BNSF ZERO-AND NEAR ZERO-EMISSION FREIGHT FACILITIES PROJECT (ZANZEFF) DATA ACQUISITION SUPPORT

BNSF Contract Number BF 10015561

TOPICAL REPORT:
DRAYAGE TRUCK

SwRI Project 03.24318

Prepared for:
BNSF Railway Company
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Fort Worth, TX 76131

Prepared by:
John Hedrick

July 2021

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This project was supported by the "California Climate Investments" (CCI) program.

Flexible Solutions for Freight Facilities is part of California Climate Investments, a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment — particularly in disadvantaged communities.

DESIGN AND DEVELOPMENT DEPARTMENT
POWERTRAIN ENGINEERING DIVISION

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LIST OF ACRONYMS

CAN	Controller Area Network
CARB	California Air Resources Board
CCS	Combined Charging System
CO	Carbon Monoxide
CO2	Carbon Dioxide
COFC	Container on Flat Car
Ft-lb	Foot Pounds
GCWR	Gross Combined Weight Rating
GPH	Gallons per Hour
GPS	Global Positioning System
GVW	Grose Vehicle Weight
HP	Horsepower
HPQ	Hours per Quarter
KM/Hr	Kilometer per Hour
kW-Hr/Q	kW-Hour per Quarter
LPH	Liters per Hours
MFG	Manufacture
MPD	Mile per Day
MPH	Miles per Hour
MPQ	Milage per Quarter
NO	Nitrogen Oxide
NO2	Nitrogen Dioxide
O2	Oxygen
PEMs	Portable Emissions Analyzer
PIDs	Parameters Identifiers
RPECS™	Rapid Prototyping Electronic Control System
RPM	Revolutions per Minute
RTG	Rubber Tire Gantry Crane
SJVAPCD	San Joaquin Valley Air Pollution Control District
SOC	State of Charge
SwRI	Southwest Research Institute
TDR	Time Related Demand
THC	Total Hydrocarbons
TOFC	Trailer on Flat Car
US-EPA	United States Environmental Protection Agency
VAC	Volt of Alternating Current
VIN	Vehicle Identification Number
ZANZEFF	Zero and Near Zero Emission Freight Facilities

ACKNOWLEDGEMENTS

The project would like to acknowledge:

- California Air Resources Board (CARB) Mobile Source Control Division for funding this project to investigate Zero and Near Zero Emission Freight Facilities (ZANZEFF) at the BNSF Intermodal Yard.
- This project was supported by the "California Climate Investments" (CCI) program.
    - *Flexible Solutions for Freight Facilities is part of California Climate Investments, a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment — particularly in disadvantaged communities.*
- San Joaquin Valley APCD (SJVAPCD).
    - SJVAPCD Flexible Solutions for Freight Facilities Project.
    - California Climate Investments as funding source and Grant Number: G17-ZNZE-09
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- Garrett Anderson of SwRI's San Antonio, TX office for data analysis and processing.
- Staff at BNSF's San Bernardino, CA and Stockton Intermodal Yards.
- SH&H staff, also at the BNSF San Bernardino, CA Intermodal Yard.

EXECUTIVE SUMMARY

This project is in support of the California Air Resources Board (CARB) Mobile Source Control Division's grant, which was supported by the "California Climate Investments" (CCI) program, to investigate Zero and Near Zero Emission Freight Facilities (ZANZEFF). The partner for this grant was San Joaquin Valley APCD (SJVAPCD), and BNSF Railway participated in the grant by demonstrating zero and near zero emissions cargo handling equipment, locomotive and drayage truck.

This topical report focuses on the data review on a diesel fueled truck used in drayage service and a BYD electric drayage truck, both operating in BNSF Railway's San Bernardino Intermodal Yard for more than the required 90 days. The list of parameters that SwRI recorded for this topical report is shown Appendix A.

The two trucks operated well and had very similar operating characteristics. Some of the notable observations for the two trucks are:

Loads per day:

- The diesel drayage truck averaged 8.4 loads per day while traveling 58.6 miles, with an average speed of 7.0 MPH. The diesel drayage truck completed many loads to parking lots outside of the BNSF Intermodal Yard (Rancho East and Rancho West), while in drayage operation.
- The electric drayage truck averaged 10.7 loads per day while traveling 45.6 miles, with an average speed of 5.2 MPH. Most of the loads completed by the electric drayage was inside the BNSF Intermodal Yard.

Hours of operation per day:

- The diesel truck averaged 8.8 hours per day, typically operating 5 days per week.
- The electric drayage truck operated for an average of 9.4 hours per day, also operating 5 days per week.

Energy consumption per load:

- The diesel drayage truck consumed an average of 2.0 gallons of fuel per load and at an average cost of $3.09 gallon for diesel fuel, with a calculated drayage fuel cost per load of $6.18.
- The electric drayage truck consumed an average of 14.2 kW-hr per load, and assuming an average cost of electricity of $0.186 kW-Hr, the average drayage energy cost per load is calculated to be $2.64. However, the electric energy cost could be much higher during the peak charging periods (Time Related Demand (TRD) charges where the rate varies with time of year and time of day).

There was a difference noted in the typical operating cycle between the diesel and electric drayage trucks while operating in the BNSF Intermodal Yard. To obtain a better apples-to-apples comparison in the typical operating cycles, five non-consecutive days for each truck were selected to give a better comparison of energy and cost per load between the two trucks. These five days were selected because of the common distance traveled, loads per day, hours of operation per day, and a common time of year to minimize the differences in ambient conditions. The outcome of this additional review showed that when the two trucks were operating over essentially the same route, the diesel truck consumed an average of 1.4 gallons per load with a diesel fuel cost of $4.33 per load. The electric drayage truck consumed an average of 19.9 kW-Hr per load over these five days and the electrical cost was $3.70 per load.

Refueling:

- The average refuel event for the diesel drayage truck occurred every 4.5 days and the typical time required to complete a fueling event was 40 minutes (0.67 hours). This time included drive time to travel to the off-site fueling facility, the time required to pump the average 76.0 gallons of fuel, and the return trip back to the BNSF Intermodal Yard.
- The electric drayage truck was plugged in an average of 8.1 hours per day over 75 of the 78 days that the electric truck was used, and the average charge time was 4.7 hours of the plugged-in time. The average charge power was 135.4 kW-Hr to take the State of Charge (SOC) from 64.3 percent to 99.2 percent. The electric drayage truck was usually plugged in at the end of the shift (approximately 3:30 to 4:30 PM) and this was typically at the "worst time of the day" due to the peak electric power demand charge. With more than enough "plugged in" time, compared to the charge time, the cost of electrical energy could be reduced by starting the charge after the cost of electrical energy significantly drops later in the day during "off-peak" rates.

Emissions:

- The diesel drayage truck was tested with a portable emissions analyzer (PEMs) and the PEMs NOx emissions in drayage service was ~6.4 g/Hp-Hr, which is ~15 times the US-EPA certification value of 0.423 g/hp-hr. Due to these findings, the diesel drayage truck was sent to a local International Truck dealership to investigate the cause of the high NOx emissions.

The result of this project shows that the BYD electric drayage truck was more than adequate range to handle any of the drayage operations in and around BNSF's San Bernardino Intermodal Yard. Overall, the electric drayage truck appears to be capable of operating in this environment and service, without any know issues.

1.0 INTRODUCTION

This report supports BNSF's grant from the San Joaquin Valley Air Pollution Control District (SJVAPCD). The SJVAPCD, in partnership with BNSF Railway (BNSF), received funding for the Flexible Solutions for Freight Facilities Project (Project) through the California Air Resources Board (CARB) Mobile Source Control Division's Zero and Near Zero Emission Freight Facilities (ZANZEFF) solicitation. The Project entailed demonstrating zero and near zero emissions cargo handling equipment in Stockton and San Bernardino, California, and in rail service between Stockton and Barstow, California.

SwRI supported BNSF Railway in the Project, by taking on the responsibility for the "purchase, installation, and maintenance of data logging or other data collection equipment" as detailed in Appendix F "Data Collection Requirements" of the CARB ZANZEFF grant solicitation. Appendix A of this report includes the list of items for data collection and associated primary responsibility for the RTG portion of the ZANZEFF project.

2.0 BACKGROUND

SwRI supported the ZANZEFF project by collecting data on Locomotives, Rubber Tire Gantry Cranes (RTG), Side pick cargo handlers, and drayage trucks, with examples shown in Figure 1.

Figure 1. Types of Equipment Instrumented

The goal of the project was to data log the operation of each piece of equipment for at least 90 days. The diesel drayage truck was instrumented with the data logger for a total of 307 days, from March 3, 2020 to Jan 11, 2021 and was operational for 199 days of this installed window. The electric drayage truck was instrumented with the datalogger for a total of 271 days (April 15, 2020 to Jan 11, 2021), the datalogger was operational for a total of 144 days in this window of time.

2.1 BNSF San Bernardino Intermodal Yard

The BNSF San Bernardino Intermodal Yard is located at 1535 W. 4th Street, San Bernardino, CA. The yard covers more than 150 acres and has ~35,300 feet of track. The yard also has ~1,700 on-site parking spaces for containers in five different lots and additional container parking at Rancho West, Rancho East, and the Pit Property. All locations are shown in Figure 2.

This Intermodal facility is a major component in BNSF's Inland Empire system and its primary focus is the loading / unloading of Trailer on Flat Car (TOFC), Container on Flat Car (COFC), and GM's Auto Facility (located South of Rancho West). This BNSF Intermodal Yard is used to support the transportation needs of consumer goods for many companies, including but not limited to:

- Amazon
- BMW
- Nordstom Rack
- Rite Aid
- Ross
- The Home Depot
- Walmart

Figure 2. Layout of the BNSF San Bernardino Intermodal Facility

A typical drayage truck shuttle "trip" for this yard starts and ends at the front gate checkpoint, where the driver checks in and receives load instructions. The truck proceeds to the appropriate location to pick up the load, then delivers the load to the assigned location, and then returns to the checkpoint / gate to restart the process. Figure 3 shows a typical day (9-Sept-20) for the diesel drayage truck route. On this day there were several trips to Rancho West, various trailer parking lots inside the facility, and one trip to a location outside of the BNSF property on Foothill Blvd.

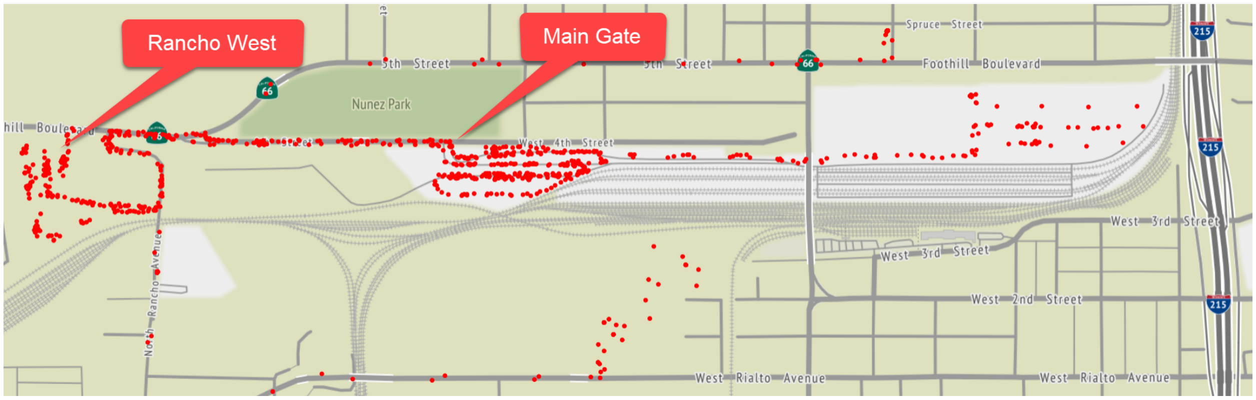

Figure 3. Diesel Drayage Travel Around BNSF's San Bernardino Intermodal Facility on 9-Sept-20

2.2 Vehicle Specifications - Diesel Fueled Drayage Truck

The diesel fueled drayage truck was a Navistar PROSTAR+ built in July of 2011. Additional truck details are shown in Table 1 and photos of the truck and various aspects of the truck are shown in Figure 4 thru 6.

Table 1. Diesel Drayage Truck Details

Make	Navistar
Model	PROSTAR+ 122 6X4
VIN	3HSDJSJR8CN554008
Date of MFG	July 2011
GVW-Rear	52,325 Pounds
GVW-Front	12,350 Pounds

Figure 4. Diesel Fueled Drayage Truck

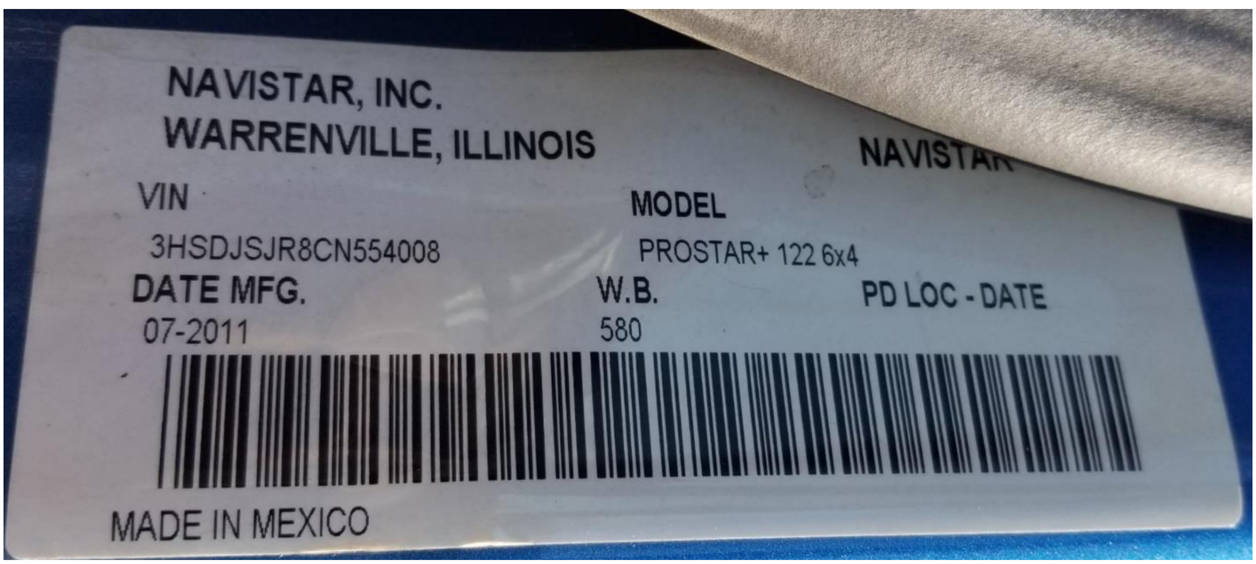

Figure 5. Diesel Fueled Drayage Truck VIN Sticker

Figure 6. Diesel Fueled Drayage Truck VIN Sticker #2

The engine in this drayage truck was a Navistar MAXXFORCE 13 that was built in 2011. The engine displacement is 12.4 liters and was rated at 430 HP @ 1,700 RPM with 1,550 ft-lb of torque @ 1000 RPM. Additional details about the engine are shown in Table 2.

