Volvo LIGHTS Project: Summary Report

Jon Gordon, CALSTART
Alexandra Ivina, CALSTART
Shuhan Song, CALSTART
Alise Crippen, CALSTART
Chase LeCroy, CALSTART
Dr. Kent Johnson, University of California, Riverside

December 2022

UC RIVERSIDE | CE-CERT

CALSTART

Acknowledgments

This report would not have been possible without the support of the California Air Resources Board (CARB), South Coast Air Quality Management District (SCAQMD), Volvo Trucks North America, Dependable Highway Express (DHE), NFI Industries (NFI), TEC Equipment, University of California at Riverside's (UCR's) College of Engineering–Center for Environmental Research and Technology (CE–CERT), and others. SCAQMD assembled the project team and led the grant application effort and the technology implementation plan. Volvo Trucks North America developed the Class 8 vehicles deployed at NFI and DHE, the providers of supply chain solutions near the San Pedro Bay Ports that demonstrated the advanced-technology equipment. TEC Equipment offered fleets the ability to lease the battery-electric trucks for real-world trials. UCR CE–CERT led the Portable Emissions Measurement System (PEMS) testing and was an instrumental partner in collecting data.

The Volvo Low Impact Green Heavy Transport Solutions (LIGHTS) Project 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.

Cap and Trade
Dollars at Work

Disclaimer

Table of Contents

List of Tables

List of Figures

List of Acronyms

Table 1: List of Acronyms

Acronym	Term
ACF	Advanced Clean Fleets regulation
ACT	Advanced Clean Truck regulation
BSR	Business for Social Responsibility
CARB	California Air Resources Board
CE–CERT	College of Engineering–Center for Environmental Research and Technology
CO	Carbon monoxide
CORE	Clean Off-Road Equipment Voucher Incentive Project
CO2	Carbon dioxide
CPS	Chint Power Systems
DHE	Dependable Highway Express
EPA	U.S. Environmental Protection Agency
ESS	Energy storage system
EV	Electric vehicle
g	Grams
GHG	Greenhouse gas
GNA	Gladstein Neandross & Associates
HD	Heavy-duty
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
kg	Kilogram
KPI	Key performance indicator
kW	Kilowatt
kWh	Kilowatt-hour
lbs.	Pounds
LCFS	Low Carbon Fuel Standard
LIGHTS	Low Impact Green Heavy Transport Solutions

Acronym	Term
NOx	Nitrogen oxides
OEM	Original equipment manufacturer
PEMS	Portable Emissions Measurement Systems
PM	Particulate matter
PV	Photovoltaic
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SOC	State of charge
TCO	Total cost of ownership
TOU	Time-of-use
UCR	University of California at Riverside
WAIRE	Warehouse Actions and Investments to Reduce Emissions
ZE	Zero-emission
ZETA	Zero Emission Transportation Association
ZEV	Zero-emission vehicle

Executive Summary

The Volvo LIGHTS (Low Impact Green Heavy Transport Solutions) Project was a unique collaboration between 15 organizations to deploy zero-emission (ZE) technologies and equipment, as well as implement efficiency improvements at several freight facility sites. This report brings together the most important findings of the project with the hope of helping other fleets accelerate their own deployments of ZE equipment strategically and cost-effectively.

The Ports of Los Angeles and Long Beach process about 40% of all U.S. imports. These goods are then trucked throughout the region to warehouses and distribution centers and subsequently distributed across the nation. The extensive goods movement sector in Southern California contributes significantly to pollution and climate change in the region. According to the Port of Los Angeles' 2020 Inventory of Air Emissions, cargo handling equipment such as yard tractors (18%) and heavy-duty (HD) vehicles such as Class 8 tractors (44%) are responsible for 64% of the port's carbon dioxide (CO2) emissions.[1] Transitioning to ZE operations is important for reduction of air pollution and carbon emissions. This project showcases one of the most advanced demonstrations of ZE technology in the freight sector, acting as a roadmap for future ZE deployments.

To assess the performance of ZE technologies deployed in this project, CALSTART worked in close coordination with the University of California at Riverside's (UCR's) College of Engineering–Center for Environmental Research and Technology (CE–CERT). Both teams assisted with the deployment of ZE technology; collected and analyzed data on the performance of ZE and baseline vehicles, infrastructure, and efficiency measures in the field; and interviewed vehicle operators, maintenance staff, and other stakeholders to capture lessons learned. This report is meant to serve other fleets and facility operators interested in transitioning to ZE technologies. The CE–CERT team produced a companion report ("Volvo LIGHTS Emissions and Activity Results") that highlights lessons learned about emissions produced from propane and diesel equipment in the field, life-cycle analysis of ZE and baseline freight-handling equipment, and analysis of the jobs created by transitioning to ZE operations. CE–CERT's report will likely become accessible to the public online in 2022.

Volvo LIGHTS involved operations of two freight facility sites in Southern California: Dependable Highway Express (DHE) in Ontario and NFI Industries in Chino. The project

---

[1] Port of Los Angeles Inventory of Air Emissions – 2020.
https://kentico.portoflosangeles.org/getmedia/7cb78c76-3c7b-4b8f-8040-b662f4a992b1/2020_Air_Emissions_Inventory

also included TEC Equipment, a dealership with locations in La Mirada and Fontana, and Volvo's first certified electric truck maintenance facility. Equipment deployed included electric forklifts, yard tractors, Class 7 box trucks, Class 8 tractors, and the associated charging infrastructure. Facilities also benefitted from the installation of solar panels, energy storage systems (ESSs), and workplace charging services. In total, over 60 pieces of ZE equipment were deployed.

ZE Equipment Deployed by Facility Type

Tables 2, 3, and 4 summarize the ZE equipment deployed at each fleet.

Table 2: ZE Equipment Deployed at DHE

Equipment Type	Count	Manufacturer
Forklifts	14	Yale
Forklift Chargers	8	Advanced Clean Technologies
Yard Tractors	2	Orange EV
Yard Tractor Chargers	2	Orange EV
Volvo VNR Class 7 Box Truck	1	Volvo
Volvo VNR Class 8 Tractors	3	Volvo
HD Truck Chargers	2	ABB
Workplace Chargers	2 units; 6 ports total	EvoCharge
Photovoltaic (PV) Solar	1 system (864 kW)	Solar Optimum
ESS	1 system (130 kWh)	CPS

Table 3: ZE Equipment Deployed at NFI

Equipment Type	Count	Manufacturer
Forklifts	8	Crown
Forklift Chargers	8	V-Force
Yard Tractors	2	Kalmar
Yard Tractor Chargers	2	Transpower
Volvo VNR Class 8 Tractors	2	Volvo
HD Truck Chargers	2	ABB
Workplace Chargers	3	EvoCharge

Table 4: ZE Equipment Deployed at TEC

Equipment Type	Count	Manufacturer
HD Truck Chargers	1	ABB

Forklifts

DHE deployed 14 Yale electric forklifts with eight Advanced Clean Technologies chargers, while NFI deployed eight Crown forklifts with eight V-force chargers. Overall, both were satisfied with the performance of the forklifts and plan to continue purchasing electric forklifts moving forward. The fleet operators were satisfied by the performance of the units as well as their business case. The ZE technology was preferred by operators that typically work with propane and lead-acid forklifts. Table 5 summarizes key performance metrics of the forklifts at each fleet.

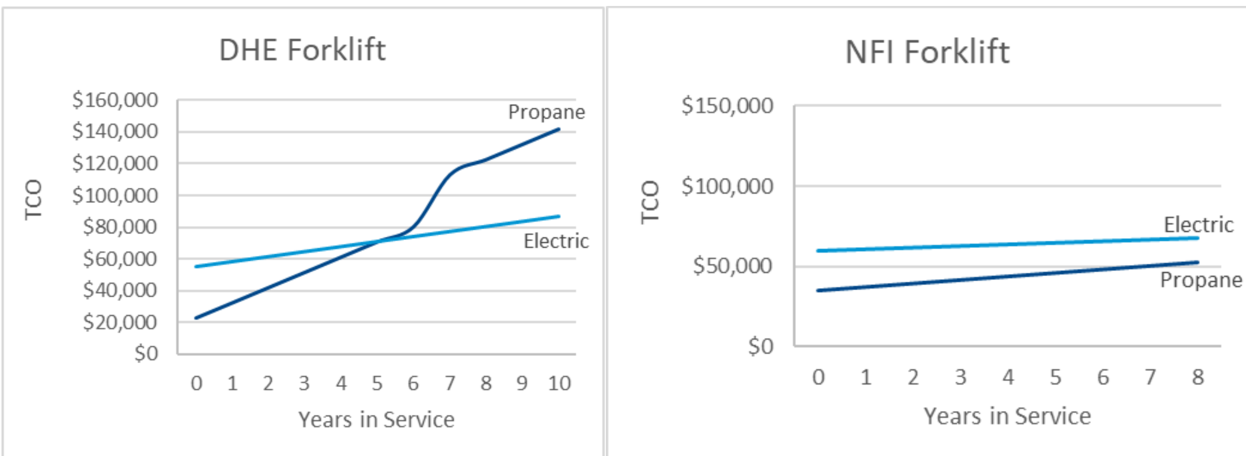
Table 5: Key Performance Metrics for Electric and Propane Forklifts

Performance Metric	DHE Electric	DHE Propane	NFI Electric	NFI Propane
Daily Operating Time (hours)	9	9	1.4	1.4
Daily Energy Charged (kWh)	28	-	7	-
Operating Cost ($/hour)	2.25	4.79	3.63	6.80
Annual Fuel or Electricity Cost with LCFS ($)	72	2,149	-82	364
Annual Emissions (kg CO2)	-	11,265	-	2,416

DHE's forklifts were standardized at 2,000 hours of operation annually, and NFI's forklifts were standardized at 319 hours of operation. Both DHE and NFI placed their electric forklifts on the same duty cycle as their baseline forklifts, meaning about 9 hours of operation per day at DHE and 1.4 hours at NFI. The electric forklifts consumed between 3 and 5 kilowatt-hours (kWh) per hour in use and saved between $2.54 and $3.17 per hour on fueling and maintenance costs compared with baseline propane forklifts. With Low Carbon Fuel Standard (LCFS) credits included, the fleets paid less than $100 to charge the electric forklifts annually and, in some cases, received more money from LCFS credits than they paid to charge the forklifts. The electric forklifts displaced 5.6 to 7.6 kilograms (kg) of tailpipe CO2 per each hour of use. In total, DHE's 14 forklifts will offset 1.57 million kg of CO2 over their 10-year lifetimes and NFI's eight forklifts will offset about 155,000 kg of CO2 over their eight-year lifetime. In total, the 22 forklifts deployed in this project will offset 1.73 million kg of CO_2, equivalent to taking 375 passenger cars off the road for a year.[2]

ZE technology generally has higher upfront costs but lower operational costs over conventional technologies, which can lead to a financial benefit over the lifetime of the vehicles. For forklifts, cost parity with propane will be reached in 6,000 to 10,000 hours of operation, after which each additional hour of operation will save the fleet money. The electric forklifts at DHE are expected to achieve cost parity with baseline forklifts at the fifth year in service. Due to the low daily utilization, forklifts at NFI are expected to be used for longer than the projected eight-year lifecycle. This is shown in the two total cost of ownership (TCO) charts below (Figure 1).

Figure 1: DHE and NFI Propane and Electric Forklift TCO



DHE's electric and propane forklifts were standardized at 2,000 hours of use per year and NFI's at 319 hours. As described above, only DHE's electric forklifts are expected to achieve cost parity with propane forklifts because their duty cycles require enough hours in use. NFI's forklift duty cycle did not require enough hours in use for electric forklifts' cheaper operational costs to make up for their higher upfront costs. Generally, the more hours electric technology is utilized, the faster it will achieve cost parity with baseline technology.

[2] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Yard Tractors

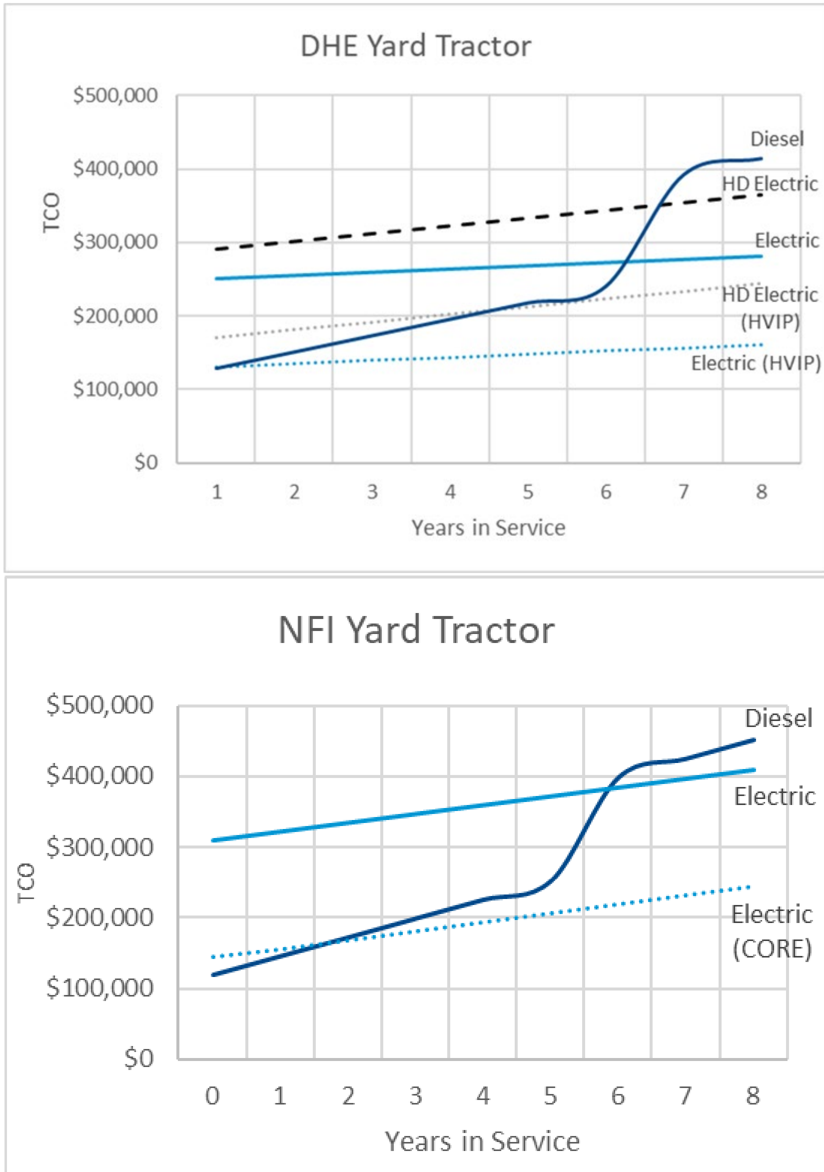
DHE deployed two electric Orange EV yard tractors with two chargers, and NFI deployed two Kalmar electric yard tractors with two Transpower chargers. Electric yard tractors were highlighted by both fleets as the best technology to transition from diesel to electric currently. The vehicles were able to meet all duty-cycle expectations, made financial sense, were preferred by operators, and could take advantage of opportunity charging easily. Table 6 below summarizes key takeaways from yard tractors at DHE and NFI.

Table 6: Key Performance Metrics for DHE and NFI Electric and Diesel Yard Tractors

Performance Metric	DHE Electric	DHE Diesel	NFI Electric	NFI Diesel
Daily Operating Time (hours)	12	12	8	14
Daily Energy Charged (kWh)	73	-	89	-
Operating Cost ($/hour)	2.30	7.42	3.54	8.83
Annual Fuel or Electricity Cost with LCFS ($)	-11	10,233	1,204	11,571
Annual Emissions (kg CO2)	-	33,669	-	21,661

Both fleets operated their yard tractors between 8-14 hours per day. Yard tractors were standardized at 3,000 hours of operation annually. The electric yard tractors consumed between 70 and 90 kWh per day, averaging between 5.8 and 10.4 kWh per hour of operation. The cost benefits of electric yard tractors were clear; the fleets saved about $10,000 per year compared to fueling a diesel yard tractor and achieved excellent emissions savings of up to 30,000 kg of CO_2 annually. The electric vehicles (EVs) also make financial sense as displayed in Figure 2 below, which shows the TCO comparisons for DHE's 80-kWh and 160-kWh HD electric yard tractor and NFI's 176-kWh electric yard tractor. The leap in diesel yard tractor TCO between Years 5 and 6 is due to the fact that diesel yard tractors are kept in service for about five years, compared to an eight-year expectation for electric yard tractors. After five years in service, maintenance costs for diesel yard tractors tend to get very costly, making the vehicle too expensive to operate.

Figure 2: DHE and NFI Diesel and Electric Yard Tractor TCO



Electric yard tractors cost about twice as much upfront as diesel yard tractors, but these vehicles are expected to achieve cost parity with diesel yard tractors due to their lower fueling and maintenance costs. Electric yard tractors reduce maintenance costs by about 75% compared to diesel yard tractors. This is due to the high cost of maintaining diesel yard tractors, which requires manual cleaning of their emissions systems and therefore causes them to experience greater downtime.

The TCO analysis in Figure 2 examines electric yard tractors with and without financial incentives from California voucher programs HVIP (Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project) and CORE (Clean Off-Road Equipment Voucher

Incentive Project). With incentive funding, both yard tractors achieved cost parity with diesel upon adoption. Without incentives, the Orange EV 80-kWh yard tractor at DHE would achieve cost parity in Year 6 and save the fleet nearly $93,000 by the end of Year 8, and the HD 160-kWh yard tractor would also achieve cost parity in Year 6, saving the fleet $65,000 after Year 8.

NFI operated two 176-kWh Kalmar electric yard tractors, which are expected to achieve cost parity in two years with incentive funding or in six years without incentives. By the end of Year 8, the electric yard tractor will save the fleet $233,000 with incentives or $67,000 without incentives.

Class 7 Box Truck and Class 8 Tractors

DHE deployed four electric Volvo trucks: one Class 7 box truck (with a 264-kWh battery), one pilot Class 8 tractor (with a 396-kWh battery), and two second generation Class 8 tractors (with 264-kWh batteries). NFI also deployed two second-generation electric Class 8 tractors (with 264-kWh batteries). All electric trucks charged using 150-kW ABB charging equipment. While most electric trucks were not expected to achieve cost parity with diesel trucks under their current duty cycles, this report explores numerous strategies to minimize EV costs in addition to other electric truck deployment learnings. Table 7 summarizes electric Class 7 box truck and Class 8 tractor performance in the field. Class 7 box trucks were standardized at 15,000 miles per year and the Class 8 tractors at 20,000 miles per year.

Table 7: Key Performance Metrics for DHE and NFI Electric and Diesel Box Trucks and Class 8 Tractors

Performance Metric	DHE e-Box Truck	DHE Diesel Box Truck	DHE e-Tractor	DHE Diesel Tractor	NFI e-Tractor	NFI Diesel Tractor
Daily Distance Driven (miles)	60	60	86	150	108	152
Daily Energy Charged (kWh)	111	n/a	189	n/a	144	n/a
Fuel and Maintenance Cost ($/mile)	0.52	0.79	0.65	1.06	0.70	1.06
Annual Fuel Cost ($)	2,469	9,643	4,211	12,857	3,300	12,857
Annual Emissions (kg CO2)	n/a	23,242	n/a	36,776	n/a	34,111

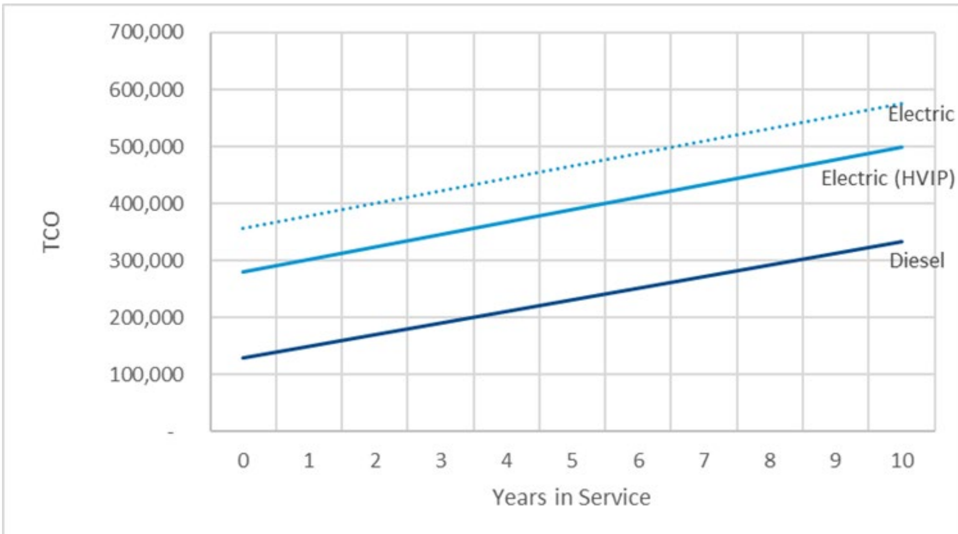
Electric box trucks (Class 7) were mostly able to meet the duty cycle of diesel trucks at DHE with fewer days out of service. As a result, DHE plans to transition their entire fleet at the Ontario facility of 10 box trucks to electric over the next few years. DHE's electric box truck drove the same number of miles as the diesel units and consumed an average of 111 kWh per day at 1.72 kWh per mile efficiency. The annual fuel savings were about $7,200, and annual emissions savings were 23,000 kg of tailpipe CO2 (equivalent to taking 5,000 passenger vehicles off the road for a year).

DHE's electric tractors (Class 8) averaged about 86 miles per day with a maximum of 150 miles, including a few opportunity charges. The current models could not meet all of DHE's regional routes, requiring a minimum of 150 miles consistently on a single charge. The tractors had an average efficiency of 2.19 kWh per mile and consumed 186 kWh per day, charging fully in two hours. The maximum reported range on a single charge was around 90 miles.

NFI's electric tractor (Class 8) averaged 108 miles per day with a maximum of 202 miles per day, including multiple opportunity charges. On average the tractor consumed 185 kWh per day with an efficiency of 1.83 kWh per mile. Operating costs were lower than diesel tractors ($0.36 to $0.41 less per mile), saving the fleets between $8,600 and $9,600 per year on fueling. Assuming each tractor operates 20,000 miles per year, it would offset about 35,000 kg of tailpipe CO2 (equivalent to taking 7,600 passenger vehicles annually).

Figure 3 examines TCO for diesel and electric box trucks at DHE driving 15,000 miles per year.

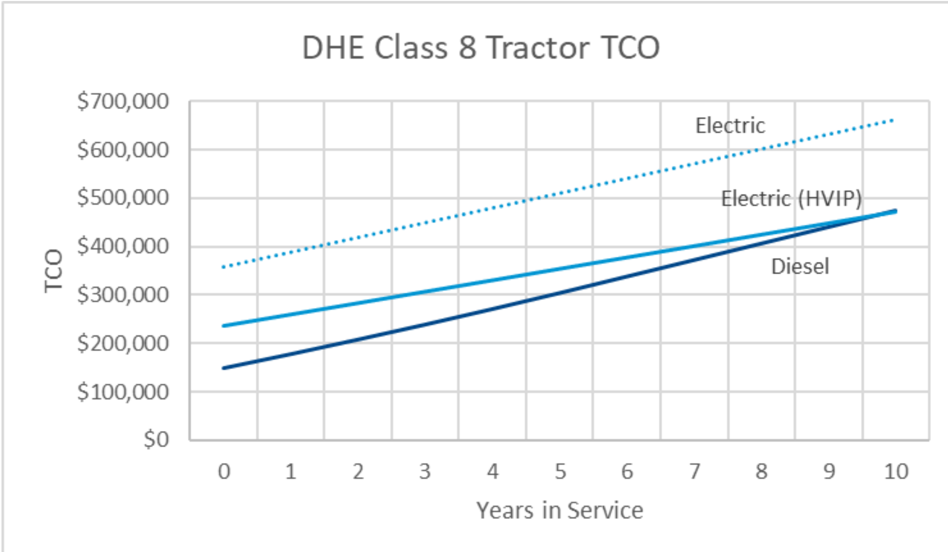
Figure 3: DHE Diesel and Electric Box Truck TCO

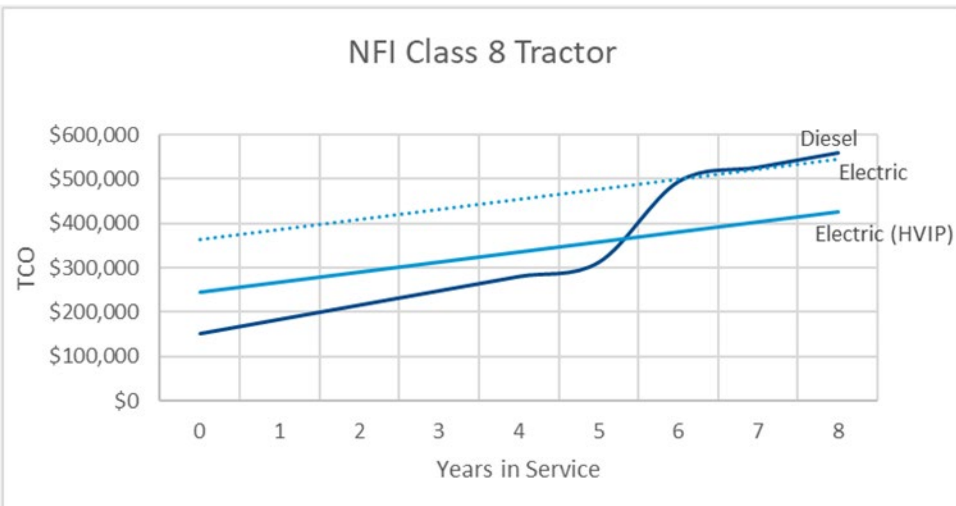


TCO of the electric box trucks is consistently higher over the 10-year period. This is due to higher insurance costs that outweigh fuel and maintenance cost savings. Insurance costs for electric trucks can be three times higher than for diesel trucks depending on insurance servicing company's procedure for calculating insurance cost. While the standard insurance rate is 4–5.5% of the upfront cost of the vehicle, Volvo Financial Services and others consider a fleet's claim history, exposure to risk in the driving area, type of product hauled, level of driver experience, and more factors that can make the difference between diesel and ZE trucks less significant. These insurance rates apply only to on-road vehicles and therefore did not impact the overall operating costs of yard tractors or forklifts.

