

Multi-Source Facility Freight Demonstration Project Demonstration of Electric Yard Tractors & Class 5 Trucks FINAL REPORT

Submitted By:
San Bernardino Council of Governments

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LIST OF ACRONYMS

A	Amperes or Amperage
AC	Alternating Current
BNSF	BNSF Railway Co.
BYD	BYD Motors, Inc.
CCI	California Climate Investments
CAN	Controller Area Network
CARB	California Air Resources Board
CPUC	California Public Utilities Commission
DAC	Disadvantaged Community
DC	Direct Current
°C	Degrees Celsius
DGE	Diesel Gallon Equivalent
DoD	Depth of Discharge
EVSE	Electric Vehicle Supply Equipment
GCWR	Gross Combined Weight Rating
GGRF	Greenhouse Gas Reduction Fund
GPM	Gallons per Minute
GVWR	Gross Vehicle Weight Rating
Kg	Kilogram
kPa	Kilopascal
kW	Kilowatt
kWh	Kilowatt-Hours
Lbs.	Pounds (US)
MPG	Miles per Gallon
MPH	Miles per Hour
m/s ²	Meters per Second Squared (acceleration)
N-m	Newton-Meter
NRTL	Nationally Recognized Testing Laboratory

LIST OF ACRONYMS - Continued

OBD	Onboard Diagnostics
RPM	Revolutions per Minute
SAE	Society of Automotive Engineers
SBCOG	San Bernardino County Council of Governments
SCE	Southern California Edison
SOC	State of Charge
UL	Underwriters Laboratory
UTR	Utility Tractor Rig
V	Volts or Voltage
W	Watts
Wh	Watt-Hours

EXECUTIVE SUMMARY

This Final Report documents the successful completion of work performed by the San Bernardino Council of Governments (SBCOG) and its Project partners BNSF Railway, BYD Motors Inc., Daylight Transport LLC, and CALSTART under California Air Resources Board Grant Agreement G14-LCTI-06, “*Multi- Source Facility Demonstration Project: Multi-Class Heavy-Duty Zero-Emission Truck Development Project for Intermodal and Warehouse Facilities*”. This Project is part of the California Climate Investments (CCI), a statewide program that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas (GHG) and criteria air pollutant emissions, while strengthening the economy and improving public health and the environment, particularly in disadvantaged communities.



This Project had as its primary objectives the design, manufacture, and demonstration of advanced technology zero-emission trucks in rigorous rail yard and freight logistics facility duty cycles. Specifically, this Project successfully accomplished the following primary Project goals:

- ***Design and Manufacture a New Advanced Technology Class 8 Battery-Electric Yard Tractor.*** Yard tractors, also commonly known as a terminal tractor, utility tractor rig (UTR), yard truck, yard goat, or yard hostler, are the most common cargo handling equipment used in on-terminal shipping container movement operations. They are used extensively at marine terminals, intermodal facilities, and warehouse and logistics facilities. The development and commercialization of battery-electric yard tractors that have the performance and demonstrated capability to supplement and potentially replace conventional diesel-fueled equipment is a key component of the California Air Resources Board’s efforts to transition cargo handling equipment to zero-emissions¹.
- ***Design and Manufacture a New Advanced Technology Class 5 On-Road Heavy Duty Truck.*** Class 5 heavy-duty trucks, with a gross vehicle weight rating of 19,500 pounds, account for more than 7,200 annual vehicle sales in California². Development and

¹ <https://ww2.arb.ca.gov/resources/documents/cargo-handling-equipment-regulation-transition-zero-emissions>

² CALSTART Market Assessment Report, April 2019.

commercialization of new Class 5 trucks addresses a key market segment and will assist in transitioning on-road goods movement to zero emissions.

- ***Operate the Advanced Technology Electric Vehicles in Rigorous Rail Yard and Freight Logistics Facility Duty Cycles in Disadvantaged Communities.*** The selection of rail yard and warehouse distribution facilities in disadvantaged communities (DAC) within Los Angeles and San Bernardino counties to serve as demonstration locations ensured the advanced technology electric vehicles would be subjected to strenuous, real world duty cycles, and that the benefits of zero-emission operations would accrue within a DAC.
- ***Conduct a Mid-Project Technology Evaluation and Incorporate Feedback into “Phase 2” Vehicle Designs.*** This Project was unique in that it was designed from the start to have an initial deployment of “Phase 1” vehicles that would, based largely on driver feedback, undergo an extensive engineering evaluation and redesign. The new design features would be incorporated to the extent feasible into the both existing vehicles and a second generation of new “Phase 2” vehicles that would also be demonstrated within DAC communities.
- ***Conduct Research into the Market Needs and Commercialization Potential for the Advanced Technology Electric Vehicles.*** Comprehensive research was performed to identify the commercialization potential for the electric vehicles developed under this Project. This is extremely important – while any one project will achieve some level of emissions reductions, the main goal is to move commercial readiness forward and achieve substantial GHG and criteria air pollutant reductions when the technology is more fully integrated into the marketplace.

Above all, this Project was a success due to the team of dedicated partners who, irrespective of the challenges presented, maintained their professionalism, helpfulness, and comradery. The Project team for this technology demonstration included the following organizations along with their respective roles in the Project:

- **California Air Resource Board (CARB)** – CARB provided the grant funding under the Multi-Source Facility Freight Demonstration Program and acted as the Program Manager for this Project. CARB provided oversight and guidance during the entire Project and

was the final authority for approving the Project scope, budget, schedule, and reporting deliverables. CARB also managed a separate data collection, monitoring, and analysis contract for CARB.

- **San Bernardino Council of Governments (SBCOG)** – SBCOG served as the Project Administrator and was the prime contractor under the CARB Grant. SBCOG had overall responsibility for the implementation of the Project, including the day-to-day Project oversight, financial administration, coordination among the team members, and reporting to the CARB.
- **BYD Motors, Inc.** – BYD was the technology provider for this Project. BYD performed final manufacturing of the heavy-duty off-road electric yard tractors and Class 5 on-road service trucks at their Lancaster, California facility. BYD also manufactured the electric vehicle supply equipment (EVSE) that was installed at the vehicle demonstration sites to facilitate recharging of the electric vehicles. BYD performed maintenance and repair of the vehicles and EVSE and coordinated with the electric utility and construction contractors on EVSE installation at three demonstration sites.
- **Daylight Transport LLC** – Daylight Transport operates a freight logistics facility in Fontana, California and served as a demonstration fleet for the BYD electric yard tractors and service trucks. In addition to operating the electric vehicles in daily revenue service, Daylight’s programmatic responsibilities included coordination with BYD in installing EVSE at their facility, monitoring of the vehicle operational status, and coordinating with BYD to expedite repairs as needed. Daylight also documented and submitted on a biweekly schedule data pertaining to demonstration vehicle maintenance and repairs.
- **BNSF Railway Company** – As a Class 1 railroad, BNSF operates multiple rail yards and intermodal facilities in Southern California. BNSF coordinated the demonstration of the BYD electric yard tractors and service trucks at two of BNSF’s Intermodal facilities: Los Angeles Hobart and San Bernardino. BNSF contracts with intermodal rail service providers at their facilities, and it is these service providers who had the role of operating the BYD electric yard tractors and service trucks, which were used to move containers within the BNSF facilities and provide service tasks within the facilities. At BNSF-Hobart, Parsec, Inc. was BNSF’s service provider during all Project demonstration

phases. At BNSF-San Bernardino, Eagle Intermodal Services, Inc. acted as the service provider from Project start in the third quarter of 2016 through the end of August 2018. As of September 1, 2018, ITS ConGlobal assumed the electric vehicle demonstration responsibilities from Eagle Intermodal Services.

- **Southern California Edison (SCE)** – SCE is the public utility that provides electric service to the Daylight Transport and BNSF facilities. SCE was responsible for performing the utility upgrades to allow installation of the BYD EVSE at Daylight Transport and the two BNSF rail facilities.
- **CALSTART** – In parallel with the demonstration of the electric vehicles, CALSTART conducted two relevant research studies and hosted one fleet-focused educational event. The first was a comprehensive Market Assessment Report that explored the potential market for the BYD electric trucks demonstrated under this Project, with the objective of identifying the best industries and applications for these classes of electric vehicles. The second report was a detailed Commercialization Roadmap, specific to the BYD electric yard tractor and Class 5 service truck, which presented a pathway forward to increase utilization of these vehicles throughout the goods movement sector. Also, and importantly, CALSTART developed and implemented a “Voice of the Customer” event wherein all interested fleets were invited to see the BYD electric vehicles firsthand, meet with the Project partners and service providers, and discuss the pros, cons, lessons learned, and funding opportunities available for integrating the BYD electric vehicles into fleet operations within other industries and agencies. Additional details of the CALSTART work projects are included in Section 5 of this Final Report.
- **Ricardo PLC (Ricardo)** – Under a separate contract with the CARB, Ricardo was responsible for conducting the monitoring, data collection, and analysis of the BYD electric vehicles demonstrated under this Project. Ricardo’s subcontractor, ZMassociates, supported this effort by installing the telematics data loggers used to collect electronic data from the BYD electric vehicles and two baseline diesel vehicles. It should be noted that BYD, Daylight Transport, BNSF, and BNSF’s service providers Parsec, Inc., Eagle, and ITS ConGlobal contributed significantly to the data collection and analysis effort, collecting and submitting on a biweekly or monthly basis data pertaining to maintenance

and repairs, baseline vehicle fuel consumption, etc. to support Ricardo's quantitative analyses.

A key "lesson learned" was that *communication* is the most essential element of a successful project, and in this regard the project partners excelled in maintaining a regular, open dialogue. As discussed further in the Results and Findings Section of this Report, SBCOG convened weekly teleconferences with all project partners participating, and it cannot be overemphasized how critical these weekly sessions, albeit brief in length, were to building team engagement and cohesiveness.

This Project commenced on May 12, 2016 and had an original Project completion date of April 1, 2019. However, due to delays in completing installation of the EVSE at the BNSF facilities, most significantly BNSF-San Bernardino, the demonstration phase was extended and a revised Project end date of March 31, 2020 approved by the CARB.

Early in the Project design phase (third quarter 2016), BNSF notified SBCOG that planned construction at the Commerce Intermodal Facility would necessitate a temporary facility closure beginning in late 2017. To avoid disruption in the installation of EVSE and potentially significant schedule delays, BNSF recommended that the demonstration be relocated to their Los Angeles Intermodal Facility – Hobart Yard. In making their recommendation, BNSF noted that no adverse impacts or changes to the expected Project outcome would result from the relocation from BNSF Commerce to BNSF Los Angeles (Hobart). The proposed site substitution was deemed acceptable to CARB and SBCOG and was formalized in an amendment to the original agreement during the fourth quarter of 2016. While this proposed BNSF location was much larger than the Commerce location, it turned out to be an excellent site that was ideal for the electric chargers and demonstration of the vehicles. This was due to the higher activity and overall layout of the facility.

The original scope of the Project called for the deployment of nine (9) Phase 1 electric yard tractors, fourteen (14) Phase 2 electric yard tractors, and four (4) Class 5 electric service trucks, as shown below in Table 1:

Table 1-1: Phase 1 and Phase 2 Vehicle Deployments – Original Scope

	PHASE 1 8Y YARD TRACTORS	PHASE 2 8Y YARD TRACTORS	PHASE 1 5F SERVICE TRUCKS	PHASE 2 5F SERVICE TRUCKS
BNSF-HOBART	3	7	1	-
BNSF-SAN BERNARDINO	3	7	1	1
DAYLIGHT TRANSPORT	3	-	1	-

The electric vehicle deployment strategy was modified during Project implementation; Table 2 illustrates the vehicle deployment numbers and locations at the conclusion of the Project:

Table 1- 2: Final Vehicle Deployments by Location

	PHASE 1 8Y YARD TRACTORS	PHASE 2 8Y YARD TRACTORS	PHASE 1 5F SERVICE TRUCKS	PHASE 2 5F SERVICE TRUCKS
BNSF-HOBART	3	7	1	-
BNSF-SAN BERNARDINO	3	7	2	-
DAYLIGHT TRANSPORT	3	1	-	-

During the course of Project implementation, CALSTART conducted three (3) research activities to identify and characterize the market for future BYD electric vehicle sales and developed a plan to capture a share of the marketplace for heavy-duty yard tractors and Class 5 on-road trucks.

CALSTART published three (3) Reports that were deliverables under the Project Grant Agreement, as follows:

- 1) Battery-Electric Class 5 Service Trucks and Class 8 Yard Trucks: Market Assessment;
- 2) Battery-Electric Class 5 Service Trucks and Class 8 Yard Trucks: Commercialization Roadmap;
and
- 3) Battery-Electric Class 5 Service Trucks and Class 8 Yard Trucks: Voice of the Customer Event

The third Report listed above documents a “Voice of the Customer” event hosted by SBCOG and CALSTART that took place at the South Coast Air Quality Management District Headquarters on August 22, 2019. This event, discussed below in Section 5.3, provided an opportunity for outside fleets to see the BYD Phase 2 8Y electric yard tractor and Class 5 service truck in person and discuss with the project implementers their experience to date using the electric vehicles in daily rail yard and logistics facility container movement operations. It also provided an opportunity for Daylight Transport and BNSF service providers to share their experience with the group, the purpose being solicit feedback that will help BYD make further improvements to their heavy-duty electric vehicle products.

This Project yielded a wealth of data and information that will assist BYD in the continuous refinement of their heavy-duty electric vehicle products. Feedback provided by the project partners relative to their overall experience in implementing this Project, their recommendations moving forward, and importantly, the key takeaways and “lessons learned”, are presented below. While hindsight is always 20/20, it is hoped that the experiences, challenges encountered, and remedies implemented on this Project will positively influence the design and implementation of future advanced technology vehicle demonstration projects.

Planning, Construction, & Charger Installation – Results & Findings

Special note: Please note that throughout this section and the entire document there are references to electric vehicle supply equipment (EVSE) which can be defined in two different ways. The first instance is when referring to the charger units themselves, the second is when it is in reference to the entire electric infrastructure as a whole.

The Project element that presented the greatest challenges was the implementation of the EVSE at the BNSF demonstration locations. Notably, there were few if any issues with constructing EVSE at Daylight Transport. The primary reason is that the Daylight Transport facility in Fontana is new construction. As such, the site accommodations to support EVSE were an element of the overall facility design, with the electric utility service construction a part of the overall facility construction. Thus, there was no need to perform demolition or reconfiguration of an existing facility, as was the case at the BNSF demonstration sites. The location of the EVSE charger installations at Daylight Transport was also planned as an element of the overall facility design; thus, there were no issues pertaining to loss of parking spaces, etc.

BNSF's experience with implementing EVSE at BNSF-Hobart and BNSF-San Bernardino was more challenging. The primary issue was delays in working with SCE. BNSF experienced long lead times in the design and construction phases of EVSE installation, and these delays ultimately required the Project demonstration phase to be extended to ensure the vehicles met their contractual operation duration obligations and that sufficient data could be collected.

Additional challenges encountered by BNSF included the construction-related costs of EVSE installation at existing facilities – much greater as compared to performing new construction as experienced by Daylight Transport. Finally, as discussed in succeeding Sections of this Report, BNSF and SCE worked closely to develop an electricity rate structure that would yield an acceptable power purchase cost as compared to the price of conventional diesel fuel.

While EVSE challenges were encountered, primarily when working with the utility, all were overcome and the EVSE was successfully installed. The key factor was SBCOG, BNSF, and SCE working together in a cooperative, constructive manner to identify the issues impeding progress and correct them.

⇒ **Key Finding:** When planning to incorporate electric vehicles, especially heavy-duty electric vehicles, into fleet operations, EVSE must be emphasized during the project planning phase. Additional design and construction time should be included in the project's critical path analysis. The potential to encounter hidden conditions, experience weather delays, etc., must be anticipated and sufficient lead time given to address likely delays. Most importantly, regular communication between all parties is essential – weekly meetings – at a minimum, help ensure all parties are aware of the current project status and allow technical or programmatic concerns to be addressed immediately.

BYD Model 5F Electric Service Truck – Results & Finding

Throughout the Project demonstration, utilization of the Class 5 electric service truck was low. At Daylight Transport the level of use did not justify retaining the vehicle. It was instead relocated to BNSF-San Bernardino.

However, the mileage and run time of the Class 5 electric service trucks was also limited at both BNSF-Hobart and BNSF-San Bernardino. The trucks were utilized frequently; however the trips

were very short because the trucks and trailers that the service truck operators were servicing are close together.

Also, there was minimum data collection for the Class 5 electric service trucks. No baseline Class 5 trucks were included in the Project; thus, there is limited ability to compare recorded performance and drivetrain efficiency data corresponding to an electric service truck to a conventional diesel Class 5 truck. For qualitative information, it is beneficial to recognize that the service truck could perform most of the duties of the current diesel service trucks, although not all of the duties. For example the battery-electric service truck could not be used to jump start other diesel trucks because it does not have a 12 volt system.

⇒ **Key Finding:** The knowledge gained from a Project is diminished if there is inconsistent monitoring, data collection and analysis across the types and classes of vehicles being demonstrated. While the original intent was to more fully utilize the electric service trucks, there is benefit from a marketing perspective to understand that Class 5 electric vehicles would likely have low use and thus offer limited environmental benefit when deployed at rail yards and logistics or warehouse facilities. An important experience gained is that battery-electric trucks may be able to replace a combustion engine truck in a variety of new applications.

