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

BNSF Contract Number BF 10015561

TOPICAL REPORT: SIDEPICK

SwRI Project 03.24318

Prepared for:
BNSF Railway Company
ATTN: Michael Cleveland
2500 Lou Menk Drive
Fort Worth, TX 76131

Prepared by:
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May 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

CARB	California Air Resources Board
CO	Carbon Monoxide
CO2	Carbon Dioxide
COFC	Container on Flat Car
corr NOx	Corrected Oxides of Nitrogen
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
ECM	Engine Control Module
EGR	Exhaust Gas Recirculation
EIA	U.S. Energy Information Administration
g	Grams
gal	Gallon
GHG	Greenhouse gas emissions
GPS	Global Positioning System
ISO	International Organization for Standardization
ITS	Intermodal Transportation and Rail Services
kg	Kilograms
kph	Kilometer per Hour
kW-Hr	Kilowatt-Hour
NOx	Oxides of Nitrogen
PEMS	Portable Emissions Measurement Systems
RPECS^{TM}	Rapid Prototyping Electronic Control System
RTG	Rubber Tire Gantry Crane
S Cal Edison	Southern California Edison
SCR	Selective Catalyst Reduction
side pick	Side Pick Container Handler
SJVAPCD	San Joaquin Valley Air Pollution Control District
SOC	State of Charge
SwRI	Southwest Research Institute
Taylor/Mi-Jack	Taylor Machine Works
THC	Total Hydrocarbons
TOFC	Trailer on Flat Car
ULSD	Ultra-Low Sulfur Diesel
US-EPA	United States Environmental Protection Agency
VAC	Volt of Alternating Current
ZANZEFF	Zero and Near Zero Emission Freight Facilities

ACKNOWLEDGEMENTS

SwRI would like to thank the following:

- BNSF Railway for the opportunity to participate in this program.
- San Joaquin Valley Air Pollution Control District (SJVAPCD).
- ITS for its accuracy of San Bernardino fueling logs.
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- Support from SwRI's Ann Arbor MI office for setup and support of the data loggers.
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- Staff at BNSF for all their help in making this project a success.

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CALIFORNIA CLIMATE INVESTMENTS
Cap and Trade Dollars at Work

EXECUTIVE SUMMARY

This Topical Report summarizes datalogger monitoring of two Side Pick Container Handlers (side picks) at BNSF Railway's San Bernardino Intermodal Facility during 2020-2021. The side picks are very large forklifts for handling ISO shipping containers. A diesel baseline side pick was compared to a battery-powered counterpart procured and deployed under BNSF's ZANZEFF grant.

The diesel side pick averaged 4.3 operating hours per day and consumed an average of 12.7 gallons of diesel fuel with an average cost of $1.23 per lift. The most active day for the diesel side pick used 53 gallons of diesel fuel over 15 hours of operation, and performed 299 lifts. The diesel side pick fuel tank had a capacity in excess of 200 gallons, which would imply 56 hours of continuous activity before refueling. Typical refueling of the diesel side pick was once a week. Refueling time was measured in minutes and could be done anywhere in the yard.

The electric side pick had a fairly large battery pack, with a 922 kW-hr capacity, and was estimated that a single charge could perform approximately 288 lifts over 25 hours of continuous operation. The typical daily use was observed to be 3.8 hours. A charge once a day or night is sufficient to keep the battery charged. The electric side pick requires up to 5 hours to fully recharge, but typically requires far less time. The electric side pick needed to be brought back to the charging station once per day. The electric side pick used an average of 188 kW-hrs of energy per its 3.8 hour operating day, and an electricity cost of $1.41 per lift.

The electric side pick was never utilized to its full potential, and there were many days during the monitoring period when it was not used. The initial training instructed the operators to return the electric side pick to the charging station to be charged when on break, during lunch, when not in use, etc. This might have given the operators the false impression that the electric side pick might not have enough battery capacity to make it through a full day of work. This "range anxiety" and the need to traverse the operating lot back to the charging station likely resulted in the operators preferentially choosing the diesel side pick over the electric side pick. However, the data from this study showed that the performance of the electric side pick was equivalent to its diesel counterpart.

Using a typical four hours per day of side pick operation, and a 10 percent maintenance or out of service time, the estimated annual diesel fuel and emissions reduction of replacing the diesel side pick with an electric side pick are presented in Table ES-1, assuming that the roughly 62,000 kW-hr of electricity needed to replace the diesel has zero GHG or criteria emissions.

Table ES-1. Estimated Annual Diesel Fuel and Emission Reductions by Replacing a Diesel Side Pick with an Electric Side Pick

Days of Operation (90 percent up time)	329
Annual Diesel Fuel Savings (gallons)	4,180
CO_2 (kg)	62,800
CO (kg)	124
Humidity-Corrected NOx (kg)	94
Total Hydrocarbons (kg)	2
Annual Electricity needed to Replace Diesel, kW-hr	62,000

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 locomotive phase of the ZANZEFF project.

2.0 BACKGROUND

SwRI supported the ZANZEFF project by collecting data on locomotives, rubber tire gantry crane (RTG), side pick cargo handler, and drayage trucks with examples shown in Figure 1.

Figure 1. Types of Equipment to be Instrumented

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 foot 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). BNSF's major customers for this facility are:

- Amazon
- BMW

- Nordstrom Rack
- Rite Aid
- Ross
- The Home Depot
- Walmart

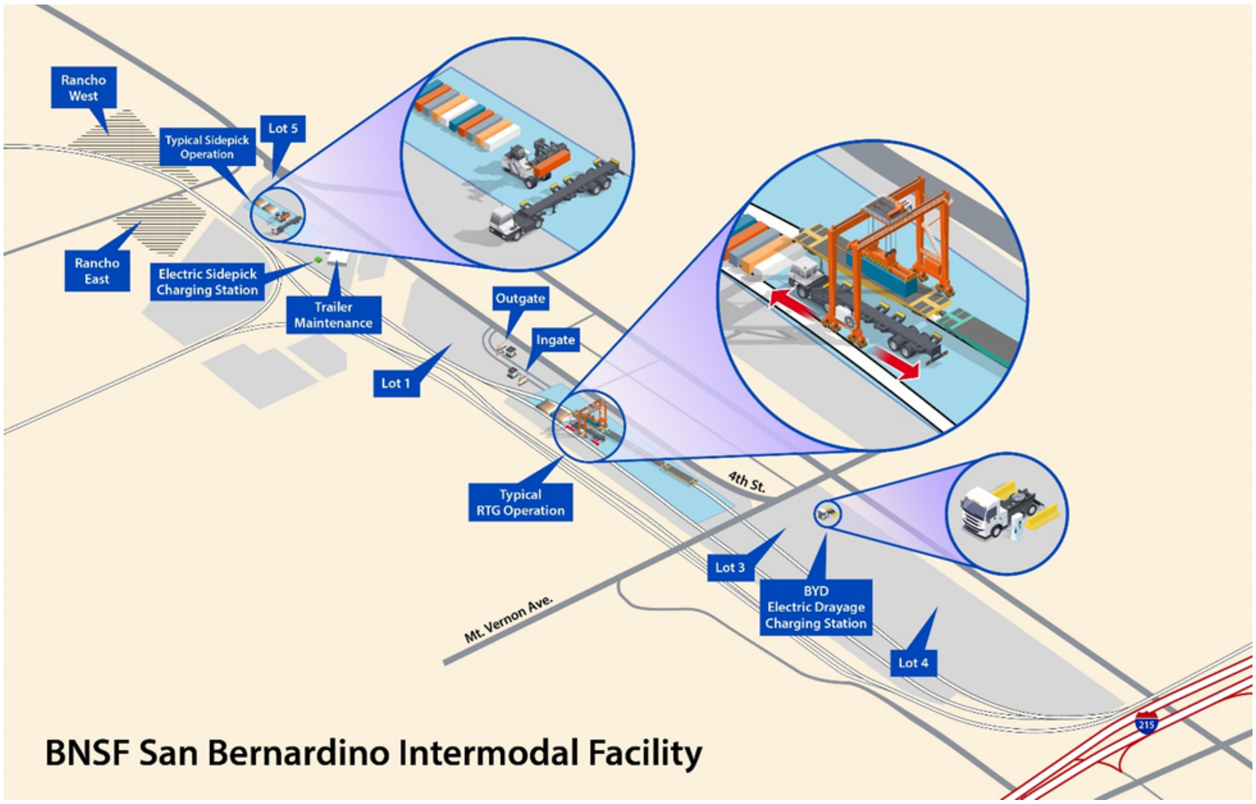


Figure 2. Layout of the BNSF San Bernardino Intermodal Facility

The Side Pick Container Handler (side pick) is a very large forklift for handling ISO shipping containers. They are generally used for transferring shipping containers from drayage or hostler trucks equipped with intermodal chassis trailers. The shipping containers can be transferred to another truck or stacked on the ground for later use. This facility had one (1) diesel side pick at the start of the program, a 100 percent electric side pick was procured and deployed at this facility as part of this project. Both side picks were usually confined to Lot 5 where the empty shipping containers are stored. The side picks do not accumulate a lot of mileage during daily use. Figures 3a, 3b, 3c, and 3d show the typical extent of their daily travel within Lot 5.

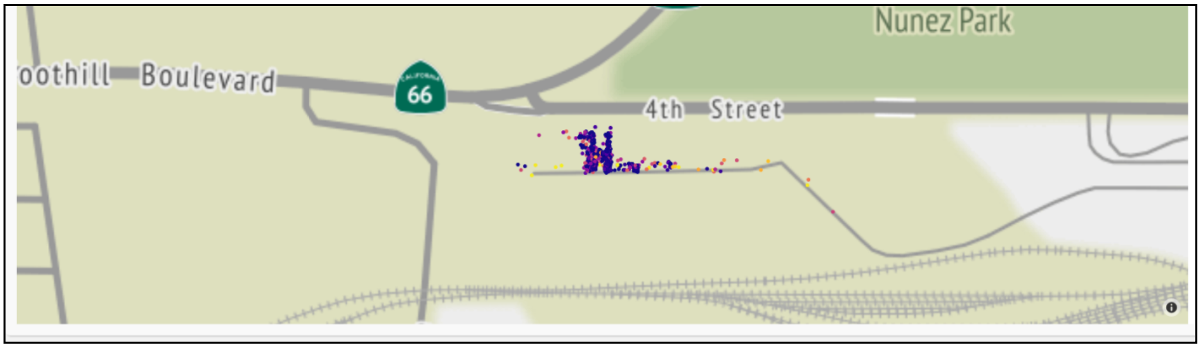


Figure 3a. Diesel Side Pick Travel Around BNSF's San Bernardino Intermodal Facility on 4-Jan-21

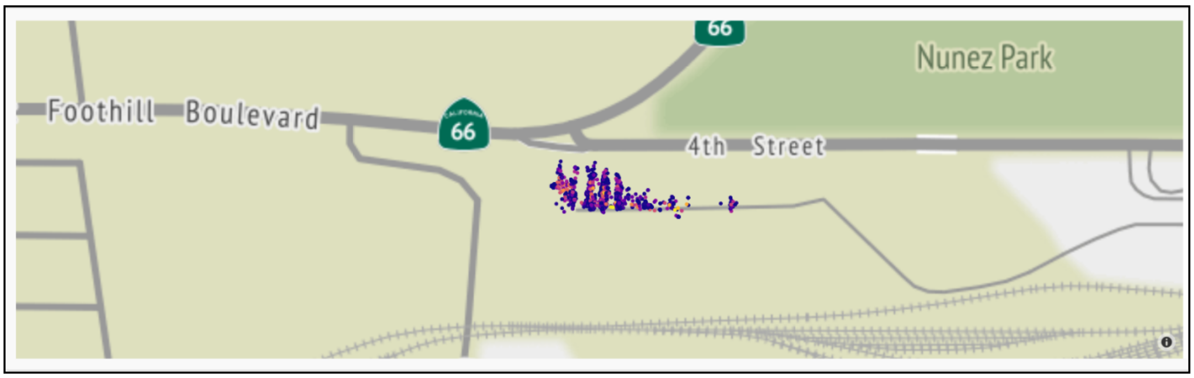


Figure 3b. Diesel Side Pick Travel Around BNSF's San Bernardino Intermodal Facility on 7-Jan-21

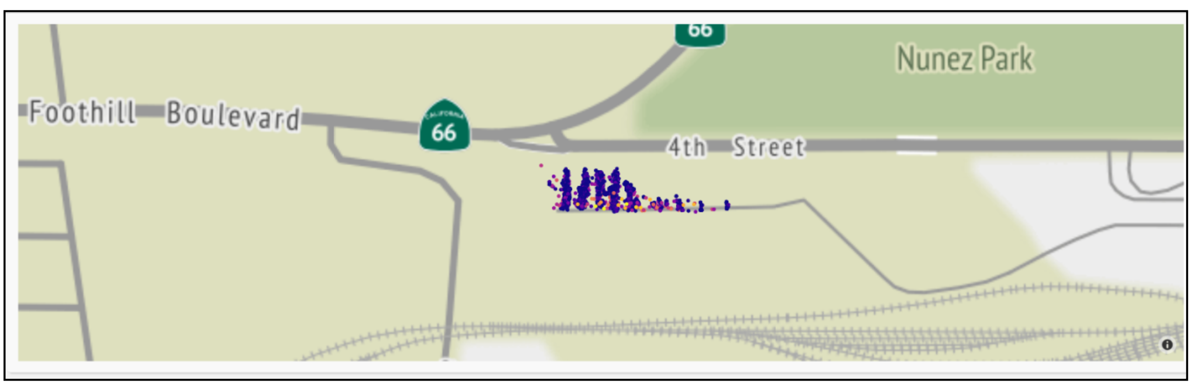


Figure 3c. Diesel Side Pick Travel Around BNSF's San Bernardino Intermodal Facility on 11-Jan-21

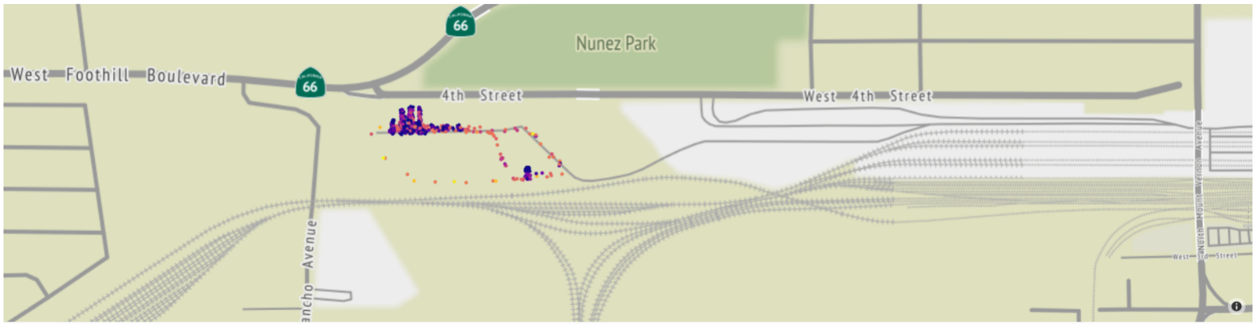


Figure 3d. Electric Side Pick Travel Around BNSF's San Bernardino Intermodal Facility on 22-Mar-21

2.2 Vehicle Specifications - Diesel Fueled Side Pick Container Handler

The diesel fueled side pick instrumented for this project was a Taylor XLC-974 built in 2018. Details of the diesel side pick are shown in Table 1 and photos of the vehicle and various aspects are shown in Figures 4 thru 7. Additional technical data is presented in Appendix B.