As electric trucks scale and battery technology improves, upfront costs will decrease and reduce insurance costs. In the meantime, upfront cost incentives will be critical to accelerate the deployment of electric trucks. Figure 4 compares TCO for Class 8 tractors at DHE and NFI, both impacted by higher insurance costs. The leap in NFI diesel Class 8 tractor cost is due to NFI's plans to keep diesel tractors in use for five years, compared to eight years for electric tractors. DHE sought to keep both diesel and electric tractors in use for 10 years.

Figure 4: Diesel and Electric Class 8 Tractor TCO





Like box trucks, higher insurance costs for electric tractors are a key reason for higher TCO. If insurance costs were equal, incentive-funded electric tractors would achieve cost parity in less than six years. NFI will keep their diesel tractors in use for five years compared to an expected eight years for electric tractors. With HVIP funding, electric tractors will likely achieve cost parity after Year 5. In general, however, electric tractor TCO is higher because of higher upfront costs and insurance costs.

EV-Certified "Master Technicians" at TEC Equipment, which has three years of experience maintaining electric trucks, provided one of the most interesting insights from this project. They estimated that maintaining diesel tractors costs $5,000 in Year 1 and gradually increases to about $10,000 by Year 5. Alternatively, electric trucks cost "about $500 total over five years." The technicians were "definitely skeptical of the electric trucks at first...but they do not have oil or grease, are really easy to work with, and do not require much maintenance."[3] The majority of maintenance events performed on the electric trucks were software updates, which TEC Equipment expects will be performed remotely in the near future. Costs for maintaining an electric truck may go up in the near future to account for the additional training that will need to be provided across the industry.

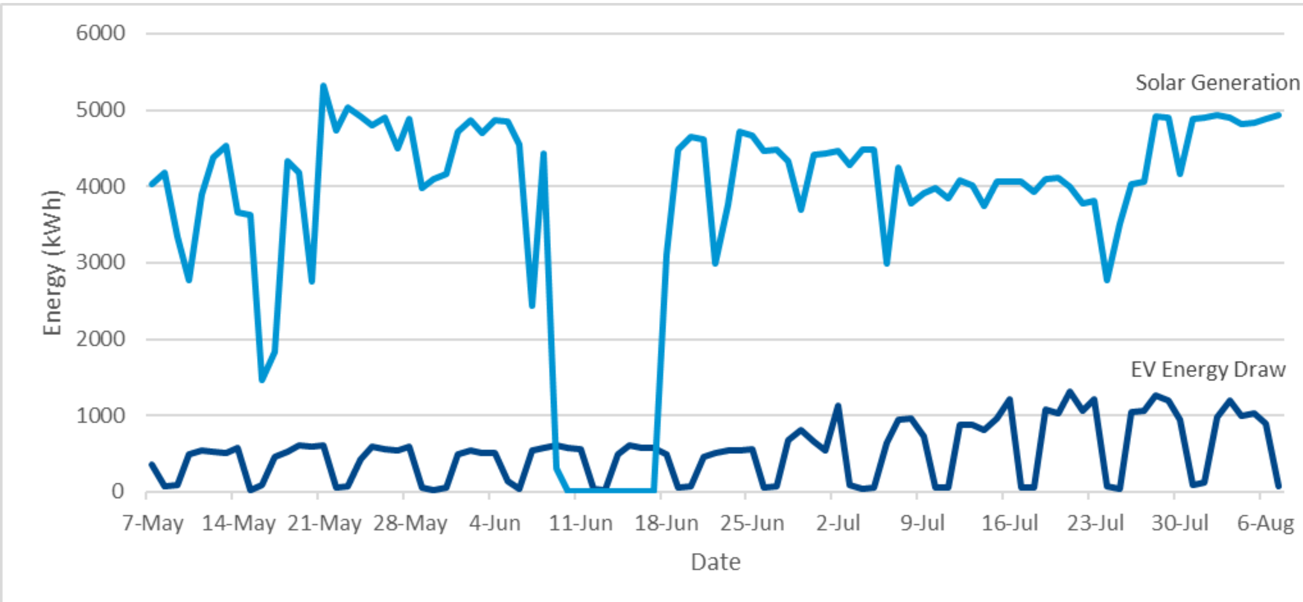
Solar and Energy Storage

DHE installed an 864-kW PV solar system and a 130-kWh ESS, and NFI was able to install a PV solar system toward the end of the project. The goal of these technologies was to provide ZE electricity to the facility and EVs, reduce energy bills, and minimize dependence on the grid. There were several lessons learned from the deployment and operation of these systems.

DHE's 864-kW solar system produced an average of about 4,100 kWh per day, about 4 kWh per panel, with a maximum of 5,326 kWh (Figure 5). It generally produced energy between 6 a.m. and 7 p.m. DHE's solar system currently produces far more energy than their facility and EVs require.

[3] Participant in anonymous fleet feedback surveys and interviews. See Section VII. User Acceptance.

Figure 5: Comparison of DHE's Solar Generation and EV Energy Draw from the Grid



About 70% of DHE's grid consumption charges were offset by solar. This does not include demand charges for the EV meter, which are paused until 2024.

EVs can impact the demand charges costs, and it is expected that the use of onsite solar and energy storage will be able to minimize the cost impact of demand charges. Another way to reduce cost is limiting demand and having vehicles charge at staggered times or at lower charge rates.

Key Findings and Fleet Recommendations

- Electric forklifts and yard tractors can meet the required duty cycle and, with regular operating hours, have a favorable and lower TCO than conventional equipment.
- Electric Class 7 box trucks were able to meet the required duty cycle but did not reach cost parity with diesel box trucks. Despite much lower fueling and maintenance costs, high insurance rates based on the vehicle's upfront cost kept the electric box truck TCO higher. Insurance rates will vary based on the insurance provider, and more data is needed on maintenance costs for electric HD trucks.
- Electric Class 8 tractors achieved a max of about 150 miles per day, including two or three opportunity charges. Most electric tractors did not achieve cost parity due to high insurance rates. Fleets should expect less expensive electric trucks with longer range to become available in the next few years.

- EVs have higher upfront costs but are much less expensive to fuel and maintain. The more hours EVs are used, the higher the operational savings compared to propane and diesel equipment.
- Charging infrastructure installation can be involving and take a longer time than expected in these early deployments. Solar PV and energy storage equipment also take considerable time and should be started early both for planning and improved coordination.
- Solar PV in combination with ESSs can offset demand charges. Fleets can also manage charging events by charging at lower power levels and/or implementing staggered charging.
- LCFS credits for onsite charging is key to EVs achieving a lower TCO.

I. Project Overview

Background

Freight movement in California accounts for about 25% of the state's transport emissions.[4] In 2019 alone, road freight emitted over 1.8 billion tons of carbon dioxide (CO_2) worldwide.[5] Southern California is one of the most congested and polluted regions of the United States and is home to the nation's two largest trading ports: the Port of Los Angeles and the Port of Long Beach. The areas surrounding these two ports, many of which are considered disadvantaged communities, are often the most negatively impacted by goods movement. As hundreds of trucks drive to and from the ports every day, these communities are most exposed to toxic tailpipe emissions. To combat this, government agencies such as the California Air Resources Board (CARB) are investing significantly in these communities and across the state to promote the demonstration and deployment of clean technologies.

This report highlights lessons learned from the Volvo LIGHTS (Low Impact Green Heavy Transport Solutions) project. The South Coast Air Quality Management District (SCAQMD) partnered with Volvo Trucks and 15 other organizations to deploy state-of-the-art, zero-emission vehicle (ZEV) technologies, along with charging, solar, and energy storage, to support the transition of freight facilities to lower their overall emissions. The Volvo LIGHTS Project was an important steppingstone for Southern California and the United States. It aimed to transform goods movement through testing and deploying cleaner technologies while also developing education and outreach components crucial for sustainable growth. The project also provided a blueprint of lessons learned for the freight sector to help accelerate the adoption of zero-emission (ZE) operations. This report, a first-of-its-kind insight into the deployment and implementation of medium-duty (MD) and heavy-duty (HD) electric vehicles (EVs), can help guide fleets across the nation in their electrification efforts.

Introduction

The Volvo LIGHTS Project demonstrated the deployment and performance of ZEVs, ZE equipment, and ZE infrastructure at two major freight facilities in Southern California:

---

4 Ports & Freights. Coalition for Clean Air. https://www.ccair.org/advocacy/ports-freight/

5 Freight Transportation. MIT Climate Portal. https://climate.mit.edu/explainers/freight-transportation

Dependable Highway Express (DHE) in Ontario and NFI Industries (NFI) in Chino. The details of these deployments are summarized by fleet in the tables below.

Table 8: Off-road Equipment Deployed at DHE and NFI

	DHE		NFI	
	Count	Original Equipment Manufacturer (OEM)	Count	OEM
Forklift	14	Yale	8	Crown
Yard Tractor	2	Orange EV	2	Kalmar Ottawa

Table 9: HD Trucks Deployed at DHE and NFI

	DHE		NFI	
	Count	Original Equipment Manufacturer (OEM)	Count	OEM
Class 7 Box Truck	1	Volvo	-	-
Class 8 Tractor	3	Volvo	1	Volvo

Table 10: Infrastructure Deployed at DHE and NFI

	DHE		NFI	
	Count	Original Equipment Manufacturer (OEM)	Count	OEM
Workplace Charging	3	EvoCharge	3	EvoCharge
Solar	1	Solar Optimum	1	Hanwha
Battery Energy Storage	1	CPS Energy	-	-

The project also included TEC Equipment, a full-service truck and trailer dealership with locations in La Mirada and Fontana. During the project, TEC in Fontana was recognized as the nation's first certified Volvo electric truck maintenance facility. TEC provided maintenance support for the new electric Volvo Class 7 box truck and Class 8 tractors, offering unique insight into the costs, barriers, and business models for maintaining electric trucks.

This report describes in detail the learnings and challenges of installing ZE infrastructure and deploying ZEVs at a freight facility, including renewable energy infrastructure such as solar and battery energy storage. Furthermore, the process of collecting, validating, and analyzing data is explained with a presentation of key results describing the performance of these technologies. Finally, a list of fleet and freight facility recommendations is provided based on insights gathered from the overall project. The primary sections of the report are outlined below with a brief description.

Data Collection and Methodology

Data sources included vehicle telematics, utility reports, fleet maintenance logs, and survey data. These data were collected and analyzed by CALSTART in collaboration with the University of California at Riverside's (UCR's) College of Engineering–Center for Environmental Research and Technology (CE–CERT) team, who was responsible for data collection on the HD trucks. This section describes in greater detail the data sources and how the data were collected, validated, and analyzed.

ZEV Assessment

The ZE and baseline technology deployed by each fleet was assessed in terms of duty-cycle performance, energy consumption, costs, and emissions. EVs were compared to the conventional baseline vehicle to assess if the new vehicle met the operating needs of the fleet. The baseline vehicles were also used to assess differences in operating costs between ZE and conventional vehicles. Due to the unique operations of each fleet and the influence duty cycle has on vehicle performance, vehicle types were assessed in the context of each fleet.

To better characterize the environmental impacts of deploying ZE technology, CALSTART partnered with CE–CERT, which conducted on-road emissions testing. The CE–CERT team went onsite at DHE and NFI multiple times to instrument the baseline vehicles with portable emissions measurement systems (PEMS) and collect real-world emissions data from vehicles during their regular duty cycles.

Charging Equipment

Multiple types of charging equipment were installed in order to accommodate the specific compatibility of the HD trucks, yard tractors, and forklifts. Additionally, the specific use case of each vehicle platform was assessed when determining both the number of chargers and the power level needed. This section describes the type of charging equipment selected and the fleet's rationale behind the selection. Details on performance specifications and plug types were also specified. Lastly, learnings from the installation and use of charging equipment are included in Section IX. Lessons Learned.

Renewable Energy Infrastructure

CALSTART also evaluated potential energy reductions and cost savings from the use of onsite solar power and battery energy storage. Installation and integration challenges of the solar and energy-storage technologies were captured to help fleets avoid common pitfalls. The upfront and annual operating costs for electric and baseline vehicles were compared to estimate their total cost of ownership (TCO) and reveal which factors played the most critical roles in achieving a lower TCO for ZE vehicles.

User Acceptance

Drivers and fleet managers interact directly with the vehicles and often have input that would not otherwise be reflected in a purely quantitative analysis. To supplement the assessment of ZEV technologies, surveys and interviews were conducted to capture the fleets' experiences, providing additional insight into how the ZE vehicles and infrastructure performed during the demonstration. Surveys and interviews were conducted in two rounds—one at the beginning of the demonstration and one near the end, capturing whether the fleet's initial impressions of ZEVs shifted over time. These data points will help inform the fleets' overall acceptance and satisfaction in ZE technologies, a critical component to the success and sustainment of any new technology deployment.

Recommendations and Lessons Learned

These sections aim to provide a list of fleet and freight facility recommendations, addressing efficiency improvements, market analysis, and future regulations. It includes a review of the growing market for sustainable supply chains, as well as the changing regulatory landscape, which has been shifting toward a ZE freight future. Such considerations will inevitably impact operations and decision-making at DHE, NFI, and others in their journey toward freight electrification. By comparing the technologies' performance, identifying potential pitfalls, and capturing important learnings, this section aims to educate both fleets and freight facilities to accelerate the successful adoption of ZE freight equipment.

Project Goals

Volvo LIGHTS was one of the largest deployments of HD ZEVs and off-road equipment to date, deploying a combination of yard tractors, forklifts, Volvo VNR Class 7 box truck and Class 8 tractors, solar, battery energy storage, workplace charging, and charging infrastructure. The overarching goals included decreasing emissions in disadvantaged communities through the demonstration of ZE technologies within fleets and their freight facilities. The learnings gathered from this project can be used to develop a blueprint for future deployment of ZE vehicles. These lessons learned will be made available to the public and leveraged in assisting future electrification efforts in the freight industry.

CALSTART assisted the fleets with their deployments and collected, analyzed, and validated data collected from the vehicles and infrastructure. Listed below are the specific project goals.

- Technical Deployment Assistance:
    - Deploy freight handling equipment, including yard tractors, forklifts, and Volvo VNR trucks, at each partner's warehouse and provide necessary technical assistance as it relates to vehicle purchases or deployment.
    - Assist with upgrades to the freight facilities at both fleet locations, with the goal of reducing energy consumption and emissions associated with freight facility handling.

  - Identify and implement operational efficiency innovations, which include a deeper understanding of the deployment efficiencies and assistance with planning for future electrification efforts for each fleet.

- Data Collection, Validation, and Analysis (quantitative: data collection; qualitative: technology acceptance feedback):

  - Collect and compare operational and performance data for baseline vehicles and electric forklifts and yard tractors to determine whether EVs could fully replace the baseline vehicles.

  - Collect freight facility data and analysis to understand the benefits of facility improvements and gained efficiencies. This activity included data and analysis on solar, energy storage, and charging infrastructure.

  - Obtain technology-acceptance feedback through surveys and in-person interviews from vehicle operators, fleet managers, supervisors, maintenance staff, and dispatchers.

This report considers all deliverables: deployment details, operational recommendations, data collection methodology and analysis, solar and energy storage analysis, vehicle and workplace-charging analyses, and user-acceptance feedback.

Project Team

Table 11 outlines the Volvo LIGHTS stakeholders and their unique roles in this project.

Table 11: Key Project Stakeholders and Roles

Logo	Organization	Description and Role
South Coast AQMD	South Coast Air Quality Management District (SCAQMD)	SCAQMD is the air-pollution-control agency for over 16.8 million people, covering Orange County and the urban portions of Los Angeles, Riverside, and San Bernardino counties. SCAQMD assembled the project team, led the grant-application effort and the technology-implementation plan.

Logo	Organization	Description and Role
	Volvo Group	Volvo is one of the world's leading manufacturers of trucks, buses, construction equipment, and marine and industrial engines, providing financing and service through production facilities in 19 countries with over 190 markets. Volvo Trucks developed the battery-electric HD truck technology equipped with connected vehicle technologies designed to improve up-time, self-learning control algorithms meant to optimize energy usage.
	Dependable Highway Express	Dependable Supply Chain Services is a full-service logistics provider established in 1950 providing trucking, warehousing and distribution, harbor drayage, third-party logistics, air freight forwarding, ocean freight forwarding, and freight transport. Dependable Highway Express, one of the company's core divisions, demonstrated the ability of battery-electric trucks and equipment in its daily operations at their Ontario facility.

Logo	Organization	Description and Role
	NFI Industries	Founded in 1932, NFI is one of the oldest and largest privately held, third-party logistics companies in North America dedicated to transportation, warehousing, port drayage, intermodal, brokerage, transportation management, global logistics, and real estate. NFI demonstrated the ability of battery-electric HD trucks and equipment to reliably move freight between Los Angeles' two major ports and inland warehouse facilities with less noise and zero emissions. NFI invested in onsite solar panels to mitigate energy costs and grid reliability.
	TEC Equipment	TEC Equipment is the West's leading full-service truck and trailer dealerships. TEC Equipment offered fleets, including DHE and NFI, the ability to lease battery-electric trucks and provided maintenance at their Fontana location.
	Gladstein Neandross & Associates (GNA)	GNA is a leading consulting firm in the clean-transportation space, providing technical, funding, creative, and strategic services to public- and private-sector clients. GNA provided overall project management and technical consulting services to the project partners and was responsible for events and marketing related to the project.

Logo	Organization	Description and Role
	Greenlots	Greenlots is powering the future of electric transportation with industry-leading software and services that equip drivers, site hosts, and network operators to efficiently deploy, manage, and leverage EV charging infrastructure at scale. Greenlots' cloud software was integrated with Volvo's truck telematics to balance the needs of the vehicle, facility, and utility grid.
	University of California, Riverside (UCR) College of Engineering–Center for Environmental Research and Technology (CE–CERT)	CE–CERT is the largest research center at UCR, bringing together researchers from multiple disciplines to address society's most pressing challenges in air quality, climate change, energy, and transportation. CE–CERT analyzed the electric trucks' performance, developed novel algorithms for dispatching EVs, and modeled the trucks' life-cycle emissions.
	CALSTART	CALSTART, North America's leading advanced transportation technologies consortium, is a member-supported nonprofit organization of more than 300 organizations, fleets, and agencies worldwide dedicated to supporting the growth of the high-tech, clean-transportation industry. CALSTART's primary responsibilities were collecting and analyzing data. CALSTART assisted with the deployment of equipment at the sites and together with CE–CERT supported data collection and analysis.

Logo	Organization	Description and Role
SOUTHERN CALIFORNIA EDISON Energy for What's Ahead	Southern California Edison (SCE)	As one of the nation's largest electric utilities, SCE is committed to keeping electricity safe, reliable, affordable, and clean today and for the future. SCE developed a grid-impact assessment and strategies to ensure SCE can provide reliable and cost-effective power to commercial fleet operators. All electric equipment in this project charged on SCE's grid.

II. Data Collection and Methodology

The collection of reliable and accurate data was foundational to assess the performance, cost, and reliability of the deployed ZE technologies. This section will cover how data were captured from each source, including details on what platforms were used and how it was accessed. Due to the nature of this project and the different vehicle and equipment types demonstrated, using a single platform to capture data across all technologies was not feasible. Data were primarily collected through data collection platforms offered by the manufacturers and were usually proprietary. In the event a manufacturer's platform did not provide the necessary data fields or was unavailable, a different data logging solution was provided by CALSTART. Due to some differences in the approaches, influenced by the vehicles and platforms used, the data collection and methodology will be covered separately for DHE and NFI.

Data Platforms

The tables below provide per fleet information on the equipment type, manufacturer for each piece of equipment used, and the platform used to collect data. In some cases, use of both SKY and Accuenergy was needed. SKY's platform was only compatible with ABB chargers and EvoCharge chargers. In order to collect vehicle specific data from yard tractors and forklifts, submeters were installed using Accuenergy's platform. Submeters did not provide as detailed per session information as SKY but were more accurate and in line with utility bills.

Table 12: Source of Data for Equipment and Chargers - DHE

Equipment Type	Manufacturer	Data Source
Forklifts	Yale	Advanced Clean Technologies View (ACTview)
Forklift Chargers	Advanced Clean Technologies	Accuenergy
Yard Tractors	Orange EV	Orange EV

Equipment Type	Manufacturer	Data Source
Yard Tractor Chargers	Orange EV	Accuenergy
VNR Trucks	Volvo	UCR Loggers
VNR Truck Chargers	ABB	SKY, Accuenergy
Workplace Chargers	EvoCharge	SKY, Accuenergy
Solar	Solar Optimum	Solar Edge
ESS	CPS	Energy Tool Base

Table 13: Source of Data for Equipment and Chargers - NFI

Equipment Type	Manufacturer	Data Source
Forklift	Crown	Accuenergy
Forklift Chargers	V-Force	MHS Lift
Yard Tractors	Kalmar	ViriCiti
Yard Tractor Chargers	Transpower	Accuenergy
VNR Trucks	Volvo	UCR Loggers
VNR Truck Chargers	Volvo	SKY
Workplace Chargers	EvoCharge	SKY
Solar	Hanwha	TBD

The platforms listed in Table 14 were used to collect data from the ZE infrastructure. CALSTART collected and analyzed the data from various chargers (forklift, yard tractors, workplace), solar, and energy storage system (ESS). When comparing data collected from Accuenergy and SKY, CALSTART's team relied more heavily on Accuenergy, which appeared to be more accurate and in line with utility bills. During this deployment, SKY had connectivity issues, resulting in some data loss. A site controller was installed in an attempt to mitigate the issues and keep the connection stable; unfortunately, this effort was unsuccessful.

Table 14: Descriptions of Project Data Platforms

Data Platform	Description	Functionality
Accuenergy	A Cloud-based free Facility Energy Metering Platform hosted by AcuCloud.	Greenlots team installed revenue grade submeters for EVs to add more detailed information on the lump sum per vehicle type of energy consumed. This was used as a backup to SKY.
Greenlots SKY	EV Charging Network Software that enables utilities, fleets, cities, retailers, auto OEMs, apartments and condos, and workplaces to efficiently deploy and manage their own network of smart EV charging stations at scale.	SKY was used at DHE, NFI, and TEC to track energy used from ABB (for VNRs) chargers and EvoCharge (for workplace) chargers. This platform provides very detailed per session data and serves as a tool for the fleets to monitor the state of chargers. Through this system a fleet manager can request technical support.
Solar Edge	Solar monitoring platform that provides enhanced photovoltaic performance and yield assurance through immediate fault detection and alerts at the module level, string level, and system level.	Solar Optimum used this performance tracking platform to monitor their installed solar system at DHE.

Data Platform	Description	Functionality
Energy Toolbase	Energy Toolbase is an industry-leading software platform that provides a cohesive suite of project modeling, storage control, and asset monitoring products that enable solar and storage developers to deploy projects more efficiently.	This platform used to monitor performance of the ESS system connected to the EV meters at the DHE facility. It includes maximization service provided to adjust the system accordingly to maximize performance per utility plan.

DHE Data Collection and Methodology

Forklift

Data on electric forklift charging, idling, and in-use events were collected between March 25 and August 12, 2021, from Yale's online platform. The data contained truck ID, battery serial number, timestamp, duration, start and end state of charge (SOC), battery voltage, and current for each event. Events included charge, in use, and idle activities. Each truck ID was paired with a single battery serial number. Data of use sessions were used to estimate the duty cycle and SOC of forklifts.

Energy charged to forklifts was reported by each charger through the ACTview platform. Data were collected from March 23 to August 10, 2021. The data included charging, duration, energy charged, current, voltage, temperature, and battery type. Durations of charging sessions were used to estimate daily and monthly charging time. The specific forklifts could not be identified on ACTview, so data could not be linked to event sessions for each forklift. Instead, total hours of charging were averaged across all 14 forklifts to estimate the time in charging.