BYD Model 8Y Electric Yard Tractor Performance – Results & Finding

An important finding of this Project was that the BYD 8Y electric yard tractor exhibited performance capabilities, including power and torque, on par with the baseline diesel yard tractors. The electric vehicles were capable of operating across multiple work shifts, averaging 8 to 14 hours of continuous operation. The strategy of recharging the vehicles on an opportunity basis, typically during lunch breaks or other break periods during a work shift, proved to be effective from a workflow standpoint.

On an energy consumption basis, the electric yard tractors have significantly greater energy efficiency. Based on a preliminary analysis of the data collected by Ricardo, the efficiency of the electric yard tractor as compared to the baseline diesel yard tractor is on the order of four to five times greater. It was also noted by data collected by Ricardo that the availability of regenerative braking captured approximately 0.30 kWh per mile. This demonstrates that the

duty cycle typically associated with yard tractors is conducive to the use of electric drivetrain vehicles equipped with regenerative braking capability.

- ⇒ **Key Finding:** While opportunity charging was effective from an operational perspective, it did not prove to be the most cost-efficient strategy. As noted by BNSF, vehicle charging often occurred during peak periods when electricity rates were highest. This resulted in higher utility costs which in turn eroded the energy efficiency benefits of the electric yard tractors. Moving forward, there is an opportunity to explore different vehicle charging strategies that meet facility operational demands but do so at times when the utility rates are lower. This will allow fleets to reap, on an economic basis, the benefit of the more efficient electric drivetrains.
- ⇒ **Key Finding:** While it is important that fleet operators do their part to develop operational strategies that allow their electric vehicles to be recharged during non-peak periods to the extent feasible, BNSF also noted the importance moving forward for the electric utilities to act in partnership with fleets to ensure electric vehicle recharging rate structures are available that are competitive with conventional fuels.

BYD Model 8Y Electric Yard Tractor Operability – Results & Findings

At the conclusion of the electric vehicle demonstration, driver acceptance of the vehicles had improved significantly. As noted by BNSF and Daylight Transport, some of their drivers stated that they preferred the electric yard tractors over the diesel vehicles. The electric vehicles offer drivers a more quiet work environment where they are not subjected to diesel exhaust.

That being said, the initial acceptance of the vehicles was low. This is attributable to several factors. At first, the electric yard tractors were viewed as more of a “novelty”, and in some cases this has been difficult to overcome. Also, the Phase 1 electric yard tractors had an ergonomic configuration that some operators disliked – they simply didn’t have the same design as the tractors the drivers were accustomed to. This resulted in operators avoiding the electric tractors in favor of more familiar diesel tractors. Also, as discussed in Section 2, the lack of an independently operated fifth wheel in the Phase 1 design had a significant negative impact on driver acceptability.

The Phase 2 electric yard tractor design largely eliminated or reduced operator concerns pertaining to ergonomics and operability. The process used to arrive at the Phase 2 design is a key positive feature of this project.

⇒ **Key Finding:** Incorporating a “two-phase” vehicle design and demonstration methodology was a key success of this Project. The Daylight Transport operators and BNSF service providers provided significant, valuable feedback to BYD, suggesting structural, ergonomic, and operational modifications that were applied to the Phase 2 vehicles. Most of the recommended modifications were essential to perform the intended work, such as shorter beaver tail prongs and an independently operated fifth wheel. BYD was methodical in capturing all of the information provided by the demonstration fleet operators and applying it to the Phase 2 yard tractor redesign. In turn, the operators and service providers felt a sense of value, knowing they had made a meaningful contribution to the refinement and design evolution of BYD’s product.

BYD Model 8Y Electric Yard Tractor Reliability – Results & Findings

The Phase 2 electric yard tractors have exhibited improved reliability as compared to the Phase 1 vehicles. As discussed in Section 2, Daylight Transport’s Phase 1 yard tractors were an earlier prototype design, and these vehicles did not demonstrate a level of reliability deemed acceptable beyond the demonstration phases of the Project. For that reason, the decision was made to retire the Daylight “Pre-Phase 1” yard tractors from service.

While the Phase 2 yard tractors have demonstrated improved reliability, opportunities remain for BYD to continue improving the vehicles with respect to reliability and durability. The long-term reliability and durability of the electric yard tractors are unknown, and this remains a primary consideration when considering adding additional electric vehicles to the fleet.

⇒ **Key Finding:** While the Phase 2 electric yard tractors achieved greater reliability as compared to the Phase 1 vehicles, BYD should strive to continue improving their vehicle reliability and durability. This will provide fleets the confidence needed to expand the use of electric vehicles in their operations.

BYD Model 8Y Electric Yard Tractor Maintainability – Results & Findings

The issues associated with electric yard tractor reliability also impacted its maintainability. While BNSF service provider mechanics and Daylight Transport were fully qualified to do regular maintenance on the electric yard tractors, they were not qualified to troubleshoot and repair more complex structural issues or faults associated with the vehicle's high voltage electric drive systems. It should be noted that the vehicles were also within the BYD warranty period; thus, it would be inappropriate for the fleet technicians and mechanics to perform work covered by the manufacturer warranty.

The primary issue encountered was that maintenance and repairs to the BYD electric vehicles required considerably more time as compared to the baseline diesel tractors. Whereas the demonstration fleets have mechanics onsite to immediately address repairs to the conventional diesel tractors, BYD was required to dispatch technicians from their Lancaster facility. On occasion, it was determined that repairs could not be performed in the field; this required transporting the electric yard tractors back to Lancaster to perform necessary repairs. This contributed to a much longer downtime for the electric yard tractors as compared to the conventional diesel vehicles.

⇒ **Key Finding:** Moving forward, it will be essential to have qualified technicians available to address repairs needed to the electric vehicles. This is especially true when the vehicles are outside of the manufacturer warranty period. It is advisable that fleets identify preferred vendors to perform this maintenance if it is not practical to employ specialized mechanics qualified to work on heavy-duty electric vehicle drivetrain systems.

Finally, the Project Team was honored to be nominated and selected to receive a **Clean Air Award** from the South Coast Air Quality Management District (AQMD). The South Coast AQMD announced the winners of its 31st Clean Air Awards on October 4, 2019. This annual awards ceremony honors individuals and businesses, public agencies, and others who are making significant contributions to cleaner air in the South Coast Air Basin. This Project received the 2019 Clean Air Award for Model Community Achievement.



Pictured from left to right: Vincent Pellecchia, BYD Motors; Lena Kent, BNSF Railway; Carlos Garcia, Daylight Transport; Jenny Herrera, SBCOG; Chase LeCroy, CALSTART; Kelly Lynn, SBCOG, Michael Baker, California Air Resources Board

INTRODUCTION

This Final Report documents the successful completion of work performed by the San Bernardino Council of Governments (SBCOG) and its Project partners BNSF Railway, BYD Motors Inc., CALSTART and Daylight Transport LLC, under California Air Resources Board Grant Agreement G14-LCTI-06, “*Multi- Source Facility Demonstration Project: Multi-Class Heavy-Duty Zero-Emission Truck Development Project for Intermodal and Warehouse Facilities*”. This Project is part of the California Climate Investments (CCI), a statewide program that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas (GHG) and criteria air pollutant emissions, while strengthening the economy and improving public health and the environment, particularly in disadvantaged communities.



This Project had as its primary objectives the design, manufacture, and demonstration of advanced technology zero-emission trucks in rigorous rail yard and freight logistics facility duty cycles. Specifically, this Project successfully accomplished the following primary Project goals:

- ***Design and Manufacture a New Advanced Technology Class 8 Battery-Electric Yard Tractor.*** Yard tractors, also commonly known as a terminal tractor, utility tractor rig (UTR), yard truck, yard goat, or yard hostler, are the most common cargo handling equipment used in on-terminal shipping container movement operations. They are used extensively at marine terminals, intermodal facilities, and warehouse and logistics facilities. The development and commercialization of battery-electric yard tractors that have the performance and demonstrated capability to replace conventional diesel-fueled equipment is a key component of the California Air Resources Board’s efforts to transition cargo handling equipment to zero-emissions³.
- ***Design and Manufacture a New Advanced Technology Class 5 On-Road Heavy Duty Truck.*** Class 5 heavy-duty trucks, with a gross vehicle weight rating of 19,500 pounds, account for more than 7,200 annual vehicle sales in California⁴. Development and commercialization of new Class 5 trucks addresses a key market segment and will assist in transitioning on-road goods movement to zero emissions.

³ <https://ww2.arb.ca.gov/resources/documents/cargo-handling-equipment-regulation-transition-zero-emissions>

⁴ CALSTART Market Assessment Report, April 2019.

- ***Operate the Advanced Technology Electric Vehicles in Rigorous Rail Yard and Freight Logistics Facility Duty Cycles in Disadvantaged Communities.*** The selection of rail yard and warehouse distribution facilities in disadvantaged communities (DAC) within Los Angeles and San Bernardino counties to serve as demonstration locations ensured the advanced technology electric vehicles would be subjected to strenuous, real world duty cycles, and that the benefits of zero-emission operations would accrue within a DAC.
- ***Conduct a Mid-Project Technology Evaluation and Incorporate Feedback into “Phase 2” Vehicle Designs.*** This Project was unique in that it was designed from the start to have an initial deployment of “Phase 1” vehicles that would, based largely on driver feedback, undergo an extensive engineering evaluation and redesign. The new design features would be incorporated to the extent feasible into the both existing vehicles and a second generation of new “Phase 2” vehicles that would also be demonstrated within DAC communities.
- ***Conduct Research into the Market Needs and Commercialization Potential for the Advanced Technology Electric Vehicles.*** Comprehensive research was performed to identify the commercialization potential for the electric vehicles developed under this Project. This is extremely important – while any one project will achieve some level of emissions reductions, the main goal is to move commercial readiness forward and achieve substantial GHG and criteria air pollutant reductions when the technology is fully integrated into the marketplace.

Above all, this Project was a success due to the team of dedicated partners who, irrespective of the challenges presented, maintained their professionalism, helpfulness, and comradery. The Project team for this technology demonstration included the following organizations along with their respective roles in the Project:

- **California Air Resource Board (CARB)** – CARB provided the grant funding under the Multi-Source Facility Freight Demonstration Program and acted as the Program Manager for this Project. CARB provided oversight and guidance during the entire Project and was the final authority for approving the Project scope, budget, schedule, and reporting

deliverables. CARB also managed a separate contract on data collection, monitoring, and analysis for this Project.

- **San Bernardino Council of Governments (SBCOG, formerly known as San Bernardino Associated Governments)** – SBCOG served as the Project Administrator and was the prime contractor under the CARB Grant. SBCOG had overall responsibility for the implementation of the Project, including the day-to-day Project oversight, financial administration, coordination among the team members, and reporting to the CARB. In early 2016, SBCOG sponsored Senate Bill 1305, consolidating the five (5) roles of San Bernardino Associated Governments: the Transportation Authority, Transportation Commission, Congestion Management Agency, and Service Authority for Freeway Emergencies into a new statutory entity; the San Bernardino County Transportation Authority (SBCTA). In August 2016 the Governor signed SB 1305 with an effective date of January 1, 2017. On November 2, 2017 the SBCTA Board of Directors approved and adopted the new brand identity for the SBCTA and the San Bernardino Associated Governments acting as the Council of Governments (SBCOG).
- **BYD Motors, Inc.** – BYD was the technology provider for this Project. BYD performed final manufacturing of the heavy-duty off-road electric yard tractors and Class 5 on-road service trucks at their Lancaster, California facility. BYD also manufactured the electric vehicle supply equipment (EVSE) that was installed at the vehicle demonstration sites to facilitate recharging of the electric vehicles. BYD performed maintenance and repair of the vehicles and EVSE and coordinated with the electric utility and construction contractors on EVSE installation at three (3) demonstration sites.
- **Daylight Transport LLC** – Daylight Transport operates a freight logistics facility in Fontana, California and served as a demonstration fleet for the BYD electric yard tractors and service trucks. In addition to operating the electric vehicles in daily revenue service, Daylight’s programmatic responsibilities included coordination with BYD in installing EVSE at their facility, monitoring of the vehicle operational status, and coordinating with BYD to expedite repairs as needed. Daylight also documented and submitted on a biweekly schedule data pertaining to demonstration vehicle maintenance and repairs.

- **BNSF Railway Company** – As a Class 1 railroad, BNSF operates multiple rail yards and intermodal facilities in Southern California. BNSF coordinated the demonstration of the BYD electric yard tractors and service trucks at two of their facilities: the BNSF - Los Angeles (Hobart) Rail Yard, and the San Bernardino Intermodal Facility. BNSF contracts with intermodal rail service providers at their facilities, and it is these service providers who had the role of operating the BYD electric yard tractors and service trucks in shipping container movements within the BNSF facilities. At BNSF-Hobart, Parsec, Inc. was BNSF’s service provider during all Project demonstration phases. At BNSF-San Bernardino, Eagle Intermodal Services, Inc. acted as the service provider from Project start in the third quarter of 2016 through the end of August 2018. As of September 1, 2018, ITS ConGlobal assumed the electric vehicle demonstration responsibilities from Eagle Intermodal Services.
- **Southern California Edison (SCE)** – SCE is the public utility that provides electric service to the Daylight Transport and BNSF facilities. SCE was responsible for performing the utility upgrades to allow installation of the BYD EVSE at Daylight Transport and the two BNSF rail facilities.
- **CALSTART** – In parallel with the demonstration of the electric vehicles, CALSTART conducted two relevant research studies and hosted one fleet-focused educational event. The first was a comprehensive Market Assessment Report that explored the potential market for the BYD electric trucks demonstrated under this Project, with the objective of identifying the best industries and applications for these classes of electric vehicles. The second report was a detailed Commercialization Roadmap, specific to the BYD electric yard tractor and Class 5 service truck, which presented a pathway forward to increase utilization of these vehicles throughout the goods movement sector. Also, and importantly, CALSTART developed and implemented a “Voice of the Customer” event wherein all interested fleets were invited to see the BYD electric vehicles firsthand, meet with the Project partners and service providers, and discuss the pros, cons, lessons learned, and funding opportunities available for integrating the BYD electric vehicles into fleet operations within other industries and agencies. Additional details of the CALSTART work projects are included in Section 5 of this Final Report.

- **Ricardo** – Under a separate contract with the CARB, Ricardo was responsible for conducting the monitoring, data collection, and analysis of the BYD electric vehicles demonstrated under this Project. CARB Contracted with Ricardo to perform this work across seven projects. Ricardo’s subcontractor, ZMassociates, supported this effort by installing the telematics data loggers used to collect electronic data from the BYD electric vehicles and two baseline diesel vehicles. It should be noted that BYD, Daylight Transport, BNSF, and BNSF’s service providers Parsec, Inc., Eagle, and ITS ConGlobal contributed significantly to the data collection and analysis effort, collecting and submitting on a biweekly or monthly basis data pertaining to maintenance and repairs, baseline vehicle fuel consumption, etc. to support Ricardo’s quantitative analyses.

A key “lesson learned” was that *communication* is the most essential element of a successful project, and in this regard the project partners excelled in maintaining a regular, open dialogue. As discussed further in the Results and Findings Section of this Report, SBCOG convened weekly teleconferences with all project partners participating, and it cannot be overemphasized how critical these weekly sessions, albeit brief in length, were to building team engagement and cohesiveness.

This Project commenced on May 12, 2016 and had an original Project completion date of April 1, 2019. However, due to delays in completing installation of the EVSE at the BNSF facilities, most significantly BNSF-San Bernardino, the demonstration phase was extended and a revised Project end date of March 31, 2020 approved by the CARB. A snapshot of key Project milestones and events is shown below in Figure 1-1, with additional details included throughout this Final Report.

Figure 1-1: Key Milestones in Implementing the Intermodal & Warehouse Facilities Electric Vehicle Demonstration Project

MILESTONE or EVENT	DATE
Project Start Date	May 12, 2016
Kickoff Meeting in Sacramento with Air Resources Board & Project Team	June 27, 2016
Site Visit to BYD Manufacturing Facility in Lancaster	September 26, 2016
EVSE Installations Complete at Daylight Transport	March 2017
Data Collection kickoff Meeting Hosted by CARB & Ricardo at Daylight Transport	September 7, 2017

EVSE Installations Complete at BNSF-Hobart	October 2017
EVSE Installations Complete at BNSF-San Bernardino	January 2017
Phase 1 Electric Yard Tractors & Service Truck Delivered to Daylight Transport	March 8, 2017
Phase 1 Electric Yard Tractors & Service Truck Delivered to BNSF-Hobart	March 31, 2017
Phase 1 Electric Yard Tractors & Service Truck Delivered to BNSF-San Bernardino	March 31, 2017
Phase 1 Demonstration Begins - Daylight Transport	March 20, 2017
Phase 1 Demonstration Begins BNSF-Hobart	October 30, 2017
Phase 1 Demonstration Begins – BNSF-San Bernardino	January 2018
Phase 1 Electric Yard Tractors Deployed at Daylight Transport Returned to BYD	March 2019
Phase 1 Yard Tractors Deployed at BNSF-San Bernardino Relocated to Daylight	June 2019
Phase 2 Electric Yard Tractors Deliveries Begin BNSF-Hobart	March 21, 2019
Phase 2 Electric Yard Tractors Deliveries Begin BNSF-San Bernardino	March 22, 2019
Phase 1 Electric Service Truck Deployed at Daylight Relocated to BNSF SB	September 2019
CALSTART Market Assessment Report Published	April 2019
"Voice of the Customer" Event Held at South Coast AQMD Headquarters	August 22, 2019
CALSTART Commercialization Roadmap Published	December 31, 2019
Phase 2 Electric Yard Tractor Deployed at Daylight Transport	January 2020
Project Completion	March 31, 2020

The following Sections of this Final Report will discuss in the detail the Project implementation methodology, specifications for the advanced technology electric vehicles and supporting charging infrastructure deployed at the demonstration sites, data collection and analysis results, and importantly, key findings and lessons learned from the project participants. As mentioned earlier, under a separate contract with CARB, Ricardo was responsible for conducting the monitoring, data collection, and analysis of the electric vehicles demonstrated in under this Project. The comprehensive data collection and analysis results will be available in a separate report from CARB, with an anticipated release date of summer 2020.

