California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Port of Long Beach Zero-Emissions Terminal Equipment Transition Project

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The Port wants to thank operators SSA Marine, Long Beach Container Terminal (LBCT), International Transportation Service (ITS), and Total Transportation Services, Inc. (TTSI) in their collaboration with the Project's technology vendors— Cavotec, BYD, and US Hybrid —to design and assess new zero-emissions equipment and vehicles. Each demonstration under this Project has been invaluable to the Port and its stakeholders in striving to achieve the zero-emission goals of the San Pedro Bay Ports' Clean Air Action Plan (CAAP).[1]

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Electric operations offer career opportunities of the future. The Port is grateful for the analysis conducted for the zero-emissions workforce as it relates to cargo-handling equipment by staff from Long Beach City College (LBCC) with critical input from the International Brotherhood of Electrical Workers (IBEW) Local 11, ITS, LBCT, SSA Marine, and TTSI. All participants completed surveys, participated in informational interviews about their programs, and shared their perspectives on the future zero-emission workforce needs.

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[1] www.cleanairactionplan.org

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance, and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued GFO-16-604 entitled "Sustainable Freight Transportation Projects" on November 29, 2016. This competitive grant solicitation was an offer to cost share the development of medium- and heavy-duty advanced technology vehicle demonstrations. The Port of Long Beach applied to GFO-16-604. The application was proposed for funding in the CEC's notice of proposed awards on February 21, 2017, and the agreement with the Port of Long Beach was executed as ARV-16-024 on July 20, 2017.

ABSTRACT

This report presents the results of the Port of Long Beach (Port) Zero-Emissions Terminal Equipment Transition Project (Project), whereby the Port led one of the nation's largest developments of medium- and heavy-duty (MHD) advanced technology vehicle demonstrations for Port operations.

The Port—in partnership with SSA Marine, Long Beach Container Terminal (LBCT), International Transportation Service (ITS), Total Transportation Services, Inc. (TTSI), multiple technology vendors, the International Brotherhood of Electric Workers (IBEW), and Long Beach City College (LBCC)—was awarded $9.755 million from the CEC under GFO-16-604 entitled "Sustainable Freight Transportation Projects" for one of the nation's largest demonstration and deployment projects for zero-emissions cargo-handling equipment (CHE).

The principal goal of the Project was to demonstrate various zero-emission cargo-handling equipment (CHE) at three container terminals. The second goal was to understand what it would take to transition four trucks running on natural gas to plug-in hybrid electric trucks capable of zero-emission operations. The third goal was to reduce greenhouse gas (GHG) and criteria air pollutant emissions, establishing workforce-training programs, and conduct outreach on the benefits of zero-emission Port technologies to other California ports, members of disadvantaged communities (DAC) and the public.

This Project sought to design, build, and demonstrate battery-electric yard tractors, grid-tied electric rubber-tired gantry (eRTG) cranes, and plug-in hybrid electric drayage trucks (PHET) powered by liquified natural gas (LNG). In a collaboration with the LBCC and the IBEW, the Project included an analysis performed on CHEs to project the workforce demand needed to support the transition to zero-emissions technology.

This Project also presents a comprehensive report of lessons learned for zero-emission design, build and demonstration that may improve zero-emission technologies soon. In the past six years alone, there has been increased participation of new technology vendors as well as crucial original equipment manufacturers (OEMs), and more interest from terminal operators looking to turnover their diesel fleets prior to any regulatory action on the horizon. It is with hope that these collaborations will support the continued advancement and eventual commercialization of zero-emission technologies for port operations.

Keywords: zero emissions, battery-electric yard tractors, electric rubber-tired gantry cranes, plug-in hybrid electric trucks, workforce assessment, cargo handling equipment

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Introduction and Background

The Port of Long Beach (Port)[2] is a major gateway for U.S.-Asia trade and is committed to reducing air pollution from its operations. The Port has set a goal of achieving zero-emissions by 2030 for all cargo-handling equipment and by 2035 for on-road trucks.

To achieve this goal, the Port has launched several initiatives, including investing in the development and advancement of zero-emission technologies, providing financial incentives for the purchase of zero-emission vehicles, collaborating with stakeholders to develop infrastructure for zero-emission vehicles, and educating the public about zero-emission technologies.

The Port has made significant progress in its zero-emissions journey. In 2022, the Port's electric cargo-handling equipment fleet grew to 19%, the largest such fleet in the United States. Since the 2017 Clean Air Action Plan (CAAP) Update, the Port was awarded over $326 million in grants to further the development and deployment of zero emissions equipment, vehicles, and infrastructure in Port operations[3].

The Port worked with several industry partners on this Project to electrify its operations. These partners include Southern California Edison (SCE), Cavotec, BYD Motors, US Hybrid, International Transportation Service (ITS), Long Beach Container Terminal (LBCT), Total Transportation Services Inc. (TTSI), and SSA Marine (SSA).

The Port has made immense progress in its zero-emissions journey but continues to take significant steps toward achieving its 2030 and 2035 goals.

Project Purpose

The Zero-Emissions Terminal Equipment Transition Project (Project) designed, built, and delivered into service battery-electric yard tractors with BYD, liquefied natural gas (LNG) plug-in hybrid electric trucks (PHETs) with US Hybrid, grid-tied electric rubber-tired gantry (eRTG) cranes with Cavotec, and electric infrastructure upgrades performed by SCE. These efforts aimed to develop and deploy real world technologies that would allow the Port to progress toward their zero-emission goals for cargo-handling equipment (CHE) and drayage trucks. The Project not only demonstrated zero-emission technologies but at the same time improved air quality within the surrounding communities.

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[2] www.polb.com
[3] https://polb.com/port-info/news-and-press/

Project Scope/Key Findings

Battery-Electric Yard Tractor Demonstration

This demonstration revolved around the demonstration of 12 battery-electric yard tractors manufactured by BYD at two Port terminals, ITS and LBCT. This number was later reduced to eight battery-electric yard tractors, 7 of which were delivered to ITS and one to LBCT. The final four battery-electric yard tractors were not delivered to LBCT due to complications with the engineering design and build.

These yard tractors were powered by ten (10) BYD 200 kW electric vehicle supply equipment (EVSE) sets and two (2) Cavotec Smart Plug Systems (SPS). The project aimed to assess the feasibility and functionality of these electric yard tractors at port terminals, and several key findings emerged. The performance of the BYD Model 8Y electric yard tractor at both terminals was suboptimal. At ITS, operators faced issues like insufficient battery capacity for the terminal, a sensitive accelerator pedal, and limited seat adjustability. At LBCT, significant chassis modifications were required to accommodate regular container movement operations and to interface with the onboard vehicle navigation technology.

The BYD 200 kW EVSE, though rated for sufficient power, experienced frequent downtime, affecting its reliability. Meanwhile, the Cavotec SPS did not perform adequately during the demonstration, and electric yard tractor operators chose not to utilize it.

LNG Plug-In Hybrid Electric Trucks Demonstration

This demonstration aimed to accelerate the transition and commercialization of zero-emissions (ZE) on-road drayage trucks by demonstrating four LNG Plug-In Hybrid Electric Trucks (PHETs) that was converted by US Hybrid from older LNG trucks provided by trucking company, TTSI.

The LNG PHETs faced challenges with proprietary charging station interfaces, hindering their intended zero-emission operations. Despite software patch attempts, these issues persisted, and plans to replace charge ports were abandoned. Operational shifts in 2021 led to a move to Carson, California; however, there was no sufficient electrical infrastructure at the site to power the newly acquired Nuvve chargers. This was needed to demonstrate charging capability and zero-emission mode.

The revenue service demonstration was intended to assess truck performance over 12 months. One of the main issues encountered in this demonstration was the recurrent engine coolant and radiator failures within months of deployment. This resulted in frequent downtime, and eventually, all four trucks were removed from revenue service in June 2022 due to engine failures. Driver feedback indicated that the LNG PHETs could handle the demands of Port drayage effectively but the frequent engine cooling system and radiator failures raised concerns.

Cummins, the engine manufacturer, identified pressure cracks in the engines and proposed a costly reconstruction. Cummins suggested potential causes, such as poor engine oil management and excessive idling, though both reasons were disputed. It was suspected that the remaining three LNG PHETs may have had similar engine issues. Discussions between US Hybrid, TTSI, and Cummins regarding responsibility for the engine failures did not yield a commitment from Cummins to entirely cover the repair of the engines as was hoped.

While on-board chargers performed as designed, the charging stations could not be assessed due to compatibility issues and the trucks' ongoing engine problems. The project demonstrated promising capabilities of LNG PHETs in Port drayage operations but was plagued by recurring engine failures, challenges with charger compatibility, and uncertain repair costs.

Grid-Powered Electric Rubber-Tired Gantry (eRTG) Cranes Demonstration

This demonstration undertook a groundbreaking conversion project in collaboration with SSA and Cavotec to transform nine (9) conventional rubber-tired gantry (RTG) cranes into grid-powered electric RTG (eRTG) cranes.

The project aimed to reduce emissions and enhance operational efficiency. The conversion process involved retrofitting RTG cranes with various essential components, including a cable reel system, a guidance system, and a battery container to support off-grid operations. Initially, a guidance system was installed using a laser and alignment tape but it posed safety concerns when the crane veered too close to container stacks resulting in necessary adjustments. Eventually, in-house mechanics at SSA devised a simpler design. Their new guidance system used proximity switches with metal bars aiding in alignment.

The conversion of nine (9) RTG cranes spanned 22 months with the first eRTG crane ready for testing in May 2020, and the final guidance system implemented in November 2020. During regular operations, the eRTG cranes are grid-connected with the capability to switch to an innovative battery pack for mobile operations between container stacks or in the event of maintenance and repair. Despite the initial complexity, the eRTG cranes at SSA have been performing well.

Training and Public Outreach Campaign

The Project also delved into the Training and Public Outreach Campaign associated with the Port of Long Beach's Zero-Emissions Terminal Equipment Transition Project. This encompassed several key aspects including workforce training efforts, which discussed the training initiatives undertaken, including Long Beach City College workforce assessment, the Port of Long Beach High School Summer Internship Program, and the recommended approaches for curriculum development in the field of zero-emission technologies.

The Project also covered various strategies employed to engage the community, including press releases, promotional videos, stakeholder advisory groups, public harbor tours, participation in port community events, the development of program websites, and a presence on social media platforms. Unforeseen challenges, notably the impacts of the COVID-19 pandemic on the Project and its outreach efforts, were also addressed.

Finally, the Project included deliverables of two critical reports: the "Zero-Emission Port Equipment Workforce Assessment Report" and the "Public Outreach Summary Report." These reports provided essential insights and information on the Project's progress, challenges, and outreach endeavors.

Lessons Learned/Next Steps

This summary provides an overview of key insights and lessons learned from this Project aimed to advance sustainable and zero-emission technologies within the transportation and port industry.

The Battery-Electric Yard Tractors demonstration revealed crucial lessons, emphasizing the need for timely permitting, up-to-date technology demonstrations, and equipment validation. The LNG PHETs demonstration faced disruptions due to COVID-19, engine and fuel tank issues, and charging station compatibility challenges. The Grid-Tied eRTG Cranes demonstration highlighted the complexity of custom conversions and structural assessments, while showcasing environmental and operator benefits. The challenges with the cable reel system and guidance system were addressed through innovative problem-solving.

Looking ahead, exploring alternative ZE technologies, improving data collection, and staying informed about advancements are key next steps in the pursuit of a more sustainable and efficient transportation and port operations. In conclusion, these demonstrations have provided valuable insights and lessons learned for both the rapid evolution and adoption of ZE technologies.

CHAPTER 1: Introduction

1.1: Port of Long Beach

Imagine a port where a ship slows down on approach to reduce emissions, plugs into the electrical grid at berth instead of burning fuel to run vital systems, and is worked by zero-emissions cranes, yard vehicles, and trucks. That is our reality in Long Beach, and the goals of our tests and demonstrations are to eventually make it possible to do everywhere - Port Executive Director Mario Cordero*.*

The future of the industry is zero emissions. The Port of Long Beach will continue to generate economic opportunity as we show that jobs and environmental sustainability can work together - Long Beach Harbor Commission President Frank Colonna.

The Port of Long Beach (Port), also known as the City of Long Beach Harbor Department, is the premier U.S. gateway for transpacific trade and a trailblazer in innovative goods movement, safety, environmental stewardship, and sustainability. The Port handles trade valued at $200 billion annually and supports 2.6 million jobs across the nation, more than 575,000 in Southern California, and more than 50,000 jobs – or 1 in 5 – in Long Beach.[4] The Port has nine terminals, six for containerized cargo, 63 active berths, 76 gantry cranes, and has more than 2,000 yearly vessel calls.

Reducing the impacts of goods movement on human health and the environment ranks as a key focal point for the Port. Emissions emanating from port activities includes ocean-going vessels, heavy-duty trucks, harbor craft, cargo-handling equipment (CHE), and railroad locomotives. These sources emit diesel particulate matter, nitrogen oxides, and sulfur oxides, all of which have been widely recognized for their detrimental effects on human health and their contributions to smog formation.

1.2: Clean Air Action Plan

The Clean Air Action Plan (CAAP)[5] is a collaboration between the Port of Long Beach and the Port of Los Angeles (Ports) to reduce air pollution from port-related sources. The CAAP is a comprehensive plan, first adopted in 2006 and then later updated in 2010. In 2017, the governing boards of the two Ports approved the 2017 CAAP Update, ushering in a new era of aggressive clean air strategies for moving cargo through the nation’s busiest container port complex. The document provides high-level guidance for accelerating progress toward a zero-emission future while protecting and strengthening the Ports’ competitive position in the global economy. The 2017 CAAP Update not only targets emission reductions from port-related sources but also greenhouse gas (GHG)

[4] www.polb.com
[5] www.cleanairactionplan.org

reductions to 40% below 1990 levels by 2030 and 80% below 1990 levels by 2050. The CAAP includes a variety of strategies to reduce pollution, including the:

- Clean Trucks Program, which requires phasing out older trucks and transitioning to zero-emission trucks by 2035 with the support of the Clean Truck Fund Rate, which was implemented in 2022.
- Green Ship Incentive Program, which provides financial incentives for ships with the newest engines or an equivalent NOx-reducing technology. These engines are up to 80% cleaner than their predecessors.
- Technology Advancement Program, which provides port funding opportunities to demonstrate emerging, advanced technologies targeting any of the Ports' five source categories.

The CAAP has been successful in reducing air pollution from the Ports. Each year the Port conducts an inventory of air emissions from port-related sources, using the latest data and methodologies, to track progress for improving air quality and reducing health risks to surrounding communities. In the 2022 Port of Long Beach Emissions Inventory, emissions of sulfur oxides were reduced by 97%, diesel particulate matter were reduced by 91% and nitrogen oxides were reduced by 63% when compared to the 2005 baseline year.[6] Overall, the Ports are committed to continuing to reduce air pollution and are working to achieve their goal of zero-emissions.

The CAAP also focuses on strategies to plan for and develop infrastructure necessary for zero-emissions goods movement, strategies to improve efficiency in the freight system, and proposes cleaner and more reliable sources of energy. The CAAP is an important example of how ports can work to reduce air pollution and improve public health. The CAAP has been recognized by the Environmental Protection Agency as a national model for air pollution reduction.

1.3: Zero-Emission Initiatives

The Port of Long Beach has set a goal of achieving zero-emissions by 2030 for all cargo-handling equipment and by 2035 for on-road trucks. To achieve this goal, the Port has launched several initiatives, including:

- Investing in research and development of zero-emission technologies.
- Providing financial incentives for the purchase of zero-emission vehicles.
- Working with stakeholders to develop infrastructure for zero-emission vehicles, such as charging stations and refueling facilities.
- Educating the public about zero-emission technologies and the importance of reducing Port emissions.

The Port has made significant progress in its zero-emissions journey. In 2022, the Port's electric cargo-handling equipment fleet grew to 19%, the largest such fleet in the

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[6] https://polb.com/environment/air/#emissions-inventory

United States. Since the 2017 CAAP Update, the Port has received both state and federal grants totaling over $326 million to further the development and deployment of zero emissions equipment, vehicles, and infrastructure in Port operations.[7] These efforts greatly support cleaner air in Long Beach and its surrounding communities, especially those living in disadvantaged communities (DACs).

1.4: Industry Partnerships

For the Zero-Emissions Terminal Equipment Transition Project (Project), the Port worked with a number of industry partners to include:

- **Southern California Edison (SCE):** A utility company and Port partner who deployed make-ready infrastructure to serve nine cranes at SSA Marine (SSA) located at Pier J. The cranes are grid-tied and did not require electric vehicle supply equipment (EVSE). In addition, SCE deployed make-ready infrastructure to support over 20 EVSEs to power electric yard tractors at International Transportation Service (ITS) located at Pier G. The two SCE projects at these container terminals help support the Port's broader electrification plans.
- **BYD Motors:** A technology vendor who designed, built, and delivered seven pre-commercial, battery-electric yard tractors to ITS and five to Long Beach Container Terminal (LBCT). Ultimately, the total number of yard tractors delivered was reduced from twelve to eight; more detail will be provided in later sections.
- **Cavotec:** A technology vendor who repowered nine existing diesel RTG cranes to electric RTG cranes for redeployment at SSA. This is also the same technology vendor who manufactured the Smart-Plug System (SPS), which were deployed at ITS and LBCT for the BYD battery-electric yard tractor demonstration.
- **ITS, LBCT, TTSI, and SSA Marine:** Terminal and drayage truck operators participated in demonstrating zero-emission cargo-handling equipment and zero-emission capable LNG trucks provided by the above-mentioned manufacturers. The Port provided project management and engineering support as well as coordination with SCE for infrastructure upgrades required at SSA and ITS.
- **US Hybrid:** A technology vendor who converted four underpowered Class 8 Liquefied Natural Gas (LNG) trucks operated by trucking company, Total Transportation Services, Inc. (TTSI) into plug-in hybrid-electric trucks (PHETs) capable of zero-emissions operation and range-extended operations.
- **International Brotherhood of Electrical Workers (IBEW):** A union who represents 820,000 active members and retirees who work in a wide variety of fields, including utilities, construction, telecommunications, broadcasting, manufacturing, railroads, and government. The IBEW has members in both the United States and Canada and stands out among the American unions in the

[7] https://polb.com/port-info/news-and-press/

American Federation of Labor and Congress of Industrial Organizations because it is among the largest and has members in various skilled occupations.

- **Long Beach City College (LBCC):** A two-year community college that encompasses state of the art, technology-rich learning environments, a broad range of academic and career technical instructional programs, strong community partnerships, and economic and workforce development initiatives. For this Project, LBCC convened a zero-emission Port equipment workforce development group consisting of representatives from the Port, IBEW, terminal operators and other stakeholders with the goal to evaluate and augment existing workforce development and training programs to better support the Port's zero-emission goals for CHEs.
- **Clean Energy Fuels:** One of the largest providers of renewable natural gas with an extensive network of over 590 fueling stations across North America. The LNG PHETs under this Project are fueled at Clean Energy Fuels.

The Port is a complex system with many stakeholders, and it is important to have everyone working together to achieve the common goal of electrification. The partners listed above played an important role in the Project, and their collaboration was essential to its success.

In addition to the California Energy Commission, the Port has collaborated with and received funding awards from agencies such as the Environmental Protection Agency (EPA), California Air Resources Board (CARB), South Coast Air Quality Management District (South Coast AQMD), California State Transportation Agency (CalSTA) as well as the U.S. Department of Transportation Maritime Administration to help support the Port's electrification goals.

CHAPTER 2: Plan, Design, and Build Demonstration Vehicles

The Project Team designed, built, and delivered into service battery-electric yard tractors with BYD, PHETs with US Hybrid, grid-tied eRTG cranes with Cavotec, and electric infrastructure provided by SCE.

Overall, to successfully design and deploy the demonstration technologies, the Project Team followed a rigorous process that facilitated communication between the terminal operators and technology vendors to develop appropriate equipment for the defined use case. This process included the following steps:

- Review and plan functional requirements, duty cycle, drive schedules, and power/energy calculations.
- Identify needed design adjustments and integrate these adjustments into design documentation, bill of materials, and vehicle performance targets.
- Review documents for final design, testing, validation, and vehicle build to ensure all new criteria have been integrated.

In parallel with the equipment design, the Project Team facilitated complete and comprehensive site planning and engineering for the necessary infrastructure upgrades associated with equipment charging and locations for where recharging will take place. This included the deployment of charging stations for the yard tractors and plug-in hybrid drayage trucks, and cable trenching for the grid-connected eRTG cranes.

2.1: Design and Build Process

2.1.1: Battery-Electric Yard Tractors

International Transportation Service, Inc. (ITS) and Long Beach Container Terminal (LBCT) served as demonstration partners. In this capacity, ITS and LBCT agreed to demonstrate BYD's pre-commercial electric yard tractors in revenue service, subjecting the BYD electric tractors to rigorous, real-world marine terminal conditions. The plan was to demonstrate seven (7) BYD electric yard tractors at ITS and five (5) BYD electric yard tractors at LBCT for a total of twelve (12) units.

As discussed herein, demonstration of the electric yard tractors was completed at ITS with the full seven (7) yard tractors but only one (1) electric yard tractor was deployed at LBCT for a total of eight (8) yard tractors that were ultimately demonstrated for this Project. The reason was due to the inability of BYD to complete the build of the remaining four (4) electric yard tractors for LBCT due to LBCT-specific modifications needed to support their terminal operations and the lack of BYD technical staff to complete the work. The first four electric yard tractors for ITS were delivered in May 2020 and the remaining three electric yard tractors were delivered in August 2020, while the one electric yard tractor was delivered to LBCT in April 2019.

For the chargers, ITS facilitated onsite installation of six (6) BYD 200-kW EVSE sets and one (1) Cavotec Smart Plug System (SPS), while LBCT helped facilitate onsite installation of four (4) BYD 200-kW EVSE and one (1) Cavotec SPS. In addition, SCE deployed make-ready infrastructure to support over 20 EVSEs, which included the design and construction to support BYD EVSE and Cavotec SPS installation at ITS only. (LBCT's terminal reconfiguration and modernization efforts, which spanned nearly a decade, provided the electrical infrastructure needed to install the chargers required for this Project.[8]) SCE also oversaw the electric utility power and installation of switchgear and pull boxes up to a "make ready stub" for each BYD EVSE and Cavotec charger unit. As the electric utility partner, SCE also had a role in data collection and analysis, including a study on power quality. While CEC did not fund the power quality study, there was a requirement for the project participants to coordinate with SCE, especially as it pertained to the installation of SCE data collection equipment on EVSE chargers at ITS. A description of the parameters and metrics collected and analyzed by SCE are also included in this Final Report.

2.1.1.1: Equipment Design & Manufacturing

The BYD Model 8Y electric yard tractor was designed by BYD with major vehicle components manufactured at BYD facilities in China. Final manufacturing and assembly were performed at the BYD Lancaster facility. Although the Model 8Y electric yard tractor was characterized as "pre-commercial", the design had already undergone at least two design iterations from the configuration used in previous demonstration projects. While the Model 8Y had already been demonstrated in shipping container movement, these prior demonstrations occurred at rail hub facilities and warehouse/distribution facilities as opposed to a marine terminal operational environment.

The Model 8Y has the following technical specifications and was designed to achieve the performance parameters shown in Table 1.

Table 1 - BYD Model 8Y Electric Yard Tractor Technical Specifications

Criteria	Specification
Length	217.5 inches
Width	101.6 inches
Height	129.9 inches
Wheelbase	118.1 inches
Curb Weight	19,842 lbs.
GCWR	102,074 lbs.
Payload	> 80,000 lbs.
Top Speed	29.2
Max Gradeability	15%
Range (hours of operation)	≥10 hours

[8] https://polb.com/port-info/news-and-press/the-making-of-a-state-of-the-art-terminal-08-26-2021/

Approach/Departure Angle	27°/33°
Wheel Rim	22.5 inches x 8.25 inches
Tires	11R22.5
Suspension	Front: Leaf spring Rear: Solid mount
Brakes	Front/Rear Air drum brakes
Max Power	241 hp
Max Torque	884 lb.-ft.
Battery Capacity	217 kWh

The electric yard tractors demonstrated by ITS and LBCT conformed to the above technical specifications. Fortunately, BYD was able to customize the electric yard tractors to accommodate each container terminal's preferences and needs earlier in the Project when there was a full team of engineers assigned to the demonstration. These customizations did not alter the battery-electric drivetrain or electric yard tractor performance, and as such were not consequential to electric yard tractor acceptance testing, data collection, or analysis. Figure 1, below, shows the BYD Model 8Y electric yard tractor configuration.

Figure 1 - Example of BYD Model 8Y Electric Yard Tractors Deployed at ITS

2.1.1.2: Charging Stations (EVSEs)

Six (6) BYD EVSEs were installed at ITS and four (4) of the same EVSEs were installed at LBCT, which were dedicated solely to this Project. The chargers were manufactured at BYD facilities in China and utilize a proprietary BYD plug interface. The EVSE charger unit was configured with two plugs, each plug rated at 100 kW maximum output.

Ten (10) of the BYD electric yard tractors were configured to accept both plugs simultaneously and recharge at a maximum 200 kW rate. Additionally, the vehicles can recharge using only one plug at a maximum rate of 100 kW.

The remaining two (2) BYD electric yard tractors were configured with the Cavotec SPS mechanized charging system; however, the Cavotec-compatible electric yard tractors were also configured with one (1) additional BYD charging Port to accept one BYD EVSE plug. Thus, the Cavotec configured unit could be recharged using the Cavotec SPS, or if necessary, can use one plug from the BYD EVSE and recharge at a maximum rate of 100 kW. The specifications of the BYD EVSE are shown in Table 2.

The BYD 200 kW EVSE was not listed by Underwriters Laboratory (UL) or any other Nationally Recognized Testing Laboratory at the time of installation at the demonstration marine terminals. Because the City of Long Beach requires electrical appliance installations to be certified by UL or another nationally recognized testing laboratory, the BYD 200 kW EVSE was required to undergo independent testing, inspection, and certification or verification by a recognized testing laboratory. BYD selected TÜV SÜD America, a subsidiary of TÜV SÜD AG, to perform independent field testing and verification for their 200 kW EVSE. Additional information on the BYD EVSE verification process is included in the Testing and Commissioning Process.

Table 2 - Technical Specifications of the BYD 200 kW EVSE System

DESIGN PARAMETER	200 KW SYSTEM
Charging Mode	AC
Input Voltage	480V 3-phase
Operating Voltage Range	432V-528V 3-phase
Input Current	240A
Circuit Breaker Rating	400A
Input Power	200kW
Frequency	60Hz
Output Current	240A
Output Power	200kW
Charging Coupler Type	IEC62196-2
Wires	3 hot; 1 neutral; 1 ground
Length X Width X Height	19.69 x 15.75 x 78.74 (in)
Number Of Coupler(S)	2
Charging Cable Length	118.11in
Mounting Method	Floor-mounted
Short-Circuit Protection	Yes
Overheat Protection	Yes
Lightning Protection	Yes
Certification	TUV
Reference Standard	IEC61851/IEC62196
Enclosure Protection	IP55
Operating Temperature	-22 to +122 deg F
Surrounding Humidity	5-95%

2.1.1.3: Automated Plug System (APS) "Smart Charging"

Two (2) BYD Model 8Y electric yard tractors were modified to use the mechanized SPS designed and manufactured by Cavotec SA in Milan, Italy.

The Cavotec SPS is a mechanized system that does not require manual labor to connect or disconnect the EVSE from the electric yard tractor. The concept of operation for the Cavotec SPS is as follows: when a Cavotec SPS-configured electric yard tractor moves to within proximity to the SPS charger, a communications link is established between the vehicle's onboard Cavotec system and the external charging unit. When the vehicle has maneuvered within the specified distance and alignment position and is fully stopped, the Cavotec charging unit opens a door from which a mechanical arm extends. This mechanical arm is configured with a four-prong plug, which is inserted into the plug module on the electric yard tractor. Once properly connected, the Cavotec SPS will notify the vehicle operator of a successful docking, and charging will commence. In the event of improper vehicle alignment or other system fault that precludes successful docking and plug insertion, the vehicle operator will be notified in the cab of the unsuccessful connection.

The Cavotec SPS was designed to tolerate some misalignment between the vehicle plug module and the Cavotec charging unit. Vertical and horizontal misalignments up to 70 millimeters (mm) and a slant angle of up to three degrees (3°) between the mechanized arm plug and vehicle plug module are within the design tolerance of the SPS system. Misalignments greater than this will not result in successful docking, and the vehicle must be repositioned by the operator to within the allowable tolerance envelope.

To assist operators in achieving proper vehicle positioning and alignment when preparing for SPS docking, the Port coordinated with ITS to install guide rails in the parking stall associated with the Cavotec SPS charger. These were intended to assist the vehicle operator in approaching the SPS charger within the allowable position and slant angle tolerances. (These guide rails were not installed at LBCT since LBCT did not take delivery of a Cavotec SPS-configured electric yard tractor.)

While the BYD EVSE can accommodate power levels up to 200 kW using two 100 kW plugs, the Cavotec SPS is rated at a maximum power level of 100 kW. The technical specifications for the Cavotec SPS are outlined in Table 3.

Table 3 - Technical Specifications of the Cavotec 100 kW SPS System

Charging Side	1710x885x935mm (L x W x H)
Truck Side (Socket side)	347x500x549mm (L x W x H)
Connector	
Truck Side	PC5, 3 phase pins + N + E = 2P
Charging Station Side	PC5 Socket, max 250A, 1000V, 95mm2
Compensation tolerance	
Lateral compensation (X)	X = ± 70mm
Height compensation (Y)	Y = ± 70mm
Distance from charging station (Z)	0 – 1000mm
Angular slanting	X = 3°, Y= 3°
Rotation	± 5°
Control system	BeckHoff
Safety	Mushroom Buttons
Maximum No of Vehicle Handle	1
Weight	600kg

A schematic of the system's operations concept is shown below in Figure 2.