Table 1. Diesel Side Pick Details

Make -	Taylor
Model -	XLC-974
Serial -	S HB 42065
Year of Manufacture -	2018
GVW-	160,160 Pounds
Rated Capacity -	95,000 Pounds @ 48"

Figure 4. Diesel Fueled Side Pick

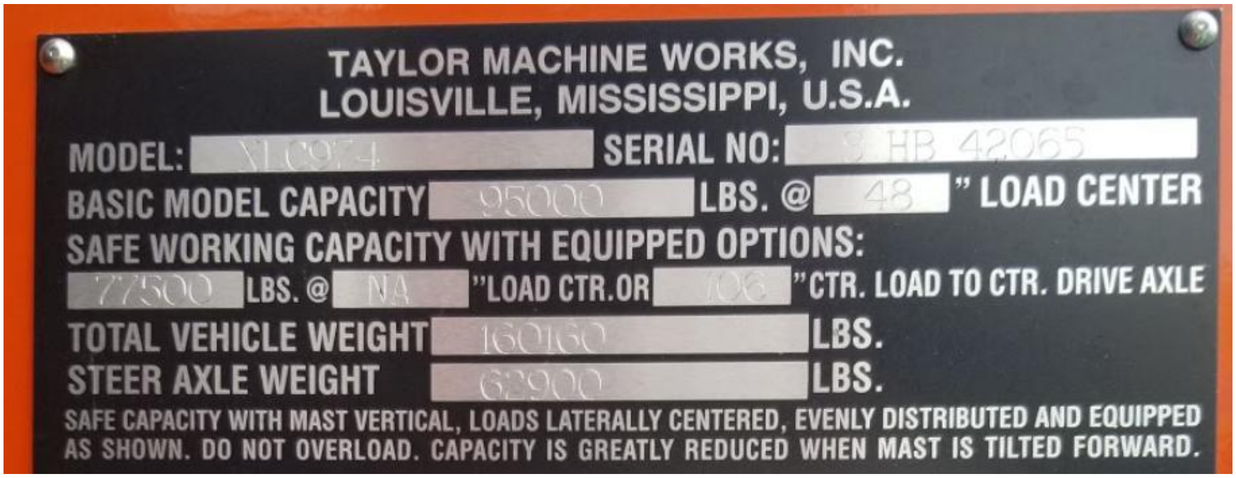


Figure 5. Diesel Fueled Side Pick VIN Sticker

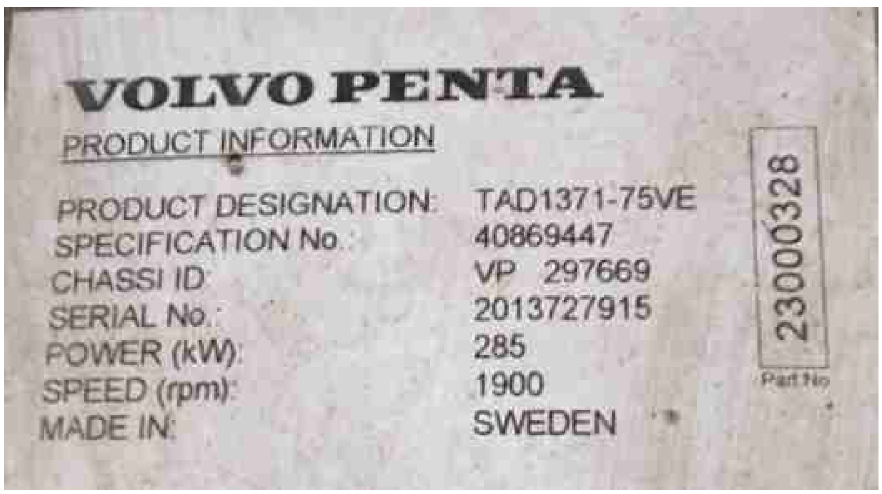


Figure 6. Diesel Fueled Side Pick Engine Specifications

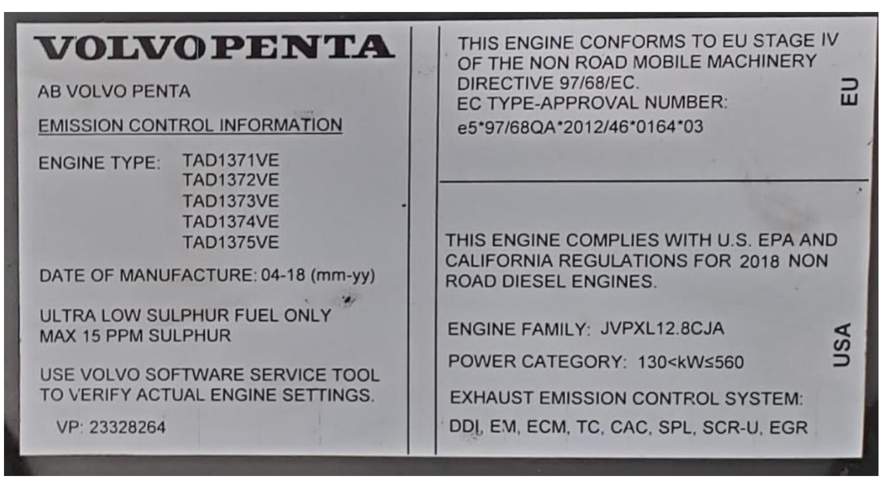


Figure 7. Diesel Fueled Side Pick Engine Emissions Data

The engine used in this vehicle is a Volvo TAD1371VE that was built in 2018. The engine displacement is 12.8 liters and rated at 285 kW @ 1,900 RPM with 1,965 Nm of torque @ 1200 RPM. Additional details about the engine are shown in Table 2.

Table 2. Diesel Side Pick Engine Details

Year Model -	2018
Engine Family –	Volvo TAD1371VE
Emissions Family –	JVPXL12.8CJA
Serial number -	2013727915
Specification -	40869447
Displacement –	12.8 liter
Ratings –	285 kW @ 1,900 RPM
	1,965 Nm @ 1200 RPM

2.3 Vehicle Specifications - Battery Electric Side Pick Container Handler

The electric side pick was built by Taylor Machine Works and is shown in Figure 8. It is a Model ZLC-974 and was built in 2020. Additional details can be seen in Figure 9 and the specifications are shown in Table 3. It is powered by a Model BYD ZLC-974 battery operating at 615V with a 922 kW-hr capacity.

Figure 8. Battery Electric Side Pick

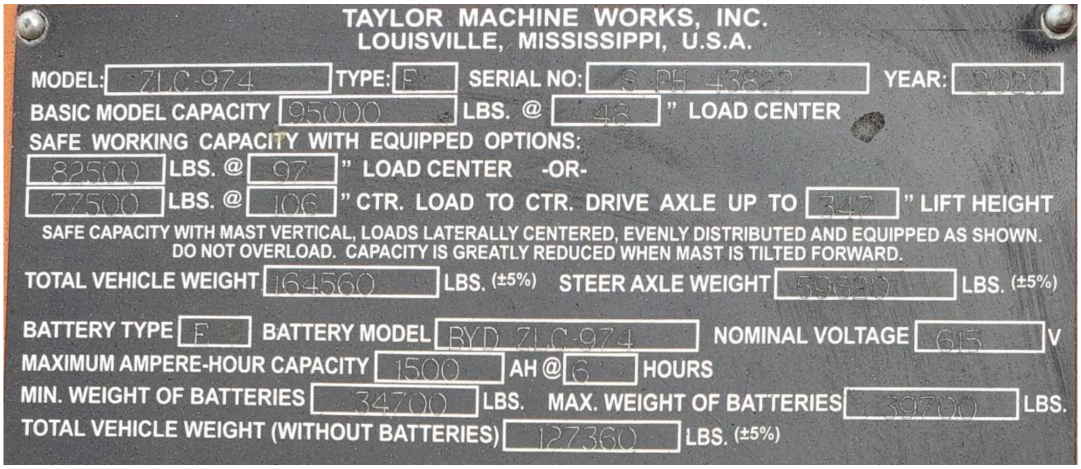


Figure 9. Battery Electric Side Pick VIN Sticker

Table 3. Electric Side Pick Details

Make -	Taylor
Model -	ZLC-974
Serial -	S PH 43822
Year of MFG -	2020
GVW-	164,560 Pounds
Rated Capacity -	95,000 Pounds @ 48”
Battery Model -	BYD ZLC-974
Nominal Voltage -	615 Volts
Battery Capacity -	922 kW-Hr

Figures 10 and 11 shows the charging port on the side of the electric side pick located on the driver side of the vehicle behind the front tire.

Figure 10. Battery Electric Side Pick Charge Receptacle

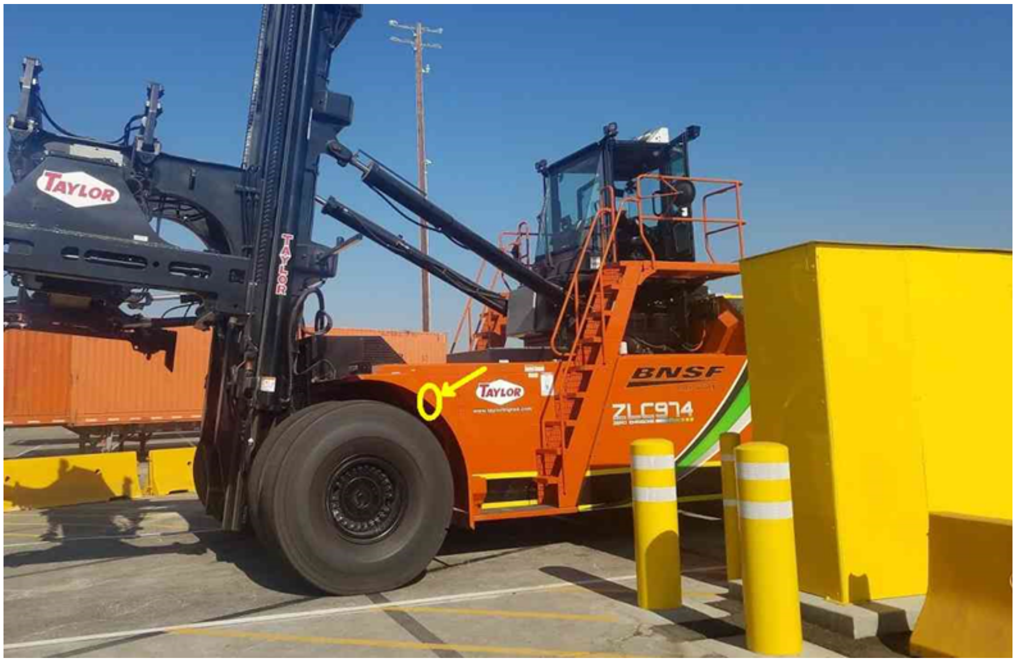


Figure 11. Battery Electric Side Pick Charge Receptacle Location

2.4 Battery Electric Side Pick Charging Station

The Battery Electric Side Pick used a dedicated BYD charging station installed for this project. The charging station uses 480 VAC three phase power. Figure 12 shows the charging station. Figure 13 shows the charging station location within Lot 5. The charging station is equipped with double charging connectors, each capable of providing 100 kW.

Figure 12. Battery Electric Side Pick Charging Station

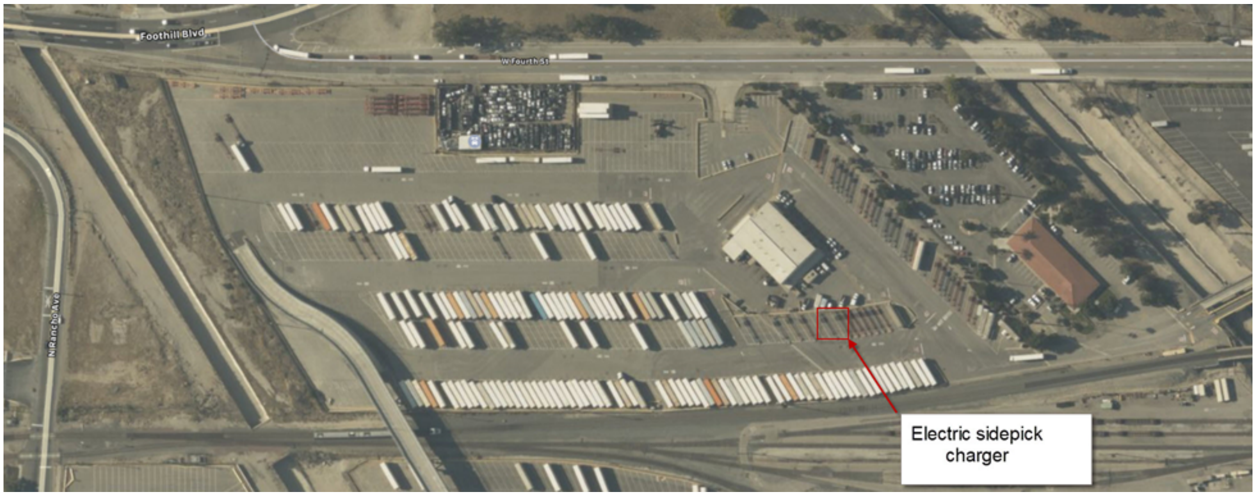


Figure 13. Battery Electric Side Pick Charging Station Location within Lot 5

2.5 SwRI RPECS Data Logger

The basics of the SwRI data logger is shown in Figure 14. 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. Built on more than 20 years of test and engine control technology.