DEMONSTRATION PROJECT IMPLEMENTATION – PREDEPLOYMENT PHASE

The following Sections detail the activities undertaken by SBCOG and the Project partners prior to the start of the revenue service demonstration and formal data collection. This includes site construction and utility upgrades to facilitate installation of electric vehicle supply equipment (EVSE, i.e., charging equipment), driver and mechanic training, as well as a pre-deployment onsite demonstration of a prototype electric yard tractor for the purpose of soliciting initial design feedback.

1.1 Demonstration Site Locations

The demonstration locations as originally proposed included the following:

- BNSF Railway Co. Commerce Intermodal Facility
- BNSF Railway Co. San Bernardino Intermodal Facility
- Daylight Transport LLC – located in Fontana, CA. Daylight Transport is nationwide expedited Less-than-Truckload (LTL) carrier.

Early in the Project design phase (third quarter of 2016), BNSF notified SBCOG that planned construction at the Commerce Intermodal Facility would necessitate a temporary facility closure beginning in late 2017. To avoid disruption in the installation of EVSE and potentially significant schedule delays, BNSF recommended that the demonstration be relocated to their Los Angeles Intermodal Facility - Hobart Yard. In making their recommendation, BNSF noted that no adverse impacts or changes to the expected Project outcome would result from the relocation from BNSF - Commerce to BNSF Los Angeles (Hobart). The two yards are adjacent. In fact, the BNSF Los Angeles (Hobart) facility is larger and it was anticipated that the trucks would be operated more, therefore improving the project. The proposed site substitution was deemed acceptable to CARB and SBCOG and was formalized in an amendment to the original agreement during the fourth quarter of 2016.

Note that for the remainder of this Final Report, the BNSF Los Angeles Intermodal Facility – Hobart Yard will be referred to as “BNSF-Hobart” or “Hobart”. Similarly, the BNSF-San Bernardino Intermodal Facility will be referred to as “BNSF-San Bernardino”.

1.2 Installation of Electric Vehicle Supply Equipment

An essential component of any battery-electric vehicle demonstration is the availability of compatible EVSE to recharge the vehicles. For this Project, the design, fabrication, construction, and commissioning of EVSE presented several technical and programmatic challenges that, while successfully resolved, did negatively impact the Project implementation schedule. The process, issues encountered, remedies implemented, and results of the EVSE implementation Project component are discussed in the following Sections. A thorough discussion of the “lessons learned” stemming from the EVSE implementation element of this Project can be found in Section 6, “Results, Findings, Lessons Learned”.

1.2.1 EVSE Implementation – Roles & Responsibilities

The design, site preparation, construction, installation, and commissioning of the EVSE at the three demonstration sites required extensive coordination between the following Project implementation partners:

- **BYD** – responsible for the design and manufacture of two EVSE charging systems compatible with the Model 8Y electric yard tractor and 5F Class 5 service truck. Technical specifications for these EVSE systems are included in Section 2.2.2. Additionally, BYD acted as a facilitator on behalf of demonstration partners BNSF and Daylight Transport during initial coordination with SCE. BYD assisted in site design, conducting electricity rate analyses, and the gathering of detailed site information prior to submittal to SCE.
- **SCE** – as the public utility electricity service provider for each of the three demonstration sites, SCE performed the utility service design and underground site construction up to the interface (stub out connector) where the BYD EVSE was installed.
- **BNSF** – BNSF coordinated extensively with BYD and SCE relative to site design and was responsible for providing SCE with computer aided design (CAD) drawings for both Hobart and San Bernardino BNSF facilities. BNSF also conducted a formal procurement to select a general contractor to install the BYD EVSE at their Hobart and San Bernardino facilities. As discussed in Section 2.2.5, below, BNSF assumed an even

larger role in coordinating with SCE to help resolve the EVSE construction delays encountered.

- **Daylight Transport** – Daylight Transport was responsible for conducting an analysis of the EVSE site design and coordinating with BYD and SCE. Daylight Transport’s Fontana facility was new construction, and as discussed in Section 6, the installation of EVSE as a part of new facility construction was more streamlined than integrating EVSE into an existing facility.
- **SBCOG** – in the capacity of Project Administrator, SBCOG closely worked with BNSF and SCE to facilitate dialogue and reach a mutually agreed to solution to EVSE construction delays that threatened adherence to the Project implementation timeline.

1.2.2 EVSE Technical Specifications

Two (2) EVSE charging systems were utilized on this Project, both manufactured by BYD. The following are the technical specifications for each charging system:

1.2.2.1: BYD 200 kW AC Charger – The BYD 200 kW AC charger was the primary EVSE installed under this Project. It is a 480 volt three-phase alternating current (AC) charging system with a maximum rated power output of 200 kilowatt (kW). The technical specification for this EVSE is shown below in Figure 2-1.

As discussed in Section 2.2.3, the 200 kW EVSE was only installed at the BNSF-Hobart and BNSF-San Bernardino demonstration sites. The EVSE installed at Daylight Transport was the BYD 100 kW EVSE. A discussion of the technical basis behind this difference in EVSE between the BNSF and Daylight demonstration sites is also included in Section 2.2.3.

Figure 2-1: 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%



1.2.2.2 BYD 100 kW AC Charger – The 100 kW BYD EVSE system is similar in design to the 200 kW EVSE in that it is a 480 volt three-phase AC charger; however, it is rated at a maximum power output of 100 kW and, as shown in the accompanying photographs, is equipped with a single charging cable as opposed to the dual charging cable configuration for the 200 kW EVSE system.

Figure 2-2: Technical Specifications of the BYD 100 kW EVSE System

DESIGN PARAMETER	100 kW SYSTEM
Charging Mode	AC
Input Voltage	480V 3-phase
Operating Voltage Range	432V-528V 3-phase
Input Current	120A
Circuit Breaker Rating	200A
Input Power	100kW
Frequency	60Hz
Output Current	120A
Output Power	100kW
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)	1
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	-22to +122 deg F
Surrounding Humidity	5-95%



1.2.3 EVSE Installations per Demonstration Site & Electric Vehicle Compatibility

A total of twenty three (23) BYD EVSE charging units were installed under this demonstration Project. Ten (10) BYD 200 kW chargers were installed at BNSF-Hobart, ten (10) BYD 200 kW chargers at BNSF-San Bernardino, and three (3) BYD 100 kW chargers at Daylight Transport.

Figure 2-3: BYD EVSE Charger Installations per Demonstration Site

	200 kW	100 kW
BNSF - Hobart	10	-
BNSF - San Bernardino	10	-
Daylight Transport	-	3

The Model 8Y electric yard tractors are designed to accommodate the higher power output associated with the 200 kW charger and are equipped with two charging ports to accept both charging cable couplers. The BYD Model 5F service truck, however, is designed to accept a

maximum charging rate of 100 kW; thus, it is equipped with one charging port to accept one EVSE charging coupler.

It is fully acceptable, however, to recharge a BYD 8Y electric yard tractor using a 100 kW EVSE charger. In this case, the one charging cable coupler is connected to one of the two available vehicle charging ports. The charging rate will be corresponding lower, thus increase the charging duration for a given vehicle state of charge as compared to using both connectors at 200 kW. This is the charging procedure that was used at Daylight Transport throughout the demonstration – only 100 kW chargers are installed at Daylight Transport.

Similarly, it is acceptable to use the BYD 200 kW EVSE to recharge the 5F service truck – in this case only one of the two available EVSE charging cable couplers is connected to the sole charging port on the 5F service truck. This is the charging procedure used at BNSF-Hobart and BNSF-San Bernardino to recharge the electric service trucks.

1.2.4 EVSE Technical Issues Encountered & Resolved

During the EVSE design and site construction, technical issues were encountered that required additional effort to fully resolve. It is important to note that most – if not all – larger scale EVSE installations encounter unforeseen technical issues. The intent of this report is not to recount each and every minor technical difficulty that was encountered and successfully resolved in the course of normal engineering and construction activity. However, a few specific technical issues encountered are noteworthy because they did impact Project schedule. One additional technical consideration, described below in Section 2.2.4.1, is addressed herein because it is uncommon for most commercial EVSE installations, but could present an issue on other future projects funded using CARB resources.

1.2.4.1 Requirement for EVSE Environmental Protection at BNSF Facilities - According to technical literature provided by BYD, the 100 kW and 200 kW EVSE systems are weatherized and can safely be used in all weather conditions without risk of shock or undue damage to the EVSE equipment. The instruction manuals recommend installers avoid areas of high humidity that could result in condensation as well as low lying areas that could result in direct water immersion.

At the time of design, construction, and installation of the BYD EVSE at the BNSF-Hobart and BNSF-San Bernardino facilities, the BYD EVSE did not carry an Underwriters Laboratory (UL) listing or any other independent certification from a Nationally Recognized Testing Laboratory. To provide the highest level of protection and safety for their service providers, BNSF specified that each BYD EVSE charging unit be shielded from the elements by installing an environmental cover over each unit. This would also help preserve the EVSE, potentially extending its useful life.

BYD took responsibility for the design and fabrication of the EVSE environmental covers. The design process commenced in the second quarter of 2017. A recommended design, including fabrication of a prototype environmental cover, was completed within approximately two months. During this time, BYD was in regular consultation with BNSF to ensure the environmental cover design met their needs and expectations. The final design was completed in the fourth quarter of 2017, with fabrication of the environmental covers completed within the first quarter of 2018.

Figures 2-4 and 2-5, below, shows a photograph of an environmental cover ready for installation at the BNSF-Hobart Yard and a cover installed over a 200 kW charger, respectively. Both Hobart and San Bernardino BNSF facilities received the protective EVSE enclosures.

Figure 2-4: EVSE Environmental Cover Manufactured by BYD for BNSF EVSE Installations at



BNSF-Hobart & BNSF-San Bernardino

Figure 2-5: EVSE Environmental Cover Installed over BYD 200 kW EVSE at BNSF-Hobart



Daylight Transport did not opt in for having the environmental covers installed at their facility in Fontana, CA. The rationale for not having environmental covers at Daylight Transport was the lower rated power output of the EVSE – 100 kW as opposed to 200 kW. For the 100 kW chargers, Daylight was comfortable with the design, technical documentation provided, and results from real-world demonstrations of the safety of the 100 kW BYD EVSE.

1.2.4.2: BNSF-San Bernardino – Noncompliant Electrical Vault: SCE identified and notified BNSF of a noncompliant SCE electrical vault, which serves a portion of the BNSF-San Bernardino facility. Delays in SCE bringing the noncompliant vault into compliance delayed the electrical design process. Notification of the noncompliant electrical vault was provided by SCE to BNSF on December 8, 2016. However, no substantive design progress was made until the electrical vault was remedied and inspected – this occurred on March 3, 2017. In addition there were other circumstances such as heavy rain which lead to flooding as well as massive wild fires in Northern California which deployed SCE staff away from the area. This resulted in an estimated nine (9) months of delay in the EVSE design at BNSF-San Bernardino.

1.2.4.3: BNSF-San Bernardino – Hidden Underground Condition – In the third quarter on 2017, BNSF reported that due to the discovery of underground conduits at the San Bernardino facility,

the SCE electrical vault needed to be relocated approximately six (6) feet to the east of the designated location. This placed the electrical vault beyond the boundary of the originally-approved easement by approximately 28 inches.

Through a collaborative effort involving the affected parties – SCE, BNSF, Spectrum/Charter Communications, and Jones Lang LaSalle, the commercial real estate company, it was agreed to accept the original easement “as is” and note the encroachment in the file.

1.2.4.4: BNSF-Hobart – Damaged EVSE Units – Also in the third quarter of 2017, BNSF took delivery of ten (10) BYD EVSE units at the Hobart Rail Yard. Upon delivery inspection, it appeared three (3) of the EVSE units had either been previously installed or had sustained damage prior to delivery.

BYD clarified that the three (3) units had been previously installed and used for testing electric vehicles at their Lancaster, California manufacturing facility. BYD sent an engineer to BNSF-Hobart and confirmed the charging units were fully functional; however, BYD agreed that the physical appearance of the three (3) EVSE units was at some point compromised.

BYD offered to replace the three (3) EVSE charger units in question with three (3) new units at BYD’s sole expense. BNSF accepted BYD’s offer to swap out the EVSE units in question and new units were received in January 2018.

1.2.5 EVSE Programmatic Issues Encountered & Resolved

The technical issues discussed above were, for the most part, resolved through a process of issue identification and evaluation, redesign, and implementation of necessary corrective actions. The programmatic issues encountered also required cooperation among the Project partners and SCE to resolve and to the extent feasible mitigate schedule impacts.

As with the technical issues, not every programmatic or administrative hiccup is reported herein – the focus is on those programmatic issues that had the potential to significantly impact the Project implementation schedule and those where “lessons learned” can be drawn that could potentially influence the design of a future advanced technology electric vehicle demonstration projects.

1.2.5.1 SCE Rate Structure Analysis for BNSF Facilities – In conducting an analysis of available electricity rate structures and the projected costs for participating in the electric vehicle demonstration, BNSF concluded that under the electric utility rate structure initially offered by SCE, the cost of electricity to power the electric yard tractors and service trucks would exceed the fuel cost associated with conventional diesel yard tractors.

The initial rate structure offered by SCE was the EV-4 rate at approximately \$0.48 per kilowatt-hour (kWh). A primary factor in the electricity rate structure was the potential to accrue high demand charges should the heavy-duty electric yard tractors require recharging during the peak electricity usage periods. “Demand charges” are additional fees that utilities charge for maintaining a constant supply of and maximum-anticipated demand for electricity. In the case of BNSF, the proposed EV-4 rate would have resulted in an electricity fuel cost that was approximately three (3) times greater when compared to what BNSF currently pays to fuel an equal number of diesel yard tractors.

This issue was elevated within SCE by BNSF Project management, and both parties engaged in a process to identify rate options, scenarios, and provisions to achieve a more reasonable rate structure for charging the electric yard tractors and service trucks at both the BNSF-Hobart and BNSF-San Bernardino locations.

The solution agreed to by SCE and BNSF was to use the CPUC-approved EV-6 rate structure that would present a more favorable financial scenario for BNSF. It should be noted, however, that even at EV-6 rates the cost to power the electric vehicles is greater than the cost incurred to fuel a diesel yard tractor but was deemed by BNSF to be adequate to move forward with the demonstration Project. BNSF will continue to collaborate with SCE to develop the most appropriate and cost-effective rate solutions feasible.

1.2.5.2 Lead Time Required for Energizing EVSE at BNSF Facilities - The most significant issues encountered during the design, site preparation, and installation of the EVSE were delays in obtaining electric equipment and delays in execution of tasks on the EVSE critical path.

Site plan documentation was developed and submitted to SCE beginning in mid-2016. The final EVSE at BNSF-San Bernardino was energized in January 2018, an EVSE implementation period of approximately 18 months.

It is important to note that an 18 month period to design and install EVSE to support multiple heavy-duty electric vehicles deployed at multiple locations is considered fairly typical and certainly falls in line with other heavy-duty electric vehicle technology demonstration projects funded by state and local regulatory agencies. The original timeline associated with EVSE installation was, in hindsight, somewhat optimistic, and a key “lesson learned” is to build sufficient slack time into the critical path to account for unforeseen challenges and probable delays.

That being said, there were specific factors that had a disproportionate impact on the overall EVSE implementation timeline. These include the following:

- Unavailability of Essential SCE Personnel – As a result of wildfires that occurred within SCE territory, SCE assigned all available personnel to assist in restoring fire-damaged infrastructure. This prioritization of engineering resources to fire-impacted areas contributed to the delay in addressing non-compliant electrical vaults, completing the EVSE design and ultimately delayed site construction.
- Additional Delays in Energizing EVSE at BNSF-San Bernardino – BNSF encountered an ongoing issue in establishing power at the San Bernardino site. This delay was likely exacerbated due to SCE staff reassignments noted above. In an effort to better understand SCE’s situation and improve communication, BNSF and SCE had weekly conference calls, which both parties agreed were beneficial.

Figure 2-6: Completed EVSE Installation at BNSF-Hobart



1.3 BYD Battery Electric Vehicles

BYD Motors, Inc. was the technology provider for the heavy-duty battery electric vehicles whose demonstration and evaluation in rigorous rail yard and logistics facility duty cycles was the primary focus of this Project. The electric vehicles demonstrated include the Model 8Y Class 8 electric yard tractor and the Model 5F Class 5 battery electric service truck.

The Project scope included an initial deployment of a limited number of “Phase 1” vehicle designs at each of the three demonstration sites. During this initial deployment, the vehicle configuration and performance would be scrutinized by the vehicle operators. The objective was to compile a list of potential Phase 1 vehicle design modifications that BYD would consider prior to manufacturing vehicles to be deployed in a second demonstration phase. The “Phase 2” electric vehicles, including both the 8Y electric yard tractor and 5F service truck, would thus incorporate “lessons learned” from the first demonstration phase. Notably, the Project scope included the retrofit of the original Phase 1 vehicles to incorporate as many Phase 2 design features as deemed feasible from an engineering and cost standpoint. The intent was to continue the demonstration using both the new Phase 2 vehicles and the Phase 1 vehicles that had been retrofit to near-Phase 2 capabilities.