Table 2. Diesel Drayage Truck Engine Details

Year Model	2011
Engine Family	Navistar MAXXFORCE 13
Emissions Family	BNVXH07570GC
Serial number	125HM2Y4123639
Model	A430
Displacement	12.4 liter
Ratings	430 HP @ 1,700 RPM
	1,550 ft-lb @ 1000 RPM
Miles @ start	484,866 (January 14, 2020)
Miles @ end	505,285 (January 11, 2021)

Reviewing the US-EPA's database of certification levels for this emissions family, it was determined that this engine was certified at 0.423 g/hp-hr NOx and 0.005 g/hp-hr of PM.

2.3 Vehicle Specifications - BYD Battery Electric Drayage Truck

The electric drayage truck was built by BYD and is shown in Figure 7. The BYD truck is a Model Q3M and was built in 2019 and several identification details can be seen in Figure 8, and the truck specifications are shown in Table 3. The BYD drayage truck had a total of 922 miles on the odometer at start of the BYD datalogging portion of the project (March 2, 2020), as shown in Figure 9, and had accumulated 6,202 miles by January 11, 2021.

Figure 7. BYD Q3M Electric Drayage Truck

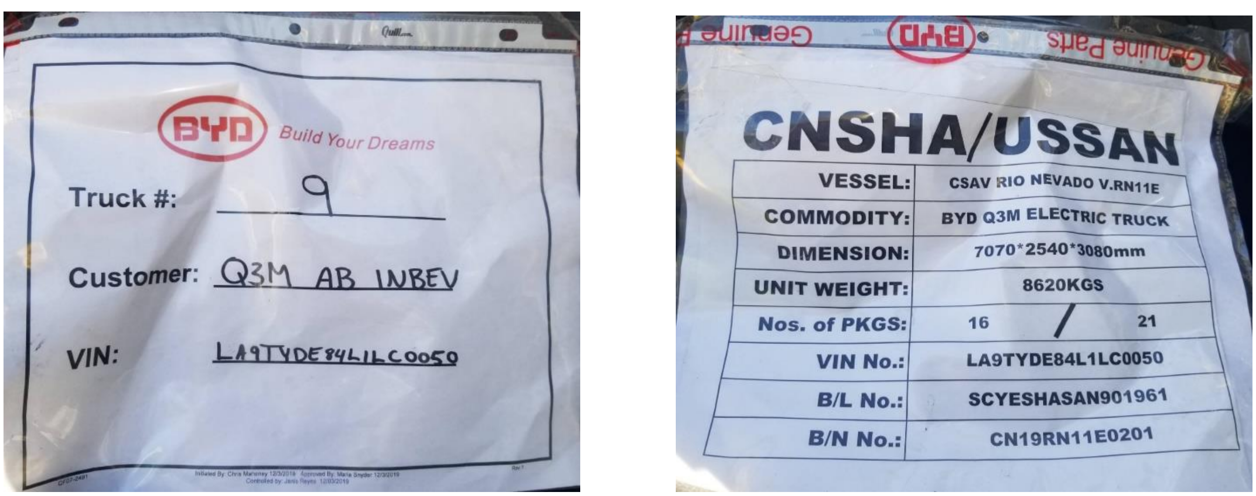

Figure 8. BYD Q3M Electric Drayage Truck Tags

Table 3. BYD Q3M Drayage Truck Specifications

Dimensions	
Length	278.3 Inch
Width	100.4 Inch
Height	121.3 Inch
Wheelbase	166.3 Inch
Curb Weight	26,235 Pounds
GCWR	105,000 Pounds
Performance	
Top Speed	65 MPH
Maximum Gradeability	25 Percent
Range	125 Miles
Approach/Departure Angle	16° / 40°
Chassis	
Suspension - Front	Leaf Spring
Suspension – Rear	Air Suspension
Brakes - Front	Air Disk
Brakes - Rear	Air Drum
Powertrain	
Maximum Power	483 Horsepower
Maximum Torque	1,770 Foot-Pound
Battery Capacity	409 kW-Hr
Charging Power - AC	33 kW AC
Charging Power – DC	120 kW or 240 kW
Charging Time - AC	13.5 Hours
Charging Time - DC	4 or 2 Hours

Figure 9. Electric Drayage Truck Odometer Reading

Figure 10 shows the charging ports on the side of the BYD truck, and it is located on the passenger side of the truck, behind the front tires, as shown in Figure 11. The upper port is a Charging Receptacle and is used by the facility to charge the truck. This port allows the truck to be charged using DC power that offers the faster charging times. The bottom port shown in Figure 10 is for the lower powered AC charging and was not used.

Figure 10. BYD Q3M Electric Drayage Truck Charge Receptacle

Figure 11. BYD Q3M Electric Drayage Truck Charge Receptacle Location

2.4 Electric Drayage Truck ChargePoint Charging Station

The BYD electric drayage truck uses a dedicated ChargePoint Express 250 charging station that was installed for this project. The ChargePoint Express 250 charging station uses 480 VAC three phase power with a 250 Amp service. Figure 12 shows the charging station with the BYD truck in the background. Figure 13 shows the combined charging system (CCS)1 charging receptacle that can be plugged into the appropriate receptacle on the side of the BYD electric drayage truck to allow charging of the truck.

Figure 12. Electric Drayage Truck Charging Station

Figure 13. Electric Drayage Truck CCS1 Charging Receptacle

The charging station system also has a web interface that provides dates that the charger was used, charging energy provided for each charging event, and the accumulated energy dispensed. Figure 14 is a graph of the data provided by the web interface for the BYD truck monitored in the project from February 2020 through January 2021.

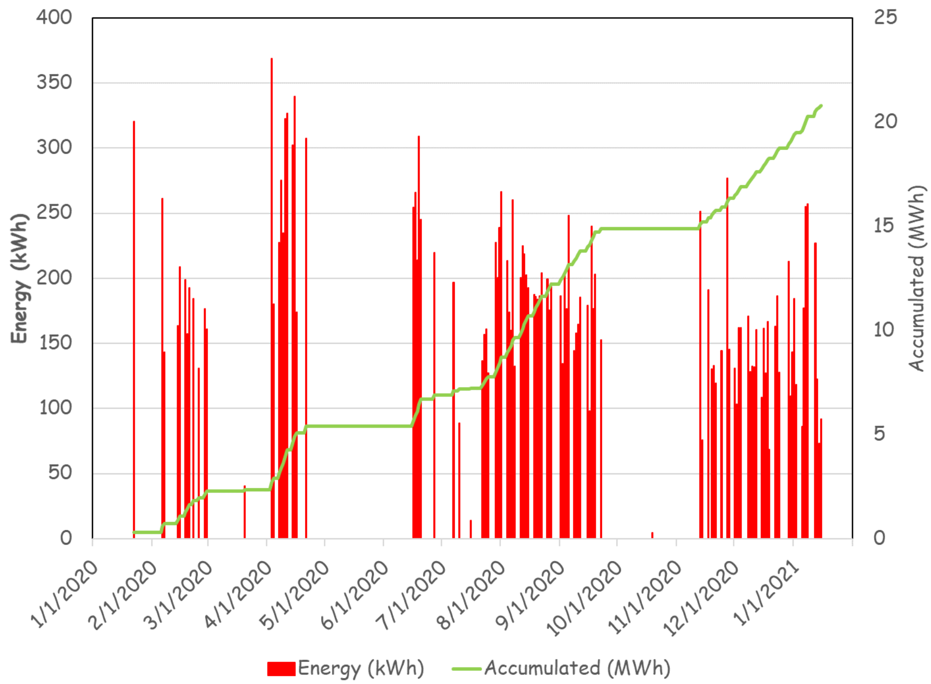

Figure 14. Charge Point - BYD Truck Charging Events and the Amount of Energy Dispensed for Each Charging Session

The BYD truck monitored for this project was the only truck allowed to use this ChargePoint charger. However, the electrical power meter that connected this ChargePoint charger to the power grid, was also connected to other chargers used for several electric hostler trucks in the BNSF Intermodal Yard. Because of this setup, there was no way to directly track the power consumed by the ChargePoint charger and determine that actual electricity cost for the BYD drayage truck, so the overall meter average rates were used.

2.5 SwRI RPECS Data Logger

A general overview of the SwRI data logger is shown in Figure 15. At the heart of the system is SwRI's Rapid Prototyping Electronic Control System (RPECS™). RPECS is a powerful, reconfigurable, crank-synchronous platform capable of high-speed data acquisition and real-time engine control. RPECS includes a wide array of modular hardware and software that can be combined to fill complex research and prototyping needs. The RPECS system has evolved over 20 years of test and engine control technology.

The RPECS system monitored the J1939 CAN communication signals from the drayage trucks. This ability to read the J1939 CAN communication greatly reduced the amount of instrumentation that was needed to meet the project goals and increases the reliability of the system.

The ZANZEFF data logger had 4G LTE system that allowed SwRI staff to access to the collected data and make software changes remotely.

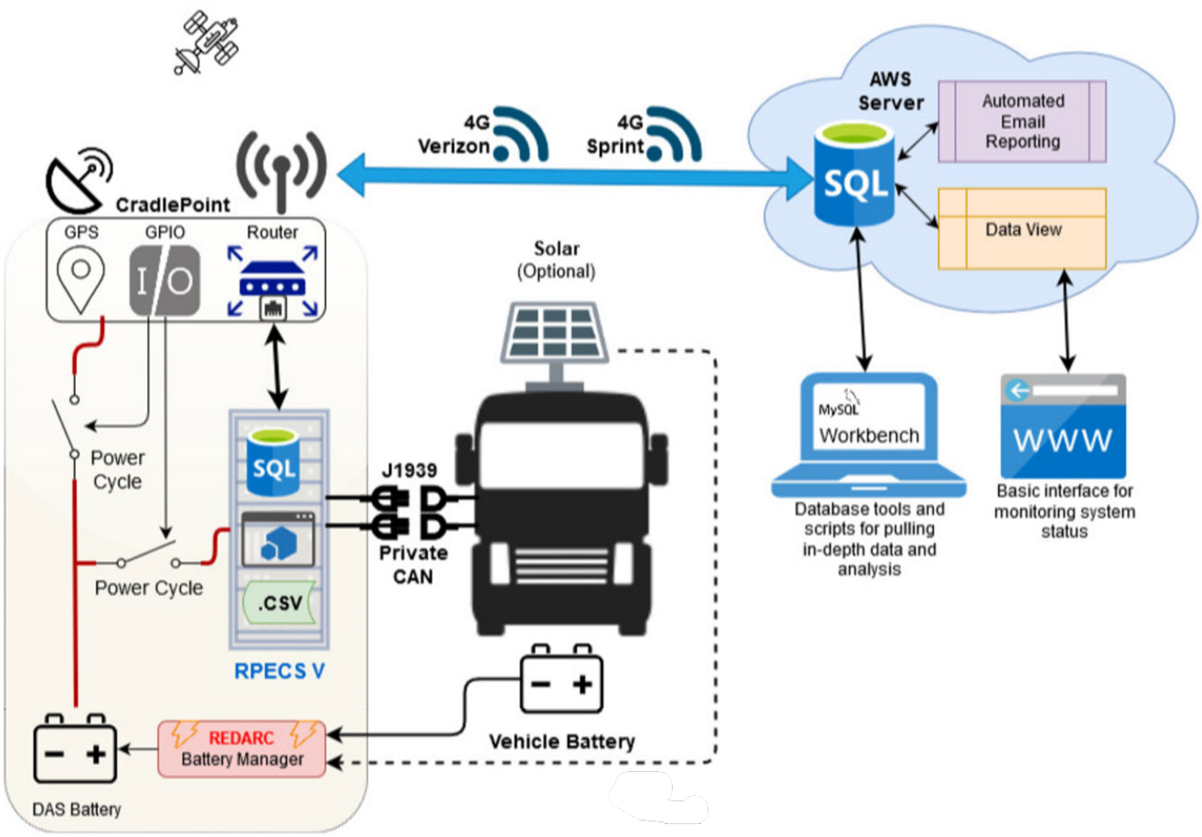

Figure 15. ZANZEFF RPECS Datalogger Overview

Figure 16 shows the RPECS system and GPS antenna installed in the rear area of the drayage truck cabs. The RPECS system was mounted inside of a Pelican case to protect the system from dust, dirt, and other environmental concerns. The GPS antenna was attached to the lid of the Pelican case, which eliminated the need to mount the antenna on the outside of the truck thus eliminating an additional penetration through the truck cab body. The RPECS system was connected to the CAN communication system under the dash of each truck, with the diesel truck location shown in Figure 17.

The J1939 data for the Navistar diesel fueled truck followed the standard protocols. The BYD truck also used J1939 protocols and BYD provided some proprietary Parameters Identifiers, (PIDs) to monitor channels of interest that are unique to this electric truck.

Figure 16. ZANZEFF RPECS Datalogger Mounted in Rear of the BYD Drayage Truck Cab

Figure 17. Location that RPECS Datalogger Tapped into the Diesel Fueled Truck's CAN Port

3.0 VEHICLE OPERATION

The following section discusses data collected from the drayage trucks. First examination of the data showed that the two trucks had different operating cycles. However, a deeper assessment of the data showed that the diesel drayage truck had a large portion of the operation that was outside of the area around the BNSF San Bernardino Yard. The diesel drayage truck operated 57 days (29.2% of the days) in non-BNSF drayage, 67 days (34.4%) operating in BNSF drayage service, and it was parked for 71 days (36.4%). By comparison, the BYD electric drayage operated in non-BNSF drayage service for only 2 days (1.4%), BNSF drayage service 73 days (50.3%), and was parked for 70 days (48.3%). Once the non-BNSF drayage service data was removed from the analysis, the comparison between the two trucks became reasonable.

