frequent: >20, semi-frequent: 10-20, infrequent: <10). In the current Assessment, the number of active trucks during the month, approximately 14,000 trucks as of October 2021, is used as the lower end estimate of the fleet size.[14,15] This yields a range from 14,000 to 19,000 trucks as a rough estimate for the required size of the drayage fleet. Notably, 2021 was a record year for cargo throughput and impacts from the global supply chain crisis and COVID-19 pandemic are implicitly included in the 2021 data. It remains to be seen how long these impacts will persist and whether 2021 will prove to be an anomalous year with respect to the drayage fleet size.

3.3. Drayage Operational Requirements

To assess the various feasibility parameters, it was important to first understand key operational metrics associated with the drayage vocation at the SPBP. As described in greater detail in Section 7, existing studies and a new survey of drayage survey operators were used to develop a definition of operational requirements for drayage trucks to be used in this Assessment. In practice, the drayage market cannot be defined as a single set of operating parameters applicable to every truck. Drayage is a continuum of daily operational needs that varies across the entire drayage fleet. Therefore, to inform Operational Feasibility and other parameters analyzed in this Assessment (see descriptions in next section), the concept of a "broadly applicable truck" (BAT) was developed. A BAT is defined as a heavy-duty truck capable of performing the vast majority of SPBP drayage operations. As shown in Table 2, a BAT is described by the minimum operational capabilities needed for a SPBP drayage truck. Table 2 also provides average operational assumptions that are used to inform various analyses in this Assessment.

[14] Port of Los Angeles, Clean Truck Program – Gate Move Analysis, October 2021. Accessed at https://www.portoflosangeles.org/environment/air-quality/clean-truck-program

[15] Between 2018 and 2021, the definition of "frequent" and "semi-frequent" changed. In the 2021 gate move analysis, Frequent is defined as >20 average moves per week and Semi-Frequent is defined as 10-20 average moves per week. These definitions are equivalent to the 2018 definitions for a five-day work week.

Table 2. Operational assumptions for a "Broadly Applicable Truck" (BAT)

Operational Parameter	Units	Value
Minimum Operational Capabilities Needed		
Maximum Shift Distance	miles	600
Maximum Shifts per Day	#/day	2
Maximum Daily Mileage	miles	800
Maximum Weight (GCWR)	lbs	80,000
Top Speed (0% grade)	MPH	60
Gradeability @0 MPH	% grade	15% at 80,000 lbs
Gradeability @40 MPH	% grade	6% at 80,000 lbs (short distance bridge climb)
Gradeability @35 MPH	% grade	6% at 57,000 lbs (sustained)
Number of Shifts Between Charging/Fueling	# of shifts	2 shifts with less than 5 hours for charging/ fueling, or 1 shift with diesel-like fueling times
Average Operational Assumption for Economic and Infrastructure Analyses		
Average Shift Distance	miles	209
Average Shift Duration	hours	9.9
Average Shifts per Day	#/day	1.4
Average Daily Operating Time	hours	14.8
Average Daily Mileage	miles	252
NOTE: some of these values and assumptions changed modestly since the 2018 Assessment. Please see Section 7 on Operational Feasibility, which identifies and further discusses such changes.		

4. Applied Parameters and Initial Screening

As with the initial effort in 2018, this 2021 Drayage Truck Feasibility Assessment applies five key parameters to examine which (if any) emerging ZE and/or LE fuel-technology platforms for Class 8 trucks are demonstrably capable of and ready for broad deployment in drayage service at the Ports. The five feasibility parameters – which were originally outlined in the previously described "Framework" document[16] – are as follows:

- Commercial Availability
- Technical Viability
- Operational Feasibility
- Infrastructure Availability
- Economic Workability (Key Economic Considerations and Issues)

All five of these parameters interact to collectively define feasibility. Failure to meet any one parameter could present a significant barrier to *wide-scale* deployment at the Ports. The first two parameters have been determined to be especially important to achieve, or at least approach achievement. Specifically, to be ready for near-term, large-scale deployment (i.e., thousands of units), a given drayage truck platform 1) needs to exist as a certified commercial product, and 2) must be technically capable to perform all necessary drayage duties in a reliable, safe and effective manner, as described further in this report and in the "Framework" document previously referenced.

Thus, the two feasibility parameters of Commercial Availability and Technical Viability were used to initially screen leading ZE and LE fuel-technology platforms that appear capable of powering Class 8 drayage trucks. All fuel-technology platforms shown to meet basic considerations for these two parameters (while applying noted guidelines, and within a three-year timeframe) were then further assessed, according to the three remaining feasibility parameters (Operational Feasibility, Infrastructure Availability, and Economic Workability). The schematic in Figure 2 depicts this basic screening procedure.

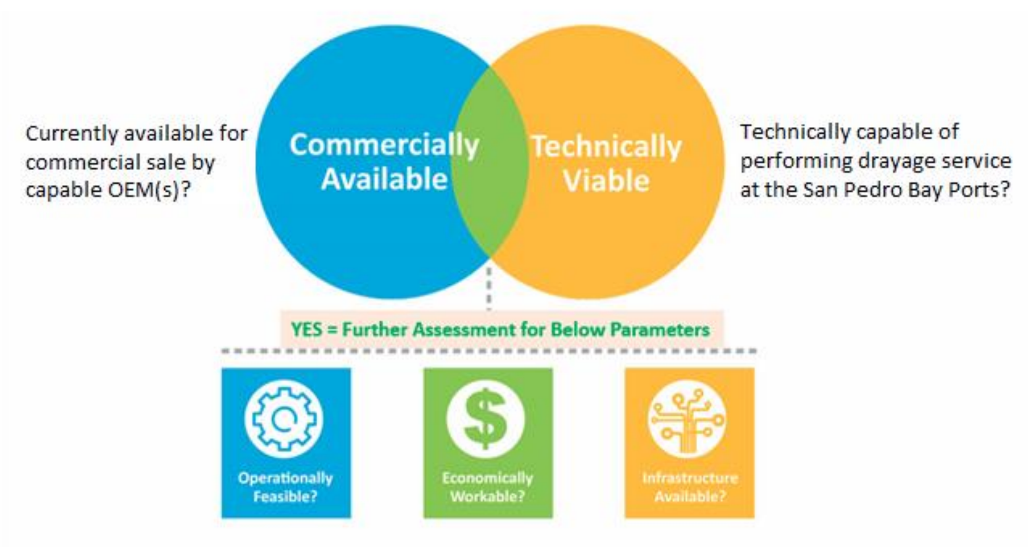


Figure 2. General screening procedure for applying feasibility parameters

[16] San Pedro Bay Ports, "Framework for Developing Feasibility Assessments", November 2017, http://www.cleanairactionplan.org/documents/feasibility-assessment-framework.pdf/.

NOTE: It is important to reiterate that this 2021 Feasibility Assessment for Drayage Trucks represents a snapshot in time. The technology and economic landscapes for clean heavy-duty transportation technologies can change rapidly. ZE and/or NZE drayage truck platforms that do not yet warrant deeper analysis (as of late-2021) could still exhibit rapid development and advancement. Recognizing this potential, the Ports intend to prepare a revised/updated feasibility assessment for drayage trucks approximately every three years, or more frequently if warranted (e.g., accelerated technological progress, significant expansion in commercial platforms, improving economics).

5. Assessment of Commercial Availability

5.1. Background: Criteria and Methodology

An emerging ZE or LE fuel-technology drayage truck platform is deemed to be commercially available when (1) it is being manufactured in similar quantities[17] and timeframes as the baseline equipment (Class 8 diesel ICE tractors), and (2) it has baseline-equivalent customer support systems for vehicle warranty, maintenance, and parts. Using additional guidance from the Framework document, specific criteria have been identified to collectively define if these two basic tests are met. Table 3 summarizes these commercial availability criteria and their base considerations.

Table 3. Criteria and base considerations used to evaluate Commercial Availability

Commercialization Criteria/Issue	Base Considerations for Assessing Commercial Availability
Production and Sales with Major OEM Involvement	Production and CARB certification by either a major Class 8 truck OEM or by a proven technology provider that has partnered with the major OEM.
Proven Network/Capabilities for Sales, Support and Warranty	Demonstrated existing (or near-term planned) network of sufficient dealerships to sell and service existing or expected drayage truck demand.
	Demonstrated ability to sell ZE and/or LE Class 8 trucking platforms that are equivalent to baseline diesel Class 8 trucks (full warranty provisions, long-term support for maintenance and parts replacement).
Sufficient Means and Timeline for Production	Demonstrated capability to manufacture sufficient numbers of Class 8 trucks (suitable for drayage) within a timeline to meet existing or expected demand.
Existence of Current and/or Near-Term Equipment Orders	Demonstrated backlog of Class 8 truck orders, or credible expression of interest from prospective customers to submit near-term orders.
Source: Based on criteria in San Pedro Bay Ports' "Framework for Developing Feasibility Assessments," November 2017.	

5.2. Production and Sales with Major OEM Involvement

5.2.1. Objectives and Methodology for Characterizing OEM Commercialization Status

A common denominator among the criteria above is the paramount role that capable heavy-duty truck OEMs must play to develop, certify, sell and support large numbers of ZE and/or LE drayage trucks. (It is also recognized that many of these major OEMs are working with, and relying upon, smaller-volume start-up OEMs, technology providers and qualified "upfitters" to help accelerate technological progress and incorporate alternative fuel systems into various ZE and LE platforms.) To help gather and summarize the current status of OEM involvement in these markets, the authors contacted senior-level representatives from major existing and emerging Class 8 truck OEMs, as well as from OEMs of Class 8 truck engines and/or drivetrains. OEM representatives were asked to provide relevant inputs via telephone interviews and/or written questionnaires. This type of "off-the-record" OEM input was combined with relevant OEM information in the public domain (e.g., websites, press releases, corporate reports, government grants, public reports on Class 8 truck demonstrations, etc.) to build a current, verifiable snapshot of overall drayage truck feasibility in 2021, beginning with commercial availability as the initial parameter to evaluate.

[17] "Similar quantities" is not meant to indicate that ZE and/or LE truck types cannot be considered "commercially feasible" unless/until they are sold in equal quantities as diesel trucks. Rather, it means they must be sold in the same order of magnitude as diesel trucks (hundreds to thousands per year).

Table 4 summarizes the different major existing or emerging Class 8 truck OEMs – and existing or emerging Class 8 truck engine/drivetrain OEMs companies[18] – that were contacted and asked to provide inputs. The specific objective was to provide key OEMs with the opportunity to anonymously[19] describe 1) their existing or near-term-planned product offerings that incorporate ZE or LE fuel-technology platforms (as previously defined); and 2) how they perceive opportunities, challenges, and timelines associated with a potential major new market for Class 8 ZE and LE drayage trucks at the SPBP.

Table 4. Class 8 truck OEMs contacted about ZE/LE products, opportunities and challenges*

Company Name	Role in Manufacturing Class 8 Trucks
Freightliner (Daimler Trucks North America)	**Existing or Emerging** Class 8 Truck OEM
Volvo Group North America	
Mack Trucks	
Kenworth	
Peterbilt Motor Co.	
Navistar, Inc.	
BYD	
Nikola Motor Co.	
Tesla, Inc.	
Toyota USA	**Existing or Emerging** Class 8 Engine / Drivetrain OEM
Cummins Inc.	
Meritor/Transpower	

Notes:
*"Contacted" refers to communications through emails and/or telephone calls. All 12 companies responded, of which 10 provided interviews.
Daimler Trucks North America recently changed "Trucks" to "Truck" in its corporate name.

Information provided by responding representatives helped to compile a profile about OEM involvement in the market for Class 8 ZE and LE heavy-duty trucks (existing and potential products, opportunities, challenges and risks). This was used to supplement and expound upon public information released by the OEMs, and prepare a revised snap-shot (late-2021) for commercial availability of Class 8 ZE and LE trucks, including reference to specific areas of major progress since release of the 2018 Assessment.

5.2.2. Pre-Commercial vs. Early Commercial and Importance of Fully Demonstrated Technology

This Assessment frequently uses the terms "pre-commercial" and "early commercial" when summarizing the commercialization status of various fuel-technology drayage truck platforms. Per CARB's use, early commercial refers to emerging-technology truck platforms that are relatively new to the market, but "have been demonstrated, are certified by CARB, come with a warranty, and are purchased or leased by the end user." Typically, these are made available to end users in small numbers and have not yet been commonly deployed in drayage service at the Ports. By CARB's terminology, a pre-

[18] Inputs and information were also sought from existing or emerging truck / component OEMs not on this list; where germane, their information has been incorporated into this report. However, the focus of this due diligence was on major OEMs that currently manufacture large numbers of trucks and/or engine and drivetrain systems.

[19] These existing and emerging OEMs were asked to provide non-proprietary answers and information. To help encourage a high rate of response and facilitate frank inputs, it was communicated to the OEMs that their information and inputs would be treated as anonymous, i.e., without attribution to any specific OEM or company representative.

commercial fuel-technology truck platform does not yet meet all of the above tests (e.g., it may not be CARB certified), and is generally "focused on first-time demonstrations of advanced technologies in new applications." Some of the ZE and LE fuel-technology truck platforms discussed in this Assessment fall somewhere between these two definitions, especially when considered in the specific context of SPBP drayage service.

Like the 2018 report, this 2021 Assessment emphasizes the critical importance of fully demonstrating pre-commercial and early commercial trucks in revenue SPBP drayage service. Demonstrations of OEM-built products are essential for all parties (OEMs, shippers, trucking companies, the Ports, fuel/infrastructure providers, permitting officials, etc.) to collectively establish and corroborate the feasibility of ZE and LE Class 8 truck platforms before attempting broad deployments.

Section 5.8 contains details about the importance of large-scale Class 8 drayage truck demonstrations that are just getting underway or planned at the Ports, and the essential role they will play to provide OEMs, trucking fleets, shippers and the Ports with first-hand operational experience on various emerging ZE and LE fuel-technology platforms.

5.2.3. Baseline for Measuring Progress Since 2018 Feasibility Assessment

As a frame of reference, the 2018 Drayage Trucks Feasibility Assessment (including its May 2020 amendment[20]) reported the following about *the status in 2018* of ZE and LE platforms (specifically for drayage truck applications):

1) **ZE** battery-electric Class 8 trucks were emerging as pre-commercial products. BYD, a relatively new heavy-duty truck OEM (for North American markets), was offering one model in relatively small production volumes. Notably, all six long-standing major heavy-duty truck OEMs (Daimler, Kenworth, Peterbilt, Volvo, Navistar, Mack) were working to develop, demonstrate and eventually commercialize Class 8 battery-electric tractors suitable for drayage applications (some OEMs were partnering with start-up OEMs and/or technology providers).
2) **ZE** fuel cell electric Class 8 trucks were being developed by multiple major OEMs (some in conjunction with technology partners) as proof-of-concept vehicles for demonstration in drayage applications.
3) **LE** natural gas Class 8 trucks had emerged from early commercial products into fully commercial products, offered by seven different major OEMs (albeit, at relatively small production volumes).
4) No other **ZE** or **LE** Class 8 truck platforms (e.g., neither diesel hybrid or nor diesel ICE) were being demonstrated in drayage applications, or sold by any OEM.

5.2.4. Recent Regulatory and Incentive Changes Driving ZE/LE Drayage Truck Deployments

Since the 2018 Assessment, numerous key changes have occurred in California's regulatory and policy landscape that are helping to drive commercialization and deployment of Class 8 trucks with ZE or LE architectures. The state's overarching goal is clear. Governor Gavin Newsom's Executive Order N-79020 – as well as CARB's 2020 Mobile Source Strategy[21] – seek to transition California's entire drayage fleet to only ZE trucks by 2035. To enable this, CARB is combining aggressive new *regulatory* measures with expanding *incentive funding* programs. This two-pronged approach is intended to expedite turnover of in-use Class 8 diesel trucks and their replacement with ZE trucks. However, CARB is also taking new regulatory actions – and revising incentive programs – designed to ensure that non-ZE (conventional ICE-equipped) trucks in California's fleet (new, or in-use) are as low-emitting as possible.

CARB's three recent key *regulatory* measures designed to collectively bring this to fruition are:

- Advanced Clean Trucks (ACT): Approved by CARB in March 2021, ACT requires Class 8 truck OEMs to sell ZE models as increasing percentages of their annual California sales. For Class 7-8 tractors, the mandated sales percentage begins at 5

[20] In May 2020, the Ports commissioned an update to the 2018 Drayage Trucks Feasibility Assessment to take into account a significant advancement in technology readiness for the NZE natural gas ICE fuel-technology platform. The 2018 Assessment complete with this May 2020 Addendum can be downloaded at https://cleanairactionplan.org/strategies/trucks/.

[21] California Air Resources Board, "2020 Mobile Source Strategy," October 28, 2021, https://ww2.arb.ca.gov/resources/documents/2020-mobile-source-strategy.

percent for model year 2024; by model year 2035 it reaches 40 percent. As an initial way to begin creating demand for ZE trucks, ACT also included a "one-time" requirement for larger heavy-duty truck fleets to report to CARB about their mix of existing trucks.[22]

- Advanced Clean Fleets (ACF): ACF is expected to be considered by CARB for adoption in late-2022; it is the "demand side" of CARB's plan to transition to an all ZE HDV fleet. As currently drafted, it will require drayage fleets to phase-in use of ZE trucks beginning in 2024. By January 1, 2035, ACF will require that all drayage trucks operated in California use zero-emission powertrains (effectively, battery-electric or hydrogen fuel cell electric). [23]
- Heavy-Duty Engine and Vehicle Omnibus Regulation (Low-NOx Omnibus, or LNO): Adopted in August 2020, LNO is a complex regulation with two bottom-line intents: 1) to ratchet down NOx certification standards for new medium- and heavy-duty vehicles (MDVs/HDVs) sold in California; and 2) to ensure that future in-use MDVs/HDVs emit low levels of NOx during real-world operation throughout their full useful lives. Relevant to this Assessment, LNO requires OEMs to sell only LE MDV/HDV trucks (specifically, with engines certified to 0.05 g/hp-hr NOx by MY 2024, and to 0.02 g/bhp-hr NOx by 2027). In addition, LNO includes provisions that "encourage" OEMs to take early action on selling ZE trucks (i.e., beyond ACT requirements), and it introduces a new optional low-NOx standard ("as low as" 0.01 g/bhp-hr) designed to incentivize OEMs to develop and sell ultra-low emitting ICE trucks.[24]

To complement these (and other) recent regulatory actions, CARB's mobile source strategy seeks to aggressively increase *funding programs* for the lowest-emitting MDVs/HDVs possible. While LE trucks are not excluded, CARB's approach is clearly ZE-focused; it concentrates on expanding funding programs that simultaneously incentivize 1) manufacturing, purchase and deployment of ZE trucks; and 2) building out of charging and hydrogen stations sufficient to support such deployments (in conjunction with the California Energy Commission).

Within the context of evolving regulatory policies and funding programs, the following subsections summarize progress and activities by OEMs since the 2018 Assessment to commercialize ZE and/or LE trucks, for potential use in California's drayage fleet.

5.2.5. Summary of OEM Progress Since 2018 to Commercialize ZE Drayage Trucks

Over the last several years, Class 8 truck OEMs (with their technology partners) have made major progress to commercialize ZE Class 8 truck platforms. In fact, according to mid-2021 telephone interviews with OEM representatives combined with public announcements, OEMs expect that 2022 will be a breakout year for commercial launches of Class 8 ZE battery-electric trucks. Class 8 truck OEMs – in some cases the same ones – also expect to achieve important milestones in 2022 to advance commercialization of fuel cell electric trucks. The following provides a high-level summary of OEM progress to commercialize Class 8 ZE trucks (both architectures).

- By the end of 2022, at least six OEMs (three traditional and three start-up) will be performing "limited-scale" production of battery-electric Class 8 trucks (primarily day cab[25] models). For individual OEMs, this will likely constitute producing hundreds (not thousands) of early commercial trucks (see definitions in the call-out box below). In most cases, actual deliveries to fleets will begin in 2023 (in part due to slowdowns in global supply chains that have limited manufacturing slots for all types of heavy-duty vehicles (HDVs)). The cost to manufacture battery-electric Class 8 trucks (especially at this relatively small scale) is significantly higher than the cost to make comparable conventional diesel trucks. Final prices

[22] California Air Resources Board, "Final Regulation Order: Advanced Clean Trucks Regulation," March 2021, https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks.

[23] California Air Resources Board, "Advanced Clean Fleets Regulation Proposed Draft Regulatory Language: Drayage Truck Requirements," Sept. 9, 2021, https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets/advanced-clean-fleets-draft-regulation-and-comments.

[24] California Air Resources Board, "Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments," December 22, 2021, https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox.

[25] "Day cab" refers to a semi-tractor with a cab that does not include sleeping accommodations.

of these battery-electric trucks have not yet been set and/or disclosed. Based on interviews with OEM representatives, they will likely be priced two-to-three times higher than comparable diesel trucks (excluding incentives).

- In 2022, at least one major vehicle OEM will initiate limited-scale production of hydrogen fuel cell engines specifically designed for Class 8 trucks in drayage applications. Under state-funded demonstrations, multiple pre-commercial Class 8 trucks using this fuel cell system have collectively accumulated tens of thousands of miles in SPBP drayage service. The price for a Class 8 truck with this fuel cell drivetrain and the on-board hydrogen storage system will likely be similar to (or higher than) a comparable battery-electric truck.

For the two ZE architectures (battery electric and hydrogen fuel cell), Class 8 truck OEMs generally identified these key challenges to overcome as they bring commercialization plans to full fruition:

- High incremental cost/price over conventional trucks – Several OEM representatives expressed concern about the affordability of ZE drayage trucks, especially for independent owner-operators who perform large percentages of container moves at the two Ports.
- Concerns about access to specialized parts – Some OEM representatives expressed concern that initially, access to specialized parts for ZE platforms may be insufficient to build and/or repair OEM products on a large scale.
- Limited charging/fueling infrastructure, and long lead times for building out stations – Nearly all OEM representatives specifically identified infrastructure build-out as the "rate-determining" step for deploying ZE trucks in drayage (even at the relatively small scale for initial truck production described above). OEM representatives stressed that fleets ordering battery-electric trucks should anticipate *at least* a 12-month lead time for siting, permitting, planning and building out charging infrastructure.

5.2.6. Summary of OEM Progress Since 2018 to Commercialize LE Natural Gas Trucks

In late-2018 when the initial assessment was prepared, all seven longstanding major heavy-duty truck OEMs were offering commercially offering Class 8 LE natural gas trucks. All make/models were equipped with the Cummins Westport 12-liter LE natural gas engine, which had not yet been fully demonstrated in drayage applications. Consequently, the 2018 Assessment characterized these trucks as early commercial products. Shortly after the 2018 Assessment was released, the Ports received credible new documentation that 20 Class 8 LE natural gas trucks powered by CWI's 11.9-liter ISX12G engine had essentially attained full commercial and technological maturity while being operated in drayage service at the Ports. To document this important change, the Ports published Addendum A[26] of the 2018 Assessment. This new information corroborated that 1) Class 8 LE natural gas trucks had achieved full technological readiness (further described in Section 6), and 2) drayage fleets serving the Ports were operating and/or ordering hundreds of these trucks.

CARB arrived at this same basic conclusion by mid-2019, as stated in staff's "technology pathways and status updates" draft release about low- and zero-emission heavy-duty vehicle technologies.[27] Specifically, CARB staff wrote the following:

> *"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 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."*

[26] Full details are provided in Addendum A of the 2018 Feasibility Assessment for Drayage Trucks, released by the Ports in May 2020, downloadable at https://cleanairactionplan.org/2019/04/03/ports-issue-final-clean-trucks-assessment/.
[27] California Air Resources Board, "Draft Technology Pathways and Status Updates," August 1, 2019, https://ww2.arb.ca.gov/sites/default/files/2019-08/draft_techpathways_08012019.pdf.

CARB staff noted that by mid-2019, U.S. sales of heavy-duty LE natural gas engines had reached "several thousand units per year."

In summary, this 2021 Assessment finds that Class 8 LE natural gas ICE trucks are robust commercial products, with proven capability for drayage operations (also discussed in Section 6 – Technical Viability and Section 7 - Operational Feasibility). Almost all major long-standing OEMs continue to include them in their product lines, and drayage fleets continue to order them. A challenge for achieving wide-scale use of Class 8 natural gas trucks at the Ports remains the relatively high-cost OEMs must pay to manufacture them (primarily due to the on-board fuel storage tanks), compared to baseline diesel trucks (see Section 9 on Economic Workability).

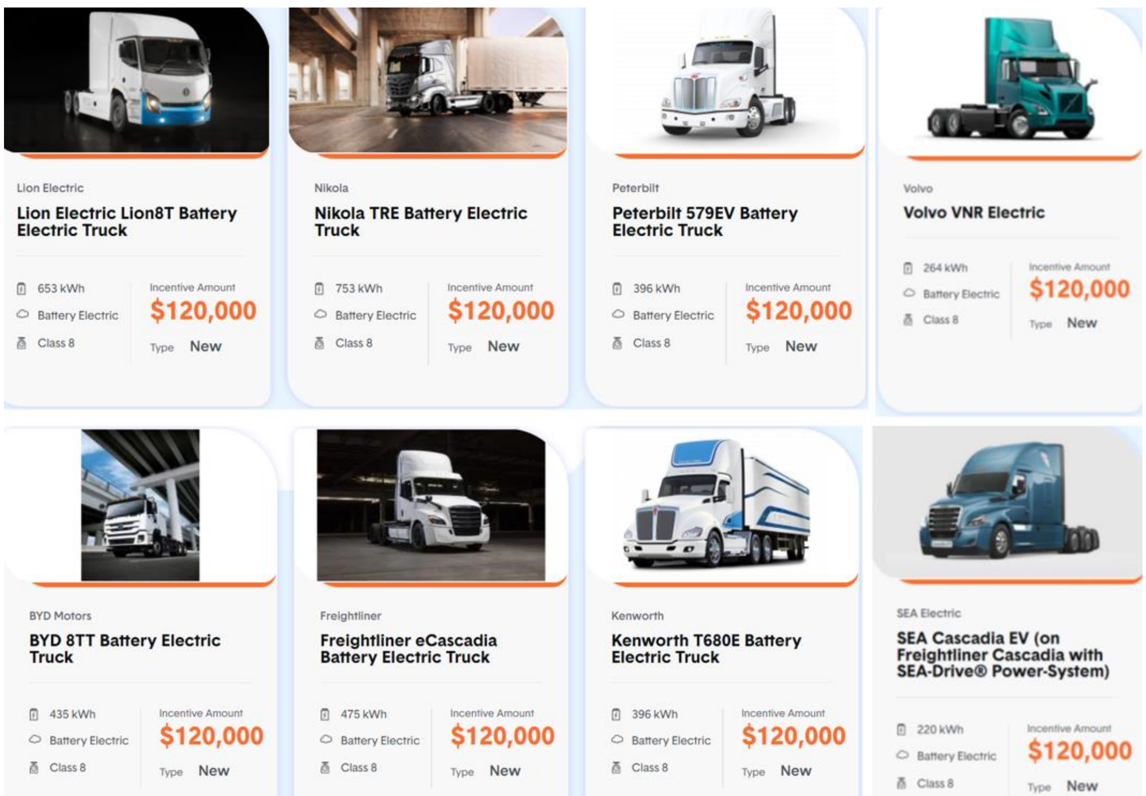


Figure 3. 2021 snapshot: ZE battery-electric Class 8 "drayage capable" trucks eligible for HVIP funding

5.2.7. Summary of OEM Progress Since 2018 to Commercialize LE Diesel Hybrids and/or ICE

As of late-2021, no OEM offers an LE plug-in hybrid model (with or without capability to provide partial ZE miles), nor a conventional ICE truck powered by a heavy-duty diesel engine certified to an emission level below baseline diesel technology. In fact, no heavy-duty diesel engine has been certified to CARB's Optional Low-NOx Standards.[28] This is unchanged from the 2018 Assessment.[29]

The subsections that follow describe specific ways – and enabling programs – by which Class 8 truck OEMs have further advanced ZE and LE truck architectures toward sufficient commercial maturity to enable widescale deployment in SPBP

[28] See https://ww3.arb.ca.gov/msprog/onroad/optionnox/optional_low_nox_certified_hd_engines.pdf for CARB's list of OLNS-certified engines.

[29] Notably, this may change by or before model year 2024. Heavy-duty diesel engine OEMs are known to be making progress to develop lower-emitting versions of existing heavy-duty diesel engines. Moreover, CARB's adoption in 2020 of the Low-NOx Omnibus regulation essentially drives OEMs continuing their California sales to build Class 8 trucks that use some type of NZE architecture retaining diesel engine technology.

drayage. As repeatedly stressed, "feasibility" under this Assessment requires that existence of Commercial Availability is combined with sufficient simultaneous achievement for Technical Viability, Operational Feasibility, Infrastructure Availability, and Economic Workability.

5.3. California HVIP: a Leading Funding Program to Help Commercialize ZE Drayage Trucks

California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) is a leading funding program to simultaneously help incentivize 1) heavy-duty vehicle OEMs to build ZE and/or LE vehicles, and 2) fleets to purchase them. Under HVIP, CARB has prioritized drayage trucks for disbursing incentive funds and enabling fleet deployments. As shown in Figure 3, CARB has approved (as of late-2021) eight ZE battery-electric Class 8 truck models for eligibility to receive HVIP incentive funds (up to $120,000 per unit and $150,000 per unit for drayage trucks).[30] Four of the eight models are built and sold by major long-standing Class 8 truck OEMs (Daimler, Kenworth, Peterbilt, and Volvo). Three models are built and sold by relatively new Class 8 truck OEMs (BYD, Lion Electric and Nikola). Sea Electric builds its Class 8 battery-electric truck by converting Freightliner Cascadia diesel trucks.

NOTE: the list of ZE Class 8 "drayage capable" trucks that are eligible for HVIP funding is dynamic; in 2022 Hyzon Motors received approval under HVIP for its "FCET8" hydrogen fuel cell electric tractor, which is a conversion of the Freightliner Cascadia day cab tractor.

Figure 3 also shows that these eight models have battery packs ranging in size from 220 kWh to 753 kWh. Battery pack size is the key determinant for a Class 8 battery-electric truck's maximum driving range, and therefore its ability to perform all types of drayage at the Ports (further discussed in Section 7).

Table 5. Summary information for Class 8 ZE battery-electric trucks eligible for HVIP funding (end of 2021)

Specification Type / Parameter	Freightliner eCascadia	Kenworth T680e	Peterbilt 579EV	Volvo VNR 4X2 Tractor	BYD 8TT	Nikola TRE	Lion Electric 8T	Sea Electric Cascadia EV
Battery Pack Capacity	475 kWh	396 kWh	396 kWh	264 kWh	409 kWh	753 kWh	653 kWh	220 kWh
Advertised Range (Miles, Maximum)	250	150	150	150	125	350	260	Not listed
Power Rating (Base Model)	391 kW	355 kW	400 kW	340 kW	355 kW	480 kW	400 kW	Not listed
Sources: HVIP website, January 2022, https://californiahvip.org/vehicle-category/heavy-duty/, including HVIP links to each OEM's specifications.								

Table 5 provides summary information and specifications (including advertised driving range) for these eight battery-electric trucks, all of which CARB deems to be "drayage capable." HVIP does not list prices (which are negotiated between the OEM/dealer and fleet awardee). In addition to dictating vehicle range, battery size is "the largest determinant" of manufacturing costs for battery-electric vehicles.[31] This implies that the Nikola TRE model will have the highest price of the trucks listed in the table. Notably, the BYD 8TT

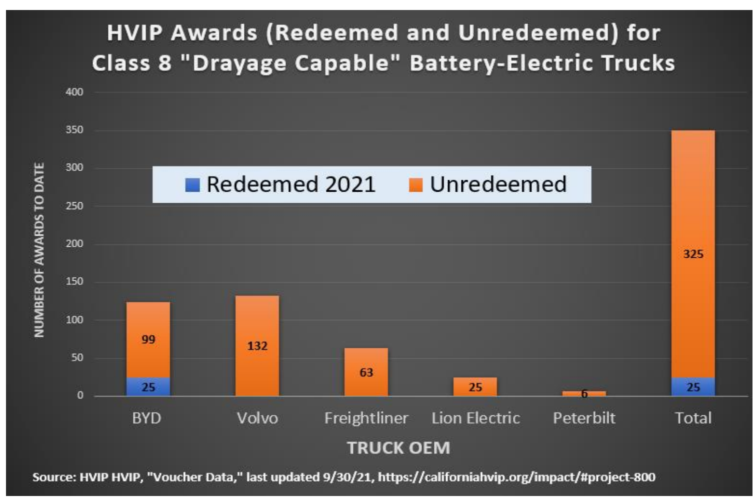


Figure 4. HVIP awards for Class 8 ZE battery-electric trucks, by OEM

---

[30] HVIP website, "Vehicle Catalog," https://californiahvip.org/vehiclecatalog/.
[31] HVIP website, "FY20-21 Implementation FAQs," https://californiahvip.org/about/#FAQ.

model began production in 2019; the other make/models are expected to start production beginning in 2022.

Figure 4 shows the total number of HVIP awards for Class 8 ZE battery-electric trucks (through September 2021), broken out by the five HVIP-certified OEMs that received orders. Notably, having begun small-volume production for HVIP in 2019, BYD has already "redeemed" 25 vouchers for its battery-electric 8TT model. Many of these 25 BYD units sold and delivered through HVIP awards are registered to perform drayage at the SPBP.

The figure also shows that collectively, these five OEMs have received 325 voucher orders that are "unredeemed" (not actually sold and delivered) as of the third calendar quarter of 2021.[32] This status appears consistent with OEM representative comments (reported anonymously above) that most companies will not start building Class 8 battery-electric trucks (including HVIP awards) before 2022, despite 2021 production dates that are implied by the HVIP webpage.

These 350 Class 8 battery-electric trucks approved for HVIP vouchers (through September 2021) were awarded to trucking fleets that operate across California, including fleets that perform drayage at the SPBP and other state seaports. Approximately 70 percent of the awarded fleets list their primary addresses as being in the South Coast Air Basin (greater Los Angeles area). Based on this, it can be deduced that roughly 240 locally domiciled Class 8 battery-electric trucks funded through the HVIP program will begin performing drayage at the two Ports over the next 12 to 18 months. Moreover, it is expected that significant numbers of additional ZE battery-electric drayage trucks – funded through a variety of other incentive programs (see Appendix for examples) – will enter the SPBP drayage fleet during this timeframe.[33] Finally, approximately 50 early commercial Class 8 ZE battery-electric trucks (from Daimler and Volvo) will enter into drayage and regional haul service in Southern California over the next 18 months, under the government-industry collaboration known as the Joint Electric Truck at Scale Initiative (please see Section 5.8).

Roughly 100 battery-electric trucks have been awarded to fleets located in the San Joaquin Valley. Using conventional diesel trucks, some of these fleets serve the SPBP by performing longer-haul drayage trips. As State agencies have acknowledged, this type of drayage service (including mountain pass driving) would likely be challenging using the battery-electric trucks currently being awarded under HVIP.[34] For example, the Bakersfield area (Interstate 5/State Route 99 trucking corridor) is about a 140-mile one-way trip from the Ports, and requires driving over the Tejon Pass (4,160 feet in elevation). A roundtrip from/to either Port would likely require opportunity charging for any of the six battery-electric Class 8 make/models launched to date (in early commercial capacities).

It appears that California-funded deployments of "drayage capable" ZE Class 8 trucks will continue to grow. Using funding from HVIP and other incentive programs, CARB has launched the "Project 800 initiative," which seeks to fund orders for 800 new ZE drayage trucks in California by the end of 2021. Project 800 is part of CARB's overarching strategy for "aggressive ZEV penetration and accelerated replacement of older vehicles," especially for heavy-duty vehicles. As one means to achieve this goal, CARB allocated an initial funding wave of $63 million under HVIP dollars to help drayage fleets purchase new ZE trucks. This would equate to 420 new drayage trucks deployed, at the maximum incentive of $150,000 per truck. According to CARB, the 800 ZE Class 8 trucks will specifically "serve California ports" and initiate "a transformational period for zero-emission drayage truck technologies." CARB notes that "planning is already underway to continue this momentum for the next 1,000 drayage trucks starting in 2022."[35] To enable this, CARB announced in late-2021 that California has "set-aside" $75 million in new HVIP funding for Class 8 ZE drayage trucks. At the base voucher amount of $150,000 per drayage truck (extended by CARB through at least December 31, 2022), this would fund deployment of 500 additional trucks.[36]

[32] Unredeemed vouchers are not guaranteed to result in sales of the corresponding vehicles. HVIP awards don't impose obligations to deploy trucks; unredeemed vouchers can be relinquished or lost if the trucks are not deployed within 18 months. Full requirements are provided in the HVIP FY 20-21 Implementation Manual, downloadable at https://californiahvip.org/purchasers/.

[33] This takes into account current long lead-times that OEMs are experiencing to fill new truck orders, even for conventional diesel trucks.

[34] California Energy Commission, "GFO-21-501 Pre-Application Workshop: Hydrogen fuel Cell Truck and Bus Technology Integration and Demonstration, staff presentation, August 3, 2021.

[35] California HVIP website, "Tracking Project 800," https://californiahvip.org/news/tracking-project-800/. Also see https://californiahvip.org/about/#FAQ.

[36] Calstart (HVIP program manager), "HVIP FY21-22 Policy Changes," email from California HVIP listserv, November 22, 2021.

5.4. OEM Public Announcements, Statements and Literature about Commercial Availability

Eligibility of a Class 8 truck model under California's HVIP program is just one metric for summarizing the current status of "commercially available" Class 8 trucks that use ZE or LE architectures. Table 6 provides a snapshot (late-2021) of the heavy-duty OEMs that have publicly indicated they now (or will soon) produce and sell ZE and/or LE Class 8 tractors. Again, it is important to recognize that these OEM offerings range from pre- and early commercial products to those that have emerged as fully commercial products (albeit, produced at low volumes relative to conventional diesel tractors).

Table 6. Snapshot of OEM commercial offerings for ZE and LE Class 8 truck types (late-2021)*

Make	Model	ZE Battery-Electric	ZE Hydrogen Fuel Cell	LE Diesel (Plug--In Hybrid or Diesel ICE)	LE NG ICE (CNG and/or LNG)
Freightliner (Daimler)	Cascadia	√	×	×	√
Kenworth	T680(e)	√	×	×	√
Mack**	Anthem	×	×	×	√
Peterbilt	579	√	×	×	√
Volvo	VN(R/L) 300	√	×	×	√
Navistar***	TBD	×	×	×	×
BYD	8TT (T9/Q3M)	√	×	×	×
Lion Electric	Lion8T	√	×	×	×
Nikola	Tre	√	×	×	×

Source: OEM websites, press releases and other publicly available literature
*These truck models vary in stage of commercialization; ZE trucks are pre-commercial or early commercial products
**Mack has focused its battery-electric commercialization efforts on refuse truck applications
***Navistar makes battery-electric trucks up to Class 6; Class 7-8 ZE truck models (BEV, FCV) are anticipated by 2024

To summarize key information in Table 6:

- Seven heavy-duty truck OEMs offer Class 8 ZE battery-electric trucks as pre-commercial or early commercial products. This represents a major increase from the 2018 Assessment, which indicated that one OEM (BYD) had initiated sales of a pre-commercial model.
- Multiple OEMs are developing and demonstrating Class 8 ZE fuel cell trucks, with intent to fully commercialize by or before 2024 (see below). However, none are yet sold as commercial products as defined in this Assessment. This is unchanged from the 2018 Assessment.
- Five heavy-duty truck OEMs offer LE trucks fueled by natural gas as fully commercial products (all powered by the Cummins Westport 12-liter ISX12N engine). This represents a modest decrease from the 2018 Assessment, which indicated that six OEMs were making and selling Class 8 LE natural gas truck models (Navistar has since discontinued this fuel-technology platform).
- No OEMs offer any other type of ZE or LE fuel-technology platform for Class 8 trucks (e.g., there are no commercially available plug-in hybrid or low-NOx diesel ICE trucks). This is unchanged from the 2018 Assessment.