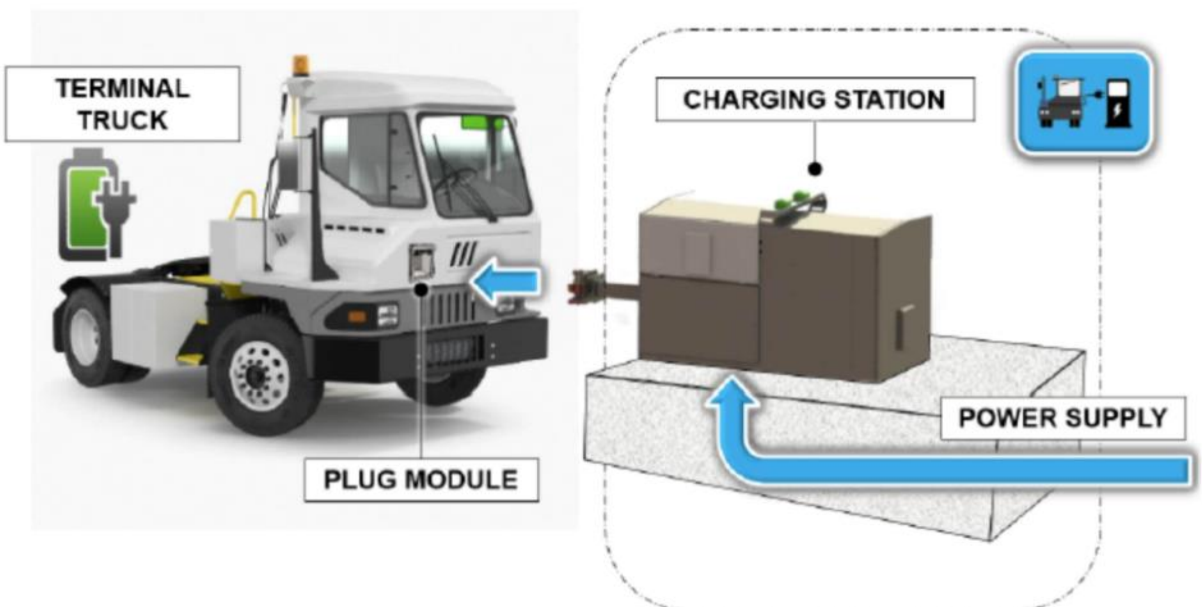

Figure 2 - Operational Concept of the Cavotec 100 kW SPS System

2.1.1.4: Modifications to BYD 8Y Electric Yard Tractor to Accommodate Cavotec Smart Plug System

The Cavotec SPS is comprised of two (2) systems. One is the charging station unit, discussed above, while the second is the components and software that are installed onboard the BYD 8Y electric yard tractor. This onboard system includes a plug module, shown schematically in Figure 2, electronic components to integrate the Cavotec plug module into the BYD Model 8Y electronic control system, and software that allows communication between the onboard plug module and the charging station.

Cavotec selected ETI Conformity Services to conduct independent third-party testing and verification of the SPS EVSE system. This is discussed further in the Testing and Commissioning Process.

Figure 3 and 4 show the Cavotec SPS plug module undergoing installation into a BYD Model 8Y electric yard tractor at BYD's manufacturing facility in Lancaster, California.

Figure 3 - Cavotec SPS Plug Module Integration into BYD Electric Yard Tractor

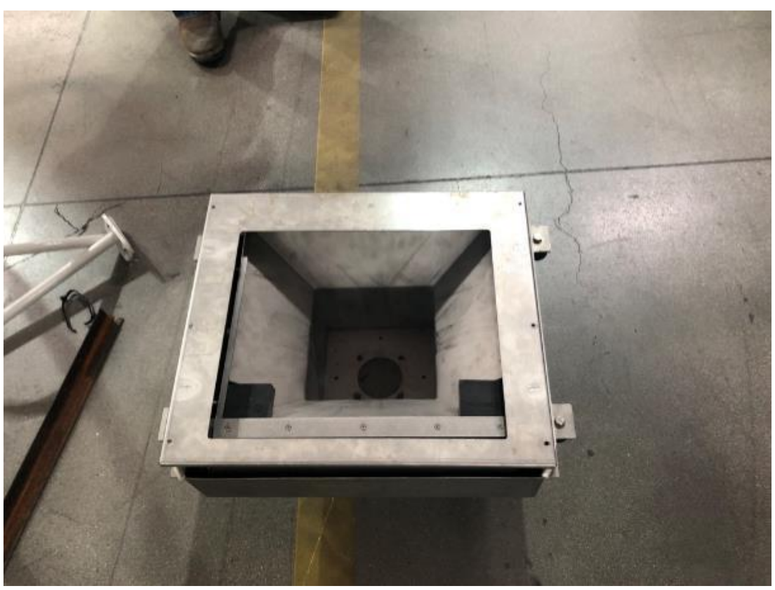

Figure 4 - Cavotec SPS Plug Module Funnel for the BYD 8Y Yard Tractor

The fully integrated Cavotec SPS and BYD 8Y electric yard tractor are shown in Figure 5 below in operation at ITS.

Figure 5 - Cavotec SPS & BYD 8Y Yard Tractor Fully Integrated and Operational

2.1.2: LNG Plug-In Hybrid Electric Trucks

Project demonstration partner, Total Transportation Services Inc. (TTSI), worked with technology vendor, US Hybrid, to repower and convert four underpowered 9-liter Class 8 drayage trucks fueled by liquefied natural gas (LNG) into LNG plug-in hybrid electric trucks (PHETs).

TTSI is a nationwide logistics provider, specializing in asset-based operations that move imports and exports across the US and Canada. TTSI consists of a network of twelve companies that are active in key marine ports and intermodal yards across the U.S. US Hybrid specializes in the design and production of powertrain components for medium and heavy-duty municipal vehicles, commercial trucks, buses, and specialized vehicles worldwide. Their powertrain components are tailored for electric, hybrid, and fuel cell technologies, ensuring zero-emission performance.

US Hybrid replaced the existing Cummins 9-liter LNG engines with new Cummins 9-liter low-NOx engines and converted the trucks to PHETs. The PHETs were intended to operate in zero-emissions mode within the San Pedro Bay Ports benefitting DACs near the Port, be capable of range-extended LNG-powered driving outside the Port and be capable of operating on renewable LNG from nearby Clean Energy Fuels stations.

The LNG PHETs are configured with 20 kilowatt onboard chargers. To support electric charging, TTSI installed one charging station, manufactured by Nuvve, and purchased a second charging station. The LNG PHETs are also able to refuel using onsite LNG fueling stations at TTSI, which operates other LNG drayage trucks. All four LNG PHETs were deployed in TTSI's revenue service and demonstration data was collected per the *2019 Liquid Natural Gas Plug-In Hybrid Electric Truck Demonstration Plan (LNG PHET Test Plan)*. It was intended that the LNG PHET demonstrations would help to accelerate the commercialization of zero-emissions (ZE) cargo handling equipment and vehicles, both at Port and at other ports throughout the state and nation.

In addition, TTSI assigned one diesel and one compressed natural gas truck to serve as baseline vehicles for the purpose of performance, efficiency, cost, and air emission comparisons.

2.1.2.1: Vehicle Design & Manufacturing

US Hybrid undertook the conversion of four, underpowered, 9-liter natural gas engine, Class 8 model year 2012 drayage trucks. The trucks were repowered with the new Cummins 9-liter low-NOx engines and engineered to include plug-in hybrid electric capabilities. The LNG PHET electric motor was designed to provide the trucks with supplementary power and torque and to engage when the LNG engine requires additional performance, such as during acceleration or uphill climbs.

US Hybrid delivered the first truck (LNG PHET #1 or LL054) in September 2019. The truck began revenue service, but due to COVID-19 facility shutdowns, LNG PHET #1 revenue service was halted in April 2020 and resumed in September 2020. US Hybrid delivered the second truck (LNG PHET #2 or LL056) in October 2020 and LNG PHET #2 began revenue service in November 2020. The third truck (LNG PHET #3 or LL057) was delivered in April 2021, later than expected due to engine performance issues. The engine issues were resolved, and the truck began revenue service. The fourth truck (LNG PHET #4 or LL058) was delivered in September 2021. LNG PHET #4 was delivered later than expected because US Hybrid transferred their maintenance shop operations from Torrance, California to a new facility in Downey, California, which halted work on the truck until the move to the new facility was completed. To make matters worse, a COVID-19 outbreak at US Hybrid further delayed work at the facility.

2.1.2.2: Charging Stations (EVSE)

The LNG PHETs were designed to plug in to a charging station at the completion of drayage services. This is intended to ensure that the LNG PHETs start each day with a fully charged battery to maximize zero-emission operations.

In May 2020, TTSI installed two BYD charging stations (from a previous truck demonstration) at their San Pedro facility, an area which is located and owned by the Port of Los Angeles to allow LNG PHETs to recharge as needed. However, after several months of testing and charging issues, it became clear that the BYD chargers had a proprietary interface resulting in communication errors when charging non BYD-manufactured vehicles such as US Hybrid's LNG PHETs.

US Hybrid attempted to solve this issue in September 2020 by applying a software code change to LNG PHET #1 (LL054) and LNG PHET #2 (LL056). The goal was to see if the software patch would allow the LNG PHETs to successfully connect to, and charge with a BYD charging station installed at US Hybrid's manufacturing facility. Although promising at first, the software patch was not successful. In addition, US Hybrid initially offered to replace the BYD charge ports; however, in February 2020, US Hybrid retracted their voluntary offer reasoning that they did not want to be held responsible for the challenges associated with BYD's utilization of non-industry standards.

In 2021, TTSI moved their management and operational oversight from San Pedro to a second facility in Carson, California, while TTSI and the Port of Los Angeles Real Estate Division continued negotiations regarding TTSI's operation at the San Pedro facility. This meant that all operations must commence at the Carson facility and operation had ceased to begin at the San Pedro facility.

The LNG PHETs were moved from San Pedro to Carson in May 2021 to allow their continued demonstration in revenue service, albeit without charging capability. To enable the LNG PHETs to charge, TTSI purchased a 480 volt, 3-phase charger from the manufacturer, Nuvve in March 2021. TTSI's new Carson facility was not yet equipped with adequate electrical infrastructure from SCE. However, the first Nuvve charger was installed at the San Pedro facility with the goal to test it on an LNG PHET in October 2021 since the site already had the required power. TTSI also ordered a second Nuvve charger in anticipation of a successful operational agreement with the Port of Los Angeles. Ultimately, TTSI and the Port of Los Angeles were unable to reach an agreement, potential installation of electrical infrastructure at the Carson facility stalled due to cost, and truck operations did not return to the San Pedro facility, where the first Nuvve charging station had been installed. The second Nuvve charging station was received in May 2022 but as of today has not been installed. Consequently, the LNG PHETs charging capability was not demonstrated and the trucks did not operate in zero-emission mode as originally intended. TTSI has retained the Nuvve chargers and plans to use them to charge electric trucks at the Carson facility, if feasible.

2.1.2.3: On-Board Chargers

On-board chargers provide power to the LNG PHET's battery while the vehicle is in operation. These chargers are integrated into the truck's system and allow the battery to be recharged using the power generated by the natural gas engine or during regenerative braking. The on-board chargers ensure that the battery remains charged, provide the necessary energy for the plug-in hybrid system to function efficiently, deliver supplementary power when needed, and help to increase the overall efficiency and range of the LNG PHETs. The energy captured by the on-board chargers would otherwise be wasted as heat in a conventional vehicle.

US Hybrid had originally identified an overseas company to develop and build the on-board chargers. In March 2020, after numerous communications and delays it became apparent that the supplier was unable to deliver the on-board chargers. US Hybrid informed the Port they would instead locate one on-board charger in-house with the intention of procuring three more (for a total of four on-board chargers). All on-board chargers arrived at US Hybrid in April 2020 and the chargers were installed into the PHETs by 2021.

2.1.2.4: On-Board Data Loggers

US Hybrid equipped each LNG PHET with a data logger to track and record performance parameters such as miles driven, fuel consumption, engine, and electric motor output. This data was collected for each LNG PHET, for each second of truck operation, producing millions of data records. The data records were post-processed to filter information useful in this analysis.

2.1.2.5: Geo-Fencing vs Geographic Position

The project had originally hoped to implement geofencing capability where trucks would be forced to operate in electrical mode when in and near the Port. This was deemed not feasible by US Hybrid, and the trucks were designed without this capability. In lieu of geofencing capability, the Port agreed to have the project characterize data within specific boundaries where the LNG PHETs would operate in zero emissions (had the chargers been in operation). The data loggers, discussed above, in addition to recording performance metrics, also collected geographic position information. The Project Team also collected valuable data on the performance of the LNG PHETs, which can be used to improve the design and implementation of future ZE cargo handling equipment and vehicles.

2.1.3: Grid-Tied eRTG Cranes

Conversion of the existing rubber-tired gantry (RTG) cranes was the first of its kind for this specific model and configuration at SSA Marine at Pier J. Specific designs and drawings for the conversion were not available and were developed as part of this effort. Cavotec provided all the necessary parts needed to convert the RTG cranes into a grid-connected eRTG crane with the capability of traveling along a stacking run; however, SSA's in-house mechanics were responsible for the placement of the retrofit parts onto the RTG crane. SSA's dedicated team designed and built a platform to house the control panel, fabricated mounting brackets for the cable reel and belt-lifting device, as well as configured a guidance system.

2.1.3.1: Equipment Retrofit & Cable Reel System

The first RTG crane was taken out of service in October 2019 to begin the guidance system design and assemble the Cavotec components. Due to the complexity and structural integrity of the RTG crane, SSA worked with the manufacturer, ZPMC, on the cable reel mounting mechanism and received plans from ZPMC in mid-January 2020. The brackets and beams required to mount the cable reel were fabricated by SSA and mounted in February 2020. By March 2020, the cable was installed onto the mounted cable reel with the gear box and the unit was temporarily connected to the grid with no issues.

2.1.3.2: Guidance System

The initial guidance system went through development and testing in parallel to the modifications on the first eRTG crane. SSA worked with Cyth Systems, a technology integration company, who developed an automated measurement and control solution using a laser guidance system. Cyth's guidance system was tested for two months using lasers, reflective, alignment tape on the ground, and a camera to ensure the programmable logic controllers' outputs met the system requirements. Figure 6 shows one of the guidance system mounted lasers.

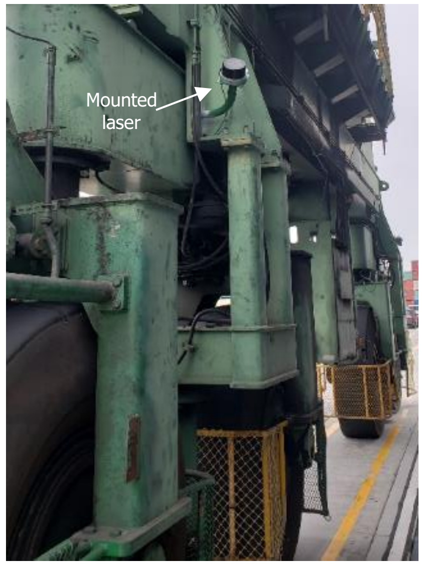

Figure 6 - Cyth Mounted Laser

By May 2020, the first eRTG crane was complete except for the guidance system. Over the next few months, Cyth continued to test the guidance system on a diesel-powered RTG crane. The initial guidance system was tested on an existing diesel RTG crane in the event the guidance system failed and caused the machine to veer off alignment causing damage to the trench, cable, or other components of the eRTG crane.

The initial guidance system also used a reflective tape adhered to the ground next to the cable trench as seen in Figure 7. One of the unexpected issues was the damage to the reflective tape caused by the RTG crane and other equipment (Figure 8) which eventually proved to be detrimental to the initial design. The second iteration used a painted line, which was more cost effective to maintain and repair.

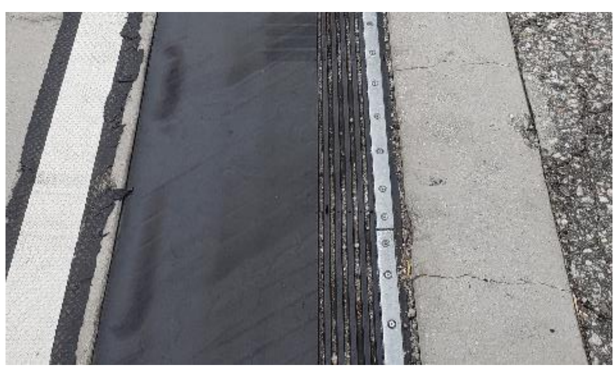

Figure 7 - Alignment Tape

Figure 8 - Damaged Alignment Tape

The initial guidance system was then tested on the eRTG crane; however, during testing in September 2020, the cable reel came within 1 to 2 inches to the container stacks, which was considered too close. SSA concluded this situation to be a major safety concern and immediately halted testing. This incident caused SSA to lose confidence in the Cyth laser guidance system, and it was ultimately scrapped from the demonstration.

A new guidance system was designed by SSA mechanics, based on using proximity switches – sensors that detect the presence of nearby objects without any physical contact – for guidance. The SSA mechanics had previously maintained this type of feedback system used on their ship-to-shore cranes. To support this new design, flat metal bars measuring 1” wide and approximately 0.25 to 0.50” thick were mounted along the stacking rows to allow the proximity switches to detect the metal bar and correct the alignment.

The SSA guidance system worked with five (5) proximity switches attached to an arm extending from the eRTG crane positioned over the metal bar, which was installed on the ground. When the middle switch sensed that it was over the metal bar, it relayed to the machine that it was moving in a straight path and no correction to the steering was needed. When the machine moved in either direction away from metal bar, the switches on either side of the switch would detect the center bar and communicate to the eRTG crane that a small correction was needed. If a small correction was not sufficient to straighten the eRTG crane and one of the outer two (2) switches detected the center bar, it communicated to the machine that a larger correction was needed to get it centered over the bar. Two (2) arms equipped with switches were mounted on either side of the crane. If the eRTG crane was moving to the left, the switches on the left side of the machine activated and guided it. If the eRTG moved too far from the metal bar, and none of the switches can read the bar, this mechanism would stop the eRTG crane, and the operator would need to correct the course to re-center the switches. Figure 9 through 11 show the concrete-mounted metal bars and switches mounted on the eRTG crane.

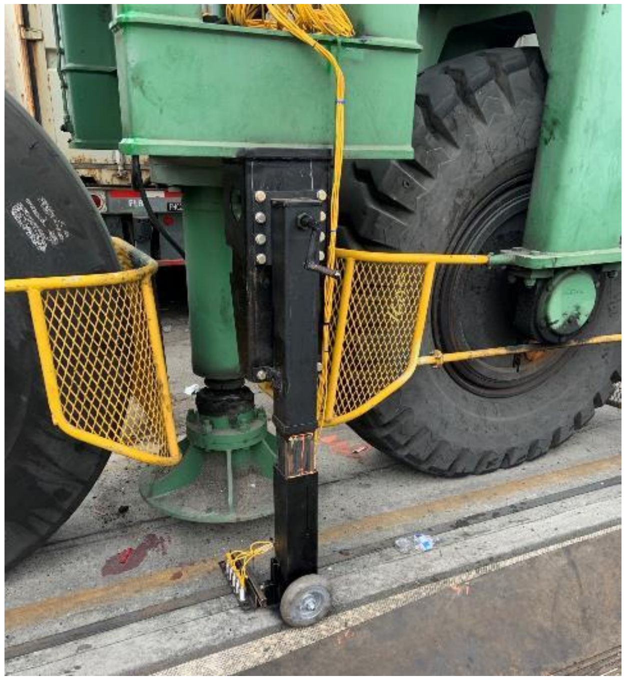

Figure 9 - eRTG Mounted Arm with Proximity Switches

Figure 10 - Proximity Switches

Figure 11 - Backside of Proximity Sensors and Metal Plate

2.1.3.3: Battery Container for Off-Grid Operations

A battery pack was ordered in March 2019 and delivered on January 16, 2020. SSA initially took on the task of setting up the charging connections for the battery pack, but due to concerns with high voltage, SSA hired a contractor, Tony Demaria Electric (TDE), in April 2020. By August 2020, the battery pack charging setup was completed and 100% charged; however, some of the smaller components of the battery pack, including the control panel, were losing power due to a faulty charger for a smaller battery that powered these components. The new charger was received and installed, with the battery pack ready to go in November 2020.

2.2: Testing and Commissioning Process

2.2.1: BYD Battery-Electric Yard Tractors

Prior to deploying the BYD electric yard tractors in revenue service at ITS and LBCT, pre-deployment validation testing was conducted by BYD at their Lancaster, California facility. Validation testing was performed on August 2, 2019, with project staff representing the Port of Long Beach in attendance to observe and document validation testing results.

The purpose was to demonstrate that the BYD electric yard tractor could meet the performance specifications outlined in the *Zero/Near-Zero Emissions Yard Tractor*

Testing & Demonstration Guidelines[9] developed by the Port of Long Beach and Port of Los Angeles and published in September 2017.

2.2.1.1: Battery-Electric Yard Tractor Testing and Commissioning

The photos below show the electric yard tractor undergoing initial performance validation testing at BYD's Lancaster facility. The following parameters were verified on a Model 8Y BYD electric yard tractor during validation testing:

- Electrical system functional test – all electrical systems, including but not limited to motive power, regenerative braking, power takeoff (PTO), interior and exterior lighting, and instrumentation verified to be functional.
- Electric yard tractor operability assessment, including verification of vehicle 5th wheel operation, interior and exterior, doors, latches, seat belts, and driver amenities.
- Electric yard tractor configuration and dimensional audit – verify that the vehicle is configured per the build specification provided by ITS.
- Electric yard tractor drivability, including top speed or verification of top speed if governed, acceleration tests, brake stop tests, and steering and handling.
- Speedometer accuracy.
- HVAC functional testing.
- Gradeability test, including starting grade.

The minimum performance specifications defined by the Port of Long Beach include those outlined in Table 4.

Table 4 - Minimum San Pedro Bay Ports Yard Tractor Performance Requirements

Minimum Performance Guideline	Performance Metric
Design Duty Cycle	One (1) 9-hour shift with no opportunity charging assumed
Freight Load Capacity	70,000 pounds (loaded container plus simple chassis or CGC)
Top Speed	25 mph at zero grade (0% grade)
Gradeability at Vehicle Launch	10% grade at 70,000 GCW
Gradeability Sustained at 10 mph	15% grade at 70,000 GCW

The vehicle performance tests outlined in Table 4 were replicated at the BYD Lancaster facility except for sustained operation at a 15% grade at a gross combined weight (GCW) rating of 70,000 pounds, as a grade that steep does not exist at or in proximity to the BYD facility. It was, however, noted at the time of testing that no significant grades exist at the ITS marine terminal complex that necessitate attainment of this

[9] "Zero/Near-Zero Emissions Yard Tractor Testing & Demonstration Guidelines"; available online at: https://cleanairactionplan.org/technology-advancement-program/application-resources/port-equipment/

performance metric. Gradeability at vehicle launch at 70,000 GCW was replicated at the BYD Lancaster facility.

A "pass/no-pass" designation was used for each tested parameter. All static vehicle tests noted above were shown to be operable and thus earned a pass rating.

Dynamic electric yard tractor testing was performed using a simulated 70,000-pound GCW configuration using concrete K-rail loaded on a flatbed trailer. Figures 12, 13 and 14 show the test configuration:

Figure 12 - BYD Electric Yard Tractor Validation Testing at BYD Lancaster Facility

Figure 13 - Simulated 70K GCW Container Used in Pre-Deployment Validation Testing

Figure 14 - BYD Model 8Y Undergoing Acceleration Validation Testing

Vehicle top speed, gradeability at launch, and energy consumption measurements were taken over an approximately 6-mile loop and multiple laps. Performance was verified by POLB representatives following in a chase car. The vehicle's state of charge was noted at the start of testing and at the conclusion of testing. Based on a known distance traveled over a known time and the level of discharge measured in the battery pack, it was calculated that the BYD electric yard tractor would have sufficient onboard energy storage to complete one (1) full shift at ITS without the need to perform opportunity charging. As discussed earlier, ITS had an expectation that the BYD Model 8Y tractor would perform two (2) full shifts, this being accomplished through opportunity charging during driver breaks and other downtime. As will be discussed, there were ultimately insufficient opportunities to recharge the electric yard tractor during a shift, and two-shift operation was not routinely achieved.

The outcome of the pre-deployment validation testing was that the BYD Model 8Y electric yard tractor achieved the minimum performance as included in the referenced *Zero/Near-Zero Emissions Yard Tractor Testing & Demonstration Guidelines*.

2.2.1.2: BYD 200 kW EVSE Testing and Commissioning

Testing and commissioning of the BYD 200 kW EVSE was conducted following installation at both ITS and LBCT. However, as noted earlier, the BYD EVSE was unable to obtain a permit from the City of Long Beach due to it not being listed by UL or certified by a Nationally Recognized Testing Laboratory.

BYD retained TÜV SÜD America to conduct independent testing and verification of the 200 kW EVSE. However, the testing and verification process encountered significant technical issues that impacted the start of the demonstration project.

At project outset, BYD informed the Port of their intent to have the BYD 200 kW EVSE commissioned by the City of Long Beach, and to that end retained OSHA-Certified

Nationally Recognized Testing Laboratory TÜV SÜD America to provide a Field Evaluation of the 200 kW EVSE. This testing was to be conducted pursuant to UL 2594 - Standard Testing for Electric Vehicle Charging Stations - and the National Electric Code (NEC).

The UL and NEC standards follow a precedent set by the City of Long Beach, which had previously commissioned a BYD 80 kW EVSE for Long Beach Transit under the same field evaluation protocol.

BYD had purportedly represented that the short circuit current rating (SCCR) of the 200 kW EVSE was 25 kiloampere (25 kA). However, during the Field Evaluation, the TÜV SÜD America inspector determined the SCCR of the EVSE was only 10kA.

It was determined that there was no feasible way to modify the BYD 200 kW EVSE in the field to achieve a SCCR rating of 25 kA. The workaround recommended by TÜV SÜD America was to install a current limiting fuse in between the SCE disconnect panel and the BYD 200 kW EVSE.

Upon further inspection of the BYD EVSE, a Port and a City of Long Beach Electrical Inspector raised additional concerns about the acceptability of the 200 kW EVSE. Of primary concern was the lack of UL-listed subcomponents, including the power cable and coupler.

BYD's position was that while individual EVSE subcomponents would not be UL listed per se, the system as a whole would abide by UL 2594 and the NEC. However, to comply with the inspectors' findings, BYD ultimately replaced the cables as well as an internal fusible link in each BYD 200 kW EVSE unit.

Independent verification of the BYD 200 kW EVSE was granted by TÜV SÜD America on December 12, 2019, and the City of Long Beach permitted the BYD EVSE on January 9, 2020.

2.2.1.3: Cavotec Smart Plug System Testing and Commissioning

The Cavotec SPS was also not UL listed and was required to undergo independent field testing and validation. Cavotec selected ETI Conformity Services (ETI) to conduct the field testing.

Issues identified by ETI included non-UL listed components, including circuit breakers, non-conforming wiring, and non-UL listed incoming power cables to the main circuit breaker.

Additionally, it was determined that a water test needed to be conducted to ensure the Cavotec SPS enclosure complied with National Electrical Manufacturers Association (NEMA) 3R /UL 508A enclosure standards.

The water test was conducted on August 27, 2019, and it was determined that the Cavotec SPS met the required enclosure standards for water entry.

As of September 19, 2019, all identified discrepancies found during the field evaluation had been resolved, including the replacement of non-UL circuit breakers, main wiring, and power cables.

Verification and commissioning of the Cavotec SPS was completed on March 26, 2020, and permitting by the City of Long Beach was complete as of April 10, 2020. Figure 15, below, shows the ETI verification sticker attached to the Cavotec SPS unit.

Figure 15 - ETI Verification Sticker Adhered to Cavotec SPS Unit

2.2.2:LNG Plug-In Hybrid Electric Trucks (PHETs)

The *LNG PHET Test Plan* provided the framework for performance testing and technical evaluation of the LNG PHETs. LNG PHET testing and commissioning activities described below were conducted in accordance with this plan.

2.2.2.1: Laboratory Chassis Dynamometer Testing

Laboratory chassis dynamometer testing was conducted to develop a performance baseline for the LNG PHETs and to gain confidence in these systems to perform, maneuver, and complete expected loaded cycles for Port operations. Four test cycles were included in the chassis dynamometer testing, which was conducted by the College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside. The test cycles were developed to simulate sustained operation over a grade, other Port drayage cycles, and were tested with the vehicle loaded to an equivalent gross vehicle weight of 69,500 pounds, which reflects the weight of a conventional tractor and payload weight. LNG PHET#1 (LL054) underwent testing at CE-CERT for chassis dynamometer testing in November 2019. It was intended that results of the CE-CERT testing would confirm the LNG PHET power ratings and help inform fine-tuning performance opportunities. However, although CE-CERT's final report in March 2020 confirmed the maximum power ratings of LNG PHET #1, the lab findings were unable to capture the added power and torque details needed to fine-tune the LNG PHET.

2.2.2.2: On-Road Testing

To capture performance functionality from added power and torque that were not captured in the CE-CERT testing, an on-road acceleration test was planned for March 2020. Due to COVID-19 shutdowns this testing was delayed to July 2020. The acceleration test provided a comparison between LNG PHET #1 (LL054), a 12-liter natural gas truck, and a 12-liter diesel truck all pulling containers of identical weights at given speeds. A data logger, installed on LNG PHET #1 (LL054), collected performance metrics, and showed that LNG PHET #1 (LL054) outperformed both the 12-liter natural gas and the 12-liter diesel trucks in speed, acceleration, and fuel economy. The data collected helped fine-tune LNG PHET #1 (LL054) prior to revenue service demonstration and informed fine-tuning opportunities for LNG PHET #2 (LL056), #3 (LL057), and #4 (LL058). The on-road acceleration testing for LNG PHET #1 was not required per the *2019 LNG PHET Test Plan*; it was conducted to capture performance functionality not assessed in the CE-CERT testing.