Energy charged from the grid was monitored through Accuenergy, with data collected between May 7 and November 30, 2021. Accuenergy was a platform used for collecting and displaying charging data for each charging technology available in the project. The four charging types were forklift, yard tractor, HD trucks, and workplace chargers. The platform was installed the first week of May 2021 and incorporated the installation of five separate submeters: one each for forklifts, VNR trucks, and workplace chargers, and two for yard tractors. These submeters all connected to the same EV-only meter, and the data were captured at a five-minute frequency. Hourly data were downloaded to estimate utility cost based on SCE's time-of-use (TOU) rate. Energy data were used to analyze charging efficiency and parameters related to energy use.

Yard Tractor

Vehicle operation data were collected through Orange EV's online platform from January 1 to December 31, 2020. The standard-duty yard tractor was labeled YGE-01, and the extended-duty tractor was labeled YGE-02. Operation data included key-on time, distance driven, SOC, and charging time. Distance driven was measured based on wheel turning, which is more accurate than measuring from GPS. Energy discharged and energy retained in the battery were calculated based on the change in SOC and the vehicle's battery capacity. These data were used to analyze the yard tractors' duty cycle, SOC, and energy consumption.

Energy charged from the grid was collected through the Accuenergy platform from May 7 to October 31, 2021. Each charger had its own submeter connected to the main EV-only meter. Submeters were revenue grade meters installed by Greenlots to assist with separating the energy use for the different charging types. On DHE's utility bill, the EV meter's energy consumption was listed once, rather than separated by submeters. Submeters helped the fleet distinguish energy consumption by equipment type. Instead of recording the total energy charged and duration of each charging session, Accuenergy recorded energy drawn from the grid, with granularity of up to every five minutes. The high level of granularity allowed for accurate estimates of cost and energy. Hourly data were downloaded to estimate utility costs using SCE's rate schedule TOU-EV-8. However, Accuenergy did not record which yard tractor charged at which charger or when a charging session started and ended. Total energy charged from the grid for both yard tractors was used to estimate charging efficiency, energy charged, and utility costs. The values were then averaged between the two yard tractors to find the value for each.

Class 7 Box Truck

Data on DHE's electric box truck were collected from Geotab dataloggers between January and July 2021. This included distance driven, energy consumed, uptime, and SOC data recorded daily. The data were analyzed to summarize the duty cycle and performance of the EVs quantitatively. Accuenergy was used to collect energy usage data from the vehicle chargers between May and December 2021. The data were used to analyze energy consumption and charging costs of the electric box truck. Fleet interviews enhanced these results with on-the-ground feedback from individuals operating and managing the vehicles.

Class 8 Tractor

Data on DHE's Class 8 electric tractor was collected from two sources. First, truck performance data were collected from Geotab dataloggers between February and October 2021. This included distance driven, energy consumed, uptime, and SOC daily data. Datalogger data were analyzed to summarize the duty cycle and performance of the electric tractors in addition to fleet interviews.

Second, Accuenergy charger data were collected between May and December 2021. This data included energy draw from the EV submeter and the date and time of the energy draw. This information was used to analyze energy consumption, charging costs, and emissions offsets of the Class 8 tractors. Fleet interviews provided insight on diesel trucks to properly compare the electric and diesel tractors.

Solar and Energy Storage

The solar analysis collected data primarily from Solar Edge, which was connected directly to the photovoltaic (PV) system. Other data sources included Accuenergy for comparing EV meter solar usage, SCE utility bills for averaging monthly bills to estimate solar savings, and Energy Toolbase for comparing energy usage from DHE's ESS. This analysis investigated data collected between May 7 and August 7, 2021.

DHE's ESS was monitored and programmed by Energy Toolbase, which provided data on the system's performance. This analysis used data from September 20 to October 31, 2021, when DHE's ESS was programmed for TOU arbitrage. This means the ESS system was programmed to output energy during on-peak hours, minimizing utility costs. Energy Toolbase data provided records for the ESS power and SOC and compared ESS usage to DHE's EV meter demand.

Workplace Charging

This analysis used data collected directly from the charging stations through Greenlots and Accuenergy from February 2 to September 1, 2021. Individual charging sessions across all charging stations were analyzed to understand the average daily duty cycle for charging. Charging station energy consumption data were inconsistent between Greenlots and Accuenergy.

NFI Data Collection and Methodology

Forklift

Vehicle usage data for NFI's Crown forklifts were collected from battery reports provided through the manufacturer's online platform. PDF reports were downloaded and converted into spreadsheets for analysis. Daily performance and energy data by type (i.e., charging, discharging, and standby/break) were available for each forklift. Downloaded data ranged from August 15, 2020, to June 11, 2021. The information was used to analyze duty cycle and energy consumption by Crown forklifts. In addition, change in SOC over time was available in graph format in February and May 2021 for each forklift, which was used to analyze SOC fluctuation qualitatively. A charging efficiency of 90% was assumed and used to convert energy retained by the battery to energy charged from the grid.

When energy is drawn from the grid, charging on SCE's TOU rate plan for business owners becomes a crucial factor in how much the fleet pays for electricity. In general, utility rates change based on season, day of the week, holidays, and hours in a day. Like DHE, NFI used rate schedule TOU-EV-8. Without data on hourly energy charged, utility costs were determined based on forklift charging windows, interviews with the fleet manager, and SCE's rate plan.

Yard Tractor

Performance data on NFI's electric yard tractors were collected between December 1, 2020, and August 31, 2021. The data were collected hourly and daily, allowing for precise insight into charging practices. The 207 days of data included distance traveled, average speed, energy used, time in use, and time charging. The performance data were used to analyze the duty cycle and energy use of the electric yard tractors. A charging efficiency of 90% was assumed in calculating the energy charged from the grid and the associated costs. Like all the equipment in the Volvo LIGHTS Project, the electric yard tractors charged on SCE's TOU-EV-8 rate plan.

Class 8 Tractor

Data on NFI's electric box truck were collected from two sources. First, truck performance data were collected from Geotab dataloggers between May and December 2021. This included distance driven, energy consumed, uptime, and SOC daily data. Datalogger data, in addition to fleet interviews, were analyzed to summarize the duty cycle and performance of the electric tractors.

Second, Accuenergy charger data were collected between May and December 2021. The data in October and November appeared realistic; all other data appeared to charge less energy than is required. Thus, only data in those two months were used in the analysis. This data included energy draw from the EV submeter and the date and time of the energy draw. This information was used to analyze energy consumption, charging costs, and emissions offsets of the electric tractors. Fleet interviews provided insight on diesel tractors to properly compare the electric and diesel tractor.

Workplace Charging

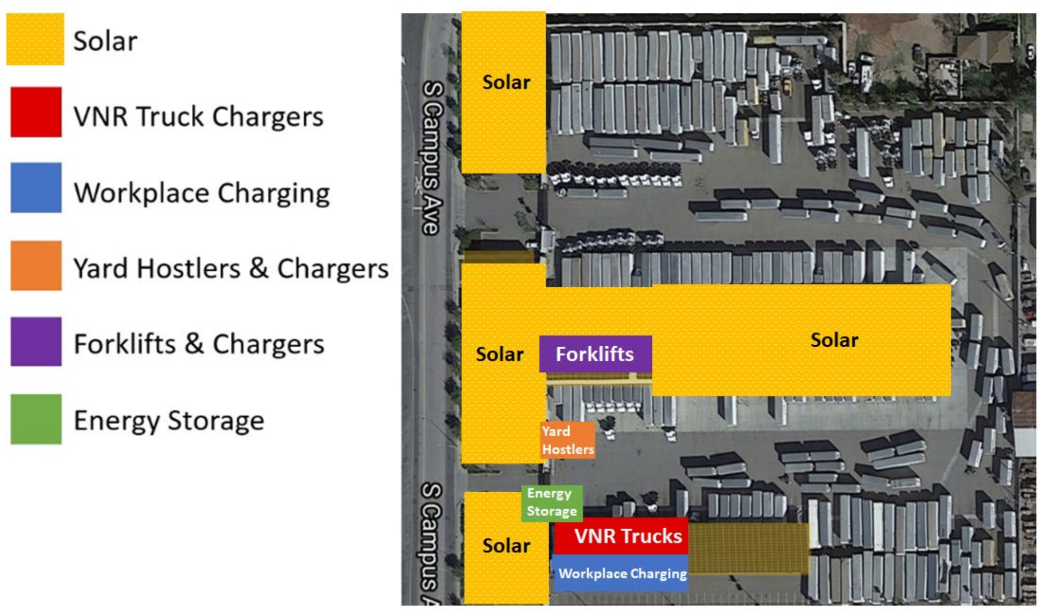
This analysis used data collected directly from the charging stations through Greenlots and Accuenergy from March 25 to November 1, 2021. Individual charging sessions across all charging stations were analyzed to understand the average daily duty cycle for charging.

III. DHE

DHE is a core division of Dependable Supply Chain Services, a full-service logistics provider established in 1950. DHE provides trucking, warehousing and distribution, harbor drayage, third-party logistics, air freight forwarding, ocean freight forwarding, and freight transport. The DHE fleet specializes in less-than-truckload shipping, transporting cargo sizes between parcels and full truckloads.

DHE Ontario, the demonstration site in California, focuses on warehouse-to-warehouse deliveries in the region. The Ontario facility is a 49,000 square-foot building and cross dock located on a 9.8-acre site. Figure 6, a bird's-eye view of the facility, shows where ZE technology was deployed. DHE's partners for the technology deployed included Advanced Clean Technologies, Orange EV, Volvo, ABB, EvoCharge, Solar Optimum, and Chint Power Systems (CPS), which is a sub-contractor of Solar Optimum.

Figure 6: DHE Facility and ZE Technology Deployments Map



For this project, DHE demonstrated the use of battery-electric trucks and equipment to transport goods and complete daily duty cycles.[6] In addition, DHE deployed and tested renewable energy technologies such as solar and energy storage. Large solar array was

[6] Freight Transportation. Climate Portal. https://climate.mit.edu/explainers/freight-transportation

installed, which was enough to fully power the facility and EV chargers and sell the extra energy produced back to the grid.

Forklifts

Forklift Introduction and Deployment Process

DHE replaced its fleet of propane-powered Toyota forklifts with 14 Yale Chase electric forklifts. DHE deployed the electric forklifts, as seen in Figure 7, the first week of June 2020. Table 15 lists the forklifts' specifications.

Table 15: DHE Propane and Electric Forklift Specifications

Specification	Electric	Baseline
Type	Electric (Li-ion)	Propane
Model Year	2020	2014
Manufacturer	Yale Chase	Toyota
Model Name	ERP040VT	-
Payload Capacity (lbs.)	4,000	-
Battery Capacity (kWh)	26.9	-

Figure 7: Yale Forklifts Deployed at DHE

The forklifts were charged by eight 11 kilowatt (kW) Advanced Charging Technologies chargers inside the facility. Initial plans were to install one charging unit for each forklift, but DHE decided against this strategy after evaluating duty-cycle requirements, equipment costs, and space allocation. Each charger was placed between two rows of forklifts, allowing easy accessibility to plug in and unplug parked equipment. However, DHE now agrees that additional spacing for infrastructure and additional chargers (currently eight chargers for 14 forklifts) will be necessary to increase flexibility for charging times.

The deployment process for the forklifts went relatively smoothly and according to schedule. Initial issues with the software, battery, and vehicle working together were fixed quickly by the forklifts' OEM.

Despite initial concerns regarding how charging the forklifts would affect operations, the equipment exceeded expectations. According to the fleet manager, user satisfaction increased. The fleet believed the battery capacity of these forklifts was sufficient, and operators greatly preferred the ZE technology's smoother braking and lack of smell and noise.

Duty Cycle and Performance

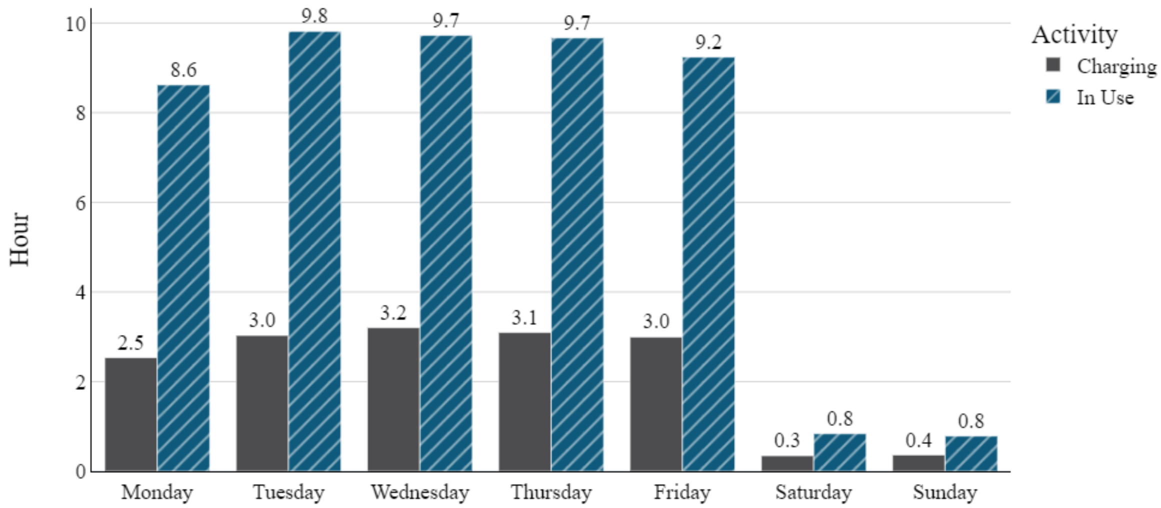
DHE operates three eight-hour shifts per day: 12 a.m. to 8 a.m., 8 a.m. to 4 p.m., and 4 p.m. to 12 a.m. Throughout the day, DHE used the 14 electric forklifts as needed for various tasks, including sweeping out tractors and moving, measuring, and restacking freight. Therefore, activity across the forklifts was not uniform. Some forklifts were not used on certain days, while others were used more than once in a single shift. Session durations and employee work schedules varied. Employees would spend a maximum of about seven hours operating the forklifts per shift. Also, the exact time employees started working did not match the shift schedule perfectly, instead depending largely on the specific needs of the day. Despite these inconsistencies, the duty cycle of forklifts provided a glimpse into how they were used and performed on average throughout the week.

Table 16: DHE Electric Forklift Time Spent Charging and In Use (hours)

Timeframe	Average Time in Use	Average Charging Time
Daily Weekday	9	3
Monthly	161	67

On average, an electric forklift at DHE was used for nine hours and charged for three hours on weekdays over two or three charging events (Table 16). Based on analyzing energy charged, the forklifts charged throughout a day, mostly around 10 a.m., 8 p.m., and 12 a.m. (see Energy Consumption Section below). Although forklifts were not generally operated on weekends, DHE employees occasionally began each week's shifts on Sunday night between 10 p.m. and midnight to prepare for Monday's activities. On weekends, the forklifts operated for an hour and charged for half an hour on average. Figure 8 outlines average in use and charging activities per forklift over the week.

Figure 8: Average DHE Electric Forklift Hours Spent Charging or In Use, April–August 2021



Energy Consumption

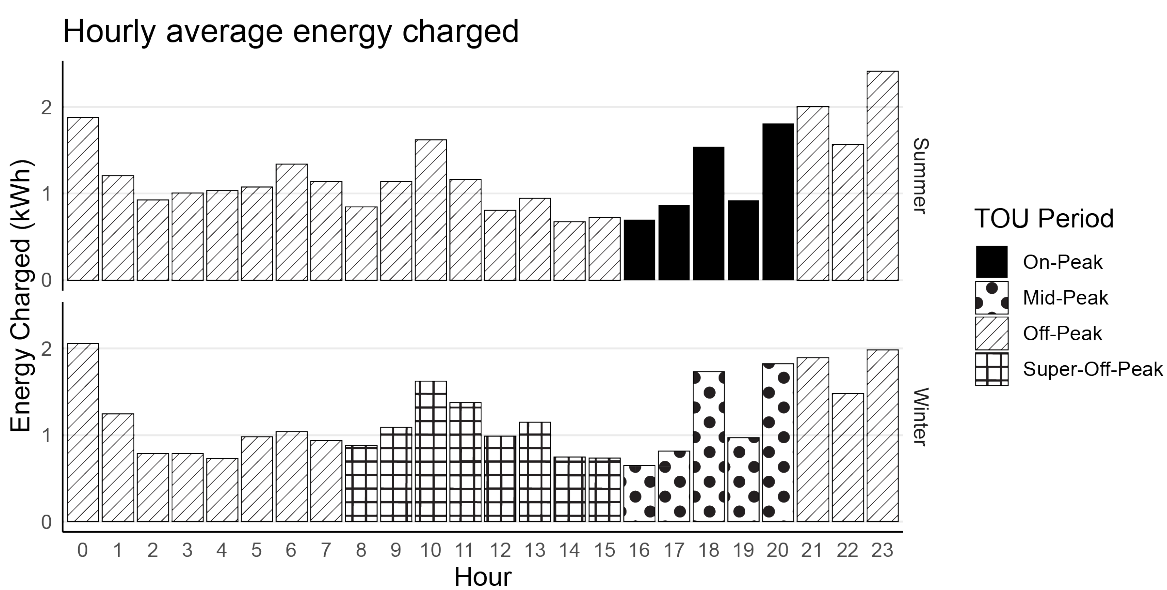
Table 17 describes key energy-use metrics for DHE's forklifts.

Table 17: DHE Electric Forklift Energy-Use Metrics

Energy-Use Metric	Measured Result
Average Monthly Amount Charged	654 kWh
Average Daily Amount Charged (weekdays)	28 kWh
Charging Efficiency	88%
Average SOC Increase	43%
Average SOC Decrease	-14%
Average Daily Max SOC	83%
Average Daily Min SOC	22%

Each forklift charged an average of 654 kilowatt-hours (kWh) per month and retained 574 kWh in its battery, indicating a charging efficiency of about 88%. This meant the battery retained 88% of the energy charged from the grid on average. Forklifts began their routes with an average of 83% SOC and completed their shifts with around 22%. They were charged about 28 kWh per day, with most charging events taking place on weekdays. The highest daily energy charged per forklift was 41 kWh, which is less than twice the 26.9-kWh battery capacity. This meant that if DHE utilized all electric forklifts throughout the day, it could meet forklifts' duty-cycle demand with a maximum of two full charges for each forklift. In addition, with 11-kW Advanced Charging Technologies chargers, each forklift would charge for four hours at most every day. Each Advanced Charging Technologies charger could provide 19 hours of charging window during off-peak or super-off-peak hours on weekdays; eight chargers together increased the number to 152 hours. The 14 forklifts required about 56 hours of charging daily, which was much less than the 152-hour charging window. Figure 9 shows how much energy was charged on average during each hour of the day and how this fit into SCE's TOU-EV-8 rate plan.

Figure 9: Average DHE Electric Forklift Hourly Energy Charged



Energy charged across the forklifts followed similar patterns in winter and summer. Energy charged values had local peaks around 10 a.m., 8 p.m., and 12 a.m., aligning with the 8 a.m. and 12 a.m. shift changes. The 4 p.m. shift change did not correspond with a peak, most likely because DHE instructed drivers to avoid charging during on-peak hours. However, drivers would often then need to charge their forklifts at 8 p.m., which fell under on-peak hours. One solution is to encourage charging of all forklifts during lunch breaks between 12 p.m. and 1 p.m., which would be off-peak in summer and super-off-peak in winter.

The peaks in Figure 9 may not represent energy trends for all months. The first and last quarters are normally the least busy times of the year. Business volume usually increases around September when stores receive their winter merchandise, drops in December, and remains low until February.

Cost

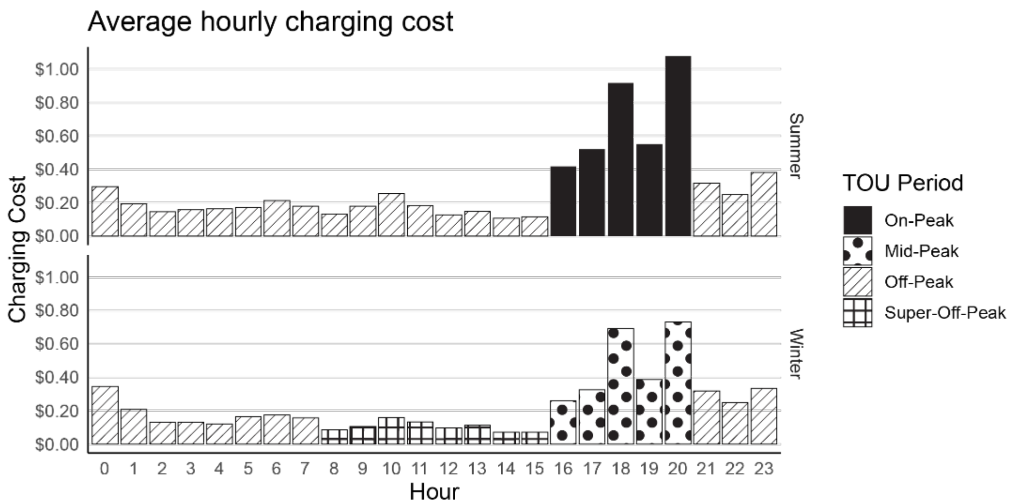
DHE's forklifts charged on SCE's TOU-EV-8 rate plan. Table 18 lists these charging costs.

Table 18: DHE Electric Forklift Daily and Monthly Charging Costs

Charging Cost	Summer	Winter
Daily Weekday Charging Cost	$7	$5.6
Monthly Charging Cost	$160	$125

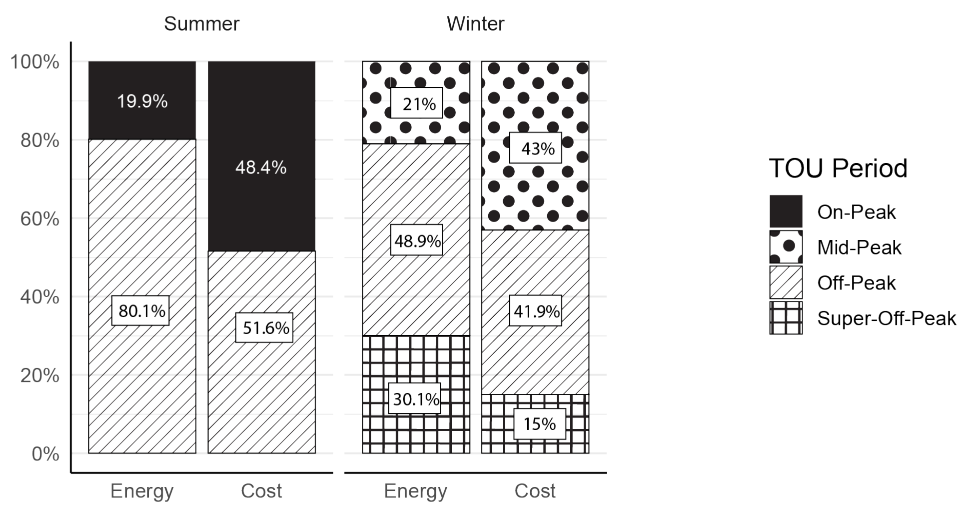
On weekdays, charging a forklift cost $7 per day in summer and $5.6 per day in winter. On average, charging each forklift cost $140 per month, with a range of $120 to $170. Since on-peak charging took place only in summer and super-off-peak only in winter, rates during the winter months were generally lower than those during the summer. The cost to charge each forklift was $160 per month in the summer and $125 per month in winter. Figure 10 displays the average charging cost incurred over each hour of the day and the respective rate plan.

Figure 10: Average DHE Electric Forklift Hourly Charging Cost by Season, May 2021 to November 2021



In both summer and winter, the most expensive charging occurred between 4 p.m. and 9 p.m. during on-peak (summer) and mid-peak (winter) pricing. Figure 11 compares the energy consumed and costs incurred during each TOU period. In summer, 80.1% of energy charged occurred during off-peak and 19.9% occurred during on-peak; 51.6% of cost then fell under off-peak and 48.4% fell under on-peak. In winter, 30.1% of energy charged occurred during super-off-peak, 48.9% occurred during off-peak, and 21% during mid-peak; 15% of cost then fell under super-off-peak, 41.9% under off-peak, and 43% fell under mid-peak.

Figure 11: Comparison of DHE Electric Forklift Percent of Energy Charged and Cost Incurred During TOU Period



A fleet's utility cost largely depended on when vehicles were charged. Nearly 50% of the costs fell between 4 p.m. to 9 p.m., even though energy charged during that time period only made up 20% of total energy charged. In contrast, only 15% of costs fell in the super-off-peak period, even though that period accounted for up to 30% of energy charged in winter.

These cost calculations assumed 100% energy consumption from the grid at SCE's TOU rates. DHE installed solar panels and energy storage in May 2021, which significantly offset total energy costs. Solar energy generated at DHE could fully cover facility-wide energy demand (see Solar and Energy Storage), waiving the utility costs of forklifts. **Accounting for solar generation reduced the monthly utility cost for a forklift to $0.**

The electric forklifts were cheaper than propane forklifts even without solar power onsite. Also, while SCE's TOU-EV-8 does not currently include demand charges, these are expected to return in 2024. At that time, limiting the number of forklifts charged at once will help avoid the high cost of high, instantaneous energy draws. Table 19 summarizes some key operational cost metrics for DHE's electric and propane forklifts.