Looking out past late-2021/early 2022, numerous OEMs have efforts underway to commercialize Class 8 ZE trucks for North American markets by or before 2024. These include the following (where applicable, updates from the 2018 Assessment are provided):

- Tesla continues to work on its Class 8 battery-electric "Semi" model, and has reportedly received hundreds of pre-orders from major long-haul trucking fleets,[37] as reported in the 2018 Assessment. Tesla initially intended to start production of its Semi model in 2020, and provided details including expected pricing.[38] However, Tesla announced in mid-2021 that Semi's launch is delayed until 2022, due to "limited availability of battery cells and global supply chain challenges."[39] As of late-2021, Tesla characterizes its Class 8 Semi model as being "in development;"[40] additional details (including the latest on pricing) are expected from Tesla in early 2022.
- Nikola Motors has modified its plan since the 2018 Assessment; it now intends to manufacture Class 8 trucks with two different ZE architectures. For the initial launch, Nikola focused on its battery-electric "Tre BEV" model; this early commercial model can be purchased (or leased) in 2021 from authorized Nikola dealers or directly from Nikola.[41] The company is using the same basic platform and electric-drive system to produce and sell two hydrogen fuel cell truck models, both of which are being designed to provide longer driving ranges than the Tre BEV model. Nikola indicates that its cabover "Tre FCEV" will be available in 2023 (500-mile range), and its sleeper cab "Two FCEV" model will be available in 2024 (900-mile range).[42] Both models are currently in pre-commercial stages of demonstration.
- Kenworth has teamed with Toyota, to design and build Kenworth T680 fuel cell electric tractors powered by hydrogen that are being designed for drayage and short-haul regional applications. At least 10 proof-of-concept T680 fuel cell tractors – which reportedly provide a 350-mile range and 15-minute fueling time – are being demonstrated at the Port of Los Angeles.[43] These appear to constitute pre-commercial units; small-volume sales are expected before 2024. Beginning in 2023, Toyota will build "production-intent" fuel cell engine / electric drive systems for this model – and a "wide variety of applications in the heavy-duty trucking sector." Toyota's initial target for the driving range of a Class 8 truck with this fuel cell system using compressed hydrogen is "over 300 miles."[44]
- Toyota is also providing its heavy-duty fuel cell system to subsidiary Hino Motors, which plans to build and commercialize Class 8 "XL8" models powered by a hybrid drive system consisting of the fuel cell and high-voltage batteries. As of late-2021 Hino and Toyota have built at least one prototype XL8 fuel cell tractor; initial testing includes Southern California drayage applications.[45]
- Navistar International has entered into a multiple party collaboration to commercialize Class 8 fuel cell electric trucks by 2024, with test vehicle demonstration beginning by late-2022.[46] The company indicates that by 2024, it will offer a commercial version of the RH Series Class 8 tractor powered by GM's fuel cell technology. Navistar and GM are targeting the tractor to provide 500 miles of range with capability to refill the hydrogen tanks in about 15 minutes.[47] Navistar has

---

[37] Matousek, M., "Tesla has a new customer for its electric Semi – here are all the companies that have ordered the big rig," Business Insider, April 25, 2018, http://www.businessinsider.com/companies-that-ordered-tesla-semi-2017-12.
[38] Thompson, C., "Elon Musk reveals new details about Tesla's upcoming Model Y SUV, the Roadster, and the Semi," Business Insider, June 5, 2018, http://www.businessinsider.com/elon-musk-reveals-tesla-model-y-roadster-and-semi-details-2018-6.
[39] Autoweek (quoting Tesla), "Here's Why the Tesla Semi Will Be Delayed," by Jay Ramey, July 27, 2021, https://www.autoweek.com/news/green-cars/a37143659/heres-why-the-tesla-semi-will-be-delayed/.
[40] Tesla, Inc., "Q3 2021 Update," downloaded at https://ir.tesla.com/#tab-quarterly-disclosure.
[41] Nikola does not provide pricing information for the Tre BEV model available for purchase in 2021. Interested fleets are invited to inquire about details.
[42] Nikola Motors website, "Semi-Trucks," accessed November 5, 2021, https://nikolamotor.com/.
[43] Kenworth, "Kenworth Video Stars Zero Emissions Kenworth T680 FCEV on the Climb to 14,115-Foot Pikes Peak Summit," January 11, 2021, https://www.kenworth.com/about-us/news/pikes-peak-video/.
[44] Toyota Newsroom, "Toyota to Assemble Fuel Cell Modules at Kentucky Plant in 2023," August 21, 2021, https://pressroom.toyota.com/toyota-to-assemble-fuel-cell-modules-at-kentucky-plant-in-2023/.
[45] Toyota Newsroom, "Toyota and Hino Truck to Jointly Develop Class 8 Fuel Cell Electric Truck for North America," 5 October 2020, accessed at
[46] Adler, Alan, "Navistar, GM and J.B. Hunt collaborate on fuel cell trucks," Freight Waves, 27 January 2021, accessed at https://www.freightwaves.com/news/navistar-gm-and-jb-hunt-collaborate-on-fuel-cell-trucks.
[47] Navistar Media Room, "Navistar Collaborates with General Motors and OneH2 To Launch Hydrogen Truck Ecosystem," 27 January 2021, accessed at https://news.navistar. com/2021-01-27-Navistar-Collaborates-with-General-Motors-And-OneH2-To-Launch-Hydrogen-Truck-Ecosystem.

also partnered with Cummins to develop a Class 8 fuel cell truck that will be tested by truckload carrier Werner Enterprises.[48]

- Hyundai is developing the "Xcient" model heavy-duty truck powered by hydrogen fuel cells, and is testing hundreds of units in Switzerland. By 2025, Hyundai plans to deploy 1,600 early commercial Xcient cabover trucks in Europe; this will be followed by (or in parallel with) commercial introduction of Class 8 Xcient trucks for North American markets.[49] To prepare for its North American launch, under the "NorCAL Zero" project (funded by various state and local agencies) Hyundai will build 30 Class 8 Xcient trucks for demonstration in Northern California. In Southern California, Hyundai (with co-funding from SOUTH COAST AQMD) will build and demonstrate at least two Class 8 Xcient fuel cell trucks.[50]

- In 2021, Daimler Truck AG and the Volvo Group AB entered into a 50:50 joint venture that includes formation of "cellcentric" – a new company focused on developing, producing and commercializing "world-class fuel cell systems" for heavy-duty trucks.[51] One focus of the Daimler-Volvo venture is to significantly cut manufacturing costs for fuel cell systems (including on-board hydrogen storage tanks), as needed to enhance the viability of hydrogen fuel cell electric systems for long-haul trucking applications.[52] The timeframe for any resulting commercial products appears to be beyond 2024.

- Start-up OEM Hyzon, which established operations in 2020, has developed a Class 8 truck model that upfits the 2022 Freightliner Cascadia chassis with Hyzon's fuel cell system. As its first customer trial in the United States, Hyzon has teamed with Total Transportation Service, Inc. (TTSI) to test the truck in SPBP drayage service. Hyzon is providing one Class 8 heavy-duty fuel cell electric truck to TTSI for a 30-day trial. The start of this demonstration was originally set to begin in late-2021,[53] but it was subsequently postponed until early April, 2022.[54] Notably, Hyzon's "update on 2021 deliveries" (January 2022, accessed at https://hyzonmotors.com/media/) implies the company is prioritizing its initial fuel cell truck deliveries for European trials.

5.5. Proven Network and Capability for Sales, Service, Parts and Warranty

This Assessment assumes that commercially available ZE and/or LE drayage trucks must be sold by OEMs that have demonstrated capability to provide essential (diesel-equivalent) support for such emerging products. Specifically, the necessary pre- and post-sales support includes existence of a proven network for selling and servicing the trucks; providing replacement parts; training fleet personnel for new procedures and equipment (including safety related); and providing diesel-equivalent warranty coverage.

Based on discussions with OEM representatives and/or survey responses, those OEMs that already offer ZE and/or LE platforms are able to meet this basic requirement. As noted by one longstanding Class 8 truck OEM, "we would not offer any ZE or LE truck types on the market that did not have full support, service, and warranty packages." OEMs that have been in the business for many decades have established, proven service networks developed for conventional vehicles that can be leveraged and adapted to support new powertrain technologies. For example, the five major OEMs that now sell LE Class 8 natural gas tractors routinely include diesel-equivalent support for these products, across all parameters.[55] Additional effort will be required to build out these networks to support ZE platforms but major OEMs are well positioned to provide this additional capability at pace with ZE truck sales.

It remains to be seen what types of buildouts, improvements and expansions will be needed to sufficiently support *thousands of new ZE and/or LE trucks*, as needed to deeply penetrate into the SPBP drayage fleet. Based on past performance, the major

---

[48] Adler, Alan, "Cummins, Navistar developing fuel cell truck for Werner testing," Freight Waves, 11 November 2020, accessed at.
[49] Hyundai, "Hyundai Motor Upgrades Design and Performance of XCIENT Fuel Cell Truck for Global Expansion," press release, May 25, 2021,.
[50] Truckinginfo.com, "Hyundai to Deploy Hydrogen-Fuel-Cell Trucks in California," July 26, 2021,.
[51] Cellcentric, https://www.cellcentric.net/en/about-us/.
[52] Cary, Nick, "Daimler, Volvo seek huge cuts in hydrogen fuel cell costs by 2027," 29 April 2021, accessed at.
[53] Hyzon, "Hyzon to provide hydrogen-powered fuel cell truck for commercial vehicle trial with Total Transportation Services," August 11, 2021, https://hyzonmotors.com/hyzon-to-provide-hydrogen-powered-fuel-cell-truck-for-commercial-vehicle-trial-with-total-transportation-services/.
[54] Personal communication to GNA from Tony Williamson, TTSI's Director of Compliance & Sustainability, January 31, 2022.
[55] Gladstein, Neandross & Associates, Questionnaire for OEMs of Drayage Trucks, August 2018.

OEMs appear fully capable to meet the basic requirements outlined for this criterion. Notably, it can be especially complex and costly for start-up OEMs to establish such systems from scratch, but public statements indicate they have prioritized rapid buildouts. In some cases, emerging OEMs use established third-party services to provide their fleet customers with the necessary service and support, including dealer and mechanic training.

Section 7 (Operational Feasibility) provides additional discussion about these important peripheral systems, from the fleet customer perspective.

5.6. Sufficient Means and Timeline for Production

This parameter refers to the ability of heavy-duty truck OEMs to collectively produce sufficient numbers of commercialized ZE and/or LE Class 8 trucks to enable systematic replacement of the entire SPBP drayage fleet; this would occur over many years according to normal truck-replacement schedules. The Framework document states that an emerging ZE or LE fuel-technology drayage truck platform cannot be considered commercially available until it is being manufactured in similar quantities and timeframes as the baseline equipment (Class 8 diesel ICE tractors). An overly strict reading of this requirement could preclude a determination that a drayage truck platform is commercially available until that platform achieves a market share similar to diesel. The requirement in the Framework is intended to preclude a finding of commercial availability for products that are being produced in small quantities that would not be sufficient to transition the drayage fleet within the timeframe of the CAAP. This implies that production volumes should be on the order of 1,000 units per year to be considered commercially available.

The 2018 Assessment reported that one start-up OEM was selling a ZE Class 8 truck model for drayage applications, but no OEM had demonstrated capability to mass-manufacture such vehicles for U.S. markets. As of late-2021, at least six more heavy-duty truck OEMs are on the cusp of commercializing Class 8 battery-electric trucks suitable for drayage service. Multiple OEMs will start production for such ZE trucks in 2022, albeit at relatively small production volumes (initially). Thus, it appears that this "Commercial Availability" parameter is now approaching full achievement with regard to battery-electric trucks, i.e., multiple OEMs will collectively be able to produce hundreds of units by late 2022.

Supplementing potential rollouts of ZE battery-electric trucks, all indications are that at least five OEMs can collectively manufacture hundreds of LE natural gas Class 8 trucks for use in SPBP drayage service over the next few years. As reported in the 2018 Assessment, one mainstream OEM stated the following:

> *"We are delivering the NZ product already today. We will build and deliver about 700 this year. There is virtually no limit on quantity of deliveries for this product given proper lead times."*[56]

In summary, it appears that hundreds (if not thousands) of ZE and/or LE Class 8 tractors could potentially be manufactured and available for port drayage by the late-2022 / early-2023 timeframe. This timeline considers supply chain issues in 2021 that have extended the time it takes for fleets to obtain new Class 8 trucks (of any fuel-technology platform). While there is some uncertainty if this parameter is fully achievable in the timeframe of this Assessment (by 2024), The Ports recognize that full turnover of the drayage fleet (to ZE platforms) will occur over a timeframe that exceeds three years, due to a combination of market dynamics and regulatory forces.

5.7. Existence of Current and/or Near-Term Equipment Orders

This Commercial Availability parameter refers to whether or not a "demonstrated backlog of orders" exists from heavy-duty trucking fleets to purchase ZE and/or LE Class 8 trucks, or at least such fleets have made near-term "credible expressions of interest" to purchase them. The previous (2018) Assessment documented that strong demand was building in late-2018 from heavy-duty trucking fleets to purchase ZE Class 8 battery-electric trucks. However, at that time fleets could only pre-order one make/model of battery-electric truck, which was essentially a pre-commercial (proof-of-concept) vehicle.

---

[56] Statement by existing major Class 8 truck OEM, in response to 2018 Questionnaire for OEMs of Drayage Trucks prepared and circulated by Gladstein, Neandross & Associates.

As reported above, much has changed since 2018. As of late-2021, almost all major Class 8 truck OEMs have announced intent to sell one or more ZE battery-electric truck models within one to two years. Fleet operator demand for this emerging OEM supply appears to be strong. California fleets have already reserved several hundred Class 8 battery-electric trucks under various programs designed to meet CARB's "Project 800" goals for drayage applications. CARB intends to expedite deployment of at least 1,000 ZE drayage trucks using this general process. [57] Similarly, there continues to be demand by heavy-duty fleets to purchase Class 8 LE natural gas trucks for use in drayage applications at the two Ports. In summary, this Commercial Availability parameter is *fully met* today for Class 8 trucks that have either ZE battery-electric or LE natural gas ICE architectures. Notably, much of the commercial demand is tied to the current availability of purchase incentives, especially in the case of battery-electric trucks.

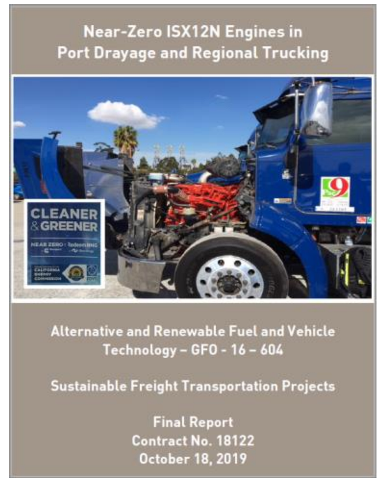


Figure 5. Final report for CEC-South Coast AQMD LE natural gas drayage truck project

For Class 8 trucks with ZE fuel cell electric architectures, this parameter is *partially* met today. Heavy-duty trucking fleets engaged in drayage have expressed significant immediate interest to test fuel cell trucks in review service. Many appear poised to begin purchasing Class 8 fuel cell trucks from capable OEMs (when they become available), if they achieve sufficient commercial maturity and are supported by a network of truck-ready hydrogen fueling stations.

5.8. Advancing Commercial Availability: Essential Role of Large-Scale Truck Demonstrations

Over the last several years, the Ports have supported state and local agencies, truck OEMs, and drayage fleets to initiate major demonstration projects designed to support and expedite ZE and LE truck commercialization and deployment. Since 2018, roughly 20 different demonstration programs have been launched to test approximately 120 pre- or early commercial Class 8 trucks in drayage service. Initial small-scale demonstrations of this kind – typically involving 10 to 20 pre-production units – are essential for OEMs and their fleet customers to test *proof-of-concept* ZE and LE truck architectures in rigorous port duty cycles. They enable OEMs, fleets and infrastructure providers to work together in documenting issues that arise in the field, and collaborate to make important software and/or hardware changes as needed. These field collaborations are instrumental in developing the next generation of pre-commercial truck platforms, which become the basis for OEMs to launch in an early commercial capacity.

As an example of this basic process, in 2018 a government-industry team began field demonstrations of 20 Class 8 natural gas trucks (multiple makes/models) powered by pre-commercial ("beta") 12-liter (ISX12N) engines from Cummins Westport, Inc. (CWI). Use of beta engines allowed the project to be performed in parallel with CWI efforts to finalize ISX12N engine development and secure CARB certification to the lowest-tier Optional Low NOx Standard of 0.02 g/bhp-hr. The specific project goal was to demonstrate Class 8 natural gas trucks with the ISX12N engine in a wide variety of port drayage and regional trucking applications. CWI repowered each engine to this LE configuration, and made other important changes to the engine and emission control system. These 20 trucks were operated in daily drayage service by multiple fleets over 12 months. During this period, CWI and the project team encountered minor engine issues, which were repaired and documented to improve the platform.

This project provided new documentation about the overall feasibility and user acceptance of Class 8 LE natural gas trucks in drayage service at the Ports, resulting in the Ports' May 2020 Addendum to the 2018 Assessment (refer back to Section 5.2.4). Full details on this demonstration program and its results are available in the final report (see Figure 5) prepared for the California Energy Commission and co-sponsor South Coast AQMD.[58]

[57] San Pedro Bay Ports, "Sustainable Supply Chain Advisory Committee July Meeting Summary," comments made by CARB staff at July 21, 2021 meeting, https://ssclalb.org/committee-meeting-summaries/.
[58] California Energy Commission, "Near-Zero ISX12N Engine in Port Drayage and Regional Trucking," Final Report for Contract No. 18122, October 18, 2019.

Notably, trucks powered by LE natural gas ICE technology are essentially variations of baseline diesel ICE trucks. By contrast, ZE battery-electric and fuel cell trucks entail revolutionary changes to manufacture and operate. Thus, it is hard to overstate the importance of conducting carefully planned, multi-year demonstrations for pre-commercial trucks with ZE architectures, initially in small numbers and then at growing scale. This is essential to help OEMs and their fleet customers fully understand operational parameters for ZE trucks like range, charging or refueling time, electric-drive performance, battery life, residual value, total cost of ownership, and requirements for build out of charging or fueling infrastructure. CARB has recognized the essential nature of ZE drayage truck demonstrations "to provide vital feedback" to OEMs as they monitor real-world performance, and enable them to "make changes in production as needed."[59] The CEO of Daimler (the world's largest truck OEM) relates this importance to the bottom line of meeting needs and expectations of fleet customers, who "want answers" before they heavily invest in new truck technologies and peripheral requirements like charging infrastructure.[60]

Fortunately, this process has been well underway for several years. As reported in the 2018 Assessment, by late-2018 roughly 20 demonstrations had begun (or were in advanced planning stages) to test approximately 65 Class 8 battery-electric trucks and 16 Class 8 hydrogen fuel cell trucks in short-haul and/or lighter-weight drayage service. Multiple long-term major Class 8 truck OEMs are involved in these pre-commercial unit demonstrations, as are certain start-up OEMs and technology providers. Key examples of Class 8 ZE truck demonstrations that are underway for drayage applications at the SPBP include the following:

- Under California's Zero-Emission and Near Zero-Emission Freight Facilities (ZANZEFF), the Port of Long Beach is leading the $100 million Phase 1 Sustainable Terminals Accelerating Regional Transformation (START) project. This project is demonstrating a wide array of pre-commercial ZE trucks and off-road equipment. This includes 15 Class 8 battery-electric Peterbilt trucks that are being tested in drayage service (five at the Port of Long Beach and 10 at the Port of Oakland). This project has helped Peterbilt identify issues in its pre-commercial Class 8 579EV model, obtain CARB certification for inclusion under HVIP funding, and move into production of early commercial units beginning in 2022.
- Under a different ZANZEFF grant, the Port of Los Angeles is spearheading the $82 million government-industry "Shore to Store" ZE freight project, for which 10 Kenworth Class 8 ZE hydrogen-powered fuel cell electric trucks are being demonstrated. Toyota uses two commercially proven fuel cell stacks from its light-duty Mirai car to power the ZE Kenworth T680 trucks. As of late-2021, all 10 fuel cell trucks were in revenue service – including seven specifically slated for performing drayage at the SPBP – and nearly 50,000 miles have been accumulated for the collective fleet. During these year-long demonstrations, the National Renewable Energy Laboratory is collecting and analyzing operational data; parameters include daily miles, fuel efficiency, hydrogen consumption, payload, and maintenance performed. The project includes build-out of two hydrogen stations (one in Wilmington), which serve as the fleet's primary hydrogen fueling stations (see next section).[61]
- In yet another ZANZEFF program, the three-year Volvo LIGHTS (Low Impact Green Heavy Transport Solutions) project has been underway since 2019. Under LIGHTS (www.lightsproject.com), the Volvo Group has teamed with South Coast AQMD and multiple private-sector partners to demonstrate 23 battery-electric trucks; the total project cost is reportedly $90 million, with about half coming from the State of California (www.caclimateinvestments.ca.gov). LIGHTS includes demonstration of five Class 8 Volvo VNR battery-electric trucks (the same platform that was subsequently certified by CARB for HVIP). NFI Logistics is among the fleets using the trucks to move freight between the two Ports and inland warehouse facilities. The project, which includes installation and demonstration of 150 kW DC fast chargers, will end in 2022. Additional information about "lessons learned" are summarized below.
- Daimler Truck North America (Daimler Trucks) launched the Freightliner Innovation Fleet demonstration in 2019,

[59] California Air Resources Board, "California Collaborative Advanced Technology Demonstration Project," accessed online on November 30, 2021, https://www.caclimateinvestments.ca.gov/2018-profiles/2018/3/15/california-collaborative-advanced-technology-drayage-truck-demonstration-project.
[60] Trucking Info.com, "Daimler Deals with Booming Market, Preps Electric Trucks," October 29, 2018, ttps://www.truckinginfo.com.
[61] South Coast Air Quality Management District, "Shore to Store FCET," presentation by Lisa Mirisola to Clean Fuels Advisory Committee, February 10, 2022.

involving 30 medium- and heavy-duty battery-electric trucks (see Figure 6 above). This includes testing of 20 pre-commercial Class 8 Freightliner e-Cascadia models in port drayage by two different fleets (NFI Logistics and Penske Truck Leasing and Logistics). Similar to the Volvo LIGHTS project, the Freightliner Innovation project will end in 2022, but it is leading to larger scale efforts such as the Joint Electric Truck Scaling Initiative (described below).

Some of these demonstration projects involving battery-electric trucks that began in the 2018-2019 timeframe are now reaching conclusion. They have successfully provided OEMs and drayage fleets with extensive experience about how to design, operate and charge battery-electric trucks. They have helped identify and address the types of issues that can be common when initially testing any new-technology commercial vehicle type in revenue operation. Examples of issues about pre- or early commercial Class 8 battery-electric trucks that have arisen (and are being addressed by OEMs and their project partners) include the following:

- Larger turning radius compared to baseline diesel trucks
- Intermittent loss of power under typical drayage truck loads
- Quality control issues with early generation electric drive systems and parts (e.g., e-axle bearings)
- AC compressor issues

Figure 6. Class 8 battery-electric trucks in Freightliner Innovation Fleet (photos: South Coast AQMD)

- Problems with high-voltage batteries
- Accelerated tire wear
- Vehicle registration and taxation issues
- Long lead times for permitting of charging equipment

At the recent conclusion of the three-year Volvo LIGHTS demonstration project (described above), Volvo and its team partners (including the two Ports) published a "Lessons Learned Guidebook." The report summarizes findings from this test of early commercial battery-electric trucks by a pair of Southern California fleets focused on San Pedro Bay Ports drayage service. The findings corroborate that a "complete ecosystem (is) needed to successfully deploy commercial battery-electric freight trucks." The Volvo team notes that the project "underscored the interdependence among diverse stakeholders" and "the need for cooperation and engagement from all" to be successful."[62]

Table 7 lists the high-level "lessons learned" and "insight gained" from the Volvo LIGHTS demonstration, specific to major types of participants and stakeholders.

[62] Volvo Group North America, "Volvo Lights: Bringing Battery-Electric Freight Trucks to Market from Demonstration to Commercialization – Lessons Learned Guidebook," March 2022, Volvo Lights Guidebook (lightsproject.com).

Table 7. Lessons and insights from Volvo LIGHTS battery-electric truck demonstration

Participant / Stakeholder Type	Lesson Learned / Insight Gained
Battery-Electric Truck OEMs	Need to adapt product offerings based on customers' unique operating requirements (i.e., range, charging frequency, operational duty cycle, dwell time) and financing needs.
Dealerships	Staff must be fully trained and equipped to provide the robust sales and service support required for customers to achieve zero-emission transportation goals while maximizing uptime.
Public Agencies (Local, State and Federal)	Will need to offer public funding and incentives during early stages of market adoption to make the transition more cost-effective for fleets of all sizes.
Fleet Operators	Will need to identify routes that are best suited for electric trucks and train their drivers and technicians to maximize efficiency and uptime.
Local Electric Utilities	Should support commercial customers with electric truck adoption by offering financial incentives and rebates for charging infrastructure, as well as hiring and training experts who can help fleets design and implement necessary facility and electrical upgrades.
EV Charging Providers	Robust public and private infrastructure will need to be developed to minimize range anxiety and extend the length of transport routes. Charging will need to be reliable and cost effective. Involving permitting authorities early will improve project success.
Technician Training Centers	Partnerships with workforce development organizations (e.g., technical colleges) are needed to ensure technicians have the proper technical training and understand all safety procedures when servicing electric drivetrains and components.
First Responders	Should receive proper training on how to safely respond in case of an incident or accident involving a battery-electric truck.
Source: "Volvo Lights: Bringing Battery-Electric Freight Trucks to Market from Demonstration to Commercialization – Lessons Learned Guidebook (see footnote in text)	

Importantly, these initial projects at relatively small scale have enabled OEMs to advance pre-commercial platforms towards the early commercial products they plan to manufacture beginning in 2022. For example, for their next generation of trucks, OEMs are expected to incorporate higher-power battery-electric systems, enhanced electric motor design, new software, improved telematics, and other upgrades designed to ensure they will meet the tough duty cycles that typify SPBP drayage trucking.[63]

These OEMs have joined with the Ports and key agencies (CARB, CEC and South Coast AQMD) to recognize the strong need to plan and implement larger-scale demonstrations of these emerging-technology Class 8 trucks, in part to test and validate the upgrades described above. As described by South Coast AQMD staff, a key specific need is to "focus priorities on large demonstrations of zero emissions drayage trucks to test and validate OEM readiness and viability" ahead of full-scale commercial launches.[64]

[63] The issues identified here – and evolving OEM improvements to address them – were independently reported to the authors in late-2021, by project managers representing the Ports and the South Coast Air Quality Management District.

[64] South Coast Air Quality Management District, "Clean Fuels Program Advisory Group Meeting," staff presentation on September 15, 2021.

In mid-2021, a government-industry consortium (including CEC, CARB, South Coast AQMD and the two Ports) launched a major new effort to specifically meet this need: the Joint Electric Truck Scaling Initiative (JETSI). This "groundbreaking" project will deploy 100 battery-electric Class 8 trucks in regional- and short-haul applications, with specific focus on drayage at the SPBP. JETSI will constitute North America's largest deployment of Class 8 battery-electric trucks. The project's major objective is to "assess feasibility" of battery electric trucks deployed at commercial scale for drayage and short-haul and/or lighter-weight goods movement applications. Total project cost is $67 million, with about half coming from the State of California. The 100 trucks will be manufactured by Daimler Trucks and Volvo based on the same models certified by CARB and listed for HVIP funding. Logistics companies NFI Industries (NFI) and Schneider will deploy all 100 battery-electric tractors on freight corridors serving the SPBP and distribution centers across Southern California (see the route map in Figure 7). Daimler Trucks will deliver 50 battery-electric Freightliner eCascadia models to Schneider and 30 units to NFI, all for intermodal operations in Southern California. Volvo will provide the remaining 20 battery-electric trucks (all VNR models), which NFI will use to perform drayage services out of El Monte, California. NFI and Schneider are also receiving JETSI funding to build out and improve the charging infrastructure at sites where the trucks will be domiciled; a total of 50 heavy-duty-capable chargers will be installed at the two sites. Initial truck deployments will begin in 2022; all will be in service by mid-2023. In total, more than 20 project partners will collaborate on the multi-year project[65] to ensure all aspects of heavy-duty fleet electrification are evaluated.[66,67,68]

Major heavy-duty truck OEMs are also moving into more-advanced stages of development for hydrogen fuel cell trucks. Under state-funded demonstrations, Kenworth and Hino are working separately with Toyota to demonstrate hybrid fuel cell-battery powerplants in pre-commercial Class 8 trucks performing drayage. While multiple long-established and start-up OEMs are working on hydrogen fuel cell engines for this application, to date, no clear consensus has emerged about which

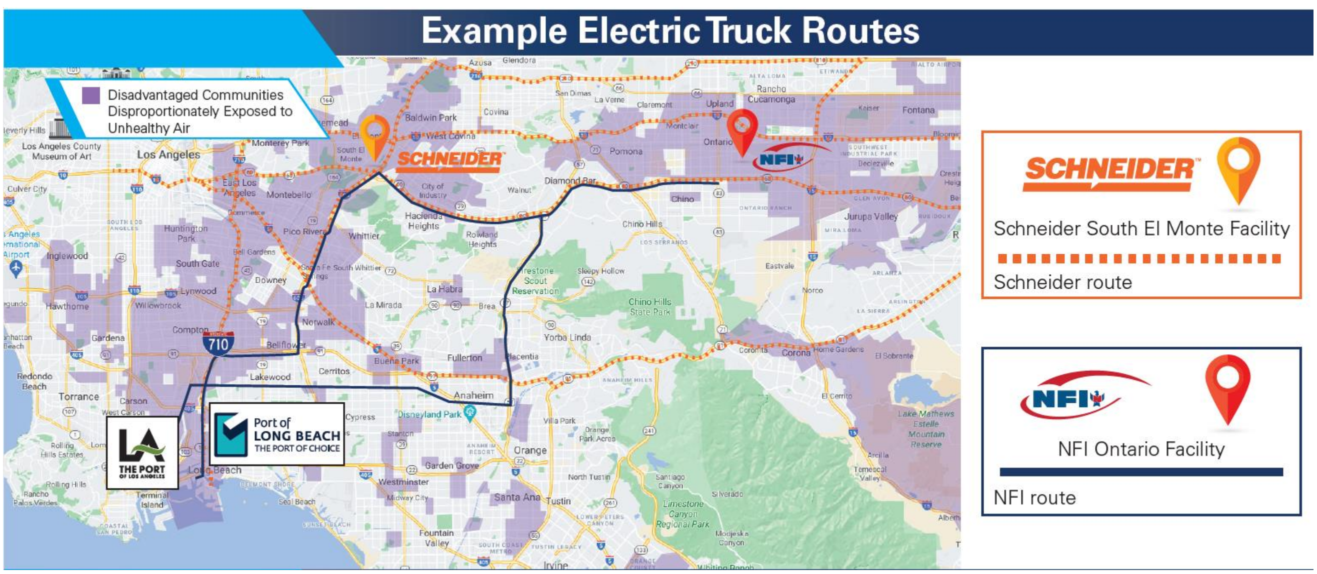


Figure 7. Example drayage routes under JETSI Class 8 battery-electric truck demonstration

architecture(s) is/are optimal (e.g., the relative size and power of the fuel cell stack versus battery pack in a hybridized electric drive train). This is one focus of major Class 8 truck OEMs, some of which have announced plans to build optimized fuel cell trucks using "ground-up" architectures.

[65] According to the South Coast AQMD, all electric trucks will be deployed by mid-2023, and the demonstration activities will conclude by March 2025.
[66] ACT Expo 2021 press conference, August 31, 2021, summary prepared by Gladstein, Neandross & Associates.
[67] South Coast Air Quality Management District, staff presentation at the Clean Fuels Advisory Committee Meeting, September 15, 2021.
[68] California Air Resources Board and California Energy Commission, "Joint Electric Truck Scaling Initiative," project flyer (undated).

For example, in late-2021 the U.S. Department of Energy (DOE) awarded $26 million in new "SuperTruck 3" funding to Daimler Trucks. Under this new effort, Daimler Trucks will design, develop and demonstrate two purpose-built Class 8 hydrogen fuel cell electric trucks for regional and long-haul applications. Under the multiyear program, Daimler Trucks plans to "develop an array of technologies" that can collectively result in an optimized fuel cell-battery hybrid drive system. The end goal is to emerge with a feasible and marketable Class 8 "long-haul sleeper" truck that delivers diesel-equivalent (or better) performance, efficiency, range and payload. For the first phase, Daimler Trucks plans to evaluate various fuel cell / battery architectures, balance-of-plant technologies, and on-board hydrogen fuel storage systems. By late 2025, Daimler Trucks will select the final system to build and demonstrate.[69]

In the largest SuperTruck 3 award, PACCAR (parent company of Kenworth and Peterbilt) is receiving $33 million in federal funding to design and build 18 Class 8 ZE trucks, including those with hydrogen fuel cell architectures to deliver longer driving ranges. Volvo Group is receiving $18 million to develop an advanced Class 8 battery-electric truck platform that could potentially also deliver longer driving ranges. Notably, all of these SuperTruck projects will be conducted over five years (i.e., they will be completed in the 2027 timeframe).[70]

The above timelines suggest that technologies and architectures for heavy-duty fuel cell electric trucks will continue evolving over the next several years. It appears that OEMs (including those working with Toyota) need time to further advance prototype vehicles, demonstrate them at scale in drayage applications, and then build them in small volumes as early commercial products. They also need to coordinate commercialization of fuel cell trucks with build-out of a suitable hydrogen fuel infrastructure. This may be why start-up OEM Nikola recently decided to first commercialize the Class 8 battery-electric "Tre BEV" model, while delaying two fuel cell truck models (the cabover "Tre FCEV" and sleeper cap "Two FCEV") until the 2023-2024 timeframe.

Notably, hydrogen fuel cell vehicles are hybridized versions of battery-electric vehicles. These two ZE architectures have many systems and subsystems in common with battery-electric vehicles. OEM advancements to develop and commercialize heavy-duty battery-electric trucks – as well as future progress under large new programs like JETSI – largely have synergy with and transferability to parallel efforts involving fuel cell-battery hybrid trucks for potential drayage application. For example, for Daimler Trucks' battery-electric Freightliner eCascadia platform (now moving into small-volume commercial production), Daimler Trucks engineers incorporated advanced design and electric-powertrain features that improved efficiency, range, and overall suitability for drayage trucking.[71] This basic platform will be further demonstrated in 30 Freightliner battery-electric trucks in drayage service, under Daimler Trucks' portion of JETSI. As the starting point under its SuperTruck 3 award, Daimler Trucks may choose to use this existing, continually improving eCascadia electric-drive system to design entirely new fuel cell electric trucks suitable for long-haul drayage applications.

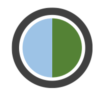
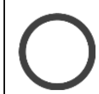
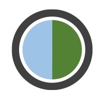
5.9. Summary of Findings for Commercial Availability

5.9.1. Status in 2021 for Leading Fuel-Technology Platforms

Table 8 summarizes the basic findings and conclusions discussed in this section on Commercial Availability. The first two columns repeat specific criteria and base considerations. The final five columns provide ratings about the relative degree to which the five core ZE and LE drayage fuel-technology platforms appear to currently meet these basic considerations, or at least show measurable progress towards meeting them by approximately 2024.

[69] Daimler Trucks North America, "Daimler Trucks North America Receives SuperTruck 3 Award," November 1, 2021, https://daimler-trucksnorthamerica.com/PressDetail/daimler-trucks-north-america-receives-supertruck-2021-11-01.
[70] DieselNet, "US DOE announces SuperTruck 3, Low GHG Vehicle awards," November 3, 2021, https://dieselnet.com/news/2021/11doe.php#:~:text=The%20US%20Department%20of%20Energy,vehicle%20(EV)%20charging%20infrastructure.
[71] *Ibid*.

Table 8. Summary of ratings by key criteria: 2021 Commercial Availability

Commercialization Criteria	Base Considerations	Assessment of Criteria Achievement in 2021 by Leading ZE and NZE Fuel-Technology Drayage Truck Platforms				
		ZE Battery-Electric	ZE Fuel Cell	LE Hybrid Electric	LE NG ICE	LE Diesel ICE
Production and Sales with Major OEM Involvement	Production and CARB certification by either a major Class 8 truck OEM, or by a proven technology provider that has partnered with the major OEM.					
Proven Network/Capabilities for Sales, Support and Warranty	Demonstrated existing (or near-term planned) network of sufficient dealerships to sell, service, warranty and provide parts for all commercially deployed drayage trucks.					
Sufficient Means and Timeline for Production	Demonstrated capability to manufacture sufficient numbers of Class 8 trucks (suitable for drayage) within timeline to meet existing or expected demand.					
Existence of Current and/or Near-Term Equipment Orders	Demonstrated backlog of orders, or credible expression of interest from prospective customers to submit near-term orders.					

Legend: Commercial Availability (2021)

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

Source of Ratings: based on OEM survey responses, OEM product information, various government sources, and consultant's industry knowledge.

5.9.2. Discussion and Implications to Overall Feasibility

Collectively, the above estimated levels of achievement provide an objective snapshot about the commercialization status of Class 8 trucks powered by five core fuel-technology platforms. Discussion follows about 1) the specific rationale used to derive these ratings for each of the fuel-technology platforms; and 2) the overall implications to this 2021 Drayage Truck Feasibility Assessment.

ZE Battery-Electric – As described above, Class 8 truck OEMs (including technology partners) have made major progress since 2018 to commercialize ZE battery-electric trucks suitable for drayage. Based on public announcements and other indicators (e.g., credible orders from fleets), 2022 will initiate commercial launches of Class 8 ZE battery-electric trucks by multiple OEMs, albeit at relatively low volumes of production and deployment. At least six OEMs (three traditional and three start-up) will initiate limited-scale production of battery-electric Class 8 trucks (primarily day cab models). Individual OEMs appear likely to produce and sell hundreds of early commercial trucks for national rollouts; government incentive efforts (e.g., HVIP and Project 800) indicate that most of these units will be deployed for SPBP drayage. Based on OEM range estimates, early commercial battery-electric models will initially be restricted to short-haul and/or lighter-weight drayage applications. In parallel with rolling out small-volume production, major OEMs (e.g., Daimler Trucks and Volvo) will be scaling up from relatively small demonstrations into larger-scale efforts for improved versions of their Class 8 battery-electric trucks. Larger, more-comprehensive demonstrations will be essential for all stakeholders to fully resolve issues and problems that are common with early commercial launches of emerging fuel-technology platforms.

Notwithstanding these existing challenges for Class 8 battery-electric trucks (high cost/price, range limitations, ongoing need to improve technological viability and robustness, and long lead times to build-out charging infrastructure), <u>Class 8 battery-</u>

electric tractors now achieve key criteria for Commercial Availability (in short-haul and/or lighter-weight drayage applications). Subsequent sections of this Assessment discuss important caveats and needs that define overall "feasibility" (Section 6 on Technical Viability, Section 7 on Operational Feasibility, Section 8 on Infrastructure Availability, and Section 9 on Economic Workability.)

ZE Hydrogen Fuel Cell – OEM efforts to commercialize Class 8 fuel cell trucks are progressing well. One major vehicle OEM (Toyota) plans to initiate near-term limited-scale production of hydrogen fuel cell engines specifically designed for Class 8 drayage truck applications. Under state-funded demonstrations, at least two major heavy-duty OEMs are working with Toyota to demonstrate this fuel cell system in pre-commercial Class 8 trucks performing drayage service at the Ports. To date, there is no clear consensus among OEM participants (and/or their technology-providing partners) about which architecture(s) is/are optimal for Class 8 fuel cell trucks (e.g., the relative size and power of the fuel cell stack versus battery pack in a hybridized electric drive train). This is one focus of at least one major Class 8 truck OEM (Daimler Trucks), which has announced plans to build an optimized fuel cell truck suitable for long-haul drayage applications, using a to-be-determined "ground-up" architecture.

Hyundai is leading one of the world's largest OEM efforts to develop and demonstrate purpose-built hydrogen fuel cell trucks. As previously described, Hyundai is developing the "Xcient" Class 8 fuel cell truck, and plans to deploy 1,600 early commercial Xcient cabover trucks in Europe by 2025. [72] This will be followed by (or in parallel with) commercial introduction of Class 8 Xcient trucks for North American markets.[73] To prepare for its North American launch, under the "NorCAL Zero" project (funded by various state and local agencies) Hyundai will build 30 Class 8 Xcient trucks for demonstration in Northern California. In Southern California, Hyundai (with co-funding from South Coast AQMD) will build and demonstrate at least two Class 8 Xcient fuel cell trucks in regional and long-haul service, including drayage at the SPBP complex.[74] Hyundai's current U.S. deployments of Xcient fuel cell trucks constitute precommercial demonstrations. Under its 30-truck deployment targeted to begin in mid-2023, Hyundai's Xcient fuel cell trucks may achieve early commercial status.

In sum, heavy-duty fuel cell electric truck architectures are likely to continue evolving over the next few years, as OEMs advance prototype vehicles into pre- and early commercial products. Thus, while major progress has occurred since 2018, in late-2021 it appears unlikely that any OEM (major or startup) will commercialize Class 8 fuel cell tractors before the 2024 timeframe. Consequently, this fuel-technology platform does not yet achieve key criteria for Commercial Availability.

Notably, the technology and commercialization landscapes for heavy-duty fuel cell trucks could change quickly. They share many common electric-drive components and systems, such as traction motors and power electronics, with battery-electric trucks; OEM commercialization efforts for the former will continue to help expedite fuel cell electric trucks. Given the important OEM-backed, synergistic activity to commercialize Class 8 hydrogen fuel cell trucks, this fuel-technology platform warrants further evaluation in the next section on Technical Viability (the second parameter used to screen for overall feasibility).

However, as was reported in the 2018 Assessment, the rate-determining step for commercializing fuel cell trucks may be more related to hydrogen fuel than the technology of fuel cell engines (including balance-of-plant subsystems), which have become technologically proven and robust in the light duty market and at limited scale in the transit market. The timeline for fleets to gain ready access to affordable hydrogen fuel remains uncertain. Opportunities and challenges associated with hydrogen fuel are further discussed in subsequent sections.

ZE Grid-Electric – Class 8 electric-drive tractors that are directly powered by the electricity grid (i.e., via a catenary system) currently have no clear OEM interest or commercialization pathway. Therefore, no further evaluation is warranted in this 2021 Drayage Truck Feasibility Assessment. However, it is possible that future Assessments will need to revisit such technology for evolving commercialization potential.

---

[72] Hyundai, "XCIENT Fuel Cell, " https://trucknbus.hyundai.com/global/en/products/truck/xcient-fuel-cell.
[73] Hyundai, "Hyundai Motor Upgrades Design and Performance of XCIENT Fuel Cell Truck for Global Expansion," press release, May 25, 2021,.
[74] Truckinginfo.com, "Hyundai to Deploy Hydrogen-Fuel-Cell Trucks in California," July 26, 2021.

Low- Versus High-Volume Commercialization Phases for Emerging HDV 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 improvement, supply chain competition, and economies of scale. Incentive projects that focus on early commercial deployment tend to support fleet expansion within progressive fleets that are interested in "testing the waters" of advanced technology. In higher-volume production, incentives can help support the transition of the technology to wide-scale adoption." **CARB**, "Appendix D: Long-Term Heavy-Duty Investment Strategy Including Fiscal Year 2021-22 Three-Year Recommendations for Low Carbon Transportation Investments," Proposed Fiscal Year Funding Plan for Clean Transportation Incentives, October 2021, https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program/low-1.

LE Hybrid Electric - As reported in the 2018 Assessment, Class 8 tractors with hybrid-electric drive systems (using either diesel or natural gas ICE technology) have been built and demonstrated over the last decade. These efforts have been led by mainstream OEMs, as well as technology providers. However, no mainstream OEM has yet commercialized a Class 8 tractor with hybrid-electric drive. Notably, CARB's 2019 adoption of the Advanced Clean Trucks Regulation (ACT)[75] may provide greater impetus for OEMs to specifically pursue plug-in hybrid-electric architectures for Class 8 trucks This is because ACT formally defines a "near-zero-emission vehicle" (NZEV) as being an "on-road plug-in hybrid electric vehicle" that can achieve "all-electric range" (i.e., it has capability to operate in zero-emissions mode for a prescribed portion of the daily driving range). Additionally, CARB's "Low-NOx Omnibus" regulation (adopted in mid-2020) may drive OEMs to design, build and sell Class 8 trucks with plug-in electric drive systems (beginning with model year 2024). For purposes of this Assessment, such an "NZE" hybrid-electric Class 8 truck (i.e., one that meets CARB's ACT definition) is considered to be a specialized LE architecture (i.e., it does not meet CARB's ZE definition). In sum, while there is no clear commercialization pathway or timeline for drayage trucks using plug-in hybrid electric drive (with or without "all-electric range"), it is possible that future Assessments (or updates) will need to revisit such technology for its emerging commercialization potential.

LE Natural Gas ICE - Drayage trucks powered by natural gas ICE technology have now fully achieved "Commercial Availability" status, according to the key criteria and considerations outlined in this Assessment (derived from the Ports' joint Framework document). Specifically, today's Class 8 natural gas trucks are 1) mass-produced and sold by multiple major Class 8 truck OEMs; 2) available in a wide array of different day cab and sleeper truck models; 3) powered by CWI's drayage-proven, CARB-certified 12-liter ISX12G LE engine; 4) capable of providing diesel-equivalent performance and range in all three general types of drayage trucking, and 5) fully supported by OEMs for the key provisions identified in the table (warranty, parts, maintenance, training, etc.). One key market risk factor for this particular fuel-technology platform is that currently, only one engine manufacturer (CWI) is selling heavy-duty natural gas engines suitable for Class 8 heavy-duty trucks used in drayage. Additional discussion on this fuel-technology platform is provided in subsequent sections of this Assessment.