The RPECS system can also read the J1939 CAN communication signals from the Side Pick Container Handler. This ability 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 a redundant 4G LTE systems that allows SwRI staff to access to the collected data and make software changes remotely.

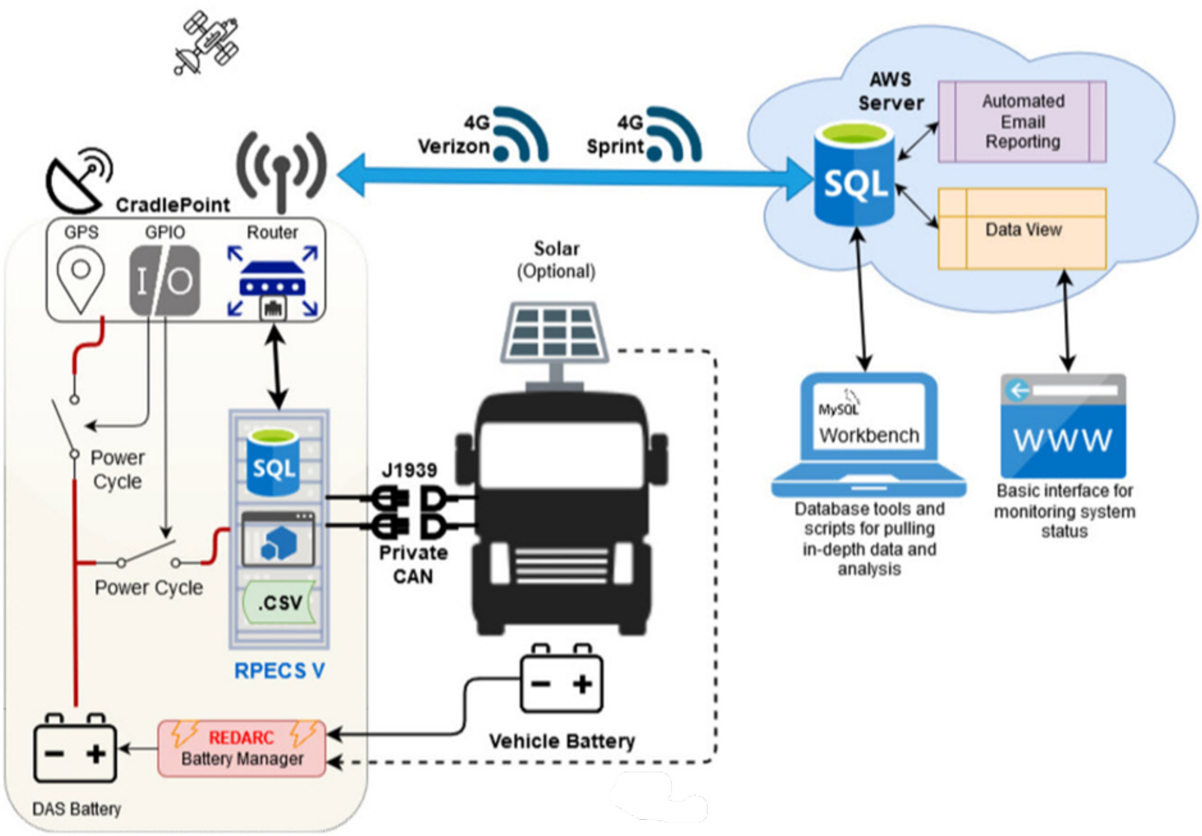


Figure 14. ZANZEFF RPECS Datalogger Overview

Figure 15 shows the RPECS system and GPS antenna that was installed in the cabin area of the Electric Side Pick Container Handler. The RPECS system was installed inside of a Pelican case to protect the system from dust, dirt, and other environmental issues. The GPS antenna was mounted to the lid of the Pelican case, which eliminated the need to mount the antenna on the outside of the vehicle and add a penetration through the vehicle cabin. The RPECS system on the electric side pick was connected to the system CAN bus in the electrical enclosure mounted in front of the vehicle cabin, with the location shown in Figure 16. The diesel side pick had an identical cabin arrangement; however the RPECS system was connected to the CAN bus diagnostic port located in the engine compartment.

The Diesel and Electric Side Pick Container Handlers were instrumented on July 16, 2020. The diesel side pick began logging ECU data transmitted on the CAN bus but did not observe any of the internal system parameters necessary to track its use. The electric side pick was not broadcasting any internal system parameters either. Taylor/Mi-Jack provided a software update for the electric side pick on October 19, 2020. The diesel side pick received a software update on October 20, 2020. Therefore, data analysis was only conducted over the period of October 2020 to March 2021.

Figure 15. RPECS Datalogger Mounted in the Electric Side Pick Cab

Figure 16. Location Where RPECS Connected to the Electric Side Pick's System CAN Bus

3.0 VEHICLE OPERATION

The following section discusses data collected during the time that the Side Pick Container Handlers were instrumented. The data analyzed herein this report covers the period of October 2020 to March 2021. The dataloggers were removed on March 30, 2021.

3.1 Description of Daily Use / Duty Cycle

Typical daily use in this report is based on hours of operation, number of lifts, and fuel or power consumed. Table 4 summarizes the data for the days that the side picks were used to perform lifts. The summary data is based on the average of the daily values. Note that for summary data which includes calculations such as lifts per hour, this does not equal average lifts divided by average hours. The remainder of Section 3 and Section 4 of this report provide details on the information summarized in Table 4.

Table 4. Typical Operation Based on Daily Observations

	Diesel			Electric		
	AVG	STD	MAX	AVG	STD	MAX
Days logged with lifts	92			89		
Hours per Day of Operation	4.3	3.7	16.1	3.8	2.7	11.9
Lifts per day	46	52	299	45	38	156
Lifts/Hr	8.9	4.2	21.1	11.1	4.3	23.1
Fuel/Power Used per Day (gal or kW-hr)	12.7	10.8	52.8	187.5	115.4	544.7
Lifts/(gal or kW-hr)	2.88	1.27	5.84	0.21	0.09	0.38
Fuel/Power Cost - $/(gal or kW-hr)	$2.735			$0.2371		
Cost/Lift	$1.23	$0.88	$7.23	$1.41	$0.74	$3.42
GPS Speed with Key On (kph)	1.0	0.4	2.6	2.0	0.9	5.8
Idle (Percent)	35%	9%	55%	6%	11%	67%

3.1.1 Hours of Operation

Figure 17 shows the hours of operation per day for the diesel and electric side picks. The days without lifts were not included in Table 4 but were included in Figure 17 as zero hours of operation. The diesel side pick was the preferred vehicle and was unused for only 7 days. The electric side pick had 0 hours of operation for 52 days. The number of days where the hours of operation were between 1 and 9 hours per day was similar. The majority of days saw between 1 and 5 hours of use. The longest day for the electric side pick was 12 hours. The diesel side pick had some 14, 15, and 16 hour days.

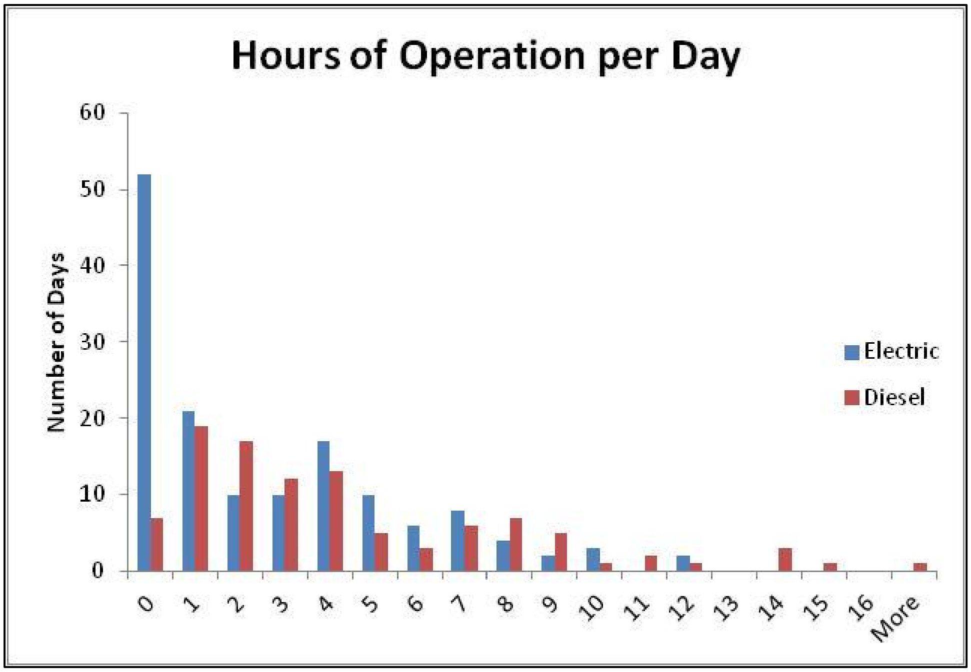


Figure 17. Hours of Operation per Day

3.1.2 Number of Lifts

The internal control system of both side picks contained a lift count parameter that increments each time the lift clamps are closed around a shipping container. The lift count parameter was broadcast on the CAN bus and was one of the parameters logged by SwRI. Figure 18 shows a histogram with the number of lifts per day for the diesel and electric side pick parsed into increments of 15 lifts. The first x-axis increment is for days that had 0 lifts per day. The second x-axis increment is for 1 to 15 lifts per day, and so on. The days without lifts were not included in Table 4.

The electric side pick was lightly used and had 0 lifts for 56 days compared to the diesel side pick which only had 0 lifts for 11 days. The days without lifts are slightly higher than days without hours of operating, due to a handful of days where there were hours of operation on a side pick, but no lifts.

The diesel side pick had a maximum number of 299 lifts per day, almost twice the maximum number of lifts per day as the electric side pick. Figure 19 shows the GPS speed data of the diesel side pick on the day it performed 299 lifts within Lot 5 over 15 hours of operation.

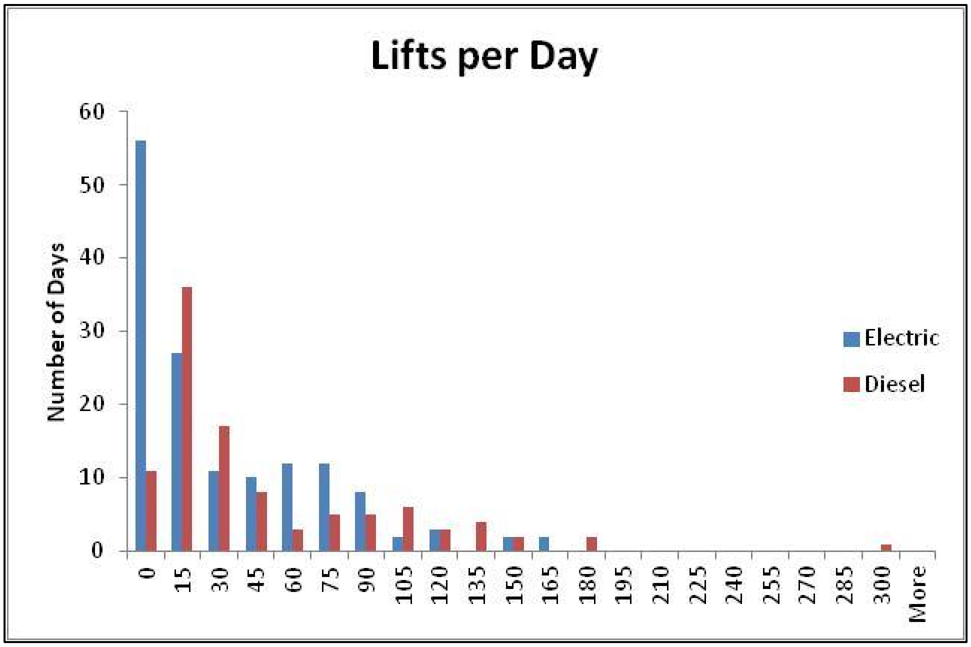


Figure 18. Histogram of Number of Lifts per Day

Figure 19. Diesel Side Pick GPS on February 15, 2021

Figure 20 shows a histogram with the number of lifts per hour for the diesel and electric side pick parsed into increments of 2 lifts per hour. The first x-axis increment is for days that the diesel side pick had 0 lifts per hour. The second x-axis increment is for 1 to 2 lifts per hour and so on. The diesel side pick had more days with fewer lifts per hour than the electric side pick. The electric side pick had more days with more lifts per hour than the diesel side pick. This indicates that the electric side pick's hourly rate of productivity is equivalent to its diesel counterpart. Most days of operation saw between 6 and 16 lifts per hour for both the diesel and electric side picks.

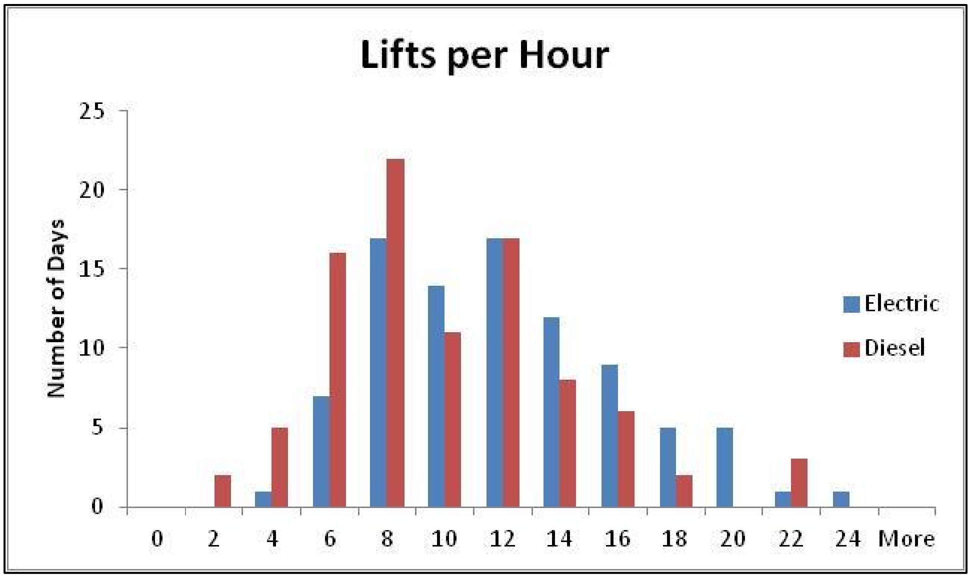


Figure 20. Histogram of Number of Lifts per Hour

3.1.3 Number of Lifts per Gallon of Diesel Fuel

The diesel side pick was fueled by a BNSF contractor that reports equipment number, amount of fuel dispensed, the time and date for all the equipment serviced. BNSF provided these reports to SwRI weekly.