The following filters were applied to the data to assure that only BNSF Intermodal Yard drayage operation was compiled:

- Limited the data to days that the trucks operated in and around the BNSF yard by visually checking the GPS maps generated for each operating day.
    - No trips to any other yard / location
        - i.e.: UP yard to the south of the BNSF yard, Barstow, East LA, Commerce, Long Beach, …
    - Data was allowed for trips to the surrounding area (i.e.: fuel, food, avoid traffic / construction, ….)
- Removed any "trips" that did not make sense for drayage operation (engineering judgement).
    - Trips that were possibly due to a logic error in the data filter or GPS dithering:
        - Trips more than 120 minutes
        - Trips that were less than 5 minutes
        - Any trip that was less than 0.5 mile

Unless otherwise stated in the following sections, all comparisons will be of drayage operation that was associated with the BNSF's San Bernardino Intermodal Yard.

3.1 Description of Daily Drayage Use / Duty Cycle

Table 4 shows some of the critical daily average data acquired from the two drayage trucks.

Table 4. Typical Drayage Operation - Daily Averages

	Diesel (Total Operation)	Diesel (BNSF Dray)	Electric (BNSF Dray)
Hours of operation	9.1	8.8	9.4
Miles (GPS)	110.6	58.6	45.6
Speed (MPH with Key On)	12.0	7.0	5.2
Loads moved	13.8	8.4	10.5
Idle (Hours)	3.7	4.0	6.4
Idle (Percent)	40.7	45.2	68.3

Figure 18 shows the power consumed by the two drayage trucks and gives a visual representation of the differences in duty cycle. As expected, the electric drayage truck duty cycle shows regeneration of the batteries during some of the braking events (negative power), which does not happen with the diesel drayage truck.

The ground speed duty cycle shown in Figure 19 shows that the Diesel truck has more operation at speeds greater than 50 MPH. The electric drayage literature stated that the truck's maximum speed was 65 MPH but the data collected shows that maximum speed was limited to ~56 MPH.

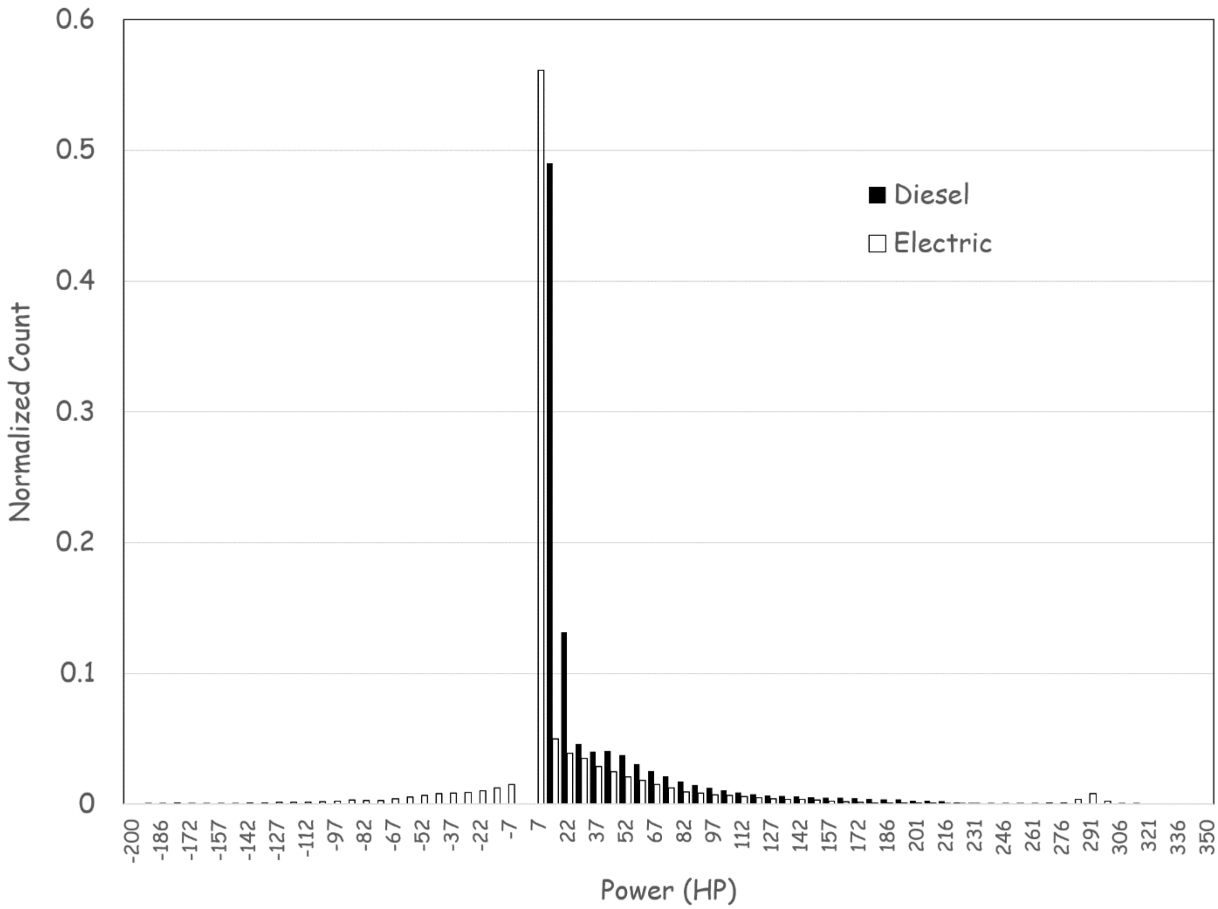

Figure 18. Drayage Truck Duty Cycle - Power

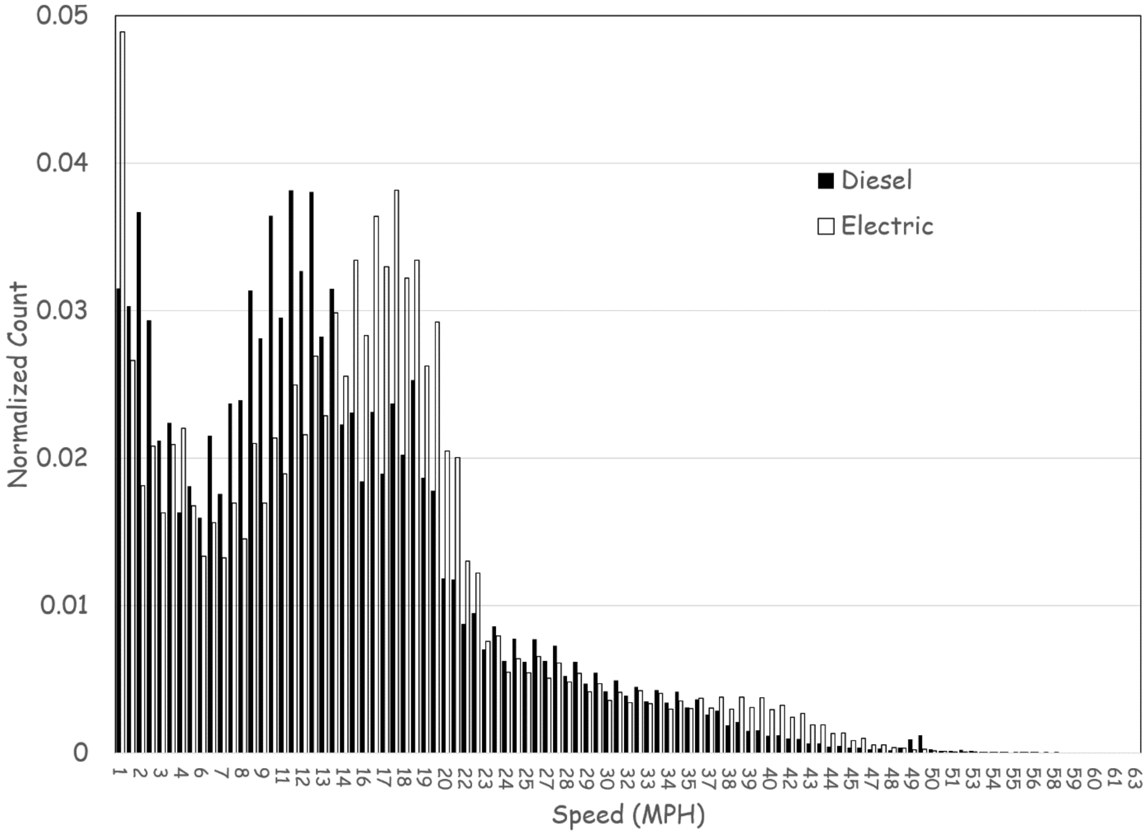

Figure 19. Drayage Truck Duty Cycle – GPS Speed

The following sections cover the parameters identified in "Appendix F" of the grant solicitation.

3.1.1 Hours of Operation Per Day

The average operating time per day was based on the "key on" time for the diesel drayage truck in BNSF drayage truck operation. The electric drayage truck used the following filters to determine the operating time:

1. Key on
2. Not parked at the charging station.
3. Only days associated with BNSF drayage operation.

Based on the criteria, the diesel drayage truck operated an average of 8.8 hours per day and the electric drayage truck averaged 9.4 hours per operating day. Figures 20 and 21 shows histograms of the hours of operation for the diesel and electric drayage trucks. For the histogram, average operating hours for each day was calculated and each day's average operating hours is shown in one of the bins on the X Axis. The Y Axis shows the sum of the days for each of the bins. As an example, Figure 20 has a bin labeled "<5.0" that has 10 samples; meaning that there were 10 days that had less than 5 hours of operation.

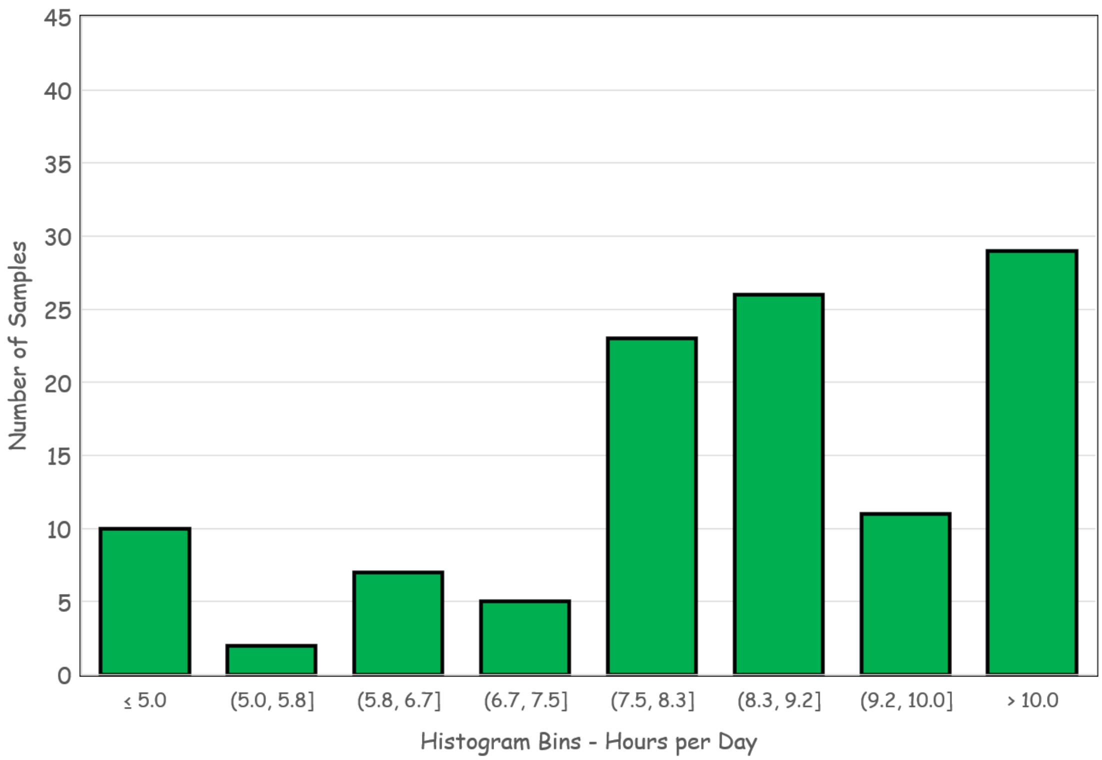

Figure 20. Histogram - Diesel Drayage Hours of Operation per Day

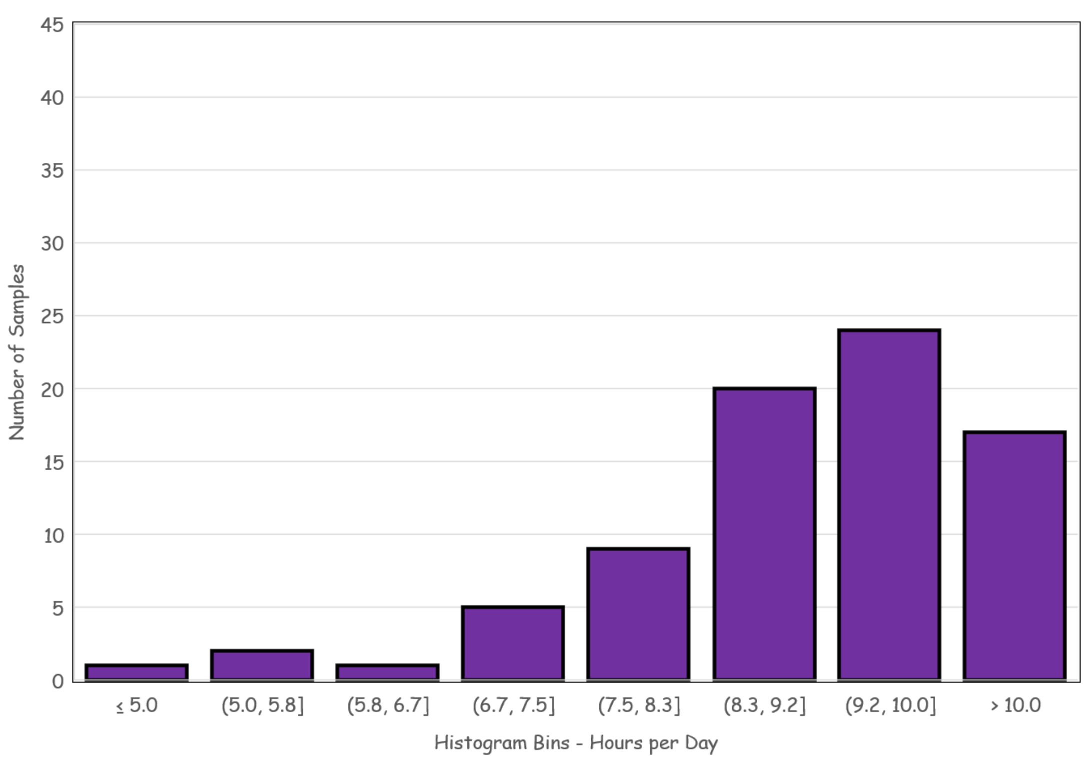

Figure 21. Histogram - Electric Drayage Hours of Operation per Day

3.1.2 Days of Operation Per Year

The RPECS Datalogger was installed on the Diesel drayage truck for a total of 307 days (March 3, 2020 to Jan 11, 2021), the datalogger system was operational for 199 days of this period because the datalogger powered down after ~2 days of inactivity and restarted after the truck was restarted. Data shows that the diesel drayage was operated in BNSF and non-BNSF drayage operation for a total of 114 of the 199 days that the datalogger was operational. Therefore, the diesel drayage operated 57.3% of the days that the datalogger was functioning. Using this information to extrapolate, the diesel drayage truck should operate approximately 209 days per year.