The *2019 LNG PHET Test Pla*n included three testing phases, as follows:

- Vehicle Verification Testing was conducted before operating the LNG PHETs on public roadways to ensure the vehicles comply with all federal, state, and Port requirements and regulations, and are suitable for safe Port drayage operation. Vehicle verification testing was conducted per the California Highway Patrol's Basic Inspection of Terminals (BIT) Program requirements. The BIT program is a tool used to assess motor carrier compliance with safety regulations, especially the maintenance of commercial motor vehicles through scheduled maintenance programs. Its primary goal is to enhance the safe operation of regulated vehicles by subjecting truck terminals to inspections by the California Highway Patrol (CHP). Any deficiencies identified in the BIT inspections were fixed prior to the on-road operation.
- Controlled On-Road Testing was intended to ensure the LNG PHETs could meet the rigors of Port drayage operations prior to entering revenue service. Per the *2019 LNG PHET Test Plan*, one LNG PHET was required to undergo on-road testing. The testing was to include near dock, local, and regional duty cycles in both LNG and hybrid modes. However, on-road testing was delayed multiple times due to radiator failures from the LNG PHET selected as well as lack of driver availability. During COVID-19, the freight transport system faced significant strain, with trucks operating at maximum capacity in revenue service during and following COVID-19 shutdowns. As a result, there was a shortage of both time and available drivers. Furthermore, on-road testing is a non-revenue service for which TTSI and it was unable to remove trucks and drivers, during COVID-19, from revenue service to accommodate non-revenue on-road testing. During the times when TTSI was able to schedule drivers for the on-road test,

the truck had to be removed from service due to radiator failure issues. Therefore, on-road testing was not conducted.

- Revenue Service Demonstration deployed the trucks in Port drayage revenue service with TTSI. TTSI recorded miles driven, fuel consumption, maintenance records, and driver surveys and provided these in monthly reports. In addition, during conversion, US Hybrid equipped each LNG PHET with a data logger to track and record various testing parameters such as miles driven, fuel consumption, engine, and electric motor output, among others.

  The revenue service demonstration was intended to show truck performance over a 12-month period of continuous service and include a minimum of 150 revenue trips. The *2019 LNG PHET Test Plan* defined the demonstration period as 12-months of uninterrupted service except for regularly scheduled maintenance. LNG PHETs were also required to be plugged into the charging stations at the end of each day and start each next day with a fully charged battery to maximize the zero-emission operations.

  Unfortunately, all four trucks experienced recurring engine coolant and radiator failures within several months of deployment. Consequently, the LNG PHETs were frequently out of service. These recurring failures ultimately led to engine failures, necessitating the removal of all four trucks from revenue service in June 2022. Although the demonstration period lasted more than 12 months, and two of the four LNG PHETs (LNG PHET #1 LL054 and LNG PHET #2 LL056) accrued more than 12 months of service, their service was frequently interrupted by coolant and radiator failures. LNG PHET #3 LL057 operated for 10 months and LNG PHET #4 LL058 operated for 6 months. These trucks were the last two trucks to be delivered and were removed from service when the first two trucks became unsafe to drive due to the recurring issues.

2.2.2.3: Charging Stations

As discussed earlier, two charging stations were purchased and one was installed. The LNG PHETs were not able to use the charging stations. The stations were not tested with these vehicles.

2.2.3: Grid-Tied eRTG Cranes

Prior to elevating an eRTG crane to operational status, each unit went through testing and certification. The crane’s high voltage system was tested after all the gear was installed. A high potential electrical testing (or HIPOT) was used to validate that the high voltage system (and related insulation) was installed correctly and functionally test all the safeguards associated with it (e.g., breakers, fused disconnects, etc.). Each eRTG crane also went through a lifting certification, which is normally done annually, and whenever major maintenance is completed.

The eRTG cranes were commissioned over a span of 22 months. The COVID-19 pandemic directly impacted the schedule of this project, both with staffing impacts, global shortages, and increased demand that saw a record number of container ships in queue off the coast of Southern California. At times, conversion efforts were put on hold in order to meet the operational needs of the terminal and accommodate the number of goods that were coming through Pier J.

The first eRTG crane was converted and ready for testing in May 2020; however, the guidance system had not been completed and tested. As described earlier, the final guidance system was ready and the eRTG crane was put into service in November 2020. The remaining eRTGs were completed per the schedule listed in Table 5. Figure 16 throughFigure 19 represent several of the completed eRTG cranes.

Table 5 - eRTG Crane Retrofit Components

eRTG Designation	SSA Crane Unit #	Date of Commission
1	36	11/9/2020
2	10	4/7/2021
3	9	5/18/2021
4	8	6/16/2021
5	37	9/7/2021
6	11	10/11/2021
7	7	3/14/2022
8	6	5/16/2022
9	19	9/6/2022

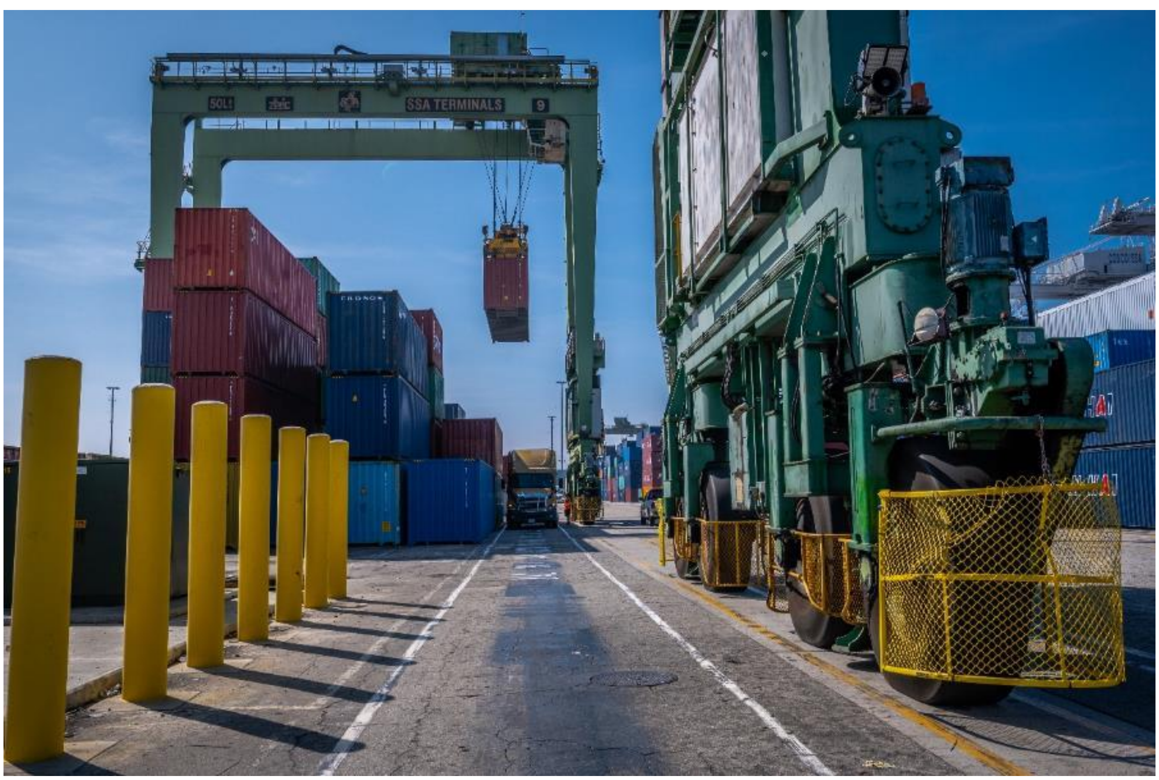

Figure 16 - eRTG 3, SSA Crane 9

Figure 17 - eRTG 4, SSA Crane 8

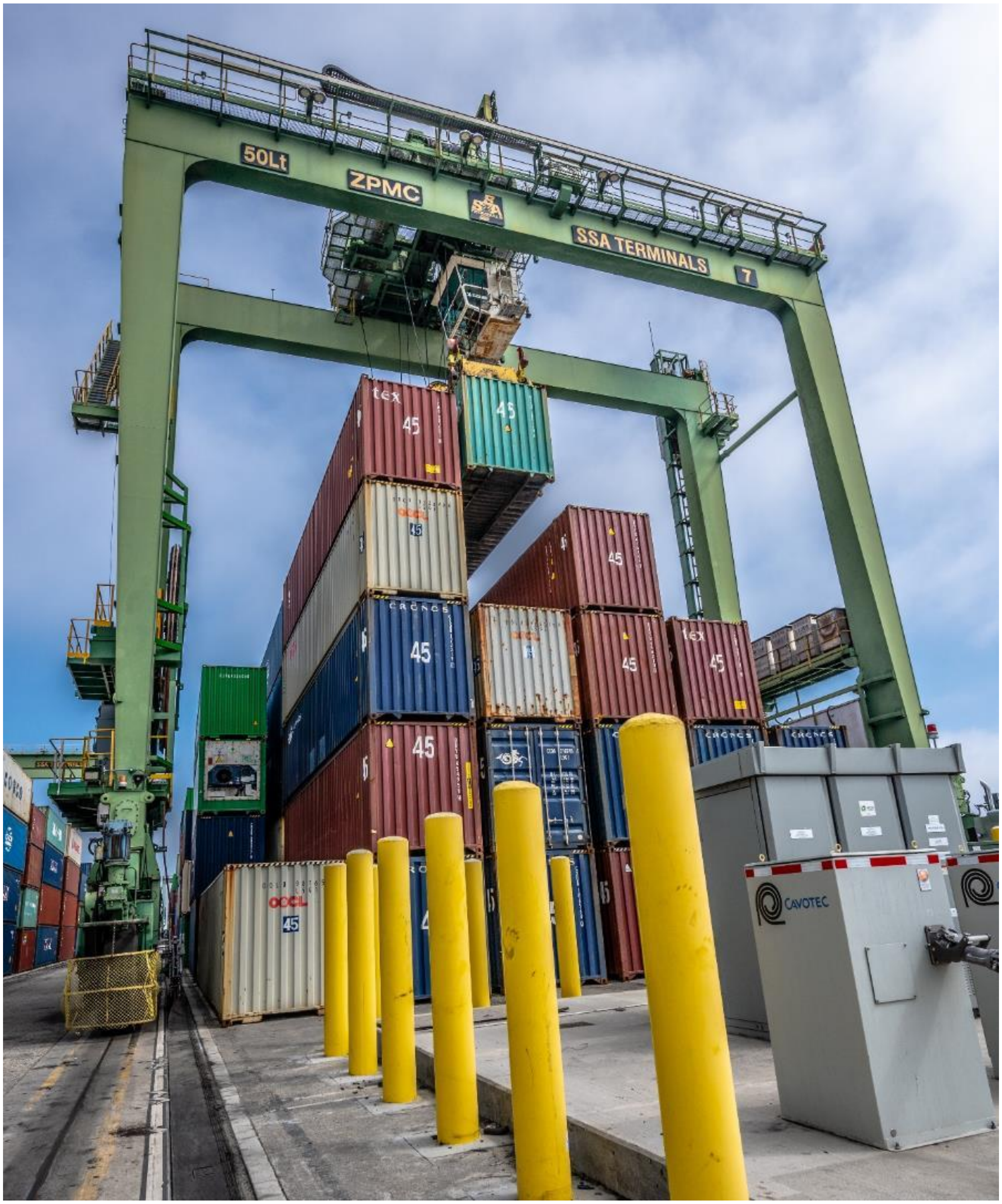

Figure 18 - eRTG 7, SSA Crane 7

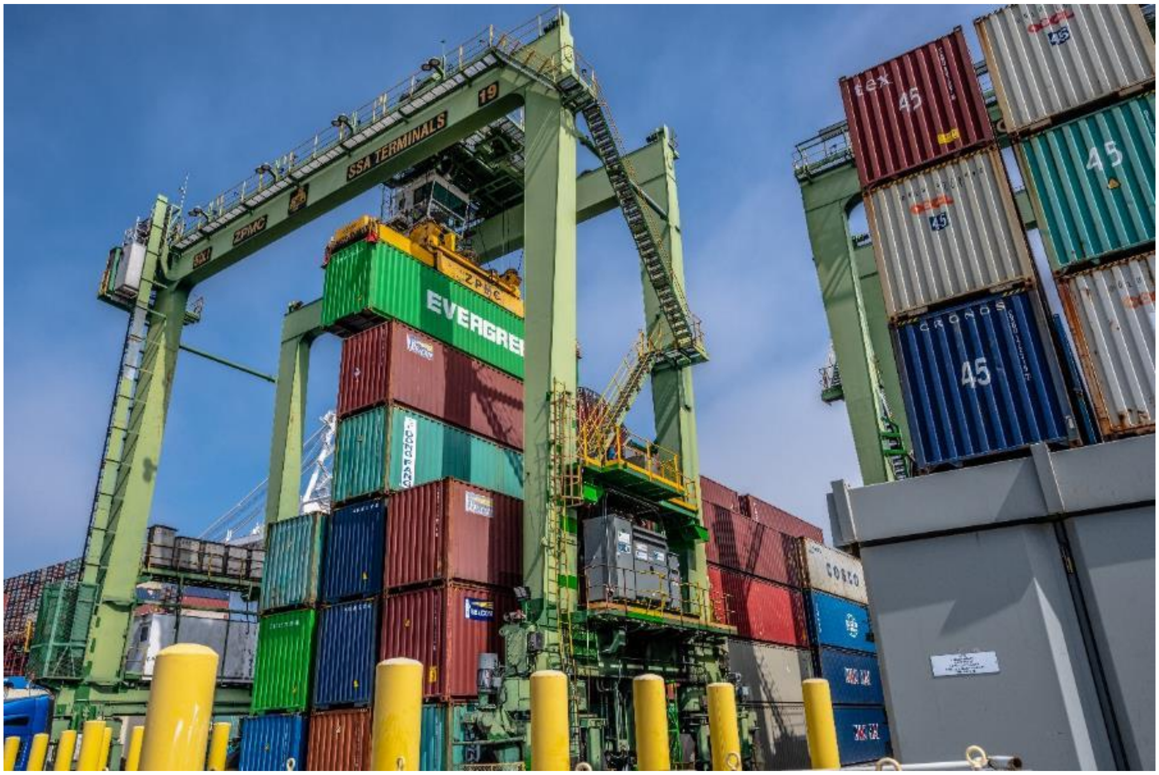

Figure 19 - eRTG 9, SSA Crane 19 (Final Conversion)

2.2.3.1: Battery Container for Off-Grid Operations

During normal operations, the eRTGs crane was plugged into the grid at the points described above. In the event SSA chooses to move an eRTG crane from one container stack to another, it would be able to unplug from the grid and plug into an innovative, first-in-the-nation alternating current (AC)/AC battery package that replaces on-board auxiliary diesel engines, and enables disconnection from the grid during normal operations. This battery package is contained within a 20-foot cargo container. Powered by this pack, the eRTG crane will be able to move from stack to stack or to the maintenance shed—all without producing any emissions. When the battery pack is not in use, it will be stored in a nearby storage shed.

The completed pack was not actually tested until February 2022, at which point, the operation was proved to be unsuccessful. The battery pack would work for a brief time but then turn off. Ultimately, a faulty inverter was identified, which required a replacement from the manufacturer. The new inverter was received in August 2022 and ELM, the battery pack manufacturer, was on-site to complete the repairs. By September 2022, the battery pack was functional and ready for testing.

As of November 11, 2022, the battery pack had been tested and was working well after the inverter replacement. The battery pack is now operational, if needed. Figure 20 to 23 show the battery pack.

Figure 20 - ELM Battery Pack

Figure 21 - Battery Pack Connector Panel

Figure 22 - Interior View of Battery Pack

Figure 23 - Rack of Individual Batteries

2.3: Additional COVID-19 Impacts

While impacts of COVID-19 were described above, other notable impacts are described below.

2.3.1.1: Battery-Electric Yard Tractors

At the start of the pandemic, ITS put a temporary halt on commissioning the EVSEs due to the development and implementation of new cleaning and disinfection procedures. In addition, BYD's modification work on the yard tractor to resolve clearance issues at LBCT was also put on hold. Illnesses at the height of the pandemic led to temporary facility shutdowns at BYD.

2.3.1.2: LNG Plug-In Hybrid Electric Trucks (PHETs)
COVID-19 shutdowns delayed the delivery of LNG PHET #2 and LNG PHET #3. After mandatory shutdowns were lifted, COVID-19 infection breakouts at the US Hybrid facility further delayed the delivery of LNG PHET #4.

Controlled On-Road Testing was intended to ensure the LNG PHETs could meet the rigors of Port drayage operations before entering revenue service. However, due to the impact of COVID-19 on freight transport, on-road testing was not completed. COVID-19 created a high demand for goods and placed enormous strain on the freight transport system. During this time, trucks were operating at maximum capacity in revenue service. This situation created a scarcity of both time and available drivers, making it impractical to allocate resources for conducting road testing by removing trucks from revenue service.

2.3.1.3: Grid-Tied eRTG Cranes
The first impacts of COVID-19 aligned with the conversion and testing of the initial RTG. The first unit was taken out of service in October 2019. Since this was the first unit to be converted, there were several lessons to be learned and as such, it was not completed until May 2020. By this time, the U.S. and most of the world was amid COVID-19 related lockdowns. Although Port workers were considered essential, contractors who needed access to the site to trouble shoot the guidance system were not. As noted above, the guidance system was one of the crucial components of the conversion, and it was not until November 2020 when the first eRTG was commissioned.

2.4: Supply Chain Disruption
2.4.1.1: Battery-Electric Yard Tractors
Of the two terminals who participated in this demonstration, LBCT experienced an issue in ordering a ground speed sensor needed for their demonstration. Due to supply chain constraints resulting from the COVID-19 pandemic, the parts were backordered, and delivery of the ground speed sensors and brackets was delayed until July 2021.

2.4.1.2: LNG Plug-In Hybrid Electric Trucks (PHETs)
The disruption in the supply chain had an impact on the availability of certain parts required to address system failures. One instance involved the on-board charger of LNG PHET #1, which experienced failure and required repair. Unfortunately, the necessary parts for the repair were unavailable for several months due to the supply chain disruption. Another notable impact was the delay of on-road testing. Since this activity was considered a non-revenue service, TTSI truck operators had to prioritize moving containers as cargo volumes were at its highest in 2021.

2.4.1.1: Grid-Tied eRTG Cranes
Since SSA required all their cranes to be 100% operational through the end of 2020, the terminal was not able to pull the next unit for conversion until early 2021. For most of 2021, SSA was able to turn around a conversion every 6-weeks; however, as the holiday months of October through December approached as well as the historic backlog at the Ports due the supply chain issues caused by COVID-19, SSA had to keep all cranes operational again. By early 2022, ports in the U.S. were clearing queues of container ships. SSA was able to resume the conversion process and complete the final three conversions by early September 2022.

2.5: Summary Reports

Individual Summary Reports for each Project component was submitted to the CEC by November 2022.

CHAPTER 3: Operations, Data Collection, and Analysis

3.1: Operations

3.1.1: International Transportation Service (ITS)

Seven (7) BYD Model 8Y electric yard tractors underwent in-use demonstration at the ITS marine terminal located at Pier G. For purposes of identification during the demonstration, the ITS yard tractors were assigned numbers ITS 500 through ITS 506. Marine terminal operations at ITS include vessel stevedoring and on-dock rail container movements. According to ITS management, the yard tractor duty cycle corresponding to rail operations is typically more rigorous when compared to other operations. As such, the initial assignment of the BYD demonstration vehicles to rail operations-only was done to prove out the performance and reliability of the zero-emission vehicles and ensure they could perform all yard tractor duty cycles at ITS.

While the original intent was to demonstrate the BYD electric yard tractors in rail operations exclusively, to increase their utilization, their use was expanded to include the flip line, where a container is picked up off the ground and mounted on a chassis for transport, at the ITS Maintenance and Repair facility (M&R).

In summary, the BYD electric tractors accrued the following usage totals during the demonstration at ITS that spanned the period of July 2020 through September 2021:

- Total Electric Yard Tractor Miles Accrued: 40,818 miles
- Total Operational Hours Accrued: 4,712 hours
- Total Electricity Consumption: 116 megawatt-hours (MWh)

In addition to the BYD electric yard tractors, ITS assigned a diesel yard tractor to serve as a baseline vehicle for the purpose of conducting performance, energy efficiency, air pollutant reduction, reliability and operability, and programmatic analyses.

3.1.2: Long Beach Container Terminals (LBCT)

The LBCT project planned to demonstrate five (5) BYD Model 8Y electric yard tractors, including one yard tractor configured to utilize the Cavotec Smart Plug-in System (SPS), at the LBCT marine terminal located at Pier E. However, only one (1) BYD electric yard tractor underwent testing, validation, and in-use demonstration.

Marine terminal operations at LBCT include vessel stevedoring and on-dock rail container movements. The project intent was to demonstrate the BYD electric yard tractors in rail operations. Like ITS, the yard tractor duty cycle corresponding to rail operations at LBCT is more rigorous when compared to other operations. As such, the initial assignment of the BYD demonstration vehicles to rail operations-only was done to prove out the performance and reliability of the zero-emission vehicles and ensure they can perform all yard tractor duty cycles at LBCT.

Unfortunately, the demonstration did not achieve the intended goal of multiple electric yard tractors used in revenue service. The BYD electric yard tractor originally delivered in April 2019 subsequently underwent testing, validation, and limited in-use demonstration in rail operations for the period commencing January 2021 until June 3, 2022, when structural damage to the electric yard tractor's fifth wheel was discovered and the vehicle subsequently removed from operations by LBCT. During that time, the electric yard tractor was driven for 95 days and accrued a total of 113.5 hours of operation. Total electric yard tractor mileage accrued at LBCT was 858 miles.

Although the demonstration at LBCT was limited, it did accomplish key tasks identified in the statement of work, including:

1) Development of electric yard tractor system and performance requirements.
2) Assessment of the duty cycles anticipated to be encountered when deployed at LBCT.
3) Development of a test plan, including validation testing, and vehicle and EVSE manufacturing, delivery, and commissioning.
4) Installation and commissioning of four (4) BYD EVSE units at LBCT.
5) Installation and commissioning of one (1) Cavotec Smart Plug-in System at LBCT.
6) Manufacturing and commissioning of one (1) BYD Class 8 battery electric yard tractor.
7) Training of LBCT Maintenance and Repair (M&R) technicians.
8) Retrofit of the BYD electric yard tractor to accommodate the LBCT container chassis (i.e., bomb cart).
9) Retrofit of the BYD electric yard tractor with the AUCOS Automatic Coupling System fifth wheel, and.
10) Retrofit of the BYD electric yard tractor with the NOW Solutions navigation system ground speed sensor.

LBCT had also identified a diesel yard tractor to serve as a baseline vehicle for the purpose of conducting performance, energy efficiency, air pollutant reduction, reliability and operability, and programmatic analyses. However, as in-use demonstration of the BYD electric yard tractor was limited, no comparative assessments between the two technologies were performed.

Four (4) BYD 200 kW EVSE were delivered and installed in 2019 and received TÜV SÜD America field verification in December 2019. These units were number #1, #2, #3, and #4.

Figure 24 documents the deployment of the BYD electric yard tractors and EVSE at LBCT.

Figure 24 - BYD Model 8Y Deployed at LBCT

3.1.3: Total Transportation Services Inc. (TTSI)

TTSI is a nationwide, asset-based coordination provider with an expertise in managing imports and exports within the US and Canada. TTSI is comprised of twelve companies that operate directly in every major Port in the United States as well as intermodal yards. The company averages over 40,000 drayage moves and 111,000 truck load moves per year.

TTSI operated all four LNG PHETs during the demonstration period. In addition, TTSI assigned one diesel and one compressed natural gas truck to serve as baseline vehicles for the purpose of performance, efficiency, cost, and air emission comparisons. TTSI provided monthly reports, and regularly participated in monthly conference calls.

3.2: Technology Performance

3.2.1: Battery-Electric Yard Tractors

From a performance perspective, the BYD Model 8Y yard tractor did not meet the needs nor expectations of the marine terminal operators. Neither marine terminal elected to retain the electric yard tractors in their fleet at the conclusion of the demonstration. The reasons as to why the electric yard truck performance was deemed inferior to the diesel baseline are summarized below.

3.2.1.1: Battery Electric Yard Tractor Performance at ITS

The BYD electric yard tractors did successfully demonstrate the ability to pull container/chassis weights consistent with loads encountered under rail operations. Thus, from a standpoint of acceleration, speed, and maneuverability, the BYD yard tractors demonstrated comparable performance to a diesel baseline yard tractor.

However, ITS represented that the electric yard tractors offered inferior performance in the following areas:

- Insufficient Battery Capacity to Allow Operation for Two Consecutive Shifts. The original intent was to utilize opportunity charging during a shift to augment the overnight charging; however, opportunity charging of a sufficient duration was often not available or not taken advantage of – this limited the use of the electric yard tractors to a single shift.
- Overly Sensitive Accelerator Pedal. Drivers complained that the accelerator pedal on the electric yard tractor was very sensitive compared to the diesel yard tractors operated at ITS. The drivers stated that the electric yard tractor would initially lurch forward when the accelerator pedal was engaged, and that it was difficult to feather the accelerator. BYD believed the issue was more associated with unfamiliarity with the characteristics of electric drive, and that drivers would acclimate to the differences in pedal feel over time.
- Inadequate Adjustability of Driver Seat and Overall Issues with Driver Accommodations and Ergonomics. Drivers stated there was insufficient adjustability of the driver's seat, and some yard tractor operators stated it was not feasible to operate the BYD yard tractor based on their physical size. The overall ergonomics and position of instrumentation was routinely cited as problematic, which resulted in several drivers electing to no longer operate the BYD tractor.

Although not directly related to the performance of the Model 8Y electric yard tractor demonstrated, it was suspected that the electric tractor was not the most current or technologically advanced yard tractor offered by BYD. It is likely this directly influenced ITS' decision to not retain the BYD electric yard tractors at the end of the demonstration, as they were perceived to be obsolete technology, and that a new generation of BYD yard tractor had, or would soon become, commercially available.

3.2.1.2: Battery Electric Yard Tractor Performance at LBCT

Like the experience at ITS, it was not an issue of towing capacity, speed, or acceleration. Rather, the primary vehicle performance issue at LBCT was required modifications to the tractor chassis to allow driver maneuvers encountered at LBCT during regular container movement operations to be performed, commonly referred to as the "jack knife turn." This modification across all tractors destined for LBCT required significant labor on the part of BYD and resulted in significant schedule delay.

Also, as discussed below, the BYD electric yard tractor required modifications to accommodate the automated fifth wheel used on all yard tractors operating at LBCT. Additional modifications were needed to allow vehicle compatibility with the onboard vehicle navigation technology.

Each of these factors contributed to the conclusion that the BYD Model 8Y, as configured during the demonstration, was not compatible with LBCT marine terminal operations. Extensive modifications were needed to meet LBCT's performance requirements, which from a practical standpoint required a substantially redesigned and reengineered electric yard tractor. As discussed earlier, BYD was unable to complete the build of the remaining four electric yard tractors primarily due to the high turnover in 2022. The loss of key technical staff who oversaw the LBCT-required modifications on the first unit was no longer with BYD. Unfortunately, new BYD personnel were not provided with the historical knowledge needed for successful modifications to the remaining units for LBCT.

3.2.1.3: BYD 200 kW EVSE

The BYD EVSE was rated at a sufficient power level to fully recharge the Model 8Y electric yard tractor overnight. As such, the power rating was deemed adequate for ITS. The performance issues associated with the BYD EVSE were related to frequent downtime, which was attributed to a perceived lack of robustness in design and manufacturing. In addition, the lack of a cable management system, quality control, supply voltage transient intolerance, and the lack of onboard data storage to record event history beyond the last event contributed to the sentiment that the EVSE did not perform as well as had been expected.

While the 200 kW EVSE expectations were not met, the EVSE did perform well enough to support electric yard tractor operations over 40,818 total miles and 4,712 total hours of electric yard tractor operation at ITS.

Note that utilization of the 200 kW EVSE at LBCT was very limited; thus, it is infeasible to draw meaning EVSE performance conclusions from such a limited dataset.

3.2.1.4: Cavotec SPS

The Cavotec SPS did not perform adequately during the demonstration because terminal operators opted not to use it to charge the electric yard tractors.

It should be noted that the Cavotec EVSE installed at ITS and LBCT was the first generation SPS. At the end of the demonstration period, Cavotec announced that a second generation SPS had been developed based upon issues encountered and lessons learned from the first generation SPS at ITS.

3.2.2: LNG Plug-In Hybrid Electric Trucks

Operator surveys were used to ascertain the overall performance of each LNG PHET. The surveys were filled out by truck drivers each time a truck was operated and evaluated factors such as truck pulling power, handling, braking, noise level, ride comfort, and overall rating. In addition to performance information, the operator surveys also gathered data on fueling as well as weather and traffic conditions. In general, operators reported that the LNG PHET performed well in that they were able to handle the rigors of Port drayage, accelerate with a full load, and transit over bridges without issues.

However, within several months in revenue service the trucks began experiencing failures in the engine cooling system and radiators. These issues resulted in the trucks being out of service more than 45 percent of the time. The trucks were inspected, cooling hoses were replaced, and the radiator in Truck #2 LL056 was replaced twice within eighteen months. However, the failures continued and there was suspicion that the failures were tied to a larger issue. TTSI and US Hybrid found cracks in engine components and concluded that the failures were with the Cummins engine. Truck #2 LL056 was removed from service and transferred to Cummins, the engine manufacturer, where the engine was disassembled and inspected. In November 2022, Cummins identified pressure cracks in the engine that damaged multiple engine components. Cummins proposed to reconstruct the engine at a cost of $98,000 and in February 2023, reduced the price to $62,000. For comparison purposes, the cost of each original Cummins engine was $110,000. Cummins has alluded that the engine failure may be due to one of the following:

- Poor engine oil management. TTSI does not believe this to be the reason because it is their policy to perform oil changes every 10,000 miles. However, TTSI does not typically maintain these records and was unable to provide them.
- Excessive idling. Given that drayage trucks do idle as part of normal activity and that Cummins is responsible for setting the idling parameters on the engine, TTSI and US Hybrid believe that this was an unlikely reason for failure unless Cummins set idling parameters incorrectly.

It was also suspected that the remaining three LNG PHETs had the same engine issues. US Hybrid and TTSI participated in negotiations with Cummins to discuss responsibility for the engine failure and whether the trucks were salvageable. However, based on updates from US Hybrid and TTSI, it was not likely that Cummins would fix the engines at no cost and TTSI had stated that they will not incur additional cost to fix the engines.

3.2.2.1: On-Board Chargers

In summary, on-board chargers charge the LNG PHET’s battery while the vehicle is in operation and enhance truck performance and efficiency. The on-board chargers performed as designed during the demonstration period and no significant issues were identified.