LE Diesel ICE – Until at least one heavy-duty engine OEM successfully certifies a drayage-suitable heavy-duty diesel engine to a CARB optional low-NOx standard (preferably 0.02 g/bhp-hr or lower), this fuel-technology platform does not meet noted standards for Commercial Availability. However, heavy-duty engine OEMs are making good progress to develop and commercialize ultra-low-emission diesel engines. CARB's 2020 adoption of the Low-NOx Omnibus regulation is further driving and expediting such efforts. Thus, it is possible that future Assessments (or updates) will need to revisit LE diesel ICE technology for its emerging commercialization potential, provided that CARB regulations allow its use in drayage service.

---

[75]California Air Resources Board, "Final Regulation Order: Advanced Clean Trucks Regulation," https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks.

6. Assessment of Technical Viability

6.1. Background: Criteria and Methodology

The federal government, manufacturers, and researchers often assign Technology Readiness Level (TRL) ratings to help track, assess and describe the technological maturity of emerging products, as they progress towards commercialization. Typically, these scales range from TRL 1 (just emerging as a basic principle) to TRL 9 (fully proven for technological maturity in (or near) its final commercial-ready form). TRL ratings can be very useful for tracking progress with new types of heavy-duty transportation technologies. For this 2021 Drayage Truck Feasibility Assessment, snapshot TRL ratings – updated where applicable from the 2018 Assessment ratings – have been assigned to emerging ZE and LE platforms. This provides an objective, standardized means to gauge and compare technical readiness for broad commercial deployment at the SPBP over the next several years.

The U.S. DOE has published a guidebook[76] designed to help government researchers conduct technology readiness assessments. DOE's guide includes a standardized TRL scale that is useful for tracking and assessing progress for HDV prototypes that are being developed, demonstrated and/or commercialized under government funding. DOE has established definitions for each of nine TRLs, as summarized in Table 9 below; this is a condensed version of DOE's TRLs in the referenced guidebook.

Technologies achieve a TRL level when they meet defining characteristics of that level. Because some of the technologies discussed in this Assessment are currently at TRL 7 or lower, it is worth emphasizing the difference between a TRL 7 versus a TRL 8 technology. A technology achieves TRL 7 when a full-scale prototype is demonstrated in the relevant environment. This TRL focuses on a prototype being evaluated in a real-world environment, with a key objective to feed that data back into further design revisions. Note that TRL 7 does not require *successful* demonstration of the prototype. By contrast, achieving TRL 8 does require a successful demonstration of a product in its final or near-final form. In many cases, a manufacturer may demonstrate multiple generations of a design in an effort to move from TRL 7 to TRL 8. Therefore, a technology may be considered TRL 7 if it has been demonstrated in a prototype form, even if the demonstration has not yet proven the product to be successful in achieving OEM and/or end user targets, needs and objectives.

[76] U.S. Department of Energy, "Technology Readiness Assessment Guide", September 15, 2011, https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04a/@@images/file.

Table 9. Definitions for Technology Readiness Levels (TRLs) adapted from U.S. DOE

Relative Stage of Development	Corresponding TRL #	DOE's TRL Definition / Description (condensed / abbreviated)
Systems Operations	**TRL 9**	**Actual system in its final form** and operated **under full range of operating conditions**.
Systems Conditioning	**TRL 8**	**Actual system completed and qualified through test and demonstration**. The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the **end of true system development**.
	TRL 7	**Full-scale, similar prototype system demonstrated in relevant environment**. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment.
Technology Demonstration	**TRL 6**	**Engineering/pilot-scale**, similar (prototypical) system validation in **relevant environment**; represents a **major step up** from TRL 5
Technology Development	**TRL 5**	**Laboratory scale**, similar system validation in **relevant environment**: basic technological components are integrated so that system configuration is similar to (matches) final application in almost all respects.
	TRL 4	**Component and/or system validation in laboratory environment**: basic technological components are integrated to establish that pieces will work together; this is **relatively "low fidelity"** compared with the eventual system.
Research to Prove Feasibility	**TRL 3**	These TRLs range from **Initiation of active research & development (TRL 3)** down to **Basic principles observed and reported** (TRL 1)
	TRL 2	
Basic Research	**TRL 1**	
Source: adapted from U.S. DOE, "Technology Readiness Assessment Guide," Table 1: Technology Readiness Levels, September 2011.		

6.2. Estimated 2021 TRL Ratings (with Prognosis for 2024)

DOE's TRL system provides a straightforward, concise and defensible tool to compare the technological maturity of various emerging fuel-technology platforms that have the clearest potential for wide-scale application in drayage trucking over the next several years. Using DOE's system, updated (from 2018) TRL ratings have been assigned for the core ZE and LE platforms discussed in this report, and educated prognoses have been made for how those TRL ratings are expected to change by 2024. These TRL ratings were derived by applying publicly available information (e.g., OEM technical specifications), survey responses directly submitted by the OEMs, and various footnoted technical reports / sources.

The following summarizes the assigned 2021 TRL rating for each key platform, and the corresponding prognosis for improvements expected by (or before) 2024.

- **ZE** battery-electric drayage trucks are currently at **TRL 7 to 8** (moving into final form during demonstration and systems conditioning). *This is a full step higher than the TRL rating for the 2018 Assessment*. Multiple OEMs are now offering Class 8 battery-electric trucks listed by CARB as early commercial products under the HVIP incentive program. While this implies TRL 8 to 9, it does not appear that any of these OEM models have been fully demonstrated in their final form.

Initial drayage demonstrations conducted at relatively small scale indicate that OEMs have improved battery-electric technology for Class 8 trucks since 2018, exhibiting increased range and charging speeds. Notably, current-generation models are only suitable for short-haul and/or lighter-weight applications, and do not meet the full range of duty cycles needed to perform all types of SPBP drayage. In addition, these platforms pose inherent challenges (mostly related to battery cost and energy density) that OEMs must continue to address before broad sales and deployment can occur. Additionally (as described in the previous section), pre-production battery-electric platforms have exhibited problems during demonstrations (e.g., drivetrain issues, accelerated tire wear, non-optimal vehicle-charger interface) that are not uncommon for pre-production commercial truck platforms in the early stages of demonstration, and still may require OEMs to design and implement new hardware and/or software changes. All of these factors lead to a late-2021 TRL rating of 7 to 8 for battery-electric trucks in the specific context of performing drayage at the SPBP.

Fortunately, initial demonstrations are enabling OEMs to improve the technical viability of pre-production battery-electric trucks suitable for short-haul and/or lighter-weight drayage applications. Moreover, OEMs are planning and initiating much-larger-scale demonstrations, which are expected to further accelerate learning curves for OEMs and their drayage fleet customers. With all this technological momentum being realized under strong OEM-government support, it appears very likely that Class 8 battery-electric trucks will move up to **TRL 8 to 9* by (or before) 2024** (***TRL 9 for short-haul and/or lighter-weight drayage applications).

- **ZE** fuel cell drayage trucks are currently at **TRL 7** (full-scale prototype demonstration in relevant environment). *This has increased from TRL 5-to-6 under the 2018 Assessment*. Multiple capable OEMs are working on Class 8 fuel cell trucks, which offer the key benefits of battery-electric trucks (zero emissions, high-efficiency electric drive) combined with advantages provided by ICE trucks (near-diesel-equivalent refueling time and driving range). Heavy-duty fuel cell systems for Class 8 trucking continue to evolve technologically, but no clear consensus has emerged among OEMs regarding optimal architecture(s) for hybridization with heavy-duty battery systems. Toyota's announced plans to manufacture and sell heavy-duty fuel cell systems beginning in 2023 appears to be a significant accelerator for technological (and therefore commercial) maturity, based on Toyota's proven track record commercializing robust fuel cell engines for light-duty vehicles and its ongoing collaborations with heavy-duty OEMs (e.g., Kenworth and Hino). Additionally, the steady technological progress transit bus OEMS and their technology partners are making with heavy-duty fuel cell engines[77] will help advance Class 8 truck applications. Taking into account these factors, it is estimated that Class 8 fuel cell trucks suitable for drayage <u>may</u> move up to **TRL 8 by 2024**.
- **LE** plug-in hybrid drayage trucks continue to be at **TRL 5 to 6** (technology development and demonstration). Although not a ZE architecture (due to onboard fuel combustion), this fuel-technology platform offers OEMs high-efficiency electric drive and a key advantage: it enables "zero-emission mile" operation over a small portion of its driving range. This can be very attractive for shorter-haul and/or lighter-weight drayage service conducted in / around disadvantaged communities such as those that adjacent to the SPBP. Currently, there is no clear commercialization pathway or timeline for drayage trucks using plug-in hybrid electric drive (with or without "all-electric range"), and no heavy-duty OEMs are sending clear and strong signals about commercialization of such products. As previously noted, CARB's 2019 adoption of the ACT regulation may provide greater impetus for OEMs to specifically pursue plug-in hybrid-electric architectures for Class 8 trucks, if they can achieve "all-electric range." Additionally, CARB's "Low-NOx Omnibus" regulation (adopted in mid-2020) may drive OEMs to design, build and sell Class 8 trucks with plug-in electric drive systems (beginning with model year 2024). Provided there is sufficient new OEM interest and commitment, Class 8 plug-in hybrid trucks suitable for drayage service <u>could potentially</u> move up to **TRL 7 (or higher) by 2024** with sufficient market demand.

[77] According to a 2020 tally by the National Renewable Energy Laboratory (NREL), there are approximately 64 fuel cell buses (built by four different bus OEMS using four different fuel cell powertrain types) under active demonstration in the U.S.; another 30 units are being developed. See https://www.nrel.gov/hydrogen/fuel-cell-bus-evaluation.html.

- **LE** natural gas ICE drayage trucks are currently at **TRL 9** (actual system in its final form, operated under a full range of conditions). This TRL rating was assigned in 2020 (up from TRL 8), after the Ports commissioned an update to the 2018 Assessment. The 2020 update corroborated and incorporated a significant, well-documented advancement in technology readiness for Class 8 natural gas ICE trucks operated in drayage. Today, this fuel-technology platform is technologically robust and well proven.[78]
- **LE** diesel ICE drayage trucks are currently at **TRL 5 to 6** (technology development and demonstration). To date, no heavy-duty diesel engine has been certified to CARB's OLNS. However, promising government-industry research efforts continue (e.g., at Southwest Research Institute). The basic goal is to achieve very low NOx emissions (preferably the lowest-tier 0.02 g/bhp-hr level already achieved by multiple heavy-duty natural gas and propane engines), while also managing key tradeoffs (fuel efficiency/GHG emissions, cost, durability and reliability). CARB's Low-NOx Omnibus regulation will require heavy-duty engine OEMs to continue pushing to develop and certify LE diesel ICE technology for commercialization no later than 2024. Thus, Class 8 LE diesel trucks could leapfrog from the current TRL 5 to 6 level up to **TRL 8 or 9 by or before 2024.** Notably, this would require sufficient time for OEMs and fleets to successfully demonstrate that such trucks can provide acceptable durability and reliability in drayage trucking operations at the SPBP.

6.3. Comparison to CARB's Latest Drayage Truck "Snapshot" TRL Ratings

In late-2021, CARB staff released its "Proposed FY 2021-22 Funding Plan for Clean Transportation Incentives." Appendix D of the document provides "technology status updates" from CARB staff for various on- and off-road vehicle / equipment types with ZE and LE architectures. This includes CARB staff's estimated TRL ratings (NASA[79] scale, as of mid-2021). Those TRL ratings include the following caveat: "CARB recognizes that technology status represents only part of the commercialization story, and that a number of other metrics need to be assessed to also evaluate market readiness." Staff specifically cites the need to account for "issues such as infrastructure, workforce training, the needs of small fleets, total cost of ownership (TCO), and supply chain management."[80]

CARB staff used a series of graphs (accompanied by narrative) to summarize draft TRL ratings for emerging HD ZE and LE fuel-technology platforms in various applications, including drayage. The following summarizes highlights from CARB staff's draft TRL rankings that are most relevant to this Assessment.

ZE Class 8 battery-electric trucks for "short-range[81]" drayage applications are rated by CARB at TRL 9. They are in a "late pilot/early commercial stage of technology readiness." Relative to the previous year (2020) rating, CARB staff's late-2021 TRL rating is higher by about one-half step. Staff cited strong year-over-year progress by major manufacturers to design, test, improve and commercialize Class 8 battery-electric trucks suitable for drayage. While acknowledging that "the range of technology readiness is wide," CARB staff essentially cited commercial rollouts by multiple capable OEMs in 2022 as corroboration that ZE battery-electric short-haul drayage trucks have achieved TRL 9. Notably, staff has also recently emphasized that significant remaining challenges must be addressed before battery-electric trucks can be widely adopted and deployed, especially in challenging Class 8 applications like drayage:

[78] The 2018 Assessment complete with this May 2020 Addendum can be downloaded at https://cleanairactionplan.org/strategies/trucks/.
[79] CARB staff uses the National Aeronautics and Space Administration (NASA) scale for its TRL ratings (https://www.nasa.gov). Like the DOE scale used in this 2021 CHE Assessment, NASA's scale uses TRL 1 through TRL 9. The two scales are very similar for basic definitions applying to each TRL rating. As an example, NASA's TRL 9 rating refers to "Actual system flight proven through successful mission operations;" DOE's TRL 9 refers to "Actual system operated over the full range of expected mission conditions."
[80] California Air Resources Board, "Appendix D: Long-Term Heavy-Duty Investment Strategy Including Fiscal Year **2021-22** Three-Year Recommendations for Low Carbon Transportation Investments," Proposed Fiscal Year Funding Plan for Clean Transportation Incentives, October 2021, https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program/low-1.
[81] CARB staff did not define "short-range" drayage, but it is assumed to be equivalent to the 160-mile daily range described in the proposed Advanced Clean Fleets regulation pending rulemaking expected in late-2022.

"Continued barriers to wider Battery Electric Vehicle adoption include infrastructure, high incremental cost, limited vendor and product selection, range, the business case, and TCO / payback period."[82]

ZE Class 8 hydrogen fuel cell trucks are rated by CARB at TRL 7 to 8; they are in a "early pilot" stage of development and demonstration. This reflects nearly a full step move up from CARB's 2020 TRL rating of "early 7." Staff notes that drayage trucks are a "prime candidate to take advantage of the benefits of fuel cell technology." To pursue this potential, major OEMs and partnerships working on fuel cell trucks, with fuel cell powertrains "emerging as a potential market entrant for heavy weight, duration, and longer distance applications by 2023." [83]

NOTE: CARB dropped the "short-range" descriptor used for battery-electric drayage trucks when describing fuel cell trucks. This reflects the fact that fuel cell trucks are refueled relatively rapidly and more like diesel trucks. As such, they are less-constrained by range than current-technology battery-electric Class 8 trucks, and more capable of providing sufficient range (300+ miles) to operate over longer-haul drayage routes.

Class 8 LE natural gas trucks are not specifically addressed by CARB's draft 2021 TRL ratings. However, staff assigned a **TRL 9** rating to CWI's LE ISX12G engine, which powers Class 8 natural gas truck models that are commercially offered by at least five truck OEMs.

Table 10 compares CARB staff's estimated TRL ratings (summarized above as of late-2021[84]) with TRL rating assigned by the authors for this 2021 Assessment. This is done for the five leading ZE and LE fuel-technology platforms. The last two columns note 1) the degree of difference (if any) between CARB's draft TRL rating and this 2021 Assessment's rating, and 2) observed reasons, where the degree of difference is significant.

Table 10. Comparison of CARB snapshot 2021 TRL ratings: key ZE or LE platforms for drayage trucks

Class 8 Truck Fuel-Technology Platform	2021 CARB TRL* (Draft)	2021 Feasibility Assessment TRL	Degree of Difference	Observed Reason(s) for Difference (if Applicable)
ZE Battery Electric	9	7 to 8	~1½ TRL	CARB's TRL rating for drayage trucks appears to equate commercial availability with a TRL rating of 9; this Assessment evaluates commercial availability and TRL separately. CARB's TRL rating for ZE battery electric is specific to "short-haul" drayage applications (assumed to be 160 miles per day); this 2021 Assessment TRL ratings are based on the average daily range requirement (refer to Table 13).
ZE Hydrogen Fuel Cell	7 to 8	6 to 7	~1 TRL	This Assessment denotes TRL 8 as "actual system completed and qualified through test and demonstration," with technology "proven . . in its final form." This stage is not yet met (e.g., OEM fuel cell-battery architectures continue to evolve).
LE Plug-in Hybrid Electric	6 to 7	5 to 6	~1 TRL	2021 Assessment is focused on TRL of OEM-built demonstration trucks, of which there are currently none.
LE NG ICE	9**	9	(None)	N/A.
LE Diesel ICE	6	5 to 6	~1/2 TRL	Insignificant.

*CARB uses the TRL rating system developed by NASA, while the authors of this Assessment use the U.S. Department of Energy's TRL rating system. For purposes of this assessment, the differences in these two scales are insignificant.
**CARB staff does not specifically call-out Class 8 trucks or any other specific type of on-/off-road application. Staff assigned a TRL 9 rating to multiple "0.02 g NOx" natural gas (and propane engines) that OEMs commercially offer as options in on-road Class 8 tractors.

[82]CARB, "Appendix D: Long-Term Heavy-Duty Investment Strategy Including Fiscal Year **2020-21** Three-Year Recommendations for Low Carbon Transportation Investments," Proposed Fiscal Year Funding Plan for Clean Transportation Incentives, undated, https://ww2.arb.ca.gov/sites/default/files/2020-11/appd_hd_invest_strat.pdf.
[83]CARB, "Appendix D: Long-Term Heavy-Duty Investment Strategy Including Fiscal Year **2021-22** Three-Year Recommendations for Low Carbon Transportation Investments, October 2021, https://ww2.arb.ca.gov/our-work/programs/low-carbon-transportation-investments-and-air-quality-improvement-program/low-1.
[84]CARB, *Ibid*.

6.4. Additional Reference for Assessing Technical Viability

In mid-2018, the North American Council on Freight Efficiency (NACFE)[85] published a guidance report titled "Electric Trucks – Where They Make Sense."[86] The NACFE report provided a 2018 snapshot about the overall market maturity and technical viability of battery-electric trucks (Class 3 to Class 8) for use in commercial fleets. NACFE's key conclusions relevant to Class 8 trucks for drayage included that:

- Battery-electric vehicles will have an increasing role in freight transportation in Class 8 applications, although suitability to replace diesel trucks "is very dependent on vehicle class and duty cycle."
- The transition to battery-electric trucks in specific market segments "will be drawn out over decades, sharing space with traditional diesel and gasoline powertrains and also competing with other new technologies like fuel cells and hybrids."
- Battery-electric trucks "will not be a solution for every market." Heavy-duty fleets with a mix of fuel-technology platforms (e.g., diesel, natural gas, hybrid and battery-electric) that are optimized for specific routes and duty cycles "will likely be the norm through 2050."

In January 2022, NACFE released a new summary report titled "Electric Trucks Have Arrived: Documenting a Real-World Electric Trucking Demonstration."[87] This report summarizes findings and conclusions from numerous interviews NACFE conducted with fleets demonstrating pre- and early commercial electric trucks. The three-week-long demonstrations occurred in four key commercial trucking applications, one of which was "heavy-duty regional haul tractors"; this included Class 8 trucks performing SPBP drayage service. Early adopter fleets were asked about their perceptions on technological maturity, reliability / downtime, total cost of ownership, charging cycles, and other metrics. The call-out box below provides NACFE's key "Results and Additional Findings."

[85] NACFE describes itself as "an unbiased, fuel agnostic organization" that "supports development of efficient, environmentally beneficial, and cost-effective freight technologies" for North American markets. NACFE's guidance reports are designed to inform commercial truck fleets about the benefits, challenges and payback of emerging truck technologies, to "help develop confidence in their adoption."

[86] North American Council for Freight Efficiency, "Guidance Report: Electric Trucks – Where They Make Sense", May 2018, obtained directly from NACFE (available online at https://nacfe.org/report-library/guidance-reports/).

[87] North American Council for Freight Efficiency, "Electric Trucks Have Arrived: Documenting a Real-World Electric Trucking Demonstration," January 2022, https://nacfe.org/run-on-less-electric-report/.

Notably, NACFE's highlighted comments (see call-out box) continue to provide a realistic outlook in late-2021. NACFE corroborates this Assessment's finding that heavy-duty truck OEMs have made major progress since 2018 to develop, test and commercialize Class 8 battery-electric trucks. NACFE concurs that the next one-to-two years are expected to result in significant efforts by multiple OEMs to manufacture Class 8 electric trucks – albeit at small scale – and their fleet customers to deploy them. However, there are many inter-related challenges to develop, manufacture, deploy and support new fuel-technology platforms for heavy-duty trucking – especially given the long "headstart" of diesel ICE technology. Progress is achieved over many years through a deliberate, iterative process that involves a wide range of private and public stakeholders.

6.5. Summary of 2021 Findings for Technical Viability

The Technical Viability parameter evaluated under this 2021 Feasibility Assessment for Drayage Trucks is closely related to the previous parameter (Commercial Availability), as well as the parameter that follows (Operational Feasibility). All three parameters are measures of technological maturity for emerging ZE and LE Class 8 trucking platforms, and their ability to meet fleet/motor carrier needs for acceleration, gradeability, driving range, fueling time, durability/reliability, safety and others (see Section 7 on Operational Feasibility).

NACFE on Early Adopter Fleet Perceptions of Heavy-Duty Battery -Electric Trucks (late 2021)

- Selecting the right duty cycle for deploying battery-electric trucks is extremely important. Currently, "electric trucks do not make sense in every application, and fleets that deploy them in the wrong applications are going to be disappointed with the results they get."
- Class 8 heavy-duty day cab regional hauling (including drayage) entails duty cycles that are "sensitive to range and payload weight needs."
- Key remaining challenges for heavy-duty electric trucks are shorter driving range, longer charging times, and limited fueling infrastructure.
- Fortunately, "long established truck makers and newcomer tech companies are hard at work" to improve battery energy density, reduce vehicle weight, and improve driving range.
- Organized efforts are also underway to address charging infrastructure issues that can "make electric trucks more suitable for longer haul use."
- Battery-electric truck "ecosystem inertia" is in its early stages with many solutions emerging that will support adoption in the next several years.
- The industry needs to develop standards in the areas of charging, repair, maintenance and training.
- "Huge demand" exists from OEMs and fleets to obtain "real-world information" on heavy-duty electric trucks and charging infrastructure.

-North American Council on Freight Efficiency (NACFE): 1) "Electric Trucks Have Arrived: Documenting a Real-World Electric Trucking Demonstration, January 2022; and 2) "When it comes to EVs, Duty Cycle Matters," ACT News, February 2022.

To specifically gauge technical viability, the study authors assigned TRL ratings (based on the U.S. DOE's scale and definitions) to a mix of ZE and LE platforms with the potential for incorporation into the SPBP drayage fleet over the next several years. **TRL 8** is the stage at which a given platform becomes near final or final, and has adequately exhibited technical viability through test and demonstration. **TRL 9** constitutes DOE's highest rating; this is the stage at which full technical viability has been achieved and definitively documented. [88]

[88] U.S. Department of Energy, "Technology Readiness Assessment Guide", September 15, 2011, page 9, https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04a/@@images/file

Table 11 (the third column) summarizes this Assessment's findings (as of late 2021) for the TRL ratings of leading Class 8 truck fuel-technology platforms that are in development and/or commercialization by major OEMs. These TRL ratings are specific to drayage truck operation at the SPBP. The fourth column provides an "educated prognosis" for how each TRL rating may change (improve) by 2024 (or sooner). The last column provides additional rationale for each prognosis.

Table 11. Summary: 2021 Technical Viability using TRL values (with 2024 prognoses)

TRL	Relative Stage of Development	Late-2021 TRLs for Leading Fuel-Technology Platforms (Drayage)	~2024: Educated Prognoses (by or before)	Comments / Basis for 2024 Educated Prognosis
TRL 9	**Systems Operations**	LE NG ICE (TRL 9)	LE NG ICE (TRL 9); ZE Battery (TRL 8 to 9)	**ZE Battery Electric:** strong ongoing OEM progress gained through government-funded demos at growing scale will raise this platform to TRL 8 to 9* (*short-haul and/or lighter-weight drayage applications)
TRL 8	**Systems Conditioning**	ZE Battery (TRL 7 to 8)	ZE Fuel Cell (TRL 8)	**ZE Fuel Cell:** OEM technical progress will accelerate as optimized fuel cell/battery architectures emerge; on-board hydrogen storage continues to improve on cost and performance
TRL 7		ZE Fuel Cell (TRL 7)	LE Diesel ICE (TRL 6 to 7, or higher?)	**LE Plug-in Hybrid (not shown):** OEM interest is hard to gauge, but plug-in architecture enables valued "zero-emission mile" capability
TRL 6	**Technology Demonstration**	LE Diesel ICE (TRL 5 to 6)		
TRL 5	**Technology Development**			**LE Diesel ICE:** could "**leapfrog**" to TRL 8 or 9, but only if suitable diesel engine(s) get certified to 0.02 g/bhp-hr NOx (or other CARB OLNS)
TRL 4				

Source: TRL methodology adapted from U.S. DOE, "Technology Readiness Assessment Guide, Table 1: Technology Readiness Levels, September 2011 (see footnote). TRL ratings estimated based on input from 1) OEM surveys, 2) various technical reports, 3) demonstration activities, and 4) meetings with and/or inputs from CARB and South Coast AQMD technical staff.

The following summarizes this 2021 Assessment's findings about Technical Viability, as of late-2021:

- Class 8 **ZE** battery-electric drayage trucks are currently at **TRL 7 to TRL 8** (systems conditioning for early commercialization). Strong progress through multiple major OEM development and demonstration projects supported by the Ports, CARB, CEC and South Coast AQMD has moved Class 8 battery-electric trucks up a full TRL notch since the 2018 Assessment. Class 8 battery-electric trucks are entering the threshold of early commercialization for short-haul and/or lighter-weight drayage. Notably, OEMs will need additional demonstration time for larger-scale deployments (e.g., JETSI) to identify and address ongoing technology challenges. These are necessary to identify and address ongoing technology challenges, and advance the technology for capability to perform successfully across the full range of drayage duty cycles. If this gets accomplished, Class 8 battery-electric trucks are expected to reach TRL 8 to 9 by 2024. The TRL rating of 9 is specifically estimated for short-haul and/or lighter-weight drayage applications.

- Class 8 **ZE** hydrogen fuel cell trucks have now reached **TRL 7.** Multiple Class 8 OEMs (traditional and start-up) are making good technological progress through focused pre-commercial demonstrations, which has helped move them up a full

TRL notch since the 2018 Assessment. If this work continues at the current (or faster) pace, Class 8 hydrogen fuel cell trucks are expected to reach TRL 8 by 2024.

- Class 8 **LE** natural gas trucks are rated at **TRL 9** today. They have reached full technical viability and maturity, as documented in the May 2020 Addendum to the 2018 Assessment, and are fully commercial products.

- No other ZE or LE fuel-technology platform currently achieves a TRL rating at or above the **6-to-7** range. This could change rapidly (e.g., with emergence of heavy-duty diesel engines certified by OEMs at LE levels, in response to CARB's Low-NOx Omnibus rule).

6.6. Focus for Remainder of 2021 Feasibility Assessment for Drayage Trucks

The methodology of this 2021 Feasibility Assessment for Drayage Trucks initially applied two key parameters, Commercial Availability and Technical Viability, to screen leading Class 8 fuel-technology platforms. Those that currently meet the basic criteria and considerations for Commercial Availability and Technical Viability (or exhibit strong likelihood to achieve them soon) were selected for further assessment, by applying the remaining three parameters (Operational Feasibility, Infrastructure Availability, and Economic Considerations).

The rationale for this is straightforward. Until a particular fuel-technology platform has 1) achieved (or is approaching) the minimum threshold for technical viability, and 2) become (or can soon become) a fully certified product offered by a major Class 8 truck OEM, it is premature and overly speculative to evaluate its potential for broad-scale deployment in the SPBP's drayage fleet over the next few years (the timeframe of this study).

Consequently, the remainder of this 2021 Assessment focuses on further characterizing the feasibility of Class 8 drayage trucks powered by two fuel-technology platforms that meet the above tests today: 1) **ZE** battery-electric and 2) **LE** natural gas ICE.

Important Notes:

1) Nothing in this 2021 Feasibility Assessment for Drayage Trucks precludes or discourages expanded development, demonstration and deployment of pre-commercial ZE and NZE fuel-technology platforms that have not yet reached TRL 8. In fact, both Ports are already supporting efforts to test a variety of truck platforms with TRL ratings in the 5-to-7 range. This is especially true in cases that include major involvement and cost sharing by Class 8 truck OEMs (see Section 5.8).

2) This Assessment is a snapshot of drayage truck platforms for late-2021. The Ports intend to conduct the next feasibility assessment within three years, or sooner if technological and market conditions warrant an accelerated schedule.

7. Assessment of Operational Feasibility

7.1. Background: Criteria and Methodology

Operational feasibility for a given drayage truck type refers to its ability to meet the essential needs of SPBP drayage companies to move cargo efficiently, affordably and safely at the Ports. The fundamental question for any emerging fuel technology platform is: will it be able to move containers (or other cargo) as well as – and preferably better than – the baseline diesel technology which it is intended to replace?

It is difficult to overstate the importance of end users (drayage trucking companies) gaining real-world experience with – and confidence in – the operational feasibility of any emerging drayage truck platform before widely deploying it in revenue service. To date, most trucking companies have not had much opportunity to gain much operational experience with emerging ZE and LE drayage truck platforms. This is especially true for the two leading ZE architectures (battery-electric and hydrogen fuel cell). Fortunately, ongoing and near-term demonstration and deployment programs now reaching conclusion have successfully provided OEMs and participating drayage fleets with extensive experience about how to design, operate and charge battery-electric trucks. They have helped identify and address the types of issues that can be common when initially testing any new-technology commercial vehicle type in revenue operation (see Section 5.8), and OEMs are likely to significantly improve their next generation of commercially available battery-electric trucks in many areas. Table 12 below lists the criteria that have been applied (within the scope and timeline of this Assessment) to evaluate if various fuel-technology platforms for drayage trucks can meet base considerations to be deemed operationally feasible. As shown, these base considerations focus on post-purchase parameters from the end user's perspective, including those that are vehicle-related (e.g., power, torque, acceleration and handling, fuel economy / range, driver comfort, availability of replacement parts) and those that are facility-related (e.g., fueling logistics, required time to fuel, need for facility upgrades).

Table 12. Criteria for establishing Operational Feasibility for emerging drayage truck platforms.

Operational Feasibility Criteria / Issue	Base Considerations for Assessing Operational Feasibility
Basic Performance	Demonstrated capability to meet drayage company needs for basic performance parameters including power, torque, gradeability, operation of accessories, etc.
Range	Demonstrated capability to achieve per-shift and daily range requirements found in San Pedro Bay Ports drayage.
Speed and Frequency of Fueling / Charging	Demonstrated capability to meet drayage company needs for speed and frequency to fuel / charge such that revenue operation is not significantly reduced relative to diesel baseline.
Driver Comfort, Safety, and Fueling Logistics	Proven ability to satisfy typical drayage trucking company's needs for comfort, safety and fueling procedures.
Availability of Replacement Parts and Support for Maintenance / Training	Verifiable existence of and timely access to (equivalent to baseline diesel) all replacement parts needed to conduct scheduled and unscheduled maintenance procedures.
	Verifiable existence of maintenance procedure guidelines and manuals, including OEM-provided training courses upon purchase and deployment of new trucks.
Affordable Access to Vehicle-Specific Facility Modifications	Proven ability for drayage fleets to gain affordable access to any new facility upgrades and modifications that will be necessary to house, service, maintain, and/or refuel/recharge a given drayage truck fuel-technology platform.
Source: Based on criteria in San Pedro Bay Ports' "Framework for Developing Feasibility Assessments," November 2017.	

7.2. Drayage Company Survey: Scope and Results

To assess operational feasibility, it was important to first understand key operational metrics associated with the drayage vocation at the SPBP. Existing reports generally lack sufficient detail to adequately inform this process. Consequently, an updated version of the on-line survey used to inform the 2018 Assessment was prepared and distributed to all companies registered in the San Pedro Bay Ports Drayage Truck Registry (PDTR). Additionally, the survey was sent to the Harbor Trucking Association (HTA) and California Trucking Association (CTA), which then distributed this CTP Truck Operator Survey to their membership. Written responses to the survey were received from a total of 96 companies, representing an estimated 3,000 port trucks (roughly one quarter of the active fleet, at any given time). These response rates are similar to the 2018 survey that garnered 97 responses and represented an estimated 3,300 port trucks.

This survey queried drayage truck operators about basic operational requirements, purchase costs, and annual maintenance costs. These results appear to be indicative of the breadth of drayage operations, but they should not be considered an exhaustive assessment, and the responding operators are not necessarily representative of the full population. Drayage is a complex trucking vocation, with a broad range of daily operational needs that vary from fleet-to-fleet and from day-to-day. Specific examples are discussed below.

Maximum Shift Distance – Figure 8 depicts the distribution of survey responses indicating the maximum distance travelled by drayage trucks during a single shift. The number of survey responses for each mileage bin are shown, along with the total number of trucks represented by those responses. The broad distribution of responses is indicative of the varying driving range requirements that different fleets and trucks experience.

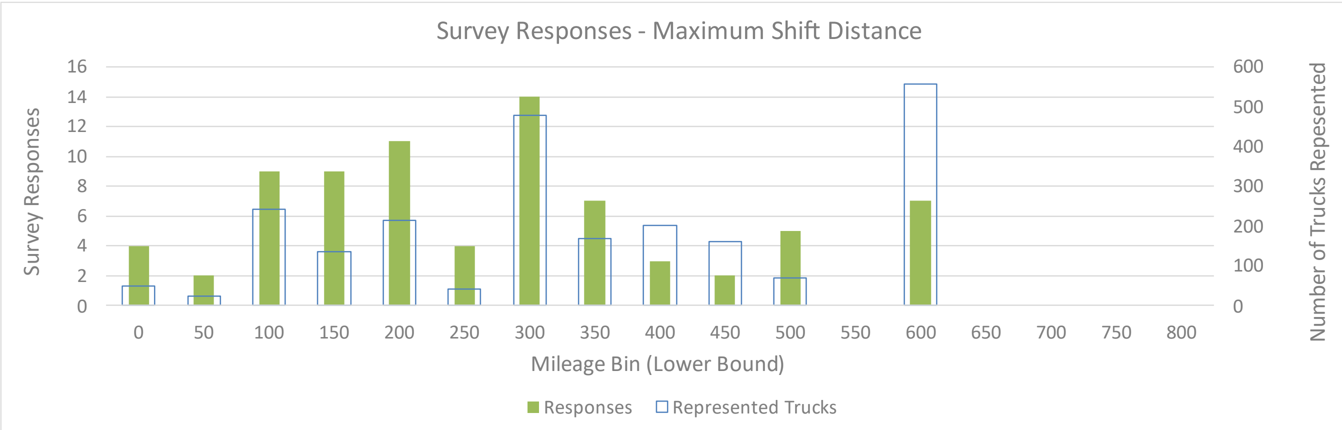


Figure 8. Distribution of survey responses for "maximum shift distance"

Figure 9 provides distributions of survey responses to four additional key operational parameters: average shift distance, average shift duration, average shifts per day, and average loaded operating weight. Results of the survey data for other questions and derived metrics used in this report are provided in Appendix C.

Average Shift Distance – The weighted average shift distance is 209 miles, while the highest average distance reported is 400 miles. As the figure shows, the most common responses were 100-200 miles, and the majority of trucks are represented by responses of 150 to 350 miles per shift. This indicates that larger fleets of drayage trucks are more likely to report higher average shift distances than smaller fleets.

Average Shift Duration – While a small number of responses indicated shift durations of less than 8 hours, the majority of responses were bounded between 8 and 12 hours, with a weighted average of 9.9 hours. The most common response was 10 hours.

Average Shifts per Day – Responses were predominantly binary, reporting either one shift or two shifts per day. Approximately half of the trucks represented are reported to average more than one shift per day. Combined with an average shift duration of 9.6 hours, drayage trucks typically operate either 9.6 hours per day or 19.2 hours per day. A truck operating 19.2 hours per day is achieved through "slip seating" of drivers, wherein the truck stops between shifts only long enough to exchange drivers and refuel, if necessary. A 19-hour daily operating period has significant implications for fueling/charging strategies and range requirements. To support these long operating periods, the truck must either: 1) fuel/charge in less than five hours and have sufficient range to serve two shifts, or 2) fuel/charge with diesel-like times (~15 minutes) between shifts.

Average Loaded Operating Weight – Responses indicated two broad categories of operating weights: 1) 30,000 to 40,000 lbs, and 2) 60,000 to 93,000 lbs. The bimodal distribution seen in the responses is typical of goods movement, where some trucks "cube out" (are limited by cargo volume) and some "weight out" (are limited by cargo weight). Approximately half of responses indicated typical operating weights of 60,000 to 80,000 lbs, suggesting that many trucks weight out, or come close to weighting out hauling relatively heavy cargo. Because most highways and interstates have an 80,000 lbs weight limit, trucks operating above this limit are likely traveling on specially designated overweight corridors hauling overweight containers or break-bulk loads.

Figure 9: Survey response distributions for key operational parameters

7.3. Comparison of Survey Findings to Other Studies

Four existing reports were identified that describe operational parameters for drayage trucks serving the SPBP. Key operational parameters from these studies are summarized in Table 13 (references 1 through 4) and compared to corresponding parameters from the 2018 and 2021 CTP Truck Operator Surveys (summarized in the final columns).

Table 13. Comparison of drayage truck operational parameters from identified studies

Operational Parameter	Units	Ref. 1. UC Irvine/ KRRI Study	Ref. 2. Ports' Zero Emission Roadmap	Ref. 3. Ports' ZE and NZE Drayage Demonstration Guidelines	Ref. 4. LA Metro Study of Drayage Truck Performance Parameters for I-710	CTP Truck Operator Survey	CTP Truck Operator Survey
Study Date		2017 (2010 data)	2011	2016	2013	2018	2021
Average Trip Distance (one-way)	miles	23.57	5 miles	*Not reported*	*40*	*Not reported*	*Not reported*
Average Trips per Day	#/day	6.22	*Not reported*	*Not reported*	*3-5*	*Not reported*	*Not reported*
Maximum Shift Distance	miles	>170	*Not reported*	*Not reported*	*Not Reported*	**600**	**630**
Average Shift Distance	miles	*Not reported*	*Not reported*	*Not reported*	120-200	**160**	**209**
Average Shift Duration	hours	*Not reported*	*Not reported*	*Not reported*	10-14	**9.9**	**9.9**
Average Shifts per Day	#/day	*Not reported*	*Not reported*	*Not reported*	1	**1.6**	**1.4**
Maximum Shifts per Day	#/day	*Not reported*	*Not reported*	*Not reported*	2	**2**	**2**
Average Daily Operating Time	Hours	*Not reported*	*Not reported*	*Not reported*	10-14	**14.8**	**14.2**
Average Daily Mileage	miles	146.6	*Not reported*	*Not reported*	120-200	**238**	**252**
Maximum Daily Mileage	miles	*Not reported*	*Not reported*	*Not reported*	200	**800**	**800**
Maximum Weight (GCWR)	lbs	*Not reported*	80,000	66,000	10,000-90,000	**80,000**	**80,000**
Top Speed (0% grade)	MPH	*Not reported*	50+	**60**	65	*Not reported*	*Not reported*
Gradeability @0 MPH	% grade	*Not reported*	20%	**15%**	*Not reported*	*Not reported*	*Not reported*
Gradeability @40 MPH	% grade	*Not reported*	6%	**6%**	6%	*Not reported*	*Not reported*
Intervals between fills (time, shifts, miles)		*Not reported*	1 shift (8 hours) or diesel-like fill times	80 miles, or 40 miles with opportunity charging/ fueling	Prefer range between fueling to be 2+ days. Refueling times of 20-30 minutes	**2 shifts, with less than 5 hours for charging/ fueling, or diesel-like refueling times**	

NOTE: **Green** text indicates values used to define "Broadly Applicable Truck" (BAT).

Report references:

1. You, S. and Ritchie, S., "A GPS Data Processing Framework for Analysis of Drayage Truck Tours" *Transportation Engineering*, July 2017, eISSN 1976-3808.
2. Port of Long Beach and Port of Los Angeles, "Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles"

7.4. Discussion of Specific References and Relevant Findings

Reference 1 – A 2017 study by researchers at UC Irvine and the Korean Railroad Institute analyzed one year of 2010 GPS data from 481 LNG drayage trucks and 64 diesel drayage trucks funded under Proposition 1B. The analysis developed a unique methodology to assess drayage operations in the context of trips and "tours" (a series of linked trips). This is the only study identified that was based on actual vehicle GPS data over such a long timeframe. While the analysis detailed daily activity estimates for both LNG and diesel trucks, diesel trucks had significantly greater daily mileage accrual than LNG trucks (146.6 miles vs 101.3 miles). For the purposes of this feasibility assessment, the diesel truck data are assumed to be more representative of the broader drayage fleet than the LNG data owing to the diesel trucks' greater operational flexibility and range at the time the study was conducted.[89] While the underlying data set in this study is the most detailed and robust of the four studies considered, the analysis did not report a number of key parameters desirable for the current feasibility assessment.

References 2 and 3 – The referenced documents in the above table are two reports from 2011 and 2016 that were jointly published by the Ports in an effort to describe minimum operational requirements for drayage trucks. For example, the 2011 "Zero Emissions Roadmap" included minimum performance requirements for short-haul drayage. Those metrics described important operational parameters like top speed and maximum operating weight. However, they did not define a number of other operational parameters. Additionally, these metrics were only focused on short-haul drayage mostly near-dock, some local), where it was envisioned that ZE technologies were most likely to initially be successful.

Reference 4 – As part of LA Metro's I-710 Corridor project, a zero-emission truck commercialization study was commissioned and completed in 2013. In support of that study, Metro conducted a survey of drayage truck operators serving the Ports to develop key performance parameters against which zero-emission technologies could be assessed. Unlike the previously discussed studies, this report sought to characterize the broader drayage market and assess a broad range of operational parameters. As shown in Table 13, the results of this study are generally in agreement with the results of the truck operator survey conducted as part of this feasibility assessment.

Importantly, the Metro report recognized the day-to-day variability of drayage operations and sought to define parameters for a "full-service truck" noting the following:

> *"Because the drivers are independent contractors, dray companies are unable to designate specific trucks as limited-service trucks. For example, a truck can't be limited to runs along the corridor, or short runs to and from the railyards. Every truck in the drayage fleet **must be a full-service truck**, able to complete any run."*[90]

7.5. Broadly Applicable Truck (BAT) Concept

Consistent with the above references, this Feasibility Assessment utilized the concept of a "broadly applicable truck" (BAT) to assist in assessing the Operational Feasibility parameter. A BAT is defined as being capable to perform the vast majority of drayage operations in the SPBP fleet, and therefore is expected to meet the "maximum" performance requirements described in Table 14. Average performance requirements are used primarily to inform the economic and infrastructure analyses. It is recognized that this BAT definition sets a relatively "high bar" for operational performance, which emerging ZE and/or LE technologies may not be able to meet today. This does not preclude the success of these technologies in niches within drayage. Similarly, the truck operator survey cannot capture every possible maximum performance requirement. Therefore, even a BAT may not meet the needs of every operator, for every cargo move.