Table 19: DHE Electric and Propane Forklift Operating Cost Comparison

Operating Cost Metric	Electric	Propane
Time in Operation (hours/year)	2,000	2,000
Annual Fuel Cost	$1,642	$2,149
Annual Fuel Cost with LCFS[7]	$72	$2,149
Cost per Hour	$0.85	$1.07
Cost per Hour with LCFS	$0.04	$1.07
Estimated Time in Service (years)	10	6

From January 2019 to June 2020, operating the propane forklifts cost an average of $2,507 per month for all 14, or $180 per forklift per month. Looking at the unit fuel cost, electric forklifts cost $0.85 per hour, while propane forklifts cost $1.07 per hour. Each electric forklift could save the fleet $40 per month without solar and $140 per month with

[7] The Low-Carbon Fuel Standard (LCFS) allows fleets to generate annual rebates for charging off the grid. For more information on LCFS, see *Section 1: Data Collection and Methodology*. https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

solar, recalling the cost of $140 to charge an electric forklift monthly. With 14 forklifts and solar operation onsite, DHE saved about $1,960 each month ($23,520 annually) in fueling costs. Table 20 and Table 21 show the inputs for calculating TCO for a propane and battery-electric, lithium-ion forklift at DHE.

Table 20: DHE Propane and Electric Forklift TCO Parameters - Capital Cost ($)

TCO Parameter	Propane	Electric
Total Purchase Price	23,000	43,000
Charging Infrastructure	-	11,945
Total Capital Cost	23,000	46,543

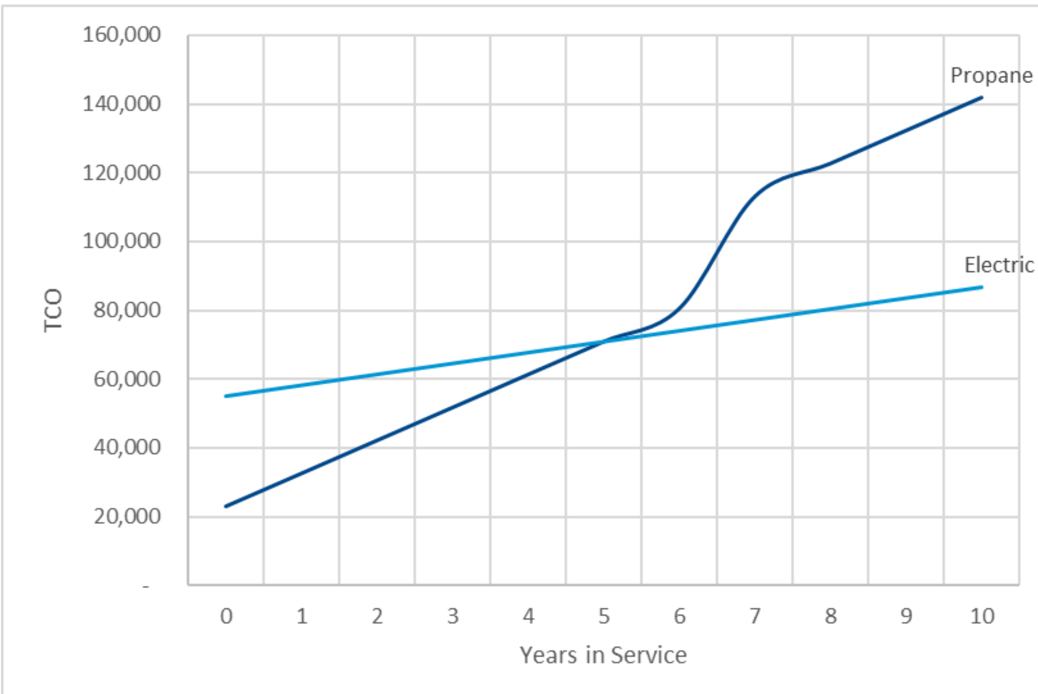
Table 21: DHE Propane and Electric Forklift TCO Parameters - Operating Costs ($)

TCO Parameter	Propane	Electric
Insurance (0%)	-	-
Annual Fueling Cost per Forklift	2,149	1,642
LCFS	-	-1,570
Annual Maintenance Cost	7,422	2,640
Total Annual Operating Cost	9,571	2,712

According to DHE, the upfront cost of a propane forklift is about $23,000 and $43,000 for an electric forklift. Yale's eight chargers cost about $20,000, and because 14 forklifts used the chargers, the charger cost per forklift was about $12,000. Notably, the costs of both propane and electric forklifts increased significantly due to recent supply chain issues, which also delayed delivery of forklifts and other equipment by several months.

DHE reported propane forklift fueling costs averaging $2,150 per year. The electric forklifts cost about $1,700 per year, and only $70 per year after receiving LCFS credits. Annual maintenance costs also showed a significant price difference between the propane and electric forklifts. As reported by DHE, maintenance on the propane forklifts averaged $7,400 compared with $2,600 for the electric forklifts. The electric forklifts were believed to save on maintenance costs with fewer moving parts and given the propane forklifts were several years older. See the Forklift section under DHE Data Collection and Methodology for more information on forklift maintenance costs and comparisons.

Figure 12: DHE Propane and Electric Forklift TCO



Lithium-ion forklifts exhibited an excellent return on investment under these conditions. Starting with an upfront cost of $43,000, nearly twice the cost of a propane forklift, the electric forklifts saved about $2,000 on fueling and $4,600 on maintenance annually. The electric forklifts were expected to achieve cost parity before Year 5. DHE plans to keep propane forklifts in service for about six years and electric forklifts for 10 years. Figure 12 accounts for this by including the $23,000 upfront cost of a propane forklift again in Year 7. By Year 10, each electric forklift would save an estimated $57,000, more than the price of two propane forklifts. Lithium-ion forklifts showed significant cost savings over diesel.

Emissions Offset

Emissions offset by electric forklifts were estimated from tailpipe emissions, measuring CO2, nitrogen oxides (NOx), and particulate matter (PM). Electric forklifts have zero tailpipe emissions, providing another significant benefit besides financial advantages. Tailpipe emissions of baseline propane forklifts were measured through PEMS testing by UCR (see ZEV Assessment under Section I. Project Overview). Table 22, Table 23, and

Table 24 below show propane forklift emissions per hour in use annually and over the 10-year lifetime of the vehicles, assuming 2,000 hours in service per year.

Table 22: DHE Propane Forklift Tailpipe Emissions per Hour

Tailpipe Emission	Grams per Hour
CO2	5,633
NOx	11
PM	1.98

Table 23: DHE Propane Forklift Annual Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	11,265
NOx	22
PM	4

Table 24: DHE Propane Forklift 10-Year Lifetime Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	112,655
NOx	220
PM	40

Each electric forklift offset 11,265 kilograms (kg) of CO2, 22 kg of NOx, and 4 kg of PM each year, which were the annual tailpipe emissions of a baseline propane forklift. Over a 10-year lifetime, each electric forklift would offset more than 112 metric tons of CO2, 219 kg of NOx, and nearly 40 kg of PM. In total, the 14 forklifts deployed through this project would offset 1,577 metric tons of CO2, 3 metric tons of NOx, and 0.5 metric tons of PM over their lifetimes.

The total amount of CO_2 offset by these 14 forklifts is equivalent to:

- 67,030 trash bags of waste;
- 3,963,421 miles traveled in an average passenger vehicle;
- Annual energy use of 189 homes; or
- 26,023 tree seedlings sequestering carbon over 10 years.[8]

Yard Tractor

Yard Tractor Introduction and Deployment Process

DHE acquired two Orange EV electric yard tractors (Figure 13) as part of this project, replacing its two diesel yard tractors. These EVs were procured in early fall 2019 using California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) funds and began operating in December 2019 following removal of the diesel yard tractors.[9] Table 25 summarizes the specifications for DHE's yard tractors.

Table 25: DHE Electric and Diesel Yard Tractor Specifications

Specification	Electric	Baseline
Fuel Type	Lithium-ion Electric	Diesel
Model Year	2019	2017
Manufacturer	Orange EV	Cummins
Model Name	T-Series	-
Battery Capacity (kWh)	80,160	-

[8] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[9] HVIP no longer funds yard tractors; both off- and on-road yard tractors are now funded through the Clean Off-Road Equipment (CORE) Voucher Incentive Project.

Figure 13: Orange EV Yard Tractor Deployed at DHE

DHE acquired two slightly different models of yard tractor: standard-duty with a battery capacity of 80 kWh (YGE-01) and extended-duty with a battery capacity of 160 kWh (YGE-02). The standard-duty yard tractor was purchased to supplement the extended-duty yard tractor as a backup during charging down time. Vehicle performance data were collected through Orange EV's online platform from January 1 to December 31, 2020.

Two Orange EV 22-kW chargers were installed on the south side of the dock. According to the DHE fleet manager, despite initial concerns about how often the equipment would have to charge, operations were not disrupted by the new practice of keeping the vehicle plugged in. Rather, functionality exceeded expectations. User satisfaction with the vehicle was positive: the equipment was quieter, cleaner, and cooler than the diesel counterparts.

Duty Cycle and Performance

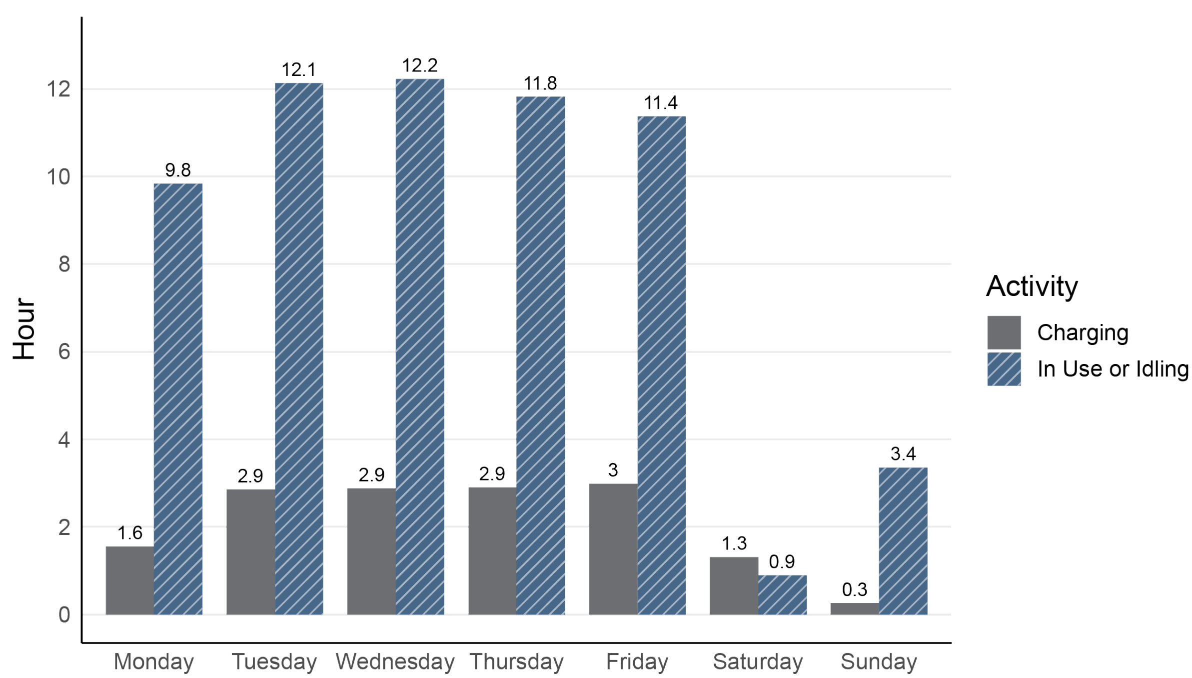
The yard tractors' primary tasks were moving containers between loading docks and readying containers for tractors to connect and tow them to another destination. The electric yard tractors were placed on the same duty cycle as the diesel vehicles. DHE generally places its newer equipment on the most demanding duty cycles, transitioning them to lighter workloads as they age. Having multiple locations allows DHE to regularly shift used equipment to other sites. After 10 to 13 years, DHE typically resells diesel yard tractors. Given the newness of EV technology, little was known regarding vehicle longevity or the demand for a secondary market. Table 26 provides a breakdown of daily and monthly usage.

Table 26: DHE Electric Yard Tractor Average Mileage, Key on Time, and Hours Charging

Timeframe	Average Mileage	Average Key on Time (hours)	Average Charging Time (hours)
Daily (weekdays)	22	11.5	2.6
Monthly	568	258	62

The electric yard tractors had the same duty cycle as the baseline diesel yard tractors, operating about 11.5 hours each workday. The vehicles spent 2.6 hours charging and were driven 22 miles. The yard tractors were charged whenever they were not in use: during breaks, lunch, between shifts, and other times they were not needed. Drivers of DHE's yard tractors changed shifts at the same hours as those driving forklifts: 12 a.m., 8 a.m., and 4 p.m. Drivers did not work on weekends, but the weekday start and end times varied. Based on conversations with DHE staff, the day shift usually had only one vehicle on duty. The early morning and night shifts were busier and had both vehicles operating. Normally, but not always, a single driver used the yard tractor during a shift. Figure 14 describes yard tractor usage throughout the week.

Figure 14: Average DHE Electric Yard Tractor Hours Charging and Discharging, January–December 2020



The yard tractors were operated mainly Monday through Friday. Sometimes, yard tractors were operated or charged late Friday and into Saturday. Similarly, operators sometimes worked Sunday evening preparing for Monday's activities, which explains the three hours of use on Sundays in Figure 14.

Idling was a normal part of the standard duty cycle. Drivers often exited the yard tractors to prepare trailers for connection/disconnection or to perform other jobs. The diesel yard tractors automatically turned off after idling for five minutes. Electric yard tractor idling was less energy intensive but also less apparent because of their silent operation; drivers may have left an electric yard tractor running (intentionally or unintentionally). While the data does not allow for distinguishing energy use by idling versus operation time, further research could help clarify the role of idling in the efficiency of these vehicles.

Energy Consumption

Table 27 summarizes electric yard tractor charging, energy use, and efficiency.

Table 27: DHE Electric Yard Tractor Energy-Use Metrics

Energy-Use Metric	Measured Result
Average Energy Charged Daily	73 kWh
Average Energy Discharged Daily	69 kWh
Fuel Efficiency	2.3 kWh per mile
Fuel Efficiency	5.8 kWh per hour
Charging Efficiency	98%

On an average weekday, with a yard tractor operating about 12 hours, the vehicle charged 73 kWh and discharged 69 kWh. Monthly, this amounted to about 1,600 kWh charged and 1,300 kWh discharged. The 80-kWh yard tractor drew about 17,400 kWh from the grid and retained 16,878 kWh in the batteries. This amounted to a charging efficiency of about 98%, although the true value was slightly less: regenerative braking produces an estimated 5% of additional energy. Using monthly energy discharged and mileage, the fuel efficiency of the electric yard tractors was about 2.29 kWh per mile and 5.8 kWh per hour. Table 28 shows the maximum and minimum SOC of the electric yard tractors.

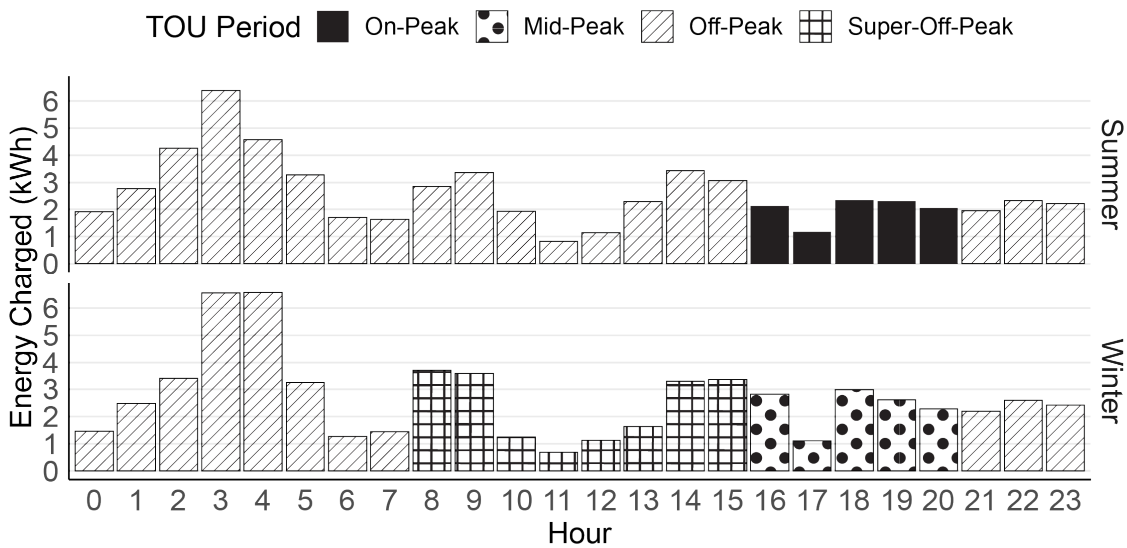
Table 28: DHE Electric Yard Tractor Maximum and Minimum SOC

SOC Metric	Percentage
Average Daily Max SOC	99%
Average Daily Min SOC	70%
Yearly Min SOC in 2020	29%

Drivers of yard tractors were instructed to opportunity charge whenever possible. Orange EV advised that keeping SOC above 50% would maximize the battery's life; in practice, SOC usually stayed above 70%. Most workdays, yard tractors started and ended with around 80% SOC, indicating that opportunity charging during breaks could match the entire energy consumption. SOC on YGE-01, the yard tractor with the smaller battery capacity, dipped below 51% on only 34 days. SOC on YGE-02 never dropped below 50%.

The data suggest that DHE might save money by investing in yard tractors with smaller battery sizes since the fleet only used a small portion of the total SOC. However, DHE expressed interest in purchasing yard tractors with larger batteries that could run more demanding duty cycles, spend less time charging, and preserve battery health by avoiding over-depleting SOC. A larger battery would also allow for slower charging to minimize demand charges. Figure 15 displays details regarding when charging occurred for typical summer and winter weekdays.

Figure 15: Average DHE Electric Yard Tractor Energy Charged by Hour and Corresponding Utility Rate on Workdays

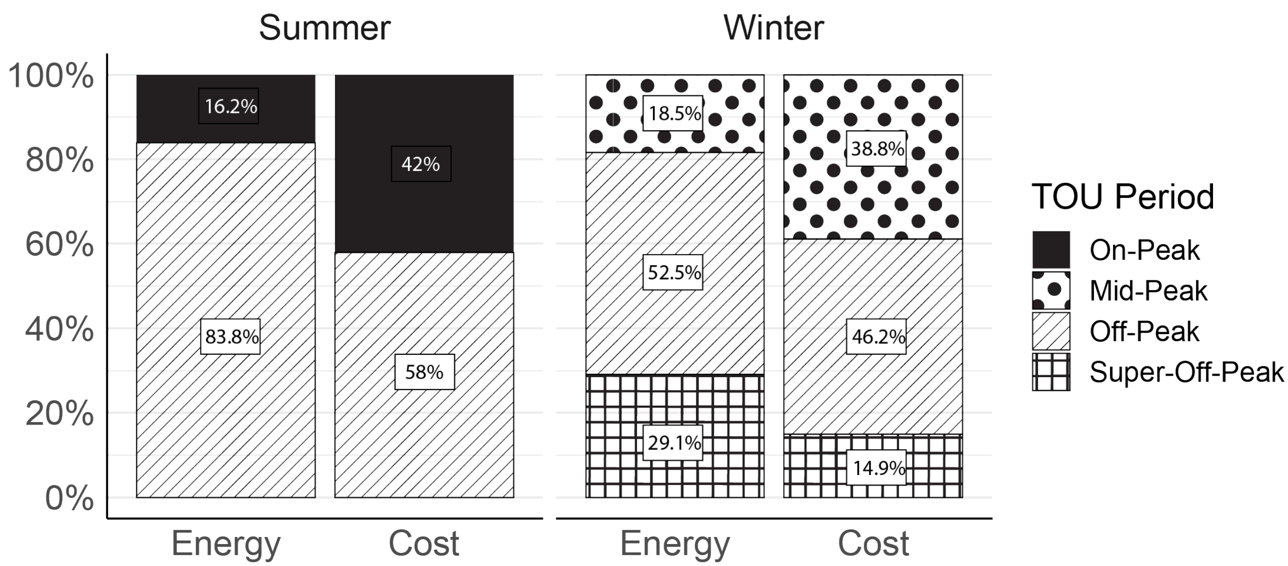


Energy charged had a primary peak around 3 a.m. to 4 a.m., with smaller peaks at 8 a.m. to 9 a.m. and 2 p.m. to 3 p.m. Fleet practices minimized energy charged during on-peak or mid-peak hours. Given that work was usually less busy during non-peak hours of the day shift (8 a.m. to 4 p.m.), DHE instructed drivers to plug in all yard tractors at the start of this shift. This practice helped ensure that yard tractors charged as much as possible during off-peak or super-off-peak periods and avoided charging between 4 p.m. and 9 p.m., saving money on charging costs. DHE's standard work schedule and the fact that the yard tractors were not constantly in service made it possible to manage charging effectively, even without smart-charging software.

Cost

Charging data collected from Accuenergy were coupled with TOU data from Orange EV, allowing for a thorough analysis of operating cost. Because electricity rates vary throughout the day, the energy charged shown in Figure 16 did not directly correlate with charging cost. However, Figure 16 shows the relative cost of charging versus the amount of energy consumed, broken down by the different rates.

Figure 16: DHE Electric Yard Tractor Energy Charged and Charging Cost



Around the same amount of energy per hour was charged between 9 p.m. and 11 p.m. as 4 p.m. to 9 p.m., but the latter costs per hour were about three times as expensive. This emphasizes the importance of avoiding charging during on-peak hours. Despite DHE's manual charge management efforts, a hefty portion of energy costs fell during the most expensive charging times. The relatively small amount of energy charged in the late afternoon/early evening comprised a disproportionate amount of the total cost. Although energy charged during on-peak and mid-peak hours was less than 20% of the total, it made up about 40% of the costs year-round. Table 29 compares hourly and annual fuel costs for the yard tractors.

Table 29: DHE Electric and Diesel Yard Tractor Operating Cost Comparison

Cost Parameter	YGE-01 (80 kWh)	YGE-02 (160 kWh)	Diesel
Annual Time in Operation (hours)	3,000	3,000	3,000
Annual Fuel Cost ($)	3,468	3,870	10,233
Annual Fuel Cost with LCFS ($)	859	-16	10,233

Cost Parameter	YGE-01 (80 kWh)	YGE-02 (160 kWh)	Diesel
Cost per Hour ($/hour)	1.16	1.29	3.41
Cost per Hour with LCFS ($/hour)	0.29	-0.01	3.41
Estimated Time in Service (years)	8-10	8-10	5

To compare operating costs equally for the electric and diesel yard tractors, annual time in operation was normalized at 3,000 hours. Under these conditions, fueling YGE-01 and YGE-02 cost about $3,500 and $3,900, respectively, and the diesel yard tractor cost over $10,000. YGE-02 was less efficient than YGE-01, and the time of day the two vehicles were charged varied. Regardless, the EVs cost about one-third of the diesel yard tractor fueling cost, even without LCFS credits. With LCFS credits, the fleet would barely incur costs for charging the electric yard tractors. Therefore, the electric yard tractors saved the fleet about $10,000 in fueling costs annually. In terms of cost per hour, the electric yard tractors ranged from about $1.15 to $1.30 per hour in use, compared with $3.41 per hour in use for diesel. Including LCFS credits reduced the electric charging costs between $0 and $0.30. Diesel yard tractors are expected to operate for five years before maintenance costs become too expensive, whereas electric yard tractors are expected to operate for 8-10 years and possibly more.

The power feeding the yard tractor chargers was projected to be free of demand charges until 2024. When these charges are once again levied, managing maximum power demand will be crucial to ensure the fleet continues to save on operating costs. Solar began operating in May 2021 and generated more power than current demand for all peak periods every month (see DHE's Solar and Energy Storage section). With 220 monthly hours in use for YGE-01 and 296 monthly hours in use for YGE-02, **DHE could save $7,771 annually on operational costs for both electric yard tractors with its current level of solar generation until 2024.** The tables below list the parameters used to estimate yard tractor TCO.