3.2.2.2: Charging Stations

In summary, a charging station provides a location and interface for charging the LNG PHET batteries. Despite TTSI's acquisition of two charging stations, the stations were not used. As a result, the performance of the charging stations was not assessed.

3.2.3: Grid-Tied eRTG Cranes

The nine converted eRTG cranes operated in the same way as their diesel-powered predecessors. The primary reason was that these were all conversions, maintaining the existing equipment that was powered by on-board diesel-fueled generators but now running on grid electric power. The eRTG cranes are significant improvements for operators and the environment, who immediately noticed the lack of diesel exhaust and noise in their cabs.

While the eRTG cranes operated well, to get the units up and running required a lot of money, infrastructure planning and troubleshooting as noted in the sections below. For this reason, SSA is open to other options such hydrogen fuel cells and battery plug-ins for zero-emission operations.

3.2.3.1: Equipment Retrofit
The initial conversion took the most time since it was a custom solution. Fortunately, subsequent conversions were easier and turnaround was about six to 8 weeks. It should also be noted that unique mounting brackets had to be manufactured and the structural integrity of the crane had to be confirmed with ZPMC to ensure there would be no additional stress or strain on the unit with the retrofits. Once the first retrofit was completed, SSA was able to efficiently convert the remaining units, creating a blueprint for other ports with RTG cranes at their terminal. Some minor issues were also noted when it rained but major eRTG crane components from Cavotec held up well and continued to function as designed. The minor issues are described below.

3.2.3.2: Cable Reel System
The cable reel system and its operation caused the most perceived risk. The eRTG cranes operated in a controlled environment, and units must proceed along a straight line, to allow the cable to lay within a covered trench. At the same time, the eRTG crane had to be able to reel in the cable onto the wheel as it moved towards the electrical grid connection point. The use of cable was the most intensive part of the project requiring a full length of trench for each stacking row. If cable reel systems were going to be designed into new construction, a number of considerations should be noted. Appropriate evaluation and planning are recommended. Another would be drainage. In one instance, SSA was unable to tie the trenches into existing drainage and have had the trenches fill with water after a few large storm events. This water caused the cable to float and lift the trench cover posing a safety issue for cross traffic until the water was pumped out of the trench.

3.2.3.3: Guidance System
As discussed earlier, the SSA guidance system operated using proximity switches attached to the eRTG crane. When the senor was positioned correctly, the eRTG crane moved in a straight line in the intended path and no correction to the steering was needed. The guidance system was also able to make adjustments in steering when the switches were able to detect the center bar and communicate to the eRTG crane that a small correction was needed. If a small correction were not sufficient to straighten the eRTG crane and a larger correction would be performed. Two (2) arms equipped with switches were mounted on either side of the crane. If the eRTG crane was moving to the left, the switches on the left side of the machine activated and guided it. If the eRTG moved too far from the metal bar, and none of the switches can read the bar, this mechanism would stop the eRTG crane, and the operator would need to correct the course to re-center the switches.

3.2.3.4:Battery Container for Off-Grid Operations
When needed, the battery container proved to be useful in the event an eRTG crane had to be moved to another stack. The main disadvantage is the amount of time it takes to move a unit off the electrical grid, which requires several mechanics to bring the battery pack, make the appropriate disconnections and connections, complete tasks on the unit, then reverse the entire process. It has been used sparingly due to the amount of time it takes to complete.

3.3: Data Collection
3.3.1: Battery-Electric Yard Tractors
The following discusses data collected from the BYD Geotab® data loggers, Cummins INSITE™ engine data acquisition system, and Cavotec SPS data acquisition system. The performance period for the ITS portion of the BYD demonstration spanned approximately fifteen (15) months, commencing in July 2020 with a partial deployment of BYD electric yard tractors. A complete dataset, including the baseline diesel yard tractor, BYD electric yard

tractors, and Cavotec SPS EVSE, became available beginning in August 2020. The final data collection period was September 2021.

As discussed above, data collection at LBCT was limited, as Geotab® data loggers were not installed during the testing, validation, and limited use in revenue service. As such, most detailed data collected during the demonstration is associated with the electric yard tractor deployment at ITS.

The primary data collection method for the BYD electric yard tractor utilized the Geotab®GO9™ telematics device. This device interfaced to the BYD vehicle Controller Area Network (CAN) bus and supports the Society of Automotive Engineers (SAE) J1939 engine management protocol. An illustration is shown in Figure 25.

Figure 25 - Geotab® GO9™ Telematic Data Collection Device

In addition to CAN data, the Geotab® GO9™ incorporated GPS that allowed real time vehicle location and tracking within the ITS marine terminal. Each of seven BYD electric yard tractors was outfitted with a Geotab® GO9™ device to support data collection for this project.

Seven (7) BYD Model 8Y electric yard tractors were deployed at ITS, designated by a vehicle equipment number of ITS 500 through ITS 506. BYD tractor ITS 506 was configured to use the Cavotec SPS mechanized EVSE.

Electronic data was collected for the period beginning July 2020 and was reported herein through September 2021. During this period, BYD electric yard tractors were brought into revenue service at different times. As such, not all BYD tractors operated simultaneously during this period. Additionally, ITS 501 suffered damage early in the demonstration and was returned to the BYD Lancaster facility for repairs. The level of damage sustained was not able to be repaired and as a result ITS 501 was permanently removed from the demonstration. Additionally, ITS 503 lost connectivity with the Geotab data acquisition device over a period of several months. Thus, the dataset associated with ITS 503 was incomplete.

The data collected by the Geotab® GO9™ is raw data (a sample of raw data is presented in Table 6) that must be formatted to obtain meaningful information.

Table 6 – Geotab® GO9™ Sample

Vehicle	Day	Distance (miles)	Ignition Time (HH:MM)	SOC Consumed (%)	SOC Charged (%)	Number of Charge Sessions	Charge Time (HH:MM)	Rate of SOC Consumed (per hour)	Rate of SOC Consumed (per mi)	SOC Charged/hour (%/hr)
PR#0215-ITS POLB 500 -8Y #0060 - M&R	44288.0000	0.0000	0.0032	-0.0010	0.0000	0.0000	0.0000	-0.0129		
	44289.0000	0.0000	0.0004	-0.0550	0.0000	0.0000	0.0000	-5.5000		
	44294.0000	6.8972	0.0300	-0.1070	0.0010	0.0000	0.0000	-0.1487	-0.0155	
	44295.0000	0.0621	0.0011	-0.0010	0.0000	0.0000	0.0000	-0.0387	-0.0161	
	44298.0000	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000		

	44299.0000	0.2485	0.0311	-0.0410	0.2860	1.0000	0.0261	-0.0550	-0.1650	0.4564
	44301.0000	0.0000	0.0008	-0.0860	0.0000	0.0000	0.0000	-4.3000		
	44309.0000	10.9983	0.2540	-0.2490	0.3110	1.0000	0.0264	-0.0409	-0.0226	0.4904
	44314.0000	2.6098	0.0328	-0.0290	0.0000	0.0000	0.0000	-0.0369	-0.0111	
PR#0215-ITS POLB 502 - 8Y #0066 - Flip Line	44288.0000	0.0000	0.0621	-0.2180	0.0000	0.0000	0.0000	-0.1464		
	44294.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		

Monthly data was collected for each BYD electric yard tractor deployed at ITS in dedicated locations that include ITS' Maintenance and Repair (M&R) facility, flip line (an area at the M&R where a container is picked up off the ground and mounted on a chassis for transport), vessel (an area where a container is being loaded or unloaded from off the ground or from off the vessel, and mounted on a vessel or truck chassis for transport) with the remaining locations dedicated for rail operations. The data was then reformatted into an Excel® spreadsheet for ease of data manipulation. A sample of a formatted dataset is shown below in Table 7. Note that the spreadsheet data has been broken into three sections to fit within the page borders.

Table 7 - Formatted Data Sample for ITS Electric Yard Tractor Operations

Vehicle	Date	Distance (miles)	Ignition Time (hours)	Energy Consumed (% of total battery SOC)	Energy Consumed (kWh)
ITS 500 - 0060 - M&R	4/8/21	6.90	0.72	-10.7	-23.2
	4/13/21	0.25	0.75	-4.1	-8.9
	4/23/21	11.00	6.10	-24.9	-54.0
	4/28/21	2.61	0.79	-2.9	-6.3
		20.75	**8.35**	**-42.60**	**-92.44**
ITS 502 - 0066 - Flip Line	4/14/21	18.70	2.44	-31.3	-67.9
	4/19/21	36.16	4.65	-65.0	-141.1
	4/23/21	0.56	0.35	-21.0	-45.6
	4/28/21	11.06	5.01	-16.8	-36.5
	4/29/21	14.60	0.01	-23.6	-51.2
		81.09	**12.46**	**-157.70**	**-342.21**
ITS 503 - 0062 - Vessel	4/14/21	4.97	2.95	-9.0	-19.5
	4/15/21	18.52	0.08	-29.1	-63.1
	4/20/21	45.24	5.58	-58.4	-126.7
	4/21/21	17.65	5.80	-24.5	-53.2
	4/22/21	26.35	5.92	-44.0	-95.5
	4/23/21	28.71	5.99	-48.0	-104.2
	4/24/21	9.20	0.00	-16.4	-35.6
	4/26/21	18.33	5.99	-26.3	-57.1
	4/27/21	14.35	6.03	-28.2	-61.2
	4/28/21	21.19	6.01	-30.6	-66.4
	4/29/21	21.56	6.25	-32.5	-70.5
	4/30/21	6.52	0.00	-8.7	-18.9
		232.58	**50.59**	**-355.70**	**-771.87**
ITS 504 - 0063	4/1/21	53.25	5.96	-69.4	-150.6
	4/3/21	49.65	5.30	-66.4	-144.1
	4/5/21	52.51	6.10	-66.8	-145.0
	4/6/21	52.01	5.67	-69.3	-150.4
	4/7/21	45.61	5.92	-63.5	-137.8
	4/8/21	9.94	3.02	-15.0	-32.6
	4/9/21	17.09	0.00	-23.3	-50.6
	4/11/21	47.60	5.08	-58.7	-127.4

Energy Charged (% of total battery SOC)	Number of Charge Sessions	Charge Time (hours)	Energy Consumed (% of total battery SOC) per hour	Energy Consumed (% of total battery SOC) per mile
0.1	0	0.00	-14.9	-1.55
28.6	1	0.63	-5.5	-16.50
31.1	1	0.63	-4.1	-2.26
0.0	0	0.00	-3.7	-1.11
59.80	**2.00**	**1.26**	**-28.14**	**-21.42**
0.3	0	0.00	-12.8	-1.67
70.9	2	1.32	-14.0	-1.80
11.8	1	0.28	-59.5	-37.55
0.0	0	0.00	-3.4	-1.52
13.4	1	0.38	-2740.6	-1.62
96.40	**4.00**	**1.97**	**-2830.31**	**-44.16**
10.0	1	0.30	-3.0	-1.81
38.0	1	0.71	-360.0	-1.57
31.9	1	0.63	-10.5	-1.29
26.2	1	0.79	-4.2	-1.39
39.3	1	0.98	-7.4	-1.67
42.9	1	1.09	-8.0	-1.67
48.4	1	0.85	0.0	-1.78
0.1	0	0.00	-4.4	-1.43
36.3	1	0.89	-4.7	-1.96
32.1	1	0.81	-5.1	-1.44
34.9	1	1.04	-5.2	-1.51
25.1	1	0.64	0.0	-1.33
365.20	**11.00**	**8.71**	**-412.55**	**-18.87**
63.6	3	1.29	-11.6	-1.30
71.2	1	1.18	-12.5	-1.34
66.8	2	1.27	-11.0	-1.27
69.3	2	1.31	-12.2	-1.33
63.5	2	1.35	-10.7	-1.39
0.0	0	0.00	-5.0	-1.51
38.3	1	0.78	0.0	-1.36
58.7	1	1.03	-11.6	-1.23

Energy Consumed (kWh/hour)	Energy Consumed (kWh/mile)	Energy Charged (% of total battery SOC) per hour	Energy Charged (kWh)
-32.26	-3.37	0.00	0.22
-11.93	-35.80	45.64	62.06
-8.87	-4.91	49.04	67.49
-8.00	-2.41	0.00	0.00
-61.06	**-46.49**	**94.68**	**129.77**
-27.81	-3.63	0.00	0.65
-30.31	-3.90	53.67	153.85
-129.17	-81.49	42.87	25.61
-7.28	-3.30	0.00	0.00
-5947.20	-3.51	35.60	29.08
-6141.78	**-95.82**	**132.13**	**209.19**
-6.61	-3.93	33.80	21.70
-781.20	-3.41	53.67	82.46
-22.71	-2.80	50.88	69.22
-9.17	-3.01	33.29	56.85
-16.14	-3.62	39.95	85.28
-17.38	-3.63	39.35	93.09
0.00	-3.87	57.09	105.03
-9.53	-3.11	0.00	0.22
-10.15	-4.26	40.84	78.77
-11.05	-3.13	39.74	69.66
-11.28	-3.27	33.62	75.73
0.00	-2.89	39.42	54.47
-895.24	**-40.95**	**461.66**	**792.48**
-25.26	-2.83	49.13	138.01
-27.18	-2.90	60.48	154.50
-23.77	-2.76	52.40	144.96
-26.52	-2.89	52.73	150.38
-23.29	-3.02	47.18	137.80
-10.77	-3.27	0.00	0.00
0.00	-2.96	49.30	83.11
-25.08	-2.68	57.05	127.38

Table 8 summarizes data recorded using the Geotab® GO9™ data loggers during the ITS demonstration period. This is presented as a function of Tractor ID for the specified month.

Table 8 - Activity Summary from Geotab® GO9™ Download for BYD Electric Yard Tractor Operations at ITS

Reporting Period	ITS 500 Miles	ITS 500 Hours	ITS 502 Miles	ITS 502 Hours	ITS 503 Miles	ITS 503 Hours	ITS 504 Miles	ITS 504 Hours	ITS 505 Miles	ITS 505 Hours	ITS 506 Miles	ITS 506 Hours
Jul-20	1,421.40	151	350.7	38.9	1,427.00	146	N/A	N/A	N/A	N/A	258	28.7
Aug-20	1,065.30	118.6	315.4	35.2	1,435.20	152.2	N/A	N/A	N/A	N/A	280.4	31.6
Sep-20	816.5	104.5	N/A	N/A	1,514.90	164.7	897.7	108.4	410.7	49.8	662.7	73.3
Oct-20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nov-20	502.7	69.03	115.4	25.6	276.8	37.1	1593.5	172.3	1257.7	145.9	71.2	8.8
Dec-20	2.4	0.2	26.8	5.1	29.1	11	1335.5	150.1	992.7	118.8	26.6	5.1
Jan-21	82.8	12.9	40.6	9.7	28.3	4.8	1,360.40	148.8	993.1	110.2	30.6	2.7
Feb-21	200.8	25.5	52.7	17.1	89.7	12.5	1,113.40	122.1	968.3	115.1	0	0
Mar-21	171.1	23.2	13.2	2.5	116.4	18.5	1,162.40	131.5	1,067.60	123.6	52.4	5.8
Apr-21	20.8	8.4	81.1	12.5	232.6	50.6	1,093.10	123.8	916.7	111.2	0	0
May-21	99.3	12.2	32.6	6.5	233	37.1	1,407.40	164.8	993	118.6	0	0
Jun-21	82.8	11.9	17.8	2.3	91.2	14.4	1,158.40	128.7	886.3	97.52	0	0
Jul-21	202.2	23.2	0	0	534.6	61.6	651.6	75.1	923.4	106.1	0	0
Aug-21	245.1	26.5	604.8	69.2	697.8	73.6	0	0	378.2	43.72	0	0
Sep-21	56.7	5.8	816.1	101	76.2	14.5	0	0	43.3	5.4	0	0

The electric yard tractor activity at ITS as a function of tractor ID is shown graphically in **Error! Reference source not found.**, below:

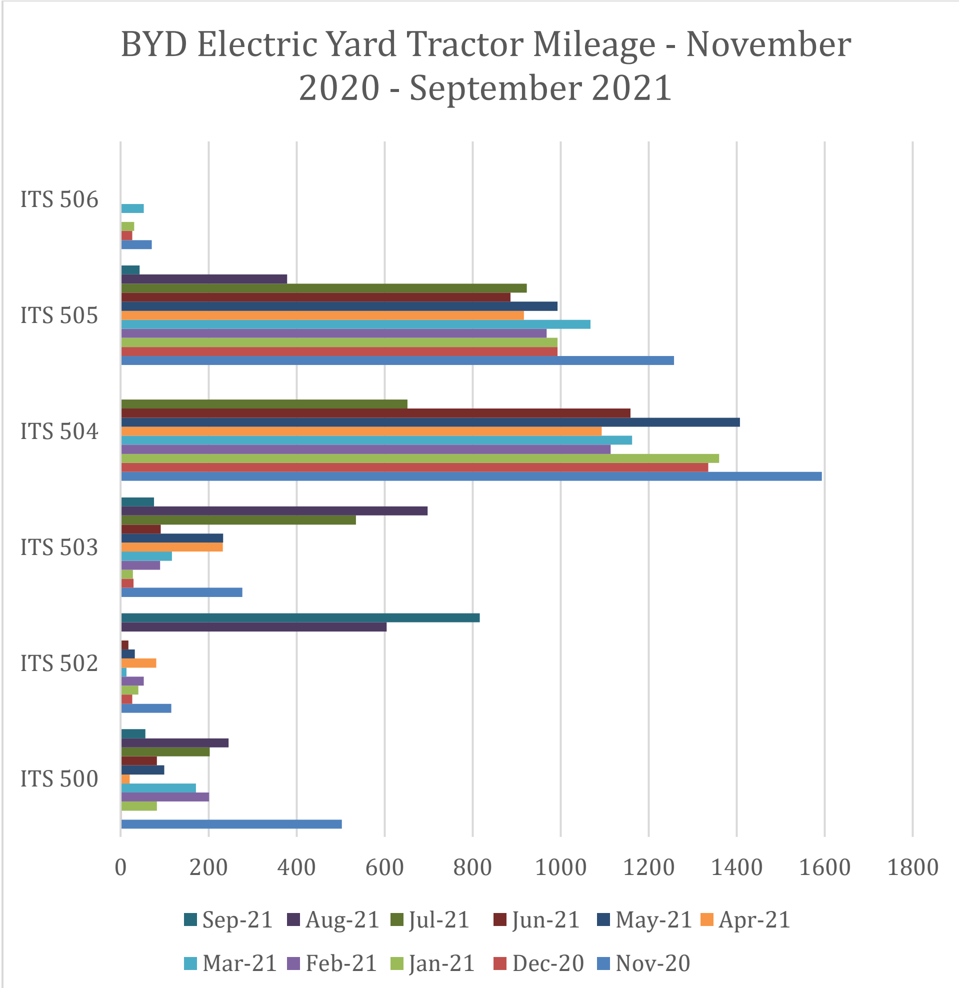

Figure 26 - Relative Utilization of BYD Electric Yard Tractors - 11/2020 to 9/2021

3.3.1.1: Baseline Diesel Yard Tractor

ITS dedicated a new Kalmar Ottawa T2 diesel yard tractor to serve as the baseline vehicle. This vehicle was equipped with the Cummins QSB6.7 Tier 4 Final diesel engine, rated at 173 hp and 760 lb.-ft of torque. The vehicle was manufactured in June 2019. Figure 27 is a photo of the baseline diesel tractor at ITS.

Figure 27 - Baseline Diesel Yard Tractor Used for Project Metrics Comparisons

LBCT had agreed to provide a diesel baseline to be used for comparative data collection and analysis; however, the LBCT demonstration did not progress to that point.

3.3.1.2: BYD 200 kW EVSE

The BYD EVSE did not have data collection or storage capability; thus, the Geotab® GO9™ device was used to acquire all information as it related to vehicle recharging.

3.3.1.3: Cavotec SPS Mechanized EVSE

The Cavotec SPS mechanized 100 kW EVSE unit had its own internal data acquisition system. Data is downloaded manually from the SPS unit approximately once each month or more frequently if needed to troubleshoot a charging issue. The data fields reported by the SPS include the following:

- Charging Event Start/Stop Date & Time.
- Charging Event Duration.
- Energy Delivered per Charging Event, kWh.
- Power Factor, kW.
- Peak Power per Charging Event, kW.
- Alarm Codes.

Table 9, below, includes data downloaded from the Cavotec SPS for the period June through September 2020. As noted earlier, only electric yard tractor ITS 506 was configured to utilize the Cavotec SPS.

Table 9 - Cavotec SPS Mechanized EVSE Data Reporting, Year 2020

Date	Charging Duration (Hours)	Energy Delivered (kWh)	Power Factor	Power Peak (kW)
3-JUN	0:59:15	89.95	0.98	97.70
4-JUN	0:42:53	0.02	0.99	0.20
18-JUN	0:20:50	32.80	0.24	97.66
18-JUN	0:10:47	0.01	0.99	0.20
18-JUN	2:41:21	155.47	0.98	97.74
18-JUN	0:59:06	88.64	0.98	97.81
20-JUN	2:41:09	157.37	0.99	97.76
22-JUN	0:04:35	2.34	0.98	44.49
22-JUN	0:50:09	79.62	0.34	97.62
22-JUN	0:34:55	53.27	0.98	97.58
23-JUN	0:50:42	80.88	0.25	97.68
23-JUN	0:40:38	61.57	0.99	97.73
24-JUN	0:52:14	83.16	0.26	97.71
24-JUN	0:48:17	74.14	0.98	97.64
25-JUN	0:55:04	84.35	0.98	97.81
25-JUN	0:53:44	77.49	0.99	97.73
25-JUN	0:00:04	0.00	0.99	0.19
26-JUN	2:01:22	97.20	0.38	97.76
26-JUN	2:01:32	90.51	0.99	97.80
9-JUL	0:06:11	4.87	0.99	73.72
18-AUG	0:02:07	0.00	0.99	0.21
21-AUG	1:07:51	104.65	0.98	97.50
26-AUG	0:43:12	65.05	0.99	97.66
31-AUG	0:46:50	74.60	0.37	97.67
2-SEP	0:54:03	83.74	0.99	97.71
17-SEP	0:55:24	84.29	0.27	97.58
17-SEP	0:33:04	52.43	0.38	97.78
17-SEP	0:02:37	3.59	0.26	97.74
17-SEP	0:02:22	3.29	0.29	97.63
17-SEP	0:04:44	0.00	0.99	0.21
17-SEP	0:31:08	38.92	0.99	97.38
18-SEP	0:52:23	79.04	0.99	97.66

18-SEP	1:01:36	84.53	0.99	97.66
19-SEP	1:57:36	176.18	0.99	97.77
19-SEP	1:31:36	139.90	0.99	97.62

As shown in Table 9, some of the charging events associated with the Cavotec SPS had significantly shorter charging durations. These datapoints likely reflect situations where the vehicle/SPS interface did not connect, or an SPS fault was detected that interrupted charging. As discussed later, the Cavotec SPS exhibited unreliable charging, and electric yard tractor ITS 506 had almost no utilization during the ITS demonstration period.

This was part of the learning associated with any new technology, with system compatibility issues identified and remedied as part of the initial startup phase. The ITS electric yard tractor demonstration reflects the growing pains commonly encountered when deploying new technology within an ongoing commercial operation.

3.3.1.4: Southern California Edison Power Quality Study

Although not an energy Commission-funded element of the demonstration, the overall project included a study conducted by SCE of power quality associated with the EVSE installed at ITS. SCE was responsible for collecting data as it pertained to grid impacts and power quality evaluation. The assessment followed the recommended practice outlined in SAE J2894/2, which provided procedures for evaluating EVSE/charger/battery/vehicle systems in terms of energy efficiency.

The objective of the power quality assessment was to monitor power quality and power disruption events within the SCE system and correlate any measured events with recorded charger faults.

Two power quality monitors were installed by SCE, the first at ITS' 66/12 kilovolt (KV) substation; the purpose was to capture total harmonic distortion at the 66 kV bus and power quality events that might affect Pier G.

The second monitor was installed on the ITS EVSE 277/480V switchgear. The purpose was to capture any power quality events at the EVSE location that might cause EVSE faults. The study was conducted over a two-week period beginning June 4, 2020, and ending June 17, 2020.

SCE shared the results with the Port in the form of a presentation, the highlights of which are noted below:

- During the study period, SCE recorded one (1) voltage transient – an oscillatory/low frequency voltage transient.
- Three (3) voltage variations were recorded; these were identified as momentary sags in supplied voltage.
- Total harmonic distortion (THD) remained within the allowable tolerance during the study period.
- A voltage sag occurred when an animal contacted the transmission lines. This resulted in a voltage sag (drop) below the 90% of nominal voltage threshold for approximately 235 milliseconds. This voltage sag was sufficient to cause the BYD EVSE at ITS to register a fault and cease charging.

- A second voltage sag was also the result of an animal contacting transmission lines. This event did not result in a voltage drop below the 90% threshold; however, it apparently was sufficient to cause a subset of the BYD EVSE to go offline.
- A third voltage sag event resulted from an unspecified event with a 500 kV transmission line. The voltage sag was recorded at 90% of nominal voltage; as a result, the EVSE at ITS went offline.
- An unknown transient event occurred which resulted in the EVSE going offline. The monitor located at the substation did not record a transient, indicating that it was likely localized at Pier G.

A finding of the SCE power quality study was that although voltage sags and transients were recorded, Society of Automotive Engineers (SAE) J2894-1 requires plug-in charging units (EVSE) to tolerate an 80% voltage sag for 2 seconds. Thus, the recorded events should not have necessarily resulted in the chargers registering a fault and going offline.

A recommendation from the SCE power quality study as it relates to the BYD EVSE was that any manufacturers looking to install EVSEs at a port terminal should review their EVSE trip settings and recovery sequence to tolerate and/or recover from a voltage sag that is within the tolerance specified in SAE J2894-1.

3.3.2: LNG Plug-In Hybrid Electric Trucks

Data collection followed the *2019 LNG PHET Test Plan*, which specified the procedures for laboratory dynamometer testing, on-road demonstration, and data collection. In summary, the testing was performed by the CE-CERT at the University of California, Riverside. The testing aimed to evaluate the performance of one LNG PHET (Truck #1 LL054), under controlled conditions, in cycles that simulate typical Port service. Although the testing confirmed the maximum power rating of the truck, it fell short of capturing the supplementary power and torque details necessary to provide additional information needed to fine-tune the truck.

In summary, the On-Road Demonstration was comprised of the following three phases: Vehicle Verification Testing, Controlled On-Road Testing, and Revenue Service Demonstration.

- Vehicle Verification Testing data consisted of BIT vehicle inspection reports. Any deficiencies identified in the BIT inspections were fixed prior to on-road operation.
- Controlled On-Road Testing was intended to verify that the LNG PHETs could successfully handle the demands of Port drayage operations before being deployed in revenue service. As discussed earlier, the LNG PHETs entered revenue service without all the planned on-road testing.
- All four trucks were deployed by TTSI in revenue service. Data collected included TTSI monthly reports and US Hybrid data logger recording as discussed below.

In addition, TTSI assigned one diesel and one compressed natural gas truck to serve as baseline vehicles for the purpose of performance, efficiency, and air emission comparisons.

Monthly Reports

TTSI prepared and submitted monthly reports for each LNG PHET and each baseline truck, which included the number of days each truck operated, fuel use, fuel cost, distance traveled, and maintenance costs in a tabular format. In addition, operator surveys were used to ascertain the general performance of each LNG PHET and were submitted as attachments to the monthly reports. The surveys were filled out by truck drivers each time the truck was operated and collected such as performance information, on a scale from one (worst) to ten (best), of the truck pulling power, handling, braking, noise level, ride comfort, and overall rating. The operator surveys also collected fueling data, weather conditions, and traffic conditions.

Although fuel use data was collected by TTSI's Omnitracs fleet management software and by the operators, it was not reliable because the truck fuel tank sensors did not operate properly. In addition, the LNG fuel tanks were poorly designed in that fuel evaporated in a matter of several days if the truck was inactive. This resulted in large evaporation losses that had little bearing on the actual fuel used by the LNG PHETs for operation. Although TTSI had planned to replace the LNG tanks with better-designed tanks, it proved to be cost prohibitive especially since the trucks had started developing radiator issues.

Maintenance records were submitted as attachments to the monthly reports for LNG PHETs and baseline trucks. These records showed both routine maintenance and breakdowns as well as the cost associated with each.

Additional Costs

In addition to fuel and maintenance costs provided in monthly reports, TTSI also provided the original cost of each LNG PHET and the cost of the Nuvve chargers. Initial costs of the baseline trucks were not available. US Hybrid provided the price of the Cummins engines and the cost to convert the trucks from LNG to LNG PHET. US Hybrid did not maintain cost records of trouble shooting issues, inspections, or modifications. Rather US Hybrid provided the total budget designated as "conversion cost." Since LNG PHETs were not able to charge with the Nuvve charging stations as discussed earlier, there were no reported electricity costs associated with the demonstration.

Data Logger

US Hybrid equipped each LNG PHET with a data logger to track and record performance parameters such as miles driven, fuel consumption, engine, and electric motor output, etc. This data was collected for each LNG PHET, for each second of truck operation. This resulted in millions of data records, which were post-processed to filter information useful for this analysis. Information provided by the data logger was used to quantify emissions. However, as discussed above, recorded fuel use included evaporation losses and as such was unreliable as a measure of fuel consumption.

The LNG PHETs were unable to charge with the Nuvve charging stations and electricity use data was not collected.

3.3.3: Grid-Tied eRTG Cranes

The nine eRTGs were equipped with Shark 250 power consumption meters to track the power consumption of each of the units. In addition, each of the disconnection points was equipped with an SEL-735 Power Consumption meter. The new 12kVA line at SSA's had a SCE revenue meter, which accounted for consumption across all nine eRTGs. A *California Energy Commission (CEC) Sustainability Freight Transportation Project (GFO-16-604), Electric Rubber-Tired Gantry Crane (eRTG) Demonstration, Data Collection Plan* was submitted in June 2018, then updated in November 2019, when the brand of power consumption meters was changed. The plan detailed the objectives to track the usage of the eRTGs, including operating hours, power consumption, any downtime due to issues with the retrofits, and operator surveys to collect information on advantages and disadvantages of the system.