Figure 21 shows the fuel dispensed and the Engine Total Fuel Used parameter broadcast by the ECM from the period between 2020-08-31 11:40 and 2021-02-17 09:43. There was a relatively small discrepancy between the amount of fuel dispensed from the fueling truck and the total amount of fuel consumed reported by the ECM. Figure 22 shows there was a 7 percent difference between the ECM total verses the dispensed total, with more fuel reported dispensed by the truck compared to the ECM reported total. The ECM calculated fuel usage was used for the remainder of this report, since the fueling truck pump may not be calibrated or temperature compensated.

The average amount of fuel used per day that the side pick was operated with lifts was 12.7 gallons. The maximum amount of fuel used in one day was 52.8 gallons on February 15, 2021 when it performed 299 lifts over 15 hours of operation.

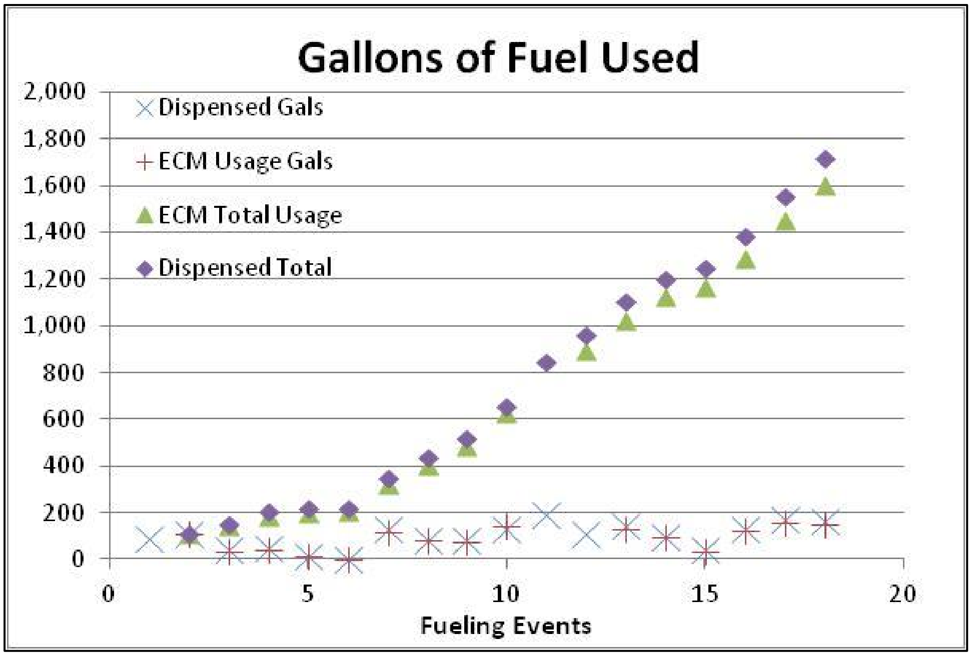


Figure 21. Gallons of Fuel Used

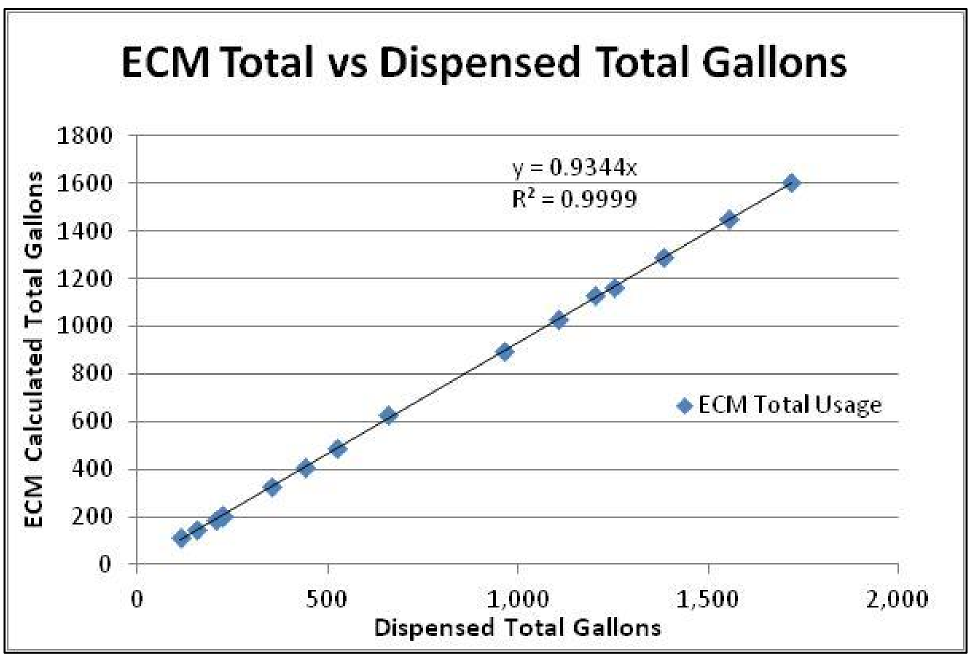


Figure 22. ECM Total vs. Dispensed Total Gallons for the Diesel Side Pick

The daily number of lifts with the corresponding fuel used for that day was used to calculate the number of lifts per gallon of fuel used. The average number of lifts per gallon of fuel observed over 92 days of observation was determined to be 2.88 lifts per gallon of diesel fuel. The maximum number of lifts per gallon was 5.84 over this same period.

3.1.4 Number of Lifts per kW-hr

The efficiency of the BYD charging station was determined by examining a period where the HV battery state of charge (SOC) was near 100 percent before and after a charging event. Two consecutive such periods occurred around the beginning of November 2020.

The November electric bill provide by BNSF for the BYD charger feeding the side pick included daily usage data on the electric meter. A day and time were selected when there was no more charging after the charging event up to midnight to align the electric side pick data with the daily usage data on the electric bill. The Charge Power parameter broadcast by the ECM once per second was totalized for the selected period to obtain kW-hrs.

Two events occurred from 10/26/2020 19:30 to 10/30/2020 12:00 and from 10/30/2020 12:00 to 11/9/2020 13:00. Since both periods were consecutive, the period from 10/26/2020 19:30 to 11/9/2020 13:00 was also examined, which is the third row in Table 5. The results of Table 5 show that the BYD charging station was about 93 percent efficient.

Table 5. BYD Charging Station Efficiency

Start	End	Start SOC (%)	End SOC (%)	Lifts	Battery Charge Amount (kW-hr)	SoCal Edison Meter (kW-hr)	Charger Efficiency (%)
10/26/2020 19:30	10/30/2020 12:00	94.4	99.5	186	784.8	842.4	93.2%
10/30/2020 12:00	11/9/2020 13:00	99.5	99.9	406	1764.6	1885.2	93.6%
10/26/2020 19:30	11/9/2020 13:00	94.4	99.9	592	2549.4	2727.6	93.5%

Table 6 shows the monthly usage and daily electricity charges from the electric bills for the BYD charging station for the electric side pick for the period July 2020 through March 2021. The average cost of electricity for this period was $0.2371 per kW-hr.

Table 6. Southern California Edison Monthly Charges

Period	Usage (kW-hr)	Cost
24-Jul-20	1943	$498.31
24-Aug-20	2748	$641.49
23-Sep-20	2020	$694.09
23-Oct-20	5096	$955.68
23-Nov-20	5166	$942.12
23-Dec-20	824	$282.61
25-Jan-21	1339	$374.57
24-Feb-21	2340	$656.81
23-Mar-21	6234	$1,523.31
TOTAL	27710	$6,568.99
	$ per kW-hr =	$0.2371

While none of the hydraulic energy from lowering containers is recovered, the electric side pick does utilize regenerative braking. The low speed and short range of the electric side pick does not recover a lot of energy, but regenerative braking can be recovered and stored in the battery.

The daily number of lifts with the corresponding energy used for that day was used to calculate the number of lifts per kW-hr used for that day. The average number of lifts per kW-hr observed over 89 days of observation was determined to be 0.21 lifts per kW-hr. The maximum number of lifts per kW-hr was 0.38 over this same period

3.1.5 Fuel/Energy Cost per Lift

The average cost of diesel fuel for the first quarter of 2021 was $2.735 per gallon. This was determined by averaging the ULSD highway price per gallon in California for the first 3 months of the year obtained from U.S. Energy Information Administration (EIA) and removing the road taxes from it (since it is off road diesel). The cost for electricity was determined to be $0.2371 per kW-hr as reported in Table 6.

The fuel or energy cost per lift was obtained by dividing the energy cost by the daily lifts per gallon or kW-hr. The average cost per lift for the diesel side pick over 92 days of observation was determined to be $1.23 per lift. The average cost per lift for the electric side pick over 89 days of observation was determined to be $1.41 per lift.

3.1.6 GPS Speed

The Side Pick Container Handlers are usually confined to Lot 5 where the empty shipping containers are stored. The Side Pick Container Handlers do not accumulate a lot of mileage during daily use. This is reflected in the daily GPS speed presented in Table 4. The average GPS speed with the key on was similar on both the diesel and electric side picks at 1-2 kph.

3.1.7 Idle Time

Idle time for the diesel side pick was determined by counting the time the engine was less than 800 rpm and the Engine Torque Mode parameter was equal to 1. The percent of time idling was obtained by dividing the idle time by the daily hours of operation. The idle percent for the diesel side pick over 92 days of observation was determined on average to be 35 percent.

Idle time for the electric side pick was determined by counting the time the Park Brake Status parameter was equal to 0 (brake off), the Charging Status parameter was equal to 0 (not charging), and the Discharge Power parameter was less than 3 kW. The percent of time idling was obtained by dividing the idle time by the daily hours of operation. The idle percent for the electric side pick over 89 days of observation was determined on average to be 6 percent.

4.0 FUEL / ENERGY CONVERSION

4.1 Change in State of Charge (SOC) and Endurance

The relatively infrequent use of the electric side pick presented a challenge in determining the change in the HV battery SOC under continuous operation. The analysis began by selecting the days with a lot of operating hours, a large number of lifts, and minimal charging events. Periods of inactivity where the Park Brake Status parameter was equal to 1 (brake on) were removed and the change in the SOC over time was plotted. The results are presented in Figure 23 and show a consistent rate of change regardless of the HV battery SOC.

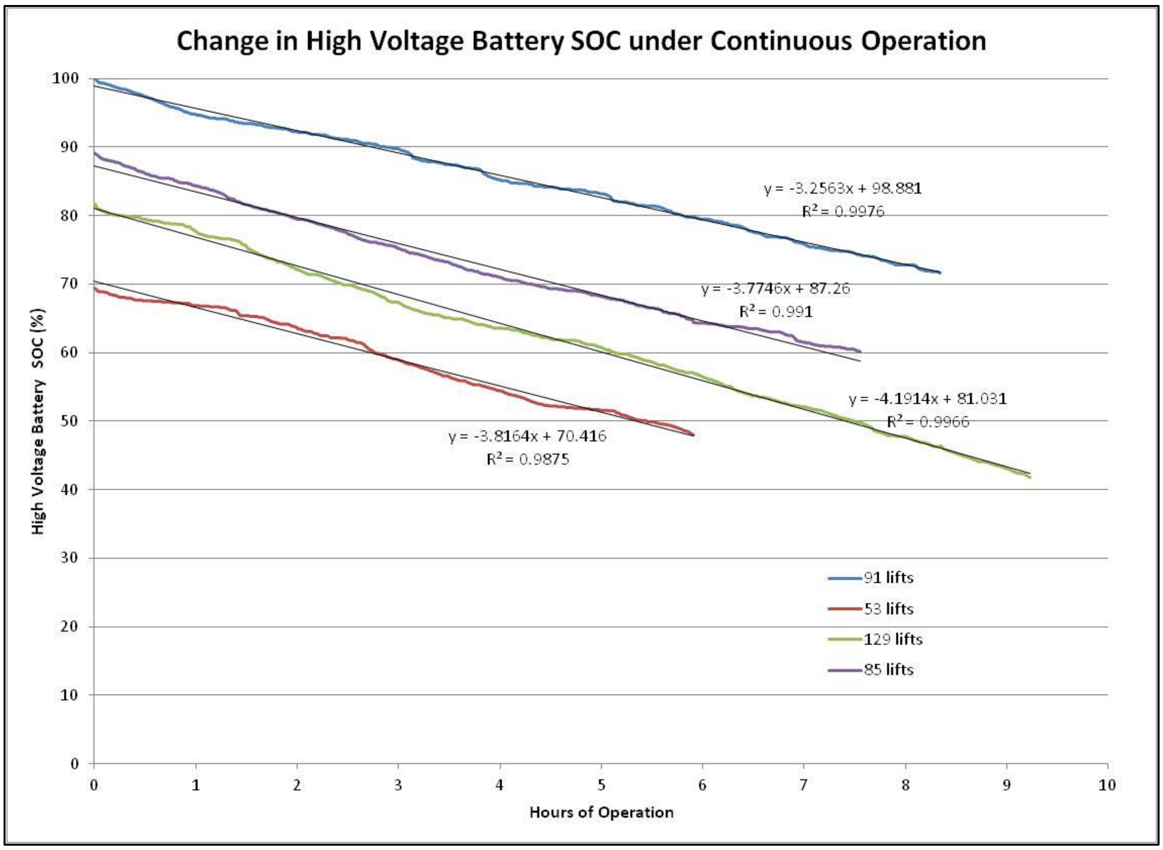


Figure 23. Change in High Voltage Battery SOC under Continuous Operation

Table 7 summarizes the statistics for the data presented in Figure 23 and shows that under continuous operation the HV battery SOC decreases by approximately 4 percent per hour. This would imply that a single charge would last for about 25 hours of continuous operation. Over the four days of observation, a total of 358 lifts were performed in 31 hours of continuous operation which would imply that a single charge could perform approximately 288 lifts over the 25 hours of continuous operation.