Table 30: DHE Electric and Diesel Yard Tractor TCO Parameters - Capital Cost ($)

TCO Parameter	Diesel	YGE-01 (80 kWh)	YGE-02 (160 kWh)
Total Purchase Price	120,000	244,950	284,950
Charging Infrastructure	-	4,000	4,000
Total Capital Cost	120,000	248,950	288,950
HVIP* Incentive	-	-175,000	-175,000
Total Capital Cost with HVIP	120,000	75,950	115,950

Table 31: DHE Electric and Diesel Yard Tractor TCO Parameters - Operating Cost ($)

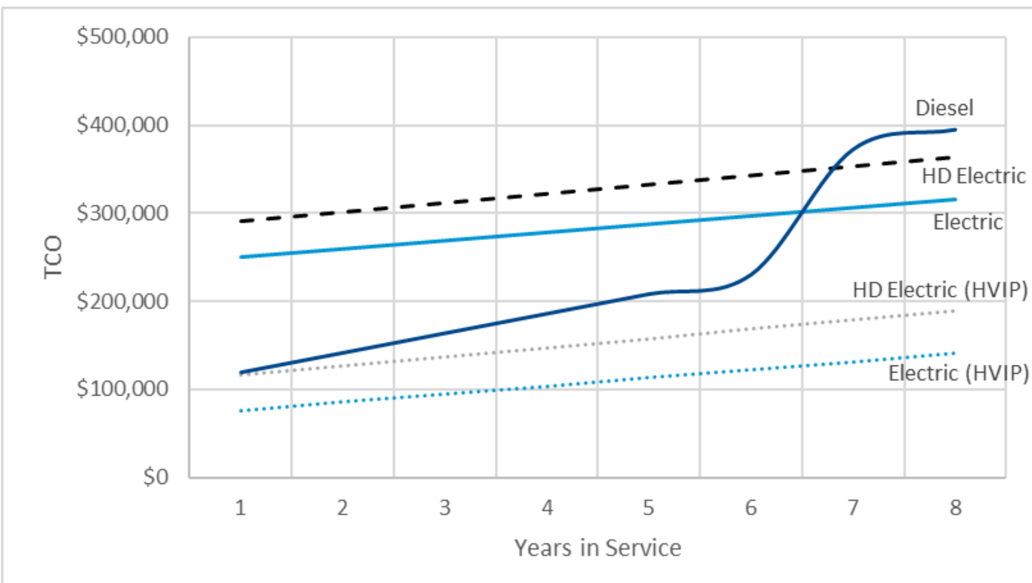
TCO Parameter	Diesel	YGE-01 (80 kWh)	YGE-02 (160 kWh)
Total Purchase Price	-	5,000	5,000
Charging Infrastructure	10,233	3,468	3,870
Total Capital Cost	-	-2,609	-3,886
Total Annual Maintenance Cost	12,018	3,424	2,753
Total Annual Operating Costs	22,251	9,283	7,737

Diesel yard tractors cost about $120,000, compared with about $245,000 for YGE-01 and $285,000 for YGE-02. The electric yard tractors received $175,000 in HVIP funding (including additional funding for being located in a disadvantaged community) and covered the price of the $4,000 charger. There was no insurance for the diesel vehicles;

insurance for the electric yard tractors was $5,000 per year given HVIP requirements to be on-road compliant and insured accordingly. DHE's diesel yard tractors were not on-road certified, but DHE set aside $5,000 annually for internal insurance for the electric yard tractors. That said, DHE did not operate the electric yard tractors on the road for more than one or two blocks carrying trailers between facilities. Moving forward, insurance would not be required for the electrics, as all yard tractors, whether on- or off-road, are now funded by Clean Off-Road Equipment Voucher Incentive Project (CORE), which does not have this requirement.

Estimated diesel fueling costs were about $10,200 annually, about $3.40 per hour of operation. The EV charging costs were based on energy consumption on SCE's TOU-EV-8 rate plan and considered LCFS reimbursements at $0.20 per kWh charged. DHE provided maintenance costs for both the diesel and electric yard tractors. Maintenance and operating costs were normalized to represent 3,000 hours of operation, which is close to DHE's annually yard tractor usage. Figure 17 shows the evolution of TCO for these vehicles over time, with and without HVIP funding.

Figure 17: DHE Diesel and Electric Yard Tractor TCO



Although the capital cost of the electric yard tractors was more than twice that of a diesel yard tractor, the fleet saved about $10,000 per year on fueling and $9,000 per year on maintenance costs. DHE kept its diesel yard tractors in service for five years compared to an estimated eight years for the electric yard tractors. The standard electric YGE-01 (80 kWh) yard tractor would achieve cost parity with diesel by Year 6 and save the fleet $92,000 by the end of Year 8. With HVIP funding, the 80-kWh truck would achieve cost parity upon purchase and save the fleet $224,000 by the end of Year 8. **An 80-kWh yard tractor with HVIP funding would cost about the same as two**

diesel yard tractors over eight years in service, which means electric yard tractors nearly save the fleet enough to purchase a second electric yard tractor.

YGE-02 (160 kWh) cost about $160,000 more upfront than a diesel yard tractor. Without HVIP funds, it would achieve cost parity in Year 6 (or about 12 years without accounting for the differences in operational lifetimes). With HVIP funds, it would cost $5,000 less upon purchase and save the fleet $218,000 by the end of Year 8. **Both models of electric yard tractor showed significant cost savings over diesel, with TCO worth up to two diesel yard tractors.**

Emissions Offset

Reduced environmental impact is a major benefit of adopting EVs. Table 32, Table 33, and Table 34 show the emissions produced by a diesel yard tractors per hour, annually, and over a 13-year lifetime assuming 3,000 hours in service per year.

Table 32: DHE Diesel Yard Tractor Tailpipe Emissions per Hour

Tailpipe Emission	Grams per Hour
CO2	11,223
NOx	22.23
PM	0.04

Table 33: DHE Diesel Yard Tractor Annual Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	33,669
NOx	66.7
PM	0.12

Table 34: DHE Diesel Yard Tractor Eight-Year Lifetime Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	269,352
NOx	533.6
PM	0.96

Using a diesel yard tractor as baseline, an electric yard tractor offsets 11,223 grams (g) of CO2, 22.23 g of NOx, and 0.04 g of PM hourly, equivalent to 33,669 kg of CO2, 66.7 kg of NOx, and 0.12 g of PM in one year of service at 3,000 hours. Over eight years of service, each electric yard tractor could potentially offset more than 269 metric tons of CO2, 534 kg of NOx, and 1 kg of PM. Combined, the two yard tractors deployed through this project would totally offset 539 metric tons of CO2, 1.1 metric tons of NOx, and 2 kg of PM over their lifetimes.

The total amount of CO2 offset is equivalent to:

- 23,318 trash bags of waste;
- 1,337,174 miles traveled in an average passenger vehicle;
- Annual energy use of 105 homes; or
- 8,908 tree seedlings sequestering carbon for 10 years.[10]

Class 7 Box Truck and Class 8 Tractors

Box Truck and Tractor Introduction and Deployment Process

DHE deployed one Class 7 pilot Volvo box truck, one Class 8 pilot Volvo tractor, and two second-generation Class 8 Volvo tractors. The data on these vehicles ranged from February 20 to October 26, 2021, for the box truck (248 days); February 20 to December 5, 2021, for the pilot tractor (288 days); and May 19 to December 5, 2021, for the two second-generation tractors (200 days).

The CE–CERT team conducted additional in-depth analysis on the electric Class 7 box truck and Class 8 electric tractors—both the vehicles operating at DHE and NFI as well as other Volvo electric trucks in operation—in their "Volvo LIGHTS Emissions and Activity

[10] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Results" report. For additional insights on performance, duty cycle, and charging, refer to their report. Table 35 displays specifications for the box truck and Class 8 tractors. CE–CERT's report will likely become accessible to the public online in 2022.

Table 35: DHE Electric and Diesel Box Truck Specifications

Specification	Electric Box Truck	Electric Tractor	Baseline Tractor
Fuel Type	Lithium-ion Electric	Lithium-ion Electric	Diesel
Model Year	2021	2021	2016
Manufacturer	Volvo	Volvo	Volvo
Model Name	VNR Box Truck	VNR Class 8 Tractor	-
GVWR (lbs.)	33,200	82,000	80,000
Battery Capacity (kWh)	264	264, 396	-

The pilot box truck had a payload capacity of 8,500 pounds (lbs.), significantly less than the 15,000 lbs. a diesel box truck could carry. However, DHE usually filled these trucks by volume without approaching the weight limit. This made the reduced cargo weight a non-issue. Volvo's next-generation electric box truck is expected to narrow the gap, with a cargo weight of 12,500 lbs. The box truck and the two second-generation tractors had battery capacities of 264 kWh, and the pilot tractor had a battery capacity of 396 kWh. The trucks were powered by two or three 132-kWh batteries.

All four trucks charged on the same two 150-kW ABB chargers. Although the chargers were rated for 150 kW, the true charging power was 131 kW, the maximum the charger cable could achieve. DHE recommended that fleets purchasing chargers ensure that they receive the expected charger power upon purchase. Charging the box trucks proved effective for DHE's operations; the box trucks returned to base every night and could be charged overnight at a slower charging rate (Figure 18), which helped avoid high TOU rates and improved battery longevity.

Figure 18: Class 8 Tractors at DHE Facility

DHE was originally scheduled to receive a second box truck but opted for a tractor instead; the company wanted to wait for the next iteration box truck with a larger battery option. Overall, DHE deemed the performance of the electric box truck successful and reported plans to transition all 10 of its box trucks to electric over the coming years. Operators of the electric box truck enjoyed the driving experience, appreciated the quiet and odorless operations, and reported that it matched the diesel's performance. The drivers did note that the battery pack was low to the ground, which made scraping a risk on steep hills. DHE operators also noted the same operational benefits for the Class 8 tractors, but they were range-limited to DHE's shortest, "regional" routes. Table 36 describes the three routes of the DHE Class 8 tractors.

Table 36: DHE Class 8 Tractor Routes

Route Type	Miles per Day	Return to Base	Purpose
Regional	150 to 200	Yes	Daily trips
Short Haul	300 to 500	Maybe	"Meet and turn" operations (drivers meet and swap trailers)
Long Haul	500	No	Longest trips

Duty Cycle and Performance

The trucks operated about five days per week, usually 12 to 13 hours per day between 8 a.m. and 9 p.m. The trucks usually drove routes in the morning and returned between 2 p.m. and 3 p.m. for a 40-minute break and an opportunity charge. According to one driver, the vehicle could achieve nearly a complete charge of 90 miles of range in that time. The vehicles regularly operated a total of about 130 miles per day, making this recharging essential. These returns to base during the day were not uncommon for the diesel trucks, but DHE ensured these stops were part of all electric routes. Table 37 lists the average and max distance operated by the trucks.

Table 37: Key Performance Metrics for DHE Electric Class 8 Tractors

Performance Metric	VNM-190	359100	359101	359102
Description	Pilot Box Truck	Pilot Tractor	Gen 2 Tractor	Gen 2 Tractor
Battery Capacity (kWh)	264	396	264	264
Avg. Distance per Day (miles)	60	82	72	102
Max. Distance Driven per Day (miles)	120	179	152	164

The box truck drove an average of 60 miles per day and a maximum of 120 miles. The 264-kWh trucks drove as far as 164 miles in a day, and the 396-kWh pilot truck reached up to 179 miles in a day, all with opportunity charges included. According to DHE, a truck ran out of energy enroute only once. This occurred during the first week of deployment on the pilot tractor, after which Volvo increased the usable battery capacity from 70% to 80%. After this adjustment, the fleet gained confidence in the trucks' range, and on one occasion, the fleet directed the dispatchers to place the electric trucks on longer routes.

While the electric tractors performed well on their assigned routes, they would not be able to operate DHE's short-haul duty cycles until they had a range of 300 miles. With that range, the truck could reach DHE's Fresno facility and recharge there, allowing electric trucks stationed in Fresno to perform the return route. The tractors were also limited to one shift per day—compared to two for diesel counterparts—because they had to charge overnight. This common issue with electric trucks can be mitigated with faster charging, batteries with higher energy densities, and opportunity charging when available. Fleets utilizing fast chargers would be advised to invest in smart-charging technology that staggers charging times to help minimize demand charges.

Energy Consumption

The energy consumed by the box truck and Class 8 tractors was critical to monitoring their performance. Table 38 outlines the daily energy charged and calculated energy efficiency.

Table 38: DHE Electric Box Truck and Class 8 Tractor Energy Efficiency

Efficiency Metric	VNM-190	359100	359101	359102
Description	Pilot Box Truck	Pilot Tractor	Gen 2 Tractor	Gen 2 Tractor
Battery Capacity (kWh)	264	396	264	264
Avg. Energy Use per Day (kWh)	111	174	142	223
Max Energy Use per Day (kWh)	214	345	281	359
Energy Efficiency (kWh/mile)	1.72	2.20	2.10	2.28

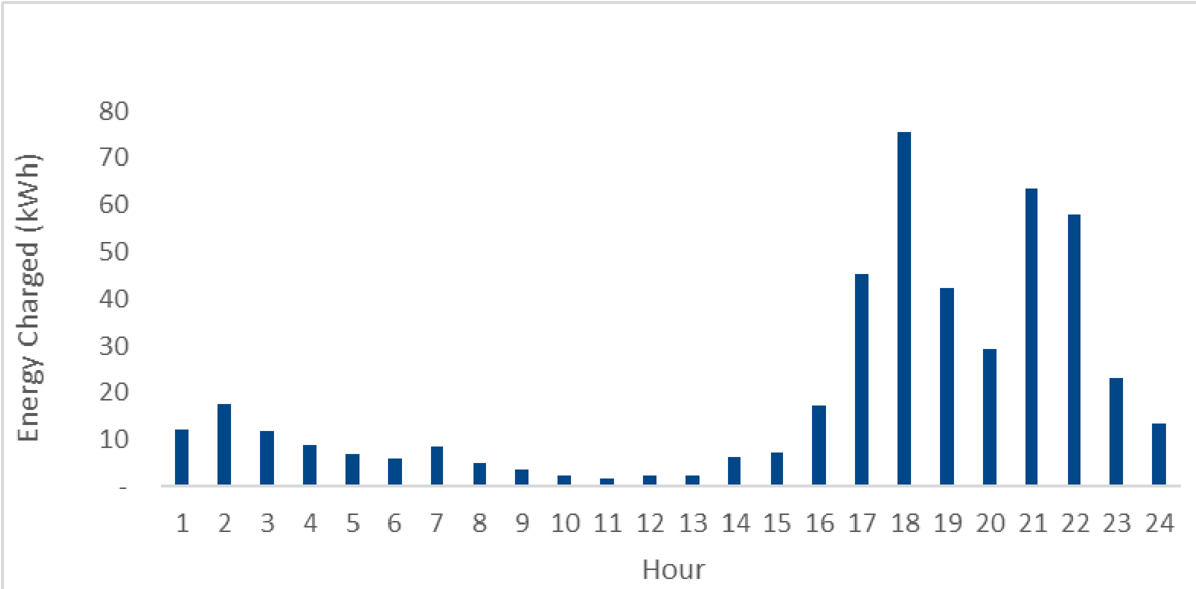
The box truck averaged 111 kWh charged per day, and the tractors averaged between 174 and 234 kWh charged per day. Assuming a charger efficiency of 94%, calculated by comparing charger data with truck-side data, the box truck had an efficiency of 1.72 kWh per mile and the tractors ranged from 2.1 to 2.28 kWh per mile. While the chargers were limited to 131 kW and could only charge one at a time, a fleet of 10 trucks could easily surpass 1-MW charging rates. Smart charging, which can manage charging power and when vehicles are charged, could help mitigate these extreme power demands and avoid future demand charges. Table 39 examines the trucks' SOC during operations.

Table 39: DHE Average Daily SOC Values by Truck

SOC Value	VNM-190	359100	359101	359102
Description	Pilot Box Truck	Pilot Tractor	Gen 2 Tractor	Gen 2 Tractor
Avg. Start SOC (%)	88	87	88	55
Avg. End SOC (%)	54	64	53	51
Avg. Max Daily SOC (%)	97	93	95	85
Avg. Min Daily SOC (%)	46	59	47	41

The trucks usually started their routes with an SOC around 90%, dipping down to about 50%. The lowest average SOC for a tractor was 34%, indicating that DHE's charging practices were conservative and never allowed the electric tractors to approach energy depletion. The data also suggests that the tractors could run slightly longer routes, perhaps reaching daily mileages in the low hundreds while retaining above 25% SOC. Figure 19 describes the average daily energy charged by the three Class 8 tractors and the Class 7 box truck.

Figure 19: DHE Class 8 Tractor and Box Truck Average Daily Energy Charged



DHE's HD trucks usually returned to base and plugged in around 5 p.m., with the most energy drawn at 6 p.m. A secondary peak occurred around 9 p.m. due to trucks arriving later than usual or serial charging increasing when one vehicle completed charging and another began. Presumably, an additional truck was plugged in around 9 p.m. or 10 p.m. SCE's rate plan TOU-EV-8 had the highest prices between 4 p.m. and 9 p.m., so adjusting this charging behavior to avoid those hours could save money.

Cost

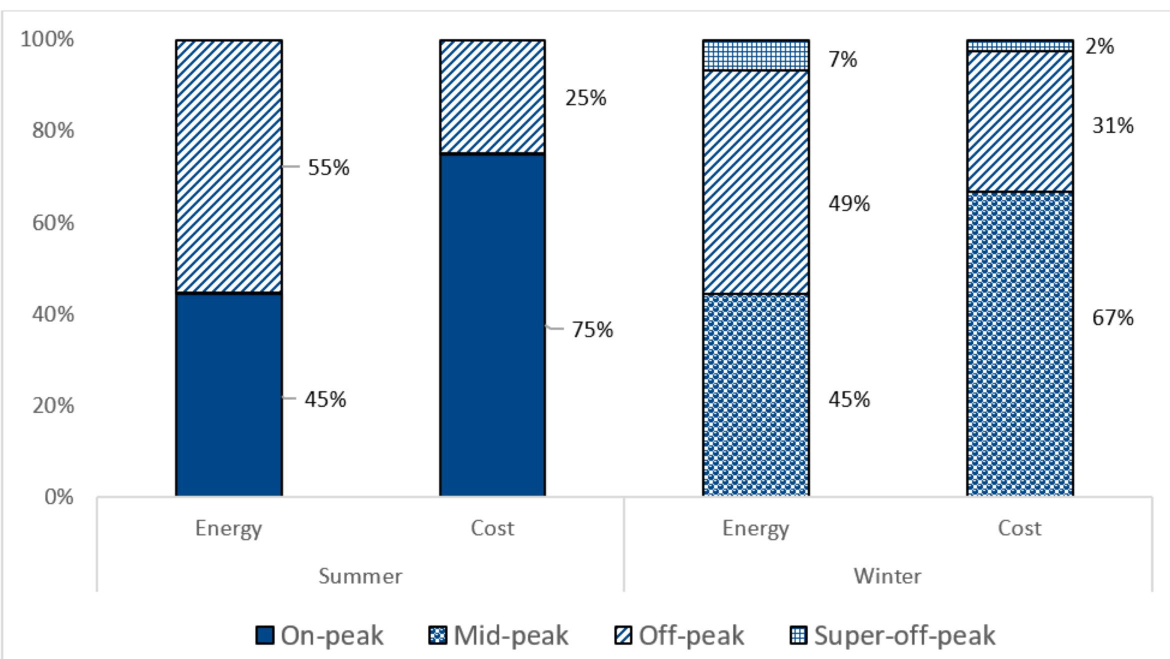
Charging data were only reliable for August, September, and October, when an overlap in charger and truck data showed charger efficiencies between 93% and 95%. To estimate annual charging costs for all four trucks, Table 40 applies the average energy charged during each hour of the day for those three months to SCE's TOU-EV-8 rate plan to estimate the annual charging costs for the three tractors and the box truck.

Table 40: DHE Class 8 Tractor and Box Truck Energy Consumption and Charging Costs

Rate	Summer (kWh)	Winter (kWh)	Summer ($)	Winter ($)
On-peak	25,723	-	15,311	-
Mid-peak	50	51,537	18	20,639
Off-peak	31,959	56,332	5,052	9,451
Super-off-peak	-	7,586	-	741
Total	57,732	115,454	20,381	30,831

Over the year, the four trucks were estimated to consume about 173,186 kWh of energy for a total cost of $51,211. This amounts to approximately 43,000 kWh and $12,000 per truck. Summer months had the highest charging rates (on-peak), which occurred from 4 p.m. to 9 p.m. on weekdays during DHE's main charging window. Figure 20 displays the difference between the energy consumption and costs during each of the four TOU periods.

Figure 20: DHE Class 8 Tractor and Box Truck Percent of Energy Charged and Costs Accumulated During Each TOU Period



Despite accounting for less than half of the total energy charged, on-peak energy made up 75% of total energy cost in the summer. In winter, the same amount of energy was consumed in mid-peak but comprised two-thirds of the total costs.

The overrepresentation of these rates in cost versus energy consumed indicate possible savings if charging times could be adjusted. In the summer, only 45% of energy was charged during on-peak times, but 75% of the costs came during this period. DHE could have saved $6,000 if it had eliminated charging between 4 p.m. and 9 p.m. during June through October. If DHE avoids those hours completely throughout the year, it could save $18,000 or pay 65% less to power these vehicles. As fleets adopt more EVs, the case for smart charging that minimizes on-peak charging and demand charges becomes even stronger. Table 41 summarizes annual fuel costs and costs per mile with and without LCFS rebates.

Table 41: DHE Diesel and Electric Box Truck and Class 8 Tractor Annual and per Mile Cost

Cost Metric	Diesel Box Truck	Electric Box Truck	Diesel Tractor	Electric Tractor
Annual Distance Driven (miles)	15,000	15,000	20,000	20,000
Annual Fuel Cost ($)	9,643	7,629	12,857	12,971
Annual Fuel Cost with LCFS ($)	9,643	2,469	12,857	3,742
Cost per Mile ($)	0.63	0.51	0.64	0.65
Cost per Mile with LCFS ($)	0.63	0.16	0.64	0.21
Estimated Years in Service	7 to 10	7 to 10	7 to 10	7 to 10

The electric and diesel box trucks drove about 15,000 miles per year, and the tractors operating DHE's regional duty cycle drove around 20,000 miles per year. The electric box trucks cost about $7,600 to charge annually, or about $2,500 after including LCFS credits. This saved the fleet about $7,000 per year compared with diesel fueling. Charging the Class 8 electric tractors cost about the same as fueling the diesel tractors but saved the fleet about $8,600 once LCFS credits were included. On the surface, it may seem that electric and conventional trucks both cost about $0.64 per mile to fuel, but the actual cost per mile for the electric truck was less than $0.20 thanks to LCFS credits. These calculations assumed diesel costs of $4.50 per gallon and a diesel truck efficiency of 7 miles per gallon. Table 42 and Table 43 list the parameters used in calculating TCO of DHE's diesel and electric trucks.

Table 42: DHE Diesel and Electric Box Truck and Class 8 Tractor TCO Parameters – Capital Cost ($)

Input	Diesel Box Truck	Electric Box Truck	Diesel Tractor	Electric Tractor
Total Purchase Price	130,000	350,000	150,000	350,000
Charging Infrastructure	-	7,500	-	7,500
HVIP Incentive	-	(85,000)	-	(120,000)
Total Capital Cost	130,000	357,000	150,000	357,00
Total Capital Cost with HVIP	130,000	265,000	150,000	237,000

Table 43: DHE Diesel and Electric Box Truck and Class 8 Tractor TCO Parameters – Operating Cost ($)

Input	Diesel Box Truck	Electric Box Truck	Diesel Tractor	Electric Tractor
Insurance (5.5%)	7,150	19,250	8,250	19,250
Annual Fueling Cost per Tractor	9,643	7,629	12,857	12,580
LCFS	-	(5,160)	-	(8,837)
Annual Maintenance Cost*[11]	2,263	100	8,400	100
Total Annual Operating Cost	19,055	22,719	29,507	21,122

The fleet approximated diesel box trucks to cost $130,000 and tractors to cost $150,000. Volvo estimated both the electric Class 7 box truck and Class 8 tractors to cost $350,000. A 150-kW charger was included in the price of the electric Class 8 tractors for $30,000. Because four trucks were charging on two chargers, this amounted to $7,500 per truck. TCO was calculated with and without HVIP incentive funding of $85,000 for the box truck and $120,000 for the tractor.

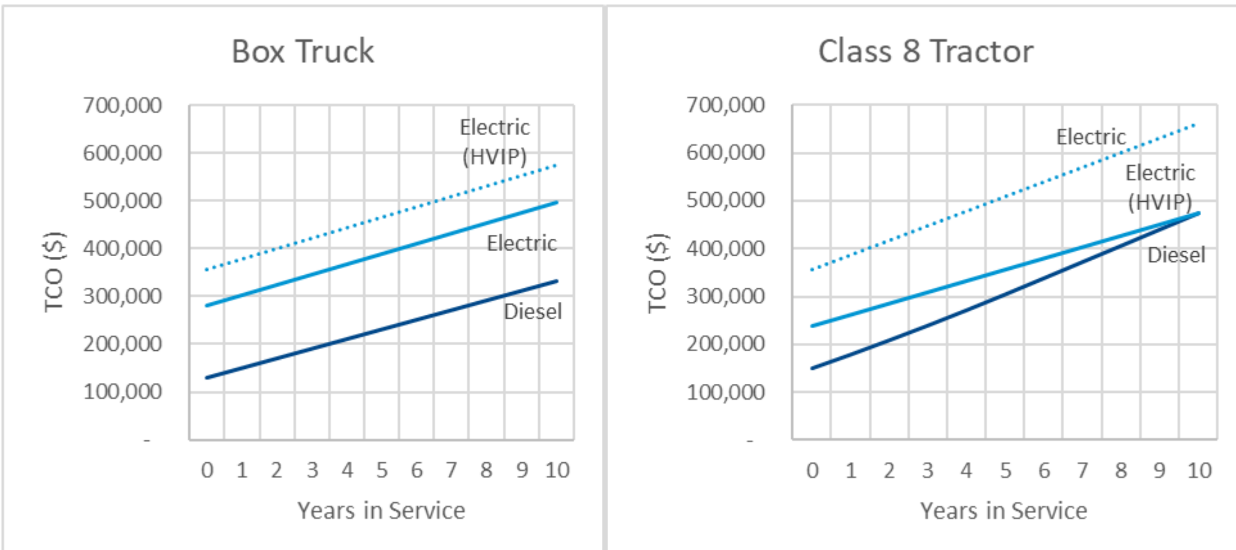
Annual insurance was estimated at 5.5% of a tractor's capital cost. Annual diesel fueling costs came from a DHE log of miles driven. The electric charging costs were estimated based on the annual kWh charged and considered the rates of SCE's TOU-EV-8, which will not include demand charges until 2024. LCFS rebates of $0.20 per kWh were integrated into the cost of charging.