3.4: Data Analysis

3.4.1: Battery-Electric Yard Tractors

Typically, yard tractors operating at ITS normally perform two shifts. There is an approximately one-hour period between 11:00 am and noon that the electric yard tractors can receive an opportunity charge, and an additional two to four hours of opportunity charging period at the end of the first shift.

The BYD electric yard tractors' ability to perform both work shifts at ITS was inconsistent due to the availability – or lack thereof – of mid-shift and end-of-shift opportunity charging. ITS 502 demonstrated the most consistent utilization during the reporting periods. However, when compared to the baseline Kalmar Ottawa diesel yard tractor, tractor ITS 502 had during its best month an overall utilization rate equal to approximately 78% of the baseline yard tractor average utilization. Thus, from an operational perspective, the BYD electric yard tractor with the greatest utilization did not fully displace an ITS diesel yard tractor.

Table 10 summarizes the BYD electric yard drive recharging metrics and efficiency during the demonstration at ITS.

Table 10 - BYD Electric Yard Tractor Monthly Charging Characteristics & Energy Efficiency

November 2020 Energy Metrics	*ITS 500*	*ITS 502*	*ITS 503*	*ITS 504*	*ITS 505*	*ITS 506*
Average Charging Session Duration (hours)	0.51	0.25	0.45	0.57	1.08	0.3
Average Charging Session Starting SOC (%)	60.7%	76.92%	65.41%	56.67%	55.61%	60.16%
Average Charging Session Ending SOC (%)	96.2%	92.21%	99.23%	96.56%	93.89%	72.91%
Average Energy Added During Charging Session (kWh)	91.79	40.27	87.76	102.63	98.29	34.38
Efficiency - miles per diesel gallon equivalent (MPGe)	10.51	8.42	9.9	11.07	11.31	3.32

December 2020 Energy Metrics	*ITS 500*	*ITS 502*	*ITS 503*	*ITS 504*	*ITS 505*	*ITS 506*
Average Charging Session Duration (hours)	0.23	0.29	0.16	0.46	1.12	2.26
Average Charging Session Starting SOC (%)	93.4%	82.93%	84.78%	54.47%	56.12%	1.10%
Average Charging Session Ending SOC (%)	99.5%	99.5%	96.68%	95.55%	96.52%	99.50%
Average Energy Added During Charging Session (kWh)	24.38	43.5	29.51	106.12	103.39	232.05
Efficiency - miles per diesel gallon equivalent (MPGe)	9.1	7.43	3.97	10.99	12.31	11.21

January 2021 Energy Metrics	*ITS 500*	*ITS 502*	*ITS 503*	*ITS 504*	*ITS 505*	*ITS 506*
Average Charging Session Duration (hr:min)	0:36	0:42	0:51	0:50	1:19	1:01

Average Charging Session Starting SOC (%)	69.24%	56.72%	60.80%	47.46%	47.92%	27.94%
Average Charging Session Ending SOC (%)	98.56%	84.63%	99.50%	91.84%	93.72%	33.19%
Average Energy Added During Charging Session (kWh)	78.15	70.07	98.31	114.67	115.47	14.07
Efficiency - miles per diesel gallon equivalent (MPGe)	10.99	7.89	5.4	10.66	12.13	1.43

February 2021 Energy Metrics	*ITS 500*	*ITS 502*	*ITS 503*	*ITS 504*	*ITS 505*	*ITS 506*
Average Charging Session Duration (hr:min)	0:37	0:22	0:34	0:47	1:02	0.44
Average Charging Session Starting SOC (%)	63.88%	83.95%	76.72%	58.67%	60.73%	41.35%
Average Charging Session Ending SOC (%)	91.62%	98.17%	99.50%	98.14%	95.25%	58.68%
Average Energy Added During Charging Session (kWh)	72.72	37.43	58.66	101.66	88.89	42.02
Efficiency - miles per diesel gallon equivalent (MPGe)	8.23	6.37	12.18	11.78	12.48	2.75

March 2021 Energy Metrics	ITS 500	ITS 502	ITS 503	ITS 504	ITS 505	ITS 506
Average Charging Session Duration (hr:min)	0:38	0:32	0:38	0:42	0:54	0:28
Average Charging Session Starting SOC (%)	56.04%	76.70%	66.77%	59.65%	61.70%	50.41%
Average Charging Session Ending SOC (%)	80.33%	96.98%	99.27%	96.03%	95.01%	62.26%
Average Energy Added During Charging Session (kWh)	83.2	563.61	84.37	94.49	85.61	30.31
Efficiency - miles per diesel gallon equivalent (MPGe)	8.56	13.82	10.55	11.03	12.54	4.31

April 2021 Energy Metrics	ITS 500	ITS 502	ITS 503	ITS 504	ITS 505	ITS 506
Average Charging Session Duration (hr:min)	0:37	0:49	0:47	0:37	0:57	0:50
Average Charging Session Starting SOC (%)	70.90%	52.96%	66.72%	62.39%	62.63%	71.50%
Average Charging Session Ending SOC (%)	99.50%	89.06%	99.50%	94.90%	94.16%	75.23%
Average Energy Added During Charging Session (kWh)	78.26	91.54	85.15	84.01	80.83	8.67
Efficiency - miles per diesel gallon equivalent (MPGe)	8.71	10.06	10.62	9.96	12.49	0.0

May 2021 Energy Metrics	ITS 500	ITS 502	ITS 503	ITS 504	ITS 505	ITS 506
Average Charging Session Duration (hr:min)	0:53	0:52	1:05	0:45	1:05	0:00
Average Charging Session Starting SOC (%)	61.93%	56.66%	52.83%	56.50%	58.95%	N/A
Average Charging Session Ending SOC (%)	99.50%	99.50%	99.50%	95.78%	93.62%	N/A
Average Energy Added During Charging Session (kWh)	99.05	107.26	119.98	101.21	93.62	N/A
Efficiency - miles per diesel gallon equivalent (MPGe)	11.85	12.53	11.85	11.95	12.17	0.0

June 2021 Energy Metrics	ITS 500	ITS 502	ITS 503	ITS 504	ITS 505	ITS 506
Average Charging Session Duration (hr:min)	0:32	0:44	0:26	0:42	1:07	0:00
Average Charging Session Starting SOC (%)	73.86%	7.80%	76.13%	58.63%	57.86%	N/A
Average Charging Session Ending SOC (%)	99.00%	53.70%	99.00%	93.43%	95.26%	N/A
Average Energy Added During Charging Session (kWh)	65.70	109.48	59.62	89.56	95.58	N/A
Efficiency - miles per diesel gallon equivalent (MPGe)	9.56	4.14	7.78	11.43	12.95	0.0

July 2021 Energy Metrics	ITS 500	ITS 502	ITS 503	ITS 504	ITS 505	ITS 506
Average Charging Session Duration (hr:min)	1:05	0:49	0:41	0:44	1:04	0:00
Average Charging Session Starting SOC (%)	49.68%	56.50%	62.15%	58.18%	58.17%	N/A
Average Charging Session Ending SOC (%)	98.68%	99.50%	96.84%	92.38%	93.80%	N/A
Average Energy Added During Charging Session (kWh)	124.93	102.22	89.70	87.79	91.16	N/A
Efficiency - miles per diesel gallon equivalent (MPGe)	12.23	1.90	12.32	10.72	12.13	0.0

August 2021 Energy Metrics	ITS 500	ITS 502	ITS 503	ITS 504	ITS 505	ITS 506

Average Charging Session Duration (hr:min)	0:41	0:45	0:40	0:00	0:55	0:00
Average Charging Session Starting SOC (%)	66.64%	57.95%	61.98%	N/A	60.93%	N/A
Average Charging Session Ending SOC (%)	97.32%	94.52%	95.62%	N/A	91.21%	N/A
Average Energy Added During Charging Session (kWh)	79.34	94.14	86.79	N/A	77.29	N/A
Efficiency - miles per diesel gallon equivalent (MPGe)	10.82	9.91	12.38	N/A	10.97	N/A

September 2021 Energy Metrics	ITS 500	ITS 502	ITS 503	ITS 504	ITS 505	ITS 506
Average Charging Session Duration (hr:min)	0:32	0:49	0:36	0:00	1:00	0:00
Average Charging Session Starting SOC (%)	73.30%	57.88%	72.80%	N/A	50.95%	N/A
Average Charging Session Ending SOC (%)	99.50%	98.44%	99.50%	N/A	84.45%	N/A
Average Energy Added During Charging Session (kWh)	68.63	104.53	69.92	N/A	84.95	N/A
Efficiency - miles per diesel gallon equivalent (MPGe)	9.28	10.62	11.46	N/A	13.00	N/A

3.4.1.1: Air Pollutant Emissions Quantification

At the conclusion of the BYD electric yard tractor demonstration, an analysis was conducted to quantify the well-to-wheel greenhouse gas (GHG) and tailpipe criteria air pollutant emission reductions resulting from the deployment of the seven zero-emission yard tractors. The analysis followed the emissions quantification methodology described in the 2017 Carl Moyer Air Quality Attainment Program Guidelines:

https://ww2.arb.ca.gov/sites/default/files/classic/msprog/moyer/guidelines/2017/2017_cmpgl.pdf.

3.4.1.2: ITS Yard Tractors - Annual Greenhouse Gas Emissions Reduction

The baseline diesel yard tractor used by ITS consumed on average approximately 5,744 gallons of diesel fuel per year. This is an extrapolation of current but limited INSITE™ data and thus subject to revision. The Carl Moyer reference tables show diesel fuel has an energy density of 134.47 MJ /gallon and a well-to-wheel carbon intensity of 102.76 g CO_2/MJ.

Multiplying the annual diesel gallons by the diesel fuel energy and the carbon intensity, as shown in Table 11, yields approximately 79.4 $MTCO_2e$ per year of GHG produced from the Kalmar Ottawa diesel yard tractor.

Table 11 - Well-to-Wheel GHG Emission Analysis (ITS Baseline Diesel Yard Tractor)

ITS Diesel Baseline Yard Tractor

Estimated Annual Diesel Fuel Usage	5,744 gallons
Diesel Fuel Energy Intensity	134.47 MJ/gal
Diesel Fuel Energy Usage	772,396 MJ/year
Diesel Fuel Carbon Intensity (Red Dye @ 15 ppm sulfur	102.76 g-CO_2/MJ
Total Well-to-Wheel GHG Emissions	79.37 $MTCO_2e$ per year

Note that the above GHG emissions data is for one (1) diesel yard tractor. Since well-to-wheel GHG modeling includes upstream generation of greenhouse gases, electric vehicles also have GHG content depending on the amount of electricity used and the carbon intensity of the electricity. The Carl Moyer methodology refers to the operational efficiency of the battery electric vehicles compared to the diesel vehicles as the Energy Efficiency Ratio (EER). The average fuel efficiency for the BYD yard tractors is approximately 11.8 miles per diesel equivalent gallon (DGE), and when divided by the diesel baseline yard tractor fuel efficiency of approximately 2.1 miles per gallon for the Kalmar Ottawa equipped with the Cummins QSB6.7, yields an EER of 5.62.

For a direct comparison, the same annual miles are assumed for the baseline diesel and battery electric yard tractors. Since the battery electric vehicles were 5.62 more efficient, their annual energy usage is found by dividing the diesel vehicle energy usage of 772,396 MJ/year by 5.62. The carbon intensity value for electricity within current Carl Moyer guidelines is 105.16 g CO2/MJ. Multiplying the energy usage by the carbon intensity, as shown in Table 12 yields a well-to-wheel GHG of 5.5 metric ton carbon dioxide equivalent (MTCO2e) per year for the battery electric yard tractors.

Table 12 - Well-to-Wheel GHG Emission Analysis - BYD Battery Electric Yard Tractor

BYD Battery Electric Yard Tractor

Diesel energy usage	772,396 MJ/year
Diesel baseline miles per DGE	2.1
Battery electric vehicle miles per DGE	11.8
Energy Efficiency Ratio (EER) for Battery Electric relative to Diesel baseline	5.62
Electric Yard Tractor energy usage	137,437 MJ/year
Electricity Fuel Carbon Intensity	105.16 g-CO_2/MJ
Total Well-to-Wheel GHG Emissions	14.45 $MTCO_2e$ per year

Therefore, the estimated annual GHG emissions reduction per battery electric yard tractor would be 79.37 – 14.45 = 64.9 MTCO2e.

3.4.1.3: ITS Yard Tractors - Tailpipe Criteria Pollutant Emissions Reduction

Since battery electric tractors have no tailpipe emissions, all the diesel baseline tailpipe emissions can be eliminated when replaced with battery electric tractors. The criteria pollutant emissions of baseline diesel tractors are also estimated using the Carl Moyer methodology. The methodology calculates annual criteria emissions based on the diesel fuel used per year, the corresponding fuel consumption rate, and the emission rate factor based on the certification level of the engine. The diesel baseline yard tractor was estimated to use approximately 5,744 gallons of fuel per year. The diesel yard tractor at ITS is equipped with Cummins QSB 6.7 engine certified to Tier 4 final standards and is rated at 173 hp. This information has been utilized to obtain the appropriate emission factors for criteria pollutant emissions shown below in Table 13. Note that criteria pollutant emissions are expressed in short tons. A conversion factor of 1 (short) ton = 907.2 kg was used.

Table 13 - Criteria Pollutant Emissions (ITS Kalmar Ottawa Diesel Tractor)

Criteria Air Pollutant	*Emission Rate Factor*	*Fuel Consumption Factor*	*Fuel consumption*	*Emission*
NO_x	0.26 g/bhp-hr	18.5 bhp-hr/gal	5,744 gal./year	0.030 ton/year*
ROG	0.05 g/bhp-hr	18.5 bhp-hr/gal	5,744 gal./year	0.006 ton/year
PM_{10}	0.009 g/bhp-hr	18.5 bhp-hr/gal	5,744 gal./year	0.0011 ton/year

*1 short ton = 907,200 g

The emissions reduction assessment illustrates the potential air quality benefits of the BYD Model 8Y electric yard tractors when deployed in marine terminal revenue service. With zero tailpipe emissions, a BYD electric yard tractor would eliminate the criteria air pollutant emissions shown above in Table 13 on a one-for-one yard tractor substitution basis.

3.4.1.4: Battery-Electric Yard Tractors at LBCT

Electric yard tractor utilization at LBCT was tracked and documented throughout the limited demonstration. The primary data collection method for the BYD electric yard tractor when deployed in revenue service was data logging using the Geotab®GO9™ telematics device. As previously discussed, this device interfaced to the BYD vehicle Controller Area Network (CAN) bus and supports the Society of Automotive Engineers (SAE) J1939 engine management protocol.

In addition to CAN data, the Geotab® GO9™ incorporates GPS that allowed real time vehicle location and tracking within the LBCT marine terminal. While this GPS feature allowed vehicle location identification; GPS was not used for yard tractor navigation within the LBCT terminal due to areas of poor GPS signal acquisition. The primary method for vehicle navigation at LBCT was an onboard navigation system manufactured by NOW Solutions.

Table 14 shows the total utilization of the BYD electric yard tractor over an approximately 17-month period, commencing on January 1, 2021, and ending on June 9, 2022. As discussed earlier, the yard tractor was removed from revenue service operation on June 3rd due to damage sustained. During this demonstration period, the BYD tractor was used for 95 days and accrued a total of 858 miles.

Table 14 - BYD Electric Yard Tractor Activity – January 2021 – June 2022

Date	
From	Jan 01, 2021
To	Jun 09, 2022
Days	525

Distance Unit	Miles

Name	Utilization %	Drive Time	Total Miles	Days Driven
PR#0214- LBCT-8Y #0055	100.00%	113:49	858	95
Grand Total	**100.00%**	**113:49**	**858**	**95**

The vehicle data acquisition was also used to collect information on vehicle charging when using the BYD 200 kW EVSE. The BYD EVSE does not have data collection or storage capability; thus, the Geotab® GO9™ device was used to acquire all information as it relates to vehicle recharging at LBCT.

During the demonstration period, the BYD yard tractor was recharged a total of 65 times. On average, the electric yard tractor consumed 20.98% of its available battery capacity per day of operation. Note that LBCT is not representing that the electric yard tractor was used an entire shift each day of vehicle operation.

The average recharge event added 29.04% to the yard tractor's state of charge (SOC), at an average rate of 22.27% SOC per hour. This is shown below in Table 15.

Table 15 - BYD Electric Yard Tractor Recharging Events – January 2021 – June 2022

Data	Results
Number of Charging Events (1/121 - 6/9/22)	65
Average Batter SOC Consumed during Operating Day	20.98%
Average Battery SOC Increase During Charging Event	29.04%
Average Rate of SOC Increase per Charging Event	22.27%

3.4.2: LNG Plug-In Hybrid Electric Trucks

3.4.2.1: General Truck Performance

Overall truck performance was obtained from operator surveys, which collected performance information of the truck pulling power, handling, braking, noise level, ride comfort, and overall rating. Truck drivers rated performance on a scale from 1 to 10, with 10 being best. The operator surveys showed that LNG PHETs performed well and were able to handle the rigors of Port drayage. The surveys indicated lower-than-expected ratings for ride comfort due to high heat temperatures in the truck cabs in the summer months. US Hybrid tried to correct this issue by installing additional insulation to the section of the exhaust pipe under the truck cab in LNG PHET #4 (LL058) in October 2021. However, the truck was taken out of service the following summer due to engine issues and it was not ascertained whether the additional insulation reduced the truck cab temperature. Drivers were not required to fill out surveys for baseline trucks. Therefore, a comparison in general performance between the LNG PHETs and baseline trucks was not possible. Table 16 below summarizes the performance.

Table 16 - LNG PHET Performance Based on Driver Surveys

Performance Metric	LNG PHET #1 (LL054)	LNG PHET #2 (LL056)	LNG PHET #3 (LL057)	LNG PHET #4 (LL058)
Pulling Power (1-10)	8.2	8.0	7.9	7.4
Handling (1-10)	8.2	8.0	7.7	7.7

Braking (1-10)	8.2	7.8	7.6	7.8
Noise Level (1-10)	7.1	6.4	7.2	7.0
Ride Comfort (1-10)	6.9	5.8	5.1	6.9
Overall Rating (1-10)	7.8	7.2	7.5	7.3

3.4.2.2: Truck Utilization

TTSI recorded the number of days each month that LNG PHETs and baseline trucks were out of revenue service due to maintenance. TTSI also provided the monthly maintenance records and costs. Monthly meetings between TTSI, US Hybrid and the Port contributed to further understanding of non-routine maintenance events. Table 17 compares the LNG PHETs and baseline trucks utilization (i.e., the number of days in a month that each truck was operating) and shows that LNG PHETs operated 54% of the time, whereas baseline trucks operated 85% of the time, on average. Maintenance records showed that all four LNG PHETs were frequently out of service due to engine coolant system and radiator failures. Coolant hoses were replaced several times and the radiator on LNG PHET #2 (LL056) was replaced twice. Eventually, the truck developed engine issues and upon further investigation by both TTSI's mechanics and Cummins it was determined that the Cummins engine had been severely damaged and the cost to fix the engine would be prohibitive given the age of the truck. The other three LNG PHETs all experienced similar engine coolant and radiator issues and although those engines were not dismantled and inspected to the same level of detail as LNG PHET #2, the engines show some pressure cracks likely have the same failures ad LNG PHET #2.

Table 17 - LNG PHET and Baseline Truck Utilization

Truck	Average Utilization
LNG PHET #1 (LL054)	53%
LNG PHET #2 (LL056)	52%
LNG PHET #3 (LL057)	56%
LNG PHET #4 (LL058)	60%
Diesel Baseline Truck	79%
CNG Baseline Truck	89%
Average Utilization of LNG PHETs	54%
Average Utilization of Baseline Trucks	85%

3.4.2.3: Cost

TTSI provided the purchase price of the underpowered LNG trucks that were converted to LNG PHET and the monthly operation and maintenance costs for the LNG PHET and baseline trucks. TTSI was unable to provide the purchase price of the baseline trucks. The price of the new Cummins engines and conversion costs from LNG to LNG PHET were provided by US Hybrid. Table 18 presents the total costs.

Table 18 - LNG PHET and Baseline Truck Costs

Truck	Capital Costs	Operation and Maintenance Costs

	Truck Cost	Cummins Engine Cost	Truck Conversion Cost	Charging Station Cost	Total Capital Cost (without truck cost)	Electricity Cost	Total O&M Cost	Total Fuel Cost
LNG PHET #1 (LL054)	$163,542	$110,000	$330,000	Total cost for two Nuvve chargers	$442,600	$0	$13,140	$59,304
LNG PHET #2 (LL056)	$163,542	$110,000	$330,000		$442,600	$0	$22,082	$49,764
LNG PHET #3 (LL057)	$163,542	$110,000	$330,000		$442,600	$0	$5,906	$48,960
LNG PHET #4 (LL058)	$163,542	$110,000	$330,000		$442,600	$0	$4,559	$15,509
LNG PHET Total	*$654,168*	*$440,000*	*$1,320,000*	*$10,400*	*$1,770,400*	*$0*	*$45,687*	*$173,538*
Baseline CNG (VCT002)	Not available	$0	$0	$0	$0	$0	$17,945	$43,153
Baseline Diesel (TEC050)	Not available	$0	$0	$0	$0	$0	$8,213	$9,588

The LNG PHETs entered revenue service on different dates and two of the four LNG PHETs were removed from revenue service due to engine failures before the end of the demonstration period. In addition, TTSI did not begin collecting monthly data for the baseline trucks until the last 8 months of the demonstration period. Since all trucks operated for different time periods and traveled different routes and distances, the total O&M and fuel costs were normalized to miles traveled to better compare costs between the LNG PHET and baseline trucks. Normalized costs are presented in Table 19. The table shows that normalized LNG PHET O&M maintenance costs were like the baseline trucks; this is surprising given how often the LNG PHETs were out of service. It is possible that some maintenance expenses were not accounted for in TTSI's monthly reports but rather included in US Hybrid's total conversion cost.

Unfortunately, US Hybrid did not maintain records of their expenditures for troubleshooting or issue resolution. The table also shows that normalized fuel costs for LNG PHETs were much higher than baseline trucks. This can be attributed to the significant fuel loss resulting from evaporation. Table 18 and Table 19 show that the capital and conversion costs to build the LNG PHETs were not offset by anticipated reduction maintenance and fueling costs.

Table 19 - Normalized LNG PHET and Baseline Truck Costs

	Normalized Operation and Maintenance Costs

Truck	Total Miles Traveled in Demonstration Period	O&M per 100 Miles Traveled	Fuel Cost per 100 Miles Traveled
LNG PHET #1 (LL054)	36,584	$36	$162
LNG PHET #2 (LL056)	22,591	$98	$220
LNG PHET #3 (LL057)	19,261	$31	$254
LNG PHET #4 (LL058)	9,283	$49	$167
LNG PHET Average	*21,930*	*$53*	*$201*
Baseline CNG (VCT002)	33,643	$53	$128
Baseline Diesel (TEC050)	14,864	$55	$65

3.4.2.4: Evaluation of Emissions

LNG PHETs emissions of particulate matter with aerodynamic diameter less than 10 microns (PM10), particulate matter with aerodynamic diameter less than 2.5 microns (PM2.5), nitrogen oxide (NOx), sulfur oxide (SOx), carbon monoxide (CO), volatile organic compounds (VOC), carbon dioxide (CO2), and carbon dioxide equivalent (CO2e or CDE) were calculated. Emissions for an average day are presented in Table 20.

Table 20 - Emissions

Truck	Description	Average Emissions (lb/day)							
		PM10	PM2.5	NOx	SOx	CO	VOC	CO2	CO2e
LNG PHET	Low-NOx, PHET	0.011	0.010	0.021	0.000	1.607	0.157	595	629
TEC050 Baseline Truck	12.8L 2016 Model Year Diesel	0.006	0.006	0.437	0.004	0.113	0.009	4267	447
VCT002 Baseline Truck	12.8L 2020 Model Year CNG	0.001	0.001	0.107	0.000	1.614	0.007	467	505

It should be noted again that since the LNG PHETs were unable to use the Nuvve charging stations, the trucks did not operate in zero-emission mode.

Since trucks operated for different time periods and traveled different routes and distances, emissions were normalized by the distance traveled and are presented in Table 21. The table shows that LNG PHET NOx emissions were calculated to be lower than baseline trucks. This was expected because the LNG PHETs were retrofitted with low-NOx engines. The table also shows that LNG PHET emissions for all other pollutants were calculated to be higher than baseline trucks. This is likely an artifact of the different emission factors used for the LNG PHET and baseline trucks as discussed below.

LNG PHET emissions were calculated using CARB's engine emission certification for this type of Cummins engine, as well as power and transit distance recorded in the LNG PHETs data loggers. Baseline trucks were not equipped with data loggers. Without the power and transit distance parameters from data loggers, engine emission certifications could not be used, and baseline truck emissions were instead calculated using emission factors from CARB's EMFAC2021 model and transit distance reported in TTSI's monthly records. Although both methodologies are correct, they can result in different emissions. For example, CARB's engine certifications identify the emission standards to which the engine is certified; this is the highest allowable set of emissions. It would be expected that actual emissions would be lower than the standard to which the engine is certified. On the other hand, CARB's EMFAC2021 model reports emission factors for a vehicle fleet and does not provide sufficient granularity for specific types of engine technologies. For the reasons identified above, it would not be meaningful to compare LNG PHET and baseline truck emissions.

Table 21 - Normalized Emissions

Truck	**Average Emissions Normalized for Distance Traveled (g/mile)**										
	PM10	PM2.5	DPM	NOx	SOx	CO	VOC	CO2	CH4	N2O	CO2e
LNG PHET	0.06	0.05	0	0.12	0	8.93	0.88	3,305	0.60	0.60	3,497
TEC050 Baseline Truck	0.02	0.02	0.02	1.76	0.02	0.46	0.03	1,720	0.00	0.27	1,801
VCT002 Baseline Truck	0.003	0.002	0	0.32	0	4.76	0.02	1,373	1.34	0.28	1,490

The LNG PHETs data loggers collected geographic position of the LNG PHETs during revenue service. The data was used to compute emissions for truck routes, which were then aggregated into zones based on their varying distances from the Port. Zone 1 reflects the Port complex, Zone 2 reflects truck transit along 710 freeway corridor (Zone 2 is also the Priority zone in the Port's Community Grants Program), Zone 3 reflects truck transit further to the west and east of Zone 2 (Zone 3 is also the Eligibility zone in the Port's Community Grants Program), Zone 4 captures truck transit outside of Zones 1 through 3.[10] **Error! Reference source not found.** shows LNG PHETs pollutant emissions in the four geographical zones. The figure shows that most emissions occurred near the Port where trucks waited at terminals. Baseline trucks were not equipped with position trackers and a comparison of LNG PHETs to baseline truck emissions by zone was not possible.

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[10] The Port's Community Grants Program invests in community projects that reduce Port impacts. https://polb.com/community/community-grants-program-main/

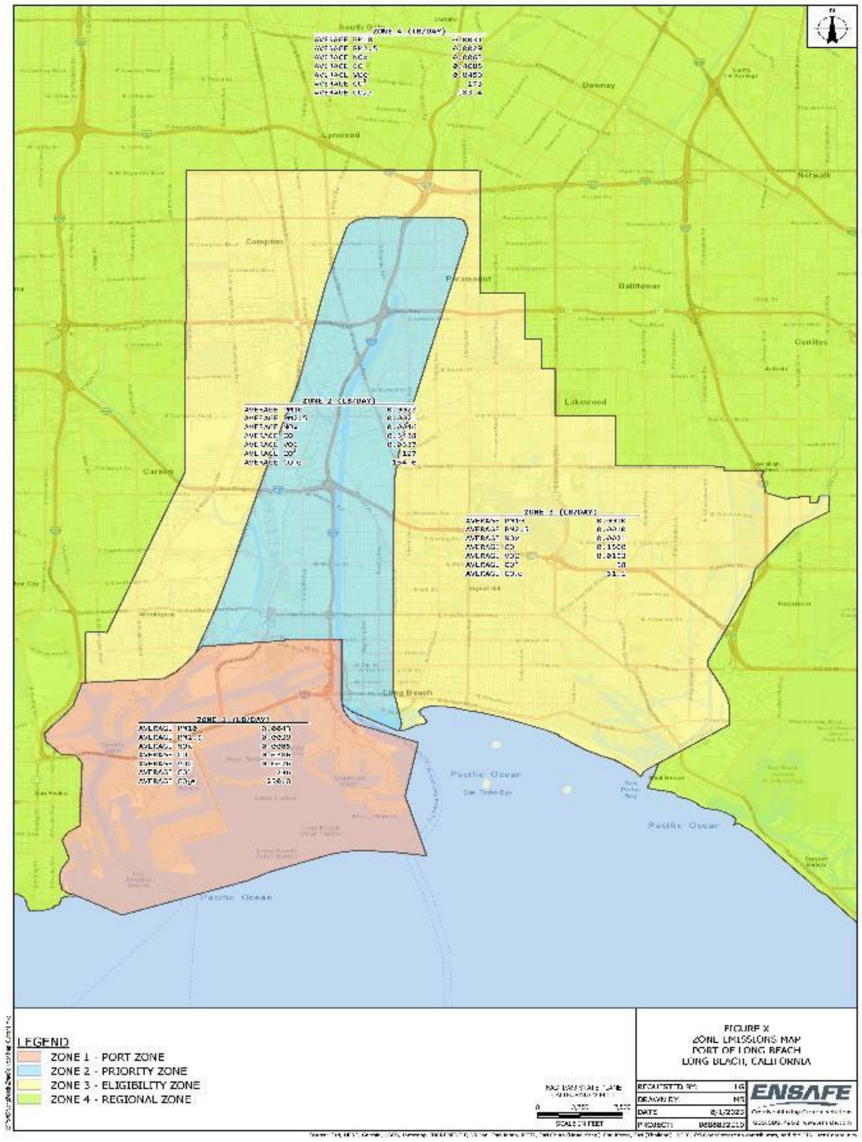

Figure 28 - LNG PHET Emissions (lb/day)

3.4.2.5: Other Items Identified in the 2019 LNG PHET Test Plan

Despite being identified in the *2019 LNG PHET Test Plan*, the duty cycle of the demonstration fleet and the expected duty cycle of future similar technology acquisitions were not evaluated as planned. However, the LNG PHETs performed well in typical Port operation and drivers reported excellent acceleration and power. The trucks were able to traverse sustained grades without loss of power. However, since the time of the grant agreement in 2017, technology has shifted away from PHET toward ZE electric trucks. Although at that time, commercial availability of ZE Class 8 trucks was uncertain, these trucks are now commercially available. TTSI has now fully replaced their fleet of diesel trucks with near-zero CNG and ZE trucks. As ZE technology advances, TTSI plans to replace their CNG trucks with ZE trucks (battery-electric and fuel cell technologies). Therefore, a comparison between the LNG PHETs and similar technology acquisitions would not be meaningful as PHETs are not likely to represent a substantial portion of the future freight transport fleet.