The electric drayage truck was instrumented with the RPECS Datalogger for a total of 271 days (April 15, 2020 to Jan 11, 2021), the datalogger was operational in BNSF and non-BNSF drayage operation for a total of 144 days in this window of time, and the system showed that the electric drayage truck was operated for 80 days of the 144 days that the datalogger was operational. Therefore, the electric drayage operated 55.6% of the days that the datalogger was functioning, which extrapolates to approximately 203 days per year.

3.1.3 Odometer/Hour Meter/MWhr Reading (Quarterly)

There are several assumptions that were applied when calculating the quarterly information in this section. These assumptions are:

- Operation - 5 days a week.
  - 65 working days per quarter.
- Both trucks are 100% available.
  - Any maintenance or repairs will occur during the "off days" when the trucks are typically not used.
  - No time will be taken off for holidays during the work week.
- Milage per Quarter (MPQ) is based on the daily average shown in Table 4.
  - Diesel = 58.6 Mile per Day (MPD)
  - Electric = 45.6 MPD
- Hours per Quarter (HPQ) is based on the average operating time, as shown in Table 4.
  - Diesel = 8.8 Hours per Day (HPD)
  - Electric = 9.4 HPD
- kW-Hour per Quarter (kW-Hr/Q) is based on "Total Charger Power" which is a sum of the battery pack power when the vehicle is charging and does not include electrical losses in the charging process.
  - Diesel = 16.9 Gallons of diesel fuel per day
  - Electric = 137.6 kW-Hr per day

Using these assumptions, the calculated values for the BNSF drayage operation are:

- Miles per Quarter (MPQ):
  - Diesel drayage truck = 3,809 MPQ
  - Electric drayage truck = 2,964 MPQ

- Hours per Quarter (HPQ):
    - Diesel drayage = 572 HPQ
    - Electric drayage = 611 HPQ
- Gallons of diesel fuel per quarter for the diesel drayage = 1,099 Gallons per Quarter
- kW-Hrs per quarter for the electric drayage = 8,944 kW-Hrs per Quarter

3.2 GPS Data

The following data is primarily derived from the GPS used with the RPECS data logger.

3.2.1 Key off / Key on Time

The diesel drayage truck average "key on" time was 8.8 hours per day of operation and the electric drayage truck operated 9.4 hours per day of operation. However, the maximum number of hours in a day with the "key on" was 16.3 hours for the diesel drayage and 17.1 for the electric drayage.

3.2.2 Miles Traveled Per Trip

The "trip" for this project started and ended at the front gate of the BNSF Intermodal Yard where the driver received instructions on where to pick up and deliver the next load. The diesel drayage truck averaged 4.1 miles per load, while the electric drayage truck average 2.7 miles per load. Figures 22 and 23 shows the distribution of the miles per load for the diesel and the electric drayage trucks. As shown in Figure 22, the diesel drayage truck had a wider distribution of miles per trip because of the number of trips made to Rancho East and Rancho West lots. The electric drayage truck had most of the trips within two to three miles, as shown in Figure 23, because this truck focused more on operating directly inside the BNSF Intermodal Yard.

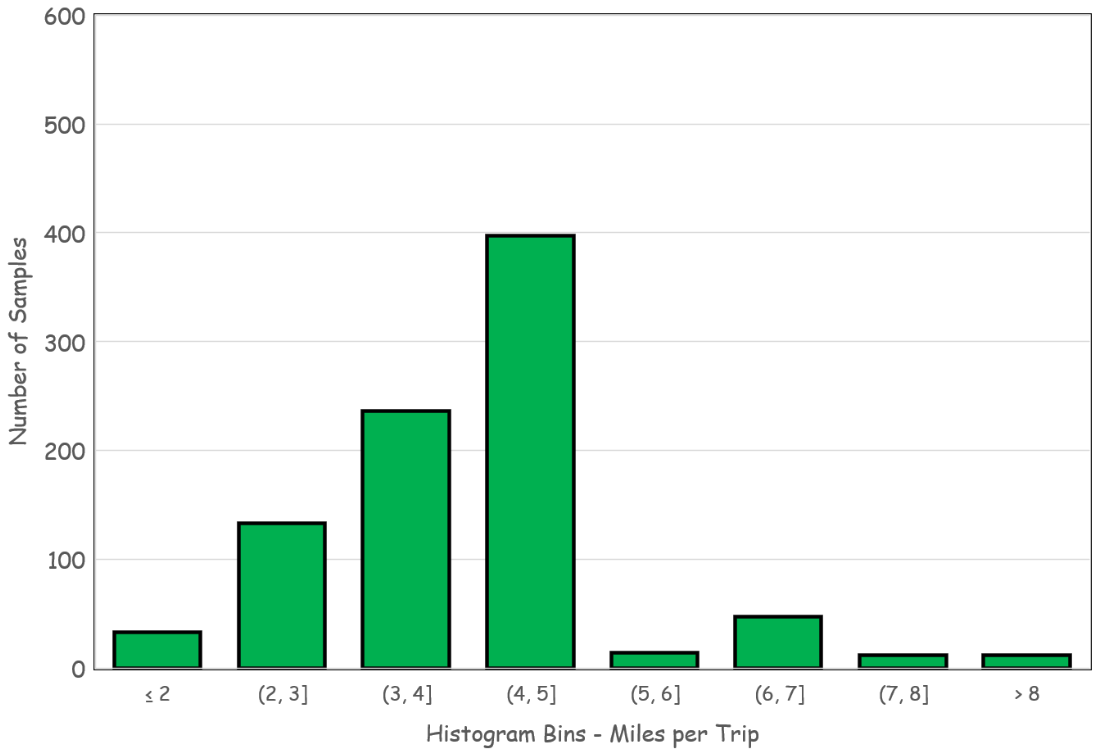

Figure 22. Histogram of Diesel Drayage Truck Miles per Load

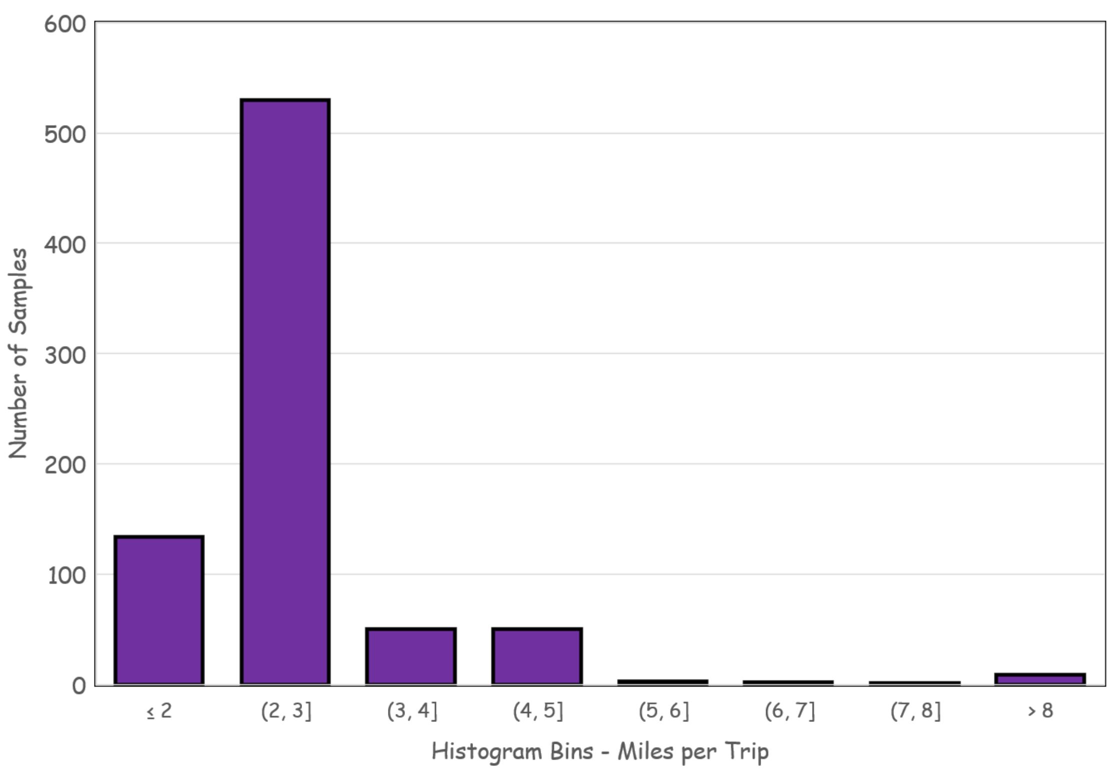

Figure 23. Histogram Electric Drayage Truck Miles per Load

3.2.3 Average Speed

The diesel drayage truck averaged 7.0 Miles per Hour (MPH) and the electric drayage averaged 5.2 MPH. Figures 24 and Figure 25 shows the distribution of average daily speeds for the diesel and the electric drayage trucks.

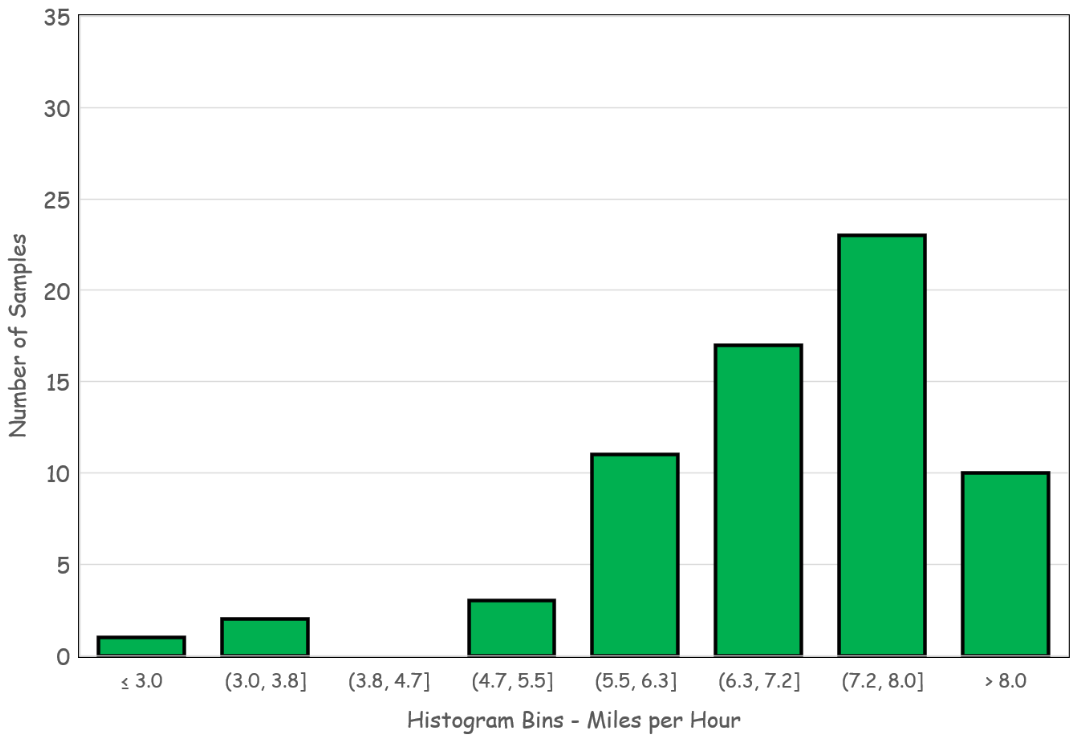

Figure 24. Histogram - Diesel Drayage Average Speed

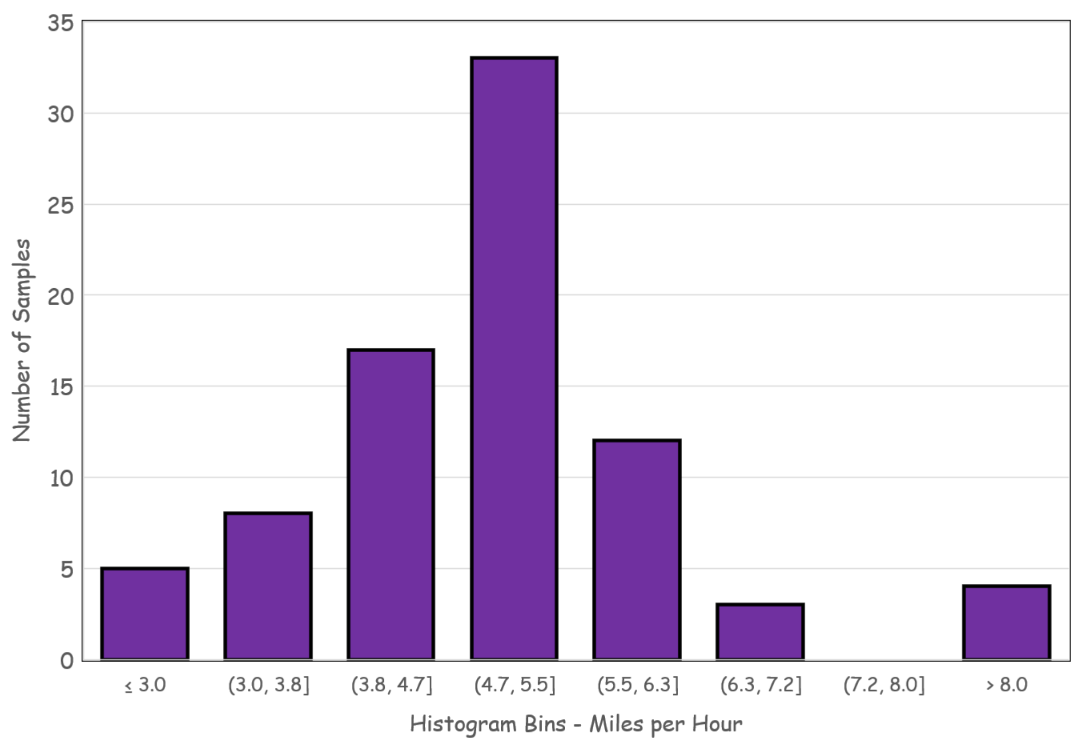

Figure 25. Histogram - Electric Drayage Average Speed

3.2.4 Number of Stops Per Mile

The average number of stops pert mile for the diesel drayage truck was 4.5 and the electric drayage truck averaged 4.1 stops per mile.