Maintenance costs for the diesel box truck came from DHE maintenance logs, and Class 8 tractor logs were based on estimates from TEC Equipment, Volvo's maintenance facility. TEC technicians estimated Class 8 diesel tractor maintenance costs of $5,000 for

[11] Annual maintenance costs are estimated at $100 based on conversations with TEC maintenance staff. While electric trucks maintenance has proven to cost less, lifetime maintenance data is limited as very few electric trucks have been in service long enough to produce fully representative data.

Year 1, increasing to $10,000 by Year 5. These technicians also managed the maintenance of Volvo's electric trucks; for the first three years these trucks were on the road, virtually no maintenance costs were reported. This TCO analysis estimated $100 per year in maintenance costs. This does not represent maintenance costs that may be incurred later in the truck's life for unique parts such as electric air compressors and electric coolant pumps, which could be expensive. Figure 21 displays the results of the TCO analysis.

Figure 21: DHE Diesel and Electric Box Truck and Class 8 Tractor TCO



While the model estimates that neither the electric box truck nor the electric tractor would achieve cost parity with diesel, additional factors should be considered. For one, the cost of a charger becomes less expensive per truck as more electric trucks are deployed. Also, fueling and maintenance costs combined save fleets over $9,500 per year for box trucks and $18,000 per year for electric tractors.

Insurance was a major barrier for electric truck TCO. At 5.5% of the vehicle's upfront cost, insurance added over $11,000 per year for the electric trucks. Cost parity would be achieved much faster if the higher capital costs of electric tractors were not compounded every year by 5.5% insurance rates. For example, if a fleet paid 5.5% on a $230,000 electric truck (the HVIP discounted cost), it would reach cost parity in less than six years. As electric tractors scale up and capital costs drop, savings will improve and cost parity will be reached well before the lifetime of the vehicle. Until then, government funding could help subsidize higher upfront and insurance costs for EVs.

Emissions Offset

The tables below summarize the per mile, annual, and lifetime emissions produced by DHE's diesel Class 7 box truck and a Class 8 tractor.

Table 44: DHE Diesel Box Truck and Class 8 Tractor Tailpipe Emissions per Mile

Tailpipe Emission	Diesel Box Truck (g/mile)	Diesel Tractor (g/mile)
CO2	1,603	1,706
NOx	0.47	5
PM	0.01	0

Table 45: DHE Diesel Box Truck and Class 8 Tractor Annual Tailpipe Emissions

Tailpipe Emission Type	Diesel Box Truck (kg)	Diesel Tractor (kg)
CO2	23,242	36,776
NOx	8	104
PM	0.2	0.02

Table 46: DHE Diesel Box Truck and Class 8 Tractor 10-Year Lifetime Tailpipe Emissions

Tailpipe Emission Type	Diesel Box Truck (kg)	Diesel Tractor (kg)
CO2	232,425	367,756
NOx	76	1,041
PM	2	0.22

Table 47: DHE Diesel Box Truck and Class 8 Tractor Mileage

	Diesel Box Truck	Diesel Tractor
Annual Mileage	14,500	20,000

Using a diesel box truck as baseline, an electric box truck will offset 232,425 kg of CO2, 76 kg of NOx, and 2 kg of PM over its 10-year lifetime with 14,500 annual miles on the road. Similarly, each electric tractor will offset 367,756 kg of CO2, 1,041 kg of NOx, and 0.22 kg of PM over 10 years with 20,000 annual miles in comparison with a diesel counterpart. The electric box truck and three electric tractors will offset 1,335 metric tons of CO2 over their lifetimes, which is equivalent to:

- 56,767 trash bags of waste;
- 3,356,597 miles traveled in an average passenger vehicle;
- Annual energy use of 160 homes; or
- 22,039 tree seedlings sequestering carbon for 10 years.[12]

Solar and ESS

Solar and ESS Introduction and Deployment Process

DHE's electric vehicle and equipment deployment included installing an 864-kW PV system and a 130-kWh ESS. Solar arrays were installed in two locations: DHE's main facility roof and newly constructed carports (Figure 22). The carports were constructed to increase the available footprint for solar while also providing shade for employee parking and equipment.

The solar array and ESS were energized in December 2020, but the solar array did not begin generating energy until May 2021; the ESS began in July 2021. DHE's ESS was not fully operational until September 2021 due to a part malfunction, which required ordering and installing new parts. DHE's ESS was initially connected to the solar array, but it had to be separated for additional tests to ensure safe transfer of energy to the grid, which led to delays in coming online. The solar and storage providers had to develop these tests in conjunction with being assessed and approved by SCE. The system testing, verification, and coordination among many stakeholders led to a five-

[12] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

or six-month delay between installation and operation. DHE used energy from the grid to charge all EVs and equipment until the solar array came online.

Figure 22: Solar Panels Installed at DHE

Solar Optimum installed an 864-KW solar PV system comprised of 2,367 Astronergy panels to supply renewable energy to the charging stations for DHE's electric forklifts, yard tractors, workplace chargers, and VNR trucks while also decreasing operational expenses. Of the 2,367 panels in the PV system, only 1,025 operated actively at the time of this analysis. Wiring and solar-inverter issues limited operations for inactive panels. The panel manufacturer and installer Solar Optimum worked on these repairs repeatedly after the installation, which led to eight system offline days in June 2021. Although the PV system was not fully operational, it still generated more energy than the EVs and equipment consumed. The surplus energy generated fed back into the grid and the facility.

Table 48: DHE Solar PV System Size

Size of one panel (ft^2)	Size of active panels (ft^2)	Size of all panels (ft^2)
20.82	21,341	49,281

Each panel was about 20.8 square feet (Table 48). With all 2,367 panels in the system, the solar system covered about 49,300 square feet.

Figure 23: Battery Storage System at DHE

The ESS installed at DHE was a 60-kW unit from CPS, with an energy capacity of 130 kWh (Figure 23). The original intent was to mitigate demand charges that DHE would encounter when drawing additional power for EV charging; however, to encourage clean technology deployment, SCE waived peak-demand charges until 2024. As a result, DHE's ESS was not programmed for peak-demand shaving and utilized TOU arbitrage instead, which schedules charging during cheaper off-peak TOU periods and discharging to the EV meter during more expensive on-peak periods. It was recommended that DHE enable this functionality before SCE's waiver of demand charges expires in 2024.

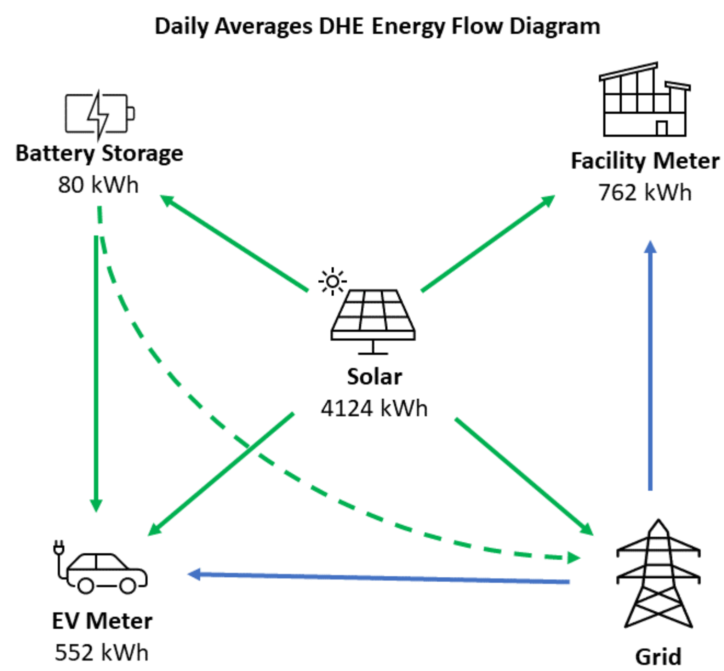
The DHE facility had two meters and one submeter installed by the utility: an EV meter for all EVs, a facility meter, and a solar submeter to track energy generation from solar. These were primarily to enable utilities to track solar production. The EV meter was on a special EV rate structure, which waived demand charges until 2024. It was connected to and received energy from three sources: onsite solar, battery storage, and SCE's grid. Table 49 summarizes key information related to the solar and storage systems.

Table 49: DHE Solar and ESS Key Information

Installation	Solar	Energy Storage
Provider	Solar Optimum	Solar Optimum
Manufacturer	Astronergy	CPS
Power Rating (kW)	864 kW	60 kW
Install Date	December 2020	December 2020
Deploy Date	May 2021	July 2021

The facility meter was connected directly to the grid and solar array but not to DHE's ESS. The solar meter split energy production between the EV and facility meter. The energy flow diagram in Figure 24 helps describe the distribution of solar-generated energy.

Figure 24: DHE Ontario's Facility Energy Flow with Daily Averages of Energy Consumption/Generation



DHE's ESS was not connected to the facility meter. DHE could not use this system to shave peak demand for the facility's bills.

Solar Usage and Performance

On average, the solar panels generated 4,100 kWh of energy daily. On a daily level, the facility was the largest consumer of solar energy (760 kWh), followed by the EV meter (522 kWh) powering all of DHE's EVs, and battery storage (80 kWh). Solar energy was distributed between the EV and facility meter based on relative consumption for each meter. Any surplus solar energy was supplied to DHE's ESS, then sold back to the grid through Net Energy Metering. Table 50 describes energy produced and hours in operation for the PV system. Because only 1,025 of the 2,367 solar panels were operating during the project's data-collection period, the energy produced was approximately 43% of the system rating.

Table 50: DHE Solar PV System Analysis, May 7 to August 7, 2021

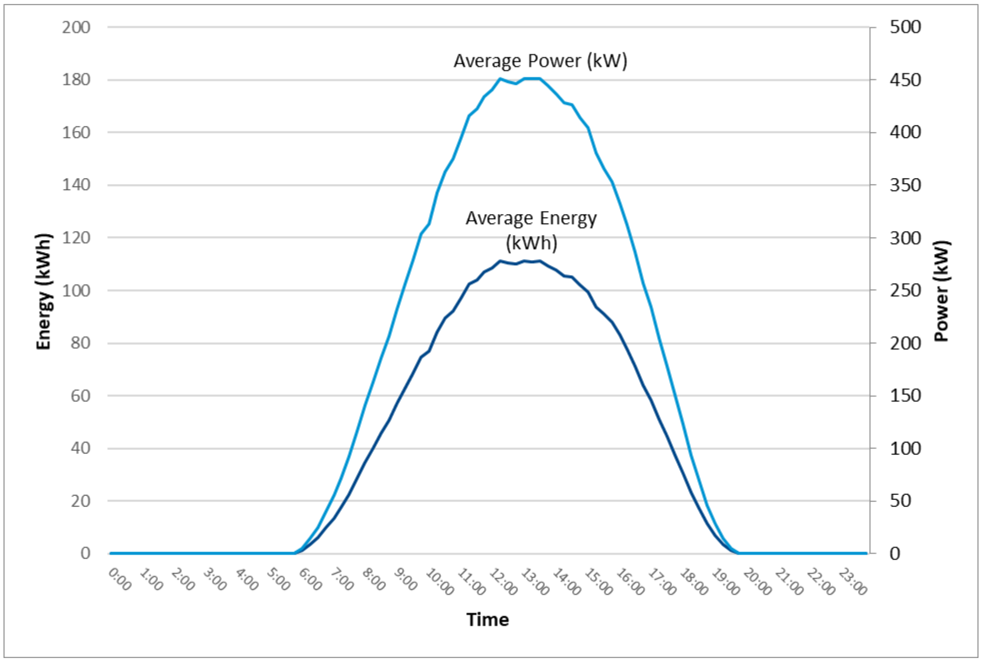
Average Daily Energy Generation (kWh)	Average Energy per Panel (kWh)	Max Daily Energy Generation (kWh)	Min Daily Energy Generation (kWh)	Average Hours of Generation per Day (hour)	Average Times of Generation per Day
4,124	4.02	5,326	316	12.8	6 a.m.–7 p.m.

Each panel produced about 4 kWh. Daily energy generation ranged from 300 kWh to 5,300 kWh. Several variables affected this, including inverter failures and maintenance work. From June 9 to June 17, 2021, the solar system was offline for maintenance. Other variables affecting solar generation included weather and cloud coverage.[13]

Between May and August 2021, the system produced energy for nearly 13 hours between 6 a.m. and 7 p.m. Notably, data was recorded only during summer months, when the PV system is expected to be at its peak. During winter months, DHE expects about nine hours of solar generation between 8 a.m. and 5 p.m. Figure 25 describes daily power and energy production from the PV system.

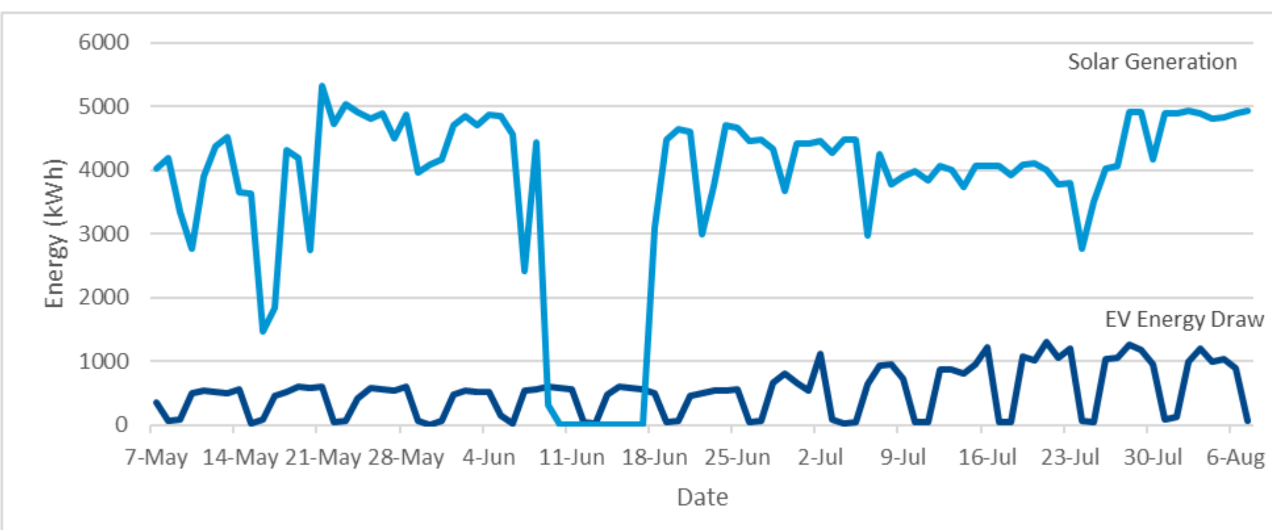
[13] Which Are the Factors that Affect Solar Panels' Efficiency? Tracesoftware. https://www.trace-software.com/blog/which-are-the-factors-that-affect-solar-panels-efficiency/

Figure 25: DHE Solar Duty Cycle Daily Average Power and Energy Production in Summer



The PV system began producing energy around 6 a.m., peaked around noon, and produced steadily decreasing amounts of energy until about 7 p.m. At its peak, the system produced 180 kWh and reached a power rating of about 280 kW. During winter, the daily power and energy peaks are expected to be lower, and the system would likely produce energy for fewer hours of the day. Over the summer, the PV system produced about 100,000 kWh monthly. Figure 26 compares PV energy generation and energy draw from the EV meter.

Figure 26: DHE EV Meter Energy Consumption Compared with Solar Generation, May 7 to August 7, 2021

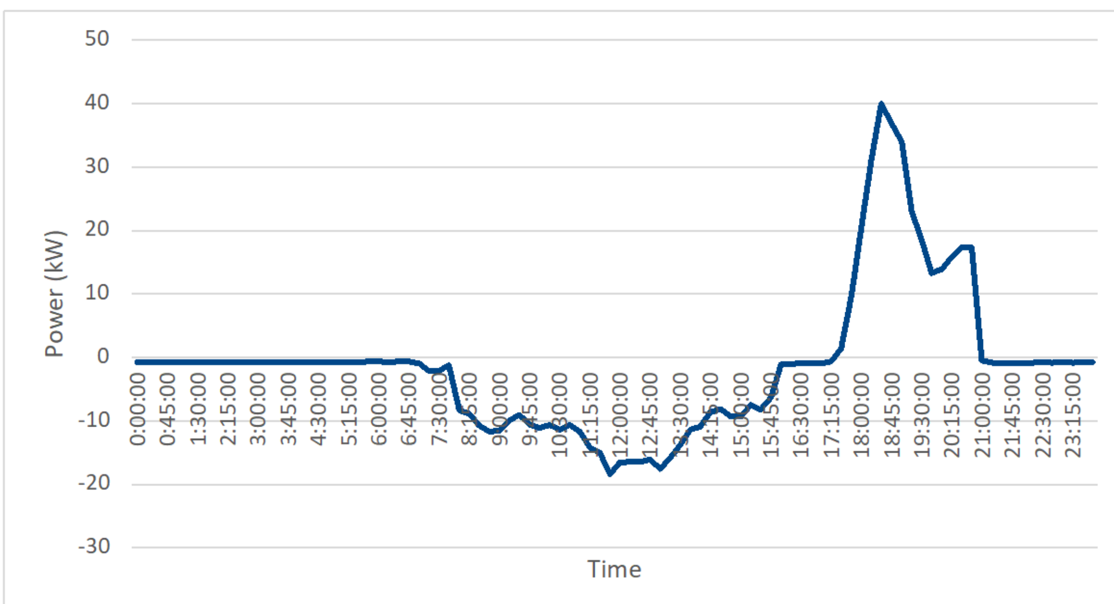


Most notably, solar generation was four to five times higher than the EV energy draw between May and August, apart from the eight-day downtime in June due to maintenance. Therefore, the maximum recorded daily draw of 1,306 kWh from EV charging could be covered by the PV system, with 68% of the total solar generation remaining.

Energy Storage Usage and Performance

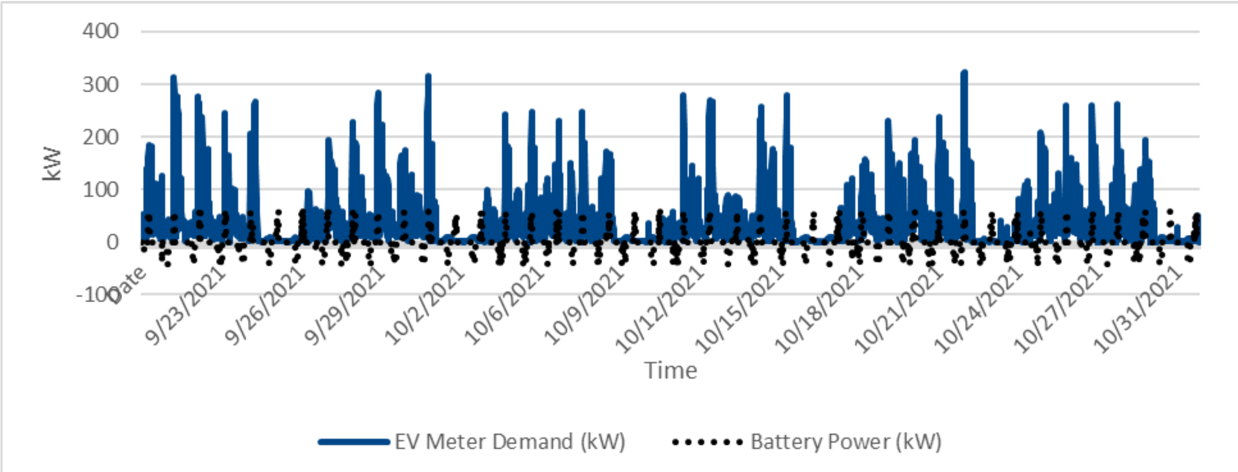
The 130-kWh ESS was programmed to perform TOU arbitrage and net energy metering. TOU arbitrage scheduled the storage system's battery to discharge when TOU rates were highest for the DHE EV meter. Net energy metering is the selling of onsite solar energy back to the grid. The battery consumes onsite solar energy and sells leftover energy back to the grid on weekends when demand from the EV meter is lower. Figure 27 describes the ESS's average daily charging and discharging pattern.

Figure 27: DHE ESS Average Charge/Discharge Cycle, September 20 to October 31, 2021



In Figure 27, negative power represents the battery charging and positive power represents the battery discharging. On an average day, DHE's ESS was charged with energy generated from the solar PV system between approximately 8 a.m. and 3 p.m. and discharged between 6 p.m. and 9 p.m. It was charged by onsite solar and discharged when grid energy was most expensive to aid in lowering utility TOU rate costs. Net energy metering typically occurred on weekends. Figure 28 shows how it responded to energy demand from the EV meter between September and October 2021.

Figure 28: DHE EV Meter Demand Compared with ESS Power, September 20 to October 31, 2021



The system charged during the day from solar energy and discharged in the evening to reduce EV demand during on-peak hours (4 p.m. to 9 p.m.). DHE's ESS regularly discharged about 75 kWh per day, virtually its entire usable battery capacity. Despite a battery capacity of 130 kWh, a maximum of 80 kWh was discharged per day. Because it had a maximum power rating of 60 kW, the maximum offset in an hour was 60 kWh. As shown in Figure 28, the EV meter regularly drew power at nearly 300 kW. To arbitrage energy more effectively from 7 p.m. to 9 p.m.—when solar no longer produces energy but the TOU period is on-peak—the system would need to be able to output energy at nearly 300 kW and have a capacity of at least 600 kWh (and likely more) to account for non-usable battery capacity. As DHE deploys more EVs, it may want to scale up the size of its ESS as well. Greater ESS capacity may become more critical to assist with peak shaving as demand charges are reintroduced for DHE's rate structure.

Net energy metering, or selling energy back to the grid, typically occurred on weekends and holidays. On weekdays, the battery was kept fully charged to allow for discharging during on-peak hours. On weekends, lower energy demand from the EV meter enabled the battery to sell energy back to the grid. SCE calculated solar credits by totaling all the energy produced from solar during each rate period every month.

Solar and ESS TCO

Solar generation primarily affected DHE's TOU energy and delivery charges for both the EV and facility meters. For all TOU hours on-peak, mid-peak, and off-peak, onsite solar generation offset DHE's grid energy consumption, meaning the solar system produced more solar energy during each rate period than the EV and facility meters ever demanded. As a result, DHE collected excess energy credits through SCE's Net Energy Metering program. For each rate period, the total amount of solar generation per kWh offset the total energy consumption. For example, if 10,000 kWh were generated and 5,000 kWh consumed during the on-peak period, this would result in net -5,000 kWh. Multiplying this amount by a delivery rate of $0.0227 results in $113.50 of excess energy credits.

According to SCE, these credits could apply to TOU charges within a 12-month period. DHE had such a surplus of excess energy credits between May and August that these credits offset all TOU delivery and generation charges during this analysis. DHE's average TOU bill savings from both the facility and EV meters across these months was $5,413.87 (about $65,000 annually) when offsetting TOU charges. Table 51 and Table 52 list the inputs in calculating TCO for DHE's solar and storage systems.