Table 7. Change in High Voltage Battery SOC under Continuous Operation

Date	Starting SOC (%)	Ending SOC (%)	Change in SOC (%)	Time (hrs)	Lifts	Y = mX + b			
						m (%/hr)	b (%)	Y (%)	R2
11/2/2020	100	71.6	28.4	8.34	91	-3.2560	100	72.83	0.9976
11/19/2020	89.1	60.1	29	7.56	85	-3.7746	89.1	60.56	0.9910
2/19/2021	81.8	41.8	40	9.23	129	-4.1914	81.8	43.11	0.9966
3/19/2021	69.4	48	21.4	5.91	53	-3.8164	69.4	46.84	0.9875
			SUM	31.05	358				
					AVG	-3.760			
					STD	0.384			

The diesel side pick consumed 53 gallons of diesel fuel over 15 hours of operation when it performed 299 lifts. The diesel side pick fuel tank has a capacity in excess of 200 gallons which would imply 56 hours of continuous activity before refueling.

4.2 Refueling Time/Charging Time

Two rates of charging were observed by the BYD charging station. The fast charging rate was observed to provide 190 kW and the lower charging rate provided 95 kW. The different charging rates are determined by how many charging connectors are used. The change in HV battery SOC during selected charging events is presented in Figure 24. The lower charging rate appears to be about 10 percent per hour which would require 10 hours for a complete charging. The fast charging rate is approximately 20 percent per hour which would imply a 5-hour recharge period.

The diesel side pick refueling rate was estimated from the fuel logs provided by BNSF to be about 4 minutes to dispense 50 gallons of diesel fuel. In addition, the diesel side pick can be refueled anywhere in the yard where the electric side pick must be returned to the BYD charging station.

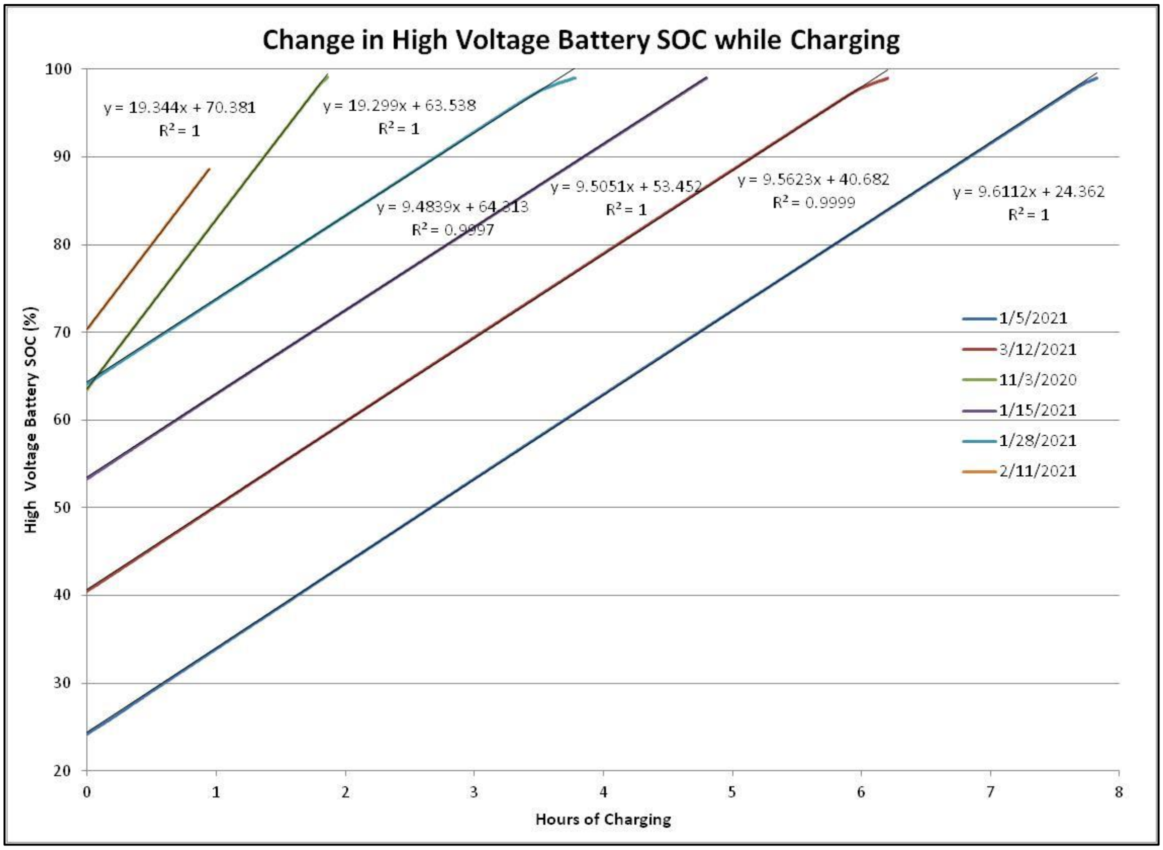


Figure 24. Change in High Voltage Battery SOC while Charging

4.3 Refueling/Charge Frequency

The diesel side pick was refueled approximately once a week. The electric side pick was charged almost every day that it was used and sometimes multiple times per day, which based on the data was probably not necessary.

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

The average number of lifts per gallon of diesel fuel observed over 92 days of observation was determined to be 2.88 lifts per gallon of diesel fuel. The maximum number of lifts per gallon was 5.84 over this same period. The average cost per lift for the diesel side pick was determined to be $1.23 per lift.

The average number of lifts per kW-hr observed over 89 days of observation was determined to be 0.21 lifts per kW-hr. The maximum number of lifts per kW-hr was 0.38 over this same period. The average cost per lift for the electric side pick was determined to be $1.41 per lift.

4.5 Fuel/Energy Consumption at Idling

Idle time for the electric side pick was determined by counting the time the Park Brake Status parameter was equal to 0 (brake off), the Charging Status parameter was equal to 0 (not charging), and the Discharge Power parameter was less than 3 kW. The energy consumption during idling was defined as less than 3 kW. The idle percent for the electric side pick over 89 days of observation was determined to be 6 percent.

Idle time for the diesel side pick was determined by counting the time the engine was less than 800 rpm and the Engine Torque Mode parameter was equal to 1. The analysis began by selecting a continuous period of days without any gaps in the data and with a lot of operating hours. The period selected was February 1, 2021 to February 21, 2021. This permitted the instantaneous fuel rate parameter broadcast by the ECM to be totalized without any interruptions. The diesel fuel consumption while idling is presented in Table 8.

Table 8. Diesel Side Pick Fuel Consumption while Idling

	2/01/21 to 2/21/21	10/20/20 to 2/22/21
Observations (Days)	21	96
Hours of Operation with Key On (Hours)	154.25	
Hours of Idle (Hours)	55.18	
Idle (Percent)	35.8%	35.3%
ECM Total Fuel Used (gallons)	445.4	
Totalized Instantaneous Fuel Used with Key On (gallons)	444.8	
Totalized Instantaneous Fuel Used while Idling (gallons)	83.6	
Fuel Used while Idling (Percent)	18.8%	
Average Instantaneous Fuel Rate while Idling (gal/hr)	1.53	

The percent of time idling was obtained by dividing the hours of idle by the hours of operation with key on. The idle percent for the diesel side pick over the 21 days of observation was determined to be 35 percent and agreed with the average daily idle percent over the entire monitoring period. The totalized instantaneous fuel used agreed with the ECM total fuel used and the fuel consumed during idling was approximately 19 percent of the total fuel used.

4.6 Electric Range / Average Electric Usage as a Function of Lifts

A single charge with the electric side pick was estimated to perform approximately 288 lifts over 25 hours of continuous operation. The diesel side pick performed 299 lifts over 15 hours of operation. The diesel side pick was estimated to perform 56 hours of continuous activity before refueling. Note that the typical day for the diesel side pick includes 35 percent idle time, with its associated fuel use and idle emissions.

5.0 EMISSIONS TESTING

The system used to measure the exhaust emissions from the diesel fueled side pick while operating at the BNSF San Bernardino Intermodal Yard was a SEMTECH-DS mobile emissions analyzer, which is known as a PEMS unit. The SEMTECH-DS is considered the industry standard for Portable Emissions Measurement Systems (PEMS). The system can monitor the raw exhaust from both spark ignition and compression ignition engines and provides CO, CO_2, 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, shown in Figure 25, 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 EPA and provided instruction on proper installation, calibration, operation, and data analysis.

Figure 25. SEMTECH-DS PEMS System

The PEMS unit was installed on the diesel side pick as shown in Figure 26. The installation required a modification to the exhaust system so that the exhaust flow sensor and sampling zone could be mounted to the exhaust stack. PEMS testing on the diesel side pick was conducted on December 4, 2020.

Figure 26. PEMS System Installed on Diesel Side Pick

5.1 Summary of Emission Testing

The PEMS testing commenced on December 4, 2020 at 10:01:47 and concluded at 14:44:16. The operation of the diesel side pick during the PEMS testing compared to the typical daily operation is presented in Table 9. The average speed during the PEMS testing was somewhat higher since it included unloaded driving loops in Lot 5 as shown in the GPS activity during the PEMS testing in Figure 27. The PEMS testing was calculated over 1.6 hours of testing. The percent of time the diesel side pick idled during PEMS testing (23 percent) was somewhat less than operation observed during the datalogging period (35 percent). The number of lifts per hour was comparable, as was lifts per gallon. The cost per lift was also comparable since the additional driving was offset by the amount of idling.

Table 9. Diesel Side Pick Typical Operation vs. During PEMS Testing

	10/20/20 to 2/22/21	12/04/20 PEMS Testing
Average Speed With Key On (kph)	1.0	3.3
Hours of Operation with Key On (Hours)	4.3	1.6
Idle (Percent)	35%	23%
Lifts per Hour	8.9	9.4
Lifts per Gallon	2.88	2.03
Cost per Lift	$1.23	$1.37

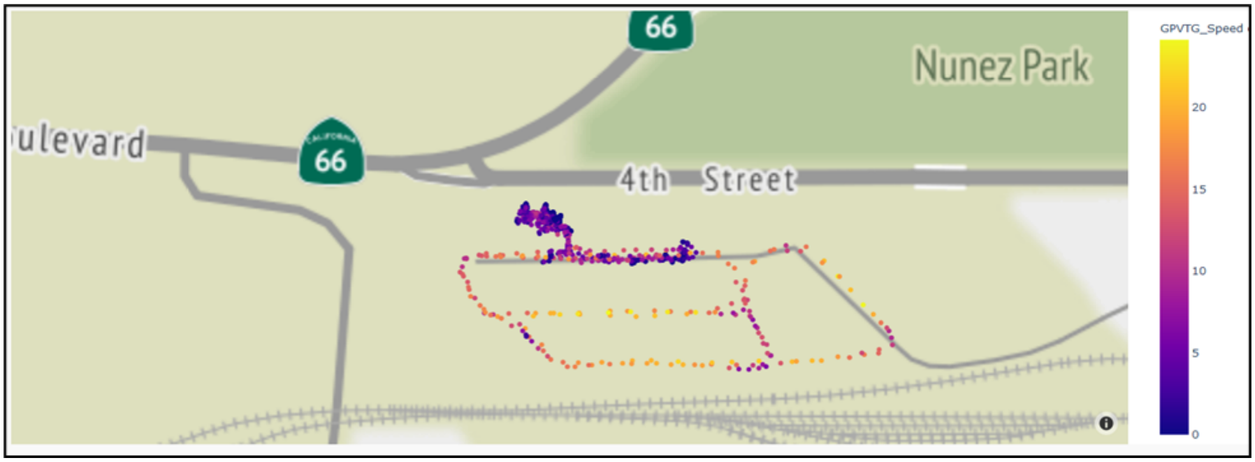


Figure 27. Diesel Side Pick GPS with PEMS System Installed

The gaseous emissions results of the PEMS testing are presented in Table 10. The gaseous emissions as they relate to daily operation are presented in Table 11.

Table 10. Emissions Results of Diesel Side Pick PEMS Testing on 12/04/20

Lifts	15
Lifts per Gallon (see Table 9)	2.03
Lifts per Hour (see Table 9)	9.4
Total Fuel Consumed (gal)	5.99
CO_2 (g/gallon)	10330
CO (g/gallon)	20.4
Humidity-corrected NO_X (g/gallon)	15.4
Total Hydrocarbons (g/gallon)	0.4

Table 11. Operational Emissions of Diesel Side Pick

	PEMS Testing Including Idle	PEMS Testing Idle Only
CO_2 (g/lift)	5089	
CO (g/lift)	10.0	
corr NO_X (g/lift)	7.6	
THC (g/lift)	0.2	
CO_2 (g/hr)	47732	18539
CO (g/hr)	94.3	31.5
corr NO_X (g/hr)	71.2	32.4
THC (g/hr)	1.8	0.8

The Volvo brochure presented in Appendix B states that this engine has SCR and "light" EGR. The EGR line in Figure 28 confirms that the engine does have EGR.

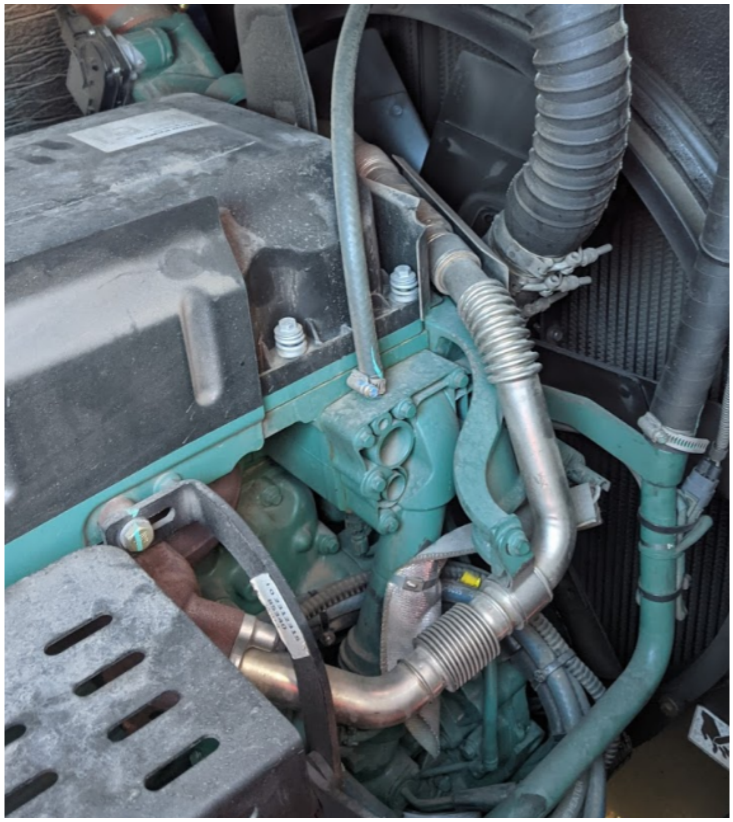


Figure 28. Diesel Side Pick EGR Piping

The CARB certification for this Volvo engine family is presented in Appendix C and shows SCR and EGR for this engine. The exhaust certification levels from Appendix C are presented in Table 12.