3.2.5 Duration Per Trip

The average trip duration for the diesel drayage truck was 33.2 minutes and the electric drayage truck averaged 45.6 minutes.

3.2.6 Idling Time

The diesel drayage truck idled for 4.0 hours over the average day or about 45.2 percent of the time that the key was "on". The maximum time spent idling was 6.5 hours in one day. For the electric drayage truck, the idle time was determined by using the following filters on the data:

1. Key on
2. Not moving
3. Not parked at the charging station
4. Only associated with BNSF drayage operation.

With these filters in place, it was determined that the electric drayage truck "idled" for 6.4 hours per day or 68.3 percent of the time that the truck was operated.

3.3 Battery Charge Capacity/Power Output (Duty Cycle)

The electric drayage truck has a published battery capacity of 409 kW-Hr. The daily average for the electrical system on the electric drayage is shown in Table 5. Based on the average state of charge (SOC) at the start of the recharge event suggests that only 36 percent of the battery capacity had been consumed after an average day of use.

Table 5. Daily Average for BYD Battery and Traction System

Time plugged in (Hrs)	8.1
Time charging (Hrs)	4.7
SOC at start of charge (Percent)	64.3
SOC at end of charge (Percent)	99.2
Total charge power (kW-Hrs)	137.6
Total positive motor power (kW-Hrs)	135.4
Total regeneration power (kW-Hrs)	33.8

4.0 FUEL / ENERGY CONVERSION

4.1 Change in State of Charge (SOC)

The average charge event for the BYD drayage truck increased the State of Charge (SOC) by 34.9 percent, with a minimum increase in SOC of 14.3 percent and a maximum increase in SOC of 73.2 percent. The duty cycle of the battery system can be inferred by the change in SOC of the charging events as shown in the histogram in Figure 26. Most of the change in SOC was between 20 and 45 percent.

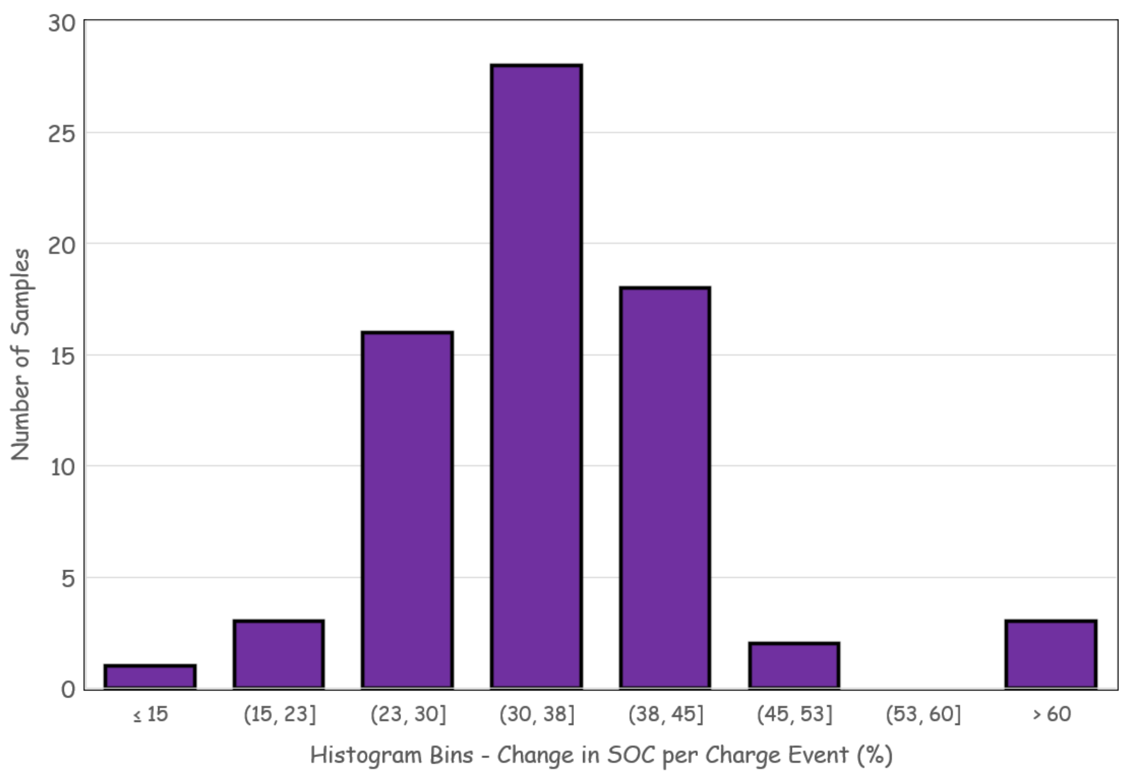

Figure 26. Histogram - Change in State of Charge

4.2 Refueling Time/Charging Time

Charging time for the electric drayage truck averaged 4.7 hours per charge event and a maximum charge duration of 11.6 hours. However, the truck was plugged in to the charger (parked at the charging station) an average of 8.1 hours with a maximum of 17.0 hours. The remaining ~6.4 hours of an average operating day are attributed to the electric drayage having the key off, but not parked at the charging station. Figure 27 shows the histogram of the charging times each day the truck was charged.

This histogram shows the electric drayage truck charging times. The x-axis lists ranges of time in hours with intervals of 2 and the y-axis lists the number of instances in which the charging times occurred. The bars above any given interval correspond to the appropriate number of times in which that specific charge time was achieved. For example, the drayage truck charged between 3 and 5 hours on 11 occasions.

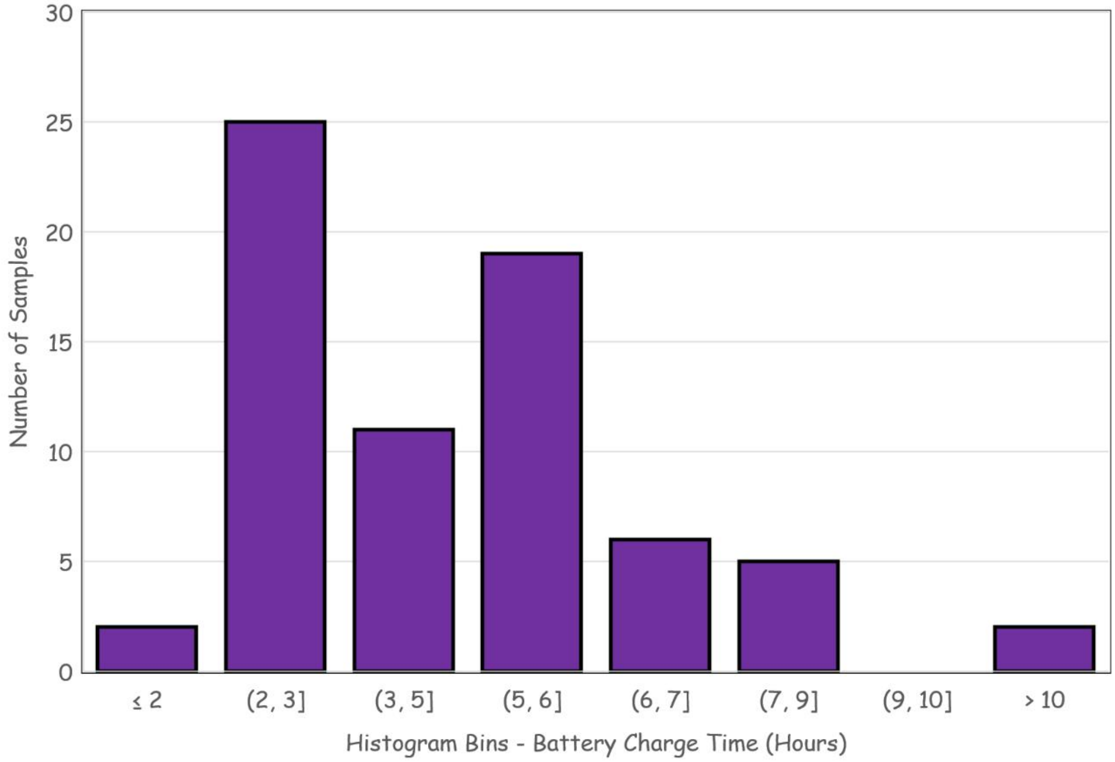

Figure 27. Histogram of BYD Electric Drayage Truck Charging Times

Reviewing the GPS data on the SwRI Diesel Drayage Dashboard showed that the preferred fueling station for the diesel drayage truck was a Chevron station located at 187 North F Street, San Bernardino, CA 92410. This fuel station is part of the G&M Commercial Filling Station network.

The roundtrip distance to the Chevron filling station is approximately 8.5 miles. Figure 28 shows the route typically taken to the filling station, generally at the start of the operating day.

Figure 28. Sample for Diesel Truck Route to Preferred Fuel Station

The preferred filling location for the diesel drayage truck, shown in Figure 29, only has automotive fuel dispensers and the US-EPA limits the maximum pumping rate for automotive fuel dispensers to less than 10 GPM.

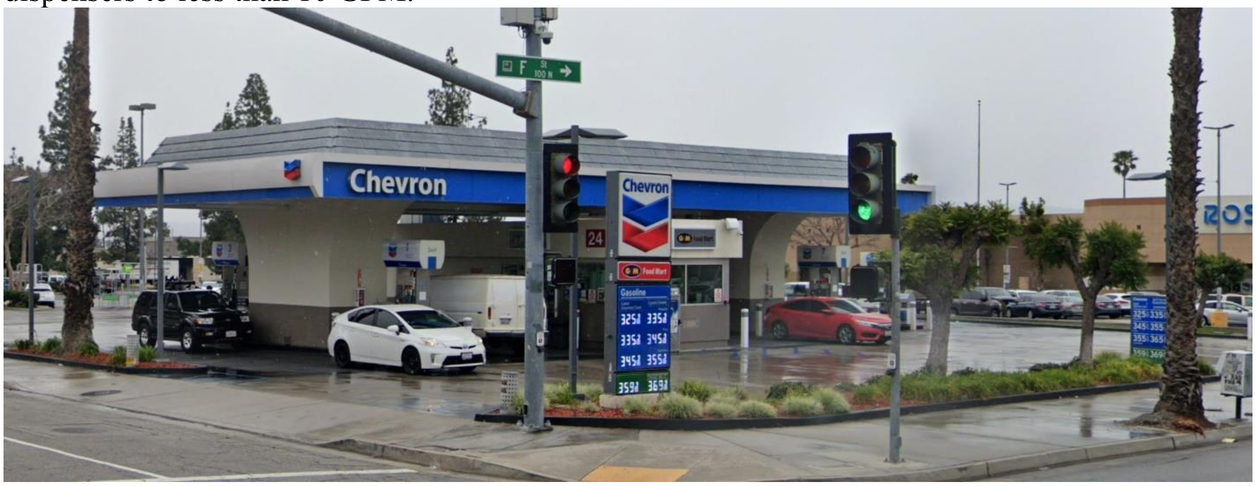

Figure 29. Google Map Street View of the Chevron Fuel Station

The fueling logs from SH&H Inc. (BNSF's contractor operating drayage trucks) shows that the average fuel dispensed was 76.0 gallons and the histogram of the gallons purchased per fueling is shown in Figure 30. This histogram profile appears to be driven by a potential limit of $250 "Net Cost" per fueling event on the G&M Commercial Filling Station charge card and the cost of diesel fuel at the time of the fueling event. The tank was rarely "filled" during the fueling event.

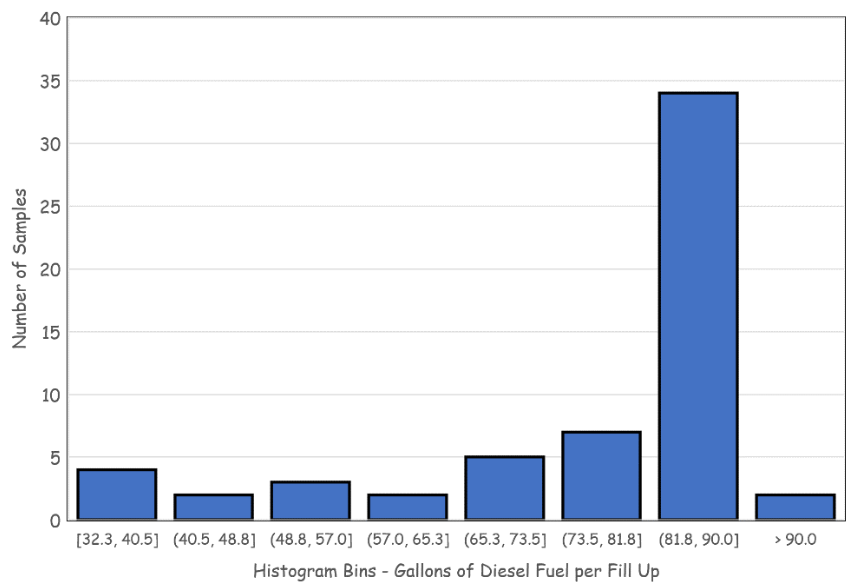

Figure 30. Histogram – Gallons of Diesel Fuel Dispensed per Fill Up

Reviewing the SwRI Diesel Drayage Dashboard, the average fueling trip took 40 minutes (0.67 hours). Most of these trips took place early in the morning, with departures for the fuel station typically between 5:35 AM and 6:35 AM, which likely reduced traffic related delays that might be encountered if the fueling events happed during rush hour. Actual time stationary at the fueling station averaged 19 minutes (0.32 hours), leaving an average round trip travel time of 21 minutes (0.35 hours).

4.3 Refueling/Charge Frequency

The diesel drayage truck refueling frequency was based on the average fueling amount discussed in Section 4.2 "Refueling Time/Charging Time" (76.0 Gallons per fueling event) and the "Fuel Used for Day [gallons]" of 16.9 gallons. Based on these average values, the truck would need to be refilled every 4.5 days of BNSF drayage operation. With a total of 67 days of the diesel truck operating in BNSF drayage service, the diesel truck would need to be refueled ~15 times.