As discussed in the following Sections, engineering design limitations, driver acceptance issues, and programmatic constraints encountered during Phase 1 necessitated a modification in the way the second demonstration phase was conducted.

That does not diminish, however, the accomplishments achieved by BYD, who with support from BNSF and Daylight Transport was successful in accomplishing an improved vehicle design that will have far greater acceptance in the commercial marketplace. The design evolution and performance improvement of the BYD products is a notable success attributable to this demonstration Project. As such, the following Sections will describe in detail the various BYD electric vehicle models and configurations demonstrated in this Project, and design modifications made to the vehicles as a result of operator feedback that significantly improved vehicle operability and driver ergonomics.


1.3.1 BYD Model 8Y Off-Road Electric Yard Tractor – Phase 1 Design

As discussed above, the Model 8Y Phase 1 electric yard tractor was intended to serve as the initial design benchmark. During the Phase 1 demonstration, which was expected to last on the order of nine (9) months, the Model 8Y would be continuously evaluated relative to its performance, operability, and reliability. Vehicle features and capabilities that could be improved were to be documented for inclusion in a Phase 2 vehicle redesign and potentially incorporated into the Phase 1 vehicles through a retrofit process.

Figure 2-7 provides the technical specifications of the Phase 1 BYD Model 8Y electric yard tractor:

Figure 2-7: Phase 1 BYD Model 8Y Electric Yard Tractor Specifications

SPECIFICATIONS	PHASE 1 BYD 8Y
Length	20.13 ft.
Width	98.43 in
Height	148.15 in.
Curb Weight	22,000 lbs.
GCWR	102,000 lbs.
Wheelbase	141.73 in.
Top Speed	56 mph
Gradeability	≥24%
Operating Range	68 miles or 8 hrs.
Tires	11R20
Front/Rear Suspension	Leaf Spring
Brake System	F/R Drum Brakes
Max. Power	245 hp (180 kW)
Max. Torque	1,106 lb-ft (1,500 N-m)
Battery Capacity	175 kWh

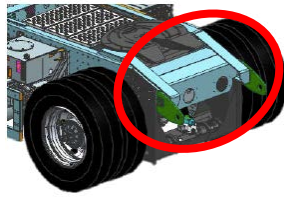


Notably, the process of incorporating Project partner recommendations into the 8Y design began prior to the manufacture of the Phase 1 electric yard tractors.

BYD coordinated a site visit to their Lancaster, California manufacturing facility to provide the Project team the opportunity to inspect a prototype electric yard tractor and provide initial feedback regarding its configuration.

This initial feedback resulted in a recommendation to modify the prototype design by modifying the vehicle behind the fifth wheel (beavertail) to lower the height by approximately 15 to 20 inches.

Figure 2-8: Model 8Y Beavertail Modification – Red Highlighted Area



To gain additional familiarity with the 8Y electric yard tractor and introduce their service provider operators to the electric technology, both BNSF and Daylight Transport conducted one-day tests of the prototype vehicle. BNSF conducted testing at their San Bernardino rail yard, and Daylight Transport at their Los Angeles Service Center. Both BNSF and Daylight Transport reported a successful one-day demonstration and each noted that overall performance of the prototype vehicle was very good.

1.3.2 BYD Model 5F Class 5 On-Road Service Truck

The electric 5F Class 5 service truck was intended to support facility operations that required an on-road licensed truck. The specifications of this vehicle are shown below:

Figure 2-9: BYD 5F Class 5 Service Truck Technical Specifications

SPECIFICATIONS	BYD 5F SERVICE TRUCK
Length	236.0 in
Width	80.5 in
Height	89.8 in
Wheelbase	132.3 in
Curb Weight	8,548 lbs.
GCWR	19,500 lbs.
Top Speed	62 mph
Max Gradeability	30%
Range	150 miles
Wheel Rim	17.5x6.75
Tires	217 / 75R17.5
Suspension	Front/Rear: Leaf Spring
Brakes	Front/Rear: Air Disc Brakes
Max Power	201 hp
Max Torque	406 lb-ft.
Battery Capacity	145 kWh



As shown above, this is a Class 5 vehicle with a gross vehicle weight rating (GVWR) of 19,500 pounds. The usable payload capacity is slightly less than 11,000 pounds at 10,952 pounds.

DEMONSTRATION PROJECT IMPLEMENTATION – DEPLOYMENT PHASE

Both the Phase 1 BYD Model 8Y electric yard tractor and Model 5F Class 5 service truck were deployed at all three (3) demonstration sites. Three (3) Phase 1 electric yard tractors and one (1) Phase 1 electric service truck were delivered to each site, as shown below:

Table 3-1: Phase 1 Vehicle Delivery & Deployment Dates

DEMONSTRATION SITE LOCATION	8Y YARD TRACTOR QUANTITY	5F SERVICE TRUCK QUANTITY	DATE ALL VEHICLES DELIVERED	APPROXIMATE DATE PHASE 1 OPERATIONS COMMENCED
BNSF-HOBART	3	1	31-Mar-17	30-Oct-17
BNSF-SAN BERNARDINO	3	1	31-Mar-17	10-Jan-18
DAYLIGHT TRANSPORT	3	1	8-Mar-17	20-Mar-17

Table 3-1 also shows the approximate date the Phase 1 demonstration period began at each demonstration site. At Daylight Transport, Phase 1 vehicle operations began on March 20, 2017. As previously noted, the Daylight Transport facility in Fontana, California is new and the BYD electric vehicles were actually delivered prior to the opening date of this new facility.

At the BNSF demonstration sites, the start of Phase 1 electric vehicle demonstration began when the EVSE installations were complete and the EVSE was energized by SCE. At the BNSF-Hobart Rail Yard, a Phase 1 “soft launch” began on or about October 30, 2017.

At BNSF-San Bernardino, the start of Phase 1 demonstration was further delayed until the EVSE was energized – this took place during January 8 – 9, 2018.

1.4 Phase 1 BYD Model 8Y Demonstration & Evaluation Process

As discussed above, a primary objective of the Phase 1 demonstration was to operate the BYD electric yard tractors and service trucks in rigorous rail yard and logistics facility operations and gather analytic data and driver feedback pertaining to potential design improvements that would be incorporated into new “Phase 2” vehicle designs. To the extent feasible, the recommended Phase 2 vehicle modifications would be retrofit into the existing Phase 1 electric yard tractors and Phase 1 electric service trucks.

However, during the Phase 1 demonstration, two vehicle modifications were performed to the Phase 1 Model 8Y electric yard tractors that were deemed essential and could not wait to be performed during the Phase 2 retrofit. These include the following:

- In the third quarter of 2017 and prior to the start of actual vehicle demonstration, BNSF coordinated with BYD to address an identified concern with the 8Y electric yard tractor beavertail extensions. As discussed in the preceding Section, BYD had modified the Phase 1 electric yard tractor beavertail based on evaluation of the initial prototype design. BNSF, however, identified that the beavertail extension prongs could potentially pose an issue with vehicle operators hitting a trailer's front support legs during the trailer⁵ coupling process. This issue was unique to the Phase 1 8Y yard tractors deployed at BNSF-Hobart and BNSF-San Bernardino and did not impact the three electric yard tractors deployed at Daylight transport. To remedy this issue, BYD transported the six Phase 1 yard tractors to their Lancaster manufacturing facility and performed the retrofit modifications. Upon completion, the vehicles were returned to the BNSF facilities.
- In the second quarter of 2018, all nine (9) Phase 1 8Y yard tractors were returned to the BYD Lancaster facility to correct a BYD-identified design deficiency in the vehicle axle. An internal bearing was showing excess wear on the BYD 8Y during internal accelerated testing. To remedy the issue, BYD replaced the bearing and its housing, and cleaned the housing to remove any residual debris. This was successfully completed and the electric yard tractors were returned to service at their respective demonstration locations.

1.5 Model 8Y Electric Yard Tractor – Transition to Phase 2 Design

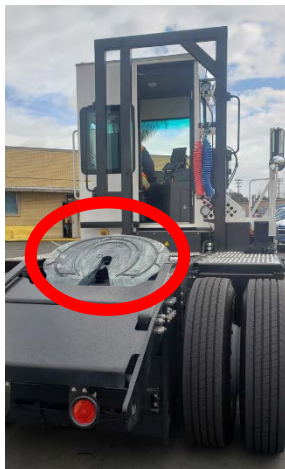
In the second quarter of 2018, BYD convened a meeting with BNSF and its service providers to review the Phase 1 yard tractor operating experience to date and solicit feedback for modifications that could be incorporated into a Phase 2 design. This meeting kicked off the Phase 2 vehicle design process.

BNSF and its service providers from Hobart and San Bernardino provided BYD with specific recommendations that could significantly improve the performance, operability, and driver ergonomics.

⁵ The specialized trailer used to move shipping containers is also known as a "chassis".

The most significant modification recommended by BNSF and its service providers was to redesign the 8Y yard tractor to allow the “fifth wheel” to operate independently of the vehicle drive system and allow it to be quickly raised or lowered while the yard tractor was in motion. The fifth-wheel coupling is the platform that provides the connective linkage between the yard tractor and the trailer or chassis the yard tractor is towing. Figure 3-1, below, illustrates the BYD fifth wheel identified within the red circle:

Figure 3-1: BYD Model 8Y Fifth Wheel Location



According to the BNSF, the original Phase 1 fifth wheel design imposed severe limitations on the utility and operability of the electric yard tractor, resulting in lower than desired utilization by the service provider operators. Thus, modifying the fifth wheel to allow independent operation was of critical importance to the success of the overall demonstration at BNSF-Hobart and BNSF-San Bernardino.

The independently operated fifth wheel was of much less concern to Daylight Transport. The typical container movement duty cycle at Daylight allowed for the yard tractor to be at a complete stop prior to raising or lowering the fifth wheel. At BNSF, however, the high number of shipping container movements was not conducive to having to fully raise the container by actuating the fifth wheel prior to the start of a yard tractor moving. Also, the yard tractor drivers at both Hobart and San Bernardino expressed safety concerns about not being able to lower a load during transit if it appeared that load might be shifting inside the container. Thus, the lack of independent operation of the fifth wheel in the Phase 1 Model 8Y yard tractor design was viewed as a limiting factor in productivity as well as posing a potential safety concern.

The need for an independently operated fifth wheel was one of several Phase 2 design modifications recommended and implemented on the Phase 2 Model 8Y electric yard tractor. All Phase 2 design changes made to the Model 8Y are discussed below in Section 3.3.

1.6 Model 8Y Phase 2 Design Modifications

In comparing the Phase 1 Model 8Y electric yard tractor to the Phase 2 design, the following design modifications were incorporated. These are shown below in Table 3-2.

As noted in the Table, the majority of design modifications were related to ergonomics and the desire to improve driver visibility. These design change recommendations were the direct result of feedback provided by the BNSF service providers.

Daylight Transport did not participate in the Phase 2 electric yard tractor evolution discussions as the original Project scope did not have Phase 2 electric yard tractors deployed at Daylight Transport. As discussed below in Section 3.6, Daylight Transport ultimately did receive one (1) Phase 2 yard tractor under this Project.

Table 3-2: BYD Model 8Y Phase 2 Modifications

No.	Phase 2 Model 8Y Design Modification	Primary Reason for Modification
1	4 way adjustable steering wheel	Better adjustability
2	Removal of radio from cab	Not allowed to use
3	Increase the height of the cab entrance to 5'10"	Cab entrance was too short for average driver to enter without ducking/risking contact
4	On demand 5th wheel operation with separate motor for 5th wheel operation	Productivity gains from one traction motor and one PTO motor
5	Roll-down window instead of a slide-back, power window option	Slide-back window was preventing drivers from observing any obstructions behind them.
6	Shortening of bobtail (rear overhang) with optimized drive axle layout	A shorter bobtail will help connection with more types of chassis
7	Power battery and controller layout revision	Re-arrange power batteries to the center of the frame to increase safety during side impact and allow easier access
8	Wider and deeper steps on both sides	Easier access from both sides with larger shoes
9	Larger battery capacity	Improvements in battery technology account for ~5% increase in energy capacity
10	Cab interior redesign	Stronger dashboard and instrument panel components accounts for increased durability and better modification flexibility
11	Lower Driver's chair back	Decrease backrest height to allow drivers to turn head and observe the rear side easier
12	Improved and Repositioned of 5th wheel lever	Larger and more ergonomic 5 th wheel operating lever to improve comfort and productivity
13	Redesigned pedal area	Drivers need more space to move their feet below the steering column
14	Pneumatic rear door	Reduced stress for operating the rear door during operation
15	Dual Cab fan	Driver comfort with AC deletion
16	Increased air compressor	Higher CFM to reduce delay when connecting to the trailer
17	Standardized battery pack	Better insulation to the environment, easier access and lower service cost
18	Shorter exterior mirror bracket	Better adjustability and narrower overall width

The technical specifications of the Phase 2 model 8Y electric yard tractor are shown below in Figure 3-2.

Figure 3-2: Technical Specifications - Phase 2 BYD Model 8Y Electric Yard Tractor

SPECIFICATIONS	PHASE 2 BYD 8Y
Length	203.7 in
Width	101.6 in
Height	141.7 in
Wheelbase	118.1 in
Curb Weight	19,800 lbs.
GCWR	102,000 lbs.
Top Speed	32 mph
Max Gradeability	15%
Range	10+ hours
Wheel Rim	22.5x8.25
Tires	11R22.5 16PR
Suspension	Front: Leaf Spring Rear: Solid
Brakes	Front/Rear: Air Drum
Max Power	241 hp
Max Torque	1,106 lb-ft
Battery Capacity	217 kWh

1.7 Phase 1 Model 8Y Yard Tractor Retrofit Feasibility Assessment

BYD, in coordination with BNSF and SBCOG, conducted a feasibility assessment to determine which Phase 2 yard tractor design improvements could be retrofit into the Phase 1 electric yard tractors. As previously noted, BNSF stressed the importance of incorporating the independently operated fifth wheel modification into the existing Phase 1 yard tractors.

BYD conducted an internal engineering evaluation of the Phase 1 electric yard tractor to design a retrofit solution to allow the fifth wheel to be operated independently of the drive motor system.

The result of the Phase 1 yard tractor engineering evaluation was that inclusion of the independent fifth wheel would require a substantial engineering effort and amount to the remanufacturing of the Phase 1 yard tractors. The costs associated with the additional engineering and manufacturing was deemed to prohibitive – it was more cost-effective to purchase a new, Phase 2 Model 8Y electric yard tractor than attempt to retrofit the existing Phase 1 units to accommodate the independently operated fifth wheel.

As the independently operated fifth wheel was by far the most critical upgrade to the Phase 1 tractors, and that this upgrade was determined to be impractical from an engineering and cost standpoint, the decision was made to forgo upgrading the Phase 1 Model 8Y yard tractors with any Phase 2 improvements. As will be discussed in the Section 4, the Phase 1 electric yard tractors at BNSF were relegated to infrequent use, especially following deployment of the Phase 2 yard tractors.

1.8 Model 5F Service Truck – Transition to Phase 2 Design

With respect to the Model 5F Class 5 service truck, the evaluation conducted by BYD in coordination with Daylight Transport and BNSF resulted in a recommendation to perform no Phase 2 upgrades. As discussed below, the electric service trucks did not receive a high level of use during this demonstration Project, resulting in a modification to the original scope to adjust the deployment locations as well as deploy fewer total electric service trucks.

1.9 Phase 2 Deployment

The original Project scope included a deployment of nine (9) Phase 1 electric yard tractors and three (3) electric service trucks as shown in the following Table.

Table 3-3: Phase 1 Vehicle Deployments

	PHASE 1 8Y YARD TRACTORS	PHASE 1 5F SERVICE TRUCKS
BNSF-HOBART	3	1
BNSF-SAN BERNARDINO	3	1
DAYLIGHT TRANSPORT	3	1

For the second demonstration phase, the Project scope included the deployment of fourteen (14) Phase 2 Model 8Y electric yard tractors, with seven (7) deployed at BNSF-Hobart and seven (7) at BNSF-San Bernardino. One (1) Phase 2 5F electric service truck was also planned to be deployed at BNSF-San Bernardino; however, as noted above, the decision had been made to not pursue development of a Phase 2 service truck design.

Table 3-4 illustrates the Phase 2 vehicle deployment plan per the original Project scope:

Table 3-4: Phase 2 Vehicle Deployments – Original Scope

	PHASE 1 8Y YARD TRACTORS	PHASE 2 8Y YARD TRACTORS	PHASE 1 5F SERVICE TRUCKS	PHASE 2 5F SERVICE TRUCKS
BNSF-HOBART	3	7	1	-
BNSF-SAN BERNARDINO	3	7	1	1
DAYLIGHT TRANSPORT	3	-	1	-

As shown above, the original Project scope did not include deployment of Phase 2 8Y electric yard tractors at Daylight Transport.

Deliveries of the Phase 2 electric yard tractors began in March 2019. One (1) Phase 2 yard tractor was delivered to BNSF-Hobart on March 21, 2019, and one (1) electric yard tractor to BNSF-San Bernardino on March 22, 2019.

At the time of delivery, BYD solicited feedback from BNSF and its service providers. Based on the initial vehicle inspections, BNSF and its service providers requested that the Phase 2 vehicles be modified to relocate a grab handle to a more ergonomic placement and to reduce a gap by the fifth wheel step. BYD made the modifications to these first two Phase 2 vehicles as well as modifying the Phase 2 design for the remaining twelve units prior to delivery.