Table 12. Exhaust Certification Levels

RATED POWER CLASS	EMISSION STANDARD CATEGORY		EXHAUST (g/kW-hr)				
			NMHC	NOx	NMHC+NOx	CO	PM
130 <= kW <= 560	Tier 4 Final	STD	0.19	0.4	N/A	3.5	0.02
		CERT	0.02	0.22		0.1	0.02

The exhaust NOx concentration presented in Figure 29 shows that it took 3-5 minutes of loaded activity before the SCR reduced the NO_X emissions. Figure 29 also shows that after a period of activity, NO_X creeps up during a 15-minute idle period. The Volvo brochure in Appendix B and the CARB certification in Appendix C state that there is no DOC or DPF for this engine.

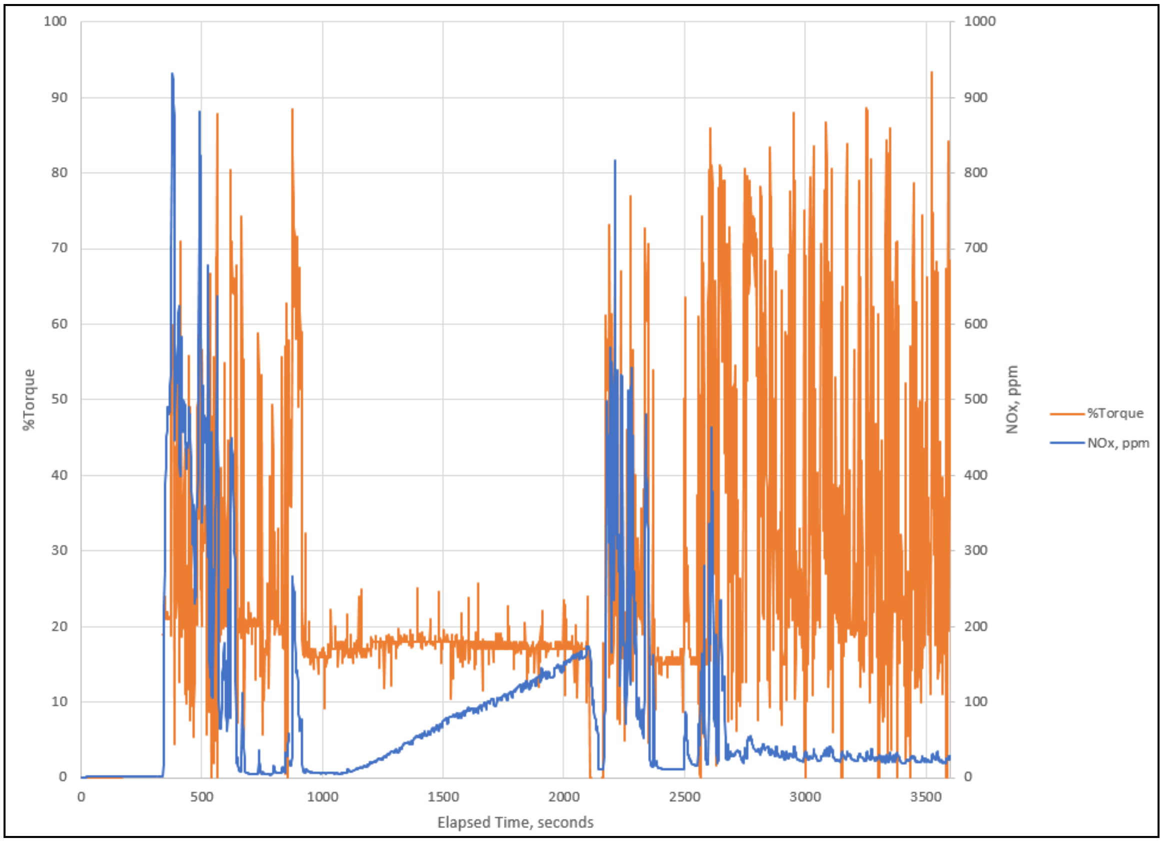


Figure 29. Diesel Side Pick NOx Creep during Idle

The corrected NOx level observed during the PEMS testing in Table 10 was observed to be 15.4 g/gallon. To compare this value to the certification data in Table 12, SwRI estimated the brake-specific fuel efficiency over the certification cycle at 0.40 lb/hp-hr (which equals 2.5 hp-hr/lb). Using a typical diesel fuel density of 7.0 lb/gallon, the fuel-specific NO_X for the CARB certification can be estimated using the equation below. Using this approach, the estimated fuel-specific NOx level observed for the certification test data in Table 12 was observed to be 2.9 g NO_X/gallon. This means that the NO_X observed from the diesel side pick was roughly 5 times that expected from the CARB certification data.

$$\text{Cert NOx} = 0.22 \frac{\text{g NOx}}{\text{kW} \cdot \text{hr}} \times 0.7457 \frac{\text{kW}}{\text{hp}} \times 2.5 \frac{\text{hp} \cdot \text{hr}}{\text{lb diesel}} \times 7 \frac{\text{lb diesel}}{\text{gallon}} = 2.9 \frac{\text{g NOx}}{\text{gallon}}$$

The difference in the NO_X level during the PEMS testing could be attributed to the difference is real-world verses certification testing. The nature of the side pick seems to be brief periods of activity every now and again, followed by an extended Idle period, which may not be ideal for SCR. SwRI captured four side pick work assignments with PEMS, and in all four assignments the NO_X starts out high and comes down after 5 or 10 minutes once the SCR becomes active. Then a few minutes later, the assignment was complete and the side pick gets parked or idles until the next time it's needed. The certification data reflects a very different duty cycle. The four work assignments SwRI captured during PEMS testing are summarized in the descriptions below and presented in Figures 30 to 33.

Side Pick PEMS Work Assignment #1 - 12/4/2020 9:08 - 9:43 AM

Description: This was an actual revenue work assignment. Moved the side pick to the container location, lifted a container from a trailer and placed it onto another trailer, then moved the side pick back to base and idled 20 minutes.

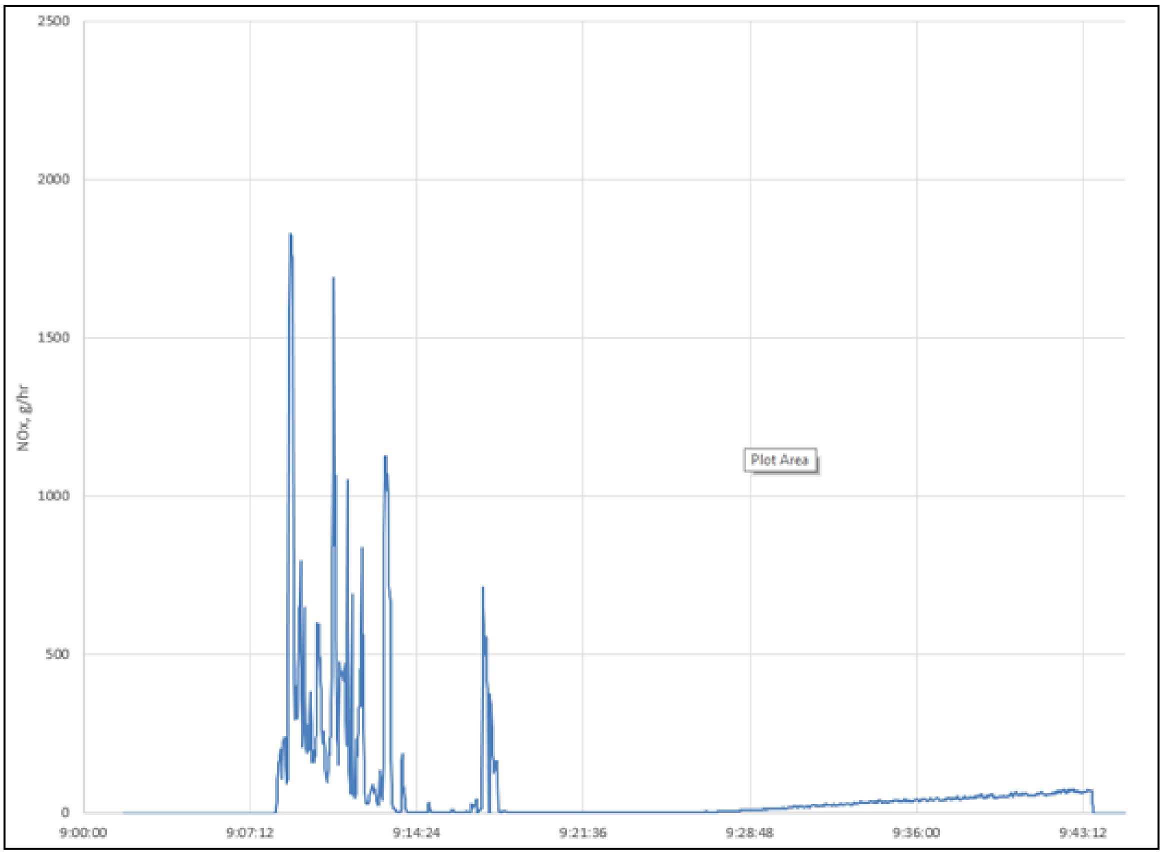


Figure 30. Plot of NOx during PEMS Work Assignment #1

Side Pick PEMS Work Assignment #2 - 12/4/2020 10:02- 10:27 AM

Description: First few minutes are revenue work assignment followed by staged work. Revenue work assignment lasted about 5 minutes and consisted of moving the side pick into position, lifting a container from a trailer and setting it onto a different trailer - total of 1 lift count. This was completed by 10:09. The staged work consisted of driving an unloaded loop in Lot 5 and then stacking and unstacking some containers (6 lifts) until 10:27 AM.

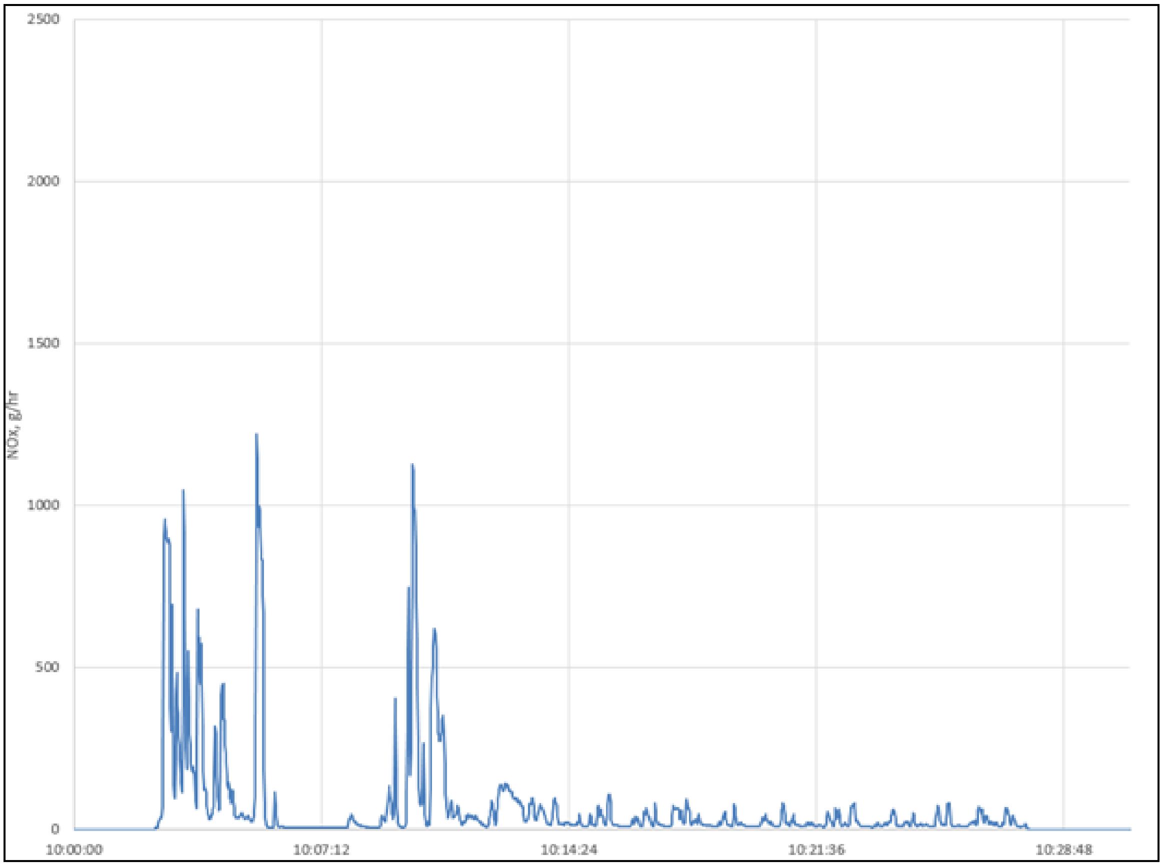


Figure 31. Plot of NOx during PEMS Work Assignment #2

Side Pick PEMS Work Assignment #3 - 12/4/2020 11:46 AM - 12:00 PM

Description: No work was available so we had to stage work. The staged work consisted of driving an unloaded loop in Lot 5 and then stacking and unstacking some containers (5 lifts) until 12:00 PM.