By comparison, the electric drayage truck was charged 75 days of the 78 days that the electric drayage truck was operated. The charging station was located on the BNSF Intermodal facility and this greatly shortens the travel time to the charging station. However, the average charging time for the electric drayage truck was 4.7 hours. For this particular application, the truck was used for a single-shift operation, so the time required to charge the truck was not an issue.

4.4 Vehicle efficiency: Energy/Fuel Consumed Per Unit of Production

The electric drayage truck averaged 10.7 loads per day and the average "Total Charger Power [kw-hr]" was 147.1 kW-Hrs, thus the average energy consumed was 13.8 kW-Hr per load. This calculated value does not include any efficiency losses in the charging station, only the power that was provided to the batteries during the charging event.

There is a CAN parameter for the BYD truck called "Motor Power", different from the "Total Charger Power", but is a strong indicator of the amount of energy that was used, as shown Figure 31. This figure shows all the trips recorded (Open Circles), with three different linear regressions, Non-Drayage, Max Drayage, and Min Drayage. Non-Drayage operation had several trips to a different (non-BNSF) rail yard in San Bernardino as shown in Figure 32, and this is considered non-typical and with no further assessment. The Maximum Drayage route is shown in Figure 33 and this operation consumes 13.1 kW-Hr per trip of motor power. The Min Drayage route, shown in Figure 34, consumed 5.2 kW-Hr Motor Power per trip.

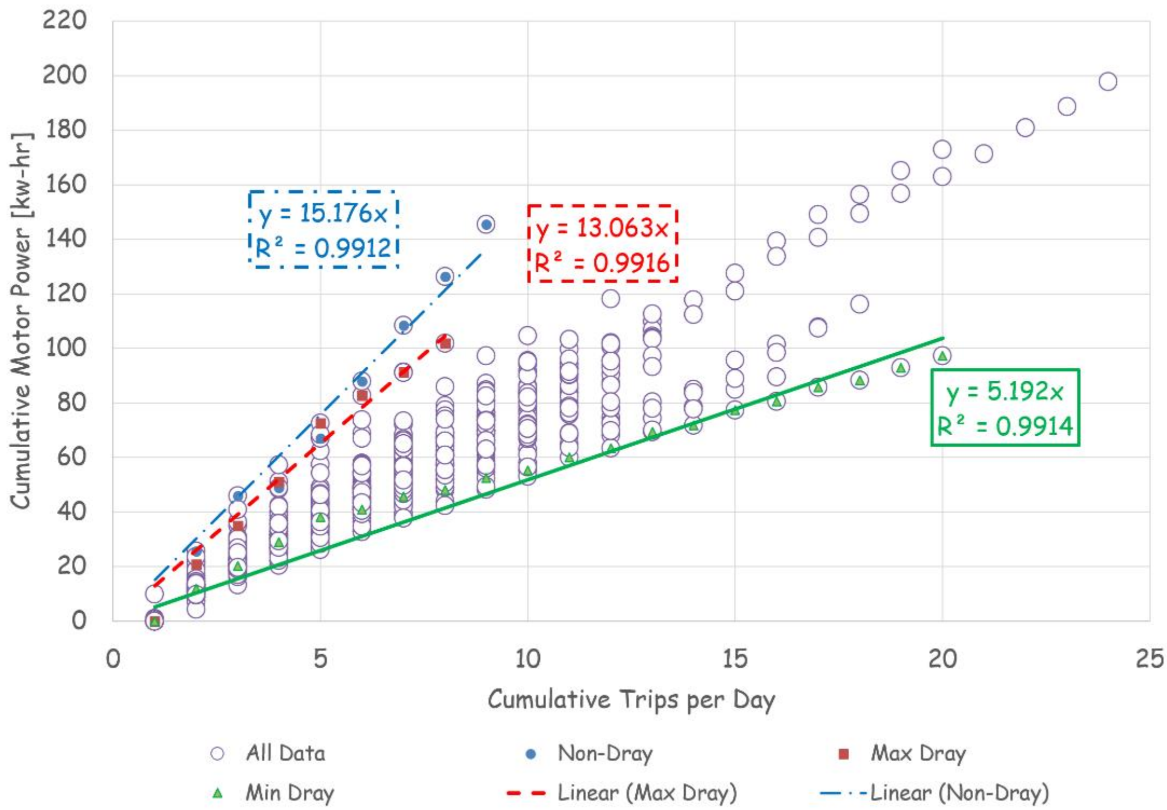

Figure 31. BYD Trips vs. Motor Power

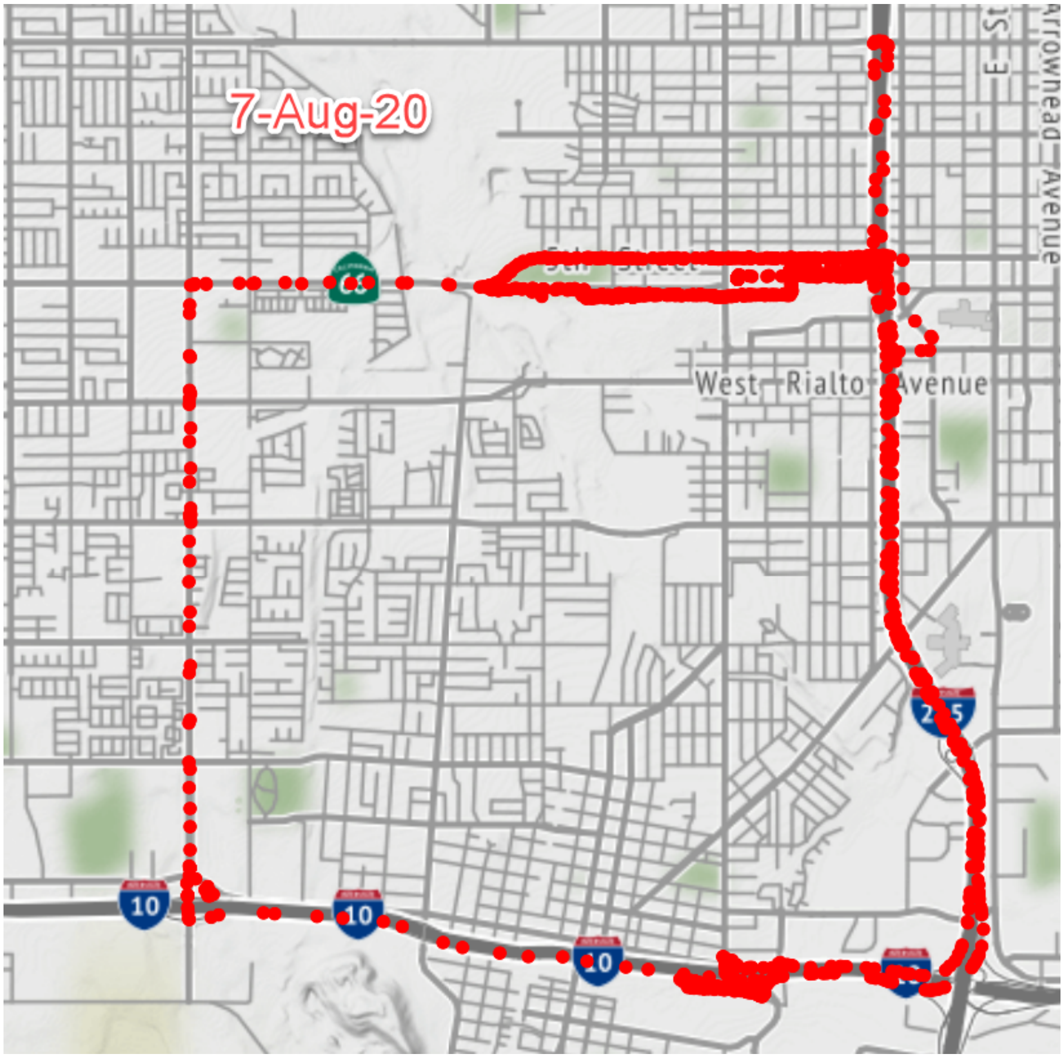

Figure 32. Non-Typical Dray Route

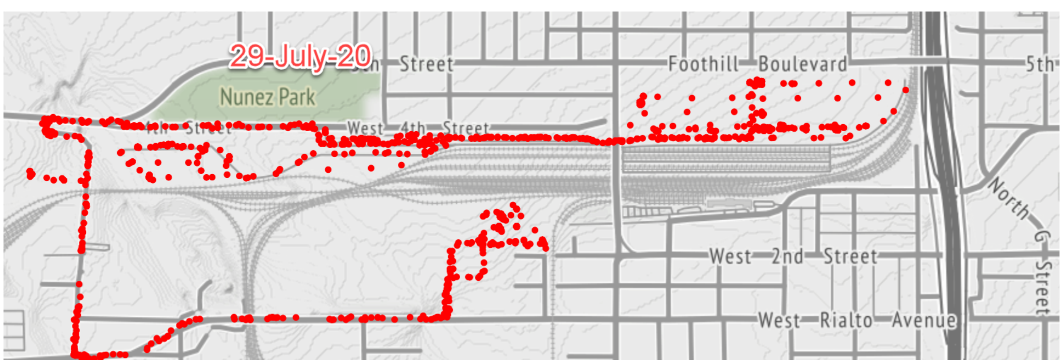

Figure 33. Maximum Power Consumption Drayage Operation

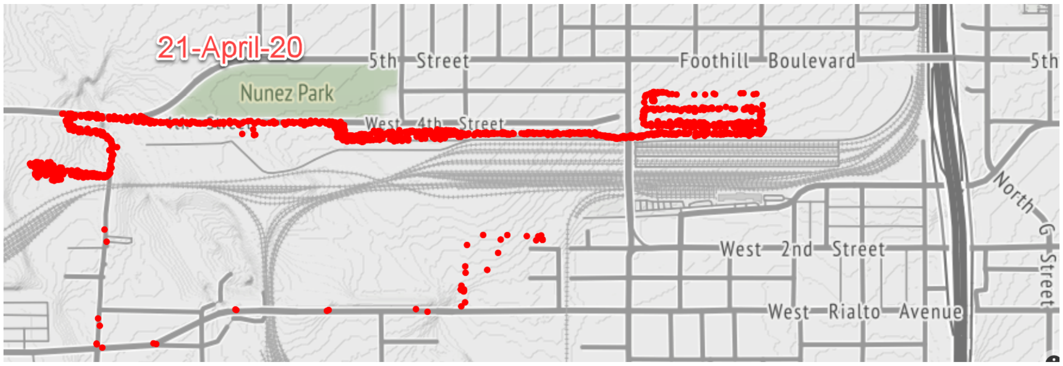

Figure 34. Minimum Power Consumption Drayage Operation

The Motor Power can be used to estimate the Battery Charge power by using a 1.55 multiplier as shown in Figure 35. This multiplier is required to cover the "overhead" needed to operate the truck that is not associated with the traction motors. This would include, but not limited to, the operation of the air compressor (for brake system, …), power steering, head lights, clearance lights, brake lights, cab air conditioner, cab heater, battery temperature management, etc. Using this multiplier, the Minimum Drayage route would require ~8.1 kW-Hr per trip of charge power and the Maximum Drayage route would require ~20.3 kW-Hr per trip of charge power. The average between the Min and the Max was 14.2 kW-Hr per trip of charging power.

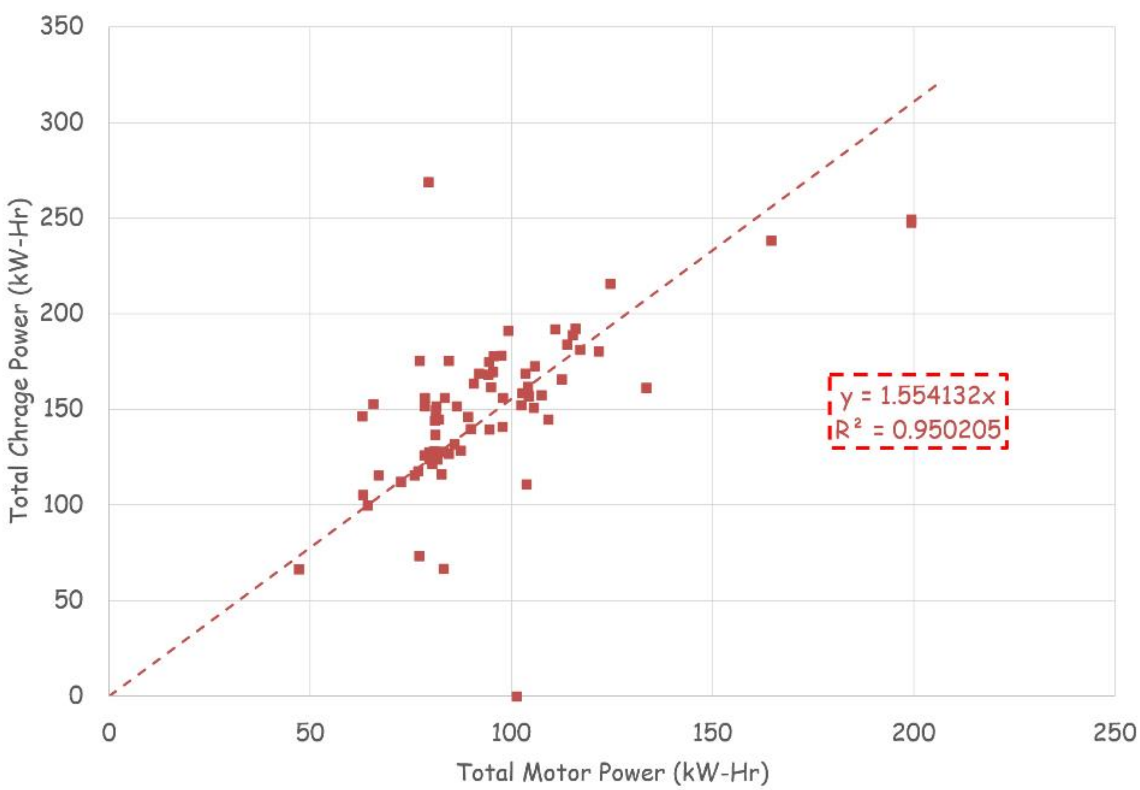

Figure 35. Electric Drayage Truck Relationship Between Total Traction Power and Total Charge Power

The diesel drayage truck average diesel consumption rate was 16.9 gallons per day and averaged 8.4 loads per day, which provides an average of 2.0 gallons per load while in BNSF drayage service.