Table 51: DHE Solar and ESS TCO Parameters - Capital Cost ($)

TCO Parameter	Solar + ESS	Baseline
Total Purchase Price ($)	2,307,000	-
Sprinkler System ($)	50,000	-
Grant Funds ($)	(1,153,500)	-
Total Capital Cost ($)	1,321,241	-

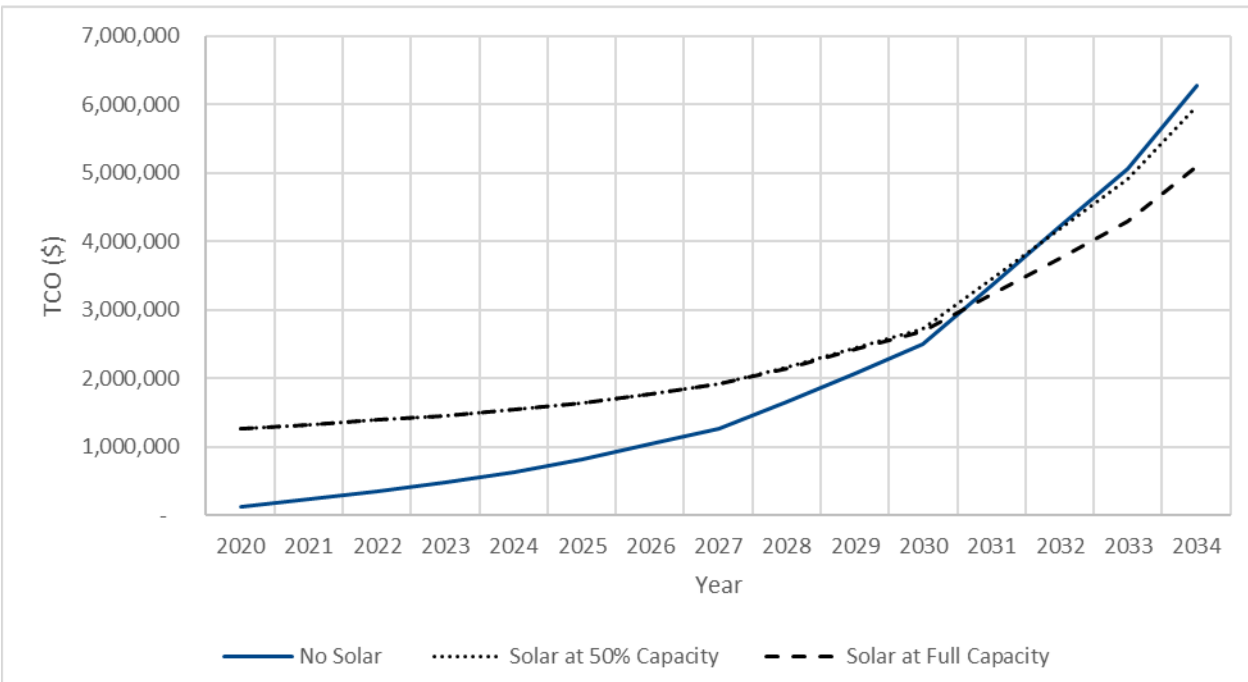
Table 52: DHE Solar and ESS TCO Parameters - Operating Cost ($)

TCO Parameter	Solar + ESS	Baseline
Bi-Annual Carport Panel Cleaning Cost ($)	5,000	-
Total Annual Operating Cost ($)	-	64,996
Annual Maintenance Cost After 10-year Warranty ($)	8,640	-

The solar PV project installation cost about $2,190,000 up front, plus $50,000 for a sprinkler system to keep the panels on the facility's roof clean and generating as much energy as possible. The 130-kWh ESS cost $117,741. The project provided $1,153,500 in upfront cost incentives, for a total capital cost of about $1,320,000.

Like the solar panels installed on the facility roof, the solar installed on the carport was not connected to a sprinkler system, which needed to be cleaned manually. The estimated biannual cost of cleaning the carport solar panels was $5,000. After the 10-year warranty expires, an estimated annual maintenance cost of $8,600 is needed to keep the solar system operating. All these costs were compared with the baseline cost of not installing solar and an ESS, which was calculated to be about $65,000. Figure 29 displays TCO of the solar and storage system.

Figure 29: DHE Solar and Storage Systems TCO



These TCO calculations were found by estimating the EV count of each vehicle type (Table 53 and Table 54). Average annual energy consumption for each vehicle type was multiplied by the estimated vehicle count per year, then multiplied by an increased battery efficiency of 1% each year. The EV count was based on DHE's fleet needs and market growth requirements from the California Advanced Clean Truck (ACT) rule. Each vehicle consumption estimate was added to create estimates for the EV meter energy demand. This was added to the facility meter demand, which was expected to remain constant. Total demand was translated to dollars, with the addition of non-by passable charges, and represented the total utility cost without solar.

The solar TCO analysis found that DHE would start saving money between 2031 and 2032, depending on the solar generation capacity as shown in Figure 25. The TCO analysis also estimated that by 2050 DHE could save $3 million at half capacity or $8 million at full capacity from solar savings.

Table 53: Average Annual Energy Consumption per Vehicle at DHE Incorporated into Solar TCO Estimates

Vehicle Type	kWh per Vehicle
Forklifts	7,848
Yard Tractors	18,412
Box Trucks	25,800
Class 8 (long-range)	262,548
Class 8 (mid-range)	175,032
Class 8 (drayage)	43,800

Table 54: Estimated Future Number of Trucks Deployed at DHE

Vehicle Type	2020	2025	2030	2035	2040	2045	2050
Forklifts	14	14	14	14	14	14	14
Yard Tractors	2	2	2	2	2	2	2
Box Trucks	1	5	10	10	10	10	10
Class 8 (long-range)	0	0	0	5	10	20	20
Class 8 (mid-range)	0	0	0	10	15	15	15
Class 8 (drayage)	5	5	10	15	15	15	15

Vehicle Type	2020	2025	2030	2035	2040	2045	2050
Total kWh consumption	391,495	494,695	842,695	4,124,755	6,312,655	8,938,135	8,938,135

The initial project proposal by solar provider Solar Optimum predicted a return on investment (ROI) of 5.2 years, which was based on possible federal and state incentives and estimated utility bill demand savings. The analysis in this report used project incentives and average TOU savings from excess energy credits to calculate an ROI of 21.8 years.

According to SCE, the solar generated by DHE could not mitigate demand charges, but ESSs could minimize those charges if programmed to do so. Demand charges would not apply toward DHE's EV meter until 2024 but did currently apply to the facility bill. As of the writing of this report, DHE's battery did not offer cost savings. Because solar produced more energy than the facility and EV meter demand, the battery was not needed to offset energy during on-peak hours. This is anticipated to change as DHE added electric trucks to its fleet and when SCE begins phasing demand charges back in starting in 2024. Though solar energy generation is only possibly during the day, the breakup of on-peak, mid-peak, off-peak, and super-off-peak rates allowed solar to produce more energy during each rate period than was demanded.

In 2024, when SCE begins phasing in demand charges, DHE's ESS can be reprogrammed to peak shave, providing energy during the highest draws of energy from the EV meter. It was not known what multiplier would be used to calculate demand charge costs, but these could significantly impact the operational costs of EVs.

Emissions Offset

Because the PV system produced no emissions, it offset the total emissions that would otherwise have been produced through SCE's electricity generation. The tables below describe the emissions offset by the solar system compared with SCE's grid per kWh, annually, and over its 30-year lifetime.

Table 55: Emissions Offset by Solar System Compared with SCE's Grid

Tailpipe Emission	Grams per Kilowatt-hour
CO2	242
NOx	0.01

Table 56: Annual Emissions Offset by Solar System Compared with SCE's Grid

Tailpipe Emission	Kilograms
CO2	364,574
NOx	7.53

Table 57: Thirty-Year Lifetime Emissions Offset (kg) by Solar System Compared with SCE's Grid

Tailpipe Emission	Kilograms
CO2	10,937,219
NOx	226

With 4,124 kWh produced daily, DHE's solar system offsets 364,574 kg of CO2 and 7.53 kg of NOx annually. Over a 30 years' lifetime, the solar system can potentially offset nearly 11,000 metric tons of CO2 and 226 kg of NOx. The amount of CO2 offset is equivalent to:

- 464,832 trash bags of waste;
- 27,485,231 miles traveled in an average passenger vehicle;
- Annual energy use of 1,312 homes; or
- 180,464 tree seedlings sequestering carbon for 10 years.[14]

[14] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Workplace Charging

Workplace Charging Introduction and Deployment Process

DHE installed five EvoCharge Level 2 charging stations for both employees and guests to power personal plug-in EVs (Figure 30). Four of the stations were 7.2-kW dual port chargers and one single port station was 7.68 kW. Charging was free for employees and guests. Instructions on how to charge and set up user accounts through Greenlots were located on the charging stations. CALSTART developed a workplace charging policy in collaboration with DHE, which it issued to all employees and guests interested in utilizing workplace charging (see Appendix C: Charging Station Signage). There was no limit on how long the charger/space could be used as long as use occurred during business hours on weekdays.

Figure 30: DHE Workplace Charger

Usage and Performance

Employees and guests of DHE used workplace chargers as needed. Table 58 shows how the five chargers were utilized by duration of charge.

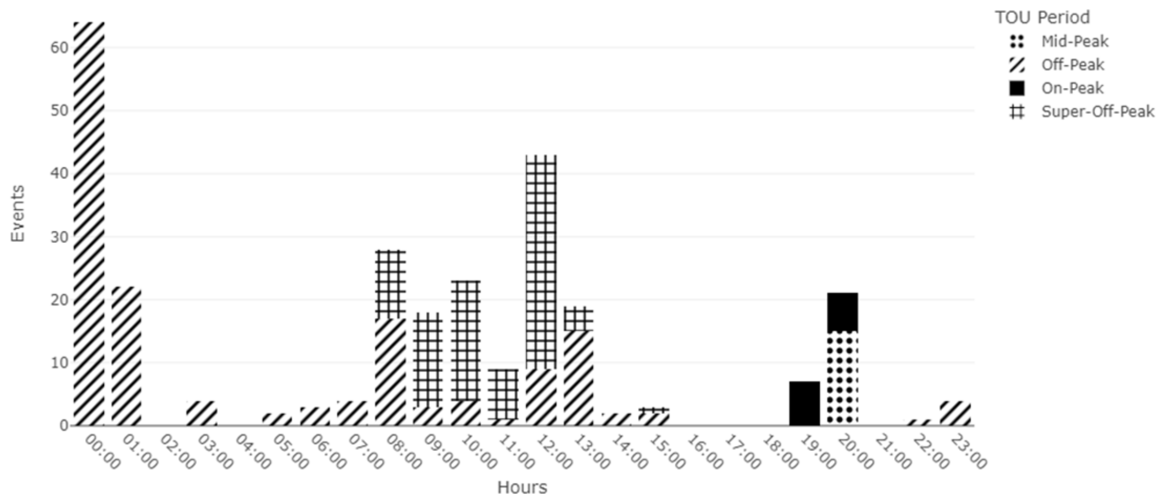
Table 58: DHE Workplace Charging Session Data, February 1 to August 31, 2021

	Charger 1	Charger 2	Charger 3	Charger 4	Charger 5	All Chargers
Total Charging Events	5	5	9	173	85	277
Average Duration (hours)	7	2	8.5	6	5	6
Max Duration (hours)	13	4.5	13	12	13.5	13.5

On average, about 1.3 charging events occurred per day. The average charging event lasted six hours, with a max of nearly 14 hours—DHE charging policy does not limit use, so employees would keep their cars plugged in for the entirety of their shift. Chargers 4 and 5 were utilized significantly more than the other three, which is likely due to certain employees using the same charger consistently.

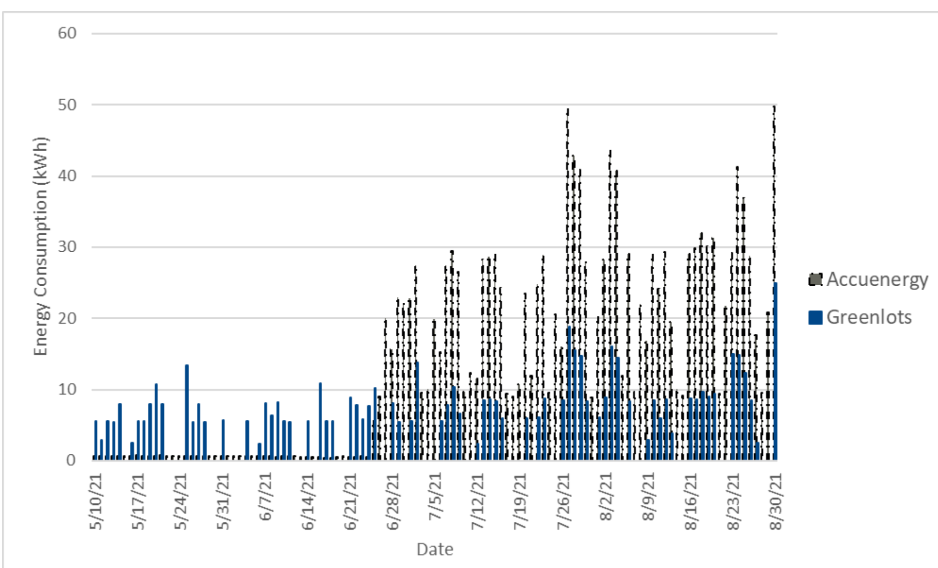
Total charging events across this data-collection period primarily occurred during off-peak and super-off-peak hours (Figure 31). The average charging session lasted 6.05 hours; the longest was 13.5 hours. Longer charging sessions typically started at night and ended in the morning.

Figure 31: Number of Charging Events Started Each Hour for DHE's Workplace Chargers, February 1 to August 31, 2021



Most charging events began between 8 a.m. and 1 p.m. A significant spike of charging events started between midnight and 2 a.m. Likely, these plug-in events corresponded with DHE's shift schedule and when employees arrived to begin shifts. Figure 31 also classifies each plug-in event by TOU period. Almost all events occurred during off-peak and super-off-peak periods, which helped mitigate the fleet's charging costs. About 30 events occurred during on-peak or mid-peak rates between 4 p.m. and 9 p.m. Figure 32 examines the amount of energy consumption.

Figure 32: DHE Workplace Charging Total Energy Charged Daily, Accuenergy vs. Greenlots



Energy

Workplace charging energy consumption was recorded using the Accuenergy and Greenlots SKY data platforms. Daily energy consumption across all five chargers was 23.05 kWh as measured by Accuenergy and 7.44 kWh by Greenlots SKY (Table 59).

Table 59: Daily DHE Workplace Charging Energy Consumption

Charging Metric	Accuenergy	Greenlots SKY
Time Collected	5/7/21–8/31/21	2/1/21–8/31/21
Total Usage (kWh)	1,597.9	1,020.9
Average Annual Usage (kWh)	8,412.3	2,715.6
Average Daily Usage (kWh)	23.1	7.4
Max Daily Usage (kWh)	49.8	24.9

While data were recorded by both Accuenergy and Greenlots SKY, CALSTART did not have confidence in data provided by the Greenlots SKY platform. The data from Greenlots SKY represented 32% of the daily average energy consumption recorded by Accuenergy. There are many possible explanations for this discrepancy. One issue noted by DHE's fleet manager was that Greenlots SKY used the UTC time zone when recording data, while the Accuenergy platform used PST. This could have contributed to different definitions of when charging sessions and energy consumption occurred across platforms. Another possible discrepancy could have been caused by issues with the site controller. On 24 days Greenlots Sky recorded no energy consumption, but Accuenergy recorded energy consumption. This missing data or days that recorded less energy consumption than Accuenergy could have been caused by failures of the site controller to maintain Wi-Fi connection and upload data to the platform.

Greenlots SKY data are displayed here because additional metering through the Accuenergy platform added cost beyond the scope of this project. Greenlots SKY data were intended to be the primary data-collection platform for both CALSTART and DHE's fleet managers.

Cost

Most workplace charging sessions consumed energy during off-peak hours, especially at midnight sessions (Figure 33). Because this was a period of lower TOU rates, this benefitted DHE, lowering the overall costs of energy consumption for workplace charging. However, there was a spike in charging consumption from 7 p.m. to 8 p.m. during on-peak TOU rates (Table 60).

Figure 33: Percentage of DHE Workplace Charging Sessions Across TOU Periods

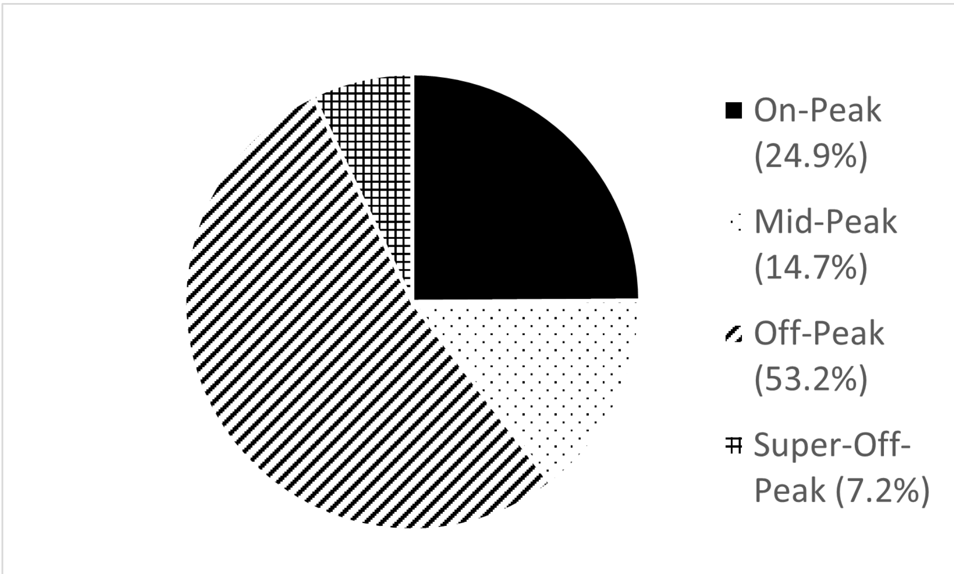


Table 60: Workplace Charging Annual TOU Cost Estimate at DHE

Rate	$/kWh	% Charging	Annual TOU Cost Estimate
On-Peak	$0.595	0.249	$1246.32
Mid-Peak	$0.360	0.147	$445.17
Off-Peak	$0.158	0.532	$707.10
Super-Off-Peak	$0.0977	0.0717	$58.92
Total Annual Cost Estimate	-	-	$2457.51

Annual TOU cost estimates for DHE workplace charging were calculated by taking the average annual energy consumption and multiplying it by the percentage of DHE workplace charging sessions across TOU periods to find the average kWh consumed for each TOU period annually, then multiplying by the average dollar per kWh rate for each TOU period. The average annual TOU cost for workplace charging was about $2,457. Charging was free for employees and guests, but DHE could impose a user fee in the future.

In the winter, the cheapest period (super-off-peak) to charge is from 8 a.m. to 4 p.m. Those who start charging at midnight should instead charge into the super-off-peak TOU if their shift ends later than 8 a.m. This would result in some savings while allowing workers to get a full or near-full charge. Most costs are from the off-peak period. Costs are lowest during the off-peak period in the summer and the super-off-peak period during the winter. The lower fee in the super-off-peak season can be taken advantage of by starting a session later in off-peak hours so that charging flows over into super-off-peak hours at 8 a.m. If smart charging is implemented, charging could be turned off between 4 p.m. and 9 p.m., when it is most expensive. This could help lower overall demand charges during on-peak periods.

Emissions Offset

The following tables describe tailpipe emissions per kWh, annually, and over 20 years from gasoline-powered vehicles that consumed the same amount of energy charged from DHE's workplace charging stations. Annual consumption of 8,412.3 kWh equates to 250 gallons of gas. With zero tailpipe emissions, vehicles charged at workplace charging stations offset the exact amount emitted by the equivalent gasoline vehicles.

Table 61: Tailpipe Emissions from Equivalent Gasoline Vehicles

Tailpipe Emission	Kilograms Per Kilowatt-Hour
CO2	8.89
NOx	0.01

Table 62: Annual Tailpipe Emissions from Equivalent Gasoline Vehicles

Tailpipe Emission	Kilograms
2,218	2,218
2.5	2.5

Table 63: Twenty-Year Lifetime Tailpipe Emissions from Equivalent Gasoline Vehicles

Tailpipe Emission	Kilograms
CO2	44,362
NOx	50

Based on data collected from workplace charging, the use of EVs can significantly reduce tailpipe emissions compared with vehicles running on gasoline. During this project, workplace charging saved 2,218 kg of CO2 emissions and 2.5 kg of NOx emissions annually. If energy consumption demand stays the same in the next 20 years—it is highly likely to increase—the workplace charging at DHE will offset 44,362 kg of CO2 and 5035 kg of NOx over its lifetime. The amount of CO2 offset is equivalent to:

- 1,885 trash bags of waste;
- 111,477 miles traveled in an average passenger vehicle;
- Annual energy use of five homes; or
- 732 tree seedlings sequestering carbon for 10 years.[15]

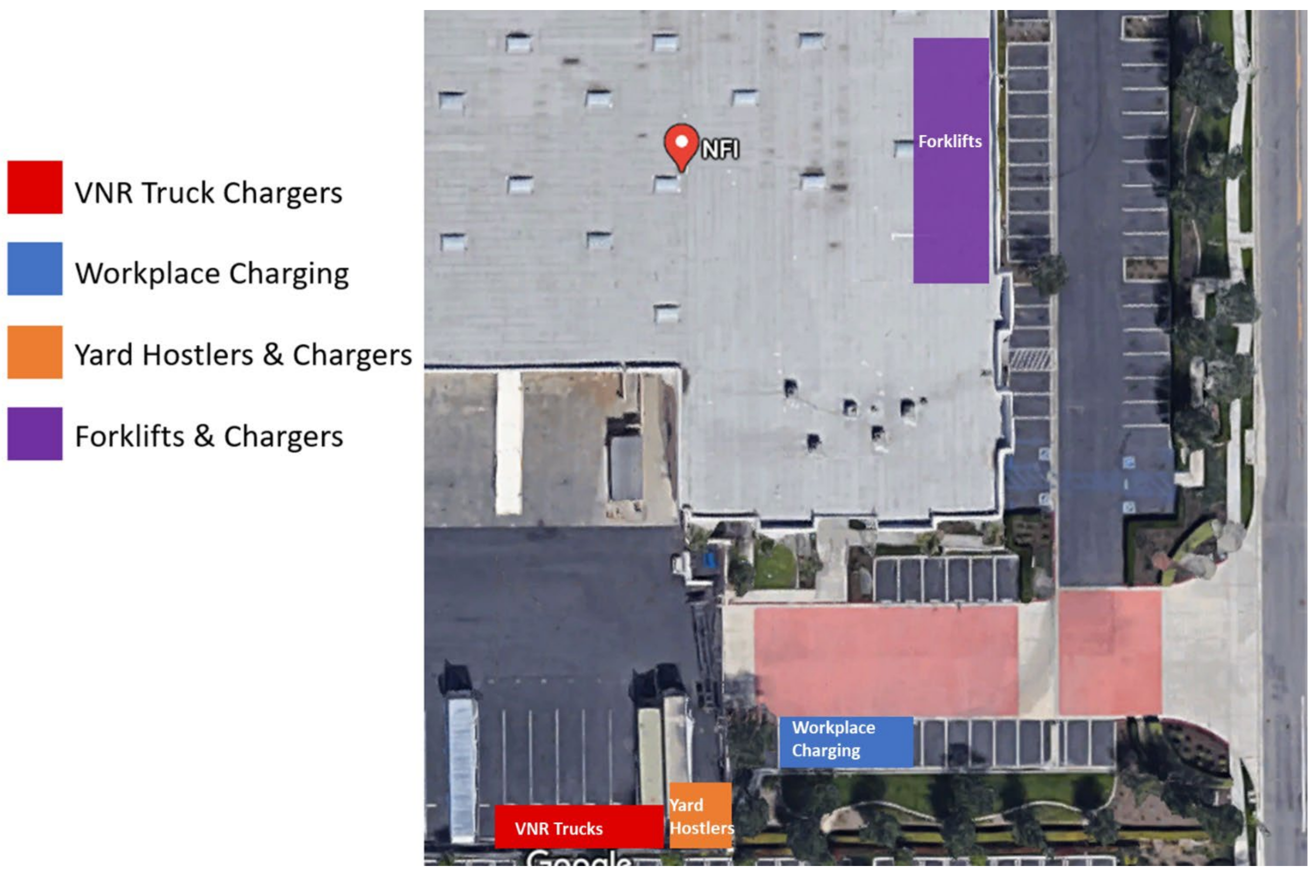
DHE should encourage more workers to adopt EVs and seek possible incentives for accessible workplace chargers.

[15] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

IV. NFI Industries

At NFI, deployment occurred at the Chino II facility (Figure 34), one of many NFI facilities in Southern California. The size of this NFI warehouse facility is 500,000 square feet. Approximately 98% of NFI's operations is drayage, so trucks transport deliveries from the Ports of Los Angeles and Long Beach. Currently, NFI's 57 truck fleet is comprised of 34 diesel, 11 natural gas, and 12 electric trucks. The electric trucks are comprised of 10 Freightliner and two Volvo trucks. On this project, NFI's technology partners included Crown, V-Force, EvoCharge, Kalmar, Volvo, ABB, and Hanwha. Between NFI and DHE, over 40 pieces of ZE technology were deployed. The fleets also installed workplace charging, solar arrays, and battery ESSs. Table 3 in the Executive Summary summarizes the deployments of vehicles, equipment, and infrastructure.

Figure 34: NFI Facility and ZE Technology Deployments Map



Forklift

Forklift Introduction and Deployment Process

NFI replaced propane-powered Nissan forklifts and lead-acid battery Crown forklifts with eight lithium-ion-battery Crown forklifts in June 2020. The lithium-ion forklifts were operated at NFI's Chino II building (Table 64).

Table 64: NFI Propane and Electric Forklift Specifications

Specification	Electric	Baseline
Fuel Type	Lithium-ion Electric	Propane
Model Year	2019	2017
Manufacturer	Crown	Nissan
Battery Capacity (kWh)	27.5	-

Eight 14.7-kW V-Force forklift chargers, model V-HFM3, were installed at the Chino II building in May 2020 and went into operation at the end of September 2020. Vehicle performance data were collected between August 15, 2020, and June 11, 2021. Unlike DHE, NFI opted to install one charger for each electric forklift (Figure 35).

Figure 35: Lithium-Ion Electric Forklifts at NFI

Using one charger for multiple forklifts lowers infrastructure costs and saves space, but it requires more planning for the charging strategy. While DHE installed only eight chargers for 14 electric forklifts, the company expressed a desire to install more chargers and to space them out to increase flexibility in charging. The determining factor for the number of chargers will be influenced largely by duty cycles. If forklifts need to be constantly charged and operated throughout the day, a 1:1 ratio of forklifts to chargers may be necessary. If forklifts are used a few hours each day, as at NFI, fewer chargers than forklifts may be an effective way to save costs and space.