All Phase 2 8Y electric yard tractors were manufactured and delivered to BNSF in phases beginning in early March 2019 and ended June 30, 2019.

One issue was encountered with the Phase 2 8Y design early in the Phase 2 deployment. The design of the crash bar on the Phase 2 electric yard tractors did not accommodate the amount of vibration the vehicles were subjected to at the BNSF railyards. The crash bar is the structure that protects the cab of the vehicle. The crash bars developed cracking at the base that necessitated a redesign. The redesign significantly shortened the height of the crash bar, but still offered protection to the vehicle cab in the event of a kingpin detaching from the yard tractor fifth wheel. The decreased height resulted in reduced stress at the base of the crash bar and eliminated any fissures. All fourteen (14) Phase 2 yard tractors were retrofitted with the new crash bar design – this modification was completed in September 2019.

Table 3-4 illustrates the BYD vehicle deployments per the original Project scope. During the demonstration phases, however, adjustments were made to the numbers and locations of electric yard tractor and service truck deployments. The following changes took place that altered how vehicles were deployed at the demonstration sites:

1. *Determination of “Pre-Phase 1” Configuration for Model 8Y Yard Tractors Deployed at Daylight Transport* – During the Phase 1 demonstration, reliability issues with the Phase 1 electric yard tractors deployed at Daylight Transport were experienced that did not occur on the Phase 1 yard tractors deployed at the BNSF sites. Upon further examination, it was determined that the Phase 1 yard tractors at Daylight Transport did in fact have a different electric drivetrain configuration as compared to the Phase 1 Model 8Y yard tractors deployed at BNSF. The Daylight Transport Phase 1 yard tractors were manufactured prior to the BNSF units, and did not incorporate the final Phase 1 design changes that were incorporated into subsequent vehicles. Due to ongoing reliability issues and resulting downtime experienced with the Daylight Transport yard trucks, these “pre-phase 1” vehicles were retired from the demonstration Project and returned to BYD in March of 2019.
2. *Repositioning of Phase 1 Model 8Y Electric Yard Tractors from BNSF* – Because the Phase 1 electric yard tractors deployed at BNSF-San Bernardino did not have an independently operated fifth wheel, the utilization at BNSF-San Bernardino was very low. However, the independent fifth wheel was not a mandatory requirement for operations at Daylight Transport. It was decided to relocate the three (3) Phase 1 yard tractors from BNSF-San Bernardino to Daylight Transport, and retire and return to BYD the three (3) pre-phase 1 yard tractors that were originally deployed at Daylight. This relocation of BNSF-San Bernardino Phase 1 yard tractors to Daylight Transport took place in June 2019.
3. *Decision to Forgo Manufacture & Deployment of fourth Service Truck at BNSF–San Bernardino* – As discussed above, the decision was made to not pursue development of a Phase 2 configuration of the 5F Class 5 electric service truck. The total number of service trucks demonstrated under this Project was three (3).

4. *Repositioning of Service Truck from Daylight Transport to BNSF–San Bernardino* – The Class 5 electric service truck had low utilization at Daylight Transport. Since the decision had been made to forgo manufacture of the Phase 2 electric service truck originally intended for deployment at BNSF-San Bernardino, it was decided to relocate the Phase 1 service truck deployed at Daylight Transport to BNSF-San Bernardino. This occurred in early September 2019. Following transfer to BNSF-San Bernardino, the service truck was outfitted with a lift gate. This modification required several weeks to complete due to unspecified delays at the installer facility.
5. *Procurement of One Additional Phase 2 Yard Tractor for Deployment at Daylight Transport* – As a result of the decision to not pursue development of the Phase 2 service truck, it was recommended that the funds intended for the fourth service truck be utilized to procure a Phase 2 Model 8Y electric yard tractor for operation at Daylight Transport.

Table 3-5, below, illustrates the addition of final Phase 2 vehicle deployments:

Table 3-5: Vehicle Deployment by Location

	PHASE 1 8Y YARD TRACTORS	PHASE 2 8Y YARD TRACTORS	PHASE 1 5F SERVICE TRUCKS	PHASE 2 5F SERVICE TRUCKS
BNSF-HOBART	3	7	1	-
BNSF-SAN BERNARDINO*	3	7	2	-
DAYLIGHT TRANSPORT	3	1	-	-

*Three (3) pre-Phase 1 yard tractors were deployed Daylight Transport originally. Three (3) Phase 1 yard tractors were relocated from BNSF-San Bernardino to Daylight Transport, and the three (3) pre-phase 1 yard tractors that were originally deployed at Daylight were retired and returned to BYD.

DEMONSTRATION PROJECT IMPLEMENTATION: IN-SERVICE OPERATIONS, DATA COLLECTION, & DATA ANALYSIS

DISCLAIMER TO THE READER: Please note that the data in this chapter is not final. This data is only a snapshot in time of a specific data gathering period and is not representative of the entire demonstration project; some of the data loggers were not operational for a major part of the demonstration period. This resulted in conflicts between the manually collected data and the electronic logger-collected data; for example, operating times displayed in the various tables vary by up to 50% between manual reports and data logger reports. Another factor was that a significant number of data loggers were installed much later than the beginning of the demonstration period. This data is subject to change in Ricardo PLC's Final Report due out summer of 2020.

The Phase 1 demonstration period commenced at Daylight Transport in March 2017 and was followed by BNSF-Hobart and BNSF-San Bernardino in October 2017 and January 2018, respectively. The Phase 2 demonstration commenced at both BNSF demonstration sites beginning in June of 2019. The Project demonstration phase ended on January 31, 2020.

Data collection and analysis took place during both demonstration phases. Data collection included both telematics data acquisition, which was accomplished using data loggers installed in the BYD Model 8Y yard tractors and 5F service trucks. Additionally, data was collected manually by both Daylight Transport and BNSF, including odometer readings, scheduled and unscheduled maintenance and repairs logs, etc.

Additionally, BNSF vehicles were equipped with Vehicle Monitoring Units (VMU), which recorded detailed data on vehicle shipping container movements. The VMU data was essential when comparing the relative productivity of the electric yard tractors as compared to a baseline diesel yard tractor, measured as the number of container movements accomplished within a specified time period.

The following Sections discuss the in-service operations of the BYD electric vehicles, and summaries of the data collection methods, and importantly, the results obtained through analysis of the collected data. The comprehensive data collection and analysis results will be available in a separate report from CARB, with an anticipated release date of summer 2020.

The daily and total hours and miles in the following tables are from operational logs provided by fleets and data collected by loggers from the vehicle. Data was collected by two different methods (operational logs, and electronic through on-vehicle data loggers) for separate purposes, and were collected over different periods of time. For these reasons, the analysis

results from the two different methods will not match. Ricardo has performed quality checks on the data and excluded any invalid data from the analysis. Vehicle utilization is estimated from operational data provided by fleets and is supposed to be the percentage of calendar days that the vehicles have been operated during the data collection and monitoring period. Downtime due to maintenance and repair is estimated from maintenance logs provided by fleets and OEM and is defined as percentage of calendar days that vehicles have reported to be out of operation and under maintenance and repair.

Tables 4-3, 4-8, and 4-12 summarize some of the major problems that either kept the vehicles out of operation for significant period of time or were a recurring issue or an expensive repair. It should be noted that these tables are meant to be a summary of major issues and not the exhaustive list of maintenance and repair logs provided by the OEM and fleet operators.

1.10 Data Collection Team

Data collection and analysis was the responsibility of Ricardo under a separate contract with CARB. Ricardo enlisted the services of a subcontractor, ZMassociates, to perform installation of the data logger units in each of the demonstration vehicles.

Prior to placing the BYD electric vehicles into service, CARB and Ricardo convened a meeting with all Project partners to discuss the data collection process. This occurred on September 7th, 2017 at the Daylight Transport facility in Fontana. At that meeting, Ricardo discussed their Data Monitoring, Collection, and Analysis Plan. The Plan outlined the data that would be collected and methodologies for performing data analysis. Importantly, this data collection kickoff meeting introduced Ricardo to the Project team, and importantly the demonstration partners BNSF and Daylight Transport, who would be responsible for manually collecting and reporting data related to vehicle operations, maintenance, and repairs.

1.11 Baseline Diesel Yard Tractors

To enable comparison of the performance, reliability, maintainability, and productivity of the BYD 8Y electric yard tractors relative to conventional diesel-fueled yard tractors, a diesel yard tractor was identified at both BNSF-Hobart and Daylight Transport and designated as the baseline vehicle for this Project. To the extent feasible, baseline vehicles should be in-use

vehicles that have the same or similar drive cycles as those of the BYD electric vehicles. It is also recommended that the baseline vehicle be the newest vehicle in the fleet.

It should be noted that baseline vehicles were identified for the yard tractors only. Due to budget limitations, no baseline Class 5 service trucks were included in the Project.

1.11.1 Daylight Transport Baseline Diesel Yard Tractor

Daylight does not operate any diesel yard tractors at their Fontana facility, the demonstration site for this Project. For the purpose of data collection, Daylight Transport designated a diesel yard tractor at their Los Angeles facility to serve as the baseline vehicle. A model year 2015 Kalmar Ottawa T2 diesel yard tractor was selected as the baseline vehicle for this Project. This vehicle is equipped with a Cummins ISB 6.7 liter diesel engine.

1.11.2 BNSF Baseline Diesel Yard Tractor

BNSF designated a model year 2015 AutoCar Xspotter diesel yard tractor as the baseline vehicle for this Project. Similar to the Daylight Transport baseline vehicle, the BNSF baseline vehicle is equipped with a Cummins ISB 6.7 liter diesel engine.

1.12 Telemetric Data Acquisition System (Data logger)

CARB selected the HEM DAWN OBD Mini Logger™ for this Project. The data loggers access the vehicle's controller area network (CAN) bus data through a Society of Automotive Engineers (SAE) J1962 onboard diagnostic (OBD) connector.

The data logger installations were performed by Ricardo and ZMassociates. The data logger plugged into the J1962 ODB port and did not require any external GPS or cellular antennae. Figure 4-1, below, illustrates the HEM data logger used in this Project:

Figure 4-1: HEM DAWN OBD Mini Logger™ Used in this Project



1.13 Manually Collected Data

In addition to the data acquired from the onboard data loggers, the demonstration partners conducted manual data collection and reported this data on a biweekly or monthly basis to Ricardo. The manually collected data includes vehicle daily operation logs, maintenance and repair logs, refueling logs for the baseline, and vehicle and charger specifications.

1.14 BYD Model 8Y Electric Yard Tractor - Comparison to Baseline Diesel Yard Tractor

This Section includes the summary of the results of the data collection and analysis work performed by Ricardo on behalf of CARB. It is important to note that at the time of completion of this Project, Ricardo remained under contract to CARB and was continuing to analyze the data collected. Ricardo will prepare a final report for data collection, monitoring and analysis for CARB for this Project in the summer of 2020. The data provided in this project final report are preliminary summary data.

1.14.1 Drive Cycle Comparisons – Daylight Transport

The electric yard tractor duty cycle imposed by rail work at BNSF-Hobart and BNSF-San Bernardino differed from the duty cycle the electric yard tractors deployed at Daylight Transport were subjected to. The duty cycle at the BNSF demonstration sites was more rigorous, in part due to the longer distances traveled during a container movement, the rougher terrain at the rail yards, and the number of container movements performed during an average shift. For example, the average daily mileage was much greater for the electric yard tractors at the two BNSF facilities than those at Daylight Transport. This *does not* imply that the BYD electric yard tractors at Daylight Transport weren't subjected to strenuous cargo movement operations over multiple work shifts – the duty cycle data confirms that they were. That said, the differences in duty cycle between Daylight Transport and the BNSF facilities does preclude a direct comparison of the data collected at their respective facilities. For example, one cannot compare baseline yard tractor operations at Daylight Transport directly against electric yard tractor operations at BNSF-San Bernardino.

It is for this reason that data is presented based only for the facility at which it was collected, and no direct comparisons are made across demonstration sites. As will be shown, the results and conclusions drawn with respect to performance, reliability, and overall efficiency do differ as a function of demonstration location, a reflection of each facility's unique duty cycle requirements.

Table 4-1, below, shows the duty cycle analysis performed for the BYD Model 8Y electric yard tractors at Daylight Transport. This can be compared to the baseline diesel yard tractor deployed at Daylight Transport, shown in Table 4-2. Note that BYD Tractors 1, 2, and 3 correspond to the original Phase 1 (aka pre-Phase 1) yard tractors deployed; as previously noted these were returned to BYD in March 2019, with BYD 4, 5, and 6 being relocated from BNSF-San Bernardino to Daylight Transport. All electric yard tractors that operated at Daylight are thus included in the data collection and analysis. It should also be reiterated that the baseline diesel yard tractor used for comparative purposes at Daylight did not operate at the Fontana location. The baseline diesel yard tractor operates at the Daylight Transport Los Angeles facility; thus, a degree of uncertainty is introduced when comparing the electric duty cycle versus the diesel duty cycle, as they reflect operations performed at different facilities.

As shown in the tables below the electric yard tractors are fully utilized at Daylight Transport, with average daily use for the most part exceeding that of the baseline vehicle. The electric yard tractors also exhibit performance equal to the diesel yard tractor. Although as noted on the preceding page, the duty cycle at the BNSF demonstration sites was more rigorous, including much higher average daily mileage than experienced by the electric yard tractors at Daylight Transport.

1.14.2 Powertrain Analyses – Daylight Transport

Tables 4-1 and 4-2 presents a summary of the data collected from the onboard data loggers and manual collection for the electric and baseline diesel yard tractors deployed at Daylight Transport Fontana and Daylight Transport Los Angeles, respectively. What is most obvious is the relative energy efficiency of the electric yard tractors as compared to the diesel unit – *the electric yard tractors are greater than five (5) times more efficient.*

DISCLAIMER TO THE READER: Please note that the data in this chapter is not final and is subject to change in Ricardo PLC’s Final Report due out summer of 2020. This data is only a snapshot in time of a specific data gathering period and not representative of the entire demonstration project. In some cases, the data loggers were not working for a big part of the demonstration and/or installed much later than the demonstration period began. It is likely that the operational usage of the electric yard tractors and baseline yard tractors is underreported due to issues that were encountered with the data loggers throughout the project.

Table 4-1: Daylight Fontana - Operation Summary (1/2)

Drive cycle		pre-Phase 1 Yard Truck			Phase 1 Yard Truck		
		Daylight-Fontana BYD-1 (Yard Truck)	Daylight-Fontana BYD-2 (Yard Truck)	Daylight-Fontana BYD-3 (Yard Truck)	Daylight-Fontana BYD-4 (Yard Truck)	Daylight-Fontana BYD-5 (Yard Truck)	Daylight-Fontana BYD-6 (Yard Truck)
Operating Data (Manual Data)	Average daily operating time (hours)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
	Total Operating Time (hours)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
	Average daily distance (miles)	30.0	27.6	19.9	29.6	27.1	23.7
	Total Distance (miles)	4202	4773	1794	5618	1982	1657
Operating Data (Electronic Data)	Average daily operating time (hours)	11.4	10.0	7.2	11.5	7.3	5.7
	Total Operating Time (hours)	2728	1690	1050	769	74	268
	Average daily distance (miles)	24.3	24.3	15.8	26.5	14.9	13.2
	Total Distance (miles)	5797	4096	2280	1772	149	622
Speed	Average speed (mph)	2.1	2.4	2.2	2.3	2.0	2.3
	Max speed (mph)	28.3	29.3	29.1	19.9	19.4	19.5
Performance	Fuel Efficiency (Miles/DGE) (in case of EV add kWh/mile also)	11.5 miles/DGE (3.2 kWh/mile)	11.0 miles/DGE (3.3 kWh/mile)	11.6 miles/DGE (3.2 kWh/mile)	13.2 miles/DGE (2.8 kWh/mile)	11.3 miles/DGE (3.3 kWh/mile)	12.8 miles/DGE (2.9 kWh/mile)
	Estimated Range	52 miles (est.) (based on 80% usable battery capacity)			56 miles (est.) (based on 80% usable battery capacity)		
	Fueling / Charging Frequency	Up to 5 times/day					
Availability	Vehicle Utilization (% of calendar days)	57%	64%	42%	72%	28%	26%
	Downtime due to maintenance & repair (% of calendar days)	21%	6%	25%	0%	15%	0%

Table 4-2: Daylight Fontana - Operation Summary (2/2)

Driving cycle		Daylight Hooper Diesel Yard Truck
Operating Data (Manual Data)	Average daily operating time (hours)	Not Available
	Total Operating Time (hours)	Not Available
	Average daily distance (miles)	18.9
	Total Distance (miles)	7976
Operating Data (Electronic Data)	Average daily operating time (hours)	8.2
	Total Operating Time (hours)	2669
	Average daily distance (miles)	19.2
	Total Miles (miles)	6251
Speed	Average speed (mph)	2.3
	Max speed (mph)	27.3
Performance	Fuel Efficiency (Miles/DGE) (in case of EV add kWh/mile also)	2.1 miles / DGE
	Estimated Range	100 miles (est.)
	Fueling / Charging Frequency	Once every 2-3 days
Availability	Vehicle Utilization (% of calendar days)	67%
	Downtime due to maintenance & repair (% of calendar days)	0%

1.14.3 Vehicle Reliability – Daylight Transport

As shown in Table 4-3, the electric yard tractors did exhibit a higher failure rate as compared to the diesel baseline yard tractor. This is expected when demonstrating a new technology; however, as previously noted, BYD tractors 1, 2, and 3 had sufficiently high downtime that they were retired from service.