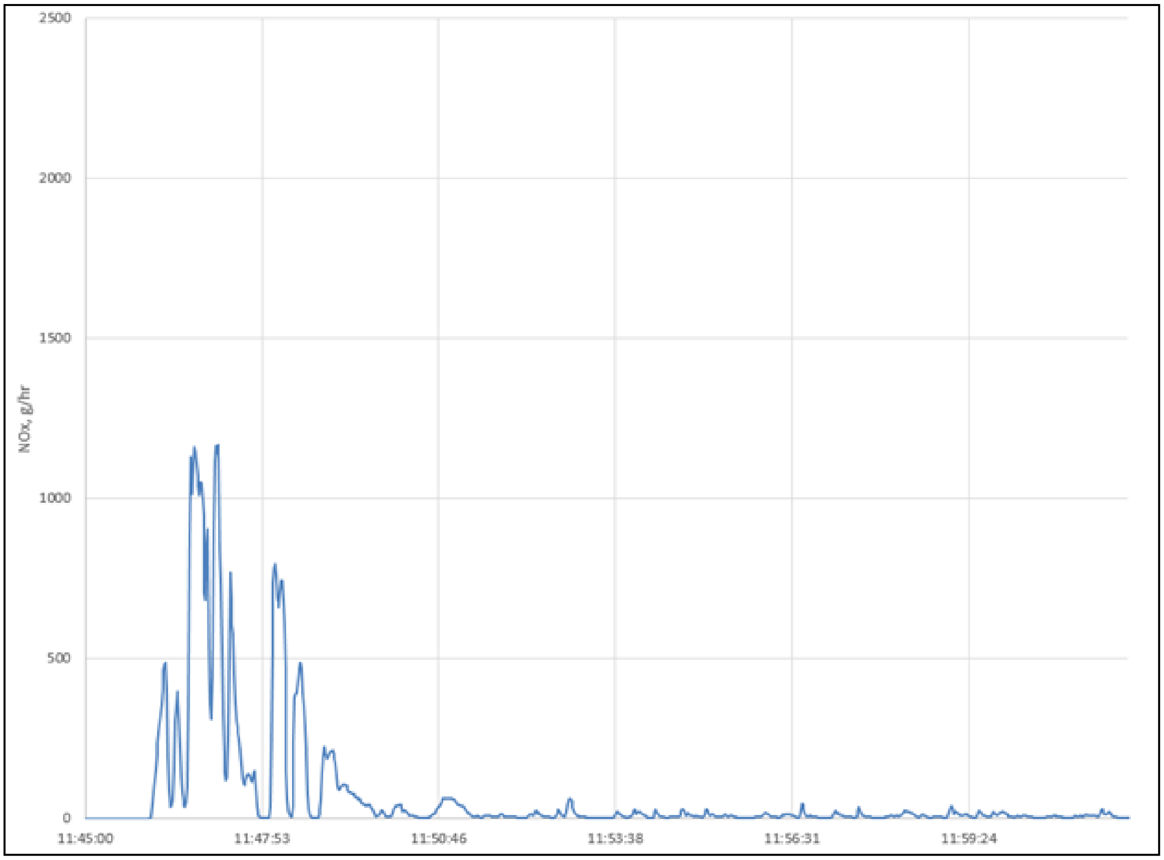


Figure 32. Plot of NOx during PEMS Work Assignment #3

Side Pick PEMS Work Assignment #4 - 12/4/2020 13:23 - 13:42

Description: Actual revenue work assignment followed by 5 minutes of driving unloaded laps around Lot 5. Revenue work assignment consisted of two lifts. Moved a container from one trailer to another, and then moved a tank trailer from one trailer to another.

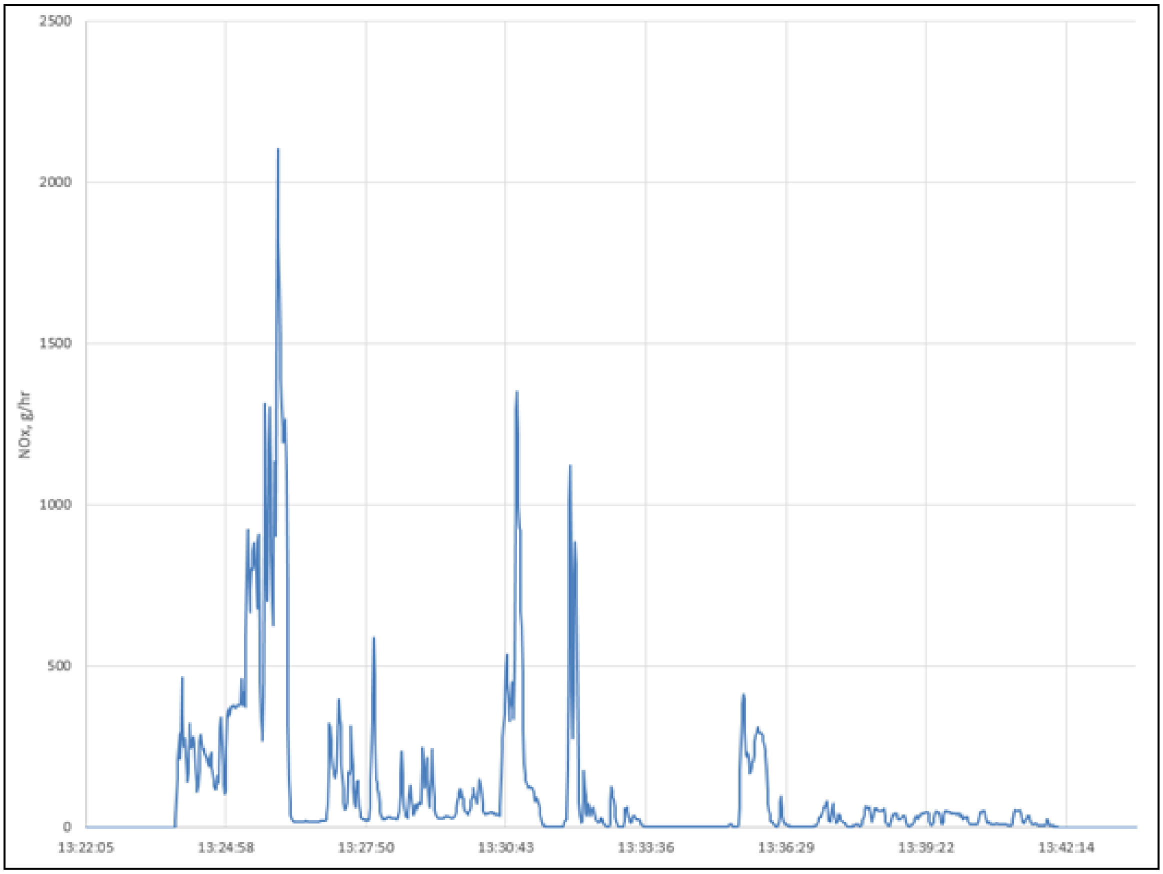


Figure 33. Plot of NOx during PEMS Work Assignment #4

In these examples, the NOx levels start out high and drop once the SCR becomes active. The total NO_X emitted during an average day for a side pick at BNSF San Bernardino (4.0 hours) is about 285 grams per day. We can assume that 10 percent of the time the diesel side pick is down for repair or service, and the diesel side pick operates about 329 days per year. The annual NO_X production of the diesel side pick is about 94 kg per year.

6.0 MAINTENANCE

Table 13 summarizes the maintenance logs for the two sidepicks as reported by BNSF.

Table 13. Sidepick Maintenance Logs

Start Date	End Date	Elapsed Time	Affected Component	Impact	Root Cause	Repairs Made	Parts Replaced	Cost to Repair	Repair Time (hrs)	Odometer/Hour Meter Reading	Comments
6/2/2020	6/2/2020		Diesel RTG	NONE	LEAKING TUBE LINE	Install tube line	tube line		4		crane in pad for repairs replace leaking tube line.
6/16/2020	6/17/2020	1	Side Loader Charger	No Charging	BYD Charger breaker tripped	Reset breaker	N/A	N/A	0.5		Reset the breaker and inspected the charger
7/30/2020	7/31/2020	1	Side Loader Charger	No Charging	BYD Charger breaker tripped	Reset breaker	N/A	N/A	0.5		power surge from grid causing breaker to trip? BYD to investigate
	July		Side Loader	System error	?	downloaded data messages		$ 225	1		Checked side loader and downloaded data messages
8/7/2020	8/13/2020	6	Side Loader	Charge Error; no power to	100A Fuse Blown	Replaced Fuse	Fuse	$ 600	4	198	Side loader could not be charged; inspected BMS; discovered main fuse was blown
8/11/2020			Diesel side loader	none	out of adjustment	adjust limit swith	none		1		while cycle unit seen limit switch out of adjutment.
8/13/2020	8/21/2020	8	Side loader		Failed DC/AC convertor	Replaced DC/AC convertor	DC/AC Convert	$ 22,885	5		Cab A/C not working replaced DC/AC converter
8/14/2020	8/14/2020		Side Loader	AC not cooling cab		added 3lbs freon NC	Freon		1.5		
8/26/2020			Diesel side loader	NONE	didn't have low coolant sensor	install coolant sensor	coolant sensor		4		
9/2/2020	9/2/2020		Side loader	no impact; upgrade only	Motor coupler upgrade	Upgrade motor coupler	Motor Coupler	Warranty	9		The coupler is like a drive shaft that connects the motor to pump to drive the unit. It was replaced because soft metal on original coupler would have led to premature failure. Taylor made the decision to upgrade because of previous experience on failures
9/3/2020	9/3/2020		Diesel side loader	Routine 165-hr. PM	N/A	N/A		$ 459	10		
9/29/2020	9/29/2020		Side Loader Charger	no charging	Unknown	update software			3		Got callled a couple time charger not charging check found breaker tripped. Emailed Rob and he send Pann out
10/5/2020	10/5/2020		Diesel side loader	Routine 165-hr. PM	N/A	N/A		$ 618	12		
1/10/2021	1/10/2021		Electric Side Loader	PM				$ 50	8		Routine PM
2/20/2021	24-Feb	4 days	Electric Side Loader	Breakdown	Machine would not go into gear	replaced shifter	new shifter	$ 525	4		joystick replacement?; computer chip ... shifter more complex; thought it was just a switch, but it has some circuitry to it to communicate with the modules
2/20/2021			Diesel side loader	unexpected event	Machine ran with low DEF fluid	Cleared the code & refilled DEF		$ -	1		Required Volvo service call to reset the codes
2/25/2021			Diesel side loader	Breakdown	No communication with ECM	Taylor updated software	?	$ 250	4		

7.0 SUMMARY

This Topical Report summarizes datalogger monitoring of two Side Pick Container Handlers (side picks) at BNSF Railway's San Bernardino Intermodal Facility during 2020-2021. The side picks are very large forklifts for handling ISO shipping containers. A diesel baseline side pick was compared to a battery-powered counterpart procured and deployed under BNSF's ZANZEFF grant.

The diesel side pick averaged 4.3 operating hours per day and consumed an average of 12.7 gallons of diesel fuel with an average cost of $1.23 per lift. The most active day for the diesel side pick used 53 gallons of diesel fuel over 15 hours of operation, and performed 299 lifts. The diesel side pick fuel tank had a capacity in excess of 200 gallons, which would imply 56 hours of continuous activity before refueling. Typical refueling of the diesel side pick was once a week. Refueling time was measured in minutes and could be done anywhere in the yard.

The electric side pick had a fairly large battery pack, with a 922 kW-hr capacity, and was estimated that a single charge could perform approximately 288 lifts over 25 hours of continuous operation. The typical daily use was observed to be 3.8 hours. A charge once a day or night is sufficient to keep the battery charged. The electric side pick requires up to 5 hours to fully recharge, but typically requires far less time. The electric side pick needed to be brought back to the charging station once per day. The electric side pick used an average of 188 kW-hrs of energy per its 3.8 hour operating day, and an electricity cost of $1.41 per lift.

The electric side pick was never utilized to its full potential, and there were many days during the monitoring period when it was not used. The initial training instructed the operators to return the electric side pick to the charging station to be charged when on break, during lunch, when not in use, etc. This might have given the operators the false impression that the electric side pick might not have enough battery capacity to make it through a full day of work. This "range anxiety" and the need to traverse the operating lot back to the charging station likely resulted in the operators preferentially choosing the diesel side pick over the electric side pick. However, the data from this study showed that the performance of the electric side pick was equivalent to its diesel counterpart.

Using a typical four hours per day of side pick operation, and a 10 percent maintenance or out of service time, the estimated annual diesel fuel and emissions reduction of replacing the diesel side pick with an electric side pick are presented in Table 14, assuming that the roughly 62,000 kW-hr of electricity needed to replace the diesel has zero GHG or criteria emissions.