To compare the two trucks more closely and to generate more of an "apples-to-apples" comparison, five non-concurrent days (listed in Table 6) were further investigated. The days selected because they had similar drayage routes, trips, trips per day, and time of year so that the ambient temperatures are similar. Table 7 shows the average data between the two trucks, which is a much closer comparison than the overall data set that is shown in Table 4. The result of this analysis shows that there is less difference in the cost per load between the two trucks.

Table 6. Days Selected to Accurately Compare Vehicle Efficiency Per Unit of Production

	Electric	Diesel
Day	Date - Trips	Date - Trips
1	7/23 – 10	7/22 – 10
2	7/24 – 10	7/23 – 14
3	7/29 – 8	7/24 – 12
4	7/30 – 12	7/25 – 10
5	7/31 - 13	7/29 – 8

Table 7. Comparison of Data Over the Selected Days

	Electric	Diesel
Avg # of trips per day	10.6	10.8
Avg load distance (total day miles/# of loads)	4.9	5.2
Avg gallons per day	--	14.7
Avg gallons per load	--	1.4
Avg kW-Hr per day	211.1	--
Avg kW-Hrs per load	19.9	--
Diesel Cost ($/Gallon)	--	3.09
Electric Cost ($/kW-Hr)	0.186	--
Cost per load	$3.70*	$4.33

* Does not include electrical losses during the battery charging process.

4.5 Fuel/Energy Consumption at Idling

The electric drayage truck did require power during the time that the truck was not moving, while the key was on. This power was used to operate the air compressor (for brake system), power steering, head lights, clearance lights, brake lights, cab air conditioner, cab heater, battery temperature management, etc. The SwRI Electric Drayage Truck Dashboard showed that the energy consumption when the truck was stationary averaged ~2.0 kW. With an average idle time of 6.4 hours per day, the energy consumed due to idling was 12.8 kW-Hrs per day. This is equal to about $2.38 in electrical cost.

The diesel drayage truck idled on average 4.0 hours per day, which accounted for 45.2 percent of the average daily "key on" time. The SwRI Diesel Drayage Truck Dashboard showed the CAN reported fuel rate of 2.2 Liters per Hours (LPH) or 0.58 Gallons per Hour (GPH), for a total of 2.3 gallons per day for the idle fuel consumption. This equates to $7.11 per day to idle the diesel engine, at an average diesel price of $3.09 per gallon.

4.6 Electric Range / Average Electric Usage as a Function of Trip Duration

On 7-Jan-21, the electric drayage truck was operated for 173.1 Miles in a non-BNSF drayage service. Figure 36 shows the ground speed (kM/Hr) and SOC (%) vs time and Figure 37 shows the truck route, which generated the maximum distance traveled in one day during the monitoring period. The SOC for this day went from 100 percent to 45 percent while working in the BNSF Intermodal yard at San Bernardino (elevation of 1,050 feet) and then making a delivery to Barstow (elevation of 2,238 feet) and returning to San Bernardino. This suggests that the range of the BYD truck is well above the published range shown in Table 3 of 125 miles with this route, loads, ambient conditions, traffic, and changes in elevation.

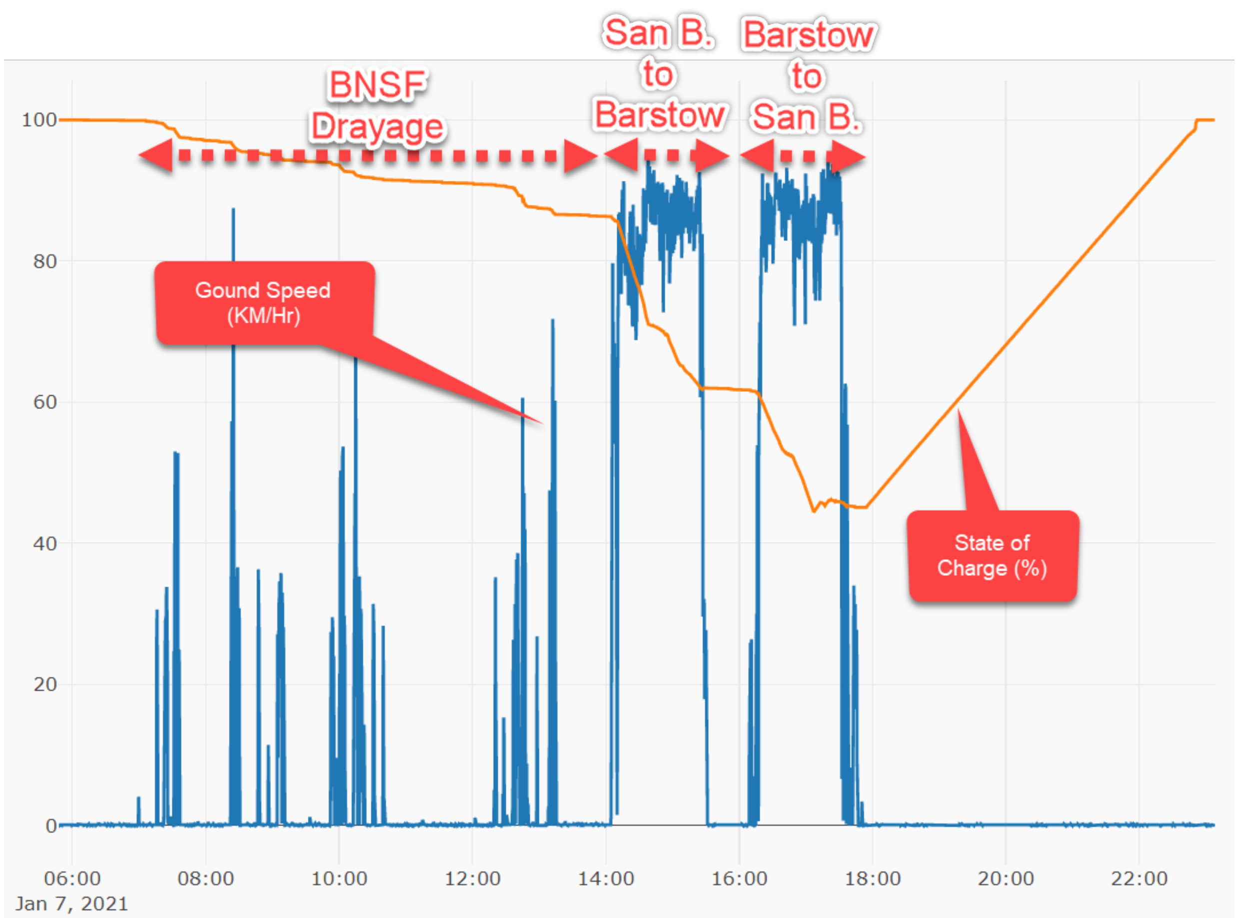

Figure 36. Electric Drayage Truck Non-BNSF Drayage Operation - Ground Speed and SOC vs. Time

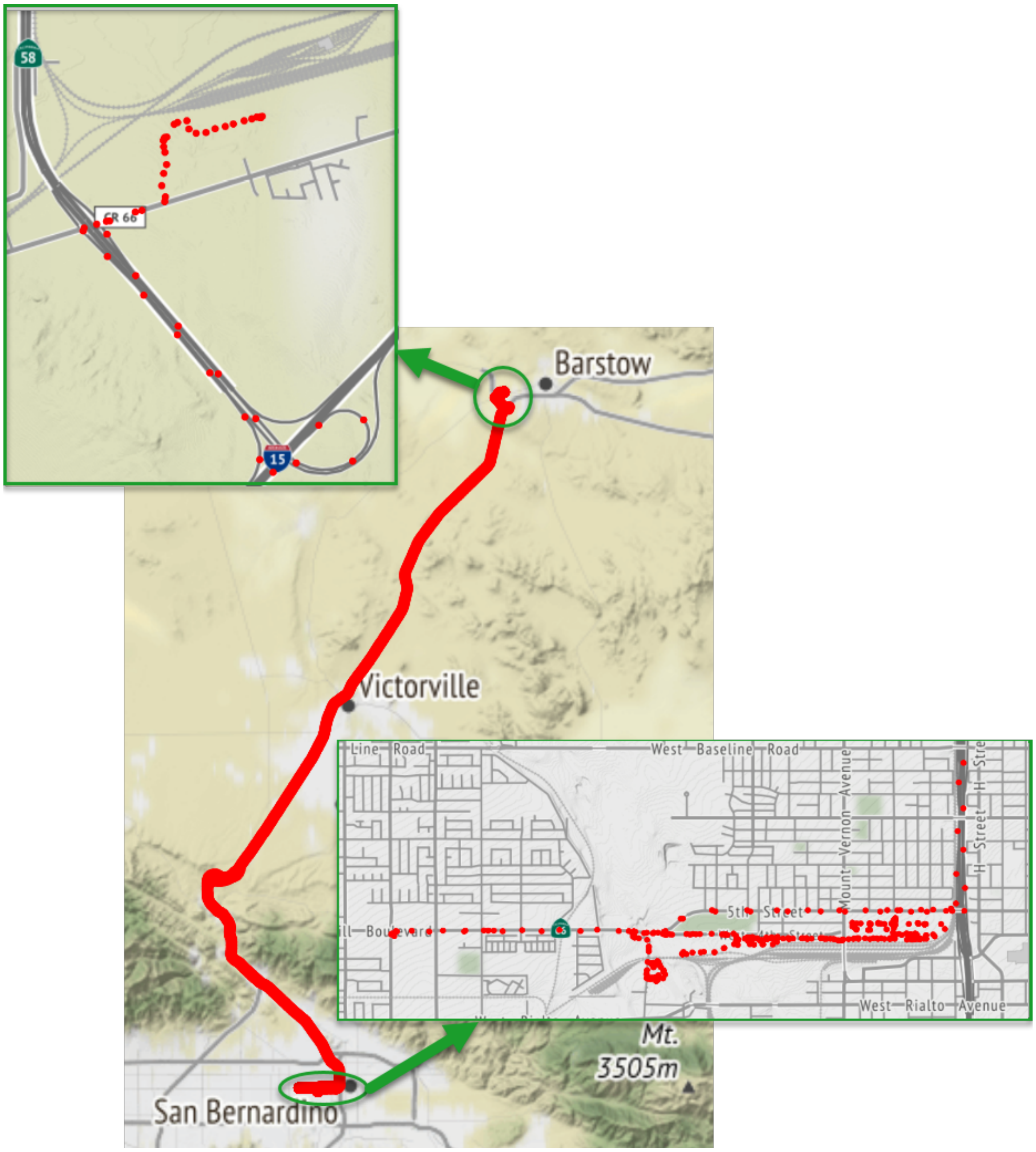

Figure 37. Electric Drayage Truck Non-BNSF Drayage Operation Map

Figure 38 shows the cumulative miles per day vs the total traction power for the BYD electric truck while in drayage service. The non-typical drayage operating data was removed from this data but is shown separately in Figure 38. The total traction power was 2.2 kW-Hr per mile and can be converted to total charge power buy using a multiplier of 1.55 (Figure 35), so the average total charge power while in typical BNSF drayage service is calculated to be 3.41 kW-Hr per mile. With a published battery capacity of 409 kW-Hr, the range for BNSF drayage operation is calculated to be 120 miles [409 kW-Hr / (3.41 kW-Hr / mile)] assuming the BYD truck's control system will allow the battery SOC to go to zero. This calculated range is slightly below, but very close to the published 125 mile range.

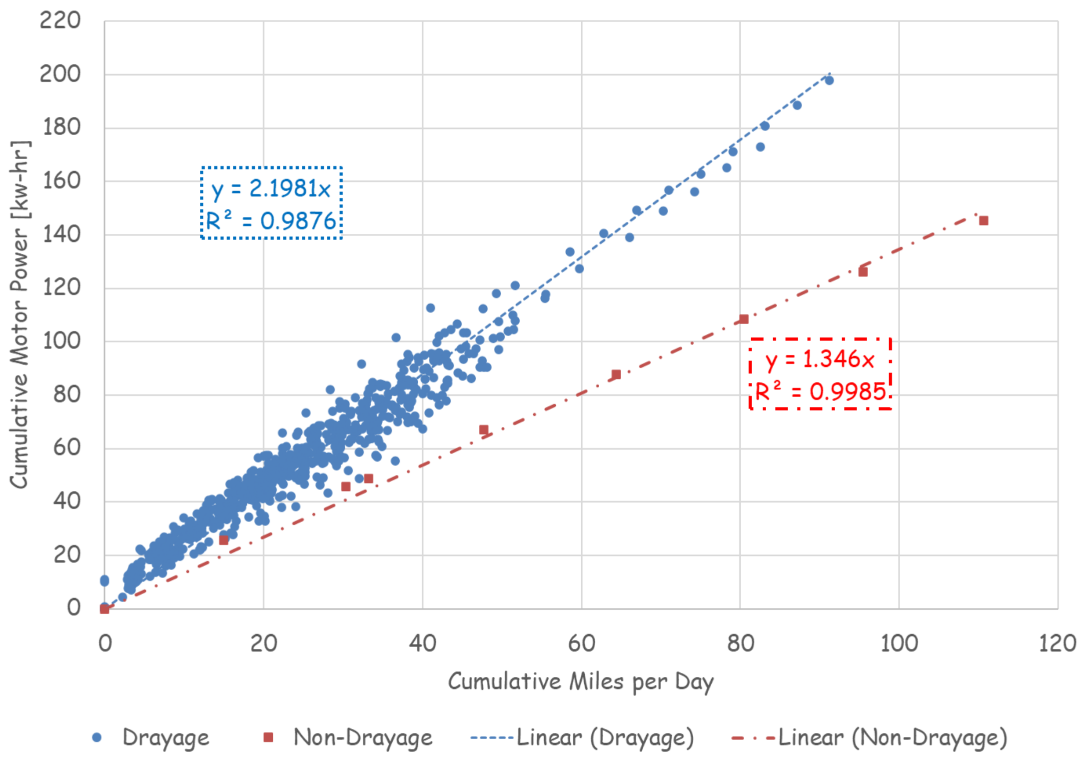

Figure 38. Electric Drayage Truck Miles vs Traction Power

5.0 EMISSIONS TESTING

The system used to measure the exhaust emissions from the diesel fueled drayage truck while operating around the BNSF's San Bernardino Intermodal Yard was a SEMTECH-DS mobile emissions analyzer, like the one shown in Figure 39, which is known as a PEMS unit. The PEMS can monitor the raw exhaust from both spark ignition and compression ignition engines and provides CO, CO2, O2, NO, NO2 and THC emissions concentration.