Table 4-3: Daylight Fontana - Summary of Major Maintenance Issues

Fleet Location	Vehicle	Major Problems Encountered
Daylight Fontana	Yard Truck BYD-1 (pre-Phase 1)	<ul style="list-style-type: none"> • Battery issue kept the vehicle out for 2 months, after which it was returned to BYD for good. • Battery water leak kept vehicle out of service for five (5) days • Air conditioning unit required replacement, and kept the vehicle out of service for three (3) days • 9 other maintenance events kept the vehicle out of service for additional 10 days
	Yard Truck BYD-2 (pre-Phase 1)	<ul style="list-style-type: none"> • Major battery water leak issue kept vehicle out of service for 12 days in December • Battery water leak kept vehicle out of service for five (5) days • This vehicle was also returned to BYD
	Yard Truck BYD-3 (pre-Phase 1)	<ul style="list-style-type: none"> • Battery related issue caused the vehicle to be out of service for 49 days after which it was returned to the BYD for good • Battery pack issue occurred twice and kept vehicle out of service for 39 days • Logger removed from vehicle mid-November and was not re-installed
	Yard Truck BYD-4 (Phase 1)	<ul style="list-style-type: none"> • No maintenance conducted since vehicle started operations at Daylight facility
	Yard Truck BYD-5 (Phase 1)	<ul style="list-style-type: none"> • Hydraulic oil leaking and needed O-ring replacement • DC-DC convertor needed replacement, keeping the vehicle out of service for 40 days
	Yard Truck BYD-6 (Phase 1)	<ul style="list-style-type: none"> • No maintenance conducted since vehicle started operations at Daylight facility
Daylight Los Angeles	Baseline Diesel #150584	<ul style="list-style-type: none"> • New 5th wheel installed • Most frequent issues were related to Diesel Exhaust Fluid system

1.14.4 Overall Performance Comparison

The overall performance comparison of the BYD Model 8Y electric yard tractors as compared to the diesel baseline is shown below in Table 4-4. Again, the significant data point related to the energy efficiency of the electric drivetrain as compared to a diesel combustion engine is shown in the following table.

Table 4-4: Yard Tractor Performance Comparison - Daylight Transport

	AVERAGE OF ALL ADVANCED TECHNOLOGY VEHICLES		AVERAGE OF BASELINE
	BYD #1-#3	BYD #4-#6	Diesel Yard Truck
Fuel Efficiency (kWh/Mile For Electric Vehicle, Miles/DGE For Baseline)	11.4 Miles/DGE (3.2 kWh/Mile) (Daylight BYD #1-#3)	12.4 Miles/DGE (3.0 kWh/Mile) (Daylight BYD #4-#6)	2.1 Miles Per DGE (Daylight Los Angeles #150584)
Range (Miles)	52 Miles (Est.) (Based On 80% Usable Battery Capacity)	56 Miles (Est.) (Based On 80% Usable Battery Capacity)	100 Miles (Est.)
Refueling Or Recharging Time & Frequency	EV Charging Frequency Varies From Multiple Times A Day To No Charging Needed On Certain Days	EV Charging Frequency Varies From Multiple Times A Day To No Charging Needed On Certain Days	Once Every 2-3 Days
Vehicle Power	180 kW	180 kW	123 kW
Vehicle Downtime Due To Maintenance (%)	17%	0% (BYD #4, 6) 15% (BYD-#5)	0%

1.15 Data Collection Analysis and Results - BNSF-Hobart

A similar analysis of was conducted for the BYD Model 8Y electric yard tractors and diesel baseline unit operated at BNSF-Hobart, the results of which are included in the following Sections.

1.15.1 Drive Cycle Comparisons

BNSF-Hobart: The duty cycle analysis shown in Table 4-5, 4-6 and 4-7 indicate modestly higher utilization of the diesel baseline yard tractor; however, this is most apparent with the Phase 1 electric yard tractors that saw more limited use due to the lack of an independently operated fifth wheel.

1.15.2 Powertrain Analyses – BNSF–Hobart

The difference in efficiency for the electric drivetrain yard tractors as compared to the diesel baseline was even more apparent at BNSF-Hobart. Of particular note is the apparent increase in electric yard tractor efficiency when comparing the BYD Phase 1 tractors (BYD EH-1, 2, and 3) to the Phase 2 electric yard tractors (BYD EH-4 through EH-10).

The baseline diesel yard tractor at BNSF-Hobart exhibited twice the fuel economy as compared to the diesel baseline at Daylight Transport for unknown reasons – both vehicles are equipped with the same model year Cummins 6.7 liter diesel engine. This is most likely attributable to the difference in duty cycle; the differences in duty cycle often prevent the direct comparison of data analysis results between demonstration sites.

DISCLAIMER TO THE READER: Please note that the data in this chapter is not final and is subject to change in Ricardo PLC’s Final Report due out summer of 2020. This data is only a snapshot in time of a specific data gathering period and not representative of the entire demonstration project. In some cases, the data loggers were not working for a big part of the demonstration and/or installed much later than the demonstration period began. It is likely that the operational usage of the electric yard tractors and baseline yard tractors is underreported due to issues that were encountered with the data loggers throughout the project.

Table 4-5: BNSF-Hobart - Operation Summary (1/3)

Drive cycle		Phase 1 Yard Truck			Service Truck
		BNSF-Hobart EH-1 (BYD Yard Truck)	BNSF-Hobart EH-2 (BYD Yard Truck)	BNSF-Hobart EH-3 (BYD Yard Truck)	BNSF-Hobart ED-1 (BYD Service truck)
Operating Data (Manual Data)	Average daily operating time (hours)	9.1	8.0	8.1	Not Available
	Total Operating Time (hours)	2053	2010	1932	211
	Average daily distance (miles)	66.2	47.1	45.4	Not Available
	Total Distance (miles)	12976	11782	10907	814
Operating Data (Electronic Data)	Average daily operating time (hours)	8.1	6.3	7.6	1.1
	Total Operating Time (hours)	1931	1254	1144	117
	Average daily distance (miles)	61.1	43.4	54.1	7.4
	Total Distance (miles)	14597	8984	8170	750
Speed	Average speed (mph)	7.6	7.2	7.1	6.4
	Max speed (mph)	29.2	41.7	29.1	37.7
Performance	Fuel Efficiency (Miles/DGE) (in case of EV add kWh/mile also)	21.2 miles/DGE (1.7 kWh/mile)	20.7 miles/DGE (1.8 kWh/mile)	20.8 miles/DGE (1.8 kWh/mile)	40.3 miles/DGE (0.9 kWh/mile)
	Estimated Range	95 miles (est.) (based on 80% usable battery capacity)			129 miles (est.) (based on 80% usable battery capacity)
	Fueling / Charging Frequency	Up to 7 times/day			Up to 2 times/day
	Vehicle Utilization (% of calendar days)	44%	44%	52%	Not available

Availability	Downtime due to maintenance & repair (% of calendar days)	3%	10%	6%	Not available
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Table 4-6: BNSF-Hobart - Operation Summary (2/3)

Drive cycle		Phase II Yard Truck						
		BNSF-Hobart EH-4 (BYD Yard Truck)	BNSF-Hobart EH-5 (BYD Yard Truck)	BNSF-Hobart EH-6 (BYD Yard Truck)	BNSF-Hobart EH-7 (BYD Yard Truck)	BNSF-Hobart EH-8 (BYD Yard Truck)	BNSF-Hobart EH-9 (BYD Yard Truck)	BNSF-Hobart EH-10 (BYD Yard Truck)
Operating Data (Manual Data)	Average daily operating time (hours)	10.4	9.9	13.0	9.0	11.0	10.6	11.5
	Total Operating Time (hours)	1870	1606	1897	1693	1878	2075	2145
	Average daily distance (miles)	79.8	72.9	100.5	61.2	76.1	83.1	90.2
	Total Distance (miles)	14358	11811	14680	11559	12935	16203	16770
Operating Data (Electronic Data)	Average daily operating time (hours)	10.4	9.0	9.8	8.5	10.1	No data	7.9
	Total Operating Time (hours)	1160	1208	1447	1394	1605		1196
	Average daily distance (miles)	80.5	67.3	76.7	59.7	71.7		84.2
	Total Distance (miles)	9016	9020	11346	9797	11403		12710
Speed	Average speed (mph)	7.8	7.5	7.8	7.0	7.1		7.8
	Max speed (mph)	31.2	29.6	31.9	31.9	32.2		27.1
Performance	Fuel Efficiency (Miles/DGE) (in case of EV add kWh/mile also)	23.9 miles/DGE (1.5 kWh/mile)	21.5 miles/DGE (1.7 kWh/mile)	23.6 miles/DGE (1.6 kWh/mile)	21.6 miles/DGE (1.7 kWh/mile)	23.1 miles/DGE (1.6 kWh/mile)	22.3 miles/DGE (1.6 kWh/mile)	
	Estimated Range	105 miles (est.) (based on 80% usable battery capacity)					105 miles (est.)	
	Fueling / Charging Frequency	Up to 9 times/day					Up to 9 times/day	
Vehicle Utilization (% of calendar days)		62%	65%	59%	79%	70%	82%	77%

Availability	Downtime due to maintenance & repair (% of calendar days)	24%	29%	11%	13%	25%	14%	19%

Table 4-7: BNSF-Hobart - Operation Summary (3/3)

Driving cycle		BNSF-Hobart - Diesel Yard Truck
Operating Data (Manual Data)	Average daily operating time (hours)	12.5
	Total Operating Time (hours)	6317
	Average daily distance (miles)	96.8
	Total Distance (miles)	44824
Operating Data (Electronic Data)	Average daily operating time (hours)	11.5
	Total Operating Time (hours)	4358
	Average daily distance (miles)	91.0
	Total Miles (miles)	34506
Speed	Average speed (mph)	7.9
	Max speed (mph)	34.9
Performance	Fuel Efficiency (Miles/DGE) (in case of EV add kWh/mile also)	4.8 miles/DGE
	Estimated Range	240 miles (est.)
	Fueling / Charging Frequency	Once every 2-3 days
Availability	Vehicle Utilization (% of calendar days)	95%
	Downtime due to maintenance & repair (% of calendar days)	0%

1.15.3 Vehicle Reliability – BNSF-Hobart

Table 4-8 lists technical issues encountered at BNSF-Hobart for the BYD electric yard tractors compared to the baseline unit. Note that the cracked rear cab support was a systemic failure experienced on all Phase 2 BYD Model 8Y tractors. This issue was corrected by redesigning and manufacturing a new assembly. All Phase 2 electric yard tractors were subsequently retrofitted with the new design.

Table 4-8: BNSF-Hobart - Summary of Major Maintenance Issues

Fleet Location	Vehicle	Major Problems Encountered
	BYD Vehicles (Fleet wide)	<ul style="list-style-type: none"> • CARB has communicated that the fleet has been struggling with reliability issues with the Phase 1 trucks. • During the initial deployment period, the Phase 2 vehicles were out of service for a substantial period for rework of the crash bar (behind the cab). This issue had affected all 7 BYD Phase 2 trucks deployed at BNSF-Hobart
BNSF-Hobart	Yard Truck EH-1 (Phase 1)	<ul style="list-style-type: none"> • Leak and misalignment of boom cylinder had to be fixed twice, and kept the vehicle out of service for 6 days • Hydraulic for the support cylinder of the 5th wheel leaking, causing the vehicle to be out of service for 3 days • 19 other repair and service events, causing the vehicle to be out of service for 11 days
	Yard Truck EH-2 (Phase 1)	<ul style="list-style-type: none"> • Transmission issue caused the vehicle to be out of service for 20 days in mid-October 2018 • Coolant not circulating in the vehicle, causing the vehicle to be out of service for 13 days from late May to mid-June 2019 • 21 other repair and service events, causing the vehicle to be out of service for 28 days
	Yard Truck EH-3 (Phase 1)	<ul style="list-style-type: none"> • Drivetrain issue caused the vehicle to be out of service for 11 days in September 2018 • Fifth wheel issue at the end of September 2018, vehicle out of service for 9 days • Left rear air valve was leaking and needed repairs; vehicle out of service for 3 days • 16 other repair and service events, causing the vehicle to be out of service for 15 days
	Yard Truck EH-4 (Phase II)	<ul style="list-style-type: none"> • Fifth wheel issue (fifth wheel won't go up) in early April 2019 (this issue is prior to start of data collection) • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service since end of May 2019 to mid-July 2019 (53 days)
	Yard Truck EH-5 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service since 21 June 2019 and went back into operation on 24 July 2019 (34 days) • Performed repairs in battery clusters with the vehicle unserviceable for 8 days • Repaired valve on leaking air-bags, with vehicle out of service for 8 days • Fifth wheel stuck and won't rise, causing the vehicle to be out of service for 7 days • Fifth wheel hydraulic leak caused the vehicle to be unavailable for 6 days
	Yard Truck EH-6 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service since last week of June 2019 until mid-July 2019 (21 days) • Shifter not working causing transmission issue; the issue was fixed after the shifter was removed, cleaned and reprogrammed. The truck was out of service for 3 days
	Yard Truck EH-7 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service since last week of June 2019 until mid-July 2019 • Hydraulic oil leak caused vehicle to be out of service for 7 days
	Yard Truck EH-8 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service starting first week of June 2019 until end of July 2019 (52 days) • Vehicle had drivetrain electrical problems. Drive system unit was reset, but the vehicle was out of service for 3 days
	Yard Truck EH-9 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service starting first week of July 2019 until end of July 2019

Fleet Location	Vehicle	Major Problems Encountered
	Yard Truck EH-10 (Phase II)	<ul style="list-style-type: none"> Rework of the crash bar (behind the cab), resulting in the being vehicle out of service since last week of June 2019 until end of July 2019 Leaking water pump caused the vehicle to be out of service for 21 days. The water pump was replaced before the vehicle was put to service again
	Diesel Baseline #166248	<ul style="list-style-type: none"> Multiple instances of '300 hours P/M service' which includes cleaning of DPF filters, and minor repairs on the trucks
	Service Truck ED-1	<ul style="list-style-type: none"> No major issue reported

1.15.4 Overall Performance Comparison – BNSF-Hobart

Table 4-9 presents a summary of the performance comparison of the electric and baseline diesel yard tractors deployed at BNSF-Hobart. The most notable comparison is the fuel efficiency – a factor of greater than four (4) between the electric and diesel drivetrains.

Table 4-9: Yard Truck Performance Comparison – BNSF-Hobart

	AVERAGE OF ALL ADVANCED TECHNOLOGY VEHICLES		AVERAGE OF BASELINE
	BYD Phase 1	BYD Phase 2	
Fuel Efficiency (kWh/Mile For Electric Vehicle, Miles/DGE For Baseline)	20.9 Miles/DGE (1.8 kWh/Mile) (BNSF Yard Trucks EH#1-#3)*	22.7 Miles/DGE (1.6 kWh/Mile) (BNSF Yard Trucks EH#4-8, 10)**	4.8 Miles/DGE (BNSF-Hobart #166248)
Range (Miles)	95 Miles (Est.) (Based On 80% Usable Battery Capacity)	105 Miles (Est.) (Based On 80% Usable Battery Capacity)	240 Miles (Est.)
Refueling Or Recharging Time & Frequency	EV Charging Frequency Varies From Multiple Times A Day To No Charging Needed On Certain Days	EV Charging Frequency Varies From Multiple Times A Day To No Charging Needed On Certain Days	Once Every 2-3 Days
Vehicle Power	180 kW	180 kw	123 kW
Vehicle Downtime Due To Maintenance (%)	6.3%	19.3%	0%

Excludes service truck due to the vehicle having a different drive cycle

** No electronic data has been gathered from EH 9

1.16 Data Collection Analysis and Results – BNSF-San Bernardino

A similar analysis of was conducted for the BYD Model 8Y electric yard tractors and diesel baseline unit operated at BNSF-San Bernardino. As shown, the Phase 1 electric yard tractors did not have a high level of utilization; in June 2019 they were relocated to Daylight Transport in Fontana.