The *2019 LNG PHET Test Plan* also identified an assessment of specific jobs and economic development resulting from the demonstration project. However, since the demonstration project did not proceed as originally planned, as discussed in previous sections, data for this type of assessment could not be effectively collected.

Similarly, the *2019 LNG PHET Test Plan* identified evaluation of a scenario where the entire conventional drayage fleet that serves the Port would be replaced with LNG PHETs. As noted above, ZE Class 8 trucks are now being integrated into freight transport fleets. Furthermore, CARB's recent adoption of the Advanced Clean Trucks Program will increase the penetration of ZE heavy-duty trucks into the market. A key feature of the Advanced Clean Trucks Program is a ZE truck sales mandate that would begin in 2024 and increase to up to 75 percent ZE by 2035 depending on truck gross weight vehicle rating. CARB is also in the process of developing the Advanced Clean Fleet Program, which would apply specifically to fleets performing drayage operations. The program would also affect medium- and heavy-duty on-road vehicles with a gross vehicle weight (GVW) rating greater than 8,500 pounds, off-road yard tractors, and light-duty mail and package delivery vehicles. The program's goal is to achieve a ZE truck and bus California fleet by 2045. Given the state of ZE technology and regulatory developments, there is no longer a compelling business case for retrofitting a truck to hybrid capability.

3.4.3: Grid-Tied eRTG Cranes

The data collection, in particular the power consumption, proved to be more difficult than expected. The initial issues were with the settings of the eRTG crane mounted meters, which initially were recording values that were magnitudes of orders lower than those listed in the SCE invoices. Ultimately, the settings were corrected, and the magnitudes were the same; however, the values were still different between the eRTG mounted meters, meters at the connection points, and SCE invoices. In some cases, the consumption at the connection point was 15% greater than the eRTG reading, and the SCE value was 15% higher than the connection point. These discrepancies are still being worked out with SCE.

Based on eRTG meter readings and using a cutoff of 5000 Wh to trigger that the eRTG is operating, it was estimated that the over a 12-month period from October 2021 to September 2022, the eRTG cranes operated an estimated 20,500 hours for savings of 225,000 gallons of fuel. SSA estimated operations to be about 21,000 hours per year, for a savings of 215,000 gallons for diesel fuel. Table 22 summarizes the data collected, including cost savings over a period of 12-months. Based on the SCE invoices over the same period and using the California ultra-low sulfur diesel (ULSD) fuel prices per gallon from the U.S. Department of Energy, the cost savings was nearly $1M.

Table 22 - Summary of Data Collected

Month	# of eRTGs operating	Estimated Hours Operated	Estimated Diesel Saved (gal)	Average Monthly Price (ULSD, $/gal)	Estimated Fuel Cost Savings	Electricity Cost based on SCE Invoice	Estimated Total Cost Savings
OCT-21	6	647	7,106	$4.48	$31,843.42	$24,084.42	$7,759.00
NOV-21	6	1056	11,610	$4.75	$55,090.81	$22,457.41	$32,633.40
DEC-21	6	1740	19,123	$4.78	$91,332.92	$25,820.01	$65,512.91
JAN-22	6	1600	17,584	$4.80	$84,458.02	$27,848.08	$56,609.94
FEB-22	6	1444	15,870	$5.02	$79,634.06	$30,153.93	$49,480.13
MAR-22	7	1919	21,091	$6.13	$129,350.33	$30,943.34	$98,406.99
APR-22	7	1828	20,091	$6.26	$125,767.18	$35,748.39	$90,018.79
MAY-22	8	2202	24,199	$6.48	$156,784.41	$35,046.88	$121,737.53
JUN-22	8	2243	24,655	$6.87	$169,478.65	$36,210.80	$133,267.85

JUL-22	8	1867	20,522	$6.59	$135,178.67	$38,046.96	$97,131.71
AUG-22	9	2226	24,465	$6.12	$149,801.73	$34,410.83	$115,390.90
SEP-22	9	1708	18,777	$6.15	$115,460.15	$28,043.16	$87,416.99
Totals		**20,478**	**225,094**		**$1,324,180.34**	**$368,814.21**	**$955,366.13**

3.5: Challenges/Unforeseen Events

3.5.1: Battery-Electric Yard Tractors

The COVID-19 pandemic and subsequent disruptions to the supply chain and workforce in general had serious negative repercussions for the electric yard tractor demonstration.

Operationally, the need to sanitize the yard tractors between shifts per the COVID prevention protocol disrupted vehicle recharging opportunities and negatively impacted the electric yard tractor's ability to demonstrate two-shift capability. Supply chain disruption delayed the delivery of spare parts and delayed necessary vehicle and EVSE repairs.

Arguably, the most disruptive unforeseen challenges were a result of workforce issues at BYD. It was observed and noted that the organization suffered from high workforce turnover during the pandemic; this resulted in a lack of trained technicians to trouble shoot technical issues encountered with the electric yard tractors. This lack of available field technicians resulted in extended vehicle downtime when a vehicle or EVSE failure occurred. This was exacerbated by the lack of replacement parts, further extending vehicle downtime.

The following sections discuss additional challenges and unforeseen events in conjunction with those that were the direct result of the COVID pandemic. These are technical and operational issues associated with the electric yard tractors and EVSE that would likely have been encountered in the absence of the COVID pandemic.

Manufacturers looking to succeed in a port terminal setting need to have a local presence, trained technicians with quick response times and a robust customer service to address any needs from the terminal operator including on-site training and troubleshooting EVSEs.

3.5.1.1: ITS Demonstration

Seven-yard tractors were initially deployed at ITS. In August 2020, the second month of the demonstration period, BYD yard tractor ITS 501 was involved in a collision and was not repaired and thus did not return to revenue service.

ITS 506 was modified to utilize the Cavotec SPS charger. As a result of technical issues associated with the Cavotec SPS EVSE and its perceived lack of availability, tractor ITS 506 was used very infrequently.

The BYD 8Y electric yard tractors also experienced a mixed reception from ITS labor, especially the drivers. A survey of the drivers was conducted to understand perceived reluctance to use the electric yard tractor in favor of the diesel units. Common themes in the survey results included the following:

- The BYD electric yard tractor was more fragile and prone to damage or component failure. One respondent noted the electric yard tractor was the "complete opposite of the durable 'tank like' features of the diesel Ottawa." Respondents noted vehicle components would "fall off."
- Multiple issues were reported by drivers who had the cab door jam. The BYD Model 8Y incorporated a hydraulic assist door opening mechanism, as compared to the traditional

manual cab door of its diesel counterpart. The door issue devolved into a situation where drivers refused to operate the BYD tractor in favor of selecting a diesel unit.

- Drivers noted the frequent illumination of red dashboard lights that were perceived as warning indicators. This resulted in drivers opting for the diesel yard tractors as opposed to the electric yard tractor demonstration units, as the drivers did not want to be held responsible for damaging the demonstration tractors.
- Multiple drivers noted the unfamiliar ergonomics and the seat position of the BYD Model 8Y as compared to the diesel tractors. It was noted that the seat lacked an adequate range of adjustability; this resulted in drivers who said they were physically unable to operate the BYD tractor due to the ergonomic restrictions.

An operational issue identified by ITS was the inability of the BYD Model 8Y to complete two (2) shifts without recharging. The original concept of operations was that electric yard tractors would charge at the completion of the second shift, and then receive the opportunity recharging during driver breaks. However, it proved operationally infeasible for a driver to return the electric yard tractor to the charging location, have a gear man plug the vehicle into the EVSE, and then have a gear man available to unplug the electric tractor at the end of the break so that the driver could return to work. This resulted in electric vehicles receiving the opportunity to charge infrequently, and thus not having enough charge to complete the second shift. Also, as noted above, the need to sanitize the vehicle between shifts per the COVID protocol further reduced the time available to recharge the electric yard tractors.

While this is arguably unique to marine terminals who utilize labor with strictly defined roles and responsibilities (drivers, gear men, mechanics, etc.), ITS management concluded that a viable electric yard tractor to satisfy their operational needs would have an onboard energy storage capacity sufficient to complete two full shifts without the need for opportunity charging.

Ultimately, ITS was able to retain a group of drivers who were amenable to the technical, ergonomic, and operational differences associated with the BYD Model 8Y design as compared to the Kalmar Ottawa diesel tractor. This allowed the demonstration to progress to its completion in September of 2021.

3.5.1.2: LBCT Demonstration

LBCT has unique operational requirements that require substantial modification to the baseline BYD Model 8Y electric yard tractor configuration. As discussed below, the required vehicle modifications impacted adherence to the original demonstration timeline. Also, the final phase of validation testing at LBCT uncovered a serious structural issue with the modified AUCOS fifth wheel coupling system which had undergone modification at BYD.

Modification of the BYD Electric Yard Tractor to Accommodate LBCT Turning Radius Requirements – LBCT routinely performs a “jack knife” maneuver when positioning containers within the terminal. During early validation testing it was discovered that during a sharp turn, the bomb cart would make forceful contact with the BYD tractor structure. This was deemed an operational and safety issue and necessitated the modification of the BYD yard tractor frame. BYD subsequently modified the yard tractor to accommodate this maneuver, and no further issues were encountered. It was intended that the four remaining BYD electric yard tractors would be similarly modified prior to delivery to LBCT.

Installation of the NOW Solutions Navigation System – LBCT utilizes an onboard navigation system provided by NOW Solutions to increase container movement efficiency. The navigation systems were delivered in January 2021; however, after delivery an electric yard tractor compatibility issue was identified.

The system uses sensors installed onboard the yard tractors to obtain data used in terminal navigation. One of the essential sensors measures the rotational rate of the yard tractor driveshaft – this data is used to compute yard tractor speed. However, as the BYD electric yard tractor does incorporate a driveshaft component, an alternative sensor design was required to compute an accurate vehicle speed.

It was determined that a ground speed sensor could be used as a compatible alternative for the NOW Solutions navigation system. BYD designed a bespoke bracket to mount the ground speed sensor in the correct position. Due to supply chain constraints resulting from the COVID-19 pandemic, parts were backordered, and delivery of the ground speed sensors and brackets was delayed until July 2021. The use of the ground speed sensor in lieu of the driveshaft rotation sensor was successful, and it was intended that the four additional BYD electric yard tractors would be outfitted similarly.

Modification of the BYD Electric Yard Tractor to Accommodate the AUCOSystem Automatic Coupling System – LBCT utilizes the AUCOS automatic coupling fifth wheel on all of their yard tractors. This system allows for auto-connection of air lines, electric connectors, and datalinks through the AUCOS kingpin to the AUCOS fifth wheel. Automatically connecting all air, electric, and data connections between the tractor and the container chassis/bomb cart improves safety and production efficiency by allowing the operator to remain in the cab.

During manufacture of the first LBCT BYD electric yard tractor unit at BYD's Lancaster, CA manufacturing facility, it was noted that the baseline BYD yard tractor configuration does not allow direct replacement of the original equipment Holland fifth wheel with the AUCOSystem automatic coupling fifth wheel. This is due to interference with structural and mechanical elements of the BYD tractor directly below the fifth wheel installation location. Further, the available space for fifth wheel installation cannot be readily increased on the BYD tractor without making substantial design changes. This occurred on or about August 20, 2019.

To facilitate installation of the AUCOS system, BYD engineers designed modifications to the electric yard tractor structure, relocated structural, electrical, and hydraulic components, and increased the available fifth wheel envelope to the extent feasible. Additionally, and importantly, BYD made modifications to the AUCOS fifth wheel itself to fit withing the allowable envelope.

LBCT expressed concerns with BYD's modification of the AUCOS fifth wheel system, specifically questioning whether the modifications altered the structural integrity of the AUCOS fifth wheel. To address LBCT's concerns, BYD retained an independent structural engineer to review the proposed fifth wheel design modifications.

The independent structural engineer subsequently concluded that the proposed modifications to the AUCOS fifth wheel would accommodate the stress profile anticipated during in-use operation at LBCT without a risk of failure. This finding was ultimately satisfactory to LBCT; however, the delay associated with identifying this issue, retaining outside engineering support, and conducting independent engineering analysis resulting in a BYD manufacturing schedule impact of several months.

On June 3, 2022, LBCT notified the Port that during routine maintenance and inspection of the BYD electric yard tractor, technicians discovered the pins that hold the fifth wheel assembly in place were bent, most likely due to the modifications to the substructure required to accept/support the AUCOS fifth wheel. The yard tractor was subsequently pulled from LBCT's operations and is currently parked at the terminal.

The uncertainty on how to reengineer the BYD electric yard tractor to accommodate the AUCOS fifth wheel was a key element of BYD's decision to discontinue participation in the LBCT demonstration project. BYD did not have the engineering and manufacturing resources in place to redesign and subsequently modify the remaining four (4) electric yard tractors and was unable to commit to a delivery schedule that would fit within the remaining time of the LBCT demonstration project.

3.5.1.3: EVSE Challenges/Unforeseen Events

BYD 200 kW EVSE

The proprietary BYD EVSE demonstrated acceptable availability during the demonstration period but did present technical challenges intermittently. The overall reliability, using uptime as the metric, varied from EVSE unit to unit. Troubleshooting EVSE offline events proved challenging during the demonstration, as the BYD EVSE installed at ITS and LBCT did not have an event data recording capability. The EVSE did have the ability to generate fault codes; however, these were often not retained by the EVSE unit. Quality control issues led to the overall sentiment that the EVSE was not robust in either design or manufacture.

As noted in the SCE Power Quality Study, above, there was the appearance that the BYD EVSE was not robust in its ability to contend with voltage lags on the order of 10% lower than nominal voltage. BYD EVSE units going offline were correlated against voltage sags that the EVSE should have tolerated if compliant with SAE J2498-1.

The lack of a cable management system on the BYD EVSE also created issues with marine terminal labor and management – a work around was proposed and implemented; however, it was not the preferred solution for handling heavy EVSE cabling, as it still required manual lifting of the cables without a system to adequately offset a portion of the cable weight. The marine terminal gear men responsible for plugging and unplugging the electric yard tractors did complete the tasks, but the need for a cable management system for future high power EVSE installations at marine terminals is a "lesson learned" from this demonstration.

At the conclusion of the demonstration, BYD disclosed that the next generation of electric yard tractor would not use BYD proprietary EVSE but would rather conform to the Combined Charging System Combo 1 (CCS1) charging standard.

Cavotec Smart Plug System

The Cavotec SPS was a first generation mechanized EVSE system that had not previously been demonstrated in a marine terminal environment. The system demonstrated poor functionality and reliability and was underutilized by the electric yard tractor drivers due to its perceived unreliability.

As mentioned earlier, the Cavotec SPS is comprised of two systems, one onboard the electric yard tractor that includes a plug module and associated components and software, and the mechanized charging EVSE unit. The first technical issue encountered was a failure of the two SPS components to communicate – the onboard vehicle system could not establish a communications link with the charging unit that would activate the mechanical arm/plug. This issue required a significant amount of time and effort to resolve.

Additional technical issues continued to present themselves throughout a brief demonstration period. It was noted by ITS that the Cavotec electric yard tractor, designated as ITS 506, frequently had its plug module door jam. The charging unit door that shielded the mechanized arm/plug was also prone to jamming or not actuating. It was estimated by ITS that nonfunctional access doors on either the vehicle or charging unit "accounted for 50%" of the failed vehicle/charger coupling events.

ITS noted that Cavotec technicians were frequently required to be onsite to assist the vehicle driver in connecting the electric yard tractor to the SPS system.

This lack of reliable functionality resulted in a reluctance on the part of drivers to utilize ITS 506 so that they would not need to deal with the Cavotec SPS to recharge the vehicle. As such, both the Cavotec SPS and electric yard tractor ITS 506 were infrequently used during the demonstration period.

3.5.2: LNG Plug-In Hybrid Electric Trucks

The project encountered several challenges and unexpected events that delayed equipment deliveries, compromised testing, and rendered several project elements infeasible to analyze. The following summarizes these events and identifies document sections that provide additional discussion.

- COVID-19 disrupted the economy, production, and workforce, and in turn delayed LNG PHETs build, delivery, and maintenance. Additional discussion of how COVID-19 shutdowns and supply chain disruptions affected the demonstration was described earlier.
- LNG PHETs experienced failures in the engine cooling system and radiators. These failures eventually led to engine failures and all four trucks had to be removed from revenue service. Two of the trucks were unable to complete 12 months of revenue service and all four trucks were unable to complete 12 uninterrupted months of service. Additional discussion in the context of truck performance has been discussed.
- LNG truck fuel tanks had been poorly designed prior to conversion to LNG PHETs. This resulted in large fuel loss due to evaporation and rendered collected fuel data unreliable for the purposes of comparing to baseline trucks or quantifying potential fuel displacement by the LNG PHETs.
- TTSI installed two BYD charging stations to allow LNG PHETs to charge at the end of the day. However, after several months of testing and charging issues, it became clear that the BYD chargers had a proprietary interface that caused communication errors with charging with non BYD-manufactured vehicles. US Hybrid attempted to solve this issue by applying a software code change; the software patch was not successful. An amendment to the subcontract agreement was needed to cover the cost of upgrading the LNG PHET onboard chargers to comply with the International Electrotechnical Commission standard. TTSI was then able to purchase a Nuvve charging station and installed it at the San Pedro facility.

  The charging station proved to be problematic and costly. In hindsight, ensuring that on-board chargers and charging stations comply with the same International Electrotechnical Commission standard at the initial design stage would have proven more cost efficient and timely.
- Despite TTSI's acquisition of two Nuvve charging stations, the stations were not utilized due to the reasons detailed earlier. As a result, the performance of the charging stations was not assessed, and zero-emission operations were not realized.

- During the data analysis phase of the demonstration, it became apparent that insufficient information was collected for the baseline trucks to allow for robust comparison to the LNG PHETs. The baseline trucks were part of the regular TTSI fleet and did not have data loggers that provided power and geographic position information. Without power data, the emissions analysis relied on default emission factors from California's emissions inventory (CARB EFAC2021), which incorporates a fleet mix of trucks based on historical and projected information.

3.5.3: Grid-Tied eRTG Cranes

The biggest challenge for the eRTG was the guidance system. SSA Marine spent a few months with an outside developer to come up with a custom designed system. Without a similar conversion operating in the world, this made it difficult to install an off-the-shelf guidance system. Once SSA Marine moved past the 3rd party design, their in-house mechanics came up with a simpler design, as discussed earlier.

CHAPTER 4: Lessons Learned/Next Steps

4.1: Battery-Electric Yard Tractors

Technology demonstration projects such as those implemented at ITS and LBCT are conducted for the primary purpose of gathering data and information that can subsequently be used to advance the state of that technology. In that respect the demonstrations of BYD electric yard tractors, EVSE, and the Cavotec SPS were successful in that it resulted in lessons learned that can and are being applied to the next generation of advanced technology zero-emission vehicles and infrastructure.

The following are the principal lessons learned from the battery electric yard tractor demonstration:

- Ensure all necessary listings, certifications, or verifications needed to allow timely permitting of equipment and apparatus are understood and in place prior to equipment installation: The demonstration at ITS and LBCT was significantly delayed due to the lack of UL listing of the BYD and Cavotec EVSE, and independent testing and verification by a Nationally Recognized Testing Laboratory (NRTL) was required before the City would issue permits to allow the EVSE to be energized. In future demonstrations of EVSE, including pre-commercial EVSE, ensure the equipment is UL listed or independently verified by a NRTL before the project begins and the equipment is installed. All manufacturers of EVSE should understand this requirement and ensure their equipment is compliant before participating in a funded demonstration project.
- Do not demonstrate a vehicle or technology offered by a manufacturer if there is doubt that technology represents the state-of-the-art for that technology: The demonstration partners expressed their concern that the electric yard tractors and EVSE supplied by the manufacturers did not represent the most current generation of that equipment. It was expressed that the vehicles and EVSE represented "obsolete technology." By the end of the demonstration, BYD had left the EVSE market and modified the model 8Y electric yard tractor to be compatible with the CCS1 charging standard. Cavotec was already preparing to demonstrate their second generation SPS before the ITS/LBCT demonstration was completed. While the manufacturers will most likely represent that these design iterations were in large part a direct result of the ITS/LBCT demonstrations, the decision to not retain any of the demonstration assets was primarily due to the sense that these assets were now obsolete. There was a concern that technical support for the earlier generation vehicle would not be available moving forward given the introduction of a newer model.
- Ensure equipment and technologies have been adequately tested and their functionality validated prior to deployment in a funded demonstration project: Given the inability for the Cavotec SPS system components to communicate with each other, and the level of redesign and rework required to obtain functioning EVSE, it calls into question whether Cavotec had conducted testing and system validation before the SPS was shipped and installed. The failure modes observed upon initial testing would have likely been encountered had that equipment undergone integrated bench testing and quality assurance at the manufacturer facility. In future demonstrations, it should be incumbent upon the manufacturer or technology vendor to demonstrate through controlled documentation that adequate testing of the hardware and software had been

performed, and that the equipment had passed quality assurance and quality control oversight.

- To the extent feasible, understand any unique operational or technology compatibility requirements from the demonstration partners prior to vehicle and equipment deployment: The project partners were not aware of the requirement to integrate a vehicle tracking and navigation system unique to LBCT into the BYD yard tractor. This requirement introduced significant schedule delays, as additional engineering design was required, and additional components procured - procurement lead time was further exacerbated by the pandemic-induced supply chain disruption. Also, it was not fully understood at the beginning of the demonstration at LBCT that the AUCOS fifth wheel system would be incompatible with the BYD Model 8Y electric yard tractor. Had these requirements been known upfront, the necessary engineering evaluations could have been performed to determine technical feasibility, candidate engineering solutions, and likely cost and schedule impacts that would have allowed program management to make a go/no-go decision on whether to proceed with deployment at that marine terminal site.

4.2: LNG Plug-In Hybrid Electric Trucks

The continuous and rapid advancement of zero-emission trucks have led to zero-emission technologies surpassing the LNG PHET technology during this demonstration. Nevertheless, technological demonstrations continue to play a crucial role in generating interest, driving improvements, and gaining valuable insights. A key insight gained from this demonstration is the complexity of technology retrofits, requiring seamless integration and coordination among all components.

The following are the principal lessons learned from the LNG PHET demonstration:

- COVID-19 Disruption: The COVID-19 pandemic significantly disrupted the project by causing delays in equipment deliveries, production, and maintenance, impacting project timelines and testing.
- Engine Cooling System and Radiator Failures: Engine cooling system and radiator failures in the LNG PHETs led to engine breakdowns, resulting in all four trucks being taken out of revenue service before completing the intended service duration.
- Poorly Designed LNG Fuel Tanks: The original design of LNG fuel tanks, prior to conversion to LNG PHETs, caused significant fuel loss due to evaporation. This made it challenging to obtain reliable fuel consumption data for comparing with baseline trucks.
- Charging Station Compatibility Issues: The proprietary interface of BYD charging stations caused communication errors when used with non-BYD vehicles. This issue necessitated a software code change but when that failed, the chargers from Nuvve Corporation were purchased instead. Nuvve Corporation is a company that provides electric vehicle (EV) charging solutions and vehicle-to-grid technology.
- Underutilized Charging Stations: Despite acquiring Nuvve charging stations, they were not utilized due to the challenges with compatibility, rendering zero-emission operations unattainable.
- Lack of Sufficient Baseline Truck Data: The baseline trucks lacked data loggers, making it challenging to collect comprehensive power and geographic position information for robust comparisons with LNG PHETs. Recommendation is made to enhance data collection methods and ensure that baseline trucks and LNG PHETs are equipped with data loggers to enable thorough and reliable performance evaluations in future projects.

- Rapid Advancements in Zero-Emission Technologies: The pace of advancements in zero-emission technologies surpassed LNG PHET technology during the project, highlighting the importance of staying up to date with technological developments. TTSI will continue to monitor the rapidly evolving zero-emission technology landscape and stay at the forefront of advancements. It is important to note that as of 2021, the state of technology for full battery-electric drayage trucks is at the near-final or final stage at which the technology has adequately exhibited technical viability through test and demonstration.[11]
- Technology Retrofit Complexity: Retrofitting technology requires seamless integration and coordination among all components, which can be challenging. Consideration of partnerships with large OEM facilities for smoother processes should be explored.

When asked, TTSI indicated that they planned to retain the LNG PHETs temporarily following the project's conclusion. While repurposing the trucks would be desirable, the primary challenge remains with the Cummins Engine. Given the rapid evolution of zero-emission technologies, however, TTSI will continue to explore and evaluate other ZE technologies. In the meantime, TTSI will continue to test ZE battery-electric Class 8 trucks on a trial basis from companies like Nikola Corporation with their sights also set on ZE fuel-cell EV options as well.

4.3:Grid-Tied eRTG Cranes

The following are the principal lessons learned from the eRTG crane demonstration:

- Conversion Complexity: The initial conversion of diesel-powered cranes to electric eRTG cranes was a custom solution and required a significant amount of time, money, and infrastructure planning. Subsequent conversions were more streamlined, taking about six to eight weeks. This highlights the importance of thorough planning and the potential for efficiency gained with experience.
- Structural Integrity: The retrofit required unique mounting brackets and confirmation of the structural integrity of the cranes to ensure no additional stress or strain. The need for custom solutions and structural assessments should be anticipated in similar projects.
- Environmental and Operator Benefits: The eRTG cranes were well-received by both operators and the environment due to the lack of diesel exhaust and reduced noise. Transitioning to eco-friendly equipment can yield positive results in terms of sustainability and operator satisfaction.
- Cost Considerations: The conversion process was costly, and SSA is now open to exploring alternative zero-emission technologies such as hydrogen fuel cells and battery plug-ins. Cost considerations should be balanced against the environmental benefits.
- Cable Reel System Challenges: The cable reel system posed challenges, including proper planning for trenching and drainage. Future projects using this technology should carefully evaluate the design, drainage, and safety considerations of the cable reel system.
- Guidance System Development: Developing a custom guidance system was challenging due to the lack of off-the-shelf solutions for eRTG cranes. Innovations and problem-solving in this area were necessary, and the process evolved over time.

[11] https://cleanairactionplan.org/strategies/trucks/

- Battery Container Mobility: The use of a battery container for moving eRTG cranes between stacks proved useful but time-consuming. The trade-off between mobility and the time required for disconnections and connections should be considered.

In taking the next steps, SSA has continued to research alternative technologies like hydrogen fuel cells and battery plug-ins to expand zero-emission operations and potentially reduce costs. Through this Project, knowledge and experience gained from the conversion process, especially regarding custom solutions, structural assessments, and guidance systems, will be shared with other ports and terminals considering similar projects. In the meantime, both the Port and SSA will continue to stay informed about advancements in ZE technology and equipment to remain at the forefront of sustainable port operations and to reduce the environmental impact of the terminal.

CHAPTER 5: Training and Public Outreach Campaign

5.1: Workforce Training Efforts

5.1.1: Long Beach City College

The Port of Long Beach engaged Long Beach City College (LBCC) to perform a workforce gap analysis related to their demonstration of 25 new or converted zero emission vehicles. In addition to the gap analysis, it included project related equipment adoption projections which may drive workforce needs, as well as estimates on the creation of new jobs. This effort, Port of Long Beach Zero-Emissions Terminal Equipment Transition Project, is funded by the California Energy Commission.

5.1.1.1: Equipment Adoption Projections

In projecting the workforce demand needed to support the transition to zero emissions technology, as well as the specific skills needed for roles, equipment adoption rates were estimated including reflections on the range of issues driving the speed of adoption, especially by the terminal operators. There are several inhibiting factors that may impact the pace of adoption thereby impacting the labor needs, mainly the cost of infrastructure and immature technology, the cost of batteries, technical factors including the speed of charge, and the maturity of the vehicles.

5.1.1.2: Potential Job Growth

In projecting adoption rates, LBCC was able to also project potential job creation. It considered three categories related to Port electrification: vendor jobs (pilot vendors were all local) in retrofitting or manufacturing, operator jobs in maintenance, and infrastructure jobs for installation of charging or electric power service. It found that most of the workforce needs for Port electrification will be workers in the infrastructure area, vendor needs supporting Port equipment will also absorb new workers with new skills, and maintenance will likely be a retraining mission of existing workforce.

5.1.1.3: Competencies

Through interviews with original equipment manufacturers (OEMs), terminal operators, labor representatives, and subject matter experts LBCC identified the needed skills and competencies for entry level and incumbent workers. There are 29 key skills within eight broad areas including Battery Safety, Battery Theory, Charging Components, Electrical Connections in Corrosive Environments, Equipment Maintenance, General Electrical, Mechanical Aptitude, and Zero Emission Technology. Both OEMs and terminal operators reported that servicing these electric vehicles is less labor intensive than diesel and believed that existing mechanics should be able to service these new vehicles with current skills and minimal training.

5.1.1.4: Community College Programs

Through interviews, surveys, and the review of course details and program offerings in 23 colleges, LBCC has identified four regional colleges that have both advanced transportation programs and electrical programs as well as already integrated zero emissions technology concepts into their curriculum. In addition, there are 13 that have advanced transportation programs with zero emissions concepts integrated. These colleges are geographically diverse, including Los Angeles and Orange Counties, which provide the larger community with greater access to their training and education programs.

In addition, several community colleges in the region have not-for-credit offerings for incumbent workers in advanced transportation. These classes are fee-based and operate on full cost-recovery, rather than being priced on a per unit basis. Employers often pay training fees for their workers to attend the training, or they take advantage (if they qualify) of funding from the State to subsidize training fees. Regionally, Long Beach City, Cerritos, and LA Trade Tech Colleges offer not-for-credit training around alternative fuels.

5.1.1.5: Long Beach Unified School District Educational Pathways

Nationally there is a movement to transition high schools into industry-focused academies which are smaller in scale within comprehensive high schools and have robust industry engagement and a career focus. This approach is called Linked Learning and the programs are referred to as pathways. Long Beach is already ahead of many cities across the nation with the full implementation of linked learning and we have identified seven high schools with pathways related to the Port’s zero emission work. In fact, there are nine middle and high schools that have integrated curriculum on electric vehicle technology. There is a good geographic distribution of programs throughout the city offering access to students throughout Long Beach.