The gradeability requirement (40 MPH at 6 percent) warrants additional evaluation. As described in the Ports' demonstration guideline document, this gradeability requirement is specified at 80,000 lbs gross combined weight (GCW). To achieve this

---

[89] As previously described, LNG trucks listed in the PDTR were predominantly equipped with 8.9L engines having horsepower ratings of only 320 HP; consequently, they were recommended for drayage applications with a GCW of 66,000 lbs or less.

[90] Papson, A. and Ippoliti, M., "Key Performance Parameters for Drayage Trucks Operating at the Ports of Los Angeles and Long Beach", November 15, 2013, page 14, http://www.calstart.org/Libraries/I-710_Project/Key_Performance_Parameters_for_Drayage_Trucks_Operating_at_the_Ports_of_Los_Angeles_and_Long_Beach.sflb.ashx.

gradeability on a continuous basis would require approximately 640 HP. Approximately 540 HP is required to deliver the power to support the elevation change (change in potential energy of the vehicle) and 100 HP is required for aerodynamic losses, rolling resistance, auxiliary systems, and driveline losses.[91] This power rating is well outside the capabilities of nearly all on-road trucks in the U.S. Closer review of the guideline document clarifies that the gradeability requirement is intended to address the steepest grades experienced on the Vincent Thomas Bridge. (Approaches to the Heim Bridge have a similar maximum grade; the new Gerald Desmond Bridge has a maximum grade of five percent.) The guideline document provides a bridge crossing test cycle that begins the approach at 50 MPH and declines to 30 MPH, requiring approximately 250 HP of continuous engine power. This 250 HP power demand is assumed to be equivalent to the intended gradeability requirement in the guideline document and is well within the capability of trucks currently serving the ports.

While the gradeability requirement for port bridge crossings is easily met by most Class 8 truck platforms, the requirement for a 6 percent gradeability has other relevant applications to drayage. Two major truck routes travelling north out of the basin are the I-5 and I-15 freeways. Both freeways have long grades of approximately 6 percent (the Tejon Pass on I-5 and the Cajon Pass on I-15) as they climb out of the basin and over the local mountains. A trip from the SPBP to the top of either pass would require a 100-mile one-way trip, implying a 200-mile minimum shift distance for a single round trip. An analysis of the survey data indicates that trucks with an average shift distance of at least 200 miles have a weighted average reported operating weight of 61,200 lbs. This is similar to a study of average heavy-duty vehicle weights that found the average weight of a Class 8 semi-tractor with single trailer was 59,000 lbs.[92]

Figure 10 depicts the engine power required to climb a 6 percent grade at various speeds with GCWs of 61,200 lbs and 80,000 lbs. The majority of drayage trucks are equipped with engines producing 400-500 HP, implying that the gradeability of a typical drayage truck is 25 to 30 MPH at 6 percent grade and 80,000 lbs GCW, or 35 to 40 MPH at 6 percent grade and 61,200 lbs GCW. In the 2018 Assessment, it was assumed that a 35 MPH sustained speed at the reported average GCW of 57,000 lbs was a reasonable benchmark and consistent with the range of trucks serving the ports. This implies a minimum engine horsepower rating of 400 HP or a tractive power rating (power at the rear wheels) of 320 HP. While the most recent CTP Operator survey data slightly increases the assumed average operating weight for these longer haul trucks, from 57,300 lbs to 61,200 lbs, the effective change in required engine power is small. Hence, the requirement of 400 HP for a 57,300 lbs load at 25 MPH defined in the 2018 Assessment is maintained for the 2021 Assessment. It is noted that fleets regularly traversing these mountain passes with loads near 80,000 lbs would see maximum sustained climbing speeds of 25 MPH and may not find such performance acceptable.

[91] National Research Council, "Review of the 21st Century Truck Partnership, Second Report", The National Academies Press, 2012. Estimated power demand for aerodynamic losses, rolling resistance, auxiliary loads, and driveline loses are based on reported average load curves in Table 5-1 and Figure 5-1 of the referenced report.

[92] Carrigan, C. and Ray, M., "Assessment of the MASH Heavy Vehicle Weights for Field Relevancy", 96th Annual Meeting of the Transportation Research Board, October 31, 2016, http://docs.trb.org/prp/17-01043.pdf.

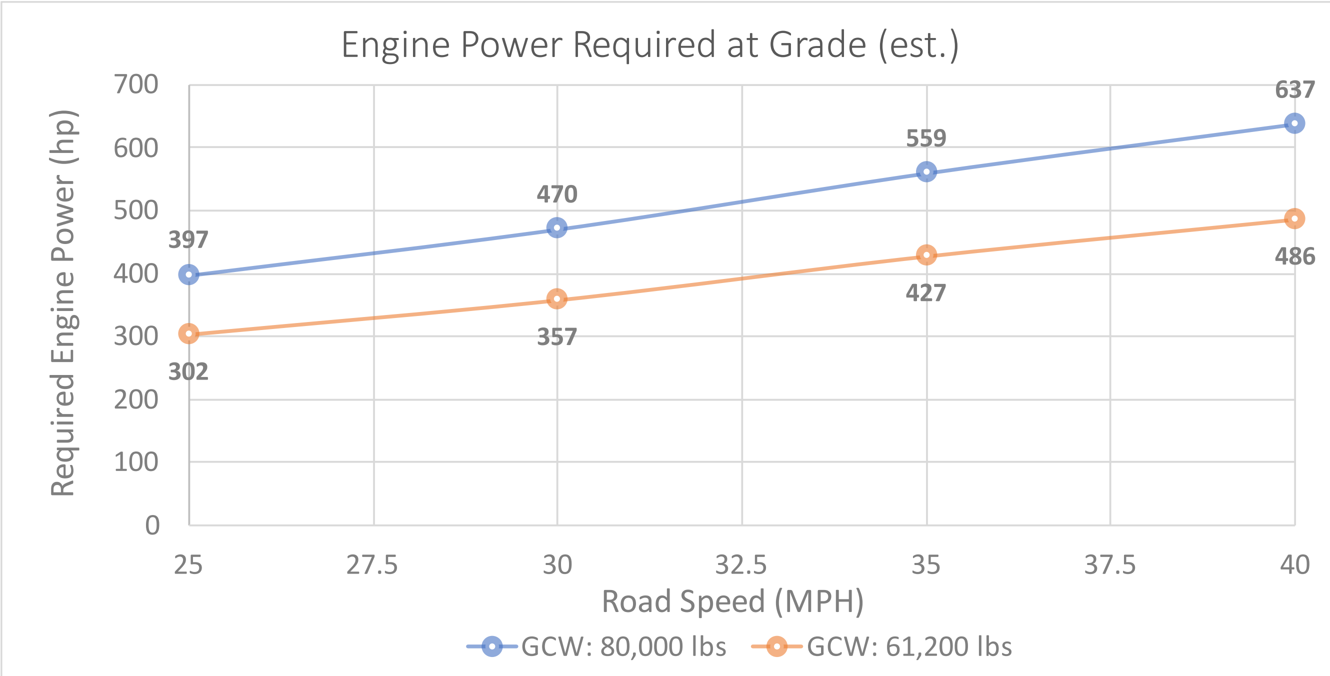


Figure 10: Estimated engine power required to sustain at a 6 percent grade

7.6. Application of Operational Feasibility Criteria

In this section, the performance assumptions previously summarized in Table 13 (derived from the noted sources) have been applied to further assess the operational feasibility of the two fully screened drayage truck platforms (ZE battery-electric and LE natural gas ICE). Application of these assumptions helps measure which key criteria are met, which collectively provides a snapshot of operational feasibility.

The exercise to determine which of these two platforms can meet drayage operational requirements is dependent on configurations for existing products. For both platforms, manufacturer specifications for typical Class 8 day cab semi-tractors have been used as sources for typical performance ratings.

7.6.1. Basic Performance

The basic performance parameters and requirements for BAT are defined in Table 14. These include top speed, gradeability, and Gross Combined Weight Rating (GCWR). These performance specifications do not explicitly set torque or horsepower requirements that are commonly used as a point of comparison between traditional ICE Class 8 trucks. This is because trucks based on electric drivetrains may not have directly comparable torque/horsepower specifications but can still achieve the gradeability, load, and top speed requirements for the vocation.

The results of the 2021 CTP Operator Survey are similar in many respects to the results of the 2018 survey. To maintain consistency with the 2018 Assessment, the basic performance parameters and requirements for BAT defined in Table 14 are only updated where significant differences between the two surveys exist. Specifically, only the Average Shift Distance, Average Shifts per Day, and Average Daily Mileage values have been updated based on the results of the 2021 CTP Operator Survey.

Table 14. Operational assumptions for a Broadly Applicable Truck (BAT)

Operational Parameter	Units	Value
Minimum Operational Capabilities Needed		
Maximum Shift Distance	miles	600
Maximum Shifts per Day	#/day	2
Maximum Daily Mileage	miles	800
Maximum Weight (GCWR)	lbs	80,000
Top Speed (0% grade)	MPH	60
Gradeability @0 MPH	% grade	15% at 80,000 lbs
Gradeability @40 MPH	% grade	6% at 80,000 lbs (short distance bridge climb)
Gradeability @35 MPH	% grade	6% at 57,000 lbs (sustained)
Shifts Between Charging/Fueling	# of shifts	2 shifts with less than 5 hours for charging/ fueling, or 1 shift with diesel-like fueling times
Average Operational Assumption for Economic and Infrastructure Analyses		
Average Shift Distance	miles	209
Average Shift Duration	hours	9.9
Average Shifts per Day	#/day	1.4
Average Daily Operating Time	hours	14.8
Average Daily Mileage	miles	252

Table 15 compares the performance specifications of a typical natural gas drayage truck equipped with a 12-liter engine and a typical battery-electric truck to the basic performance requirements previously described. As shown, both the natural gas and battery-electric platforms are capable of meeting minimum performance specifications.

Table 15. Comparison of basic performance capabilities

Basic Performance Parameter	Units	Requirement	Typical Natural Gas Semi-tractor	Typical Battery-electric Semi-tractor
Top Speed	MPH	60+	✓ 65	✓ 65
Maximum Weight (GCWR)	lbs	80,000	✓ 80,000	✓ 82,000
Gradeability @ 0 MPH and 80,000 lbs GCW	%	15%	✓ 25%	✓ 25%
Gradeability @ 40 MPH – bridge climb at 80,000 lbs GCW	%	6%	✓ >6%	✓ >6%
Gradeability @ 35 MPH – sustained at 57,000 lbs GCW	%	6%	✓ 6%	✓ >6%

It is noted that the 2022 study by NACFE described in Section 6.4 included three weeks of data collected from Volvo VNR electric trucks operated by NFI, based out of Chino, California. The data collected in the NACFE study provide a good early look at how Class 8 trucks have been operated during inland drayage truck operations. A review of the highest mileage day in that data set indicated that the truck consumed approximately 2 kWh/mile, giving the truck a range of just under 200 miles. On that day, the truck travelled 178 miles in a single shift. During that shift, it performed a mid-day opportunity charge of approximately one hour, where approximately 20 percent state of charge was added. The truck ended that single shift with 30 percent state of charge. While that state of charge is not sufficient for a second shift, another opportunity charge in the evening could potentially have restored another 20 percent state of charge, bringing the battery to roughly half full and allowing for another 100 miles of operation. This is type of operation is reasonably consistent with the "Average Operational Assumptions" shown in Table 13 and used for the Economic and Infrastructure analyses described later in this 2021 Assessment.

The data indicate that the Volvo VNR configured with a 396 kWh battery pack is capable of meeting the requirements of the average 1-shift operation, but would require extended charging between the first and second shift to accommodate a second shift. Unfortunately, the end time of the first shift in this particular demonstration fell around 4 pm and would require charging between shifts to occur during the on-peak utility period and result in higher electricity costs that modeled in the Assessment.

7.6.2. Range (Including Degradation)

Any ZE or LE architecture must have sufficient range to meet the operational requirements of the trucking industry and should maintain this ability over the life of the truck, that is, should not experience significant degradation that results in performance loss.

Range

Operating range requirements are based on the maximum distance travelled per-shift and per-day. Range for each platform is based on an assumed fuel economy and onboard energy/fuel storage capacity.

The operating range for the electric truck was determined from the manufacturer's stated battery capacity of 475 kWh (see Table 5) and an energy consumption rate (fuel economy) of 2.1 kWh/mile. This is the average rate reported by CARB in their analysis of Energy Economy Ratios (EER) for heavy duty trucks under the Low Carbon Fuel Standard (LCFS) program.[93] (EER refers to relative efficiency; CARB assumes Class 8 battery-electric trucks have an EER of 5.0 compared to their baseline diesel ICE counterparts.) The actual energy consumption rate is dependent on duty cycle; however, the data used by CARB are based on several drayage duty cycles and fall within the range of 2.0 to 2.4 kWh/mile. It is worth noting that the test cycle data used by CARB do not include the effects of heating or air conditioning loads. Nor do the data include other parasitic loads that might be present in some drayage trucks, such as electronic data recorders, telematics systems, or hydraulic pumps. Therefore, the 2.1 kWh/mile energy consumption rate is considered a reasonable but potentially optimistic estimate of the average energy consumption rate that would be seen in a broad deployment of electric trucks. It is noted that the estimated range of 226 miles is slightly lower than the 250-mile range stated by the manufacturer. The calculated range of 226 miles is used for transparency of assumptions and consistency with drayage-specific duty cycle test results available in literature. It is noteworthy that OEM-stated ranges for current Class 8 battery-electric truck models have increased by 40 to 70 percent since the 2018 Assessment, indicating significant progress for this parameter over the last three years.

For the natural gas platform, a 160 diesel gallon equivalent (DGE) CNG fuel system is assumed. CNG fuel tank packages can range in capacity from 60 DGE to more than 270 DGE. The 160 DGE system represents a reasonable midpoint configuration that offers sufficient range to meet the range requirements for the BAT specification. Results from the 2021 CTP Truck Operator Survey indicated an average diesel fuel economy of 6.8 miles per gallon.

Range for the CNG fuel package is based on an assumed fuel economy of 5.8 miles/DGE and was calculated by assuming a 15 percent fuel economy penalty for natural gas trucks versus a typical diesel truck. This estimate is based on a comparison of testing of a 12-liter near-zero natural gas truck[94] and prior testing of a 12-liter diesel truck[95] by the University of California, Riverside. The comparison of the test results indicated that the fuel economy of the 12-liter natural gas truck is 10 percent lower than that of a comparable diesel engine when measured over the Urban Dynamometer Driving Schedule (UDDS) test cycle. However, a comparison of emissions averaged over the three drayage truck test cycles indicated a 20 percent fuel

---

[93] California Air Resources Board, "Analyses Supporting the Addition or Revision of Energy Economy Ratio Values for the Proposed Low Carbon Fuel Standard Amendments," Appendix H to the Initial Statement of Reasons, March 2018, https://www.arb.ca.gov/regact/2018/lcfs18/apph.pdf.

[94] Johnson, K. and Cavan, G., "Final Report: Ultra-Low NOx Near-Zero Natural Gas Vehicle Evaluation ISX12N 400," University of California at Riverside, April 2018, https://ucrtoday.ucr.edu/wp-content/uploads/2018/08/CWI-LowNOx-12L-NG_v03.pdf.

[95] Miller, W. and Johnson, K., "In-Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty Engines," South Coast Air Quality Management District, September 2013, https://www.cert.ucr.edu/research/efr/2013_AQMD_in-use_retrofit_Miller.pdf .

economy penalty. A 15 percent fuel economy penalty for natural gas was selected as the midpoint between these two sets of results. It should be noted that CARB and Argonne National Laboratories currently assume a 10 percent fuel economy penalty for Class 8 CNG semi-tractors in their CA-GREET 3.0 and GREET[96] 2021 models, respectively. Therefore, the 15 percent fuel economy penalty represents a conservative estimate of the CNG truck's fuel economy relative to these emissions models. Additionally, the usable capacity of the CNG system was reduced to 87 percent (139 DGE) of the stated capacity based on manufacturer data sheets and accounts for the gas remaining in the fuel tanks after the fuel system reaches a minimum operating pressure of 290 psig.[97]

As shown in Table 16, the natural gas truck platform is capable of meeting the maximum shift distance requirement. To meet the maximum daily range requirement, the truck would need to be at least partially fueled or equipped with a larger fuel tank package. Configurations of up to 190 DGE are available and would provide greater than 800 miles of range at the assumed 5.8 miles/DGE fuel economy. Typical dispensing rates for CNG stations designed for heavy-duty vehicles are in the 5-10 DGE/minute range, which allows heavy-duty NG trucks to fully refuel in approximately 15-30 minutes.

Table 16. Comparison of vehicle range capabilities

Operating Range Parameter	Units	Requirement	Typical Natural Gas Semi-tractor	Typical Battery-electric Semi-tractor
Maximum shift distance (range between fueling/charging)	miles	600	✓ 800 (160 DGE fuel package)	× 226
Maximum Daily Range (with 30 minute refuel/recharge time)	miles	800	✓ 1,600	× 262 @150 kW × 286 @250 kW
Maximum Daily Range (no refuel/recharge time limit)	miles	800	✓ 1,420	× 452
✓Meets BAT specification	×Does not meet BATS specification			

The battery-electric truck's maximum shift range of 226 miles is significantly below the 600-mile performance requirement, as is the maximum daily range. Maximum daily range was determined based on a 30-minute fueling/charging window between shifts, where trucks are operated two shifts per day.[98] If the truck could be fully charged between shifts, the maximum daily range would be twice the maximum shift distance, or 452 miles. While the range capabilities of current-technology battery-electric trucks do not meet the BAT specification, they are sufficient to meet the average shift and average daily range of drayage trucks when new. This implies that this ZE truck platform could meet the range requirements for a meaningful fraction of drayage operations, but not all such operations. Battery degradation will reduce the effective range of the truck as it ages (as discussed below), further limiting the fraction of drayage operations that could be met by current battery-electric trucks over their lifetime.

Range Degradation

The range values provided in Table 16 are implicitly based on new trucks. As trucks age, their effective range will decrease. In the case of a battery-electric truck, its range declines as the battery system's usable capacity degrades over repeated charging cycles. The degradation rate is highly dependent on battery chemistry, battery system design, depth of discharge, recharging rate, environmental conditions, and duty cycle of the vehicle. These factors make predictions for degradation of a battery-electric truck difficult. Adding to this difficulty, current iterations of battery-electric trucks have only recently begun

[96] "GREET" is the acronym for Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies model; "CA-GREET" refers to the GREET version modified by CARB for emissions modeling in California.
[97] Quantum Fuel Systems product page, http://www.qtww.com/product/q-cab-cng-fuel-system/.
[98] Most manufacturers current BEV offerings are limited to a maximum 150 kW charging rate. Future product offerings are anticipated to increase the charging speeds to 250 kW or greater. Assumed 30-minute recharge time provides 75 kWh available to use during a second shift. Future charging speeds would provide 125 kWh or more for use during a second shift.

demonstrations in drayage operations. No trucks have yet accrued sufficient mileage and/or charge cycles to make meaningful estimates of battery degradation based on demonstration data. Electric buses are the most mature heavy-duty electric vehicle segment upon which to draw analogous operational data, and it is noted that BYD offers a 12-year battery warranty on its electric buses. Assuming the buses charge once per day, the buses would accrue approximately 3,100 charge cycles over 12 years, similar to a battery-electric drayage truck. Batteries are assumed to reach their end of life when they have less than 80 percent of their original capacity remaining.[99] BYD indicates that the cycle life of its lithium iron phosphate cells is 3,000 to 5,000 cycles, depending on the depth of discharge per cycle.[100] However, a transition to battery chemistries that can achieve higher driving distances (e.g., those with higher nickel content, which increases energy density) may result in reduced cycle life, at least in the near term as battery chemistries continue to mature.[101] Consequently, a battery-electric truck operator should anticipate that the maximum range of the truck could degrade to 80 percent of its original range over the course of its service life.

In the case of natural gas trucks, range will decrease as its fuel economy decreases, due to engine and driveline wear. The degradation in fuel economy of a well-maintained vehicle should be minimal. It is noted that neither CARB's EMFAC model nor EPA's MOVES model include any significant deterioration of vehicle efficiency for heavy-duty trucks as they age. Consequently, it is assumed that the ability of natural gas trucks to meet range requirements will not deteriorate significantly over the vehicle's life.

7.6.3. Speed and Frequency of Fueling/Charging

Diesel drayage trucks are currently fueled by three methods: 1) fueling at commercial facilities (i.e., truck stops), 2) on-site wet hosing, and 3) on-site fueling stations at motor carrier facilities. The Metro study reported that approximately two thirds of fleets rely on commercial fueling facilities and the remaining third provide fueling on-site.[102] Additionally, the study noted that baseline diesel trucks are typically refueled every two to four days while LNG trucks typically refuel every day. An increased frequency of fueling generally represents an increased operational burden as it requires additional driver time, wet hosing costs, and/or out-of-route miles for travel to fueling stations.

For the roughly two thirds of fleets that rely on commercial fueling facilities, a fueling/charging frequency of two to four days would be consistent with current diesel practices and should not represent a significant increased operational burden, provided that the fueling stations are within reasonable proximity to drayage operators.

For the remaining one third of fleets that currently fuel trucks at their facilities, a requirement to shift to off-site commercial fueling facilities would represent an operational change that could lead to significant increased costs. Fortunately, both battery-electric and natural gas trucks are routinely charged/fueled on-site. Electric trucks in particular are anticipated to rely almost exclusively on on-site charging between shifts and overnight.

Note that, as discussed in Section 4, technologies that did not pass the Commercial Availability/TRL screening were not included in subsequent analyses (Operational Feasibility, Economic Workability, or Infrastructure Availability). This includes fuel cell technology. Consequently, no further discussion is included below regarding operational feasibility of fueling hydrogen fuel cell trucks. However, it is likely that this will need to be revisited in future assessments or updates by the Ports.

---

[99] "Electric Buses in Cities", Bloomberg New Energy Finance, March 29, 2018, https://data.bloomberglp.com/bnef/sites/14/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

[100] Presentation by BYD, 2016, https://www.theicct.org/sites/default/files/BYD%20EV%20SEDEMA.pdf, and https://byd-forklifts.com/wp-content/uploads/2018/BYD8Y.PDF

[101] "Electric Buses in Cities", Bloomberg New Energy Finance, March 29, 2018.

[102] Papson, A. and Ippoliti, M., "Key Performance Parameters for Drayage Trucks Operating at the Ports of Los Angeles and Long Beach", CALSTART, November 15, 2013, http://www.calstart.org/Libraries/I-710_Project/Key_Performance_Parameters_for_Drayage_Trucks_Operating_at_the_Ports_of_Los_Angeles_and_Long_Beach.sflb.ashx.

Centralized Fueling/Charging

For the assumed natural gas platform with a 160 DGE fuel system and maximum range of 800 miles, the estimated average daily mileage of 252 miles reported in Table 14 implies a fueling interval of two to three days. This is consistent with current diesel fueling frequencies. The time required for each fueling event is likely to be longer for CNG vehicles than for diesel vehicles. Fueling a 160 DGE CNG system (139 DGE usable) at 10 DGE/minute requires approximately 14 minutes of fill time. By comparison, diesel fuel pumps often operate at 20 to 40 gallons per minute. Providing an equivalent 800 miles of range for a diesel truck would require 118 gallons of diesel fuel that could be delivered in three to six minutes. The additional 8-11 minutes of fueling time required every two to three days equates to two to five minutes of driver time per day, on average. This impact is assumed to be inconsequential with respect to overall daily operations.

While several battery-electric platforms are identified in Table 5, this Assessment uses the specifications for the Daimler Trucks eCascadia as it has the longest range of the platforms identified. This truck would be recharged approximately once per day, on average. At the current manufacturer-specified maximum charging rate of 150 kW, recharging the truck would require 3.5-4 hours.[103] This represents 35 percent of the duration of a single shift and is anticipated to represent a significant operational efficiency impact to fleets.

Table 17. Estimated fueling/charging rates required for single-shift and two-shift trucks

Shifts per Day	Average Daily Range	Typical Natural Gas Semi-Tractor: Fueling Rate	Typical Battery-Electric Semi-Tractor: Charging Rate
Single-Shift Trucks	209 miles	0.9-11.9 SCFM, average 5.8 SCFM	6-79 kW, 36 kW average
Two-Shift Trucks	275 miles	2.4-75 SCFM, average 27 SCFM	16-500 kW, 177 kW average

On-site Fueling/Charging

Provided it is conducted during typical non-operating periods, the ability to charge or fuel ZE and LE truck platforms while unattended eliminates much of the added operational burden that can occur with for trucks having longer-than-diesel fueling times. To allow unattended fueling/charging, the truck must remain parked and connected to the charging/fueling infrastructure for an extended period of time. Trucks operating only one shift per day are expected to have 10 to 14 hours of downtime. These trucks typically also travel fewer miles per day than trucks that operate two shifts per day, reducing the amount of energy that must be transferred during fueling/charging. An analysis of the collected survey data indicates that the combination of extended non-operating time and lower daily mileage for single shift trucks results in modest charging and fueling requirements. As shown in Table 17, single shift electric trucks would require between 6 kW and 79 kW average charging rates, with an average rate of 36 kW across all survey results. These power levels are well within existing power ranges for DC fast chargers that currently operate between 50 kW and 350 kW. Similarly, natural gas fuel flow rates are low, ranging from 0.9 standard cubic feet per minute (SCFM) to 11.9 SCFM per truck, with an average of 5.8 SCFM. Typical natural gas compressors for transportation applications have capacities of 250 to 750 SCFM, allowing a single compressor to potentially support dozens of single-shift trucks in a time-fill application (i.e., overnight fueling).

Trucks operating two shifts exhibit a broader range of charging/fueling rates. Power demand for EV charging could range from 16 kW to 500 kW, and averages 177 kW across all survey responses. DC fast chargers utilizing plug-in charging are not currently available in power levels above approximately 400 kW, although this is expected to change in the near future as the EV industry works towards establishing charging standards with 1,000 V to 1,500 V charging voltages. It should be noted that the 500 kW rate was somewhat of an outlier, with the second highest power demand calculated at 375 kW. Chargers are

[103] Charging rates decrease when batteries are outside their bulk charge region (typically, 20-80% state of charge), leading to longer recharge times for trucks that utilize the majority of their daily range.

available at this power level, although they currently require liquid cooled cables and accordingly are more expensive and have a larger installation footprint than non-cooled systems. The fueling rate for natural gas trucks ranged from 2.4 SCFM to 75 SCFM and averaged 27 SCFM. As noted previously, CNG compressors are available in a broad range of flow rates and could support the full range of fueling rates estimated here.

7.6.4. Driver Comfort, Safety, and Fueling Procedures

An operationally feasible technology must provide a similar level of driver comfort and safety as existing diesel trucks. Additionally, fueling procedures must be practical and safe to perform.

Driver Comfort

Driver comfort is a difficult metric to assess as it is highly qualitative and varies for each driver. Ride quality, sound levels, visibility, and various amenities all impact the driver's sense of comfort within a particular truck. Additionally, it must be recognized that the current drayage fleet is comprised of a mix of new and used trucks produced by the major Class 8 truck manufacturers, with a broad range of specifications relating to driver comfort (differing cabin packages, seat designs, axle positions, etc.). To assess a minimum level of driver comfort for the purposes of this feasibility assessment, it is assumed that any truck platform that can be configured similarly to existing diesel trucks would be sufficient.

Current battery-electric truck offerings include aero cab designs that are nearly identical to modern diesel trucks and cab-over designs that differ from the typical "conventional cab" or "aero cab" designs prevalent in the drayage fleet today. The cab-over design can offer increased visibility and improved low-speed maneuverability relative to conventional cabs, providing a degree of improved driver comfort in some applications. However, broad driver acceptance of the cab-over design remains to be proven owing to the limited number of drayage trucks with this design currently in operation. Battery-electric truck designs using aero cab designs meet the minimum standard for driver comfort in this feasibility assessment. It should also be noted that battery-electric trucks, in particular, exhibit very low noise levels and reduced vibration that are routinely noted by drivers as positive aspects of this technology. These characteristics can lead to reductions in driver fatigue and significant improvements in overall driver comfort as compared to the typical diesel truck.

Natural gas trucks are currently offered by all six major Class 8 truck manufacturers. These natural gas offerings are part of the standard vehicle specification and ordering process and can be equipped with a broad range of equipment options. They are also available on a number of standard chassis. Consequently, natural gas trucks are assumed to meet the minimum threshold for driver comfort. It is also noted that natural gas trucks are generally quieter than diesel trucks and offer potentially superior driver comfort for an otherwise equivalently specified truck.

Safety

Heavy-duty vehicle safety in the U.S. is largely regulated under Federal Motor Vehicle Safety Standards (FMVSS) implemented by the National Highway Traffic Safety Administration (NHTSA). The FMVSS covers a broad range of requirements for vehicle design, construction, and operation. Heavy-duty vehicle manufacturers are required to certify that their vehicles are compliant with FMVSS before offering the vehicles for sale. Unlike light duty vehicles, heavy duty vehicles do not have crash test ratings issued by NHTSA. Rather, NHTSA conducts studies of real-world crashes and incorporates that information into future proposed modifications to the FMVSS. Consequently, heavy-duty truck manufacturer certifications of compliance with FMVSS requirements are used as the minimum threshold for assessing basic vehicle design safety for purposes of this assessment. Because these certifications are required for vehicle sales in the U.S., it is assumed that all commercially available vehicles meet the minimum safety requirements for this Assessment.

There are often additional safety concerns raised with respect to the use of high-voltage batteries or natural gas in a heavy-duty vehicle. While these concerns are reasonable to raise, it must be recognized that tens of thousands of heavy-duty natural gas vehicles (both CNG and LNG) have been deployed in the U.S. The current body of literature does not support the idea that these vehicles pose a higher risk relative to diesel vehicles. Similarly, more than 1.7 million light-duty plug-in EVs have been deployed in the U.S. through 2020[104] and an estimated 600 heavy-duty transit vehicles are in operation (2019 data).[105] NHTSA has published guides specifically to assist people with safely maintaining and operating electric and hybrid-electric vehicles equipped with high voltage battery packs, and concluded that such vehicles do not generally present greater safety risks than conventional ICE vehicles.[106]

However, the risks associated with heavy-duty BEVs are clearly different, and must fully be understood in advance of wide deployment. The reality is that fleet operator experience with high-voltage battery packs remains very limited. Safety issues remain for adopting fleets to understand, train for and address (in conjunction with vehicle OEMs and third-party maintenance providers). Recognizing the importance of safety, Volvo joined with the National Fire Protection Agency to document and address the potential hazard specifically for the lithium-ion battery packs in their VNR Electric model.[107] Of course, the need to address new safety issues is not unique to battery-electric vehicles; it is common for emerging transportation technologies. OEMs will continue to better understand and address battery safety as they work with their technology partners to improve the technological and commercial maturity of battery-electric trucks, and/or different battery chemistries and manufacturing techniques emerge. Prior to larger-scale use, OEMs need additional field testing to address remaining safety issues associated with heavy-duty BEVs. This process is well underway in conjunction with adopting fleets and third-party maintenance providers. This provides additional real-world use for all parties to understand and manage potential hazards (e.g., shock, thermal events and sudden loss of power). In sum, OEMs are working hard with fleets and other partners to resolve such issues for their next-generation commercial heavy-duty BEVs.

Fueling/Charging Procedures

Charging of heavy-duty battery-electric trucks and fueling of heavy-duty CNG trucks both entail straightforward practices requiring minimal training of fleet personnel. An exception is noted with regard to high-power overhead charging of electric vehicles, as is seen in some transit bus applications. Overhead charging requires additional driver training to properly align the vehicle with the overhead charging system and to follow the appropriate procedures to initiate the charge. However, no electric drayage truck is currently being equipped for this type of charging interface. It seems likely that high-power overhead charging will be confined to transit applications for the next several years. It is possible that future assessments will need to revisit this issue.

Neither type of infrastructure (CNG or battery-electric) requires personnel to wear protective clothing/equipment during the fueling/charging process. Consequently, it appears that neither fuel-technology platform imposes a significant incremental operational burden on end users, relative to current diesel fueling procedures.

7.6.5. Truck Weight Impacts

Battery-electric and natural gas trucks are both typically heavier than comparable diesel trucks. As shown in Table 18, a typical day cab diesel truck is estimated to weigh 18,128 lbs when fully fueled with 130 diesel gallons and diesel exhaust fluid (DEF).[108] A comparable fully fueled natural gas truck would weigh approximately 20,000 lbs.[109] The reported curb weight for Freightliner's current battery-electric truck is 23,500 lbs,[110] representing an incremental weight of 5,400 lbs over a typical diesel truck.

---

[104] Oakridge National Laboratories, "National Energy Data Book", Table 6.02, 2021

[105] Federal Transit Administration, "2019 Annual Database Revenue Vehicle Inventory," 2021, https://www.transit.dot.gov/ntd/data-product/2019-annual-database-revenue-vehicle-inventory

[106] See for example National Highway Traffic Safety Administration, "Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped with High Voltage Batteries, DOT HS 811 574, January 2012.

[107] National Fire Protection Association in conjunction with Volvo Trucks, "NFPA Quick Response Guide: Volvo VNR Electric," https://www.nfpa.org/-/media/Files/Training/AFV/Emergency-Response-Guides/Volvo/ERG-Volvo-VNE21-06-2021-2019-version.ashx.

[108] Based on typical drayage truck specifications provided by Vehicle Velocity Group. 130 diesel gallons provides equivalent range to a 160 DGE CNG fuel system.

[109] Based on Quantum Q-Cab 160 DGE CNG fuel system. http://www.qtww.com/product/q-cab-cng-fuel-system/.

[110] South Coast AQMD, Clean Fuels Advisory Program Group, September 15, 2021. Presentation by Phil Barroca.

Table 18. Estimated truck curb weights

Truck Components / Systems Estimated for Weight	System and Total Weights (lbs) by Truck Type (Day Cabs)			
	Diesel ICE	CNG ICE	Current BEV	BATS BEV
Base Truck	17,000	17,000	23,500	10,900
Fuel System and Fuel	919	3,067	included	19,400
DEF and Tank	209	0	0	0
Total Curb Weight	**18,128**	**20,067**	**23,500**	**30,300**
Incremental Weight vs Diesel	-	1,939	5,372	12,172

Estimating the weight of a battery-electric truck that meets the BATS standard for range is difficult. This is because no Class 8 truck has been commercially offered to date that is equipped with the required battery capacity. Tesla's Semi with a rated range of 500 miles comes close to the BAT specification, but Tesla does not publish the estimated curb weight of the truck. NACFE estimates that the powertrain of a Class 8 diesel truck weighs approximately 6,100 lbs, excluding fuel. Deducting this weight from the baseline diesel truck weight of 17,000 lbs implies a base chassis weight of 10,900 lbs for an electric truck. The battery weight is estimated for a 1,260 kWh battery pack and an energy density of 72.5 Wh/lb.[111] An estimated 2,000 lbs of additional weight is assumed to account for traction motors, power electronics, cooling systems, and other associated equipment, resulting in a projected curb weight of 30,300 lbs for a BATS-compliant battery-electric truck. Notably, these are very rough estimates and extensive light-weighting of the chassis (e.g., Tesla's claim) could reduce the curb weight of a BATS-compliant truck below the indicated estimate. However, it could also increase costs.

As a truck's curb weight[112] increases, the payload carried by the truck may need to be reduced to remain within weight limits. The blue line in Figure 11 depicts the maximum payload capacity (weight of the trailer and cargo) that could be carried by a standard five-axle semi-tractor that is subject to California bridge weight limits.[113] As the curb weight of the tractor increases, the maximum potential payload decreases at a rate of 2:1. That is, for every one pound increase in the weight of the tractor, the maximum payload capacity decreases by two pounds. The vertical lines on the figure indicate the curb weight of the diesel, CNG, and battery-electric trucks shown in Figure 11 and their intersection with the blue cargo capacity line indicates their maximum cargo capacity at their assumed curb weight. Assuming the average weight of a container chassis is 7,000 lbs, a typical diesel truck could transport a container weighing up to 49,000 lbs (56,000 lbs total cargo capacity – 7,000 lbs trailer weight). An equivalent CNG truck would be limited to a maximum container weight of 45,000 lbs while a battery-electric truck would be limited to a 38,000 lbs container weight. A BAT-compliant battery-electric truck would be limited to a container weight of 24,400 lbs.

[111] Approximate energy density of Proterra E2 and Tesla Model 3 battery packs

[112] The curb weight is the weight of the vehicle without occupants or cargo.

[113] These weight limits are typically 12,000 lbs for a front single axle, and 34,000 lbs for each of the tandem axles on the tractor and trailer. This results in a maximum allowed vehicle weight of 80,000 lbs.

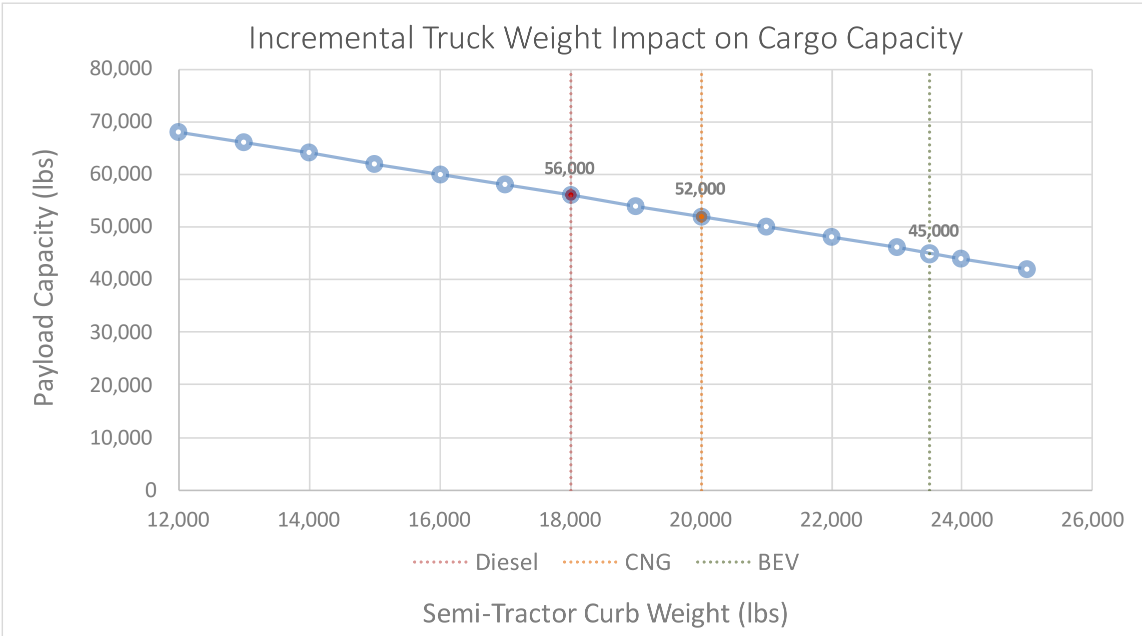


Figure 11. Incremental truck weight impacts on cargo capacity

For the 57,000 lbs average GCW discussed in Section 7.5, an 18,000 lbs diesel truck would carry a 32,000 lbs load. This is within the estimated cargo capacity for the current battery-electric truck. For a BAT-compliant truck, the 32,000 lbs cargo would exceed the carrying capacity of the truck. To carry this load, a BAT truck would be restricted to overweight corridors, require the use of tridem or spread trailer axles, or utilize full trailers rather than semi-trailers. While technically possible, these options all create operational inefficiencies relative to diesel carrying these average loads.

A significant portion of respondents to the 2021 Drayage Operator Survey indicated maximum operating weights of 70,000 to 80,000 lbs, implying a maximum cargo weight of 52,000 to 62,000 lbs. The heaviest loads, at or near 80,000 lbs, are typically bulk haulers rather than those transporting shipping containers. For these operators, incremental weight of the truck creates an equivalent loss in cargo capacity. For example, a natural gas truck with a 2,000 lbs incremental weight would reduce the truck operator's cargo capacity by 2,000 lbs.

For truck operators using a typical 5-axle semi-tractor/trailer combination, the natural gas truck's additional 2,000 lbs of tractor weight does reduce the maximum cargo capacity to 52,000 lbs and would imply a diesel equivalent GCW of 70,000 lbs. Trucks operating over 70,000 lbs GCW on a typical five-axle tractor/trailer would likely face operational challenges with a typical natural gas truck. Light-weighting and careful sizing of the fuel system could reduce this weight penalty. For example, specifying a 123 DGE CNG system would reduce the truck's weight by 600 lbs.

Assembly Bill (AB) 2061 passed in 2018 essentially allows ZE and LE trucks to exceed weight limits on the tractor by up to 2,000 lbs and operate as high as 82,000 lbs GCW.[114] Because the language of the bill allows both the GCW of the tractor/trailer and the weight limits on the tractor itself to increase by 2,000 lbs, this change effectively eliminates the typical weight penalty for LE natural gas trucks. It also reduces the effective weight penalty of the battery-electric truck by 2,000 lbs, allowing the truck to haul up to 40,000 lbs containers. This increase allows the battery-electric truck to transport many of the containers moved through the ports. However, maximum loading of shipping containers can easily exceed 40,000 lbs. For example, shipper OOCL recommends a 39,500 lbs maximum container weight for dry 20-foot containers, but up to 44,500 lbs for dry

[114] "AB-2061 Near-zero-emission and zero-emission vehicles", California Legislative Information, https://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill_id=201720180AB2061

40-foot containers.[115] Consequently, it is assumed that current battery-electric trucks would be unable to legally transport many of the 40-45-foot shipping containers moving through the Ports. A BATS-compliant battery-electric truck would be limited to approximately 28,400 lbs containers, making it unsuitable for much of the cargo transported in the Ports.

7.6.6. Availability of Replacement Parts and Support for Maintenance / Training

Maintenance and repair of ZE and LE heavy-duty trucks can be subdivided into three broad categories of activity: preventative maintenance, repair of standard systems, and repair of ZE and LE fuel systems. Preventative maintenance activities include vehicle inspections, fluids and filter changes, tire and brake system maintenance, etc. Preventative maintenance may be performed by the truck owner, a leasing company, or a local maintenance facility.

Repairs of standard systems refers to maintenance and repair of systems on the vehicle that are typically present on diesel vehicles. Examples include suspension systems, air or hydraulic lines, and low voltage electrical systems. This category specifically excludes high voltage systems and power electronics in electric vehicles and high-pressure fuel systems in CNG vehicles.

Repairs of ZE and LE fuel systems refers to specialized, fuel-specific systems that require special training, tools, and facilities to repair.

Battery-Electric Vehicles

It is important to note that "all-electric vehicles typically require less maintenance than conventional vehicles." This is because they have "far fewer" moving parts, a general lack of fluids to refill, and reduced brake wear resulting from regenerative braking systems.[116] Still, heavy-duty battery-electric trucks do require maintenance, repairs, and new parts. Much of these requirements involve very different types of vehicle subsystems, compared to ICE vehicles with conventional drivetrain systems.