1.16.1 Drive Cycle Comparisons – BNSF-San Bernardino

The duty cycle analysis shown in Table 4-10 is for the electric yard tractors operated at BNSF-San Bernardino:

Table 4-10: BNSF-San Bernardino - Operation Summary (1/2)

Drive cycle		Phase I Yard Truck			Phase II Yard Truck	
		BNSF-San Bernardino BYD-1 (Yard Truck)	BNSF-San Bernardino BYD-2 (Yard Truck)	BNSF-San Bernardino BYD-3 (Yard Truck)	BNSF-San Bernardino BYD-4 (Yard Truck)	BNSF-San Bernardino BYD-5 (Yard Truck)
Operating Data (Manual Data)	Average daily operating time (hours)	4.6	6.9	4.9	14.4	10.5
	Total Operating Time (hours)	1047	1198	742	209	2401
	Average daily distance (miles)	69.7	45.9	30.4	108.5	80.6
	Total Distance (miles)	1790	1780	2574	16345	17335
Operating Data (Electronic Data)	Average daily operating time (hours)	7.2	8.8	6.9	11.4	No data
	Total Operating Time (hours)	1291	1720	1404	1045	
	Average daily distance (miles)	46.6	56.8	43.5	83.5	
	Total Distance (miles)	8387	11077	8833	7677	
Speed	Average speed (mph)	6.5	6.4	6.3	7.3	
	Max speed (mph)	40.4	22.5	39.8	32.9	
Performance	Fuel Efficiency (Miles/DGE) (in case of EV add kWh/mile also)	21.3 miles/DGE (1.7 kWh/mile)	20.0 miles/DGE (1.8 kWh/mile)	19.4 miles/DGE (1.9 kWh/mile)	21.5 miles/DGE (1.7 kWh/mile)	
	Estimated Range	93 miles (est.) (based on 80% usable battery capacity)			92 miles (est.) (based on 80% usable battery capacity)	
	Fueling / Charging Frequency	Up to 6 times/day			Up to 9 times/day	
Availability	Vehicle Utilization (% of calendar days)	55%	47%	56%	65%	
	Downtime due to maintenance & repair (% of calendar days)	3%	6%	7%	17%	

Table 4-11: BNSF-San Bernardino - Operation Summary (2/2)

Drive cycle		Phase II Yard Truck					Service Truck
		BNSF-San Bernardino BYD-6 (Yard Truck)	BNSF-San Bernardino BYD-7 (Yard Truck)	BNSF-San Bernardino BYD-8 (Yard Truck)	BNSF-San Bernardino BYD-9 (Yard Truck)	BNSF-San Bernardino BYD-10 (Yard Truck)	BNSF-San Bernardino BYD Service Truck
Operating Data (Manual Data)	Average daily operating time (hours)	11.6	11.7	13.8	8.5	17.4	No data
	Total Operating Time (hours)	2048	1995	2169	1390	2416	
	Average daily distance (miles)	81.8	82.2	96.8	55.4	122.6	
	Total Distance (miles)	14886	14390	15219	9424	17524	
Operating Data (Electronic Data)	Average daily operating time (hours)	11.1	9.1	12.7	7.6	11.4	
	Total Operating Time (hours)	2026	552	1823	1339	2422	
	Average daily distance (miles)	82.4	67.4	92.8	53.0	84.4	
	Total Distance (miles)	15000	4109	13362	9319	17933	
Speed	Average speed (mph)	7.4	7.4	7.3	7.0	7.4	
	Max speed (mph)	34.1	32.9	34.4	33.3	35.5	
Performance	Fuel Efficiency (Miles/DGE) (in case of EV add kWh/mile also)	19.2 miles/DGE (1.9 kWh/mile)	20.1 miles/DGE (1.8 kWh/mile)	18.5 miles/DGE (2.0 kWh/mile)	19.8 miles/DGE (1.9 kWh/mile)	20.1 miles/DGE (1.8 kWh/mile)	
	Estimated Range	92 miles (est.) (based on 80% usable battery capacity)					
	Fueling / Charging Frequency	Up to 9 times/day					
Availability	Vehicle Utilization (% of calendar days)	95%	89%	74%	79%	57%	
	Downtime due to maintenance & repair (% of calendar days)	6%	0%	24%	0%	1%	

1.16.1 Vehicle Reliability – BNSF-San Bernardino

Table 4-12: BNSF-San Bernardino - Summary of Major Maintenance Issues

Fleet Location	Vehicle	Major Problems Encountered
	BYD Vehicles (Fleet wide)	<ul style="list-style-type: none"> • CARB has communicated that the fleet has been struggling with reliability issues with the Phase 1 trucks. Because there is 1 motor which is used to perform 2 functions, the Phase 1 yard trucks can either move, or put the fifth wheel down, but not perform both simultaneously, which impacts their ability to operate faster and poses perceived safety hazard. This led to vehicles not being used in regular service since January 2019. • During the initial deployment period, the Phase II vehicles were out of service for a substantial period for rework of the crash bar (behind the cab). This issue had affected all 7 BYD Phase II trucks deployed at BNSF-Hobart
BNSF-San Bernardino	Yard Truck BYD-1 (Phase I)	<ul style="list-style-type: none"> • Vehicle was unable to charge, causing the vehicle to be out of service for 7 days • Vehicle stuck in neutral, kept the vehicle out of service for 2 days
	Yard Truck BYD-2 (Phase II)	<ul style="list-style-type: none"> • Air compressor noise and smell of electrical fire kept the vehicle out of service for 8 days • Vehicle not running because of failure of supplemental battery, causing it to be out of service for 10 days
	Yard Truck BYD-3 (Phase I)	<ul style="list-style-type: none"> • Battery needed to be replaced, vehicle out of service for 10 days in late January 2019 • Leaking brake canister, vehicle was out of service for 5 days • 300 hours PM service
	Yard Truck BYD-4 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service since mid-June 2019 for a total of 35 days. Vehicle was repaired and put back into service on 22 July 2019 • Master battery shut down with the error message of leakage in the high voltage system. However, the vehicle was able to operate in limited capacity • Multiple Service events reported by fleet
	Yard Truck BYD-5 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service late May 2019 to mid-July 2019 for a total of 59 days • Driver seat was broken and had to be replaced
	Yard Truck BYD-6 (Phase II)	<ul style="list-style-type: none"> • Rear door was not operational, causing vehicle to be out of service for 2 days • Rework of the crash bar (behind the cab), resulting the vehicle being out of service for 10 days in August 2019
	Yard Truck BYD-7 (Phase II)	<ul style="list-style-type: none"> • Air leakage in the dashboard valve, although the vehicle was still operational based on manual logs submitted by the fleet
	Yard Truck BYD-8 (Phase II)	<ul style="list-style-type: none"> • Rework of the crash bar (behind the cab), resulting in the being vehicle out of service since 7 July 2019 until mid-August 2019 (42 days) • Vehicle had to be re-programmed as it was stuck in the same transmission gear and was

Fleet Location	Vehicle	Major Problems Encountered
		out of service for 4 days.
	Yard Truck BYD-9 (Phase 1I)	<ul style="list-style-type: none"> No major problems reported
	Yard Truck BYD-10 (Phase 1I)	<ul style="list-style-type: none"> No major problems reported
	BYD Service Truck	<ul style="list-style-type: none"> Battery pack needed repair, keeping vehicle out for 25 days

1.16.2 Overall Performance Comparison – BNSF-San Bernardino

Table 4-13: Yard Tractor Performance Comparison – BNSF-San Bernardino

	AVERAGE OF ALL ADVANCED TECHNOLOGY VEHICLES		AVERAGE OF BASELINE**
	BNSF-San Bernardino Phase 1 (BYD #1-#3)	BNSF-San Bernardino Phase 2 (BYD #4-#10)*	
Fuel Efficiency (kWh/Mile For Electric Vehicle, Miles/DGE For Baseline)	20.2 miles/DGE (1.8 kWh/mile) (BNSF-San Bernardino BYD#1-#3)	19.9 miles/DGE (1.9 kWh/mile) (BNSF-San Bernardino BYD#4-#10)	4.8 miles/DGE (BNSF-Hobart #166248)
Range (Miles)	92 miles (est.) (based on 80% usable battery capacity)	99 miles (est.) (based on 80% usable battery capacity)	240 miles (est.)
Refueling or Recharging Time & Frequency	EV charging frequency varies from multiple times a day to no charging needed on certain days	EV charging frequency varies from multiple times a day to no charging needed on certain days	Once every 2-3 days
Vehicle Power	180 kW	180 kW	123 kW
Vehicle Downtime Due To Maintenance (%)	5.3%	7.8%	0%

*Does not include BYD-5 or Service Truck as no data has been transmitted for those vehicles.

**Using baseline from BNSF-Hobart as there are no baseline vehicles at BNSF-San Bernardino.

MARKET RESEARCH & COMMERCIALIZATION ROADMAP DEVELOPMENT

During the course of Project implementation, CALSTART conducted three (3) research activities to identify and characterize the market for future BYD electric vehicle sales and developed a plan to capture a share of the marketplace for heavy-duty yard tractors and Class 5 on-road trucks.

CALSTART published three (3) Reports that were deliverables under the Project Grant Agreement, as follows:

1. Battery-Electric Class 5 Service Trucks and Class 8 Yard Trucks: Market Assessment;
2. Battery-Electric Class 5 Service Trucks and Class 8 Yard Trucks: Commercialization Roadmap; and
3. Battery-Electric Class 5 Service Trucks and Class 8 Yard Trucks: Voice of the Customer Event

The third Report listed above documents a “Voice of the Customer” event hosted by SBCOG and CALSTART that took place at the South Coast Air Quality Management District Headquarters on August 22, 2019. This event, discussed below in Section 5.3, provided an opportunity for outside fleets to see the BYD Phase 2 8Y electric yard tractor and Class 5 service truck in person and discuss with the project implementers their experience to date using the electric vehicles in daily rail yard and logistics facility container movement operations. It also provided an opportunity for Daylight Transport and BNSF service providers to share their experience with the group, the purpose being to solicit feedback that will help BYD make further improvements to their heavy-duty electric vehicle products.

The following Sections provide highlights of CALSTART’s reports – it is anticipated that the complete documents will be available on the CARB Website.

1.17 Market Assessment

The goal of Market Assessment was to explore and assess the potential market for BYD electric trucks and understand what their best applications and sales opportunities are in the near term. The market segments of interest are fleets that use either of the two (2) vehicle types, yard tractors and Class 5 service trucks, overlaid by the constraints that the vehicle can deliver services best to fleets with more distance-limited route structures and access to regular daily recharging.

To conduct this assessment, CALSTART used a variety of approaches in an attempt to understand and characterize what is still an evolving marketplace. CALSTART conducted research to identify issues and requirements that are creating the market for zero-emission transport, to highlight barriers holding it back, and to determine basic vehicle market volumes and segmentation.

CALSTART designed, circulated, and analyzed fleet surveys to help further identify user constraints and needs that would impact fleet willingness to purchase battery-electric trucks. Based on this understanding, CALSTART then structured and performed business case analyses of these trucks based on the mileage, fuel use, and length of service found in duty cycles most conducive to their success. These business cases provide insight into the commercial viability of the BYD products.

Results of the Market Assessment for the BYD battery-electric yard tractor and service trucks were presented for five (5) areas:

1. **Market Drivers:** What are the local, state, national, and global requirements, benefits, incentives, and other trends driving interest and consideration for investing in zero-emission electric trucks?
2. **Market Barriers:** What are the issues holding back acceptance and purchase of zero-emission battery-electric trucks, including infrastructure costs, energy costs, maintenance and parts support, reliability concerns, and lack of familiarity?
3. **Market Survey:** What are the concerns and interests of user fleets of the two targeted classes of vehicles and resolving what issues would make them more willing to purchase?

4. **Business Case:** What are the fuel and operational savings of battery-electric trucks, the simple payback time for switching today to a more expensive battery electric truck, the long-term benefits of such an investment, and how might they change over time?
5. **Market Size:** What is the total market size for the vehicles in California and the nation and what is the actual “addressable” market, or the subset of the full market for which the vehicles are currently suited?

Electric drive trucks are now entering the market globally in increasing volumes and California is one of the early markets in this transformation. Following on the initial success of electric transit buses, the next market segments that have been identified as most promising based on previous CARB and CALSTART research will be medium-duty delivery, shuttles, school buses and Class 8 yard trucks. They form a steadily growing expansion pathway for electric commercial vehicle capability. These emerging vehicles can build on the similar component sets that are transferable from transit platforms. They are also capable of providing user acceptable operating range, operating costs, and reliability for several applications. Additional applications are anticipated to follow as volumes increase and supply chains expand, helping to further reduce cost.

In this context, CALSTART found that there are meaningful market opportunities immediately available for the two (2) BYD electric trucks that form the focus of this market assessment. The early markets are very clearly urban drive cycle based or focused around facility support. The market drivers highlighted in this assessment are creating a steady, strong and growing momentum for the shift of some truck applications to electric drive, whether to address urban air quality or climate emissions. Moreover, the business case is improving, and when the incentives offered by California are taken into consideration, the trucks can satisfy most fleet’s needs for payback periods and can provide for more sophisticated fleets a positive net present value for their investment. Interestingly, the business case analysis finds less payback sensitivity to high or low conventional fuel cost scenarios, and more sensitivity to the initial cost. Thus, Incentives in this early market are critical to the economic success of battery electric trucks based on current payback expectations.

Nonetheless, fleet concerns and needs must guide truck manufacturer actions when it comes to sales and support planning. Fleets are very sensitive to reliability and service concerns. A truck

that does not perform, or is out of service awaiting repairs, costs them money and potentially lost work. Fleets are very concerned about access to adequate and affordable electric infrastructure, though this issue shows signs of improving substantially in California with utilities able to invest in truck and bus charging infrastructure installation. Fleet users clearly must evaluate the risk of moving to a less familiar powertrain and fuel (electricity), and with that the unknown future value of the truck at resale or replacement points. All these issues add risk factors for a fleet decision.

For a manufacturer like BYD to be successful, it must then evaluate how to address, reduce, or eliminate a sufficient number of these risks to give fleets the confidence to make their purchase. Given the incentives that already exist in California, and the expanding funding going to infrastructure, one of the prime risk areas to focus next must be in addressing and assuring vehicle reliability, timely support, and availability of maintenance service. These are not new issues and have been identified in previous reports on electric truck barriers and needs.⁶ Possible strategies to address this important fleet risk factor could include:

- Providing extended warranties on electric trucks that give confidence to a fleet that it will not be left alone with new technology and unknown costs at three years, the standard warranty period, but less than half the normal first user life of a work truck.
- Establishing service and maintenance centers in major sales regions to provide confidence that any repair issues will be addressed quickly and locally and not leave a vehicle out of service.
- Establish and notify fleets that locally accessible “loaner” trucks will be available during any unexpected (not scheduled) down time.
- Make the commitment to institute strong quality control and check processes in the still low volume manufacturing process to ensure fleets receive and accept a high reliability product.

⁶ CALSTART, Best Fleet Uses, Key Challenges, and the Early Business Case for E-Trucks: Findings and Recommendations of the E-Truck Task Force, 2012.

- Establish deeper and longer lasting fleet operation and maintenance training on the electric trucks to ensure users are driving and servicing the vehicles correctly and for optimum performance.

In terms of the actual markets themselves, it is important to note that the Class 5 category on its own is one of the smallest - if not the smallest - truck classes in terms of volume. Therefore, it offers the most limited potential market if it remains the only target and battery-electric range capabilities do not significantly expand over just the next few years. That being said, the Class 5 chassis and vehicle differs very little from the adjacent weight classes, Class 4 and Class 6. The components are very common and because it is electric drive, many of the powertrain components, including energy storage, are in many cases directly transferable. Therefore, BYD, which already supports these similar chassis, should look less at the weight class itself and more at the applications. The fundamental powertrain underlying a Class 4, 5 or 6 offering is extremely similar and could provide the basis of multiple vehicle offerings. When the volumes in these classes are combined, even when reduced to reflect only the number of trucks performing urban delivery and service applications, it becomes a much more attractive investment opportunity.

1.18 Commercialization Roadmap

The market assessment report evaluated the market potential for the BYD electric trucks. The Commercialization Roadmap provides direction towards the best possible applications and sales opportunities in the near term, with attention focused on market segments that use either of the two vehicle types, overlaid by the constraints that the vehicle can deliver services best to fleets with more distance-limited route structures and access to regular daily refueling (charging). The assessment included research on the factors that are creating the market for zero-emission transport, the barriers holding it back, and the basic vehicle market volumes. Fleet surveys were also included to help further identify user constraints and needs that would impact fleet willingness to purchase battery-electric trucks. A business case analysis of these trucks was constructed based on the mileage, fuel use, and length of service found in duty cycles most conducive to their success.

1.19 Voice of the Customer Event

A Voice of the Customer (VOC) event was hosted to introduce potential fleets to the BYD electric vehicles and to collect fleet feedback to better understand their attitudes toward adopting zero-emission technology. While many fleets are not aware of how advanced battery-electric vehicles are or how their fleets may benefit from them, they certainly have opinions on where the market is headed. Motivating specific feedback from these fleets was very useful in shaping an understanding of the future market for zero-emission trucks. Leaders of fleets that use one or both vehicle types covered were invited to attend, along with government agency representatives, vehicle manufacturers, and associated project staff. Presenters spoke to the audience to explain how the electric trucks work, discuss the infrastructure requirements necessary to employ them, raise awareness of funding opportunities, and answer questions from the fleets.

The VOC event took place on August 22, 2019 from 10 a.m. to 2 p.m. at the South Coast Air Quality Management District facility in Diamond Bar, California. Approximately 50 people attended, including 26 fleets. Marketing for this event was conducted primarily by email invitations, with CALSTART using its contact resources to target the most likely users of the trucks being showcased. More than 2,000 fleets, primarily based in Southern California, were invited.

The Project demonstration fleets came together as a panel to discuss the vehicles from their unique perspectives. The fleet representatives included:

- Parsec, Inc. a BNSF service provider at the Los Angeles (Hobart) facility;
- ITS ConGlobal, a BNSF service provider at the San Bernardino facility; and
- Daylight Transport in Fontana

Each fleet gave an overview of their role in the project and talked about what their experience has been with the BYD vehicles. This segment was especially useful for the attendee fleets because no matter how extensive the theoretical benefits of the vehicles are, hearing from a peer company in the industry in their own words is much more convincing. The different fleet experiences are summarized below.

1.19.1 Parsec, Inc. – Parsec, Inc. operated a total of ten (10) BYD Model 8Y yard tractors, each with its own charging station installed earlier in the project. Their overall fleet at this site consists of more than 150 diesel yard tractors, so the electric yard tractors were a novelty onsite. Yard tractors are the main workhorse vehicles for Parsec, Inc. “The BYD vehicles were used in day-to-day intensive operations.” operations. One of the Class 5 BYD service trucks was provisioned to this fleet and saw moderate use.