Table 14. Estimated Annual Diesel Fuel and Emission Reductions by Replacing a Diesel Side Pick with an Electric Side Pick

Days of Operation (90 percent up time)	329
Annual Diesel Fuel Savings (gallons)	4,180
CO_2 (kg)	62,800
CO (kg)	124
Humidity-Corrected NOx (kg)	94
Total Hydrocarbons (kg)	2
Annual Electricity needed to Replace Diesel, kW-hr	62,000

APPENDIX A

ZANZEFF Appendix F - Data Collection Objectives & Responsibilities

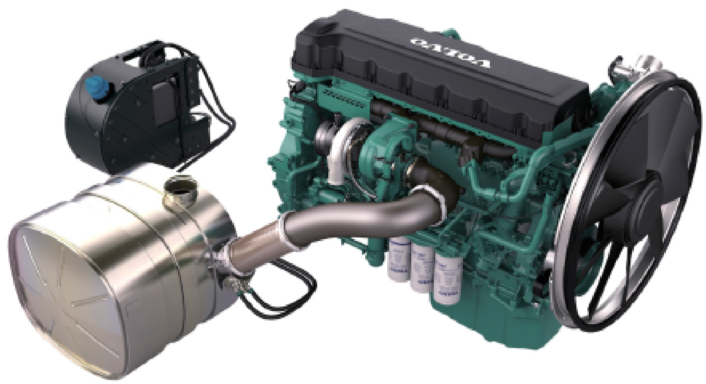
		Side Loader	
	Data Collection Method	**Diesel**	**Electric**
Appendix A - Vehicle Specification			
Manufacturer	OEM Specification	SwRI	SwRI
Model	OEM Specification	SwRI	SwRI
Model year	OEM Specification	SwRI	SwRI
Gross vehicle weight	OEM Specification	SwRI	SwRI
Fuel type	OEM Specification	SwRI	SwRI
Propulsion system description	OEM Specification	SwRI	SwRI
Engine label photos	OEM Specification	SwRI	NA
Appendix B - Vehicle Operation			
Description of daily use / duty cycle	Data Logger/CAN	SwRI	SwRI
Vehicle usage:			
Hours of operation per day	Data Logger/CAN	SwRI	SwRI
Days of operation per year	Data Logger/CAN	SwRI	SwRI
Odometer/Hour meter/MWhr reading (quarterly)	Data Logger/CAN	SwRI	SwRI
GPS data:			
Key off / Key on	Data Logger/CAN	SwRI	SwRI
Miles traveled per trip	Data Logger/CAN	NA	NA
Average speed	Data Logger/CAN	NA	NA
Number of stops per mile	Data Logger/CAN	NA	NA
Duration per trip	Data Logger/CAN	NA	NA
Idling/queuing time	Data Logger/CAN	SwRI	SwRI
Battery charge capacity/power output (duty cycle)	Data Logger/CAN	NA	SwRI
Appendix C - Vehicle / Equipment Performance			
Vehicle zero emission range/work performed per charge	OEM Specification/Data Logger	NA	Taylor
Operator Feedback	Survey/Focus Group	BNSF/ITS	BNSF/ITS
Operational Feedback (ability to perform function, advantages, etc.)	Survey/Focus Group	BNSF/ITS	BNSF/ITS
Appendix D - Fuel / Energy Consumption			
Amount of fuel/electricity supplied	Fuel Log/Utility Data	ITS	BNSF
Fuel price per unit when a vehicle is fueled	Manual	BNSF	BNSF
Include electricity rates as applicable	Rate Data	BNSF	BNSF
State of charge (SOC) increase, if applicable	Data Logger	NA	SwRI
Refueling time/charging time	Data Logger	NA	SwRI
Refueling/charging source:			
Grid	Rate Data	NA	BNSF
On-site fueling	Rate Data	BNSF	NA
Refueling/charge frequency	Data Logger	SwRI	SwRI
Vehicle efficiency: energy/fuel consumed per unit of production	Data Logger	SwRI	SwRI
Fuel/energy consumption while idling (if applicable)	Data Logger	SwRI	SwRI
All-electric range and average electric usage in hybrids as a function of trip duration and work output, if applicable	Data Logger	NA	SwRI
Appendix E - Maintenance			
Type of maintenance:			
Scheduled	Maint Records	ITS	ITS
Unscheduled	Maint Records	ITS	ITS
Equipment modification	Maint Records	ITS/BNSF	ITS/BNSF
Repairs:			
Date	Maint Records	ITS	Taylor
Description of problem	Maint Records	ITS	Taylor
Description of repair performed	Maint Records	ITS	Taylor
Parts replaced	Maint Records	ITS	Taylor
Odometer/hour meter reading	Maint Records	ITS	Taylor
Actual repair time	Maint Records	ITS	Taylor
Time out of service W/ explanation for extended delay	Maint Records	ITS	Taylor
Appendix F - Safety			
Service interuptions or delays: (relevant issues that drove SI or delays)			
Equipment malfunction caused	Field Reports	ITS/BNSF	ITS/BNSF
Other relevant causes	Field Reports	ITS/BNSF	ITS/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.	PEMS/Data Logging	SwRI	NA

APPENDIX B

TAD1371-1375VE

12.78 litre, in-line 6 cylinder - 285, 315, 345, 375 & 405 kW

EU Stage IV / US EPA Tier 4 Final



TAD1371-1375VE is a powerful, reliable and economical off-road Diesel Engine range built on the Volvo Group in-line six concept.

Low cost of ownership
World class fuel efficiency combined with high uptime as well as low cost of ownership.

Compact & simple installation
As optional equipment all material needed in order to install the engine can be ordered from Volvo Penta. Installation guidelines as well as drawings and CAD models are easy to access. The result is an engine that is easy to install.

Durability & low noise
Long experince with base engine development reduces risk of downtime. Well-balanced to produce smooth operation with low noise.

Power & torque
Maximum power and torque available at low rpm. As a result noice as well as fuel consumption is very low. Useful engine speed for the TAD1371-1375VE is due to power and torque layout very flexible.

Low exhaust emission
Efficient injection as well as robust engine design in combination with optimised SCR technology and a light EGR contributes to excellent combustion and low fuel consumption.

Easy service & maintenance
Easily accessible service and maintenance points contribute to the ease of service of the engine. As optional equipment possible to remote mount filters and service points.

- **Proven and straight-forward design - built on Volvo Group technology**
- **Low cost of ownership and operation**
- **High power and torque already at low engine speed**
- **SCR and light EGR only - no DPF, DOC or regeneration**
- **Compact, simple installation and easy to service**
- **Similar engine footprint for all emission standards**
- **Wide range of optional equipment**

Technical description

Engine and block
- Cast iron cylinder block
- Wet, replaceable cylinder liners
- Replaceable valve guides and valve seats
- Overhead camshaft and four valves per cylinder

Lubrication system
- Full flow disposable spin-on oil filter, for extra high filtration
- Gear type lubricating oil pump, gear driven by the transmission
- Oil level sensor at startup

Fuel system
- Electronic high pressure unit injectors
- Fuel prefilter with water separator and water-in-fuel indicator / alarm
- Gear driven low-pressure fuel pump
- Fine fuel filter with manual feed pump and fuel pressure switch

Cooling system
- Available as power pack or base engine.
- Belt driven coolant pump with high degree of efficiency

Turbo charger
- Electronically controlled Waste-gate

Electrical system
- Engine Management System (EMS) 2.3, an electronically controlled processing system which optimizes engine performance. It also includes advanced features for diagnostics and fault tracing.
- The instruments and controls connect to the engine via the CAN SAE J1939 interface. Options available for engine control equipment.

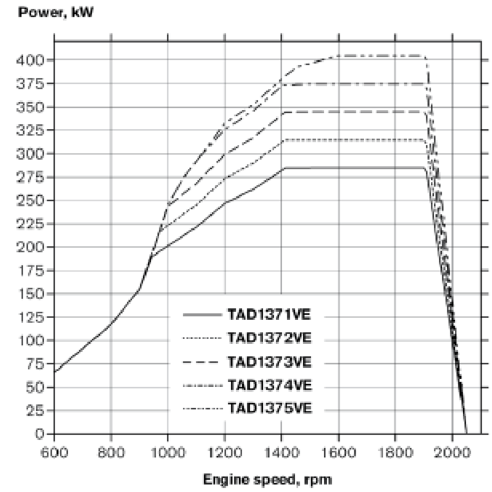
Exhaust aftertreatment system
- SCR and light EGR only
- Airless urea injection
- Wide range of options available, including different sized AdBlue® / DEF tanks (also possible for OEM to design own tank).

TAD1371-1375VE

Technical data

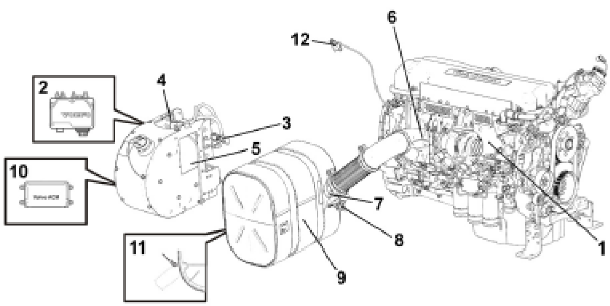
Engine designation TAD1371-1375VE
Configuration and no. of cylinders .... in-line 6
Displacement, l (in³) 12.78 (780)
Method of operation 4-stroke
Direction of rotation (viewed towards flywheel) .... anti-clockwise
Bore, mm (in.) 131 (5.16)
Stroke, mm (in.) 158 (6.22)
Compression ratio 17.8:1
Dry weight, engine only, kg (lb) 1267 (2793)

Engine	kW	Hp	rpm	Max Nm
TAD1371VE	285	388	1900	1965
TAD1372VE	315	428	1900	2175
TAD1373VE	345	469	1900	2380
TAD1374VE	375	510	1900	2595
TAD1375VE	405	551	1900	2650

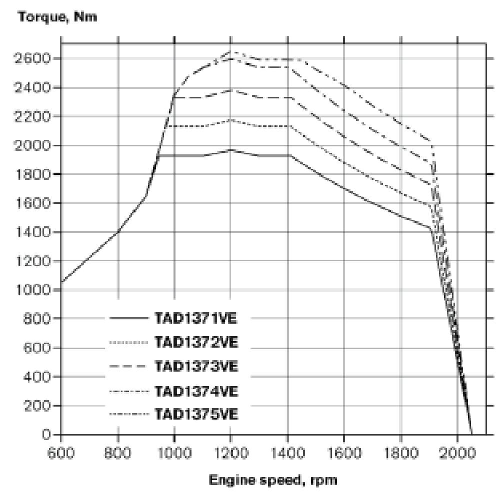


Main components, Principal layout

The illustration shows the main components of the aftertreatment system and its piping connections.

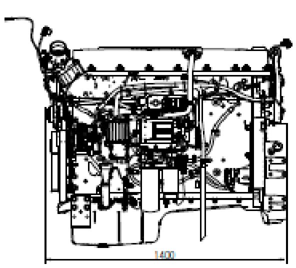


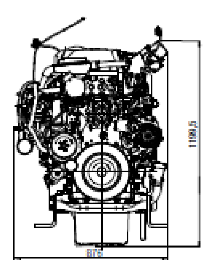
1 Engine
2 Pump Unit (PU)
3 Solenoid Valve, heating/cooling
4 AdBlue®/DEF Level Sensor
5 AdBlue/DEF Solution Tank
6 NOx Sensor
7 Temperature Sensor Exhaust
8 Dosage Valve (DV)
9 Muffler with Catalytic Converter
10 Aftertreatment Control Module (ACM)
11 NOx Sensor
12 Temperature Sensor Air

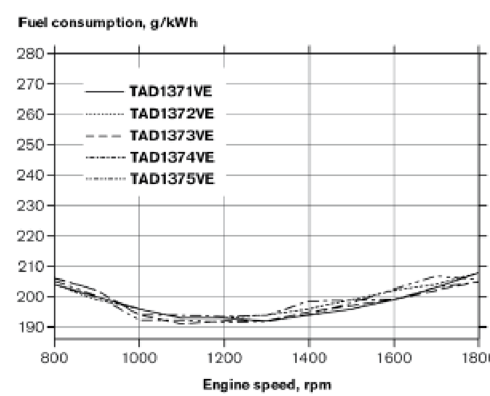


Dimensions

Not for installation. Dimensions in mm.







APPENDIX C

CALIFORNIA AIR RESOURCES BOARD	AB VOLVO PENTA	EXECUTIVE ORDER U-R-014-0165 New Off-Road Compression-Ignition Engines

Pursuant to the authority vested in the Air Resources Board by Sections 43013, 43018, 43101, 43102, 43104 and 43105 of the Health and Safety Code; and

Pursuant to the authority vested in the undersigned by Sections 39515 and 39516 of the Health and Safety Code and Executive Order G-14-012;

IT IS ORDERED AND RESOLVED: That the following compression-ignition engines and emission control system produced by the manufacturer are certified as described below for use in off-road equipment. Production engines shall be in all material respects the same as those for which certification is granted.

MODEL YEAR	ENGINE FAMILY	DISPLACEMENT (liters)	FUEL TYPE	USEFUL LIFE (hours)
2018	JVPXL12.8CJA	12.8	Diesel	8000

SPECIAL FEATURES & EMISSION CONTROL SYSTEMS	TYPICAL EQUIPMENT APPLICATION
Electronic Direct Injection, Turbocharger, Charge Air Cooler, Electronic Control Module, Exhaust Gas Recirculation, Smoke Puff Limiter, Selective Catalytic Reduction-Urea	Crane, Loader, Pump, Compressor, Generator Set

The engine models and codes are attached.

The following are the exhaust certification standards (STD) and certification levels (CERT) for hydrocarbon (HC), oxides of nitrogen (NOx), or non-methane hydrocarbon plus oxides of nitrogen (NMHC+NOx), carbon monoxide (CO), and particulate matter (PM) in grams per kilowatt-hour (g/kW-hr), and the opacity-of-smoke certification standards and certification levels in percent (%) during acceleration (Accel), lugging (Lug), and the peak value fror either mode (Peak) for this engine family (Title 13, California Code of Regulations, (13 CCR) Section 2423):

RATED POWER CLASS	EMISSION STANDARD CATEGORY		EXHAUST (g/kW-hr)					OPACITY (%)		
			NMHC	NOx	NMHC+NOx	CO	PM	ACCEL	LUG	PEAK
130 ≤ kW ≤ 560	Tier 4 Final	STD	0.19	0.40	N/A	3.5	0.02	N/A	N/A	N/A
		CERT	0.02	0.22	-	0.1	0.02	-	-	-

BE IT FURTHER RESOLVED: That for the listed engine models, the manufacturer has submitted the information anc materials to demonstrate certification compliance with 13 CCR Section 2424 (emission control labels), and 13 CCF Sections 2425 and 2426 (emission control system warranty).

Engines certified under this Executive Order must conform to all applicable California emission regulations.

This Executive Order is only granted to the engine family and model-year listed above. Engines in this family that are produced for any other model-year are not covered by this Executive Order.

Executed at El Monte, California on this 20 day of November 2017.

Annette Hebert, Chief
Emissions Compliance, Automotive Regulations and Science Division

Engine Family	JVPXL 12.8CJA				
Engine Code	I	II	III	IV	V
Engine Model	**TAD1371 VE**	TAD1372 VE	TAD1373 VE	TAD1374 VE	TAD1375 VE
BHP@rpm (SAE Gross)	**382@1900**	422@1900	463@1900	503@1900	543@1900
Fuel Rate mm/stroke@peak HP (for diesel only)	**208**	229	248	268	290
Fuel Rate (lbs/hr)@peak HP (for diesel only)	**133**	146	159	171	185
Torque@rpm (SAE Gross)	**1965 Nm@1200**	2175 Nm@1200	2380 Nm@1200	2595 Nm@1200	2650 Nm@1200
Fuel Rate mm/stroke@peak torque	**264**	290	317	348	353
Fuel Rate (lbs/hr)@peak torque	**107**	117	128	141	143
Emission Control Devices Per SAE J1930	**DDl, EM, ECM, CAC, TC, SPL, SCR-U, EGR**	DDl, EM, ECM, CAC, TC, SPL, SCR-U, EGR	DDl, EM, ECM, CAC, TC, SPL, SCR-U, EGR	DDl, EM, ECM, CAC, TC, SPL, SCR-U, EGR	DDl, EM, ECM, CAC, TC, SPL, SCR-U, EGR