As described in this Assessment, OEMs offering Class 8 battery-electric trucks suitable for drayage are still in early stages of commercialization that essentially entail advanced demonstration modes. Thus, the number of deployed Class 8 battery-electric trucks remains small. Currently, truck manufacturers (with their technology partners) provide most service and maintenance, beyond basic preventative maintenance. Major established truck OEMS (e.g., Daimler, Volvo, Peterbilt, and Kenworth) now selling early commercial battery-electric trucks are able to take advantage of their long-established, robust service and parts networks and systems. Newer or emerging Class 8 truck OEMs are working hard to build-out their service and parts networks, commensurate with truck rollouts. It is noteworthy that each make/model of heavy-duty battery-electric truck now eligible for funding under California's HVIP (e.g., Volvo VNR Electric, Freightliner eCascadia, BYD 8TT, Kenworth T680E) must be covered by an OEM warranty, and have ready access to OEM-affiliated facilities to provide "vehicle service, warranty service, and repairs statewide."[117]

Specific examples of how OEM efforts to service battery-electric trucks and provide parts include the following:

- Volvo sells its VNR Electric model in combination with its "Volvo Gold Contract" specifically designed to provide comprehensive support for its heavy-duty battery-electric trucks. Volvo's offering includes scheduled and preventive maintenance, towing and vehicle repair, "including the vehicle's lithium-ion batteries and the complete electromobility

[115] "Operational Restrictions," OOCL, https://www.oocl.com/usa/eng/localinformation/operationalrestrictions/Pages/default.aspx
[116] U.S. Department of Energy Alternative Fuels Data Center, "Maintenance and Safety of Electric Vehicles,"
[117] California HVIP, "Implementation for the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), March 15, 2022,

system, to ensure peak vehicle uptime, performance and productivity." Details are provided in Volvo's service brochure[118] and the recent "lessons learned guidebook"[119] from the Volvo LIGHTS demonstration.

- Freightliner (Daimler) indicates it offers "the industry's best service network" for its eCascadia model. This includes nearly 500 Freightliner dealership locations across North America. Specialized training is provided for all technicians working on battery-electric trucks. Freightliner has established a goal to provide a "24-hour or less turnaround time" for service and repairs on its trucks, including the eCascadia.
- BYD provides up to 40 hours of training (operating, preventative maintenance) to fleets that purchase their vehicles. BYD's heavy-duty BEV manufacturing facility in Lancaster, California offers a local source of technicians and parts to repair BYD units deployed in Southern California. It appears that BYD has the necessary elements to support a maintenance and repair supply chain for heavy-duty battery-electric trucks performing drayage for the San Pedro Bay Ports, but this supply chain will not be tested until additional heavy-duty trucks are deployed into regular service.

Based on these types of announcements, OEMs have made strong progress to ensure early adopters of Class 8 battery-electric trucks will have sufficient access to service facilities and replacement parts. However, additional efforts and investments will be required to further build-out these networks as needed to fully support growing ZE truck deployments. As discussed in Section 5.5, major OEMs are well positioned to provide this additional capability, at pace with ZE truck sales.

Natural Gas Vehicles

Heavy-duty natural gas vehicles in Southern California are currently supported by several large truck dealership networks including Vehicle Velocity Group (Daimler/Freightliner), Inland Kenworth, Rush Trucks (Peterbilt), and TEC (Volvo). Additionally, Cummins Pacific has two facilities in Southern California providing engine OEM support for the only heavy-duty natural gas engine currently available for Class 8 trucks. Finally, these trucks can also be serviced by a number of truck leasing companies and third-party maintenance providers. This substantial network of service providers is composed of many of the same companies that provide service and parts for the Class 8 diesel market in Southern California. These companies are capable of performing all necessary maintenance and repair of heavy-duty natural gas trucks.

Vehicle owners can perform basic preventative maintenance work on natural gas vehicles, following Cummins-provided preventative maintenance schedules. Additionally, Cummins offers parts and maintenance information through its standard QuickServe system. Specialized maintenance facilities are not required to perform preventative maintenance or repairs provided those repairs do not require disturbing the natural gas fuel system.

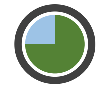
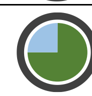
Repair of natural gas-specific systems requires specialized training and appropriately equipped maintenance facilities. As noted in the Metro study, only the largest fleets generally own and operate their own maintenance facilities. The majority of fleets are expected to have any such services, and major repairs in general, performed by third party service centers such as the vehicle and engine dealerships previously noted.

7.7. Summary of Findings for Operational Feasibility

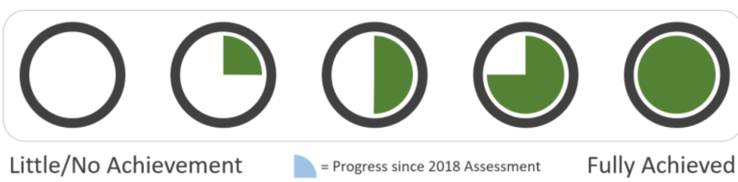
Table 19 summarizes the specific criteria and base requirements (outlined above) applied in this Feasibility Assessment to collectively establish whether the two fully screened ZE or LE drayage truck platforms are "operationally feasible" today. In the final column of the table, snapshot ratings are provided of the degree to which these platforms already meet these basic considerations today.

[118] Volvo Trucks USA, "The Volvo VNR Electric," VNR Electric I Volvo Trucks USA, accessed May 2022.
[119] Volvo Group North America, "Volvo Lights: Bringing Battery-Electric Freight Trucks to Market from Demonstration to Commercialization – Lessons Learned Guidebook," March 2022, Volvo Lights Guidebook (lightsproject.com).

Table 19. Summary of ratings by key criteria: 2021 Operational Feasibility

Operational Feasibility Criteria/Parameter	Base Considerations for Drayage Platforms to Achieve Operational Feasibility	Achievement of Criteria in 2021 for Commercially Available Drayage Truck Platforms	
		ZE Battery-Electric	LE NG ICE
Basic Performance	Demonstrated capability to meet drayage company needs for basic performance parameters including power, torque, gradeability, operation of accessories, etc.		
Range	Demonstrated capability to achieve per-shift and daily range requirements found in San Pedro Bay Ports drayage.		
Speed and Frequency of Fueling/Charging	Demonstrated capability to meet drayage company needs for speed and frequency to refuel / recharge such that revenue operation is not significantly reduced relative to diesel baseline.		
Driver Comfort, Safety, and Fueling Logistics	Proven ability to satisfy typical drayage trucking company's needs for comfort, safety and refueling procedures (for the operator).		
Availability of Replacement Parts and Support for Maintenance/Training	Verifiable existence of and timely access (equivalent to baseline diesel) to all replacement parts needed to conduct scheduled and unscheduled maintenance procedures.		
	Verifiable existence of maintenance procedure guidelines and manuals, including OEM-provided training courses upon purchase and deployment of new trucks.		

Legend: Operational Feasibility **(2021)**



Source: Based on Drayage Truck Operator Survey responses, footnoted studies, OEM product information, and consultant's industry knowledge.

Rationale for the above ratings for Operational Feasibility, and broad implications to the overall 2021 Drayage Truck Feasibility Assessment, are as follows:

ZE Battery-Electric – Class 8 truck OEMs (with their technology partners) have made significant progress since 2018 to improve pre-production ZE Class 8 truck platforms. These improvements have led to better operational feasibility for their fleet customers. The fact that OEM-stated ranges have increased 40 to 70 percent since the 2018 Assessment informs the ¼ pie increase for the Range parameter in the table. As of late-2021, it appears that the early commercial battery-electric trucks that will enter into series production (at small volume) in 2022 and 2023 will be capable of meeting basic performance requirements for short-range (up to 226 miles; refer back to Table 16) and/or lighter-weight drayage operations. They are likely to generally outperform diesel trucks with respect to power, torque, and gradeability. However, range, weight, and recharging time remain barriers that limit applicability of these trucks. In particular, the incremental weight of current-technology Class 8 battery-electric trucks could be a significant barrier to wider adoption in drayage applications.

The 2018 Assessment noted that driver comfort and safety were not expected to pose major barriers to adoption for Class 8 battery-electric trucks. Since that time, OEMs have further improved their pre-production battery-electric trucks for these parameters. They are working on multiple cab designs that offer increased visibility and improved low-speed maneuverability relative to conventional cabs, providing a degree of improved driver comfort in some applications. While broad driver acceptance remains to be proven through large-scale deployments, it appears that battery-electric truck designs now meet the minimum standards for driver comfort in this feasibility assessment. It should also be noted that they exhibit very low noise levels and reduced vibration; early adopter drivers are routinely signaling approval for these characteristics. Moreover, this can lead to improved overall driver comfort and significant reductions in fatigue and relative to conventional diesel trucks.

Based on the nearly two million light-duty plug-in cars on U.S. roads today – and approximately 600 buses with similar high-energy battery packs – battery-electric trucks appear to not pose higher safety risks relative to diesel vehicles. However, the risks are clearly different, and must fully be understood in advance of wide deployment. Charging heavy-duty electric vehicles does not require personnel to wear protective clothing/equipment, which may be indicative that this process does not pose special safety hazards for charging personnel. However, the reality is that overall fleet operator experience with high-voltage battery packs remains very limited. Consequently, significant safety issues remain – including potential for thermal events – that adopting fleets need to understand, train for and address (in conjunction with vehicle OEMs, third-party maintenance providers, first responders, and other stakeholders).

LE Natural Gas ICE – Class 8 trucks powered by natural gas ICE technology now achieve full "operational feasibility" for LMCs performing drayage at the Ports. As demonstrated at the Ports and documented in the May 2020 Addendum to the inaugural 2018 Assessment[120] – and corroborated by CARB staff[121] – Class 8 trucks powered by CWI's 12-liter LE natural gas engine have proven their capability and technological robustness to meet the operational needs of LMCs using them for SPBP drayage. In terms of the "pie" ratings, this represents a one-quarter step increase since the 2018 Assessment.

LE natural gas trucks continue to offer the only alternative technology (ZE or LE) that can achieve the daily range requirements and fueling intervals expected by drayage operators. The additional fueling time they require relative to diesel trucks is assumed to be inconsequential, with respect to overall daily operations.

Driver comfort and safety are essentially equivalent to diesel trucks, now that natural gas variants are available in many of the same models as diesel trucks, with a broad range of equipment options. Fueling procedures are straightforward and do not pose barriers to adoption.

Drayage trucks equipped with the noted CWI 12-liter natural gas engine are fully supported by OEMs for the key provisions identified in the table (warranty, parts, maintenance, training, etc.). Several major dealerships and service networks exist in the region today that are fully capable of servicing these trucks. These operations can be expanded and/or transitioned from diesel-oriented operations as needed, to service a much-larger natural gas truck fleet.

---

[120] The 2018 Assessment complete with this May 2020 Addendum can be downloaded at https://cleanairactionplan.org/strategies/trucks/.

[121] California Air Resources Board, "Draft Technology Pathways and Status Updates," August 1, 2019, https://ww2.arb.ca.gov/sites/default/files/2019-08/draft_techpathways_08012019.pdf.

8. Assessment of Infrastructure Availability

8.1. Criteria and Methodology

Availability of suitable fueling infrastructure is essential for the Ports to transition to the drayage fleet to ZE and LE fuel-technology platforms within the timeframes prescribed by the CAAP. Regardless of the energy form utilized (e.g., natural gas, hydrogen and/or electricity), fleets that deploy ZE and LE drayage truck platforms will require convenient and safe access to affordable fuel.

Note that for the purposes of this feasibility assessment, "infrastructure" includes the fuel dispenser/charger as well as the other equipment and site improvements needed to supply the dispenser/charger. Examples of infrastructure components include compression systems, transformers, switch gear, conduit, piping, and the associated site work and permitting needed to install this equipment.

The key criteria and base considerations that were collectively used to assess Infrastructure Availability are listed in Table 20 below.

Table 20. Criteria for establishing Infrastructure Availability for emerging drayage truck platforms

Infrastructure Criteria / Parameter	Base Considerations for Assessing Infrastructure Availability
Dwell Time at Station	Fueling/charging can be accommodated within typical work breaks, lunches, other downtime compatible with trucking company schedules and operational needs.
Station Location and Footprint	Fleets have existing onsite access to fueling infrastructure, or can be fueled/charged conveniently and affordably off site, at public or private stations. New infrastructure can be installed without extensive redesign, reconfiguration or operational disruptions and there is sufficient electrical or natural gas capacity at the site.
Infrastructure Buildout	Infrastructure can be constructed at a pace consistent with fleet adoption and able to meet fleet fueling/charging requirements by the end of the assessment period.
Existence of / Compatibility with Standards	A sufficient body of codes and standards exist from appropriate organizations that enables safe and effective fueling/charging. The fueling/charging station technology has already been installed at other trucking companies in the U.S., with sufficient time to assess performance and safety.
Source: Based on criteria in San Pedro Bay Ports' "Framework for Developing Feasibility Assessments", November 2017.	

8.2. Important Considerations Associated with the Baseline Diesel Infrastructure and Fleet

8.2.1. Number of Stations and Convenience of Location

The existing network of diesel stations presents a very high bar for any alternative fuel platform to replicate. There are roughly 2,500 retail diesel stations located within a typical drayage haul of the two Ports.[122] As further described, neither electric charging nor natural gas fueling stations currently come close to achieving this level of buildout, in terms of station numbers and strategic locations.

[122] The California Energy Commission reports that there are 5,183 retail diesel stations in California (https://www.energy.ca.gov/data-reports/energy-almanac/transportation-energy/california-retail-fuel-outlet-annual-reporting). Roughly half are located in Southern California. Los Angeles County alone has more than 1,000 diesel stations.

Given the relatively few fueling/charging stations compared to the quantity required to support the full drayage fleet, major station build-outs will be needed if large numbers of battery-electric and/or natural gas drayage trucks are to be rapidly deployed over the next several years. The pace of the build-out will need to be commensurate with the numbers of tractors deployed for each type. The new stations will either be dedicated facilities in trucking company yards, or retail stations. In either case, they will need to be installed relatively rapidly, with a clear return on investment for the entities that build them (taking into account any available government incentives). And, as described in the next section, it will be very important that this station build-out aligns with the scope and scale of the SPBP fleet and the relative percentage of trucks using battery-electric and natural gas ICE powertrains.

8.2.2. Infrastructure Implications of Common Truck Parking Procedures

Drayage trucks may park overnight at a motor carrier's facility or parked at various parking lots throughout the region. At motor carrier facilities, parking space is often limited, and the site layout may create significantly congested parking that creates challenges for siting charging or fueling infrastructure (see Figure 12). Off-site parking locations can include the truck owner's private residence, street parking, or rented space at other commercial properties that may or may not be engaged in trucking. At this time, trucks that are parked at locations other than motor carrier facilities are in large part going to be impractical to serve with fueling/charging infrastructure at the parking location.

Figure 12. Examples of truck parking at motor carriers

An analysis of responses to the 2021 Drayage Truck Operator survey indicates that approximately half of trucks park overnight at a motor carrier facility. This is significantly lower than the estimated 72 percent in the 2018 Assessment and the 80-90 percent of trucks returning to their yard at the end of the day reported in the Metro study. The reasons for the significant change in responses to the survey are unclear, but it remains clear that both public and private charging will be important for drayage electrification. Because of the previously noted challenges with providing on-site charging/fueling for trucks that do not park at motor carrier facilities, it is assumed that these trucks would largely need to be served by fast charging/fueling facilities in a manner similar to existing diesel fuel stations. Such stations could potentially be located at a motor carrier's facility or at public access fueling stations.

8.3. Application of Criteria to Battery-Electric Charging Infrastructure

Charging infrastructure can be designed to recharge vehicles at a wide range of power levels, ranging from a few kilowatts to several megawatts. The vehicle design limits the maximum charging speed, while operational requirements determine the minimum acceptable charging rate. The currently available Class 8 semi-tractors considered in this Assessment have a maximum charging rate of 150-185 kW, allowing the trucks to be recharged in as little as 2.5 hours. However, fast charging rates generally incur higher utility costs, require costlier infrastructure, and may accelerate deterioration of vehicle batteries. Where possible, it is preferred to charge a vehicle at the slowest rate that meets the operational requirements of the fleet.

8.3.1. Station Location and Footprint

Similar to the process described in section 8.4.1, an estimate of the number of trucks that could be served by on-site charging infrastructure was developed based on responses to the Drayage Truck Operator survey and assumptions about the typical footprint of charging infrastructure. For each response to the 2021 Drayage Truck Operator survey, an estimate of the required minimum average charging rate was determined based on the average daily mileage and number of shifts reported. These charging rates were translated into space requirements based on an assumed footprint of 7.5 kW per square foot. This footprint is primarily based on the footprint of a DC fast charging power cabinet in the 50 kW to 200 kW power range. It does not include the footprint of dispensers, switchgear, or utility transformers. Many of these additional pieces of equipment serve several power cabinets, potentially making their relative contribution less significant than the power cabinets. Note, however, that when very high power levels (multi-megawatt site demands) and/or high utility supply voltages are utilized, the footprint of the supporting equipment can become significant. It is also noted that placement of charging infrastructure may have impacts on overall facility layouts that can magnify the apparent space claim of the chargers. Examples may include, but are not limited to requiring head-in parking of vehicles rather than tail-in parking, installing charger "islands" to accommodate limited cord lengths and charge port positions on the truck, and set back requirements that preclude placement of chargers at the head of existing parking stalls. The results of this analysis indicate that approximately 52 percent of trucks that park on-site could be served by on-site charging infrastructure. Combining this result with the estimated 50 percent of trucks that park on-site implies that approximately 26 percent of the fleet could be served by on-site charging. For this 26 percent of the fleet, the total additional footprint for DCFC power cabinets is estimated at 86,000 to 117,000 square feet. The total space claim is likely to be higher when accounting for the various layout issues described above.

As with the counterpart analysis for CNG stations (next section), these are very rough estimates that cannot account for individual site conditions. For example, many trucking sites have limited access to electrical power, and would need to work with their local utility (Southern California Edison, the Los Angeles Department of Water & Power, or other municipal utilities) to make significant infrastructure and costly changes. Consequently, the practicable potential for on-site charging could vary from this calculated estimate.

Assuming that 26 percent of trucks could be charged on-site, the remaining 74 percent of trucks would require public access fast-charging stations or public/private overnight parking with charging options. At this time, there are only two examples of public access heavy-duty DC fast charging stations in the US. One station is located at the Port of Long Beach and has been developed as part of a battery-electric drayage demonstration project with Shippers Transport. The site offers two DC fast-charging lanes, providing up to 150 kW charging rates. The second site is the Energy Island facility in Portland, Oregon and was developed by Portland General Electric and Daimler Trucks as an innovation center. Energy Island is equipped with multiple lanes and eight dispensers. Power levels range from 150 to 350 kW and will eventually incorporate megawatt-level chargers as part of early trials of Mega Charging Standard equipment. While only two demonstration-focused facilities exist, WattEV – a new market entrant seeking to develop large scale, commercial DC fast charging truck stops – has initiated a project in Bakersfield, California that is planned to provide up to 40 high-power DCFC lanes, and traditional truck stop operators may follow suit in time. There are no fundamental technical barriers to creating these facilities; however, this requires gaining access to suitable land, and significant operational and cost challenges exist for fleets and facility operators. For example, dwell times at a public access charging station will be lengthy. As discussed in Section 7.6.3, charging times could exceed 2.5 hours. Making a rough assumption that the majority of trucks would seek to charge in a four-hour window before or after a shift, this would imply a total charging time of 8 hours per day for the majority of public access charging stations. For the estimated drayage fleet of 14,000 to 19,000 trucks, with 74 percent of that fleet relying on public charging, space could be required for 3,200 to 4,400 trucks charging simultaneously. As a rough approximation, a typical diesel truck stop was considered and found to have ten fueling lanes and occupy 60,000 square feet for the fueling lanes and support buildings. This implies a ratio of approximately 6,000 square feet per fueling lane and allows for the turning areas required for a semi-tractor with a connected trailer. At 6,000 square feet of land per fueling lane, providing simultaneous charging for 3,200 to 4,400 battery-electric trucks would require 480 to 660 acres of land. Space requirements could be greater or less than this rough estimate, but until large public access charging stations for heavy duty trucks are demonstrated, it is not possible to accurately gauge the true space requirements. At a minimum, the space requirements will be significant and have yet to be identified, making the construction of sufficient public access charging infrastructure to serve a fully electrified drayage fleet over the next three years effectively impossible.

Table 21 summarizes the implied energy throughput in gigawatt hours (GWh) at the on-site and public stations that would be required for a drayage fleet of two sizes (14,000 trucks and 19,000 trucks). Note that these calculations reflect the 2.1 kWh/mile assumed energy consumption rate of the truck and an 85 percent wall outlet-to-wheels efficiency.[123]

Table 21. EV charging infrastructure: required throughput estimates

Fueling Station Type / Location	14,000 Truck Fleet	19,000 Truck Fleet
On-site Stations		
Trucks Served	3,640	4,940
Daily Energy Throughput	2.27 GWh	3.62 GWh
Public Stations		
Trucks Served	10,360	14,060
Daily Energy Throughput	6.45 GWh	10.30 GWh
Total Daily Energy Throughput	**8.72 GWh**	**13.92 GWh**

8.3.2. Infrastructure Buildout

Much of the daily energy requirements for the drayage fleet would be supplied overnight, with some trucks operating only single shifts and having as much as 14-16 hours available for charging. Based on the weighted average charging rate of 177 kW required for the fleet, it is estimated that total power demand could peak at 2.5 gigawatts (GW) regionally for a 14,000-truck fleet and 3.4 GW for a 19,000-truck fleet. While this is clearly a substantial new electrical load, it only represents about four to 10 percent of the combined peak load of 30 GW in the LADWP and SCE territories (see Table 22). Additionally, because much of this load is likely to occur predominantly during off-peak periods, EV charging can serve to level the overall demand curves for each utility and potentially reduce costs across the system. Despite these benefits and the relatively small increase in region-wide aggregate load represented by a potential electric drayage fleet, it must also be recognized that these loads would be concentrated in regions where trucks currently park and would create more acute utility infrastructure challenges than if they were spread across utility service territories.

Table 22. Relative sizes of SCE and LADWP utilities

Size Indicator	Southern California Edison[124]	Los Angeles Department of Water and Power[125]
Service Territory (mi^2)	50,000	464
Service Population (ppl)	15,000,000	1,500,000
2020 retail sales (MWh)	85,399,000	21,130,000
2020 peak load (MW)	23,133	6,502[126]
2020 Capital Projects Budget ($)	5,536,000,000[127]	1,600,000,000[128]

Interviews with staff from SCE (in 2018 and 2021) and LADWP (in 2018) reveal that there is a high level of confidence that the five-year load forecast at the Ports can be met by their respective existing electricity supply systems. This Assessment does not include new loads for battery-electric truck charging, because neither utility is currently able to forecast where and when drayage trucks might charge. It is clear that some trucks are domiciled near the Ports and may benefit from grid

[123] Wall-to-wheels efficiency based on California Air Resources Board, "Analyses Supporting the Addition or Revision of Energy Economy Ratio Values for the Proposed Low Carbon Fuel Standard Amendments," Appendix H to the Initial Statement of Reasons, March 2018, https://www.arb.ca.gov/regact/2018/lcfs18/apph.pdf.

[124] Edison International, "Edison International and Southern California Edison 2020 Annual Report", 2021, https://www.edison.com/content/dam/eix/documents/investors/sec-filings-financials/2020-eix-sce-annual-report.pdf.

[125] Los Angeles Department of Water & Power, "Briefing Book: 2019-2020", https://www.ladwp.com/cs/idcplg?IdcService=GET_FILE&dDocName=OPLADWPCCB629209&RevisionSelectionMethod=LatestReleased.

[126] This peak was set in 2017. Peak demand reductions since 2017 have slightly reduced this figure in 2020 but specific values were not readily available.

[127] SCE reported this amount in capital expenditures for 2020.

[128] LADWP reported this amount of its budget dedicated to capital projects.

improvements made to support growing port electrical loads. However, many trucks are domiciled well outside SPBP boundaries, and will require infrastructure improvements throughout the respective service territories of the two utilities. Both utilities are implementing programs to develop charging stations suited for heavy-duty trucks in their service territories, although such programs are in varying stages of implementation. There is significant uncertainty over how rapidly new charging stations and subsequent EV charging loads will be deployed, given the highly innovative and relatively nascent state of this market. Similar limitations on technical certainty prevent each utility from developing a long-term infrastructure plan for a fully electrified port system. Specific knowledge gaps facing the utilities include drayage truck battery capacities and charging rates; truck charging times and locations; charging equipment interface standards and exceptions; and timelines for scaled-up EV deployments.

While both utilities are engaged in supporting the growth of the heavy-duty EV truck market, some context is warranted for the scale of charging infrastructure development needed to support the drayage fleet. Tesla's current U.S. Supercharger network for light-duty cars consists of 1,219 sites and 12,320 charging stalls.[129] At a peak power of approximately 924 MW[130], the entire Tesla Supercharger network is substantially smaller than the estimated charging infrastructure required to fully electrify the port drayage fleet. This level of development is likely to strain or wholly exceed the capabilities of existing DC fast charger suppliers and the associated supply chain of designers, installers, and maintenance support staff in the region. While electrical infrastructure development could occur by 2024 to support a meaningful number of Class 8 battery-electric trucks, it does not appear practicable to perform the level of buildout needed to electrify a majority of the SPBP drayage fleet by 2024.

8.3.3. Codes and Standards

EV charging infrastructure has developed rapidly over the last decade as multiple light-, medium-, and heavy-duty vehicles have come to market. In the U.S., there are multiple charging interfaces and standards in use; the following summarizes those that are most relevant to drayage trucks and this 2021 Assessment.

- **Combined Charging System (CCS)** – In the U.S., the CCS Type 1 connector is commonly used on U.S. and German auto manufacturers' vehicles and on various heavy-duty trucks and buses. For example, early commercial battery-electric trucks from Daimler and Volvo use CCS1 connectors for fast charging. Rates of 50-150 kW are common for light-duty vehicles, but the CCS standard supports charging rates greater than 350 kW. These higher power rates may require the use of liquid-cooled cables. Additionally, the standard contains specifications for overhead (catenary) charging interfaces, but these interfaces are currently only being applied to transit buses in the U.S. The CCS standard is compatible with emerging charging protocols with higher charging rates (more than 1 MW) that are intended to support BEVs in heavy-duty trucking and similar applications (see below). Notably, challenges remain regarding interoperability, due to significant differences that remain among CCS chargers from various EVSE manufacturers. This can result in the need for OEMs to develop new calibrations and reflash control modules to enable their battery-electric trucks to use a new charger, even though it meets the CCS standard.
- **CharIN Megawatt Charging System (MCS) standard** – This under-development "megacharger" protocol and system is specifically focused on charging Class 6-8 battery-electric commercial vehicles with large battery packs able to accept charging rates above 1 MW.[131] In fact, the target is to charge Class 6-8 battery-electric trucks with 200-600 kWh batteries within "20-30 minutes," requiring power levels over 2 MW.[132] The standard is intended to support charging at up to 3.75 MW (1,250V and 3000A). In a government-industry collaborative effort, the MCS system/standard/hardware have been tested on a preliminary basis at the National Renewable Energy Laboratory (NREL).[133] If commercialized as expected, the

[129] Alternative Fuels Data Center Station Locator, http://www.afdc.energy.gov/stations
[130] Tesla operates multiple generations of chargers, at up to 250 kW. Power is typically shared between two stalls. For this example, the average power level per stall is assumed to be 75 kW.
[131] Society of Automotive Engineers, "Mega push for heavy-duty EV charging," May 27, 2021, https://www.sae.org/news/2021/05/megawatt-charging-for-electric-trucks.
[132] CharIn, Presentation to the International Transport Forum, February 2020. https://www.itf-oecd.org/sites/default/files/docs/charging-infrastructure-standardisation-developments-bracklo.pdf
[133] CharIn, Retrieved February 2022. https://www.charin.global/technology/mcs/ .

MCS standard will offer a much faster charging time for Class 8 battery-electric trucks compared to the incumbent CCS system.

- **Tesla Megacharger System** – Tesla is one of the founding members of the CharIN MCS working group and is developing its "Megacharger" system with the intent of being consistent with the under-development MCS standard. It is anticipated that Tesla and other equipment manufacturers will produce equipment based on the MCS standard prior to its finalization, allowing them to support near-term truck deployments. Long term, Tesla is not expected to produce a proprietary Megacharger system that does not comply with the MCS standard.
- **Conductive Automated Connection Devices (Society of Automotive Engineers J3105)** – J3105 is a recommended practice for conductively charging BEVs using automated connection devices (ACD). Various types of connections can be used with this interface (e.g., cross-rail, pantograph, pin and socket). This charging protocol/interface has primarily been applied for battery-electric transit buses, but it also includes configurations used for "non-standard applications" such as port cargo-handling equipment.[134]
- **Wireless Power Transfer (Society of Automotive Engineers J2954/2)** – J2954 defines wireless power transfer standards for light-, medium-, and heavy-duty vehicles. Also called "inductive charging," wireless power transfer allows vehicles equipped with "receiving" modules to collect power from a transmitter coil that is typically embedded in a parking stall or road surface. The currently approved J2954 standard applies to light-duty vehicles at charging rates up to 22 kW. J2954/2, which is currently under development, extends the standard to medium-/heavy-duty vehicles and increases power levels up to 500 kW.[135]
- **Proprietary AC/On-board Charging** – Some heavy-duty vehicle OEMs integrate battery charging power electronics onboard the vehicle. This allows the vehicle to accept standard AC utility power – typically as 240V single phase or 208-480V three phase power. The external "charging" equipment is technically electric vehicle supply equipment (EVSE) that acts primarily to safely connect, monitor, and disconnect the AC power from the vehicle. Because the power electronics are incorporated into the vehicle, the external EVSE can be significantly less expensive than comparable DC fast chargers. Typically, it is proprietary to a specific vehicle manufacturer. This type of charging solution is largely being phased out for second- and third-generation battery-electric vehicle models.

Of these various charging standards, the existing CCS standard and the developing compatible version for megacharging (MCS standard) appear to be emerging as the dominant standards in the HDV space. However, even within the established CCS standard, ongoing revisions may be needed to increase charging voltages, allow for a range of charging rates, and implement various features defined in other charging standards like ISO 15118. This means that battery-electric truck operators may encounter significantly variable charging performance at stations, even if those stations support the same charging standard employed by the truck. As charging voltages increase over time to support higher power levels, older vehicles will likely find that they cannot take advantage of these higher charging rates. However, the landscape for heavy-duty EV charging infrastructure is rapidly maturing. CCS, and the Mega Charging Standard (MCS) that is effectively the next generation of CCS designed for heavy-duty vehicles, will likely be the standard around which the industry consolidates.

The existence of codes and standards for electric charging infrastructure do not guarantee that local authorities will not impose additional permitting requirements that can create significant barriers to infrastructure development. Local requirements can include limitations on grid interconnection voltages, fault current ratings, land use restrictions, extended plan reviews, lengthy utility timelines to energize equipment, etc. The diversity of charging equipment and associated power levels can further add complexity to the permitting process, as local authorities may have experience with light-duty charging infrastructure but not with heavy-duty charging infrastructure. While these issues will ultimately be addressed as local authorities and infrastructure developers gain experience, early infrastructure projects will undoubtedly require more time to permit than later projects, slowing the pace to develop infrastructure in the near term.

---

[134] Society of Automotive Engineers, "Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices Infrastructure-Mounted Pantograph (Cross-Rail) Connection J3105/1_202001," January 20, 2020, https://www.sae.org/standards/content/j3105/1_202001/?src=j3105_202001.

[135] https://www.sae.org/standards/content/j2954/2/

8.4. Application of Criteria to Natural Gas Fueling Infrastructure

CNG fueling infrastructure can be configured for time-fill or fast-fill fueling rates. Public access fueling stations are configured for fast-fill dispensing, similar to diesel fuel stations, with dispensing rates of 10 DGE/minute being readily achievable. Private stations may be configured as either time-fill or fast-fill, depending on the fleet and site requirements. In a time-fill configuration, multiple trucks are connected to a single fuel compressor and filled slowly over the course of several hours. In this configuration, CNG fueling is analogous to overnight charging of EVs. Time-fill solutions are generally a less expensive fueling strategy for fleets than fast-fill stations because the slower fill rate over a longer period of time allows for the use of smaller compressors and reduced station energy consumption. Time-fill stations may also be equipped with a priority hose that allows the full output of the compressors to be directed to a single hose. In this use case, fueling for other trucks is suspended while the priority hose acts as a fast-fill dispenser.

8.4.1. Station Location and Footprint

An estimate of the fraction of trucks that could be served by on-site fueling infrastructure was made using rough estimates of the typical footprint of a CNG compression system. For each response to the 2021 Drayage Truck Operator survey, an estimate of the average fuel flow rate was determined based on the average daily mileage and number of shifts reported. These flow rates were translated into space requirements based on an assumed footprint of 16 feet by 50 feet for an 800 SCFM CNG compression system. The resulting space requirement was then compared to the respondent's estimated available space for fueling infrastructure. Sixty percent of respondents indicated that less than 500 square feet was available for fueling infrastructure (the lowest option offered in the survey) and are assumed to be too space constrained to accommodate fueling infrastructure on-site. The results of this analysis indicate that approximately 52 percent of trucks that park on-site could be fueled with CNG on-site. Combining this result with the estimated 50 percent of all surveyed trucks that park on-site implies that approximately 26 percent of the fleet could be served by on-site, time-fill fueling.

Notably, these are very rough estimates and each site's conditions are unique. Parameters that affect viability of fueling infrastructure include availability and capacity of utility supplies, facility layout and traffic patterns, property setback requirements, overhead power lines, and other issues. The true potential for on-site fueling could be greater or less than the estimate made here.

Assuming that 26 percent of trucks could be fueled on-site, the remaining 74 percent of trucks would require public access fast-fill stations. Table 23 summarizes the implied fuel throughput of the on-site and public stations that would be required for a 14,000-truck and a 19,000-truck drayage fleet.

Table 23. CNG fueling infrastructure: required throughput estimates

Station Type	Fueling Parameter	14,000 Truck Fleet	19,000 Truck Fleet
On-Site	No. of Trucks Served	3,640	4,940
	Daily Fuel Throughput	158,100 DGE	214,600 DGE
Public	No. of Trucks Served	10,360	14,060
	Daily Fuel Throughput	319,800 DGE	610,800 DGE
Total Daily Fuel Throughput		**477,900 DGE**	**825,400 DGE**

8.4.2. Infrastructure Buildout

The range of daily fuel throughput for the public stations is estimated at 319,800 to 610,800 DGE. As a point of comparison, Clean Energy's existing LNG and CNG (LCNG) fueling station at 3400 E I St in Wilmington is currently equipped with 50,000 gallons of LNG (23,400 DGE) fuel storage. Fuel storage at this station can be increased to 100,000 LNG gallons (35,200 DGE), and the current six fueling lanes can be expanded to ten lanes. This site can dispense LNG to a truck as either LNG or CNG (LCNG station). Assuming one full turnover of the LNG storage tanks per day, it would require between 9 and 17 similar stations to meet the estimated public fueling demand. To build this out by 2024, this would imply a construction rate of 3-6 large public access stations per year. Additionally, CNG stations supplied by utility pipeline could be constructed in lieu of LCNG stations or as complements to LCNG station development.

There are currently 10 LNG fueling stations and 64 CNG fueling stations within the Southern California region (approximately 100 miles of the Ports).[136] The combined spare capacity of these stations has not been analyzed, but it is expected that substantial unused CNG and LNG dispensing capacity is available to support some growth of a natural gas drayage fleet before additional infrastructure is required. The estimated total fleet need for 9 to 17 large LCNG stations or an equivalent combination of LCNG and pipeline CNG stations is not unreasonable. Further, if fleets do not construct on-site fueling at the rate needed to support 26 percent of trucks, additional public fueling stations would be required. It is anticipated that fuel suppliers would step in to construct this level of fueling infrastructure if there is clear demand in the market. However, this scale of geographically concentrated natural gas fueling infrastructure development (more than 500,000 DGE per day of fueling capacity) has not been achieved anywhere in the U.S. over a three-year timeframe. While station design and construction for a single station could be completed in a six to twelve-month timeframe, numerous factors may extend station construction timelines. These factors include site selection, permitting challenges, utility improvements, and equipment lead times. Clean Energy notes that it was able to construct 70 LNG stations in a 12-month period, as part of its America's Natural Gas Highway program. The company has high confidence that it and other natural gas fuel providers could develop sufficient infrastructure in the three-year period considered in this Assessment.

Since the 2018 Assessment, several natural gas fuel station operators have communicated to the Ports a strong willingness and readiness to construct fueling stations at pace with the deployment of natural gas truck orders and deliveries. While it is not possible to be certain that station development could occur at a pace to match a full transition of the drayage fleet to natural gas over three years, it is reasonable to assume that sufficient station deployments could occur to support a majority of drayage trucks by 2024.

8.4.3. Codes and Standards

CNG vehicles are regulated by well-defined codes and standards that define tank pressures, connector types, and safety systems. All modern heavy-duty trucks and CNG fueling stations in the U.S. are built to these standards, allowing for essentially universal interoperability between fueling stations and trucks. Older stations may be equipped with lower flow nozzles (NGV-1) rather than the heavy-duty nozzles (NGV-2) that are provided with modern heavy-duty stations. Additionally, some older stations offer 3,000 psi fueling pressures, rather than the industry standard of 3,600 psi. This does not necessarily prevent a new truck from fueling at an older station, but the truck may experience partial fills and/or extended fueling times. For the purposes of this analysis, it is assumed that all new fueling infrastructure would be developed with the intent to supply heavy-duty trucks and would therefore support high flow nozzles and 3,600 psi nominal fueling pressures, as is the current industry standard practice.

It is also important to note that, while codes and standards exist for natural gas fueling infrastructure, the permitting requirements imposed by local authorities can create significant barriers to infrastructure development. These requirements vary by jurisdiction and permitting entity. Where a local authority is unfamiliar with natural gas fueling stations, time may be required to educate the local authority regarding the appropriate codes and standards of practice before a permit can be secured. Additionally, local authorities may require that some equipment be listed by a particular listing entity while the equipment is listed by an alternative agency. Listing equipment with a new agency is a time consuming and costly process that can significantly delay or terminate a project.

These are only some of the potential barriers that may be encountered in the permitting process. Many municipalities now have examples of operational natural gas fueling stations in their jurisdiction and this facilitates permitting of additional stations. However, projects that have unique attributes (portable/temporary stations, proximity to certain activities/facilities, etc.) can face unique permitting challenges that extend timelines and add costs.

[136] Alternative Fuels Data Center Station Locator, http://www.afdc.energy.gov/stations. Limited to stations with heavy-duty vehicle access.

8.5. Additional References for Assessing Infrastructure Availability

North American Council on Freight Efficiency (NACFE) – As previously noted, in 2018 NACFE[137] identified several "hot button" issues specifically related to building out charging infrastructure for heavy-duty battery-electric trucks. Table 24 summarizes each infrastructure-related issue, and NACFE's key associated findings. While NACFE identified these infrastructure-related issues in 2018, they remain generally relevant today.

Table 24. "Hot button" infrastructure-specific issues identified by NACFE for battery-electric trucks

Issue Topic	Summary of NACFE's Infrastructure-Related Findings (Relevant to Class 8 Drayage)
Affordable Access to Charging Infrastructure	Off-shift charging of vehicles is possible today with existing systems. Commercial battery-electric trucks need fast charging speeds (sub 30-minute), which requires high capacity production charging systems that are only in a "conceptual phase" today. While "high speed systems are thought feasible by a range of experts," their "practicality is still a question."
Speed of Charging	Charging speeds depend on each fleet's duty cycles, as well as specific route scheduling. While many operations have defined cycles that permit off-cycle daily charging, Class 8 fleets that require sub-30 minute charging may not yet be able to find "practical commercial vehicle capable charging technology."
Grid Readiness for Large-Scale Charging	Major market penetration for commercial battery-electric trucks will be on "a decades time scale." The U.S. has energy production capacity for significant volumes of electric cars and trucks. Adding vehicle charging stations to a warehouse or factory is like adding a new line, a process utilities regularly perform for commercial sites. High rate charging expected for any sub-30 minute charging of commercial vehicles, does create a significant demand on the grid. Alternatives to mitigate this through leveling and storage systems are being considered.
Source: Summarized (by the authors) from Section 31 of referenced NACFE report.	

As indicated in the table, the NACFE study concluded that charging infrastructure for Class 8 battery-electric trucks will need to be built-out on a "decades scale." However, NACFE also concluded that "new business opportunities" could spur utilities and third parties to significantly accelerate that timeline with a focus on building charging stations for use at factories and warehouses. NACFE noted that the lack of current infrastructure for heavy-duty battery-electric trucks is actually "an opportunity for market growth," when considering synergy with vehicle development:

> *"Infrastructure generally always follows product innovation. New technologies spawn development of improved infrastructure. That development encourages product market penetration, a recurring cycle seen in many new technologies."*[138]

2018 UC Davis Report on Battery-Electric and Fuel Cell Technologies - In October 2018, researchers from the Institute of Transportation Studies at the University of California, Davis released a report titled "A Comparison of Zero-Emission Highway Trucking Technologies."[139] This report provided a detailed review of the "challenges and costs" – related to both vehicles and infrastructure – associated with three ZE fuel-technology platforms for long-haul trucking: 1) battery-electric with "dynamic

---

[137] North American Council for Freight Efficiency, "Guidance Report: Electric Trucks – Where They Make Sense", May 2018, obtained directly from NACFE (available online at https://nacfe.org/report-library/guidance-reports/).
[138] North American Council for Freight Efficiency, "Guidance Report: Electric Truck – Where they Make Sense", 2018, page 100.
[139] Zhao, Hengbing, PhD; Wang, Qian; Fulton, Lewis, PhD; Jaller, Miguel, PhD; Burke, Andrew, PhD; University of California, Davis, "A Comparison of Zero-Emission Highway Trucking Technologies," October 2018, https://escholarship.org/uc/item/1584b5z9.

inductive charging"; 2) catenary electric; and 3) hydrogen fuel cell. LE technologies (natural gas or propane ICE) were not included in this assessment.

The study was specifically focused on long-haul Class 8 trucks with daily driving ranges and trip distances well in exceedance of the norm for drayage trucking. Still, many of the key findings and conclusions from this 2018 study address challenges with – and remain relevant to – building out new charging or fueling infrastructure for Class 8 drayage trucking. These include the following:

- There are "significant infrastructure challenges" associated with building out charging/fueling infrastructure for battery-electric, grid-electric, and hydrogen fuel cell HDVs.
- It would take "massive investments" to build the "truck accessible hydrogen stations and highway electric charging infrastructure" that would be needed to implement a regional ZE trucking corridor.
- "At this time, it is difficult to fully assess the cost of fueling and charging infrastructure for the zero-emission long-haul trucking technologies. Better estimates of the cost of the infrastructure and how this scales will be possible after more and larger demonstrations of the technologies are completed."[140]
- "In the near-to-mid-term, electrifying an entire state or regional highway system or deploying large hydrogen stations at many truck stops would require very large investments even though there could initially be few zero-emission long-haul trucks in use. Low utilization would make it very difficult to justify the high investment costs."[141]

8.6. Major California Initiatives to Build Out ZE Truck Charging/Fueling Infrastructure

State and local agencies, energy/fuel providers, and the two Ports are collectively taking action to build-out charging/fueling infrastructure for the initial ZE heavy-duty HDVs that serve (or will serve) SPBP drayage operations. Much of this has occurred since preparation and release of the 2018 Assessment.