The fleet was very open about their experience with the vehicles, fully admitting that they were not particularly excited about adopting this technology but agreed to when BNSF asked them to do it. They had some worries in the beginning, including operator skepticism and doubts about performance. A more subtle reservation was related to the near-silent operation of these electric vehicles; there was some trepidation that the lack of noise could be a safety issue. It is much more obvious when a diesel truck is operating near you because of the relentless combustion noise coming from the engine. However, no specific incidents were mentioned. The charging stations did take 4-5 months to install, which was longer than initially planned for. Ultimately, the operators became acclimated to the trucks and began using them with more frequency. The maintenance burden was significantly reduced relative to the conventional vehicles, with much less maintenance, fewer fluid changes, and no filters to change, which was very much appreciated by the fleet. Over the longer term, the fleet expressed concerns as to whether the battery life would degrade or if charging issues would surface, but in the meantime, they have not noticed the trucks dipping below the 40% state of charge level despite only charging the trucks during lunch and break periods.

1.19.2 ITS ConGlobal - Similarly, ITS ConGlobal received ten (10) BYD Model 8Y yard tractors and a single Class 5 service truck to run in their daily operations. This compares with 57 diesel Class 8 yard tractors in their standard fleet. ITS reported no difference in performance between the conventional diesel and electric yard tractors. Twenty-four hours per day and seven days per week the trucks performed to the fleet’s standards. Every two (2) hours during normal operations there is downtime which provides a short window for charging, and this proved enough to keep the vehicles powered. However, the longer time to fuel as compared to a diesel model was noticed and considered a minor challenge. A few parking spots were lost due to the

footprint of the vehicle chargers installed on-site, which translates to lost revenue for the company. This charger location was optimal for the fleet's workflow, but it required significant trenching for conduit to reach the chargers, adding time to the installation period. Reliability remained a concern for the fleet, reflecting their caution, despite the vehicles performing adequately over the course of the deployment.

The positive aspects appreciated by this fleet include the quiet operation, which made communication over their radios significantly easier, and the lack of diesel odor made for a better experience for drivers. Maintenance was again cited as being greatly decreased relative to conventional baseline models.

1.19.3 Daylight Transport - The third fleet, Daylight Transport, had a unique situation when it comes to deploying electric vehicles. The BYD trucks were deployed at a new facility in Fontana that was recently built from the ground up to incorporate sustainability at every level of their operations. The use of BYD equipment, three (3) Phase 1 Model 8Y yard tractors and one (1) Class 5 service truck, was thus planned into the development of the facility. The management at the company has decided to go forward with clean energy use (worksite is LEED certified) and this particular deployment occurred at a facility using solar panels to power all operations, including vehicle charging. Because the worksite was only recently built and this deployment was planned from the beginning, they experienced no issues with installing the charging infrastructure. Similar to the rail yard operators, they have an intensive workload with twenty-four hour operation six days per week. This schedule translates to 18 hours of truck time per day, so the vehicles were charged during any down time such as breaks or lunch. Fleet managers expressed initial concerns over reliability, ease of use, and performance. In the early stages of this project, there were challenges to overcome in assimilating these new trucks, but eventually six out of seven operators said they would choose to drive electric over conventional models. As expected, preventive maintenance was much less than typical diesel trucks over the course of the project. The Class 5 service truck was eventually moved to BNSF-San Bernardino as there was little use for it at the Daylight Fontana facility.

RESULTS, FINDINGS, & “LESSONS LEARNED”

This Project yielded a wealth of data and information. Section 4 presented the analytically derived results from the data logging of the BYD electric and baseline diesel vehicles, and Section 5 described feedback provided by the drivers who operate the vehicles on a daily basis. All of this information is valuable and will assist BYD in the continuous refinement of their heavy-duty electric vehicle products.

This Section will summarize additional feedback provided by the project partners relative to their overall experience in implementing this Project, their recommendations moving forward, and importantly, the key takeaways and “lessons learned”. While hindsight is always 20/20, it is hoped that the experiences, challenges encountered, and remedies implemented on this Project will positively influence the design and implementation of future advanced technology vehicle demonstration projects.

1.20 EVSE Planning, Construction, & Charger Installation – Results & Findings

The Project element that presented the greatest challenges was the implementation of the EVSE at the BNSF demonstration locations. The lessons learned from this experience are discussed below.

Notably, there were few if any issues with constructing EVSE at Daylight Transport. The primary reason is that the Daylight Transport facility in Fontana is new construction. As such, the site accommodations to support EVSE were an element of the overall facility design, with the electric utility service construction a part of the overall facility construction. Thus, there was no need to perform demolition or reconfiguration of an existing facility, as was the case at the BNSF demonstration sites. The location of the EVSE charger installations was also planned as an element of the overall facility design at Daylight’s facility; thus, there were no issues pertaining to loss of parking spaces, etc.

BNSF’s experience with implementing EVSE at BNSF-San Bernardino was more challenging, and also challenging but to a lesser extent at BNSF-Hobart. The primary issue was delays in working with SCE. BNSF experienced long lead times in the design and construction phases of EVSE installation, specifically on SCE’s side of the meter, and these delays ultimately required

the Project demonstration phase to be extended to ensure the vehicles met their contractual operation duration obligations and that sufficient data could be collected.

Additional challenges encountered by BNSF included the construction-related costs of EVSE installation at existing facilities – much greater as compared to performing new construction as experienced by Daylight Transport. Finally, as discussed in preceding Sections of this Report, BNSF and SCE worked closely to assess options for an electricity rate structure that would yield an acceptable power purchase cost as compared to the price of conventional diesel fuel.

While EVSE challenges were encountered, primarily when working with the utility, all were overcome and the EVSE was successfully installed. The key factor was SBCOG, BNSF, and SCE working together in a cooperative, constructive manner to identify the issues impeding progress and correct them.

⇒ **Key Finding:** When planning to incorporate electric vehicles, especially heavy-duty electric vehicles, into fleet operations, EVSE must be emphasized during the project planning phase. Additional design and construction time should be included in the project's critical path analysis. The potential to encounter hidden conditions, experience weather delays, etc., must be anticipated and sufficient lead time given to address likely delays. Most importantly, regular communication between all parties is essential – weekly meetings – at a minimum, help ensure all parties are aware of the current project status and allow technical or programmatic concerns to be addressed immediately.

1.21 BYD Model F5 Electric Service Truck – Results & Finding

Throughout the Project demonstration, utilization of the Class 5 electric service truck was low. At Daylight Transport the level of use did not justify retaining the vehicle. It was instead relocated to BNSF-San Bernardino.

However, the mileage and run time of the Class 5 electric service trucks was also limited at both BNSF-Hobart and BNSF-San Bernardino. The trucks were utilized frequently; however the trips were very short because the trucks and trailers that the service truck operators were servicing are close together.

Also, there was minimum data collection for the Class 5 electric service trucks. No baseline Class 5 trucks were included in the Project; thus, there is limited ability to compare recorded

performance and drivetrain efficiency data corresponding to an electric service truck to a conventional diesel Class 5 truck.

⇒ **Key Finding:** The knowledge gained from a project is diminished if there is inconsistent monitoring, data collection and analysis across the types and classes of vehicles being demonstrated. While the original intent was to more fully utilize the electric service trucks, there is benefit from a marketing perspective to understand that Class 5 electric vehicles would likely have low use and thus offer limited environmental benefit when deployed at rail yards and logistics or warehouse facilities. An important experience gained is that battery-electric trucks may be able to replace a combustion engine truck in a variety of new applications.

1.22 BYD Model 8Y Electric Yard Tractor Performance – Results & Finding

An important finding of this Project was that the BYD 8Y electric yard tractor exhibited performance capabilities, including power and torque, similar to baseline diesel yard tractors. The electric vehicles were capable of operating across multiple work shifts, averaging 8 to 14 hours of operation per day with opportunity charging during brief down-time periods. The strategy of recharging the vehicles on an opportunity basis, typically during lunch breaks or other break periods during a work shift, proved to be effective from a workflow standpoint.

On an energy consumption basis, the electric yard tractors have significantly greater energy efficiency. Based on a preliminary analysis of the data collected by Ricardo, the efficiency of the electric yard tractor as compared to the baseline diesel yard tractor is on the order of four to five times greater. It was also noted by data collected by Ricardo that the availability of regenerative braking captured approximately 0.30 kWh per mile. This demonstrates that the duty cycle typically associated with yard tractors is conducive to the use of electric drivetrain vehicles equipped with regenerative braking capability.

⇒ **Key Finding:** While opportunity charging was effective from an operational perspective, it did not prove to be the most cost-efficient strategy. As noted by BNSF, vehicle charging often occurred during peak periods when electricity rates were highest. This resulted in higher utility costs which in turn eroded the energy efficiency benefits of the electric yard tractors. Moving forward, there is an opportunity to explore different

vehicle charging strategies that meet facility operational demands but do so at times when the utility rates are lower. This will allow fleets to reap, on an economic basis, the benefit of the more efficient electric drivetrains.

⇒ **Key Finding:** While it is important that fleet operators do their part to develop operational strategies that allow their electric vehicles to be recharged during non-peak periods to the extent feasible, BNSF also noted the importance moving forward for the electric utilities to act in partnership with fleets to ensure electric vehicle recharging rate structures are available that are competitive with conventional fuels.

1.23 BYD Model 8Y Electric Yard Tractor Operability – Results & Findings

By the conclusion of the electric vehicle demonstration, driver acceptance of the vehicles had improved significantly. As noted by Daylight Transport and BNSF, some of their drivers stated that they preferred the electric yard tractors over the diesel vehicles. Overall, some drivers noted that they thought the electric vehicles offered them less engine noise, other drivers commented that there was a reduced smell of diesel. That being said, the initial acceptance of the vehicles was low. This is attributable to several factors. At first, the electric yard tractors were viewed as more of a “novelty”, and in some cases this has been difficult to overcome. Also, the Phase 1 electric yard tractors had an ergonomic configuration that some operators disliked – they simply didn’t have the same design as the tractors the drivers were accustomed to. This resulted in operators avoiding the electric tractors in favor of more familiar diesel tractors. Also, as discussed in Section 2, the lack of an independently operated fifth wheel in the Phase 1 design had a significant negative impact on driver acceptability. The Phase 2 electric yard tractor design largely eliminated or reduced operator concerns pertaining to ergonomics and operability. The process used to arrive at the Phase 2 design is a key positive feature of this project.

⇒ **Key Finding:** Incorporating a “two-phase” vehicle design and demonstration methodology was a key success of this Project. The Daylight Transport operators and BNSF service providers provided significant, valuable feedback to BYD, suggesting structural, ergonomic, and operational modifications that were applied to the Phase 2 vehicles. Most of the recommended modifications were essential to perform the intended work, such as shorter beaver tail prongs and an independently operated fifth wheel. BYD was methodical in capturing all of the information provided by the demonstration fleet

operators and applying it to the Phase 2 yard tractor redesign. In turn, the operators and service providers felt a sense of value, knowing they had made a meaningful contribution to the refinement and design evolution of BYD's product.

1.24 BYD Model 8Y Electric Yard Tractor Reliability – Results & Findings

The Phase 2 electric yard tractors have exhibited improved reliability as compared to the Phase 1 vehicles. As discussed in Section 2, Daylight Transport's Phase 1 yard tractors were an earlier prototype design, and these vehicles did not demonstrate a level of reliability deemed acceptable beyond the demonstration phases of the Project. For that reason, the decision was made to retire the Daylight "Pre-Phase 1" yard tractors from service.

While the Phase 2 yard tractors have demonstrated improved reliability, opportunities remain for BYD to continue improving the vehicles with respect to reliability and durability. As noted in Section 4, many of the component failures and system breakdowns were related to the vehicle chassis and structure as opposed to the vehicle electric drivetrain components. The long-term reliability and durability of the electric yard tractors are unknown, and this remains a primary consideration when considering adding additional electric vehicles to the fleet.

⇒ **Key Finding:** While the Phase 2 electric yard tractors achieved greater reliability as compared to the Phase 1 vehicles, BYD should strive to continue improving their vehicle reliability and durability. This will provide fleets the confidence needed to expand the use of electric vehicles in their operations.

1.25 BYD Model 8Y Electric Yard Tractor Maintainability – Results & Findings

The issues associated with electric yard tractor reliability also impacted its maintainability. While the Daylight Transport and BNSF service provider mechanics were fully qualified to do regular maintenance on the electric yard tractors, they were not qualified to troubleshoot and repair more complex structural issues or faults associated with the vehicle's high voltage electric drive systems. It should be noted that the vehicles were also within the BYD warranty period; thus, it would be inappropriate for the fleet technicians and mechanics to perform work covered by the manufacturer warranty.

The primary issue encountered was that there was significantly more down-time due to repairs to the BYD electric vehicles compared to the baseline diesel tractors. Whereas the demonstration

fleets have mechanics onsite to immediately address repairs to the conventional diesel tractors, BYD was required to dispatch technicians from their Lancaster facility. On occasion, it was determined that repairs could not be performed in the field; this required transporting the electric yard tractors back to Lancaster to perform necessary repairs. This contributed to a much longer downtime for the electric yard tractors as compared to the conventional diesel vehicles. With respect to general maintenance, the required service time for the electric vehicles was shorter than the diesel tractors.

⇒ **Key Finding:** Moving forward, it will be essential to have qualified technicians available to address repairs needed to the electric vehicles. This is especially true when the vehicles are outside of the manufacturer warranty period. It is advisable that fleets identify preferred vendors to perform any repairs if it is not practical to employ specialized mechanics qualified to work on heavy-duty electric vehicle drivetrain systems.

1.26 Data Collection & Analysis

This Project successfully collected a significant amount of data, both analytic data collected via the onboard data loggers, as well as data collected manually by the project partners. This data will be beneficial to the California Air Resources Board, BYD, and many others because it provides significant insight into the performance, reliability, productivity, and cost-effectiveness of the battery electric trucks in this project. Challenges were encountered, however, primarily due to multiple failures experienced with the data loggers. The reliability of the data loggers proved to be an ongoing issue and required the efforts of Daylight and BNSF personnel to assist in data logger troubleshooting.

It was also noted that there was limited data from the BYD EVSE relative to the amount of energy dispensed – in this respect the Project would have benefited from installation of “smart charger” metering technology to independently record energy dispensed from the EVSE.

⇒ **Key Finding:** Data collection and analysis are essential components of an advanced technology vehicle demonstration project. It is important to use measurement equipment whose reliability has been previously demonstrated. Also, it is important to ensure that the necessary personnel responsible for the maintenance of the data collection equipment are available so as not to shift that responsibility to demonstration partners.

FOLLOW-ON ELECTRIC VEHICLE UTILIZATION PLANS

Daylight Transport and BNSF have each stated their intentions to continue using the electric vehicles and EVSE demonstrated under this Project in their daily operations.

Daylight Transport will take ownership of the three (3) Phase 1 Model 8Y electric yard tractors received from BNSF in June 2019 and one (1) Phase 2 Model 8Y electric yard tractor that was placed into service in January 2020. The three Phase 1 electric yard tractors were provided under the terms of a lease agreement that covered the demonstration period. Daylight has agreed to purchase these vehicles at zero cost with exception of taxes and applicable fees and take title to those Phase 1 vehicles. The Phase 2 electric yard tractor will be purchased by Daylight again at zero cost with exception of taxes and applicable fees, as the vehicle was procured using funds provided by CARB under the Multi-Source Facility Freight Demonstration award. Daylight Transport has also agreed to purchase the three (3) 100 kW EVSE chargers which had been provided by BYD. The EVSE element of this Project was not funded under the Multi-Source Facility Freight Demonstration award.

At the conclusion of this Project, BNSF purchased the EVSE charging equipment from BYD. This includes ten (10) 200 kW chargers at the BNSF-Hobart Rail Yard and ten (10) 200 kW chargers at the BNSF-San Bernardino Intermodal Facility.

The fourteen (14) Phase 2 electric yard tractors demonstrated by BNSF were purchased for zero cost with exception of taxes and applicable fees by BNSF's service providers at both Hobart and San Bernardino. Seven (7) Phase 2 yard tractors were purchased by Parsec, Inc., who performs intermodal rail transportation services at the BNSF-Hobart Rail Yard, and seven (7) Phase 2 yard tractors by ITS ConGlobal, BNSF's service provider at the San Bernardino Intermodal Facility.

As noted, utilization of the Phase 1 yard tractors by ITS ConGlobal has been substantially lower as compared to the Phase 2 electric yard tractors and the existing fleet of diesel yard tractors and the Phase 1 yard tractors will be returned to BYD.

Parsec, Inc. and ITS ConGlobal also purchased the three (3) Phase 1 electric service trucks at zero cost with exception of taxes and applicable fees. One (1) electric service truck will remain at BNSF-Hobart, and two (2) at BNSF-San Bernardino.

Daylight Transport and BNSF will continue to work with BYD to identify qualified vendors to perform maintenance and repairs on the electric vehicles beyond the initial warranty period. This is especially important for troubleshooting and repairing the high current systems on the BYD vehicles that requires a level of electrical system expertise beyond that currently available to Daylight Transport's fleet mechanics and BNSF's service providers. It was noted during discussions with BNSF that access to qualified electric vehicle technicians is a key factor when considering a potential expansion of electric vehicles into their fleet.

STATEMENT OF CHANGES IN CASH MATCH AND IN-KIND CONTRIBUTIONS

There were a multitude of changes and delays that occurred throughout this project. The first was the major change of the BNSF location in Los Angeles County. In addition, there were multiple delays throughout the project resulting from SCE related delays. Lastly, there was reduced usage because of the downtime of the Phase 1 yard tractors due to the safety concerns related to the 5th wheel. As a result, expenditures of the original Cash Match and In-Kind Contributions were not met 100%. These impacts and their resulting changes were discussed with the funding agency CARB along the way. The Project team appreciates the flexibility provided by CARB of the entire process; the project was more successful as a result.



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