The PEMS systems used for this project was provided by the US-EPA in Ann Arbor, MI. Training on the PEMS system was held at SwRI's Ann Arbor, Michigan office on 16-October-20 by Carl Fulper of the US-EPA. Mr. Fulper is the PEMS coordinator for the US-EPA.

Figure 39. SEMTECH-DS PEMS System

The PEMS unit was installed behind the truck cab, as shown in Figure 40. The installation required modification to the exhaust system so that the exhaust flow sensor and sampling zone was mounted below the truck cab. PEMS testing on the diesel drayage truck was conducted December 2, 2020, the data was reviewed on December 3^{ed}, and the PEMS equipment was pulled off the truck on December 4^{th}.

Figure 40. PEMS System Installed on Diesel Drayage Truck

5.1 Summary of Emission Testing

Diesel drayage truck completed three loads with the PEMS system installed. The map of the truck route with the PEMS system active is shown in Figure 41. Table 8 shows the results of the PEMS testing on the diesel drayage truck on December 2, 2020.

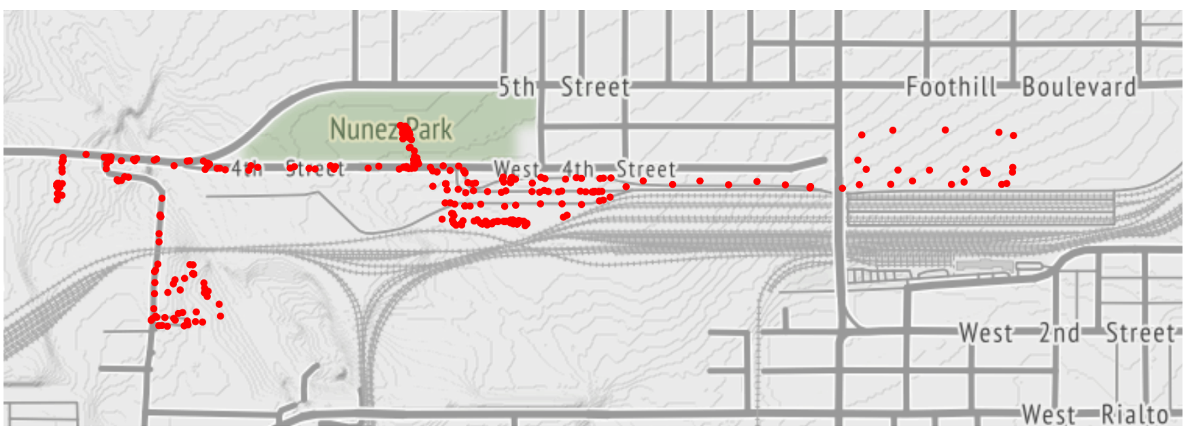

Figure 41. Route of Diesel Drayage Truck with PEMS System Installed

Table 8. Diesel Drayage Truck PEMS Results

Average Distance Traveled per Load (Mile)	2.89 [(A)]
Average Fuel Consumed per Load (Gallon)	0.97 [(B)]
CO_2 (g/Gallon)	10,299
CO (g/Gallon)	21.0
NOx (g/Gallon)	128.7
Corrected NOx (g/Gallon)	111.7
THC (g/Gallon)	5.7
CO_2 (g/Load)	9,973
CO (g/Load)	20.3
Corrected NOx (g/Load)	108.2
THC (g/Load)	5.5

A = Average distance traveled in drayage service was 4.1 mile per load and 5.2 miles per load for the non-consecutive 5 days selected for a detailed comparison.

B = Average diesel fuel per load was 2.0 gallons while in drayage service and 1.4 gallons per load for the non-consecutive 5 days selected for a detailed comparison.

As shown in Table 2, the specific engine "emissions family" for the 2011 Navistar truck tested was BNVXH07570GC. The EPA Certification Database (https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment) shows that the EPA certification NOx level for this engine family is 0.423 g/hp-hr. This emissions level is determined by operating the engine in a tightly controlled and calibrated test cell over the EPA HD transient test cycle which includes a cold-start and a hot-start test.

Comparing this EPA certification value to the PEMS data requires using the following assumptions:

- CARB fuel density = 7.0 lb/Gallon
- Diesel fuel efficiency over the EPA FTP cycle = 0.40 lb/hp-hr.
    - Engineering judgment

With these assumptions, the equation to convert the humidity corrected NOx (g/Gallon) measured during PEMS testing to the same units (g/Hp-Hr) that were reported in the EPA data is:

$$\frac{111.7 \text{ grams NOx / Gallon } * \text{ 0.40 lb / Hp - Hr}}{\text{7 lb / Gallon}}$$

The outcome of this calculation shows that the PEMs NOx emissions was ~6.4 g/Hp-Hr which is ~15 times the US- EPA certification value of 0.423 g/hp-hr. Due to these findings, the diesel drayage truck was sent to an International Truck dealership to investigate the cause of the high NOx emissions.

6.0 MAINTENANCE AND REPAIRS

A summary of drayage truck maintenance and repairs are provided in Attachment B. This summary worksheet was provided by BNSF and included in this topical report for completeness.

Local maintenance and repair technicians did not play an active role in the ChargePoint charger repairs because the equipment was still under warranty during the demonstration period. As noted in Appendix B, the ChargePoint (CP) charger had a total of 79 days of down time. The first CP repair occurred between 6-March-20 and 3-April-20 (total of 28 days) and resulted in the charger being completely replaced under warranty. The second CP repair was completed between 25-Sept-20 and 13-Nov-20 (total of 51 days). This repair was problematic due to the need for the CP staff to be eRailSafe certified before they could access the BNSF property and then the availability of the repair parts. It was determined that the "power module" had failed and this repair also required a "data repair kit". The second repair was estimated to be $10,000 in parts and an additional $325 labor, but these costs were covered by CP's "assure station warranty".

There was only one logged repair of the BYD drayage truck; a repair that was driven by a motor overheating alarm. The repair occurred between 20-April-20 and 22-April-20 (a total of 2 days) and consisted of an upgrade to the high voltage unit software. The new software provided a new threshold temperature for motor overheating alarm. The cost for this repair was ~$150.

The diesel drayage had three logged repairs, but the duration and timing of the repairs are difficult to extract from the provided data. The three repairs were:

1. Wiring issue with the truck / trailer light connection at the rear of the truck cab.
    a. No start or stop dates were listed.
    b. The worksheet showed 5 days need to complete the repairs.
2. Replacement of the high-pressure common rail pump and EGR valve.
    a. Start date was 1-Oct-20, but no completion date was listed for this repair.
    b. Without a completion date or elapse time being listed, there is no way to determine the total number of days required to complete the repair.
    c. The datalogger did not restart until 2-Dec-20 due to dead batteries in the datalogger system.
        i. Caused by the extended time that the truck engine did not operate.
3. Replaced three batteries
    a. Start and stop date for the repair was 24-Nov-20, so it is assumed that the repair took less than one day.

At the time of this report, no additional information about repairs on the diesel drayage truck has been provided. However, in mid-February 2021, S&H took the diesel drayage truck to a Navistar dealer to complete repairs to correct the higher than expected engine out exhaust emissions.

7.0 CONCLUSIONS

This report documents datalogging results comparing a BYD electric drayage truck and a diesel fueled drayage truck. While this topical report does not address the capital cost for the BYD electric drayage truck, the installation and purchase cost of the battery charger system, maintenance and other associated costs, the report does allow for an energy and emissions comparison for the operation of the trucks.

Some of the notable observations for the two trucks are:

Loads per day: The diesel drayage truck averaged 8.4 loads per day while traveling 58.6 miles, with an average speed of 7.0 MPH. The electric drayage truck averaged 10.7 loads per day while traveling 45.6 miles, with an average speed of 5.2 MPH. Most of the electric drayage operation was inside the BNSF Intermodal Yard.

Hours of operation per day: The diesel truck averaged 8.8 hours per day, typically operating 5 days per week. The electric drayage truck operated for an average of 9.4 hours per day, also operating 5 days per week.

Energy consummation per load: The diesel drayage truck consumed an average of 2.0 gallons of fuel per load and at an average price of $3.09 gallon for diesel fuel, the cost per load was $6.18. The electric drayage truck consumed 14.2 kW-hr per load and assuming an average cost of electricity of $0.186 kW-Hr, the cost per load was calculated to be $2.64. However, the electric energy cost could be much higher during the peak charging periods (Time Related Demand (TRD) charges where the rate varies with time of year and time of day).

There was a difference in the "typical" operating cycle between the diesel and electric drayage trucks while operating in the BNSF Intermodal Yard. To calculate an "apples-to-apples" comparison, five non-consecutive days were selected to give a better comparison of energy and cost per load between the two trucks. These five days were selected because of the common distance traveled, loads per day, hours of operation per day, and a common time of year to minimize the differences in ambient conditions. The outcome of this additional review showed that the diesel truck consumed an average of 1.4 gallons per load with a diesel fuel cost of $4.33 per load. The electric drayage truck consumed an average of 19.9 kW-Hr per load over these five days and the electrical cost was $3.70 per load.

Refueling: The average refuel event for the diesel drayage truck occurred every 4.5 days and the average time required to complete a fueling event was 40 minutes (0.67 hours), which includes the round-trip travel time. The electric drayage truck was plugged in an average of 8.1 hours per day over 75 of the 78 days that the electric truck was used and the average charge time was 4.7 hours of the plugged-in time. The average charge power was 135.4 kW-Hr to take the State of Charge (SOC) from 64.3 percent to 99.2 percent.

Emissions: The diesel drayage truck was fitted with a portable emissions analyzer (PEMs) and the PEMs calculated NOx emissions was ~6.4 g/Hp-Hr which is ~15 times the US-EPA certification value of 0.423 g/hp-hr. Due to these findings, the diesel drayage truck was sent to an International Truck dealership to investigate the cause of the high NOx emissions.

The data shows that the BYD electric drayage truck is “fit for purpose” in the BNSF San Bernardino Intermodal Yard. This assessment is based on the availability of the truck, the loads per day, speed that the truck was able to complete the loads; all of which was analogous to the diesel fueled drayage truck.

Attachment A
SwRI's Reporting Requirements - Drayage Truck

	Drayage Diesel	Drayage Electric
Appendix A - Vehicle Specification		
Manufacturer	SwRI	SwRI
Model	SwRI	SwRI
Model year	SwRI	SwRI
Gross vehicle weight	SwRI	SwRI
Fuel type	SwRI	SwRI
Propulsion system description	SwRI	SwRI
Engine label photos	SwRI	NA
Appendix B - Vehicle Operation		
Description of daily use / duty cycle	SwRI	SwRI
Vehicle usage:		
Hours of operation per day	SwRI	SwRI
Days of operation per year	SwRI	SwRI
Odometer/Hour meter/MWhr reading (quarterly)	SwRI	SwRI
GPS data:		
Key off / Key on	SwRI	SwRI
Miles traveled per trip	SwRI	SwRI
Average speed	SwRI	SwRI
Number of stops per mile	SwRI	SwRI
Duration per trip	SwRI	SwRI
Idling/queuing time	SwRI	SwRI
Battery charge capacity/power output (duty cycle)	NA	SwRI
Appendix C - Vehicle / Equipment Performance		
Vehicle zero emission range/work performed per charge	NA	BYD
Appendix D - Fuel / Energy Consumption		
Amount of fuel/electricity fueled	SH&H	BNSF
Fuel price per unit when a vehicle is fueled	BNSF	BNSF
Include electricity rates as applicable	BNSF	BNSF
State of charge (SOC) increase, if applicable	NA	SwRI
Refueling time/charging time	NA	SwRI
Refueling/charging source:		
Grid	NA	BNSF
On-site fueling	SH&H	NA
Refueling/charge frequency	SwRI	SwRI
Vehicle efficiency: energy/fuel consumed per unit of production	SwRI	SwRI
Fuel/energy consumption while idling (if applicable)	SwRI	SwRI
All-electric range and average electric usage in hybrids as a function of trip duration and work output, if applicable	NA	SwRI
Appendix E - Maintenance		
Type of maintenance:		
Scheduled	SH&H	SH&H
Unscheduled	SH&H	SH&H
Equipment modification	SH&H/BNSF	SH&H/BNSF
Repairs:		
Date	SH&H	BYD
Description of problem	SH&H	BYD

Description of repair performed	SH&H	BYD
Parts replaced	SH&H	BYD
Odometer/hour meter reading	SH&H	BYD
Actual repair time	SH&H	BYD
Time out of service W/ explanation for extended delay	SH&H	BYD
Appendix F - Safety		
Service interuptions or delays: (relevant issues that drove SI or delays)		
Equipment malfunction caused	SH&H/BNSF	SH&H/BNSF
Other relevant causes	SH&H/BNSF	SH&H/BNSF
Appendix G - Emissions Testing		
Tailpipe emissions test for vehicles/equipment that are not 100% zero emission, and their respective baseline vehicles/equipment using PEMS technology.	SwRI	NA

Attachment B
Charger Repairs

Start Date	End Date	Elapsed Time (Days)	Affected Component	Impact	Root Cause	Repairs Made	Parts Replaced	Cost to Repair	Repair Time (hrs)	Odometer/ Hour Meter Reading	Comments
	Feb	5	Dray Truck	Marker Light Malfunction	Shorted wires on 7 pin connection	Rewiring	N/A	$225.00	1.5		When connected to the trailer, the marker lights only come on when operator hits the brakes. Issue caused by shorted wires at the tractor trailer 7 pin connection. Technician rewired 7 pin connector, fixed the issue.
03/06/20	04/03/20	28	Dray Charger - CP	No Charging	Unknown	Replaced charger	Charger (complete unit)	Warranty		N/A	
04/20/20	04/22/20	2	Dray Truck	Engine Overheating		High-voltage unit software upgrade	Software	$150.00	1		Upgraded the 6 in 1 high voltage unit software. The new software sets up new threshold temperature for motor overheating.
09/25/20	11/13/20	51	Dray Charger - CP	No Charging / Limited Power	Power Module failure	Replaced Power Module and PM data repair kit	PM and data repair kit	$10,325	2		Factors in repair delays include eRailSafe certification for repair technicians and repair part availability; power module part expense = $10K + $325 labor; Repair covered by CP "assure station warranty."
10/01/20		?	Diesel dray truck	Air Intake / Stuttering Engine		Replaced core high pressure pump, EGR value					
11/24/20	11/24/20	0	Diesel dray truck			Replaced 3 batteries		$400			