Examples of key projects and initiatives to build out infrastructure for ZE HDVs serving the two Ports include the following:

- Under the previously described CARB ZANZEFF grant, the Port of Los Angeles is spearheading build-out of hydrogen fueling infrastructure for the "Shore to Store" project. Two hydrogen fueling stations have been built to serve the aforementioned 10 Kenworth T680 Class 8 fuel cell electric trucks. The hydrogen station in Wilmington will be completed and commissioned in early 2022; a second station in Ontario is complete and began operation in mid-2021. These stations serve as the primary hydrogen fueling stations fuel cell trucks performing drayage at the SPBP; 12-month technology demonstrations began in May 2021.[142]

- CEC is spearheading infrastructure build-out initiatives that complement CARB's vehicle-focused deployment efforts. For example, in late-2021 CEC approved a three-year $1.4 billion 2021–2023 Investment Plan Update, which "prioritizes medium- and heavy-duty infrastructure." This includes $690 million to fund charging/fueling stations for "1,150 zero-emission drayage trucks," as well as funds that support "in-state ZEV manufacturing, workforce training and development, and near- and zero-emission fuel production." The funds will become available in the 2022-2023 timeframe, and "distributed to projects through a mix of competitive funding solicitations and direct funding agreements."[143] Notably, the targeted number of ZE drayage trucks (1,150) for supporting with new infrastructure aligns well with Project 800 initiative led by CARB, which seeks to rollout 1000+ ZE drayage trucks using HVIP and other state-funded grant funds (refer back to Section 5).

[140] *Ibid*, page 42.
[141] *Ibid*, page 42-43.
[142] South Coast Air Quality Management District, "Shore to Store FCET," presentation by Lisa Mirisola to Clean Fuels Advisory Committee, February 10, 2022.
[143] California Energy Commission, "CEC Approves $1.4 Billion Plan for Zero-Emission Transportation Infrastructure and Manufacturing," news release, November 15, 2021, https://www.energy.ca.gov/news/2021-11/cec-approves-14-billion-plan-zero-emission-transportation-infrastructure-and.

Other examples of efforts to expand charging/fueling infrastructure for heavy-duty ZE trucks include the following (also see Section 12: Appendix B – Relevant Incentive Programs):

- California's Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program) provides incentive funding for "cleaner-than-required engines, equipment and other sources of pollution providing early or extra emission reductions." A new feature since the 2018 Assessment is that the Moyer Program can now fund non-residential electric vehicle charging stations (new stations, or conversion/expansion of existing stations). This includes DC fast chargers "along freeway roadway corridors" and at "destination centers" where conventional diesel SPBP drayage trucks routinely operate and fuel.[144]
- South Coast AQMD's Clean Fuels Program, which has been providing funds for heavy-duty ZE infrastructure for several years (e.g., the Daimler Trucks Innovation fleet and the Volvo LIGHTS program), continues to "prioritize" battery-electric and hydrogen fuel cell infrastructure in its 2022 Plan Update. Proposed projects include "large deployment projects" of battery-electric trucks and infrastructure, "microgrid demonstrations" to support large ZE truck deployment projects, and support of "advanced high power quick charge infrastructure" for battery-electric trucks. More than 50 percent of South Coast AQMD $24 million 2022 budget is allocated toward these types of infrastructure projects to support ZE HDVs, including drayage trucks.[145]
- EnergIIZE (Energy Infrastructure Incentives for Zero- Emission Commercial Vehicles) is the "nation's first commercial vehicle fleet infrastructure incentive project." Funded by CEC and implemented by CALSTART, EnergIIZE provides incentives for charging/fueling infrastructure for medium- and heavy-duty battery-electric and hydrogen fuel cell vehicles that are operated and domiciled in California. EnergIIZE includes a "Funding Finder Tool" (https://fundingfindertool.org/?) that helps fleets and other stakeholders search for incentive funding programs based on location (zip code), fleet type, type of ZE HDV (battery electric or fuel cell electric), and other parameters.[146]
- CEC and CALSTART have also teamed with the Electric Power Research Institute and other public-private partners to implement the Research Hub for Electric Technologies in Truck Applications (RHETTA). This "grant opportunity" program is focused on the developing, advancing, and deploying "innovative high-power charging infrastructure along key freight corridors that promote the adoption of Class 7 and 8 battery electric zero-emission (ZE) trucks." Phase 1 of this program goes from 2021 to 2025.[147]
- Southern California Edison (SCE) is implementing a five-year $356 million Charge Ready Transport Program. SCE has received approval from the California Public Utilities Commission to install electric infrastructure at customer sites to support charging of battery-electric vehicles, including heavy-duty drayage trucks. The program also allows SCE to offer rebates to customers for the purchase of charging stations. For fleets operating in SCE's business territory – which includes MTOs at the Port of Long Beach – Charge Ready Transport helps them electrify their fleet by guiding them "through every step of the process . . . including installing the infrastructure you need to support your fleet at low or no cost" to the fleet. An overview of Charge Ready Transport is available at https://www.sce.com/evbusiness/overview, with details at https://crt.sce.com/program-details.[148]
- Los Angeles Department of Water & Power (LADWP) offers infrastructure funding to support charging of battery-electric vehicles (including heavy-duty trucks) for its customers. This includes a "Commercial EV Charging Station Rebate program" that opened on November 19, 2021. This program includes funding for eligible fleets to install Level

[144]California Air Resources Board, Carl Moyer Memorial Air Quality Standards Attainment Program 2017 Guidelines," https://ww3.arb.ca.gov/msprog/moyer/guidelines/2017gl/2017_gl_chapter_10.pdf.
[145] South Coast Air Quality Management District, presentation by Joseph Impullitti to South Coast AQMD Clean Fuels Advisory Group, September 15, 2021.
[146] "EnergIIZE Factsheet," revised December 2021, https://www.energiize.org/.
[147] Electric Power Research Institute, presentation by Mark Duvall to South Coast AQMD Clean Fuels Advisory Group, September 15, 2021.
[148] Southern California Edison, "Energy for What's Ahead," presentation prepared by Aaron R. Dyer (Senior Project Manager for eMobility), for the 2022 AQMD Advisory Group Meeting (Mobile Source Working Group Meeting #2 – Zero Emission Infrastructure, February 4, 2022.

2 and DC Fast Charger stations. Various other types of support are provided to assist fleets with planning, installing and permitting commercial EV charging stations.[149]

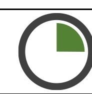
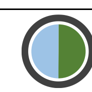
- Southern California Gas Company is proposing to develop "the nation's largest green hydrogen energy infrastructure system ... to deliver clean, reliable energy to the Los Angeles region." As initially discussed, this "Angeles Link" program will help supply heavy-duty trucks with renewable hydrogen, to be produced by converting "up to four natural gas power plants to green hydrogen." Additional information is provided at Angeles Link | SoCalGas.

8.7. Summary of Findings for Infrastructure Availability

Table 25 summarizes whether, according to the specific criteria and base considerations outlined above, the two commercially available ZE or LE drayage truck platforms have sufficient "infrastructure availability" as of late 2021. In the final column of the table, snapshot ratings are provided about the degree to which they already meet these basic considerations today, or at least are showing measurable progress towards achieving them by the end of 2024.

Following the table, further discussion is provided about 1) the rationale used to assign the ratings in the table, and 2) the broad implications to the overall 2021 Drayage Truck Feasibility Assessment.

Table 25. Summary of ratings by key criteria: 2021 Infrastructure Availability

Infrastructure Criteria/Parameter	Base Considerations for Assessing Infrastructure Availability	Achievement of Criteria for Remaining Drayage Truck Platforms	
		ZE Battery-Electric	LE NG ICE
Dwell Time at Station	Fueling/Charging can be accommodated within typical work breaks, lunches, other downtime compatible with trucking company schedules and operational needs.		
Station Location and Footprint	Fleets have existing onsite access to fueling infrastructure, or can be fueled/charged conveniently and affordably off site, at public or private stations. New infrastructure can be installed without extensive redesign, reconfiguration or operational disruptions and there is sufficient electrical or natural gas capacity at the site.		
Infrastructure Buildout	Infrastructure can be constructed at a pace consistent with fleet adoption and able to meet fleet fueling/charging requirements by the end of the assessment period.		
Existence of/Compatibility with Standards	A sufficient body of codes and standards exist from appropriate organizations that enables safe and effective refueling/recharging. The refueling/recharging station technology has already been installed at other trucking companies in the U.S., with sufficient time to assess performance and safety.		

Legend: **Infrastructure Availability (2021)**

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

Source: based on preliminary OEM survey responses, OEM product information, various government sources, and Tetra Tech team's industry knowledge.

ZE Battery-Electric – The key advancement for battery-electric charging infrastructure since the 2018 Assessment has been emergence of the Combined Charging Standard (CCS) as the leading charging standard in the heavy-duty vehicle space,

[149] Los Angeles Department of Water & Power, "Electric Vehicles," https://www.ladwp.com/ladwp/faces/ladwp/residential/r-gogreen/r-gg-driveelectric?_adf.ctrl-state=w9lmjlkdp_17&_afrLoop=998089180844563.

although CCS has challenges that are still to be resolved. This and other advancements have significantly improved the "Existence of / Compatibility with Standards" parameter in the table above. Notably, even within the CCS standard, battery-electric truck operators may encounter significantly variable charging performance at stations, even if those stations support the same charging standard employed by the truck. While codes and standards for electric charging infrastructure are normalizing, local authorities may still impose additional permitting requirements due to relative unfamiliarity with the technology (especially with regard to stations specifically designed to charge HDVs). This could create significant barriers to infrastructure development. While these issues will ultimately be addressed as local authorities and infrastructure developers gain experience, early infrastructure projects will undoubtedly require more time to permit than latter projects, slowing the pace of infrastructure development in the near-term.

The parameters of "Station Location and Footprint" and "Infrastructure Buildout" have not significantly changed since the 2018 Assessment, although important efforts are underway. Both utilities are implementing programs to develop charging stations suited for heavy-duty trucks in their service territories; such programs are in varying stages of implementation. Not surprisingly given the highly innovative and relatively nascent state of this market, significant uncertainty remains about how rapidly new charging stations and subsequent EV charging loads will be deployed. Similar limitations on technical certainty prevent each utility from developing a long-term infrastructure plan for a fully electrified port system. Specific knowledge gaps that slow the pace for locating and building stations include drayage truck battery capacities and charging rates; truck charging times and locations; charging equipment interface standards and exceptions; and timelines for scaled-up EV deployments.

Where overnight charging is possible, station dwell times are largely a non-issue as drivers are not required to be present during the charging process. However, it is very likely that public access charging infrastructure will be needed to support fleets that do not have appropriate locations to support overnight charging for trucks. To date, no example of a commercial public access charging station for heavy-duty trucks exists in the U.S., leaving open many questions about the feasibility of such an approach.

The scope of an infrastructure build-out to charge a fully electrified drayage fleet is substantial. It does not appear to have any U.S. parallel with regard to the size, capacity, and speed of build-out that will be needed to deploy such a charging network. As described in a mid-2021 Port of Long Beach report focused on this specific topic, building public charging stations for battery-electric trucks currently entails a "poor business case." Moreover, building such a charging network may be premature because truck OEMs are "not yet designing" their battery-electric trucks for faster charging rates that are beginning to become available.[150] Clearly, this situation is dynamic, and some companies are working hard to prove-out the business model of rapidly building public charging stations that can serve Class 8 battery-electric trucks in Southern California. However, it remains uncertain if there will be sufficient will and/or investment to build-out the full extent of the charging infrastructure needed to serve the drayage fleet. Given these current uncertainties and challenges, it appears highly unlikely (if not impossible) that a full-scale drayage-focused charging infrastructure could be built out by 2024.

LE Natural Gas ICE – Drayage trucks powered by natural gas ICE technology are farthest along the path of "infrastructure availability." There are currently 10 LNG fueling stations and 64 CNG fueling stations in the Southern California region (within approximately 100 miles of the Ports). It is expected that substantial unused CNG and LNG dispensing capacity is available to support initial growth as needed for an expanding natural gas drayage fleet. While additional public fueling stations may be required, it is anticipated that fuel suppliers would step in to construct this level of fueling infrastructure, provided there is clear market demand. Several natural gas fuel station operators have communicated strong willingness and readiness to construct fueling stations at pace with deployment of LE natural gas drayage trucks. While it is not possible to be certain that station development could occur at a pace to match a full transition of the drayage fleet to natural gas over three years, it is reasonable to assume that sufficient station deployments could occur to support a majority of drayage trucks by 2024.

[150] Port of Long Beach, "Fueling the Future Fleet: Assessment of Public Truck Charging and Fueling Near the Port of Long Beach," prepared by Starcrest Consulting Group, LLC, September 2021, downloaded at https://polb.com/environment/our-zero-emissions-future/#program-details.

NOTE: For subsequent feasibility assessments (i.e., beyond this 2021 Assessment) the ports may not require or perform in-depth analysis of conventional heavy-duty natural gas ICE trucks. Class 8 tractors using this fuel-technology platform have achieved near-complete overall feasibility across the full range of drayage applications at the San Pedro Bay Ports. Moreover, CARB's two tandem regulatory actions – the adopted ACT and the proposed ACF regulations – are moving new on-road heavy-duty trucks in California towards electric-drive architectures that provide at least partial operation with zero emissions. However, it is possible (if not probable) that one or more OEMs will develop and commercialize truck architectures that use low-emitting heavy-duty natural gas engines hybridized with plug-in electric drive systems that *achieve a prescribed amount of all-electric range*. Through adoption of the ACT regulation, CARB has created general motivation for OEMs to pursue this general pathway. Specifically, ACT provides flexibility for OEMs to shift sales between weight classes, bank and trade credits, earn early credits, and meet part of their compliance obligation by selling trucks that meet this basic "NZE" definition.[151] The Ports will be ready to assess such Class 8 truck architectures for feasibility, if and when they emerge as pre- or early commercial products that are compliant with CARB regulations and allowed entry into drayage service in California.

[151] See CARB's "Final Regulation Order: Advanced Clean Trucks Regulation," https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks.

9. Assessment of Economic Workability

9.1. Criteria and Methodology

This subsection compares the capital costs (CapEx) and operational costs (OpEx) associated with purchasing and deploying ZE or LE platforms as compared to baseline diesel costs. This includes the costs of installing and maintaining specialized fueling infrastructure. It considers the availability of government incentives to buy down the capital costs of vehicles, equipment, and fueling infrastructure.

The key parameters and base considerations that were collectively used to assess economic considerations and issues are listed in the table below.

Table 26. Criteria for assessing Economic Workability for emerging drayage truck platforms

Economic-Related Criteria / Issue	Base Considerations for Assessing General Economic Workability
Incremental Vehicle Cost	The upfront capital cost for the new technology is affordable to end users, compared to the diesel baseline.
Fuel and Other Operational Costs	The cost of fuel / energy for the new technology is affordable, on an energy-equivalent basis (taking into account vehicle efficiency). Demand charges / TOU charges (if any) are understood and affordable. Net operational costs help provide an overall attractive cost of ownership.
Infrastructure Capital and Operational Costs	Infrastructure-related capital and operational costs (if any) are affordable for end users.
Potential Economic or Workforce Impacts to Make Transition	There are no known major negative economic and/or workforce impacts that could potentially result from transitioning to the new equipment.
Existence and Sustainability of Financing to Improve Cost of Ownership	Financing mechanisms, including incentives, are in place to help end users with incremental vehicle costs and/or new infrastructure-related costs, and are likely remain available over the next several years.
Source: Based on criteria in San Pedro Bay Ports' "Framework for Developing Feasibility Assessments", November 2017.	

Cost comparisons between baseline diesel trucks and alternative low emission technologies are made on a TCO basis using the average operating assumptions shown in Table 27. The results of this analysis are presented and discussed following a presentation of the major cost elements in the TCO model.

Table 27. Average operating assumptions

Average Operational Assumption for Economic and Infrastructure Analyses		
Average Shift Distance	miles	209
Average Shift Duration	hours	9.9
Average Shifts per Day	#/day	1.4
Average Daily Operating Time	hours	14.8
Average Daily Mileage	miles	252

9.2. Incremental Vehicle Capital/Financing Costs

The purchase price of a new drayage truck is a function of several factors including equipment specifications, warranties, demand, and purchase volume discounts. To establish a reasonable baseline diesel truck cost, respondents to the drayage truck operator survey were asked to estimate the average purchase price, including taxes, for new and used drayage trucks. As shown in Table 28, the weighted average of the reported purchase price for new trucks was $132,525 and the weighted average price for used trucks was $50,338. These prices are inclusive of taxes. For new trucks, taxes are assumed to include a 12 percent federal excise tax (FET) on new commercial trucks and a 10.25 percent state sales tax. Used truck prices include only the 10.25 percent sales tax.

NOTE: prices estimates were collected in mid-2021. Subsequently, substantial price increases occurred due to COVID-related supply chain constraints, which contributed to unusually high inflation affecting all financial sectors. Price increases for the shown parameters occurred prior to preparation of this Assessment, and consequently are not fully reflected in the economic analyses that follow. Notably, high inflation has impacted pricing on baseline diesel drayage trucks and fuel, as well as ZE or LE truck models and the energy they consume.

Table 28. Baseline diesel purchase prices per survey responses

	New Truck Purchase Price	Used Truck Purchase Price
Average	$132,382	$54,934
Weighted Average	$132,525	$50,338
Mode	$150,000	$50,000
Standard Deviation	$32,198	$17,416

Electric truck pricing is based on truck OEM estimates and on examples in the New York Truck Voucher Incentive program and other public sources. The New York program lists allowed voucher incentive for most Class 8 battery-electric trucks at the program cap of $185,000.[152] Because program rules restrict the incentive amount to 95% of the incremental cost of the truck, this implies that the incremental cost of most Class 8 battery-electric trucks in the program is $200,000 or more. When applied to the average cost of a new diesel truck of approximately $132,000, the estimated cost of the battery-electric truck is in excess of $330,000.

Peterbilt recently provided pricing for its 579EV tractor with a list price of $596,681, but a Sourcewell Customer Price of $334,167.[153] For purposes of this Assessment, the Sourcewell Customer Price is taken to be a more realistic representation of the typical price available to most purchasers. This price does not include sales tax or FET.

In a December 2019 study conducted by ICF International, the authors estimated the incremental cost of a Class 8 tractor with a 500-kWh battery at $215,000, resulting in an estimated purchase price of $375,000.[154] The authors are not clear as to whether or not this price includes sales tax or FET.

In CARB's TCO analysis for battery-electric trucks (BETs) under ACT Regulation, staff estimated the price of a BET to be $475,000 in 2018 declining to $232,000 in 2024. Linearly interpolating between the two reference years implies a 2021 BET truck cost (before taxes) of about $354,000.[155] While these reductions may occur by 2024, current retail pricing and trends between the 2018 and 2021 Assessments do not indicate that such steep declines in BET pricing are yet being realized.

[152] https://www.nyserda.ny.gov/All-Programs/Truck-Voucher-Program/How-the-Program-Works/Funding-Amounts
[153] Sourcewell, Peterbilt Motors contract #060920-PMC for CY2021-2024.
[154] https://efiling.energy.ca.gov/GetDocument.aspx?tn=236878
[155] California Air Resources Board, "Appendix H: Draft Advanced Clean Trucks Total Cost of Ownership Discussion Document," posted October 22, 2019, accessed from https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks.

In the 2018 Assessment, battery-electric truck costs were estimated at $300,000 to $350,000. One surveyed truck OEM indicated a typical sale price of $300,000 for an electric Class 8 truck. It must be noted that the pricing indicated above is representative of older models. For example, in the 2018 Assessment BYD noted that the $300,000 price point does not apply to the newer 8TT model equipped with a 422 (563 for extended range) -kWh battery pack, but that pricing had not yet solidified for the new model.[156]

In total, the estimates above indicate the typical cost of a battery-electric truck to be in the range of $330,000 to $375,000, excluding sales tax and FET. This is similar to the price range estimated in the 2018 Assessment. However, the trucks represented in the current Assessment are substantially more capable than the available trucks in 2018; incorporating much larger battery packs and offering significantly greater range. For purposes of this Assessment, a truck equipped with a 475-kWh battery pack is considered as the baseline configuration. An estimated purchase price of $350,000 is assumed for this baseline vehicle.

The baseline battery-electric truck configuration considered in this feasibility assessment is equipped with a 475 kWh battery pack capable of a 226-mile range at an energy consumption rate of 2.1 kWh/mile. This is sufficient range to serve the average truck working a single shift, but it is well below the 600-mile range needed to serve the BAT specification. To meet this specification, an electric truck would need an estimated 1,260 kWh of battery capacity. No electric truck is currently commercially available with such range. To estimate the purchase price of an electric truck with a 600-mile range, it is assumed that the primary driver of incremental cost would be the incremental cost of the larger battery pack. There is very little literature or available data on heavy-duty vehicle battery pack costs. NREL estimated the cost of heavy-duty battery packs by applying a 1.5 cost multiplier to the projected cost of light-duty battery packs.[157] Approximate values of the battery pack price projections from the NREL study are shown in Figure 13. In the 2020 timeframe, heavy-duty battery pack costs are estimated at $370/kWh. A recent study by MJ Bradley used similar numbers ($375/kWh) for current heavy-duty battery pack costs, although the authors forecast a far steeper decline in future battery costs, to roughly $86/kWh by 2030. [158] To produce a truck with a 1,260-kWh battery pack would require adding 785 kWh of capacity to the baseline electric truck configuration, at an estimated cost of $290,000. This would result in an estimated purchase price of $640,000 for a battery-electric truck with sufficient range to meet the BAT specification.

[156] Comments provided by BYD on the Draft version of this Feasibility Assessment, January 30, 2019.
[157] Jadun P. et al, "Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050", 2017. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy18osti/70485.pdf
[158] Lowell D, Culkin J, "Medium- & Heavy-Duty Vehicles: Market Structure, Environmental Impact, and EV Readiness" July, 2021. https://www.mjbradley.com/sites/default/files/EDFMHDVEVFeasibilityReport22jul21.pdf

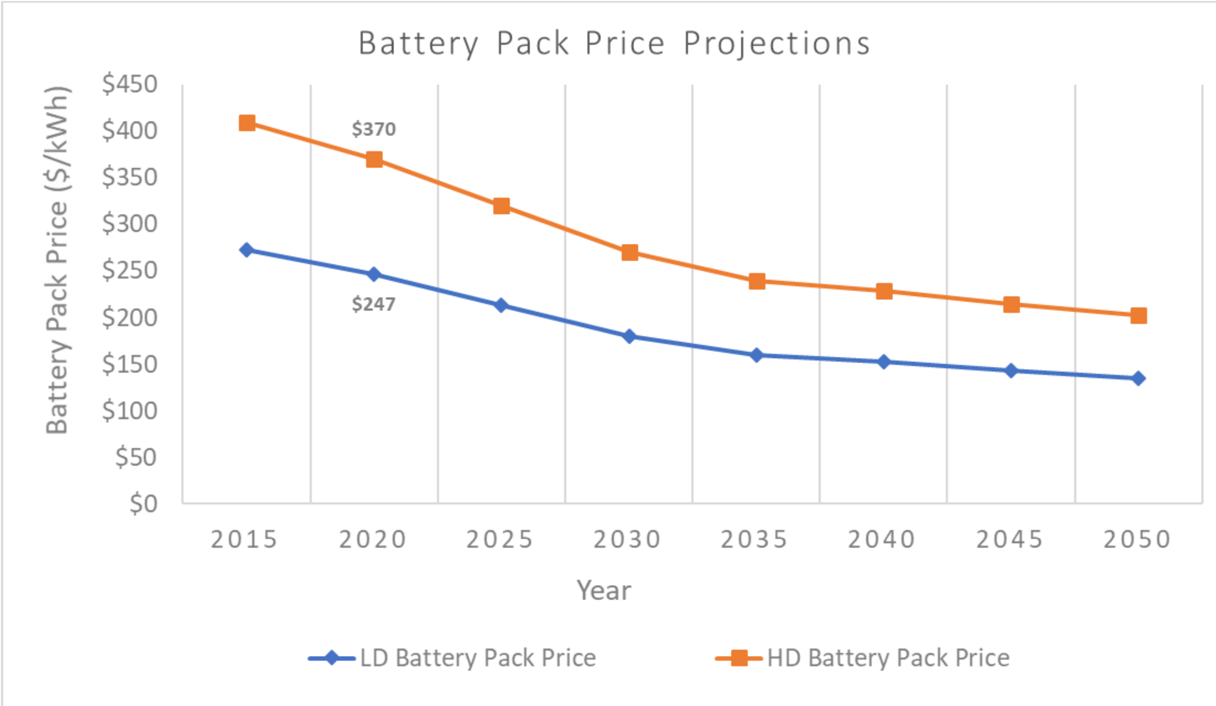


Figure 13. Battery pack price projections

Natural gas truck purchase price estimates were based on a reported incremental cost for CNG trucks relative to a new diesel truck. Truck OEMs indicated an average incremental cost of $55,000 pre-tax. This is consistent with estimates from natural gas industry experts for trucks with fuel systems capacities of 120 to 160 DGE.

Table 29 summarizes the purchase price assumptions for each of the vehicle configurations analyzed as of mid-2021. Notably, at the time this report was finalized, prices for all vehicle types had increased substantially due to supply chain challenges, inflation and other factors.

Table 29. Vehicle purchase price assumptions (mid-2021)

Cost Type	Used Diesel	New Diesel	LE CNG	Current BEV	BAT BEV
Purchase Price	$45,179	$103,039	$158,039	$350,000	$640,000
Taxes	$5,160	$29,487	$35,164	$77,875	$142,400

When considering the cost of purchasing a new truck, it is important to recognize that many drayage truck owners are owner/operators or fleets with low asset bases. These companies are very likely to require financing to purchase new trucks, particularly under accelerated replacement scenarios and/or when purchasing alternative fuel trucks that have significantly higher purchase prices than baseline diesel vehicles.

In mid-2018, the Ports' Sustainable Supply Chain Advisory Committee[159] heard from several major truck manufacturers and truck financing entities regarding the challenges of and needs for financing new natural gas and battery-electric drayage trucks. In response to that meeting, nine organizations provided estimated finance costs, interest rates, and loan/lease terms to inform the Committee's ongoing discussions. The interest rates considered ranged from 8 percent to 19 percent, depending on credit risks of applicants. An average interest rate of 12.5 percent was calculated from participant responses,

[159] "Sustainable Supply Chain Advisory Committee," https://www.portoflosangeles.org/environment/progress/advisors/

representing a mid-range credit risk assumption. Additionally, all organizations quoted terms of five or six years, with one organization quoting up to seven years. The most commonly quoted term was five years. Based on these responses, the financing costs for truck purchases assumes a 12.5 percent interest rate and a five-year loan term.

9.3. Fuel, Operational, and Maintenance Costs

Estimates of fuel costs and other operational and maintenance costs were developed and incorporated into the economic modeling of the total cost of ownership for each vehicle configuration. These estimates are summarized in Table 30 and described in the following sections. The basis of the fuel economy estimates used in this analysis are detailed in Section 0. As can be taken from the table ("Fuel Cost per Mile" row), a battery-electric truck (current or BATS) is assumed to have an electricity cost of $0.37 per mile, compared to a fuel cost of $0.50 per mile for the baseline diesel ICE (used or new). This reduced energy/fuel cost per mile (about 25 percent) is attributable to the battery-electric truck's 2.2 times higher fuel economy in miles per DGE (mpDGE).

Table 30. Assumptions for estimating fuel and maintenance costs (mid-2021)

	Units	Used Diesel ICE	New Diesel ICE	LE CNG ICE	Current BEV	BATS BEV
Fuel Economy	mpDGE	6.8	6.8	5.8	15.1	15.1
Fuel Price	$/DGE	$3.38	$3.38	$2.80	$5.54 (SCE) $5.67 (LADWP)	$5.54 (SCE) $5.67 (LADWP)
Fuel Cost per Mile*	**$ / mile**	**$0.50**	**$0.50**	**$0.48**	**$0.37**	**$0.37**
Maintenance	$/mi	$0.29	$0.21	$0.21	$0.11	$0.11
Diesel Exhaust Fluid (DEF)	% of diesel	4%	4%	N/A	N/A	N/A
DEF Price	$/gal	$3.60	$3.60	N/A	**N/A**	N/A
BEV fuel cost per mile uses average electricity price between SCE and LADWP ($5.61 per DGE)						

9.3.1. Fuel Price

Diesel fuel costs are based on the average on-road diesel fuel price in California for 2020, as reported by the U.S. EIA.[160] CNG fuel prices are based on averages for the West Coast as reported by the U.S. DOE in the Clean Cities Alternative Fuel Price Report.[161] These prices are based on retail pump pricing and are inclusive of all federal and state motor fuel taxes. Because the Metro study indicated that drayage fleets primarily use commercial fueling facilities, fuel prices for public access (retail) stations are used. Diesel trucks also consume diesel emission fluid (DEF) as part of the operation of the selective catalytic reduction (SCR) system used to control NOx emissions. The consumption rate of DEF is typically specified by the manufacturer as a percentage of the fuel consumption. For example, a 4 percent DEF consumption rate indicates that 4 gallons of DEF would be used for every 100 gallons of diesel fuel. DEF costs were estimated by reviewing current DEF prices reported at Flying J's California truck stops.[162]

Electricity pricing for EV charging is complex and varies based on several factors, including power demand, time of day, utility rate structure, and total energy consumption. To estimate average electricity costs for EV charging, three charging scenarios were evaluated:

1. A truck performing the average daily operations shown in Table 27. This truck is assumed to travel 252 miles per day and charge once per day over nine hours.

---

[160] U.S. Energy Information Administration, Weekly Retail Gasoline and Diesel Prices https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_sca_a.htm
[161] US Department of Energy, "Clean Cities Alternative Fuel Price Report", July 2021, https://www.afdc.energy.gov/uploads/publication/alternative_fuel_price_report_july_2018.pdf
[162] Pilot Flying, https://pilotflyingj.com/fuel-prices/ reviewed October, 2021.

2. A truck performing the average daily operations for a single-shift truck. This truck is assumed to travel 193 miles per day and recharge over 14 hours.
3. A truck performing the average daily operations for a two-shift truck. This truck is assumed to travel 329 miles per day and recharge over five hours beginning at the end of the second shift.

In the scenarios described in the following table, all charging is assumed to complete by 6:00 am for service of the ports by 7:00 am. Additionally, each charging scenario was evaluated under three tariff rates; SCE's TOU-EV-9 (2-50 kV) and LADWP's TOU A-2 rates. The LADWP rate includes a $0.025/kWh discount for EV charging. Further, in this 2021 Assessment, cost modeling under the TOU-EV-9 rate now includes an anticipated phase in of demand charges and reduction of energy charges after 2024. The costs presented here represent the 12-year average cost of electricity under the TOU-EV-9 rate. The results of the analysis are summarized in Table 31. Costs for the Average Truck scenario ranged from $0.148-$0.153/kWh, with an average rate of $0.151/kWh. The Single-Shift Truck scenario costs were similar to the Average Truck scenario, ranging from $0.152-$0.154/kWh. The Two-Shift Truck scenario costs $0.165-$0.191/kWh and averaged $0.178/kWh.

The 2018 Assessment's economic analysis estimated a substantial difference in average electricity costs between SCE and LADWP. Because that analysis did not model the cost impacts associated with the end of the demand charge waiver under the TOU-EV-9 rate, the analysis presented an optimistic cost estimate for SCE customers using this rate. The result of the SCE EV rate analysis was to lower costs for EV charging relative to a general services rate such as the one modeled for LADWP. However, under the revised analysis, the difference in the "average" electricity cost between the LADWP and SCE TOU-EV-9 rates is negligible for all but the Two-Shift Truck scenario. A scenario was also evaluated for an average truck that partially recharges between shifts. Under this scenario, the truck completes a 193-mile shift, recharges sufficiently to complete a 59-mile shift, and then completes the second shorter shift before returning to base to fully recharge overnight. In this scenario, the brief charging period between shifts demands substantially more power than the overnight charging period and occurs when time-of-use energy and demand charges are higher. The result is an average electricity cost of $0.274/kWh under the LADWP rate and $0.205/kWh under the SCE rate, roughly 30 to 80 percent higher than the cost of the Average Truck scenario that charges entirely overnight. This highlights the challenge evaluating costs for EVs under a diverse range of operating scenarios within the drayage market. For the purposes of this economic analysis, it is assumed that fleets would employ overnight charging almost exclusively. This is a best-case scenario as overnight charging is expected to be applicable only to a subset of the fleet that has access to parking locations with charging infrastructure. In this case, electricity costs are assumed to be the rates for the Average Truck scenarios of $0.148/kWh (SCE) and $0.152/kWh (LADWP).

Table 31. EV charging cost analysis results (mid-2021)

Scenario	Average Truck	1-shift Truck	2-shift Truck	Average Truck	1-shift Truck	2-shift Truck	Average Truck w/ mid-day recharge	Average Truck w/ mid-day recharge
Utility	SCE	SCE	SCE	LADWP	LADWP	LADWP	SCE	LADWP
Rate Schedule	TOU-EV-9	TOU-EV-9	TOU-EV-9	TOU A-2	TOU A-2	TOU A-2	TOU-EV-9	TOU A-2
Daily Mileage (mi)	252	193	329	252	193	329	252	252
Daily Energy (kWh)	623	477	813	623	477	813	623	623
Daily Operating Time (hours)	15	9.6	19	15	9.6	19	15	15
Charge Window	9p-6a	9p-6a	1a-6a	9p-6a	9p-6a	1a-6a	10p-6a, 4p-5p	10p-6a, 4p-5p
Total Energy (kWh)	162,496	124,451	212,147	162,496	124,451	212,147	162,496	162,496
Peak Power (kW)	69	53	163	69	53	163	146	146

Energy Charges ($/yr)	$16,275	$12,465	$20,832	$16,864	$12,916	$22,646	$20,152	$17,143
Demand Charges ($/yr)	$4,766	$3,650	$11,201	$7,471	$5,722	$17,557	$10,043	$27,112
Fixed Charges ($/yr)	$3,061	$3,061	$3,061	$336	$336	$336	$3,061	$336
Total Cost ($/yr)	$24,102	$19,176	$35,094	$24,671	$18,973	$40,539	$33,256	$44,591
Average Cost ($/kWh)	**$0.148**	**$0.154**	**$0.165**	**$0.152**	**$0.152**	**$0.191**	**$0.205**	**$0.274**

9.3.2. Maintenance Costs

Baseline maintenance costs are calculated from responses to the 2021 Drayage Truck Operator survey. The majority of responses to the survey produced a calculated cost per mile between $0.03 and $0.50, with $0.25/mile as the average cost across all responses. The responses were then divided into two groups, based on whether the fleet indicated it typically buys new trucks or used trucks. The average cost per mile for new trucks is calculated at $0.21/mile. This estimate is similar to the American Transportation Research Institute's estimated repair and maintenance costs for 2020 of $0.229/mile for small carriers (less than 20 trucks per fleet).[163] The average cost per mile for used trucks, based on the survey responses, is $0.29/mile.

Battery-electric truck maintenance costs are assumed to be 50 percent less than the diesel baseline. This assumption is based on comments from electric truck OEMs in their responses to the Truck Manufacturer survey. Unfortunately, there is little in-use demonstration data available to validate this assumption, particularly for the next generation battery-electric trucks that are just now beginning to enter series production. Additionally, these maintenance costs do not incorporate the potential cost of a battery pack replacement over the 12-year life of the truck. As previously noted, BYD currently offers a 12-year warranty on its battery packs in transit applications. Because the cost estimates used in this feasibility assessment exclude the cost of a battery pack replacement, it is implicitly assumed that the battery pack will last the full life of the vehicle or that the sales price assumed would include a 12-year battery warranty when vehicles are produced and sold in high volumes. BYD notes that it does not offer a 12-year warranty on batteries in truck applications. Additionally, the economic assessment for the ACT regulation assumes a mid-life battery pack replacement that is not included in this Assessment. Hence, these are likely optimistic assumptions that cannot be further improved until maintenance cost data and more substantial battery life information are available for drayage applications.

Natural gas truck maintenance costs are assumed to be equal to diesel maintenance costs. The literature contains various conflicting reports of natural gas maintenance costs relative to diesel, with some analyses reporting reduced maintenance costs and others reporting increased maintenance costs. It is likely that the differences in these results are attributable to various confounding factors in the analyses and to differences in the maintenance practices between fleets. It should also be recognized that some fleets experienced very high maintenance and repair costs for many of the natural gas drayage trucks deployed between 2007 and 2012. These trucks were equipped with an 8.98.9-liter natural gas engine rated at 320 HP. This engine is recommended for trucking applications with GCWs of less than 66,000 lbs.[164] Operators that placed the engine in applications above 66,000 lbs incurred engine damage and high repair costs. The current analysis assumes the use of a 12-liter natural gas engine rated at 400 HP and intended for trucks operating at up to 80,000 lbs. Therefore, the higher failure rates and associated maintenance costs of the 8.9-liter engine observed by some operators are not assumed to be indicative of the maintenance costs of the 12-liter engine.

[163] Leslie, A. and Murray, D., "An Analysis of the Operational Costs of Trucking: 2021 Update", 2021. Prepared for the American Transportation Research Institute.
[164] "ISL G", https://www.cumminswestport.com/models/isl-g

9.3.3. Insurance, Registration, and Depreciation Costs

The cost impacts of insurance, registration, and depreciation are often overlooked in TCO analyses. All of these costs are strongly influenced by the purchase cost of the vehicle and infrastructure.

California DMV vehicle license fees (VLF) for commercial vehicles are based on the market value of a truck, calculated using a standard depreciation schedule and applied to the sales price of the truck.[165] Per statute, the VLF is calculated as 0.65 percent of the current market value. As shown in Table 32, the greater purchase price of natural gas and battery-electric vehicles increases the VLF proportionally and can add substantial costs over the 12-year life of the vehicle.

Commercial trucks operate under many different types of insurance covering cargo, general liability, non-owned equipment, and physical damage to the truck. While the costs for most of these coverages are independent of the cost of the truck, physical damage coverage is generally calculated as a percentage of the current market value of the truck. Insurance costs are highly dependent on individual circumstances, but an approximate cost of 3 percent of the truck's market value is used to estimate the insurance premium for physical damage coverage. As with the VLF, a higher purchase price increases the estimated market value of the truck and the associated insurance premium.

Table 32. Vehicle license fee and insurance cost assumptions (at purchase price, mid-2021)

Year	Market Value	Diesel	NGV	Current BEV	Diesel	NGV	Current BEV
		($103,039)	*($158,039)*	*($350,000)*	*($103,039)*	*($158,039)*	*($350,000)*
		Vehicle License Fee			*Insurance Cost*		
		0.65% of Market Value			3% of Market Value		
1	100%	$670	$1,027	$2,275	$3,091	$4,741	$10,500
2	90%	$603	$925	$2,048	$2,782	$4,267	$9,450
3	80%	$536	$822	$1,820	$2,473	$3,793	$8,400
4	70%	$469	$719	$1,593	$2,164	$3,319	$7,350
5	60%	$402	$616	$1,365	$1,855	$2,845	$6,300
6	50%	$335	$514	$1,138	$1,546	$2,371	$5,250
7	40%	$268	$411	$910	$1,236	$1,896	$4,200
8	30%	$201	$308	$683	$927	$1,422	$3,150
9	25%	$167	$257	$569	$773	$1,185	$2,625
10	20%	$134	$205	$455	$618	$948	$2,100
11	15%	$100	$154	$341	$464	$711	$1,575
12	15%	$100	$154	$341	$464	$711	$1,575

Unlike VLF and insurance costs, depreciation provides a cost reduction for fleets that are able to take advantage of the tax benefits. Current federal tax rates for businesses are 21 percent and California tax rates for C-type corporations are 8.84 percent, resulting in an effective tax rate of 29.84 percent.[166] Because depreciation of business equipment such as heavy-duty trucks is tax deductible, the depreciation of a truck creates a tax shield that reduces taxes paid in a year when depreciation is applied. Estimating the value of depreciation for the average drayage truck operator is difficult. The rules for depreciation are complex and truck operators may be structured as a number of different types of business entities including sole proprietorships, partnerships, and corporations. Each of these entities have different tax rules and specific tax situations

[165] California Revenue and Taxation Code §§10751, 10752, and 10753.5
[166] 26 U.S. Code § 11, https://www.ftb.ca.gov/businesses/faq/717.shtml.

may limit the value of depreciation deductions in a given year. For the purposes of this analysis, the value of equipment depreciation to the total cost of ownership is calculated as 29.84 percent of the capital cost (equal to the effective tax rate assumed for a C-type corporation) and it is assumed that the equipment owner(s) of the truck and charging infrastructure are able to fully benefit from the associated deductions over the life of the equipment.

9.4. Infrastructure Capital and Operational Costs

Diesel and natural gas fueling are assumed to be provided predominately through commercial fuel stations where the capital and operational costs of the fueling infrastructure are incorporated into the fuel price. As described previously, the fuel pricing used in this analysis reflects actual pump pricing at public access stations. For this reason, the costs of infrastructure for diesel and natural gas vehicles are assumed to be zero.

Owing to the length of time required to recharge electric trucks, it is assumed that they will be charged primarily through DC fast charging infrastructure installed at fleet facilities or other locations that provide overnight parking stalls for drayage trucks. The cost of this new charging infrastructure is not included in the electricity pricing assumptions described previously. Based on the electricity charging rate analysis, the typical drayage truck would require a peak charging rate of 69 kW. This charging rate is based on a charging window roughly equivalent to the truck's overnight downtime and implies that a one-to-one ratio of chargers to trucks is required. While a single charger could potentially serve multiple trucks, this would either require a charger with a higher charging rate (and higher cost) or require trucks to share charging infrastructure but have non-overlapping charging windows. While both of these situations are possible, for the purposes of this economic comparison it is assumed that the typical use case would require a one-to-one ratio of chargers to trucks. Costs for the charger and associated infrastructure are based on CARB estimates for a 60 kW DC fast charger and installation, totaling $105,000 per charger.[167] Similarly, under the ACT regulation, CARB estimated the installed cost for a 100 kW DC fast charger to be $105,000 per charger.[168] The full cost of the charger and installation are attributed to a battery-electric truck. It is recognized that the installation costs reflect long-lived improvements such as trenching, conduit, switch gear, and power lines. The service life of these improvements should extend well beyond the 12-year useful life of the first electric trucks deployed. However, to levelize the cost of this infrastructure over a period greater than the 12-year life of the vehicle, a fleet would need to amortize the investment over very long timeframes that are not the norm for commercial fleets.

Maintenance costs for EV charging infrastructure are also taken from CARB estimates and assume $240/year in inspection costs and the replacement of one charging connection over ten years, producing a levelized cost of $415 per year.