5.1.1.6: International Brotherhood of Electrical Workers (IBEW)

Apprenticeship and Training Programs: The IBEW’s Local 11 union branch, which covers the greater Los Angeles area, currently represents 11,700 members and this year they accepted 600 new apprentices. They continue to train new apprentices and retrain and upskill existing members to work in the growing field of zero emissions technology. In addition to the traditional apprenticeship path, IBEW offers the Electric Vehicle Infrastructure Training Program (EVITP) which is the highest standard in training and certification for the installation of electric vehicle infrastructure.

5.1.1.7: Recommendations

The bulk of the work of educating and training the future and incumbent workforce will fall to community colleges and to LBCC’s labor partners. Community colleges work with a unique set of challenges, and a lack of flexible funding is the greatest. Colleges have the talent in their faculty, the tools and equipment in their labs, and a captive and eager audience in their students. What we lack, however, is funding to be able to quickly develop training in response to changing technologies and industries’ demands. With additional flexible funding for short term incumbent worker training, we are not only able to meet the immediate needs of local industry, but also pilot new curriculum that can then be integrated into our existing credit bearing certificates and degrees updating those programs to better prepare the future workforce.

5.1.2: Port of Long Beach High School Summer Internship Program

Long Beach Unified School District is a linked learning district, meaning that each of the 14 comprehensive high schools have been converted into industry-themed pathways from 9th-12th grades. Students enter as freshmen into industry academies or pathways of study where they stay for their high school career. These industry themes include construction, business and finance, energy environment and utilities, engineering and architecture, and others. In addition to inventorying the community college programs, we also reviewed high school offerings to see where there was an introduction to zero emissions concepts or technology.

To support this approach, The Port of Long Beach High School Summer Internship Program is a six-week paid internship program for high school students who are interested in careers in international trade and related fields. The program is designed to give students hands-on experience working in the Port, and to help them learn about the different career opportunities available.

The internship program is open to high school juniors and seniors who reside in Long Beach or attend a high school in the Long Beach Unified School District service area. Students must have a minimum 2.5 GPA and be available all six weeks of the program.

Interns work in a variety of departments, including:

- Cargo Operations
- Engineering
- Environmental Affairs
- Finance
- Human Resources
- Information Technology
- Marketing and Communications
- Planning and Development
- Safety and Security
- Trade Compliance

Interns gain experience in a variety of tasks, such as:

- Conducting research
- Preparing presentations
- Writing reports
- Working with data
- Using computer programs
- Networking with professionals

The Port of Long Beach High School Summer Internship Program is a great opportunity for students to learn about the Port and to explore potential career paths. The program is also a valuable way to gain experience and to network with professionals. For more information about the Port of Long Beach High School Summer Internship Program, please visit the Port's website: https://polb.com/internships.

5.1.3: Curriculum Recommendations for Zero-Emission Technologies

LBCC has been able to identify four regional colleges that have both advanced transportation programs and electrical programs as well as already integrate zero emissions technology concepts into their curriculum. These colleges are also geographically diverse, providing the larger community greater access to their training and education programs. In addition, there are 13 that have advanced transportation programs with zero emissions concepts integrated. Related, LBCC has an agreement with the IBEW Local 11 to provide apprenticeship credit for students that enter their program with a degree from LBCC. This helps to provide an attractive pathway for students into a career supporting this new technology.

These existing programs provide a solid foundation for which to continue to build, and we as a region are by no means starting from nothing in building out certificates and degrees to meet the needs of the future workforce.

5.1.3.1: Recommendations for Community Colleges Serving Entry Level Workers

Review the skills outlined in this report. These competencies were identified by industry as critical needs for workers due to the anticipated increase in electrification of vehicles and equipment (and the associated infrastructure). Colleges can use this information to modify existing programs in such a way as to enhance students' readiness for the expanded use of ZEVs in industry.

Develop cross-disciplinary programs. While all regional community college advanced transportation programs touched in some manner on ZEV, the infrastructure curriculum is typically housed in electrical programs. Given the intersection of advanced transportation and electrical programs in real world applications, it behooves students who are majoring in one discipline to take courses in the other discipline. Certificates that package classes from both programs are a way to encourage students to self-select a cross-disciplinary course selection. Ideally, associate degrees themselves should have cross-disciplinary approaches as well.

Create non-credit exploratory courses/certificates. Non-Credit courses require enrollment in the college but are not credit bearing. These courses are often used to provide Basic Adult Education to help individuals become college ready, but they are also used to deliver occupational education fundamentals, such as courses to learn the Microsoft Suite of programs. Non-Credit introductory courses/certificates in Advanced Transportation and Electrical can provide general preparation for the credit programs and act as pipelines into the programs.

Meet as a workgroup with other colleges. The robustness of the existing programs varies and there's value in coming together as a workgroup once or twice a year to share challenges and successes.

Work with the Los Angeles Economic Development Corporation (LAEDC). The LAEDC's Center for a Competitive Workforce is already partnered and receiving funding to work with the regional colleges and can provide a wealth of knowledge regarding labor market demand, internships, and growth, as well as direct connections with companies not only for hiring opportunities, but also for work-based learning opportunities integrating them into the classroom experience.

Seek funding for faculty professional development in this new technology as well as for industry engagement events.

Expand the number of colleges who serve as feeders to the IBEW. This typically requires a robust associate degree program that will meet the rigor of the IBEW apprenticeship, which is one of the more challenging unions to enter.

Actively follow the two Ports' progress in adopting this new technology. The Ports are leading the charge in ZEV adoption. Long Beach, especially, is really pushing the envelope on electrification of new types of equipment. Their activities in this arena will invariably predict similar efforts to come in the wider sector and can help colleges get ahead of the curve when it comes to having relevant and on-demand programming.

5.2:Community Outreach and Engagement

5.2.1: Press Releases

The following is a partial list of media events and press coverage specifically related to this grant project.

- This project was mentioned in a Long Beach Press-Telegram article published January 12, 2018, entitled "Multi-million plan to reduce pollution begins with conversions of cranes at Port of Long Beach."
- Rose Siengsubcharti, the Contract Project Manager for the CEC Grant, was interviewed by the Long Beach Business Journal as part of their bi-weekly PORTSIDE column in an article published January 16, 2018. Rose discussed efforts regarding technology demonstration geared to reduce or eliminate air pollution from Port operations.
- On April 4, 2018, the Port held a media event at SSA to announce the project's launch. The event included speeches from Port leadership, Harbor Commissioners, SSA, and Southern California Edison, and it resulted in numerous news articles in local and national publications.
- Port staff were interviewed by the Long Beach Business Journal. Staff discussed how the Clean Air Action Plan is driving technology innovation at the San Pedro Bay Ports, specifically mentioning this grant. The article is dated April 23, 2018.
- The April 2018 "Your Port Community Newsletter" highlights the resumption of spring Harbor Tours, which always include information under this grant. It also discusses the April 4 community workshop on the Port Master Plan, which incorporates the use of zero-emission equipment under this grant as recommended by the CAAP under its planned land use.
- The April 2018 Port of Long Beach Monthly Newsletter, Tie Lines, highlights projects under this grant in an article entitled, "Steps to a Zero-Emission Goal: Green Technology Projects Test Efficiency and Viability."
- On May 4, 2018, the Journal of Commerce (JOC.com) published an article entitled "LA-LB ports say zero-emissions cargo equipment viable by 2030." Heather Tomley, Director of Environmental Planning, is quoted in the article discussing this grant, as are representatives from ITS and BYD.
- On July 11, 2018, Maritime Professional published an article entitled "Driving Efficiently Towards Zero-Emissions." Mario Cordero, Port of Long Beach Executive Director, and Heather Tomley, Director of Environmental Planning, are quoted in the article discussing this grant.
- On November 14, 2018, Heather Tomley, Acting Managing Director of the Planning & Environmental Affairs Bureau, visited Pier J with the Wall Street Journal and conducted an interview on zero- emissions projects for a podcast. She spoke specifically on projects under this grant.
- On June 18, 2018, there was a Long Beach Business Journal article, "San Pedro Bay Ports to Give Update on Clean Air Action Plan."
- On June 26, 2018, there was a Daily Breeze article, "Updates on Agenda for Long Beach-Los Angeles Ports' Clear-Air Plan Meeting in San Pedro."
- On February 3, 2019, CityLab Magazine discusses this grant in detail in an article entitled, "SB 100 is Moving Cities in California Toward Zero- Emission Futures."
- On May 20, 2020, Matthew Arms, Director of Environmental Planning, participated in an interview with Pacific Maritime Magazine that covered the demonstration in this grant.
- On October 8, 2020, Port Communications provided a press release to highlight ITS' yard tractor demonstration with BYD.

5.2.2: Promotional Videos

The Port created four videos about this project, which can be found on the Port's YouTube channel. Links are provided below:

https://www.youtube.com/watch?v=Uoe1m5HlX44
https://www.youtube.com/watch?v=y8liGfNXdtY
https://www.youtube.com/watch?v=a1V80I4TANg
https://www.youtube.com/watch?v=R1R0Nyu8QIc

5.2.3: Stakeholder Advisory Groups

The Port worked with the listed Stakeholder Advisory Groups and held the following meetings:

- **Technology Advancement Program (TAP) Advisory Committee Meetings.** The TAP is a joint effort of the Port of Long Beach and Port of Los Angeles to provide funding for emerging port-related technology demonstrations. The Advisory Committee helps evaluate projects for funding and hears updates on Port technology projects. The Committee consists of representatives from each Port, South Coast Air Quality Management District (AQMD), California Air Resources Board, California Energy Commission, and U.S. Environmental Protection Agency. The Committee met every six to eight weeks during the Project period, and the Port provided project updates at each meeting.
- **CAAP Implementation Stakeholder Advisory Committee Meetings.** As previously mentioned, the Port provided project updates at quarterly CAAP meetings, which were held jointly with Port of Los Angeles. Operators and industry groups routinely attended these meetings. The meetings are currently held virtually and are open to the public.
- **California Energy Commission Ports Collaborative Meetings.** CEC held these meetings quarterly, providing the opportunity for California ports to share updates about CEC-funded projects and to discuss subjects for future collaboration.
- **San Pedro Bay Ports Sustainable Supply Chain Advisory Committee Meetings.** The Port provided updates about the Project at four of these meetings, which were attended by representatives from Port of Los Angeles, utilities, industry groups, South Coast AQMD, and environmental-justice organizations.

Port staff provided updates on this project at the following Technology Advancement Program (TAP) Advisory Committee meetings:

- October 11, 2017
- December 6, 2017
- January 17, 2018
- February 28, 2018
- May 23, 2018
- June 27, 2018
- August 15, 2018
- November 7, 2018
- March 20, 2019
- June 5, 2019
- October 9, 2019

- November 20, 2019
- January 22, 2020
- July 1, 2020
- August 26, 2020
- October 21, 2020
- December 16, 2020
- February 10, 2021
- April 7, 2021
- June 2, 2021
- July 28, 2021
- September 22, 2021
- January 12, 2022
- March 9, 2022
- May 4, 2022
- June 29, 2022
- August 24, 2022
- October 19, 2022
- December 14, 2022
- February 8, 2023
- April 5, 2023
- June 12, 2023

Port staff provided updates on this project at the following Clean Air Action Plan Implementation Stakeholder Advisory Committee meetings:

- March 29, 2018
- June 26, 2018
- September 26, 2018
- December 19, 2018
- March 13, 2019
- June 25, 2019
- October 3, 2019
- January 15, 2020
- June 24, 2020
- October 14, 2020
- January 27, 2021
- October 19, 2021
- February 1, 2022
- June 1, 2022
- October 12, 2022
- March 8, 2023
- July 25, 2023

Port staff provided updates on this project at the following California Energy Commission Ports Energy Collaborative meetings:

- January 19, 2019
- November 18, 2019

- August 31, 2020
- October 5, 2020
- December 14, 2020
- April 22, 2021

Updates on this project were provided at the following San Pedro Bay Ports Sustainable Supply Chain Advisory Committee meetings:

- March 28, 2018: Southern California Edison discussed projects pertinent to this grant.
- July 15, 2020
- November 18, 2020
- September 15, 2021

5.2.4: Public Harbor Tours

April 2017
Leadership Long Beach
Universidad Estatal de Sonora
Youth Leadership Long Beach*
Staff Narration Training
Lifeguard Conference
California State University, Long Beach Job Shadow*
California State University Long Beach, California State University Los Angeles, & Centro de Enseñanza Técnica y Superior (CETYS) Universidad Mexicali Civic Center Architecture Design Team

May 2017
Community Harbor Tour
Community Harbor Tour
CSULB Mechanical & Aerospace Engineering and Retired Port of Long Beach Engineers

October 2017
Poly Pac Rim Academy*
California State University, Long Beach International Business Association
Academy of Global Logistics*
Latino Employee Organization

November 2017
CETYS & Universidad de Sonora CETYS Campus Tijuana
Khmer Parent Association & United Cambodian Counsel
Consumer Affairs Student Association & Male Leadership Academy
Clean Cargo Working Group
California State University, Long Beach Human Resources Shadow Day
California State University, Northridge/California State University, Dominguez Hills
International Association of Emergency Managers
Latinos in Action

January 2018
Wrightwood Elementary

March 2018
Pacific Sociological Association
College groups from:*
- USC
- Occidental College
- Santa Monica College
- CSULB-Geography
- CSULB-Human Resources Management Association

June 2018
Community Harbor Tour
Community Harbor Tour
Community Harbor Tour
Cabrillo High School Academy of Global Logistics (AGL) Teacher Institute*
Metropolitan Water District Board Members
Long Beach Bar Association
California State Polytechnic University, Pomona; VA Center; Gold Star Manor
Bixby Hills Neighborhood Association; Community Harbor Tour
Community Harbor Tour
Environmental Affairs and Planning Bureau harbor tour for its agency partners, which was narrated by Environmental Planning staff and discussed zero-emission equipment and infrastructure in great detail, including projects covered under this grant. Over 100 people attended this tour, including representatives from:
- Alameda Corridor Transportation Authority
- Army Corp of Engineers
- CA Air Resources Board
- CA Coastal Commission
- CA Department of Fish & Wildlife
- CA Department of Transportation
- CA State Lands Coastal Commission
- City of Long Beach, Office of Sustainability
- City of Long Beach, Public Works
- City of Long Beach, Health & Human Services
- City of Long Beach, Water Department
- Department of Toxic Substances Control
- Federal Highway Administration
- Gateway Cities Council of Governments
- Gateway Water Management Authority
- Los Angeles Metropolitan Transportation Authority
- Los Angeles Regional Water Quality Control Board
- Natural History Museum of Los Angeles County
- Navy BRAC PMO
- South Coast Air Quality Management District
- State Water Quality Control Board
- University of California, Los Angeles
- University of Southern California
- United States Coast Guard Marine Safety Office

July 2018
Community Harbor Tour
Summer High School Internship Program*
Southeast Fellows High School Delegation; City of Long Beach Public Works
Long Beach Grand Prix staff
Community Harbor Tour
Belmont Heights Community Association
Mayor's Fund for Education (California State University, Long Beach "Bridging the Gap" program); Shanghai Maritime University, California State University, Dominguez Hills; Local Elected Official Office interns
Education & Leadership Institute "Business of Success Beyond Sports" (BOSS) Summer Camp
Community Harbor Tour*
Ocean Residents Community Association
Community Harbor Tour
Latinos in Action

August 2018
Long Beach Heritage
Community Harbor Tour
World Robot Olympiad, Tsinghua University Alumni
Association of Southern California
Community Harbor Tour
City Council District 6
City Council District 8
Bluff Park Neighborhood Association, Alamitos Heights Improvement Association
Community Harbor Tour
City Council District 9
City of Long Beach LB Coast
Los Angeles Regional Water Board
City Council District 1
City Council District 2

September 2018
PFLAG
Pacific Rim Academy*
CSULB Faculty*
Community Harbor Tour
Community Harbor Tour
Long Beach Council District 3
CETYS Mexicali, Tijuana
Dean International, Long Beach Council District 5
United Cambodian Council
Long Beach City Auditor's Office, Community Tour
USC Transportation Research, CETYS Mexicali

October 2018
American Association of Port Authorities
Modern and Contemporary Latin American and Latino Art
Air Quality Management District and California State University, Los Angeles

Male Leadership Academy
Academy of Global Logistics at Cabrillo High School*
California State University, Long Beach; Latino Employee Organization*
California State University, Long Beach; Port of Long Beach employees*

November 2018
California State University, Long Beach
Navy Region Southwest

February 2019
Pacific Gateway Workforce & Innovation Network*
CSULB, USC Metrans, Boeing, SCAQMD, Pepperdine University
Port employees and their children for Bring Your Child to Work Day*

March 2019
Engineering Externship, Long Beach Unified School District*
Long Beach City College Leadership*
Job Shadow Day, Human Resources students from various colleges*
Cal State Long Beach, Santa Monica College, USC, CETYS Mexicali

April 2019
Leadership Long Beach
Long Beach Unified School District*
San Gabriel Valley Council of Governments
CETYS Mexicali, Universidad Autónoma de Baja

May 2019
General Community Harbor Tour
General Community Harbor Tour
General Community Harbor Tour
General Community Harbor Tour
Muha's Kindergarten Class*
Poly High School & Anaheim Discovery Christian School & IQ Air Clean Air Team*

June 2019
Bixby Knolls Neighborhood Association
General Community Harbor Tour
General Community Harbor Tour
General Community Harbor Tour

July 2019
General Community Harbor Tour
General Community Harbor Tour
BOSS Camp Harbor Tour
General Community Harbor Tour
ORCA Harbor Tour
General Community Harbor Tour
Bacolod Delegation Harbor Tour

August 2019
General Community Harbor Tour
General Community Harbor Tour
General Community Harbor Tour
General Community Harbor Tour

September 2019
General Community Harbor Tour
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October 2019
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General Community Harbor Tour
General Community Harbor Tour

November 2019
General Community Harbor Tour
General Community Harbor Tour
General Community Harbor Tour

December 2019
McBride High School Harbor Tour*

January 2020
Youth Leadership*

February 2020
CRC Electric Program Investment Charge Forum

March 2020
Harbor Tour – College Day

** Tours to support youth workforce development efforts.*

5.2.5: Port Community Events

In addition to the regular meetings listed above, Port staff provided information about this project at the following meetings and events:

- On August 31, 2017, the Port held a project kick-off meeting with the California Energy Commission. The Port took CEC representatives on a tour of Long Beach Container Terminal and discussed project outcomes and grant management.
- On January 30, 2018, the Port held a Terminal Operator Funding Workshop, presenting upcoming grant opportunities that help terminal operators purchase near-zero and zero-emissions equipment. More than 70 people attended, and 12 major manufacturers of zero-emissions terminal equipment were present with equipment on hand and answered questions about their products.
- On October 11, 2018, the Port met with representatives from Britain, Germany, Norway, Sweden, and the Netherlands from the Forum of European Highway Research Laboratories. They discussed energy efficiency, clean vehicle technologies, and the proposed development of new goods movement technologies, including projects under this grant.
- On June 15, 2018, the Port attended a meeting between the Port of Long Beach, Port of Los Angeles, and the South Coast Air Quality Management District. The Port presented information from this grant while discussing zero-emission pilot projects and clean air and climate initiatives, including cargo handling equipment.
- On June 20, 2019, the Port participated in a roundtable at the annual transportation emission reduction opportunities. One of the topics discussed was the CEC/ Port of Long Beach Zero- Emissions Terminal Equipment Transition Project.
- On October 2, 2019, the Port and the City of Long Beach hosted a California Clean Air Day Celebration where this grant was mentioned at the Long Beach Civic Plaza
- On October 15, 2019, the Port provided an update on the Port's demonstration project efforts and the lessons learned at the Smart Port of the Future Town Hall Meeting in Long Beach.
- On July 13, 2020, the Port staff provided a presentation about this grant at a FuturePorts Members meeting.
- On August 17, 2020, the Port presented an update on this grant as part of a panel session at the 2020 West Coast Collaborative Partners Meeting.
- On September 29, 2020, the Port provided an update on this grant at the STRIDE Collaborative Virtual Partners Meeting which is part of EPA's National Clean Diesel Campaign.
- On April 13, 2021, the Port provided an update on the Port's technology advancement efforts, including this grant, at the Department of Energy Clean Ports Working Group.
- On September 15, 2021, the Port staff presented information and status on this grant at the Sustainable Supply Chain Advisory Committee. The SSCAC meets on a bi-monthly basis with the two Ports to address challenges and opportunities for improving sustainability within the goods movement sector.

5.2.6: Program Websites

Port Website: www.polb.com

5.2.7:Social Media

Facebook: http://www.facebook.com/PortofLB

Twitter: https://twitter.com/portoflongbeach

Instagram: https://www.instagram.com/PortOfLongBeach

LinkedIn: https://www.linkedin.com/company/Port-of-long-beach/?viewAsMember=true

YouTube: https://www.youtube.com/user/portoflongbeach

5.3: Unforeseen Challenges

5.3.1: COVID-19 Impacts

The COVID-19 pandemic had a significant impact on the Port's outreach activities. Beginning in March 2020, the Port halted all in-person community outreach due to the California Stay-at-Home order and did not resume these activities until Fall 2022. Many meetings took place virtually, which impacted attendance at first. Conferences and presentations were cancelled across the nation. As a result, most of the public outreach for the Project took place between 2018 and early 2020. If not for the pandemic, the Port believes it would have reached even more people.

5.4: Reports

5.4.1: Zero-Emission Port Equipment Workforce Assessment Report

The Long Beach City College conducted a workforce gap analysis for the demonstration within this Project. The analysis encompassed workforce needs, equipment adoption projections, and potential job growth associated with the transition to zero-emission technology.

In projecting workforce demand, the report considered factors influencing the adoption rate, including cost considerations, technology maturity, battery costs, charging speed, and vehicle maturity. These factors may impact the pace of adoption and, consequently, labor needs.

The report also anticipated potential job creation, categorizing it into vendor jobs (primarily local), operator jobs in maintenance, and infrastructure jobs for charging and electrical power service installation. Most workforce requirements for port electrification will be in the infrastructure sector, absorbing new workers with new skills. Maintenance jobs are expected to involve retraining existing workers.

Competencies necessary for workers in this field were identified through interviews with key stakeholders, including OEMs, terminal operators, labor representatives, and subject matter experts. These competencies span various areas, such as battery safety, electrical knowledge, and equipment maintenance. Existing mechanics are believed to require minimal additional training to service electric vehicles, as they are less labor-intensive than diesel vehicles.

The report highlighted community college programs that integrate advanced transportation and electrical concepts into their curriculum. It identified colleges with such programs in the region, emphasizing their geographical diversity to increase access to training and education programs. Additionally, some community colleges offer not-for-credit training for incumbent workers in advanced transportation, which is often funded by employers or state subsidies to support workforce development in the region.

More information may be found in the Zero-Emission Workforce Assessment Report which is available on the Port's website.[12]

5.4.2: Public Outreach Summary Report

5.4.2.1: Introduction

In 2017, the Port of Long Beach (Port) launched what was then one of the nation's largest demonstrations and deployments of zero-emission cargo-handling equipment in partnership with the California Energy Commission (CEC). A key outcome of the Project was to advance the public's understanding and awareness of zero-emission goods movement to accelerate more widespread adoption. At the time of the Project's launch, very few pieces of zero-emission cargo-handling equipment had ever been tested on active marine terminals. Public outreach about the benefits, challenges, and opportunities around zero-emission equipment was critical in supporting future deployments.

This Public Outreach Summary Report summarizes the Port's community and industry engagement efforts related to the Project and zero-emission advancement. Between 2017 and 2022, the Port discussed the Project at more than 200 community events, conferences, meetings, and harbor tours. The Port also created an award-winning youth workforce development project to engage students from disadvantaged neighborhoods on issues related to zero-emission goods movement. The Project was mentioned in hundreds of news articles in publications such as the Wall Street Journal, Long Beach Business Journal, and American Journal of Transportation, and YouTube videos about the project received more than 4,350 views.

In total, the Port's outreach campaign directly reached roughly 23,240 people. Surveys indicated this outreach demonstrably improved the public's understanding of Port environmental initiatives, particularly related to zero-emission technology. This outreach heightened awareness about the Project, CEC's vital investment, and the broader zero-emission goods movement transition.

5.4.2.2: Project Background

In 2017, CEC awarded the Port $9.7 million for the Project, which had several different equipment and technology components designed to accelerate zero-emission goods movement, including:

- repowering nine rubber-tired gantry cranes (RTGs) at SSA Marine to full electric power,
- developing and demonstrating 12 battery-electric yard tractors at International Transportation Service (ITS) and Long Beach Container Terminal (LBCT),
- deploying "smart" charging technologies with robotic connection arms, and
- converting four liquefied natural gas (LNG) drayage trucks to plug-in hybrid-electric capability to be demonstrated by Total Transportation Services, Inc. (TTSI).

Each piece of equipment was demonstrated in a rigorous seaport environment for one year. Most of the demonstrations have concluded in 2023 except for the eRTG cranes, which were integrated into operations at SSA.

The Project also included two non-technology components: a public outreach campaign and a zero-emission workforce development assessment. The Workforce Assessment, which was

[12] www.polb.com/zeroemissions

developed by Long Beach City College, was previously submitted to CEC and is available on the Port's website at www.polb.com/zeroemissions. This Public Outreach Report does not discuss the Workforce Assessment, but it does contain information about youth workforce development efforts, which fell under the community outreach component.

The Zero-Emission Terminal Equipment Transition Project was a partnership of the following companies and organizations:

- Southern California Edison
- International Transportation Service
- Long Beach Container Terminal
- SSA Marine
- Total Transportation Services, Inc.
- Long Beach City College
- International Brotherhood of Electrical Workers
- Clean Energy Fuels
- Cavotec
- BYD Motors
- US Hybrid

5.4.2.3: Public Outreach Goals

The public outreach component was designed to achieve three goals, as described in the Port's Scope of Work with the CEC:

- Provide direct on-the-job training for high school interns through the Port of Long Beach's High School Internship Program, which is aimed at developing skills necessary for a career in zero-emission vehicle technology.
- Provide training for local high school and college teachers to develop lesson plans and curriculum for in-classroom training on zero-emission vehicle technology.
- Develop press releases, website, promotional videos, conduct tours and related outreach to disadvantaged communities and members of the public to build awareness of project benefits and to gain consumer confidence in deployed technologies.

The following sections describe how the Port achieved these goals. More details about public outreach are included in the appendices and in the monthly reports submitted to the CEC since 2017.

Public Outreach Impact

23,240 people reached from all direct outreach

460 high school students using new zero-emission curriculum

4,350 views for YouTube videos on the Project

12,625 harbor tour attendees learned about the Project firsthand

204 meetings, conferences, events, and tours

900+ media mentions

5.4.2.4: Youth Workforce Development Opportunities

Developing the pipeline of workers to support zero-emission goods movement was one of the Project's major goals. In addition to the workforce assessment completed by Long Beach City College, the Port worked closely with the Long Beach Unified School District to incorporate lessons about zero-emission goods movement into high school curricula, specifically referencing the Project. The Port also provided summer internships to high school students, particularly those from disadvantaged communities, to give them real-world work experience in zero-emission goods movement.

5.4.2.5: Zero-Emission Curriculum Development

In the fall of 2018, in partnership with the Long Beach Unified School District and California State University, Long Beach (CSULB), the Port launched an ambitious new curriculum focused on zero-emission goods movement at the Port of Long Beach Academy of Global Logistics (AGL) at Cabrillo High School.

AGL, which began in the 2016-2017 school year, combines academic curriculum with industry-relevant training and information to support academic and career development. AGL students focus on careers in global logistics and supply chain management. AGL works in direct partnership with the Port of Long Beach, Long Beach City College, and the Center for International Trade and Transportation at CSULB (CITT). Through partnerships with local colleges and industry partners, students are exposed to various pathways leading from Cabrillo High School to the world of finance, global logistics, and supply chain management. Today, AGL serves 460 students per year.

Cabrillo High School is in the heart of a disadvantaged community as defined by Senate Bill (SB) 535. Figure 29 shows Cabrillo's location. Areas in red are designated as "disadvantaged," which means those residents have high levels of poverty, unemployment, and rent burden and low levels of home ownership and educational attainment. Also, these neighborhoods are disproportionately impacted by environmental pollution. At Cabrillo High School, more than 99% of students are non-white, and 80% fall below the federal poverty line. Focusing youth workforce development activities at Cabrillo High School enabled the Port to reach students most in need of support.