9.5. Incentives

Historically, incentives have played a major role in spurring drayage truck replacement by reducing the cost of the initial capital outlay. There are uncertainties, however, surrounding the long-term availability and magnitude of incentives. Additionally, these funding programs do not necessarily align with timelines for deployment; there is funding available today for vehicle purchase, but the industry may need years to develop the fueling or charging infrastructure to support these vehicles. This effectively limits the amount of incentives that can be accessed in the near term.

Given these uncertainties, this Assessment calculates the total cost of ownership with and without incentives. The cost model considers two incentive types: a purchase incentive based on the HVIP program, and an LCFS credit revenue stream. The purchase incentive is assumed to be $120,000 plus a 10 percent voucher enhancement for vehicles deployed in Disadvantaged Communities, for a total of $132,000 for battery-electric trucks. The value of LCFS credits is based on a $186 credit price reflecting the volume-weighted average credit price for 2018 through 2020. It must be noted that credit prices under the LCFS program are based on market demand. Since the inception of the LCFS program, credit prices have varied

[167] California Air Resources Board, "Innovative Clean Transit – Costs and Data Sources", June 26, 2017, https://arb.ca.gov/msprog/ict/meeting/mt170626/170626costdatasources.xlsx. Includes costs of site work, conduit, switch gear, etc.
[168] California Air Resources Board, "Appendix H: Draft Advanced Clean Trucks Total Cost of Ownership Discussion Document," posted October 22, 2019, accessed from https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks.

substantially and prices react to a number of different influences. These include political/regulatory pressures, legal challenges to the LCFS program, CARB modifications to the LCFS regulation, and emergence of new sources of credit generation. The extension of the LCFS program's carbon intensity benchmarks through 2030 are no guarantee of the longevity of the program or a guarantee of credit prices under the program. To be conservative, it is recommended that economic workability be based on non-incentivized cost of ownership.

A more detailed explanation of the incentive funding calculations, including a description of the funding programs, can be found in Appendix B.

9.6. Total Cost of Ownership Results

The comparative cost of ownership analysis is based on the assumptions described in the preceding sections and in Appendix C. Table 33 summarizes the key assumptions for each technology and cost component. The analysis considers two versions of a battery-electric truck. The first is based on the current battery-electric truck product offering. This truck does not meet the BAT specification but could theoretically achieve the 65,520 annual vehicle miles traveled (VMT) with the estimated 252 mile/shift range. The second battery-electric truck specification is based on the estimated cost of a battery-electric truck with sufficient range to meet the BAT-compliant range requirements. Note that a fleet could theoretically achieve a greater daily range with an EV-to-diesel replacement ratio greater than one-to-one. However, this approach would entail substantial extra costs as well as require additional parking to accommodate the increased vehicle population. This analysis does not assume that a fleet would attempt to meet daily range requirements with replacement ratios greater than one-to-one.

Table 33. Summary of key assumptions (mid-2021) for cost of ownership analysis

Cost Component	Units	Used Diesel ICE	New Diesel ICE	LE CNG ICE	Current BEV	BATS BEV
Purchase Price	$	$45,179	$103,039	$158,039	$350,000	$640,000
Taxes	$	$5,160	$29,487	$35,164	$77,875	$142,400
Infrastructure	$	$0	$0	$0	$105,000	$105,000
Interest Rate	%	12.5%				
Finance Period	yrs	5				
Fuel Economy	mpDGE	6.8	6.8	5.8	15.1	15.1
Fuel Price	$/DGE	$3.38	$3.38	$2.80	$5.54 (SCE) $5.67 (LADWP)	$5.54 (SCE) $5.67 (LADWP)
VMT	miles/yr	65,520				
Maintenance	$/mi	$0.29	$0.21	$0.21	$0.11	$0.11
DEF	% of Diesel	4%	4%	0%	0%	0%
DEF Price	$/gal	$3.60				
LCFS Credit Price	$/MT	$186				

The analysis also considers a used diesel truck baseline, in recognition that many drayage trucks are "pre-owned" and were formerly used for longer-haul Class 8 trucking. It is assumed that the used diesel truck is approximately six years old when purchased and that it will have a remaining six years of useful life. Over a 12-year period, a used diesel truck is expected to be replaced once with another used truck.

Figure 14 summarizes the results of the cost of ownership analysis. CapEx represents all purchase costs (vehicle and infrastructure capital costs and sales tax), while OpEx represents combined operational expenses (fuel/electricity costs, maintenance costs, insurance, and registration fees.) The costs are reported in current 2020 dollars on a net present value (NPV) basis using a 7 percent real discount rate.[169] As shown, the cost of ownership for a new diesel truck with an average

[169] The analysis uses a 7% real discount rate per the White House Office of Management and Budget Circular A-4 (2003)

annual activity of 65,520 miles over a 12-year service life is approximately $532,000. Battery-electric truck cost of ownership is nearly identical in SCE and LADWP territories, because the two utilities have very similar average costs of electricity. The current battery-electric truck in SCE territory is estimated to cost $864,000 over 12 years, which is about $332,000 more expensive than new diesel trucks over the same service life. A BATS-compliant battery-electric truck is estimated to have a cost of ownership of $1.2 million, $666,000 greater than that of a new diesel truck due to the high capital cost of the larger battery. LE natural gas truck costs are estimated to be $594,000, within 12 percent of the total cost of ownership of a new diesel truck, and could be considered cost-competitive with new diesel trucks at the fuel price spreads assumed in this analysis.

When incentives are included in the analysis, current battery-electric trucks (but not BATS-compliant trucks) are less expensive than diesel trucks over the 12-year analysis period. Based on current HVIP funding guidelines, natural gas trucks receive no purchase incentive through HVIP. These trucks would also generate an estimated $100,000 in LCFS credit revenue using renewable natural gas (RNG). However, because these trucks are assumed to refuel at commercial fueling facilities, the value of the LCFS credit is assumed to be accounted for in the pump price and consumed by the fuel provider to source RNG. Electric trucks receive a $132,000 purchase incentive through HVIP and generate $372,000 in LCFS credits over 12 years assuming they are able to charge at their fleet facility.[170] The combined effect of these two very large incentives is to make the total cost of the battery-electric trucks substantially less than baseline diesel trucks.

By comparison, CARB estimated the 12-year TCO of diesel and battery-electric Class 8 tractors (MY 2018) under its ACT regulation to be $571,000 and $775,000, respectively. These numbers are similar to values shown in Figure 14. CARB forecasts that the TCO for battery-electric trucks will decline substantially to $416,000 for a MY 2024 tractor. This forecast reduction in TCO is based almost entirely from assumed reductions in the purchase cost. As previously noted, these reductions may occur by 2024, but current retail pricing and trends between the 2018 and 2021 Assessments do not indicate that such steep declines are yet occurring.[171]

[170] LCFS credits are earned by the charging equipment owner. Because the exact business relationships between the truck owner and charger owner that would prevail in the drayage market are not clear, it is assumed that the full value of the LCFS credit is passed to the truck owner either by direct ownership of the charger or as a reduced cost of charging.

[171] California Air Resources Board, "Appendix H: Draft Advanced Clean Trucks Total Cost of Ownership Discussion Document," posted October 22, 2019, accessed from https://ww2.arb.ca.gov/rulemaking/2019/advancedcleantrucks.

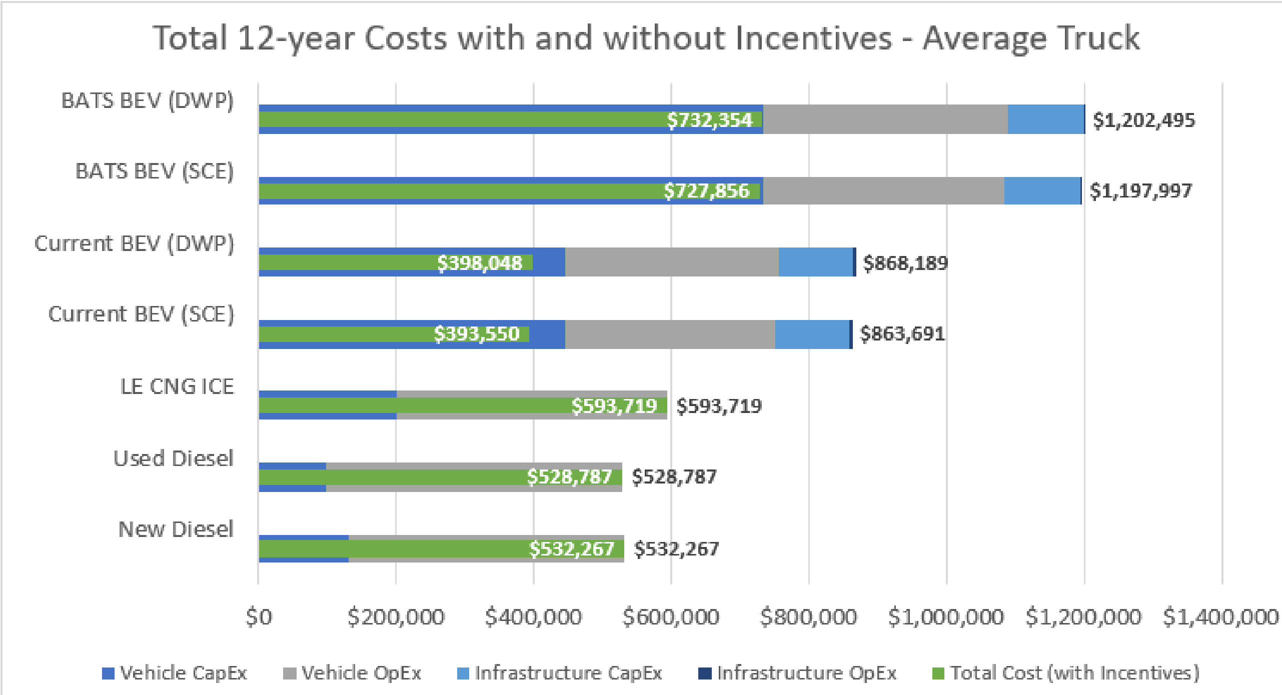


Figure 14. Total 12-year costs of ownership for "Average Truck" scenario (NPV at 7% discount rate)

Reliance on incentives to determine economic workability can be problematic. Under existing programs, incentives are not guaranteed over the 12-year operational life of a Class 8 truck used in drayage. Therefore, truck buyers must discount the value of potential incentives by including risk that 1) they may not ultimately be available, or 2) could be significantly reduced than initially projected levels. From the perspective of economic workability to the broader drayage fleet, it must be recognized that current incentive programs do not have sufficient funds to provide the purchase incentives assumed for many trucks in the drayage fleet, and HDV allocations for future programs are not yet determined or guaranteed. Examples of important incentive funding efforts specifically focused on drayage trucks include the following (also see Section 12: Appendix B – Relevant Incentive Programs):

- The Ports have established the Clean Truck Fund Rate (CTF Rate) that will be used to annually generate approximately $90 million, in its initial years of implementation. These funds will be used to help incentivize transition of the SPBP drayage fleet to zero-emission trucks.[172]
- CARB's "Project 800 initiative" has already allocated $63 million to deploy 800 new ZE drayage trucks in California by the end of 2021. Moreover, in late-2021 California "set-aside" $75 million in new incentive funding for Class 8 ZE drayage trucks, and additional funds are available through other state and local incentive programs (please see Section 12/Appendix B for additional information about relevant incentive programs for deployment of Class 8 ZE and LE drayage trucks).

Together, the two initiatives listed above provide roughly $165 million per year, at least in the 2022-2024 time frame. This is a meaningful pot of incentive funding; this would be sufficient to incentivize drayage fleets to purchase roughly 1,100 new ZE trucks.[173] However, this is approximately 10 percent of the truck replacements that would be needed to fully turn over the

[172]The Ports have similar (but not identical) CTF Rate requirements and implementation details, and vary in their Rate proceeds spending plans, with the Port of Los Angeles spending 100% of Rate revenues on ZE trucks and infrastructure. Links to details are provided in Appendix B (Section 12.1).
[173] This assumes $165 million is annually available for incentives, with the maximum incentive set for a ZE truck at $150,000.

SPBP drayage truck fleet (between 9,000 and 13,000 active trucks, please refer back to Section 3.2). Consequently (as stated earlier), the analysis for economic workability has been based on non-incentivized cost of ownership.

An assessment of the costs for a typical truck performing one shift per day was also conducted to determine whether battery-electric technology offered a significant cost advantage over diesel in the shorter-range (and/or lighter-weight) applications where current technology is better matched to operational requirements. The results are summarized in Figure 15. Alternative fuel trucks typically predicate lower costs of ownership on fuel and maintenance savings that offset the higher capital cost of these technologies. When annual mileage is lower, the benefits of reduced maintenance and fuel costs are proportionally lower but are not necessarily accompanied by reduced capital costs for the trucks. For a single-shift truck scenario the average daily mileage is assumed to be 193 miles, resulting in an average annual mileage of 50,180 miles. At this lower annual mileage, the cost of ownership for natural gas trucks (in this specific application) is approximately 15 percent higher than both new and used diesel trucks. Incremental costs for current Class 8 battery-electric trucks increase to $363,000. Because the currently available battery-electric truck on the market has a range more suitable for the Single Shift Truck scenario than for the Average Truck scenario, the results for the Single Shift scenario shown in Figure 15 are more likely to be a better representation of the truck cost of ownership than those shown under the Average Truck scenario.

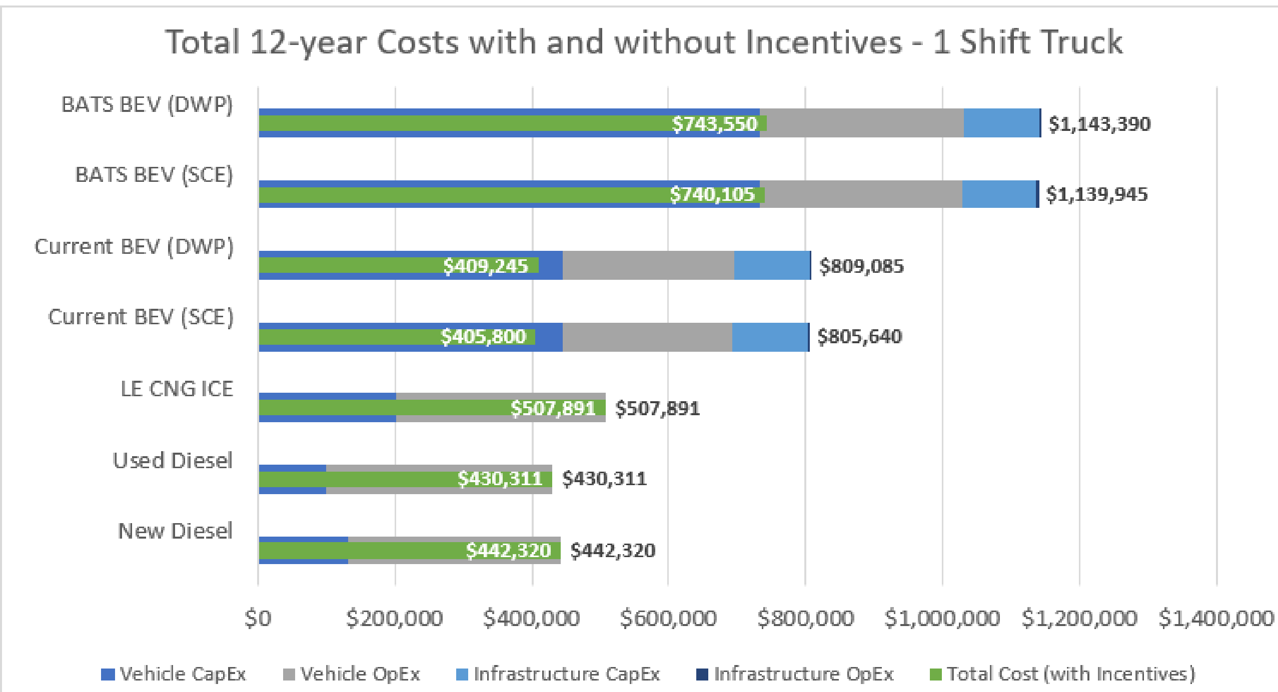


Figure 15. Total 12-year costs of ownership for Single Shift Truck scenario (NPV at 7% discount rate)

9.7. Impacts on Cargo Capacity

As discussed in Section 7.6.5, both natural gas and battery-electric trucks are typically heavier than comparable diesel trucks. Cargo capacity may be reduced by the incremental weight of these trucks. The economic impact of this lost cargo capacity varies by truck operator, but as a first approximation, it can be assumed that the operator must run additional trucks to transport the lost cargo capacity. Consequently, a 2,000 lbs reduction in capacity on a 62,000 lbs load would result in a 3.2 percent loss in cargo capacity. This would require the trucking company to operate about three percent more battery-electric trucks than diesel trucks to move the same payload. This is a rough, low-end estimate as not all loads can be conveniently split when the truck reaches 80,000 lbs. For example, a truck hauling large steel plates may find that they must remove one plate to meet the 80,000 lbs weight limit and that plate may represent more than 3.2 percent of that truck's typical capacity.

Because of regulatory changes to truck weight limits made in AB-2061 that allows ZE and LE trucks to exceed weight limits on the tractor by up to 2,000 lbs, the typical weight penalty for LE natural gas trucks is effectively eliminated.

The regulatory changes also reduce the effective weight penalty of the battery-electric truck by 2,000 lbs. For trucks operating at 80,000 lbs, this would leave a 3,400 lbs weight penalty for current battery electric trucks and a 10,200 lbs weight penalty for a BAT-compliant electric truck. These weight penalties translate into a loss of 5.5 percent and 16.5 percent of cargo capacity, respectively.

Also discussed in Section 7.6.5, current battery-electric trucks could haul up to 40,000 lbs containers with the weight increases from AB-2061. While this increase allows the battery-electric truck to transport many of the containers moved through the ports, many 40-45 foot shipping containers moving through the Ports are likely to be too heavy to legally transport with current battery-electric trucks. This restriction on cargo weight would likely translate into lost revenue for truck operators. A BATS-compliant battery-electric truck would be limited to approximately 28,400 lbs containers, making it unsuitable for much of the cargo transported in the Ports.

9.8. Cost Effectiveness, Workforce, and Cargo Diversion Considerations

The feasibility assessment framework adopted in November 2017 as part of the CAAP Update identified three additional areas of economic impact for consideration by the Ports. These areas are 1) cost effectiveness of air quality reductions, 2) workforce impacts, and 3) costs associated with potential cargo diversion.

9.8.1. Cost-Effectiveness

Cost-effectiveness, generally represented as the cost per ton of emissions reduced, is a metric typically used to assess various regulations and funding programs. A major element of any cost effectiveness analysis is the choice of the costs that will be included in the analysis. To develop cost effectiveness comparisons for this Feasibility Analysis, the non-incentivized 12-year costs shown in Figure 14 for an average truck were used.

Emissions are calculated using emissions factors from CARB's EMFAC2021 model and LCFS program, and applying those factors to the annual mileage and fuel economy (refer back to Table 33). Table 34 summarizes criteria pollutant emissions factors for a new 2021 model year diesel truck. Emissions factors were derived from EMFAC 2021's reported total daily VMT and mass emissions for drayage trucks operating in the South Coast air basin.

Table 34. Diesel emissions factors for cost-effectiveness analysis

Type of Pollutant	$PM_{2.5}$	NOx	ROG
Diesel Emissions Factor (grams/mile)	0.01	1.39	0.03

Criteria pollutant emissions reductions are estimated based on reduction factors, shown in Table 35. Greenhouse gas emissions are estimated using the carbon intensity (CI) factors, also shown in Table 35. The CI factors for traditional fuels are based on CARB's default values for diesel, CNG, and the current California-average grid and are the non EER-adjusted values.[174] An adjustment for the energy efficiency of each technology is reflected in the fuel economy assumptions for each technology, as discussed in Section 0. The CI factor for CNG shown under the Renewable/TOU column reflect the average CI for RNG as reported by CARB under the LCFS Quarterly Data Summary and is the average of the prior four quarters (Q3 2020 through Q2 2021). The CI factor for BEVs under the Renewable/TOU column is the average carbon intensity for California

[174] California Air Resources Board, Final Regulation Order, Table 7-1 "Lookup Table for Gasoline and Diesel and Fuels that Substitute for Gasoline and Diesel." https://www.arb.ca.gov/regact/2018/lcfs18/fro.pdf

grid electricity delivered between the hours of 9:00 pm and 5:00 am, as reported in Table 7-2 of the LCFS regulation.[175] This time period is consistent with overnight charging of BEVs.

Table 35. Emissions reduction factors and carbon intensity assumptions

Truck Technology	Reduction Factor			Non EER-Adjusted Carbon Intensity (gCO2e/MJ)	
	NOx	$PM_{2.5}$	ROG	Traditional	Renewable/TOU
Diesel ICE	0%	0%	0%	100.45	
ZE BEV	100%	100%	100%	75.93	84.84
LE CNG ICE	90%	0%	0%	79.21	-23.20

Results of the cost effectiveness analysis are shown in Figure 16 (criteria pollutant reductions) and Figure 17 (GHG reductions). All cost-effectiveness calculations assume a 12-year project life and criteria pollutant emissions are represented as weighted emissions[176] using the Carl Moyer program methodology (see important note below).

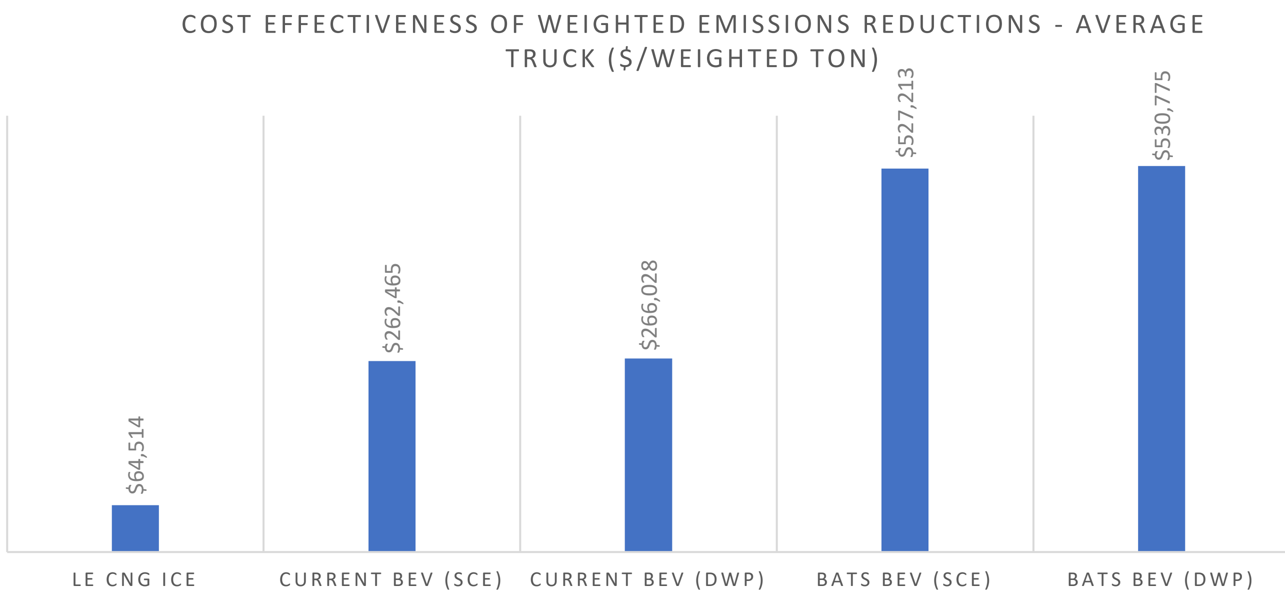


Figure 16. Cost effectiveness of criteria pollutant reductions ($/weighted ton)

As shown in Figure 16, the cost effectiveness of reducing criteria pollutant emissions by replacing a baseline diesel ICE truck with an LE CNG ICE (natural gas) truck is $64,500 per weighted ton. The cost effectiveness for replacing the baseline diesel truck with a current-model ZE battery-electric truck ranges between $262,000 and $266,000 per weighted ton. By comparison, the updated Carl Moyer Program has a standard cost-effectiveness limit of $109,000 per weighted ton reduced for truck-replacement projects. However, the guidelines provide air districts (e.g., the South Coast AQMD) with the “option” to apply a higher cost-effectiveness limits of $200,000 and $500,000 per weighted ton (depending on circumstances), for the emissions reductions that go beyond the required standard.[177]

[175] California Air Resources Board, “2021 Carbon Intensity Values for California Average Grid Electricity Used as a Transportation Fuel in California and Electricity Supplied Under the Smart Charging or Smart Electrolysis Provision.” https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/2021_elec_update.pdf.
[176] Under the Carl Moyer program, NOx, PM, and ROG emissions reductions are combined into a single weighted emissions reduction factor using the formula (NOx + ROG + 20*PM) = Weighted Emissions
[177] Cost-effectiveness limits for Carl Moyer Program are reported in Appendix C of the 2017 guidelines (with Board-approved updates effective 11/19/2021), https://www.arb.ca.gov/msprog/moyer/guidelines/2017gl/2017_gl_appendix_c.pdf

As shown in Figure 17, for greenhouse gas (GHG) reductions the cost effectiveness of the LE CNG ICE truck is $620 per metric ton (MT) using traditional natural gas, and $35 per MT using RNG. The GHG-reduction cost effectiveness for BEVs varies between $369 and $398 per MT. As a point of comparison, the LCFS credit prices ranged from $105 to $217 per metric ton between January 2018 and November 2021.[178]

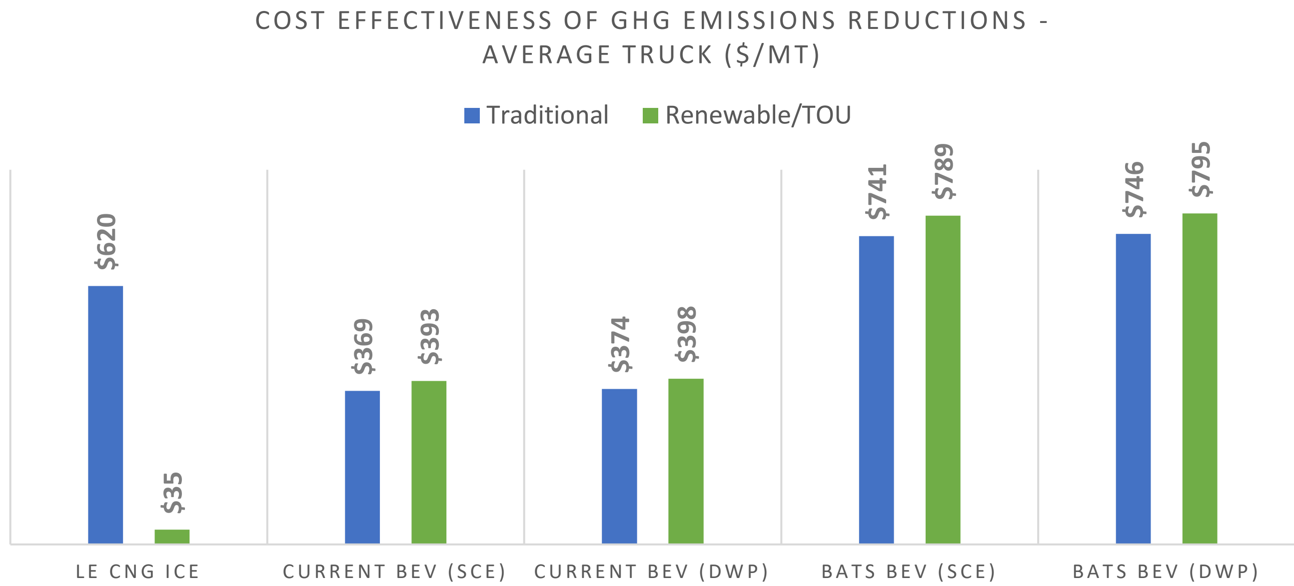


Figure 17. Cost effectiveness of GHG reductions ($/MT)

NOTE: the Carl Moyer program does not include infrastructure costs in its cost-effectiveness calculations. Removing infrastructure costs from the values in Figures 16 and 17 would reduce (improve) the cost effectiveness for battery-electric trucks by $80,000 per weighted ton and $120 per MT CO2e, respectively.

Potential for future cost-effectiveness improvements

Cost-effectiveness can be improved through lower total costs and/or greater emissions reductions. The potential for cost reductions varies by technology and pollutant. With regard to criteria pollutant cost-effectiveness, there is little or no additional emissions reduction potential that can be achieved for ZE battery-electric and LE natural gas trucks beyond their current performance levels. Consequently, improvements in cost-effectiveness will need to come from cost reductions. For GHG cost-effectiveness, both battery-electric and natural gas technologies could benefit from cost reductions and emissions reductions.

ZE Battery-Electric: As with natural gas, criteria pollutant cost-effectiveness reductions will come from increased adoption of electric vehicles and increased competition among manufacturers. As noted in Section 5.2, multiple manufacturers have announced plans to sell Class 8 battery-electric trucks as of late-2021. This emerging competition, combined with the growth of EVs in the light-duty vehicle market, could significantly reduce the current incremental cost of battery-electric trucks suitable for drayage.

GHG reductions are anticipated to come from increased penetration of renewable electricity in the California grid, consistent with state requirements under the Renewable Portfolio Standard. Additionally, some facilities may purchase electricity with a lower carbon intensity than the grid average based on additional value that can be derived from the LCFS program.

LE Natural Gas: Criteria pollutant cost-effectiveness reductions are possible with increased adoption of the technology and increased competition amongst manufacturers. Currently, only one manufacturer offers a near-zero natural gas engine

[178] Analysis based on data from California Air Resources Board LCFS Credit Transfer Activity Reports. https://www.arb.ca.gov/fuels/lcfs/credit/lrtcreditreports.htm

suitable for drayage, hence there is no direct competitive pressure to reduce equipment costs below current levels. Should additional manufacturers enter the market, competition could reduce the incremental purchase price of the vehicle. Additionally, a more robust public access fueling network should drive competition and reductions in fuel costs.

Cost-effectiveness of GHG reductions will benefit from the cost reductions already described, and could improve as lower carbon sources of RNG enter the California market. There are a number of RNG projects in development in California that will produce natural gas from food waste, green waste, and animal waste. Many of these projects will likely have lower carbon intensities than the current average carbon intensity for RNG in California.

Workforce Impacts

Costs of workforce training for alternative technology trucks are typically associated with additional training for operators and mechanics. However, because most drayage truck operators currently use third party repair facilities for service and would likely rely on these facilities and/or dealers to perform repairs, additional training is expected to be primarily limited to basic preventative maintenance. Additionally, drivers may need limited training to familiarize themselves with new fueling/charging procedures. Given that these trucks are designed to mimic diesel trucks in general design and operation, it is not expected that training will create substantial economic burdens.

To help facilitate transition to ZE trucks at scale, studies have been conducted to assess potential workforce impacts. For example, the Port of Long Beach's "Port Community Electric Vehicle Blueprint" prepared for the California Energy Commission and completed in mid-2021, "establishes a comprehensive strategy to help identify the most cost-effective technologies, financial incentives, and infrastructure upgrades for creating the model sustainable, zero-emission port ecosystem of the 21st century." The Blueprint identifies a series of "actions to be taken over the next few years to ensure the port community has the necessary ZE equipment, infrastructure, financing, workforce, and community benefits to be successful."[179]

Cargo Diversion Costs

The potential for cargo diversion and the associated economic impacts have been addressed through other studies conducted by the Ports, and have therefore not been considered in this Assessment.

9.9. Summary of Findings for Economic Issues and Considerations

Table 36 summarizes whether, according to the specific criteria and base considerations (outlined above), the two commercially available ZE or LE drayage truck platforms offer economically workable alternatives to baseline diesel trucks as of late 2021. In the final column of the table, snapshot ratings are provided about the degree to which they already meet these basic considerations today, or at least are showing measurable progress towards achieving them by the end of 2024. Notably, Table 36 shows *no changes in the "pie ratings*" (i.e., there are no blue progress slices shown) relative to the 2018 Assessment for either of the two fuel-technology types across any of the Economic Workability parameters. This is largely because the purchase price of battery-electric trucks remained relatively constant despite increases in range. Note that this represents a snapshot for late-2021. It is reasonable to expect that improvements in these various parameters for Economic Workability will be realized over the next few years, given that multiple OEMs have announced near-term commercial roll-outs for Class 8 battery-electric trucks, starting in 2022.

Following the table, further discussion is provided about 1) the rationale used to assign the ratings in the table, and 2) the broad implications to the overall 2021 Drayage Truck Feasibility Assessment.

[179] California Energy Commission; "Final Project Report: Port Community Electric Vehicle Blueprint;" prepared by the Port of Long Beach, Grant Farm, Center for International Trade & Transportation, and Zero Net Energy Alliance; CEC-600-2021-037; July 2021, https://www.energy.ca.gov/publications/2021/port-community-electric-vehicle-blueprint.

Table 36. Summary of ratings by key criteria: 2021 Economic Workability

Economic-Related Criteria/Issue	Base Considerations for Assessing General Economic Workability	Achievement of Criteria in 2021 (Commercially Available Truck Platforms)	
		ZE Battery-Electric	LE NG ICE
Incremental Vehicle Cost	The upfront capital cost for the new technology is affordable to end users, compared to the diesel baseline.	◔	◕
Fuel and Other Operational Costs	The cost of fuel/energy for the new technology is affordable, on an energy-equivalent basis (taking into account vehicle efficiency). Demand charges/TOU charges (if any) are understood and affordable. Net operational costs help provide an overall attractive cost of ownership.	◑	●
Infrastructure Capital and Operational Costs	Infrastructure-related capital and operational costs (if any) are affordable for end users.	◔	●
Potential Economic or Workforce Impacts to Make Transition	There are no known major negative economic and/or workforce impacts that could potentially result from transitioning to the new equipment.	●	●
Existence and Sustainability of Financing to Improve Cost of Ownership	Financing mechanisms, including incentives, are in place to help end users with incremental vehicle costs and/or new infrastructure-related costs, and are likely remain available over the next several years.	◕	◕

Legend: Economic Workability (2021)

○ ◔ ◑ ◕ ●

Little/No Achievement — = Progress since 2018 Assessment — Fully Achieved

Source: based on preliminary OEM survey responses, OEM product information, various government sources, and Tetra Tech team's industry knowledge.

ZE Battery-Electric – The purchase price of a Class 8 battery-electric truck is roughly two to three times greater than a comparable new diesel truck. This higher incremental cost can be offset by lower fuel (energy) and maintenance costs; in the case of BETs, cost of ownership is dependent on the fleet's realized cost for electricity. Electricity costs are dependent on numerous factors, and substantial cost differences can exist based on the charging strategy implemented at a particular location. These differences lead to a broad range of BET ownership costs. They may be comparable to diesel, or they may be substantially greater, based solely on the utility rate available to the fleet. Additional cost uncertainty exists for maintenance costs; maintenance savings costs on BETs are currently highly speculative and likely to remain so, until ongoing demonstrations provide more-robust data to refine estimates.

Because most drayage truck operators are assumed to rely on third parties to perform significant repairs that might require specialized maintenance facilities and tools, it is assumed that dealer networks and repair facilities will make the required investments (or already have made those investments) to service trucks.

Incentives currently available to battery-electric trucks can dramatically alter the cost of ownership relative to diesel trucks. Purchase incentives combined with credits through the LCFS program can reduce cost of ownership down to 25 to 40 percent of diesel trucks. Unfortunately, the long-term availability of these incentives is not guaranteed. Additionally, there are insufficient funds in current purchase incentive programs to provide incentives for more than a small fraction of the total drayage fleet.

LE Natural Gas ICE – Although a new Class 8 natural truck has a higher incremental purchase price relative to a baseline diesel truck (about 40 to 50 percent), its cost of ownership (12-year vehicle lifetime) is similar to the diesel truck. Cost of ownership and payback time are driven primarily by lower costs of natural gas fuel (on an energy-equivalent basis) compared to diesel (the "fuel price spread"). Today's typical fuel price spread between diesel and CNG provides the necessary fuel cost savings to recover the higher incremental purchase price. However, cost of ownership is sensitive to this price spread, and actual cost savings could change significantly if the price spread collapses or expands.

Infrastructure costs are generally covered by the assumed fuel prices in this analysis. However, fleets that choose to construct their own fueling stations may ultimately realize lower fuel prices and a return on investment relative to public access stations. Maintenance and support for privately owned stations are available through service contracts to third parties, or may be taken on by the station owner.

Because the majority of drayage truck operators are assumed to rely on third parties to perform significant repairs that might require specialized maintenance facilities and tools, it is assumed that dealer networks and repair facilities will make the required investments (or have already made those investments) to service trucks.

Similar to the case with battery-electric trucks (albeit, to a lesser extent), incentives remain important and uncertain determinants for the TCO of Class 8 natural gas trucks. Significantly, in 2019 (after the 2018 Assessment) CARB removed natural gas HDVs as eligible options to receive funding under HVIP. This eliminated an important source of funding to help fleets "buy down" the incremental cost of heavy-duty natural gas trucks. Today, other incentive programs and opportunities exist for Class 8 natural gas trucks; however, they are more difficult to access and their long-term availability is not guaranteed. Additionally, available funding in current incentive programs is only sufficient to help replace a small fraction of the total drayage fleet. It is noteworthy that fuel credits through the LCFS and federal Renewable Fuel Standard (RFS) allow natural gas stations to offer ultra-low-carbon RNG at an equivalent price to fossil natural gas. While this does not help improve a purchasing fleet's TCO, it enables achievement of very significant GHG reductions at no additional cost (compared to the baseline option to purchase conventional natural gas).

10. Findings and Conclusions for 2021 Feasibility Assessment for Drayage Trucks

10.1. Summary of the Assessment's Scope, Methodology and Breadth of Application

This 2021 Feasibility Assessment for Drayage Trucks applied five key parameters to examine which (if any) emerging zero-emission (**ZE**) and/or near-zero-emission (**LE**) fuel-technology platforms for Class 8 trucks are demonstrably capable of, and ready for, broad deployment in revenue drayage service at the two Ports, in 2021 or within approximately three years.

The five parameters applied to assess overall feasibility qualitatively and collectively were as follows:

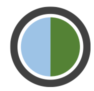
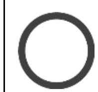
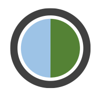
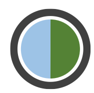
- Commercial Availability
- Technical Viability
- Operational Feasibility
- Availability of infrastructure and Fuel
- Economic Workability (Key Economic Considerations and Issues)

Two of these feasibility parameters – Commercial Availability and Technical Viability – were used to initially screen five core **ZE** and **LE** fuel-technology platforms that appear to hold the most promise to power large numbers of Class 8 drayage trucks today, or by 2024. Those fuel-technology platforms that were shown to meet basic considerations for these two parameters today (or within a three-year timeframe) were then further assessed by applying the three remaining feasibility parameters (Operational Feasibility, Infrastructure Availability and Economic Workability).

10.2. Summary of Findings: Commercial Availability

As summarized below, two ZE or LE fuel-technology platforms are (as of late 2021) are emerging as OEM built and sold Class 8 trucks suitable for drayage. The table below restates the findings on Commercial Availability. This is followed by a brief summary of the main findings.

Table 37. Summary of findings for 2021 Commercial Availability

Commercialization Criteria	Base Considerations	Assessment of Criteria Achievement in 2021 by Leading ZE and NZE Fuel-Technology Drayage Truck Platforms				
		ZE Battery-Electric	ZE Fuel Cell	LE Hybrid Electric	LE NG ICE	LE Diesel ICE
Production and Sales with Major OEM Involvement	Production and CARB certification by either a major Class 8 truck OEM, or by a proven technology provider that has partnered with the major OEM.					
Proven Network/Capabilities for Sales, Support and Warranty	Demonstrated existing (or near-term planned) network of sufficient dealerships to sell, service, warranty and provide parts for all commercially deployed drayage trucks.					
Sufficient Means and Timeline for Production	Demonstrated capability to manufacture sufficient numbers of Class 8 trucks (suitable for drayage) within timeline to meet existing or expected demand.					
Existence of Current and/or Near-Term Equipment Orders	Demonstrated backlog of orders, or credible expression of interest from prospective customers to submit near-term orders.					

Legend: Commercial Availability (2021)

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

Source of Ratings: based on OEM survey responses, OEM product information, various government sources, and consultant's industry knowledge.

- **ZE** battery-electric technology will be commercially offered in drayage-capable Class 8 trucks by multiple OEMs in 2022, and beyond. At least six OEMs (three traditional and three start-up) will initiate limited-scale production of battery-electric Class 8 trucks (primarily day cab models). Individual OEMs appear likely to produce and sell hundreds of early commercial trucks for national rollouts. Government incentive efforts (please see Section 12 – Appendix B: Relevant Incentive Programs) indicate that most of these early deployment units will be deployed for SPBP drayage. Early commercial battery-electric trucks will initially be restricted to short-haul and/or lighter-weight drayage applications. In parallel, OEMs will use larger, more-comprehensive demonstrations (e.g., JETSI) to ensure that they and their fleet customers have time to identify and resolve issues and problems that are common with early commercial launches of emerging fuel-technology platforms. Notwithstanding the remaining challenges for Class 8 battery-electric trucks (high cost/price, range limitations, ongoing need to improve technological viability and robustness, long lead times to build-out charging infrastructure, and the need to definitively prove adequacy for providing service and parts), Class 8 battery-electric tractors now largely achieve key criteria for Commercial Availability, although their use will initially be limited to short-haul and/or lighter-weight drayage applications.

- **LE** natural gas ICE technology is the dominant commercially available Class 8 truck platform powered by a ZE or LE system. At least five of the six long-standing OEMs are offering Class 8 LE trucks powered by the 12-liter Cummins Westport ISX12N engine. Drayage trucks powered by this natural gas ICE technology have now fully achieved "Commercial Availability" status, according to the key criteria and considerations outlined in this Assessment. Specifically, today's Class 8 natural gas trucks are 1) mass-produced and sold by multiple major Class 8 truck OEMs; 2) available in a wide array of different day cab and sleeper truck models; 3) powered by CWI's drayage-proven, CARB-certified 12-liter ISX12G LE engine; 4) capable of providing diesel-equivalent performance and range in all three general types of drayage trucking, and 5) fully supported by OEMs for the key provisions identified in the table (warranty, parts, maintenance, training, etc.). One key *remaining* market risk factor is that currently, only one engine manufacturer (CWI) is selling heavy-duty natural gas engines suitable for Class 8 heavy-duty trucks used in drayage.

The other three core fuel-technology platforms – ZE Fuel Cell, LE Hybrid Electric, and LE Diesel ICE – did not meet the basic criteria and considerations to be deemed commercially available in late 2021, nor do they appear on that path by 2024.

However, it is noteworthy that Class 8 ZE hydrogen fuel cell trucks have much in common with battery-electric versions, and often use the same basic OEM platforms. Truck OEMs and their partners that have announced activities to develop, demonstrate and eventually commercialize ZE fuel cell trucks include Daimler and Volvo (in a 50:50 joint venture), Kenworth (teamed with Toyota for the fuel cell engine/system), Nikola Motors, Hino (also teamed with Toyota), Navistar International (teamed with General Motors for the fuel cell engine/system), Hyundai, and start-up Hyzon. Based on these significant OEM developments and plans, the prospects appear to be good that early commercial Class 8 ZE fuel cell trucks will be available from such OEMs by late 2024 or early 2025.