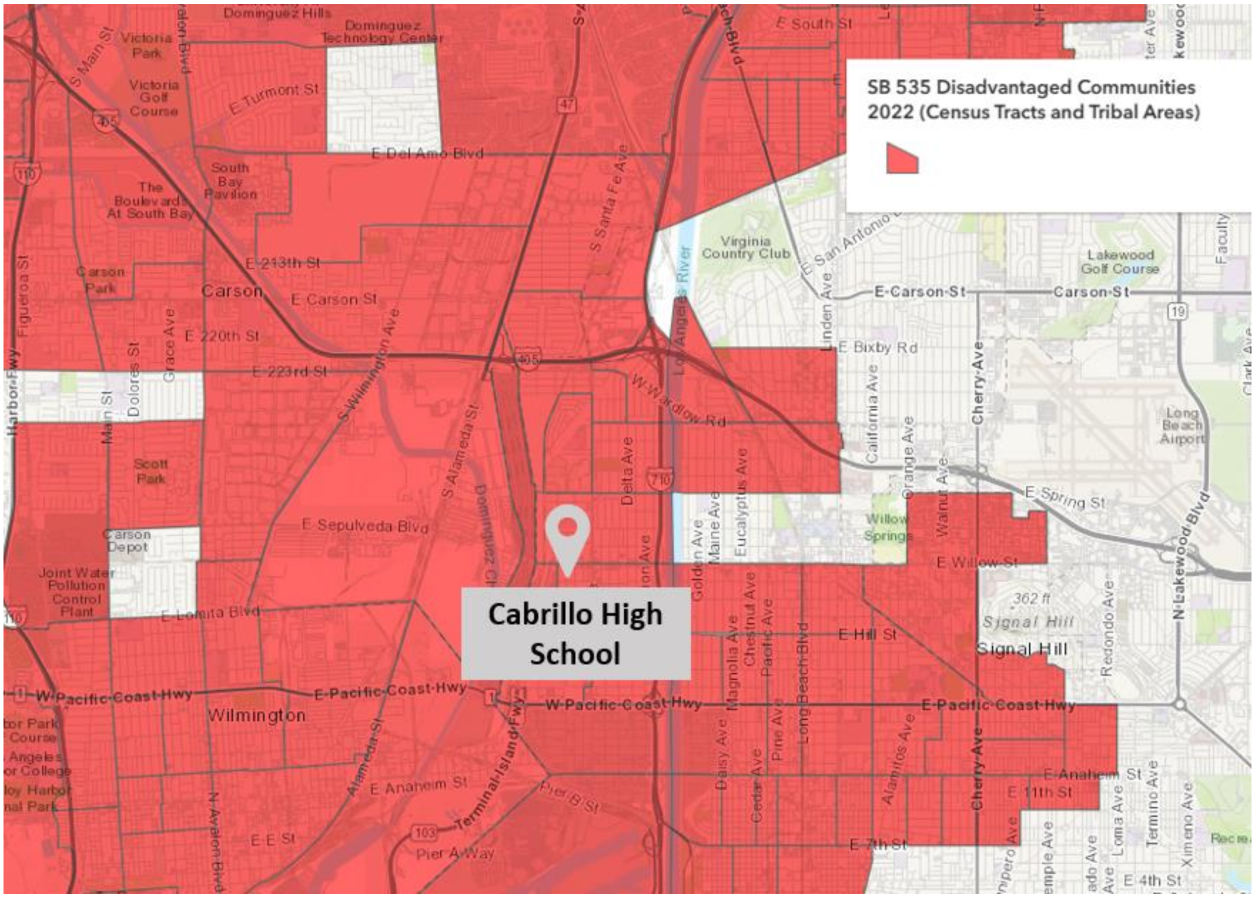


Figure 29 - Location of Cabrillo High School in Relation to DACs

Although the AGL curriculum already contained some information about the Port's environmental initiatives, the curriculum did not reflect the rapid pace of technological advancements in zero-emission cargo-handling equipment and vehicles. The Project provided a perfect case study for students to learn about this transformational change in goods movement and to tackle the real challenges and opportunities associated with zero-emission technologies. The result was the award-winning "Zero-Emissions Transformation Capstone" project. Through this project, AGL students intensively studied the technologies, air-quality benefits, engineering challenges, and financial aspects of zero-emission using the Project as a real-world example.

The project began with an inventory of high-school coursework to assess the educational pipeline from high school to college to careers in zero-emission Port operations. Long Beach City College staff met with school district leaders to identify existing programs relevant to zero-emission goods movement. The inventory found schools with automotive classes, engineering programs that also offer digital electronics, a project with Green Power that works with electric cars, five high schools and three middle schools that have electric cars, and AGL at Cabrillo High School. This work culminated in a meeting on November 1, 2018, for high school teachers in zero-emission "pathway" subjects. Teachers learned about the Project, the zero-emission adoption work at the Port, and the workforce competencies identified by Long Beach City College through its survey work. More details can be found in Long Beach City College's Workforce Assessment at www.polb.com/zeroemissions.

Then, the Port, in partnership with the school district and the Center for International Trade and Transportation (CITT), worked with AGL teachers to develop new lesson plans around zero-emission cargo-handling operations. Teachers attended CITT's 2018 Teacher Institute. This "externship" program provides training to Long Beach teachers on port-related topics. The group discussed how to incorporate lessons about zero-emissions technologies, using the Project as a case study.

> "The [Zero-Emission Transformation Capstone project] has captivated students and has proven to be a significant incentive to learn about air pollution and port operations."
>
> *- South Coast Air Quality Management District 2019 Clean Air Awards*

This work culminated in the development of the "Zero-Emissions Transformation Capstone" project. AGL students in their senior year worked in groups of five, each focusing on a different aspect of zero-emission goods movement. Issues identified through the Capstone project included:

- Air Quality and Climate Science: What health and climate related impacts are driving the need for transformation to a zero-emissions Port?
- Technology Development: What does it take to develop the equipment necessary to conduct Port operations without emissions?
- Commercialization: What are the barriers to commercializing zero emissions terminal equipment?
- Infrastructure: What type of infrastructure is needed to support this new equipment?
- Finance and Funding
- Workforce
- Communications and Outreach

Every other week, real-world industry experts presented to the students. These experts included partners such as TransPower (now Meritor), International Transportation Service, Port Engineering staff, and Port Environmental staff. Students also participated in a field trip to the Port to learn about Port operations.

In spring 2019, the student group with the best capstone report presented its findings to staff from the Port, Long Beach Unified School District, and the California Air Resources Board. The "Zero-Emission Transformation Capstone" project was so compelling, it received the 2019 Clean Air Award for "Clean Air Education and Outreach" from the South Coast Air Quality Management District.

"The program has captivated students and has proven to be a significant incentive to learn about air pollution and Port operations. AGL has a positive impact on the local student population," the organization said in awarding the Port with this honor.

The zero-emission curriculum has now been implemented in all AGL classes going forward, which ensures that 460 students each year will learn about zero-emission goods movement and potentially pursue careers in this industry.

5.4.2.6: High School Internships

Every year, the Port provides summer internships to Long Beach high school students through the Pacific Gateway Workforce Investment Network. In 2018, the Environmental Planning Division hired a summer intern to focus on projects related to zero-emission vehicle technology. The intern developed a revised Green Fleet Policy, which requires the Port to turn over fleet vehicles to newer, cleaner technologies, such as hybrid or all-electric cars. The intern also compiled data for the Zero Emissions Truck survey, which informed the truck feasibility assessment outlined in the Ports' Clean Air Action Plan Update.

When the COVID-19 pandemic and the California Stay-at-Home Order began in March 2020, the summer high school internship program was put to a halt. Three years later, the summer high school internship program has restarted and is now in full swing.

5.4.2.7: Awareness of Project Benefits

The Port garnered media attention, created promotional videos, conducted tours, held community events, and made presentations at various forums to build awareness of the Project benefits. Much of this outreach was aimed at the disadvantaged communities surrounding the Port complex, as shown in Figure 30, in red. These communities suffer directly from the poor air quality and negative health impacts associated with diesel equipment. The Port sought to educate these residents about the Project's potential to transform the goods-movement industry and dramatically improve their lives. Higher levels of awareness could bolster community support for future zero-emission efforts.

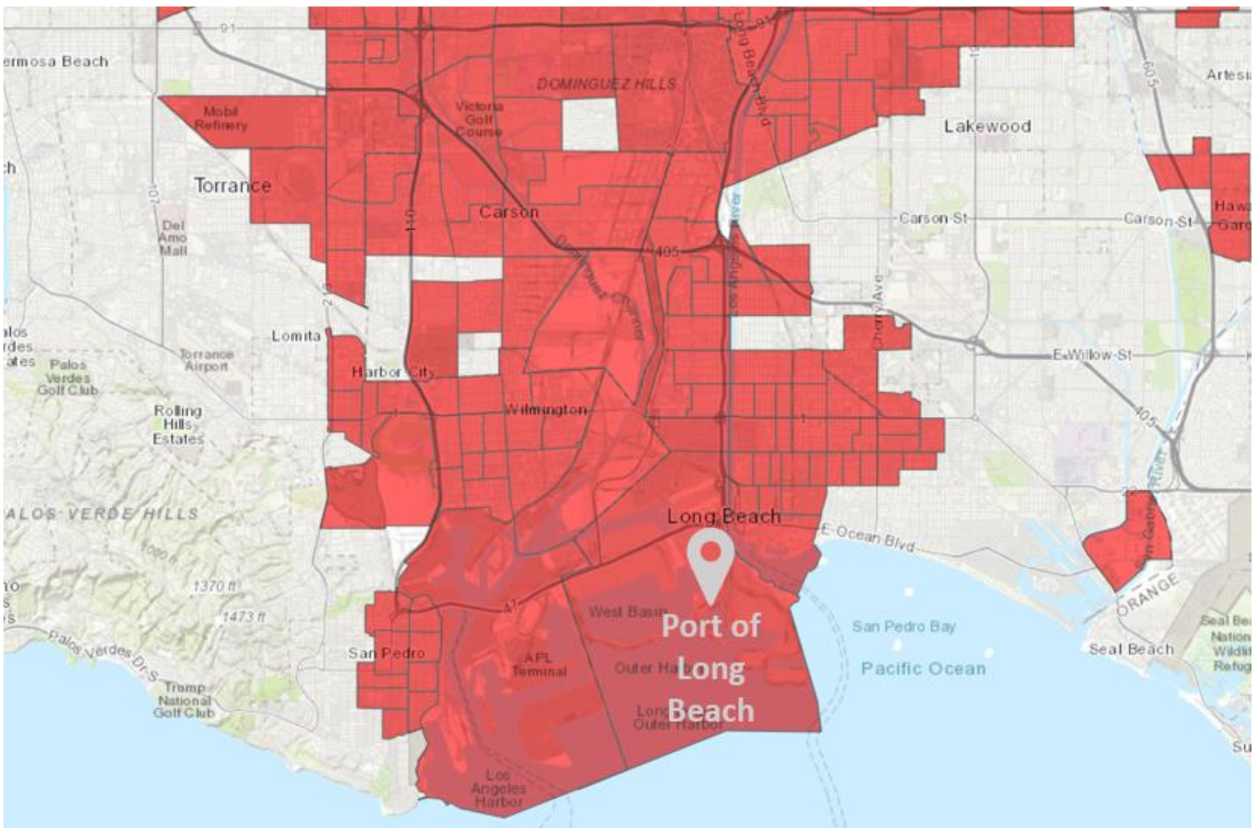


Figure 30 - Disadvantaged Communities Around the Port

Harbor tours were an important way to reach these communities. From 2017 to 2020, the Port provided nearly 50 community harbor tours open to the public as well as 90 harbor tours for specific groups, such as Long Beach Council Districts, regulatory agencies, schools, universities, neighborhood associations, and community organizations such as the Khmer Parent Association & United Cambodian Counsel and Latinos in Action. The Port also provides harbor tours in Spanish.

The 90-minute harbor tours took attendees past SSA Marine, where they could see the RTGs that would be repowered to electric technology, and to ITS and LBCT, where electric yard tractors would be deployed. Every harbor tour was narrated by a Port staff member, who shared messages about the Project as the boat passed relevant sites. These messages, as written in the 2017-2018 Harbor Tour Narration Guide, included:

- Pier J will soon be home to the nation's largest deployment of fully electric rubber-tired gantry cranes as part of a grant funded by the California Energy Commission.
- ITS will soon be testing out 7 battery-electric yard tractors as part of a grant funded by the California Energy Commission.
- LBCT will soon be testing out 5 battery-electric yard tractors as part of a grant funded by the California Energy Commission.

The harbor tours were a particularly effective way to reach audiences. Each community tour accommodated 125 passengers, and each group tour was estimated to accommodate 75 passengers for a total of 12,625 people who learned about zero-emission goods movement and saw the Project elements firsthand. The tours were effective in improving awareness about the Port's efforts. Prior to the tour, 12% of attendees reported knowing "a lot" about the Port; after the tour, that percentage rose to 83%, as shown in Figure 31, according to pre- and post-surveys.

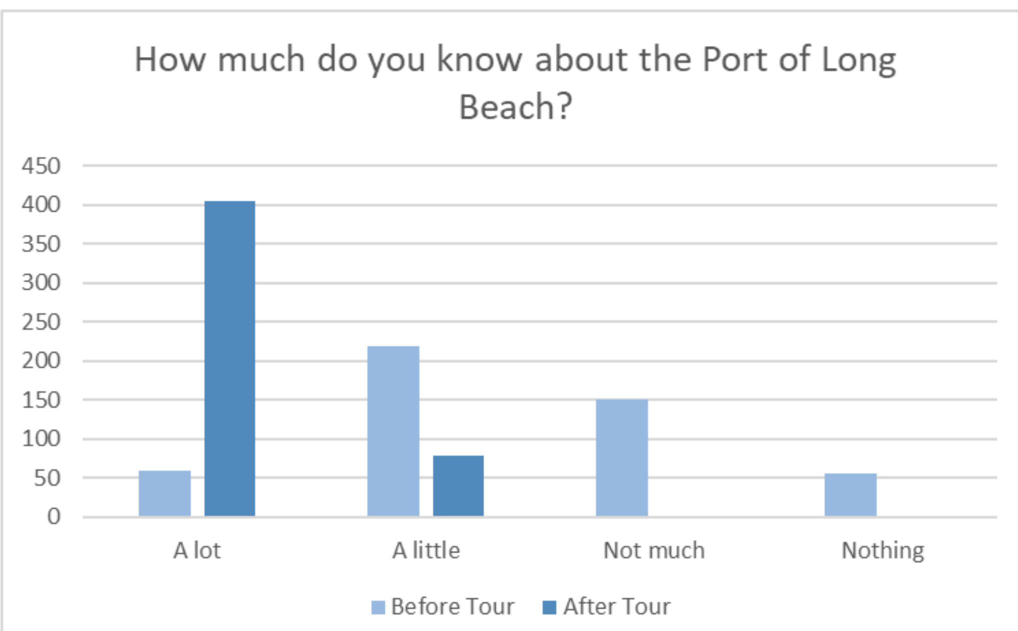


Figure 31 - Improved Awareness of the Port Before and After a Harbor Tour

The Port's Green Port Fair, held on November 5, 2022, was another major public outreach effort that increased awareness of the Port's zero-emission efforts. At the free event, attendees could stop at booths to learn more about the Port's environmental initiatives and could see displays of zero-emission cargo-handling equipment up close. More than 560 people attended the event, many from nearby neighborhoods. Press releases announcing the event highlighted the focus on zero-emission technology:

- "We welcome everyone to come by the Green Port Fair and see what we are doing every day to protect the community's health and improve air quality by aiming to reduce and eventually eliminate all emissions," said Port of Long Beach Chief Executive Officer Mario Cordero.
- "This is an occasion for residents to learn about their Port and see what we've been working on to improve air quality and safeguard the environment," said Long Beach Harbor Commissioner Sharon L. Weissman. "We are making international trade more environmentally sustainable and leading the industry toward a zero-emissions future."

Environmental-justice organizations and community groups also attended the Port's quarterly Clean Air Action Plan (CAAP) Implementation Stakeholder Advisory Group meetings. Beginning in 2018, the Port held 16 CAAP meetings, in person and then virtually during COVID-19, at which staff provided updates on the Project. These meetings gave attendees a chance to ask questions about project progress, accrued benefits, and zero-emission technology performance. Roughly 75 people attended each of these meetings.

During the project period, the Port also developed several promotional videos specifically about the Project, as follows:

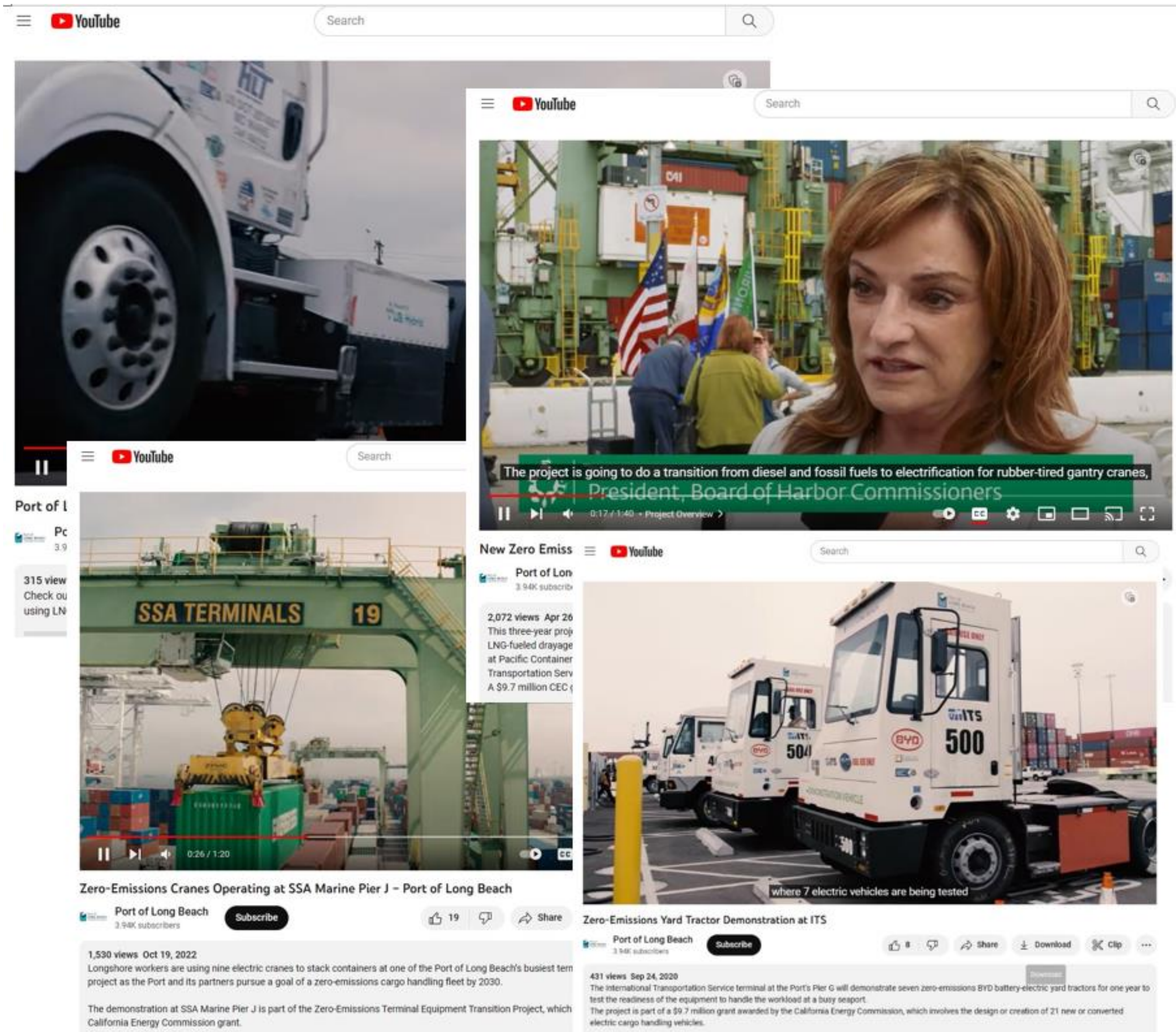
- "Zero-Emissions Cranes Operating at SSA Marine Pier J – Port of Long Beach," released October 19, 2022
- "New Zero Emission Project Starts at SSA Marine at Port of Long Beach," released April 26, 2018
- "Zero-Emissions Yard Tractor Demonstration at ITS," released September 24, 2020
- "Four TTSI Hybrid Trucks in Operation," released March 29, 2022

These videos aired on the Port's YouTube channel, which has nearly 40,000 subscribers. Combined, the videos had 4,350 views. Many more videos touched on issues generally related to the Project, including the Port's zero-emission progress, clean trucks, and youth internship programs.

The Port's public outreach also included press releases and media events to showcase the Project's technology deployments. The project was featured in numerous articles, blogs, and newsletters, and the Port's press releases were often picked up by wire services that enhanced distribution across the nation. A Google search for news stories containing the Project's keywords yielded nearly 1,000 hits, indicating the far reach of this media coverage.[13] Although it is not possible to definitively quantify the number of people reached, the Port presumes that many thousands of readers saw these articles.

All press releases, videos, and project updates can be found on the Port's Website. The Port also created a zero-emission Web portal at www.polb.com/zeroemissions, which contains reports, studies, and progress updates about zero-emission technology and demonstrations, including the Project.

[13] Google search on June 19, 2023, using terms "Port of Long Beach" "zero emission" "SSA" "crane" yielded 993 results.



5.4.2.8: Consumer Confidence in Deployed Technologies

To accelerate more widespread adoption of zero-emission equipment, it was important for the Port to communicate project benefits to those who would ultimately make buying decisions in the future – industry groups and end users. The Port also needed to communicate progress to regulatory and funding agencies, whose understanding could translate into more grants or other support to cultivate future zero-emission investments. Much of this outreach took place at a national – and even international – level, helping to advance zero-emission goods movement across the globe.

End users – terminal operators, trucking companies, and industry organizations – must have confidence in zero-emission equipment if they are to fully embrace the switch. At the time of the Project's launch, there were very few opportunities for operators to learn about zero-emission technologies and to see the equipment and vehicles firsthand. The Port created outreach opportunities to reach operators directly in unique, interactive ways.

One example was the Terminal Operator Funding Workshop held January 30, 2018. The Port discussed upcoming grant opportunities to help terminal operators purchase near-zero and zero-emissions equipment, using the Project as an example of how public investments can spur early innovation. More than 70 people attended, and 12 major manufacturers of zero-emissions terminal equipment were present with equipment on hand, including US Hybrid. Manufacturers answered questions about their products, which helped instill consumer confidence.

The Port also provided regular project updates at the standing meetings mentioned in Stakeholder Advisory Groups section.

In addition to these regular meetings, the Port presented Project updates in other industry and regulatory forums, including a FuturePorts members meeting, EPA West Coast Collaborative Partners meeting, American Association of Port Authorities meetings, at the Department of Energy Clean Ports Working Group meeting, and in a Forum of European Highway Research Laboratories meeting, among others. These meetings enabled the Port to share its experiences with other ports, agencies, and operators across the nation and even the world, stimulating broader adoption of zero-emission goods movement.

Conferences presented another opportunity for the Port to spread the word about zero-emission technology progress. Port staff members discussed the Project at roughly 40 conferences, some of which drew attendees from all over the nation. One such conference, ACT Expo, routinely draws thousands of end users, industry representatives, technology manufacturers, and seaports, who heard Project updates. Conservatively estimating 100 attendees at each conference, these presentations reached 4,000 people, helping to build understanding and confidence in zero-emission technologies.

The Port held a major press event on April 4, 2018, to announce the Zero-Emission Terminal Equipment Transition launch. The event was held at SSA and featured speeches from the Port, SSA, Southern California Edison, and CEC (Figure 32).

Figure 32 - Zero-Emission Terminal Equipment Transition Project Launch at Pier J

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SUSTAINABILITY

Long Beach Port Operators Lead the Way to Zero Emissions Goal

Partnering with SCE and others, SSA Terminals is electrifying its equipment and helping the port meet an important decarbonization goal by 2030.

PUBLISHED 05-09-23 SUBMITTED BY EDISON INTERNATIONAL

FLEET OF ELECTRIC CRANES OPERATING AT PORT OF LONG BEACH TERMINAL

October 19, 2022

SSA MARINE PIER J NOW USING NINE ZERO-EMISSIONS RUBBER-TIR

Longshore workers are using nine electric cranes to stack containers
terminals in a large-scale demonstration project as the Port and its pa
handling fleet by 2030.

The demonstration at SSA Marine Pier J is part of the Zero-Emissions
funded in large part by a $9.7 million California Energy Commission gr
Edison are partnering on the project to put into daily service 21 human-operated vehicles that are zero- or near-zero emissions at three of the Port's marine terminals and trucking company Total Transportation Services Inc. to test their performance in a real-world setting. As part of the project, SSA retrofitted nine of its existing diesel-powered rubber-tired gantry cranes to run on electricity, recently completing the last one. Watch a video about the cranes here.

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PORTS

Nation's Largest Zero-Emissions Port Project Launched In Long Beach

by Brandon Richardson April 9, 2018

Officials from the Port of Long Beach, Southern California Edison (SCE) and the California Energy Commission launched a pilot project on April 4 to test zero-emissions terminal equipment at the Pacific Container Terminal, one of three terminals included in the program.

"The Zero-Emissions Terminal Transition Project kicks off a new era in transportation electrification and the port's own transformation to zero emissions," Long Beach Harbor

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Harbor commission adopts 2024 spending plan for Port of Long Beach

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Long Beach Port Launches Zero-Emissions Project

By Aiswarya Lakshmi April 4, 2018

Officials from the Port of Long Beach, Southern California Edison and the California Energy Commission today launched the nation's largest pilot project for zero-emissions cranes and other cargo-handling equipment for seaports.

Funded mostly by a $9.7 million grant from the California Energy Commission, the project will bring 25 vehicles that are zero- or near zero-emissions to Port of Long Beach marine terminals for one year to test their performance in a real-world setting. The launch event was held at Pacific Container Terminal at Long Beach's Pier J — operated by SSA Terminals — one of three terminals participating in the project.

The ports of Long Beach and Los Angeles in 2017 approved an update to their Clean Air Action Plan, setting a goal of transitioning all terminal equipment to zero emissions by 2030.

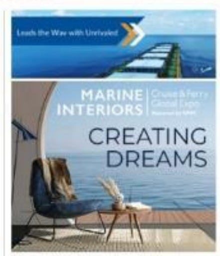
"The Zero-Emissions Terminal Transition Project kicks off a new era in transportation electrification and the Port's own transformation to zero-emissions," said Long Beach Harbor Commission President Lou Anne Bynum. "We are grateful for the partnerships with the Energy Commission and Southern California Edison that are making this a reality."

"This project is another example of the goods movement industry, equipment builders, utilities and public agencies stepping up to reach for the goal of zero emissions," said Mario Cordero, Port of Long Beach Executive Director. "Today, you can see how everyone is coming together to meet that challenge."

"The projects we are kicking off today will help to address some of Southern California's biggest challenges — cleaning up the air and reducing harmful greenhouse gases that cause climate change," said SCE President Ron Nichols. "SCE's vision for a clean energy future means partnering with the Port and other SCE customers to electrify transportation, as well as working hard to make sure the electricity that we provide to power those vehicles is produced with clean, renewable resources."

"SSA Terminals appreciates the confidence that the Port of Long Beach has shown in our company by selecting us to be part of this major project to electrify the nine large container-handling yard cranes at our Pacific Container Terminal," said Paul Gagnon, Vice President of SSA Marine Terminals. "We hope that this partnership will continue as we all strive for cleaner air quality."

The project is anticipated to reduce greenhouse gases by more than 1,323 tons and smog-causing nitrogen oxides by 27 tons each year. Also, the switch to zero-emissions equipment is expected to save more than 270,000 gallons of diesel fuel.



FEATURED VIDEO


MJP Waterjets Help Boat Owners Meet Operational Challenges


5.4.2.9: Ongoing Outreach

The benefits of the public outreach will continue well beyond the project itself. The Port maintains a robust media relations and community engagement program that broadly communicates messages about the zero-emission goods movement and the benefits of this project.

The Port routinely makes presentations to community and neighborhood groups, and it continues to hold major annual events, such as the State of the Port and Green Port Fair (next one to be held October 7, 2023), which educate hundreds of residents, community groups, industry leaders, and decision-makers about the Port's environmental investments. Harbor tours are back in full swing. In addition to the community boat tours, the Port hosts specialized harbor and terminal tours for regulatory agencies and key partners, helping to accelerate the pace of zero-emission goods movement.

Further, the Port continues to hold regular meetings for the CAAP Implementation Stakeholder Advisory Group, Technology Advancement Program, California Energy Commission Ports Collaborative, and San Pedro Bay Ports Sustainable Supply Chain Advisory Committee.

The youth workforce development efforts that began under the Project continue to expand. Each year, nearly 500 AGL high school students from disadvantaged neighborhoods benefit from the new zero-emission technology curriculum launched during the Project period. High school students receive real-world experience tackling challenges related to zero-emission goods movement and on-the-job training to prepare them for future careers.

5.4.2.10: Conclusions

The Port's outreach campaign for the Project directly reached more than 23,000 people through roughly 200 community and industry events, meetings, conferences, and tours as well as through YouTube promotional videos. It is presumed that thousands more people read about the Project in news articles, blogs, and newsletters. Many of these people were end users – terminal operators, trucking companies, and industry representatives – whose awareness was critical to broader adoption of zero-emission goods movement.

This public outreach enabled the Port to reach its goals of increasing awareness of the zero-emission goods movement, particularly in disadvantaged communities, and of increasing consumer confidence in deployed technologies. Further, this outreach will continue beyond the project itself, leveraging CEC's investment for years to come.

ABBREVIATIONS

AC	Alternating Current
ACT Expo	Advance Clean Transportation (ACT) Expo
AGL	Port of Long Beach Academy of Global Logistics (AGL) at Cabrillo High School
BIT	Basic Inspection of Terminals
BYD	BYD Motors
CAAP	Clean Air Action Plan
CAN	Controller Area Network
CARB	California Air Resources Board
CCS1	Combined Charging System Combo 1
CEC	California Energy Commission
CE-CERT	College of Engineering – Center for Environmental Research and Technology (at UC Riverside)
CHE	Cargo-Handling Equipment
CHP	California Highway Patrol
CITT	Center for International Trade and Transportation
COVID-19	Coronavirus Disease 2019
CSULB	California State University, Long Beach
DAC	Disadvantaged Communities
DPM	Diesel Particulate Matter
EPA	Environmental Protection Agency
eRTG	Electric Rubber-Tired Gantry Cranes
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment (i.e., charging stations)
GCW	Gross Combined Weight
GHG	Greenhouse Gas
IBEW	International Brotherhood of Electrical Workers
ITS	International Transportation Service
kA	Kiloampere

kW	Kilowatt
LBCC	Long Beach City College
LBCT	Long Beach Container Terminal
LBUSD	Long Beach Unified School District
LNG	Liquefied Natural Gas
MHD	Medium- and Heavy-Duty
NTRL	National Recognized Testing Laboratory
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturer
OSHA	Occupational Safety and Health Administration
PHET	Plug-In Hybrid Electric Truck
POLB or Port	Port of Long Beach
Ports	Port of Long Beach and Port of Los Angeles
Project	Port of Long Beach (Port) Zero-Emissions Terminal Equipment Transition Project
PTO	Power Take Off
SAE	Society of Automotive Engineers
SCE	Southern California Edison
SCCR	Short Circuit Current Rating
South Coast AQMD	South Coast Air Quality Management District
SOx	Sulfur Oxides
SPS	Smart Plug System
SSA	SSA Marine
TAP	Technology Advancement Program
TTSI	Total Transportation Services Inc.
UL	Underwriters Laboratory
ULSD	Ultra-Low Sulfur Diesel
ZE	Zero Emissions