10.3. Summary of Findings: Technical Viability

Technical Viability is the second of two parameters used in this study to screen the five core fuel-technology platforms for overall feasibility. The rationale for this screening procedure is straightforward. Until a particular fuel-technology platform 1) has achieved (or is approaching) the minimum threshold for Technical Viability, and 2) it meets Commercial Availability criteria (i.e., it is becoming a fully certified product offered by a major Class 8 truck OEM), it is premature to evaluate potential for broad-scale deployment in the San Pedro Bay drayage fleet within the timeframe of this 2021 Assessment.

To assess Technical Viability using common and established metrics, snapshot TRL ratings were assigned to each of the five core emerging ZE and LE platforms. It was found that two fuel-technology platforms **ZE battery-electric and LE natural gas ICE** – the same two found to meet the test for Commercial Availability – have demonstrated sufficient levels of Technical Viability (at or approaching at least TRL 8) to perform Class 8 drayage service (per the outlined parameters) at the SPBP.

Specifically:

- Class 8 **ZE** battery-electric drayage trucks are currently at **TRL 7 to TRL 8** (systems conditioning for early commercialization). Strong progress through multiple major OEM development and demonstration projects has moved Class 8 battery-electric trucks up a full TRL notch since the 2018 Assessment. Notably, OEMs will need additional demonstration time for larger-scale deployments (e.g., JETSI) to identify and address ongoing technology challenges. If this gets accomplished as anticipated, they are expected to reach TRL 8 to 9 by 2024. The estimated TRL 9 rating is specific to short-haul and/or lighter-weight drayage applications.
- Class 8 **ZE** hydrogen fuel cell trucks are currently at **TRL 7**; as such, they have not yet reached (or approached) the threshold used in this Assessment for achieving technical viability (TRL 8). However, multiple Class 8 OEMs are making good technological progress, with the result that this fuel-technology platform has moved up a full TRL notch since the 2018 Assessment. If this work continues at current (or faster pace), Class 8 hydrogen fuel cell trucks are expected to reach TRL 8 by 2024.
- Class 8 **LE** natural gas trucks are rated at **TRL 9** today. They have reached full technical viability and maturity, as documented in the May 2020 Addendum to the 2018 Assessment, and are fully commercial products.

The table below summarizes these findings.

Table 38. Summary of findings for 2021 Technical Viability and 2024 prognoses

TRL	Relative Stage of Development	Late-2021 TRLs for Leading Fuel-Technology Platforms (Drayage)	~2024: Educated Prognoses (by or before)	Comments / Basis for 2024 Educated Prognosis
TRL 9	**Systems Operations**	**LE NG ICE (TRL 9)**	**LE NG ICE (TRL 9)**; **ZE Battery (TRL 8 to 9)**	**ZE Battery Electric:** strong ongoing OEM progress gained through government-funded demos at growing scale will raise this platform to TRL 8 to 9* (*short-haul/lighter-weight drayage applications)
TRL 8	**Systems Conditioning**	**ZE Battery (TRL 7 to 8)**	**ZE Fuel Cell (TRL 8)**	**ZE Fuel Cell:** OEM technical progress will accelerate as optimized fuel cell/battery architectures emerge; on-board hydrogen storage continues to improve on cost and performance
TRL 7		**ZE Fuel Cell (TRL 7)**	**LE Diesel ICE (TRL 6 to 7, or higher?)**	**LE Plug-in Hybrid (not shown):** OEM interest is hard to gauge, but plug-in architecture enables valued "zero-emission mile" capability
TRL 6	**Technology Demonstration**	**LE Diesel ICE (TRL 5 to 6)**		
TRL 5	**Technology Development**			**LE Diesel ICE:** could "**leapfrog**" to TRL 8 or 9, but only if suitable diesel engine(s) get certified to 0.02 g/bhp-hr NOx (or other CARB OLNS)
TRL 4				

Source: TRL methodology adapted from U.S. DOE, "Technology Readiness Assessment Guide, Table 1: Technology Readiness Levels, September 2011 (see footnote). TRL ratings estimated based on input from 1) OEM surveys, 2) various technical reports, 3) demonstration activities, and 4) meetings with and/or inputs from CARB and South Coast AQMD technical staff.

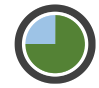
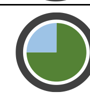
As described above, only two fuel-technology platforms meet the above tests for both Commercial Availability and Technical Viability: 1) ZE battery-electric and 2) LE natural gas ICE. Consequently, the remainder of this 2021 Assessment has been focused on further characterizing feasibility for these two platforms according to the remaining three parameters (Operational Feasibility, Infrastructure Availability, and Economic Workability).

10.4. Summary of Findings: Operational Feasibility

Results of the Operational Feasibility analysis are summarized below for the two Class 8 platforms that were determined to be Commercially Available and exhibit Technical Viability (as of late 2021): ZE battery-electric and LE natural gas ICE.

Notably, LE natural gas ICE trucks were already approaching full operational feasibility in late-2018. Consequently, the key movement under the Operational Feasibility parameter in late-2021 is the strong improvements made by OEMs with battery-electric technology for Class 8 trucks. Specifically, since the 2018 Assessment, multiple OEMs have significantly improved the capability of their pre-production products to meet the tough operational requirements of SPBP drayage. Important improvements have accrued for 1) range; 2) speed and frequency of charging; 3) driver comfort, safety and recharging; and 4) availability of replacement parts and vehicle support. The table below summarizes these findings, followed by additional discussion.

Table 39. Summary of findings for 2021 Operational Feasibility

Operational Feasibility Criteria/Parameter	Base Considerations for Drayage Platforms to Achieve Operational Feasibility	Achievement of Criteria for Remaining Drayage Truck Platforms	
		ZE Battery-Electric	LE NG ICE
Basic Performance	Demonstrated capability to meet drayage company needs for basic performance parameters including power, torque, gradeability, operation of accessories, etc.		
Range	Demonstrated capability to achieve per-shift and daily range requirements found in San Pedro Bay drayage.		
Speed and Frequency of Fueling/Charging	Demonstrated capability to meet drayage company needs for speed and frequency to refuel / recharge such that revenue operation is not significantly reduced relative to diesel baseline.		
Driver Comfort, Safety, and Fueling Logistics	Proven ability to satisfy typical drayage trucking company's needs for comfort, safety and refueling procedures.		
Availability of Replacement Parts and Support for Maintenance/Training	Verifiable existence of and timely access (equivalent to baseline diesel) to all replacement parts needed to conduct scheduled and unscheduled maintenance procedures.		
	Verifiable existence of maintenance procedure guidelines and manuals, including OEM-provided training courses upon purchase and deployment of new trucks.		

Legend: Operational Feasibility **(2021)**

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

Source: Based on Drayage Truck Operator Survey responses, footnoted studies, OEM product information, and consultant's industry knowledge.

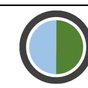
- **ZE** Class 8 battery-electric trucks have been significantly improved by multiple OEMs across many parameters since the 2018 Assessment. These improvements have led to better operational feasibility for their fleet customers. As of late-2021, it appears that the early commercial battery-electric trucks that will enter into series production (at small volume) in 2022 and 2023 will be capable of meeting basic performance requirements for short-range and/or lighter-weight drayage operations. They are likely to generally outperform diesel trucks with respect to power, torque, and gradeability. However, range, weight, and recharging time remain barriers that limit applicability of current-technology Class 8 battery-electric trucks. Additionally, safety concerns must be further addressed (e.g., the potential for thermal events in current-technology high-voltage battery packs). This fuel-technology platform is on the threshold of achieving the base operational feasibility requirements for LMCs when used in niche, short-range and/or lighter-weight drayage applications.

- **LE** Class 8 trucks powered by natural gas ICE technology now achieve full Operational Feasibility for LMCs performing drayage at the Ports. They continue to offer the only alternative technology (ZE or LE) that can achieve the daily range requirements and fueling intervals expected by drayage operators. Basic performance metrics, range, fueling frequency and speed, driver comfort and safety, and maintenance support are generally comparable to diesel trucks. Maintenance support is solid today, and scalable with increased deployments of natural gas trucks through the use of existing truck and engine dealerships.

10.5. Summary of Findings: Infrastructure Availability

With the development ZE and LE platforms progressing quickly, infrastructure has emerged as one of the most significant near-term barriers to wide-scale adoption of these technologies. Results of the Infrastructure Availability analysis are summarized below for the two ZE or LE fuel-technology platforms determined to be Commercially Available and Technically Viable for Class 8 truck platforms suitable for drayage.

Table 40. Summary of findings for 2021 Infrastructure Availability

Infrastructure Criteria/Parameter	Base Considerations for Assessing Infrastructure Availability	Achievement of Criteria for Remaining Drayage Truck Platforms	
		ZE Battery-Electric	LE NG ICE
Dwell Time at Station	Fueling/Charging can be accommodated within typical work breaks, lunches, other downtime compatible with trucking company schedules and operational needs.		
Station Location and Footprint	Fleets have existing onsite access to fueling infrastructure, or can be fueled/charged conveniently and affordably off site, at public or private stations. New infrastructure can be installed without extensive redesign, reconfiguration or operational disruptions and there is sufficient electrical or natural gas capacity at the site.		
Infrastructure Buildout	Infrastructure can be constructed at a pace consistent with fleet adoption and able to meet fleet fueling/charging requirements by the end of the assessment period.		
Existence of/Compatibility with Standards	A sufficient body of codes and standards exist from appropriate organizations that enables safe and effective refueling/recharging. The refueling/recharging station technology has already been installed at other trucking companies in the U.S., with sufficient time to assess performance and safety.		

Legend: **Infrastructure Availability (2021)**

Little/No Achievement = Progress since 2018 Assessment Fully Achieved

Source: based on preliminary OEM survey responses, OEM product information, various government sources, and Tetra Tech team's industry knowledge.

- **ZE** battery-electric truck charging infrastructure has made significant advances in developing harmonized standards since 2018. Notably, the parameters of "Station Location and Footprint" and "Infrastructure Buildout" have not significantly changed since the 2018 Assessment, although important efforts are underway. Significant uncertainty remains about how rapidly new charging stations and subsequent EV charging loads will be deployed. The Infrastructure Availability criteria is partially met today for battery-electric trucks.

- **LE** natural gas trucks rely on well-known and proven fueling infrastructure currently in use in many heavy-duty applications. Due to this long history, standards are well-known and the industry largely adheres to a single set of compatible fuel system designs that ensure broad interoperability between vehicles and stations. Fueling times are typically longer than diesel but user fleets have adapted to this modest time cost. While additional fueling infrastructure (private and public) may be required to accommodate large expansion of the natural gas drayage truck fleet, several natural gas fuel station operators have communicated strong willingness and readiness to construct fueling stations at pace with truck deployments. Notably, it is not possible to be certain that station development could occur at a pace to match a full transition of the drayage fleet to natural gas by 2024. However, it appears that this fuel-technology platform fully achieves Infrastructure Availability in terms of ability to support a large portion of the SPBP drayage fleet by 2024.

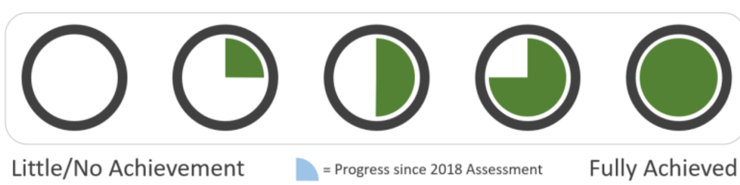
10.6. Summary of Findings: Economic Workability

The drayage truck sector is generally a low-margin, low-asset base sector. Technologies that can provide a cost of ownership similar to, or better than, diesel are needed. Results of the economic workability analysis are summarized below for the two ZE or LE fuel-technology platforms determined (as of late 2021) to be Commercially Available and have Technical Viability for Class 8 trucks suitable for drayage. Notably, there are no changes in the "pie ratings" since the 2018 Assessment, for either fuel-technology platform.

Table 41. Summary of findings for 2021 Economic Workability

Economic-Related Criteria/Issue	Base Considerations for Assessing General Economic Workability	Achievement of Criteria for Remaining Drayage Truck Platforms	
		ZE Battery-Electric	LE NG ICE
Incremental Vehicle Cost	The upfront capital cost for the new technology is affordable to end users, compared to the diesel baseline.		
Fuel and Other Operational Costs	The cost of fuel/energy for the new technology is affordable, on an energy-equivalent basis (taking into account vehicle efficiency). Demand charges/TOU charges (if any) are understood and affordable. Net operational costs help provide an overall attractive cost of ownership.		
Infrastructure Capital and Operational Costs	Infrastructure-related capital and operational costs (if any) are affordable for end users.		
Potential Economic or Workforce Impacts to Make Transition	There are no known major negative economic and/or workforce impacts that could potentially result from transitioning to the new equipment.		
Existence and Sustainability of Financing to Improve Cost of Ownership	Financing mechanisms, including incentives, are in place to help end users with incremental vehicle costs and/or new infrastructure-related costs, and are likely remain available over the next several years.		

Legend: Economic Workability **(2021)**



Source: based on preliminary OEM survey responses, OEM product information, various government sources, and Tetra Tech team's industry knowledge.

- **ZE** battery-electric trucks have substantially higher upfront capital costs (roughly two to three times baseline diesel trucks), and require significant investments in infrastructure. Incentives currently available to buy down the capital costs of battery-electric trucks can greatly reduce the cost of ownership relative to diesel trucks. Purchase incentives combined with credits through the LCFS program can reduce cost of ownership down to 25 to 40 percent of diesel trucks. Unfortunately, the long-term availability of these incentives is not guaranteed. Additionally, there are insufficient funds in current purchase incentive programs to provide incentives for more than a small fraction of the total drayage fleet. Total cost of ownership comparisons are dependent on the realized cost of electricity to the truck operator, which varies by location. Thus, fleets will experience significantly different costs of ownership relative to diesel, depending on where and how the trucks are charged. When evaluated without including purchase incentives, battery-electric trucks do not achieve the Economic Workability parameter for feasibility.

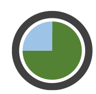
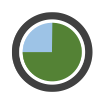
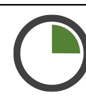
- **LE** natural gas trucks have higher upfront capital costs but an overall cost of ownership comparable to diesel trucks. These comparisons are sensitive to changes in the fuel price spread between diesel and natural gas, creating some risk to the return on the higher capital cost of natural gas trucks. Incentives can improve the cost of ownership comparison, but the long-term availability and value of these incentives is uncertain. When evaluated without including purchase incentives, TCO costs for Class 8 natural gas trucks are within 10 percent of baseline diesel trucks, and nearly achieve the Economic Workability parameter for feasibility.

10.7. Conclusion: 2021 Feasibility per All Five Key Parameters

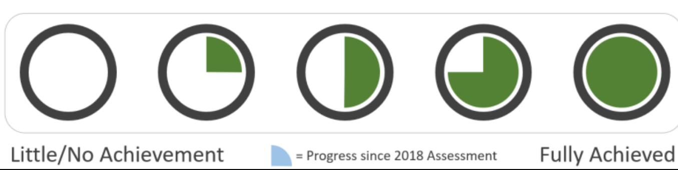
Table 42 summarizes the relative degree to which the two commercially available and technically viable fuel-technology platforms achieve each of the five key feasibility parameters today, in the specific context of drayage service for the SPBP.

NOTE: The ratings for overall achievement of each five feasibility parameter (see the table below) are based on the analysis of several criteria within that parameter. Because each criterion is important for the success of a given fuel-technology platform in drayage, the overall achievement ratings are based on the lowest criterion score for each feasibility parameter.

Table 42. Summary of 2021 overall feasibility (all five key parameters)

Feasibility Parameter / Criteria	**Overall Achievement* of Criteria in 2021 (Commercially Available / Technically Viable Truck Platforms)**	
	ZE Battery-Electric	**LE NG ICE**
Commercial Availability		
Technical Viability	**TRL 7 to 8 (moving to 8 to 9*) (*for short-haul drayage)**	**TRL 9**
Operational Feasibility		
Infrastructure Availability		
Economic Workability		

Legend: Achievement of Each Noted Parameter / Criteria (2021)



*These ratings for overall achievement of each five feasibility parameter are based on the analysis of several criteria within that parameter. Because each criterion is important for the success of a given fuel-technology platform in drayage, the overall achievement ratings are based on the lowest criterion score for each feasibility parameter.

11. Appendix A: Acceptable Data Sources

The following table summarizes the general types of data sources that are considered "acceptable" to use, as well as those types considered to be "unacceptable."

Acceptable Information/Data Sources	Unacceptable Information/Data Sources
• Technical reports, policy documents, and assessments prepared by government agencies with acknowledged fuel-technology expertise • Certification / verification Executive Orders by the California Air Resources Board or the U.S. EPA • Peer-reviewed journal articles • Industry trade group data, with sources • Technology demonstration reports prepared by equipment manufacturers, end users, and/or funding agencies • Official commercial product announcements and detailed product datasheets • Technical reports and whitepapers prepared by subject matter experts • Presentations from manufacturers and end users describing experience and/or analysis of relevant technologies and market dynamics • Material deemed to be credible, verifiable, technical, and relevant by Port representatives and/or TAP advisors	• Unsourced reports • Personal accounts or anecdotes (unless provided by individuals verified to be involved in an official capacity with activities listed in the "Acceptable" column of this table) • Policy advocacy documents without verifiable data/sources to support claims • Material that is deemed NOT to be credible, verifiable, technical, and/or relevant by Port CAAP representatives and/or TAP advisors

12. Appendix B: Relevant Incentive Programs

Below are additional details about key funding programs that pertain to purchasing ZE and/or LE Class 8 trucks suitable for drayage at the SPBP.

Notably, CARB has recently launched a "Funding Finder Tool" designed to help stakeholders search and filter available heavy-duty vehicle and infrastructure incentive programs in California. This tool (https://fundingfindertool.org/?) allows filtering of eligible incentive programs by location (e.g., county, ZIP Code), vehicle or equipment type, and other parameters.

12.1. San Pedro Bay Ports Clean Truck Fund Rate

The Clean Truck Fund Rate (CTF Rate) was jointly approved by the Ports' respective Board of Harbor Commissioners in November 2021. The CTF Rate is a primary mechanism to achieve truck-related goals of the 2017 CAAP Update. It is currently set at $10 per loaded twenty-foot equivalent (TEU) container, with a "lifetime" exemption for ZE trucks and a "limited exemption" for "low-NOx" trucks.[180] The CTF Rate is expected to annually generate approximately $90 million, in its initial years of implementation. These funds will be used to help incentivize transition of the SPBP drayage fleet to zero-emission and low-NOx trucks.[181]

The Ports are working together to develop spending priorities and other details for incentive funds collected via the CTF Rate. This includes the dollar amounts that will be allocated to incentivize ZE and low-NOx trucks; the form of incentives (e.g., grants, loans, vouchers); how the program will be administered; and other key parameters. The final package will be brought before the two Ports' respective Board of Harbor Commissioners for approval in 2022.[182,183]

12.2. HVIP Program

California's HVIP program offers incentives for the purchase of new on-road heavy-duty vehicles powered by progressively lower-emitting propulsion technologies. Funding is provided through the State's Greenhouse Gas Reduction Fund (GGRF). As of late-2021, HVIP only funds ZE fuel-technology platforms for heavy-duty Class 8 trucks (those identified in Section 5.3 of this Assessment). Theoretically, HVIP can provide incentives for either battery-electric or fuel-cell-electric trucks. Presently, however, only battery-electric versions are certified by CARB for eligibility.

In November 2021, CARB opened its "third and final wave of HVIP funding for 2021." All $63 million of this was "requested" by dealers (for their fleet customers) within a few minutes. Those funds were highly focused on deployment of ZE Class 8 trucks in drayage applications, under the Project 800 project. In March 2022, HVIP re-opened to voucher requests for a total of $430 million for eligible HDV project types; this included a special "Drayage Truck Set-Aside" of at least $75 million.[184] As of mid-2022, funds specifically set aside for drayage trucks have been fully subscribed, but CARB is still accepting and funding Class 8 tractor projects out of limited "standard HVIP funds." Details about HVIP funding allocations are continually updated and available at https://californiahvip.org/funding/.

---

[180] Low-NOx trucks are referred to as those with "natural gas fueled engines meeting the 0.02 g NOx/bhp-hr emission standard. Low-NOx trucks purchased and registered for SPBP drayage prior to December 31, 2022 are exempt from the CTF rate through 2027 (Port of Los Angeles) or through 2031 (Port of Long Beach).
[181] The Ports have similar (but not identical) requirements and implementation details. Port-specific details can be found in the two references below.
[182] Port of Long Beach, "Legislation Text, HD-21-563 Version: 1, Amendment to Port of Long Beach Tariff No. 4, Items 1000-1041 Clean Truck Program (CTP)," November 8, 2021, accessed at https://polb.granicus.com/GeneratedAgendaViewer.php?view_id=77&clip_id=7434.
[183] Port of Los Angeles, Los Angeles Board of Harbor Commissioners meeting of November 4, 2021, Regular Agenda Item No. 5 (request to approve a Temporary Order to amend POLA Tariff No. 4 establishing Clean Truck Fund and Clean Truck Fund Rate), accessed at https://www.portoflosangeles.org/commission/agenda-archive-and-videos/agendas/2021/11042021-regular-agenda.
[184] Calstart (HVIP program administrator), "HVIP FY21-22 Policy Changes," emailed announcement, November 22, 2021.

12.3. Carl Moyer Memoria Air Quality Standards Attainment Program

California's Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program) provides incentive funding for "cleaner-than-required engines, equipment and other sources of pollution providing early or extra emission reductions." Unlike HVIP, the Moyer program requires scrapping an older, in-use unit for each unit that gets replaced with a newer, low- or zero-emitting version. Projects cannot exceed cost-effectiveness limits specified in program guidelines. CARB, which makes the rules and guidelines for the Moyer Program, notes the following with regard to awards for drayage trucks:

> *Vehicles subject to the Statewide Drayage Truck Regulation may be eligible for Moyer Program Funding for up to one year before the applicable compliance deadline. Since January 1, 2014, drayage trucks have been required to be equipped with 2007 model year or newer engines. Therefore, engines older than model year 2007 are not eligible for Carl Moyer Program funding. Replacement engines certified to the 2010 emissions standards or cleaner are eligible. By January 1, 2023, all trucks subject to the Drayage Truck Regulation will be required to have a 2010 or newer model year engine.* [185]

A relatively new feature is that the Moyer Program can now fund non-residential electric vehicle charging stations (new stations, or conversion/expansion of existing stations). This includes DC fast chargers "along freeway roadway corridors" and at "destination centers" where conventional diesel SPBP drayage trucks routinely operate and fuel.[186]

Because Moyer awards are administered by local air quality management district, South Coast AQMD manages solicitations involving the SPBP. As of late-2021, South Coast AQMD's Carl Moyer Program is closed,[187] but it may reopen in 2022 with relevance to funding Class 8 trucks used in drayage.

12.4. Low Carbon Fuel Standard

California's Low Carbon Fuel Standard allows producers of alternative transportation fuels to generate credits based on lifecycle GHG reductions relative to established diesel and gasoline benchmarks. These credits can have substantial value; average prices typically have ranged from $150 to $215 per credit during 2021.[188] One credit is equal to one metric ton of GHG emissions reductions.

CARB adopted important revisions to the LCFS program that went into effect January 1, 2019. In addition to strengthening carbon-reduction requirements for transportation fuels and extending the program out to 2030, CARB adopted LCFS modifications that enable heavy-duty fleets to better monetize use of heavy-duty electric vehicles (battery-electric and fuel cell) and their associated charging/fueling stations. Specifically, CARB added a ZEV infrastructure provision that incentivizes fleets to use DC fast charging and/or hydrogen fueling stations that meet prescribed low-carbon pathways. In addition to generating LCFS credits for dispensed energy/fuel, the eligible DC fast charger or hydrogen station can generate infrastructure credits based on the capacity of the station or charger. Details are available in a series of guidance documents on CARB's LCFS website.[189]

12.5. South Coast AQMD VW Mitigation Trust Freight and Marine Projects

The Volkswagen (VW) Environmental Mitigation Trust provides hundreds of millions of dollars in California to fund emission reductions projects under the State's Beneficiary Mitigation Plan. California's VW funding plan recently allocated $60 million in funds for projects that can "accelerate the replacement of older, higher polluting engines, particularly in areas that are

---

[185] California Air Resources Board, "Carl Moyer Program: Drayage Trucks at Seaports and Railyards," accessed online on December 2, 2021, https://ww2.arb.ca.gov/our-work/programs/carl-moyer-program-drayage-trucks-seaports-and-railyards/about.

[186] California Air Resources Board, Carl Moyer Memorial Air Quality Standards Attainment Program 2017 Guidelines," https://ww3.arb.ca.gov/msprog/moyer/guidelines/2017gl/2017_gl_chapter_10.pdf.

[187] South Coast Air Quality Management District, "The Carl Moyer Memorial Air Quality Standards Attainment Program," accessed online on December 4, 2021, http://www.aqmd.gov/home/programs/business/carl-moyer-memorial-air-quality-standards-attainment-(carl-moyer)-program.

[188] California Air Resources Board, "Monthly LCFS Credit Transfer Activity Report for October 2021." Posted November 9, 2021. https://ww3.arb.ca.gov/fuels/lcfs/credit/lrtmonthlycreditreports.htm

[189] California Air Resources Board, "LCFS Guidance Documents, User Guides, and FAQs," accessed December 14, 2021, https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/lcfs-guidance-documents-user-guides-and-faqs.

disproportionately impacted by air pollution, such as freight corridors, ports, and rail yards." In the Ports jurisdiction, South Coast AQMD administers the VW plan on behalf of CARB, including allocation of funds specifically focused on helping fleets purchase new ZE or LE drayage trucks. South Coast AQMD's 2021 VW funding program was quickly oversubscribed; the next funding installment from CARB is expected sometime in 2022. Details about eligible incentive awards to help SPBP drayage fleets purchase ZE and/or LE trucks are available at https://xappprod.aqmd.gov/vw/index.html.

12.6. Other State-Funded Incentive Programs

EnergIIZE (Energy Infrastructure Incentives for Zero- Emission Commercial Vehicles) – Funded by CEC and implemented by CALSTART, EnergIIZE provides incentives for charging/fueling infrastructure for medium- and heavy-duty battery-electric and hydrogen fuel cell vehicles that are operated and domiciled in California. EnergIIZE includes a "Funding Finder Tool" (https://fundingfindertool.org/?) that helps fleets and other stakeholders search for incentive funding programs based on location (zip code), fleet type, type of ZE HDV (battery electric or fuel cell electric), and other parameters.[190]

RHETTA (Research Hub for Electric Technologies in Truck Applications) – CEC and CALSTART have teamed with the Electric Power Research Institute and other public-private partners to implement this program. RHETTA is a grant funding opportunity that is focused on developing, advancing, and deploying "innovative high-power charging infrastructure along key freight corridors that promote the adoption of Class 7 and 8 battery electric zero-emission (ZE) trucks." Phase 1 of this program goes from 2021 to 2025.[191]

12.7. Local Utility Incentive Programs for Electric Trucks and/or Charging Infrastructure

Southern California Edison Charge Ready Program – As part of a five-year $356 million program, SCE has received approval from the California Public Utilities Commission to install electric infrastructure at customer sites to support charging of battery-electric vehicles, including heavy-duty drayage trucks, forklifts, and CHE. The program also allows SCE to offer rebates to customers for the purchase of charging stations. For fleets operating in SCE's business territory – which includes trucking companies performing drayage at the Port of Long Beach – Charge Ready helps them electrify their fleets by providing guidance "through every step of the process . . . including installing the infrastructure you need to support your fleet at low or no cost" to the fleet. An overview of Charge Ready is available at https://www.sce.com/evbusiness/overview, with details at https://crt.sce.com/program-details. SCE has recently proposed two new initiatives to help electrify commercial vehicles, including a rebate for registered battery-electric drayage trucks in SCE's service territory. Funding is expected to be available in late-2022.[192]

Los Angeles Department of Water and Power EV Programs – LADWP also offers programs to support commercial battery-electric truck deployments in its jurisdiction, which includes the Port of Los Angeles. LADWP's website (https://www.ladwp.com/) indicates the utility "is committed to a clean energy future, and putting our customers first" to facilitate adoption of EVs. This includes "Charge Up L.A." rebate programs for residents and businesses, and support to install public, workplace and fleet charging stations to create "EV communities across Los Angeles." LADWP's "near-term initiatives related to battery-electric charging incentives and build outs include expanding and improving rebate programs. LADWP indicates it plans to "secure long-term program funding sources to achieve enhanced targets" for building out battery-electric vehicle charging infrastructure.[193]

---

190 "EnergIIZE Factsheet," revised December 2021, https://www.energiize.org/.
191 Electric Power Research Institute, presentation by Mark Duvall to South Coast AQMD Clean Fuels Advisory Group, September 15, 2021.
192 Southern California Edison, "Energy for What's Ahead," presentation prepared by Aaron R. Dyer (Senior Project Manager for eMobility), for the 2022 AQMD Advisory Group Meeting (Mobile Source Working Group Meeting #2 – Zero Emission Infrastructure, February 4, 2022.
193 Los Angeles Department of Water & Power, "LADWP Zero Emission Vehicle Infrastructure," presentation prepared for the 2022 AQMD Advisory Group Meeting (Mobile Source Working Group Meeting #2 – Zero Emission Infrastructure, February 4, 2022.

13. Appendix C: Truck Operator Survey Questions and Summary of Responses

The following tables summarize the results received to the Truck Operator Survey that was issued in June 2021. Calculated fields used in the initial (2018) Assessment and again in 2021 are provided, and identified as such.

Question	Survey Results

1 **How many Class 8 trucks do you operate/dispatch in Southern California (including trucks operated by contractors)?**

Less than 10	10-25	25-50	50-100	100-250	250-500	>500	Responses	Response Rate
37	27	13	7	8	2	0	94	98%

2 **Of your trucks that operate in Southern California, please indicate the percentage of trucks whose service includes at least some drayage to/from the Ports.**

0-20%	20-40%	40-60%	60-80%	80-100%	Responses	Response Rate
6	4	12	5	69	96	100%

3 **Of your trucks that operate in Southern California, please indicate the percentage of trucks whose service is exclusively providing drayage to/from the Ports.**

0-20%	20-40%	40-60%	60-80%	80-100%	Responses	Response Rate
18	5	4	6	63	96	100%

Question	Survey Results

4 **What is the average fuel economy of port trucks that you dispatch (in miles/gallon)?**

Less than 4 mpg	4 to 5 mpg	5 to 6 mpg	6 to 7 mpg	7 to 8 mpg	More than 8 mpg	Responses	Response Rate
1	7	20	38	19	9	94	98%

Average MPG		Average MPG - Used		Average MPG - New	
Min	3.5	Min	3.5	Min	3.5
Max	8.5	Max	8.5	Max	8.5
Average	6.5	Average	6.50	Average	6.48
Avg. Wghtd.	6.81	Avg. Wghtd.	6.86	Avg. Wghtd.	6.95
Mode	6.5	Mode	6.5	Mode	6.5
Std Dev	1.1	Std Dev	1.1	Std Dev	1.1
Responses	94	Responses	63	Responses	49

5 **What is the typical annual maintenance/repair cost of port trucks that you dispatch?**

All Trucks

Min	$2,650
Max	$25,000
Average	$9,207
Mode	$5,000
Avg. Wghtd.	$9,018
Std Dev	$4,961

Primarily Purchases Used Trucks

Min	$2,650
Max	$25,000
Average	$8,574
Mode	$5,000
Avg. Wghtd.	$7,497
Std Dev	$5,515

Primarily Purchases New Trucks

Min	$2,800
Max	$20,000
Average	$10,290
Mode	$-
Avg. Wghtd.	$9,176
Std Dev	$6,300

Question	
6	

All Trucks

														Calculated Field	
Average mileage per shift:		Average shifts per day:		Maximum mileage per shift:		Maximum # of shifts:		Average hours per shift:		Average number of days per week in service:		Typical Loaded Operating Weight, including cargo (lbs):		Average Daily Operating Time	
Min	25	Min	1	Min	40	Min	1	Min	0	Min	0	Min	20000	Min	0
Max	400	Max	2	Max	630	Max	3	Max	12	Max	5	Max	90000	Max	24
Average	191	Average	1.4	Average	278	Average	1.6	Average	9.6	Average	4.9	Average	54871	Average	14
Avg. Wghtd.	209	Avg. Wghtd.	1.4	Avg. Wghtd.	355	Avg. Wghtd.	1.6	Avg. Wghtd.	9.9	Avg. Wghtd.	5.0	Avg. Wghtd.	58293	Avg. Wghtd.	14.2
Mode	200	Mode	1	Mode	300	Mode	2.0	Mode	10	Mode	5	Mode	40000	Mode	10
Std Dev	98	Std Dev	0	Std Dev	160	Std Dev	1	Std Dev	2	Std Dev	0.6	Std Dev	20210	Std Dev	6
Responses	78		71		77		74		78		63		62		69

All Trucks (continued)

Calculated Field		Calculated Field		Calculated Field		Calculated Field		Calculated Field		Calculated Field		Calculated Field		Calculated Field	
Average Annual Mileage		Average Daily Mileage		Average Maintenance Cost		Average Maintenance Cost - Used		Average Maintenance Cost - New		Avg. kWh/Day		Avg. kWh/Day - 1 Shift		Avg. kWh/Day - 2 Shifts	
Min	0	Min	0	Min	$0.03	Min	$0.03	Min	$0.03	Min	0	Min	100	Min	0
Max	208,000	Max	800	Max	$0.96	Max	$0.96	Max	$0.64	Max	2000	Max	1000	Max	2000
Average	64,433	Average	257	Average	$0.25	Average	$0.29	Average	$0.21	Average	641	Average	491	Average	906
Avg. Wghtd.	60,015	Avg. Wghtd.	252.2	Avg. Wghtd.	$0.22	Avg. Wghtd.	$0.23	Avg. Wghtd.	$0.27	Avg. Wghtd.	631	Avg. Wghtd.	483	Avg. Wghtd.	822
Mode	52,000	Mode	200	Mode	$0.38	Mode	$0.96	Mode	$0.38	Mode	500	Mode	500	Mode	750
Std Dev	44,609	Std Dev	177	Std Dev	$0.25	Std Dev	$0.28	Std Dev	$0.17	Std Dev	442	Std Dev	219	Std Dev	581

Question	Survey Results
6 (cont.)	**For those trucks serving the port, please provide your best estimates of the following data points for a typical truck.**

Primarily Purchases Used Trucks

Average mileage per shift:		Average shifts per day:		Maximum mileage per shift:		Average hours per shift:		Average number of days per week in service:		Typical Loaded Operating Weight, including cargo (lbs):		Average Daily Mileage (Calculated Field)		Maximum Daily Mileage (Calculated Field)	
Min	0	Min	0	Min	0	Min	0	Min	5	Min	0	Min	0	Min	0
Max	400	Max	2	Max	600	Max	3	Max	5	Max	90000	Max	600	Max	1200
Average	183	Average	1	Average	264	Average	10	Average	5	Average	55108	Average	167	Average	289
Avg. Wghtd.	207	Avg. Wghtd.	1.3	Avg. Wghtd.	324.4	Avg. Wghtd.	10.2	Avg. Wghtd.	5.0	Avg. Wghtd.	59848	Avg. Wghtd.	264	Avg. Wghtd.	490
Mode	300	Mode	1	Mode	0	Mode	10	Mode	5	Mode	40000	Mode	0	Mode	0
Std Dev	108	Std Dev	1	Std Dev	179	Std Dev	3	Std Dev	0.0	Std Dev	25656	Std Dev	165	Std Dev	305
Responses	44		36		41		42		35		37		35		36

Primarily Purchases New Trucks

Average mileage per shift:		Average shifts per day:		Maximum mileage per shift:		Average hours per shift:		Average number of days per week in service:		Typical Loaded Operating Weight, including cargo (lbs):		Average Daily Mileage (Calculated Field)		Maximum Daily Mileage (Calculated Field)	
Min	0	Min	0	Min	0	Min	0	Min	0	Min	0	Min	0	Min	0
Max	400	Max	2	Max	630	Max	12	Max	5	Max	90000	Max	800	Max	1200
Average	206	Average	2	Average	297	Average	9	Average	5	Average	53389	Average	241	Average	374
Avg. Wghtd.	160	Avg. Wghtd.	1.8	Avg. Wghtd.	276.4	Avg. Wghtd.	9.4	Avg. Wghtd.	5.0	Avg. Wghtd.	49828	Avg. Wghtd.	274	Avg. Wghtd.	487
Mode	0	Mode	2	Mode	0	Mode	8	Mode	5	Mode	0	Mode	0	Mode	0
Std Dev	126	Std Dev	1	Std Dev	185	Std Dev	2	Std Dev	1.1	Std Dev	30688	Std Dev	223	Std Dev	356
Responses	24		26		25		25		19		18		24		23

Question	Survey Results

7 **What percentage of the trucks that you dispatch to the Port of Los Angeles and the Port of Long Beach park at one of your facilities overnight?**

0-20%	20-40%	40-60%	60-80%	80-100%	Comments	Total Responses	Response Rate
15	1	6	10	61	7	93	97%

8 **What percentage of trucks that you dispatch to the Port of Los Angeles and the Port of Long Beach refuel at your facilities?**

0-20%	20-40%	40-60%	60-80%	80-100%	Comments	Total Responses	Response Rate
58	2	2	5	27	8	94	98%

9 **How much space is available at your typical facility for additional fueling/charging infrastructure?**

<500 square feet	500-2,500 square feet	2,500-5,000 square feet	5,000-10,000 square feet	>10,000 square feet	Comments	Total Responses	Response Rate
48	17	8	3	6	8	82	85%

10 **If you own some or all of your trucks, do you typically buy these in new or used condition?**

New	Used	Comments	Response Rate
32	51	16	86%

Question	Survey Results
11	**If you own some or all of your trucks, what is the average purchase price that you pay for those trucks?**

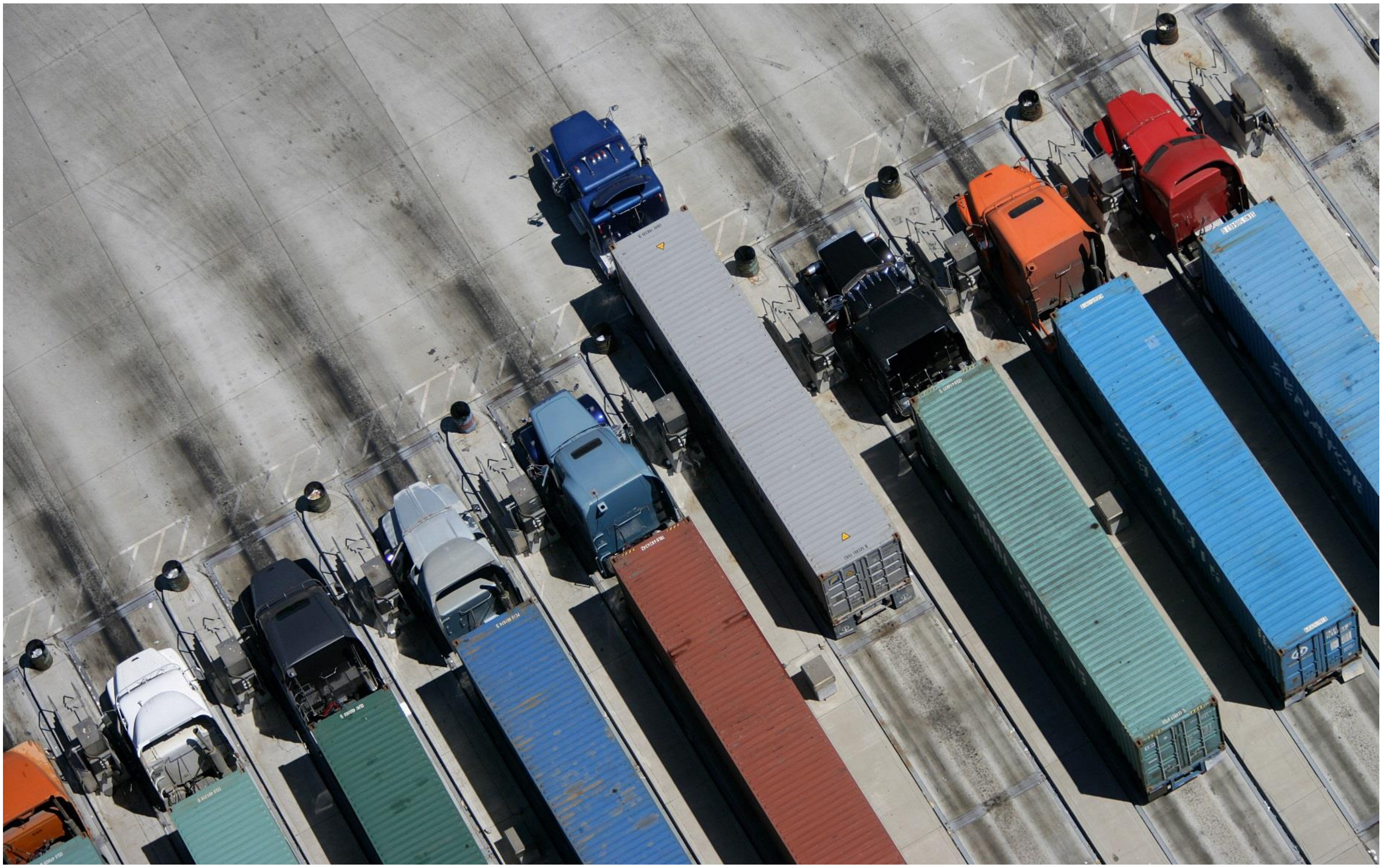
New Truck Purchase Price:		Used Truck Purchase Price:	
Min	$65,000	Min	$14,000
Max	$200,000	Max	$90,000
Average	$132,382	Average	$54,934
Avg. Wghtd.	$132,525	Avg. Wghtd.	$50,338
Mode	$150,000	Mode	$50,000
StdDev	$32,198	StdDev	$17,416
Total Responses	34	Total Responses	38

Question	Survey Results
12	**Are you considering purchasing trucks with any of the following alternative fuel platforms in the next three years?**

Natural Gas - CNG	Natural Gas - LNG	Battery-electric	Plug-in Hybrid Electric	Hydrogen Fuel Cell	Other	All of the above	None of the above	Please share any additional comments below.	Total Responses	Response Rate
21	11	19	9	5	1	8	45	13	92	96%

Question	Survey Results
13	**Grid resiliency refers to the use equipment and operational changes that allows you to continue to operate during a power outage. For example, installing solar panels and battery storage, back up generators, or other systems that can provide power. Have you begun planning or implementation around grid resiliency and energy management?**

No	I don't have the resources or technical expertise to plan for these types of projects at this time	Yes, planning only	Yes, implementing strategies	Total Responses	Response Rate
41	35	9	7	92	96%



SAN PEDRO BAY PORTS

CLEAN AIR ACTION PLAN

2021 UPDATE: FEASIBILITY ASSESSMENT for DRAYAGE TRUCKS

February 2023