Duty Cycle and Performance

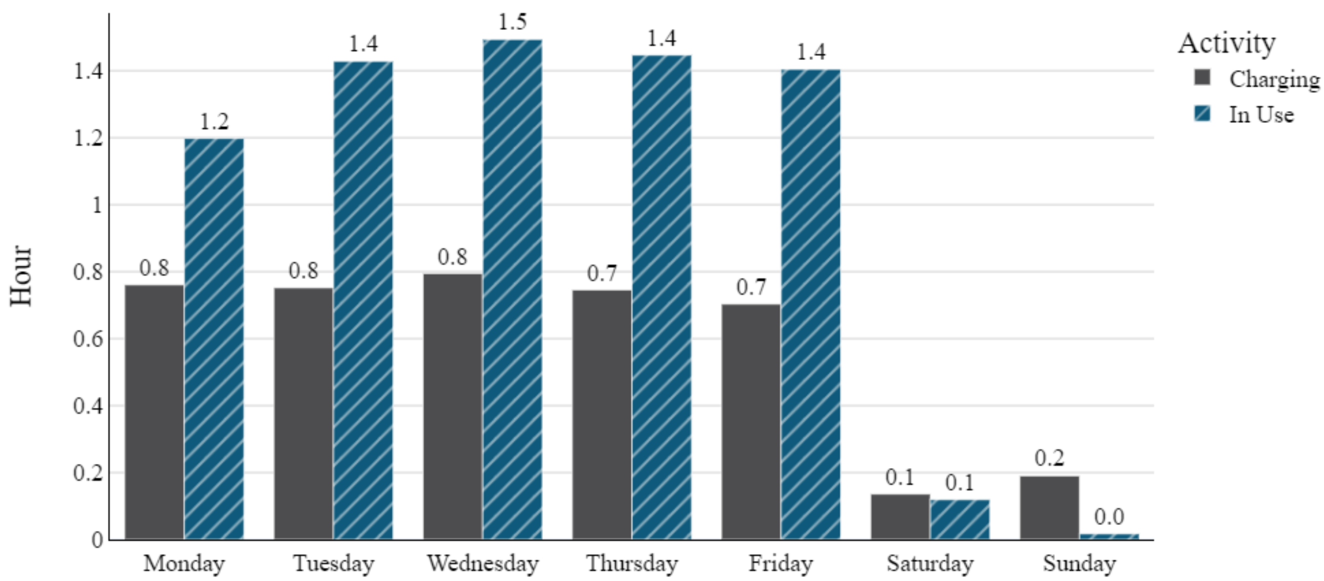
NFI had two work shifts: 6 a.m. to 2 p.m. and 2 p.m. to 10 p.m. Each shift had two 15-minute breaks and one 30-minute meal break. The electric forklifts were used to pick product off the rack, while other forklifts were used to load and unload trailers. The electric forklifts have interchangeable clamps for picking up different products; these clamps were inconvenient to swap regularly. Therefore, electric forklifts were used only during the first shift and not for most hours of the day. NFI reported that it planned to move the electric forklifts to a different facility after this project for better utilization. Table 65 describes the average charging and in-use time for the electric forklifts.

Table 65: NFI Electric Forklift Weekday Charging and Discharging Times

Timeframe	Average Charging Time	Average Time In Use
Each Weekday (hours)	0.75	1.4
Monthly (hours)	16	27

The forklifts were operated for about 1.5 hours daily on weekdays and did not operate on weekends. The forklifts charged for about 50 minutes per day on weekdays and 10 minutes per day on weekends. Opportunity charging could easily fit into NFI's 15- and 30-minute breaks, but the duty cycle did not require additional charging throughout the day. Not all eight forklifts were used every day; three were used more heavily than the others (see Energy Consumption on the following page). Figure 36 shows the time spent charging and in use for the electric forklifts.

Figure 36: NFI Electric Forklift Average Hours Spent Charging and In Use



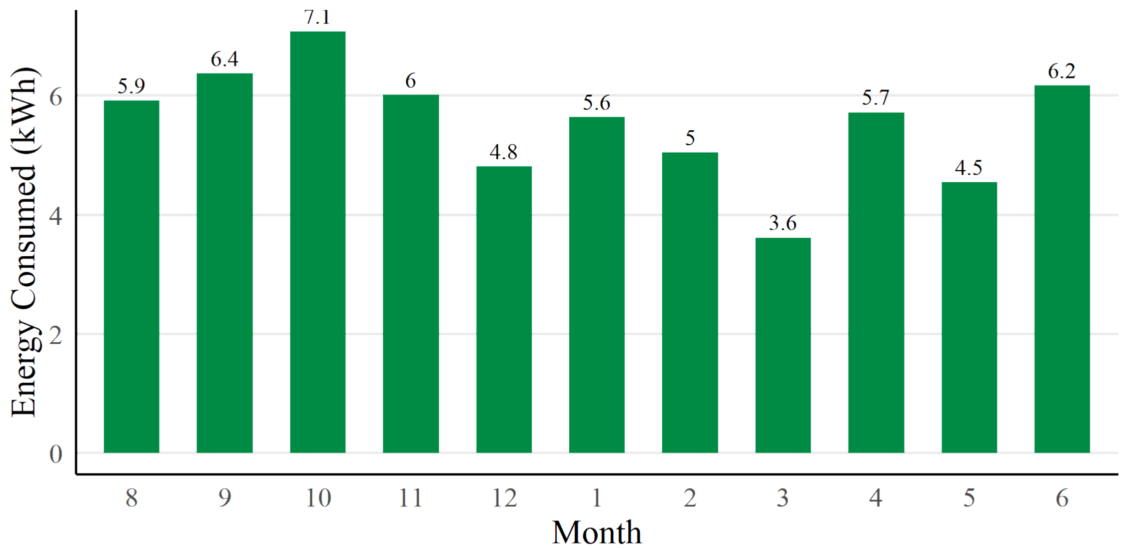
Energy Consumption

Table 66: NFI Electric Forklift Average Daily and Monthly Energy Charged and Discharged

Timeframe	Average Energy Charged	Average Energy Consumed
Daily (kWh)	7	6
Monthly (kWh)	135	111

NFI's electric forklifts charged about 7 kWh from the grid daily and used 5 to 6 kWh (Table 66). A forklift charged 135 kWh and used 111 kWh on average per month, though operation times for each of the eight forklifts varied significantly. Energy charged or discharged was tracked for each forklift in each month. Forklifts L2, L3, and L5 were used most often. Each used over 300 kWh per month in September 2020, October 2020, and April 2021; this was more than twice the average. From August 2020 to June 2021, each of those three forklifts used 1.5 MWh of energy. Forklifts L4 and L6 were used the least, with a total of about 0.7 MWh each in that time span. The inconsistent and low usage of NFI's electric forklifts contributed to plans to deploy them to more suitable uses in the future. Figure 37 shows average daily energy consumption for an individual forklift between August 2020 and June 2021.

Figure 37: NFI Electric Forklift Average Daily Energy Consumption per Month, August 2020 to June 2021



In general, the forklifts used the most energy in September and October 2020. This aligned with the holiday season rush. Starting in November, forklift operations slowed until early spring 2021. The spring uptick of energy consumption resulted from the fleet's anticipation for a rush of summer shipments. According to NFI, the workload typically increased for the holidays in early summer through late fall.

Each workday, a forklift consumed 20% to 40% SOC. Forklifts were usually charged immediately after work to 100% SOC. However, in a few cases, forklifts were used for two or three workdays without being charged, which let SOC drop to 10–20% and required recharging before returning to work. Every month or two, a forklift may have a record of SOC around 10% to 20% during work hours. Because of NFI's light duty cycle, opportunity charging and maintaining a high SOC were not prioritized for the electric forklifts; employees could easily switch to another forklift when SOC became low.

When the electric forklifts are transferred to more demanding duty cycles, it is recommended to plug them in when the second shift ends around 10 p.m. This strategy can avoid SOC dropping to 10–20%, which requires charging during work hours the next day. Keeping batteries from dropping below 20% SOC can also increase longevity. Charging during breaks is also recommended, with a priority on avoiding on-peak hours (4 p.m. to 9 p.m.).

Cost

NFI charged its electric forklifts on SCE's TOU-EV-8 rate plan. Because energy-charged data were recorded daily and not hourly, charging costs were estimated based on when forklifts usually charged as reported by the fleet. According to NFI, forklifts charged from 2 p.m. to 6 a.m. the following day and mainly between the off-peak hours of 10 p.m. to 12 a.m. Based on this information, the average charging rate was calculated to be $0.167778 per kWh in winter and $0.15808 per kWh in summer. Table 67 compares electric and propane forklift fueling costs.

Table 67: NFI Electric and Propane Forklift Operating Cost Comparison

Operating Cost Metric	Electric	Propane
Time in Operation (hours)	319	319
Annual Fuel Cost ($)	242	341
Annual Fuel Cost with LCFS	-82	341
Cost per Hour ($/hour)	0.76	1.07
Cost per Hour with LCFS ($/hour)	-0.26	1.07
Estimated Time in Service (years)	8	8

The electric forklifts operated an average of 319 hours per year. To compare the fueling costs of the two forklift types, propane forklifts were assumed to operate 319 hours per year as well. Annually, fueling the electric and propane forklifts cost about $240 and $340, respectively. Notably, with LCFS credits included at $0.20 per kWh, electric forklifts used about $80 per year less than the credit coverage for charging. NFI planned to keep both electric and propane forklifts in service for eight years. The tables below show the inputs used to calculate TCO of NFI's propane and lithium-ion electric forklifts for 319 hours in service per year.

Table 68: NFI Propane and Electric Forklift TCO Parameters - Capital Cost ($)

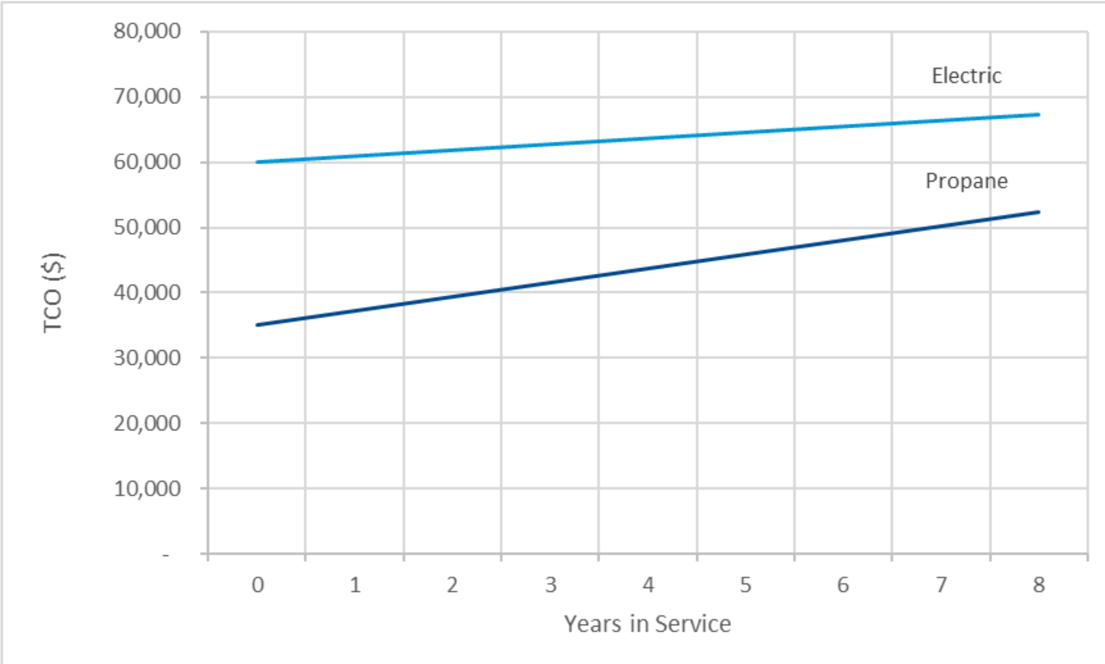
TCO Parameter	Propane	Electric
Total Purchase Price	35,000	60,000
Charging Infrastructure	-	(included)
Total Capital Cost	35,000	60,000

Table 69: NFI Forklift Propane and Electric TCO Parameters - Operating Costs ($)

TCO Parameter	Propane	Electric
Insurance (0%)	-	-
Annual Fueling Cost per Forklift	341	242
LCFS	-	-324
Annual Maintenance Cost	1,829	917
Total Annual Operating Cost	2,170	835

According to NFI, its Kalmar electric forklifts cost $60,000 per forklift, including the price of a charger. Its propane forklifts cost $35,000, which is higher and likely newer than DHE's $23,000 propane forklifts. NFI provided average propane fueling and maintenance costs per hour in use; these were used to estimate TCO for the propane forklifts. Figure 38 shows the TCO results for NFI's propane and electric forklifts.

Figure 38: NFI Propane and Electric Forklift TCO



As Figure 38 shows, NFI's electric forklifts were not expected to achieve cost parity, saving about $200 per year due to low hours in service. As a reminder, DHE's electric forklifts cost $20,000 less than their propane counterparts by Year 8 at 2,000 hours in service per year. If NFI's forklifts were used at 2,000 hours in service annually, they could reach cost parity by Year 7 and save more than $3,500 in Year 8. This demonstrates that electric forklifts should be operated as many hours as possible to recoup upfront costs quicker. In addition to operating few hours per year, NFI's propane forklifts were also newer and cost about half as much in maintenance costs as DHE's propane costs. Electric forklifts show a great return on investment when operated for many hours and when compared with older baseline forklifts.

Emissions Offset

Emissions offsets were estimated based on tailpipe emissions. Tailpipe emissions of baseline propane forklifts were measured through PEMS testing by UCR (see ZEV Assessment under Section 1. Project Overview). The tables below present the hourly, annual, and lifetime emissions produced by NFI's propane forklifts assuming 319 hours in use per year and an eight-year lifetime.

Table 70: NFI Propane Forklift Hourly Tailpipe Emissions per Hour

Tailpipe Emission	Grams per Hour
CO2	7.575
NOx	17
PM	0.04

Table 71: NFI Propane Forklift Annual Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	2.416
NOx	5.47
PM	0.013

Table 72: NFI Propane Forklift Eight-Year Lifetime Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	19.332
NOx	44
PM	0.1

With zero tailpipe emissions, an electric forklift offset 7.6 kg of CO2, 17 g of NOx, and 0.04 g of PM hourly; it offset 19,332 kg of CO2, 44 kg of NOx, and 100 g of PM over its lifetime. The eight forklifts deployed through the project could offset 154 metric tons of CO2, 350 kg of NOx and 0.8 kg of PM over their lifetimes. The 154 metric tons of CO2 offset are equivalent to:

- 6,573 trash bags of waste;
- 388,646 miles traveled in an average passenger vehicle;

- Annual energy use of 19 homes; or
- 2,552 tree seedlings sequestering carbon for 10 years.[16]

Yard Tractor

Yard Tractor Introduction and Deployment Process

NFI adopted nine Kalmar Ottawa T2E electric yard tractors in 2020 (two of which were part of the Volvo LIGHTS Project) to replace its diesel Kalmar Ottawa yard tractors (Figure 39). The electric yard tractors were compared with four diesel yard tractors in terms of performance, cost, and emissions. Table 73 summarizes the specifications for NFI's electric and diesel yard tractors.

Table 73: NFI Electric and Diesel Yard Tractor Specifications

Specification	Electric	Baseline
Fuel Type	Lithium-ion Electric	Diesel
Model Year	2020	2013
Manufacturer	Kalmar Ottawa	Ottawa
Model Name	T2E	Ottawa 4x2 DOT/EPA w/ABS
Battery Capacity (kWh)	176	-

The electric yard tractors served all eight of NFI's Chino Campus buildings. To charge the tractors, NFI added four Transpower 10-kW chargers to an existing charging infrastructure at different facilities. The chargers were delivered in May 2020 and energized in September 2020. The Volvo LIGHTS trucks were delivered in October 2020. Performance data was collected through ViriCiti between December 1, 2020, and August 31, 2021.

[16] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

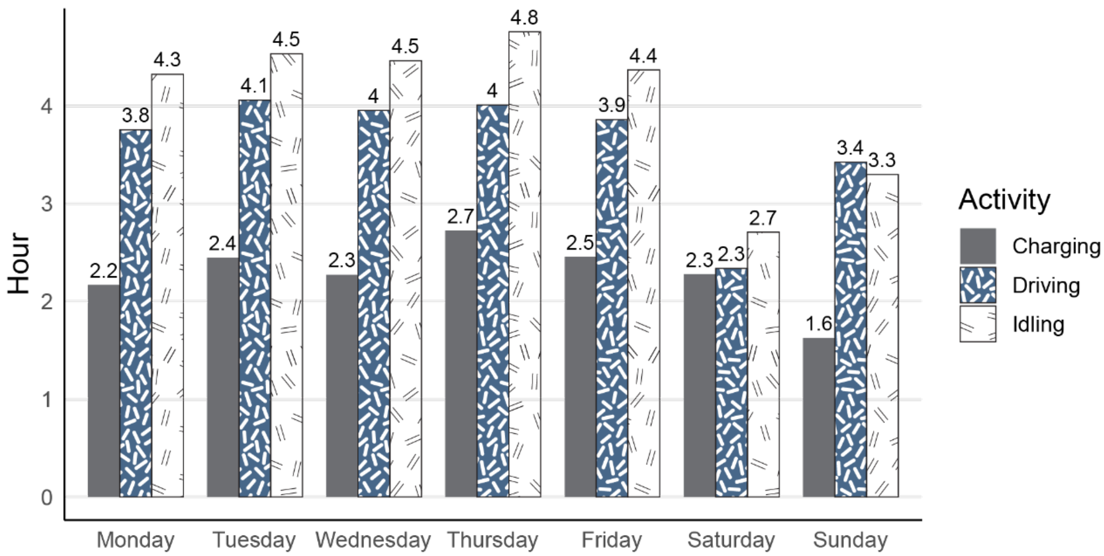
Figure 39: Kalmar Ottawa Yard Tractor at NFI

Duty Cycle and Performance

NFI yard tractors worked 24 hours a day, seven days a week. Three separate shifts were staffed: 4:30 a.m. to 1 p.m., 12:30 p.m. to 9 p.m., and 8:30 p.m. to 5 a.m. The vehicles served customers working 24 hours a day, seven days a week, as well as those not operating on weekends. In this way, the yard tractors were ready for job demands at all times but may not always operate three shifts a day. For example, a yard tractor might operate three shifts at one facility for a week, then get transferred to another facility for one or two shifts daily for another week.

Both electric and diesel yard tractors traveled 30 miles a day on average, slightly higher than 30 on weekdays, and closer to 20 on weekends. Yard tractors were used to shuttle freight among customers in eight facilities, moving pre-loaded trailers between or within facilities, sending trailers to the door for truck tractors to pick up, and picking up trailers returned by truck tractors back to the facilities. Their duty cycles were equivalent to the daily usage of the diesel yard tractors that remained in service at NFI during this project. Figure 40 shows average time spent charging, driving, and idling for each day of the week.

Figure 40: NFI Electric Yard Tractor Average Daily Time Spent Charging, Driving, and Idling



Yard tractors spent about 2.5 hours charging, 4.3 hours idling, and 3.7 hours driving per day. Charging occurred during shift turnovers. The trucks idled and drove for nearly equal amounts of time, which may seem like a high ratio. But based on conversations with the fleet managers and operators, drivers might wait between jobs, which would contribute to idling time. The yard tractors' main tasks were to move pre-loaded trailers. Drivers were not involved in the trailer loading process, so idling should not occur. In addition, drivers were not assigned to particular yard tractors and might switch between vehicles throughout the day. Drivers were instructed to turn off yard tractors when not in a vehicle, therefore switching yard tractors should not contribute to idling time.

At NFI, idling that lasts less than five minutes is classified as a short idle, such as when drivers stop at a red light. Idling for more than five minutes is a long idle and could mean, for example, that the driver was taking a break with the vehicle on. To manage long idling, NFI's diesel yard tractors were programmed with an electric auxiliary power unit that automatically shut off after five minutes of idling. The electric yard tractor's silent operation may have made it less obvious when a vehicle was on and idling during breaks. More driver instruction might prevent long idles and improve operational efficiency by ensuring vehicles are fully keyed off at breaks. Alternatively, a similar solution to the diesel units could be explored so that the electric yard tractors would automatically shut off after a set period of idling.

Energy Consumption

In an average day, NFI's electric yard tractors charged 80 kWh, consumed 57 kWh driving, and consumed 18 kWh idling. Assuming a charging efficiency of 90%, 89 kWh were drawn from the grid for charging. About 5% of driving energy was recovered via regenerative braking based on energy regenerated as logged in the data portal. Table 74 describes average energy charged and consumed by the yard tractors daily and monthly.

Table 74: NFI Electric Yard Tractor Average Energy Charged, Driven, and Idled

Timeframe	Average Energy Charged	Average Energy Driven	Average Energy Idled
Daily (kWh)	89	57	18
Monthly (kWh)	1,649	1,129	363

The electric yard tractor efficiency was 2.48 kWh per mile overall and 1.88 kWh per mile for driving only. Idling accounted for 50% of the total hours in use and 24% of energy consumption, a significant draw of energy. Although some idling was unavoidable in this duty cycle, reducing idling consumption could improve the yard tractor's overall efficiency and thus lower operational costs.

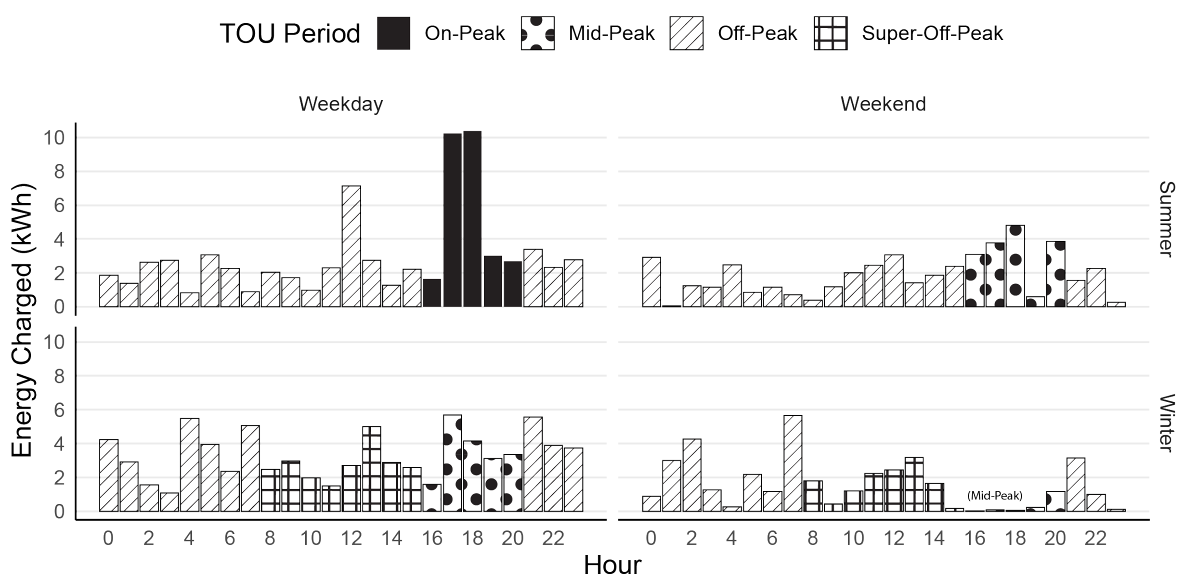
The yard tractors consumed an average of 43% SOC daily. Due to NFI's round-the-clock work schedule, average SOC at the beginning of a day was close to the average at day's end (about 80%) with a minimum between 20% and 30%. On 11 days, SOC dropped to 20%. Among the days with low SOC, several yard tractors had few hours in operation and little energy consumed. This indicates that low SOC often reflected missed charging events rather than increased usage. Table 75 presents data on fuel efficiency and daily SOC use for the yard tractors.

Table 75: NFI Electric Yard Tractor Fuel Efficiency and Daily SOC Usage

SOC Metric	Drive and Idle	Drive
Fuel Efficiency (kWh per mile)	2.48	1.88
Daily SOC Used	43%	32%

While charging time was evenly distributed over the course of a day, local peaks of energy charged were observed during on-peak hours. Energy consumption peaked at noon and 5 p.m. to 7 p.m. in the summer, especially on weekdays. In winter, yard tractors consumed energy evenly throughout the day. Additional local and minor peaks occurred around 4 a.m., 7 a.m., and 9 p.m.; in the summer, high demand was shaved during on-peak hours. A closer look at energy charged every hour in a day by month found high energy consumption during peak hours only after May 2021. Prior to that, yard tractors drew energy evenly throughout the day, similar to usage in the winter, as shown in Figure 41. High consumption between 8 a.m. and 4 p.m. would not impact utility costs, but between 4 p.m. and 9 p.m. would significantly increase costs. With this data, NFI introduced a new charging strategy, which impacted charging costs.

Figure 41: NFI Electric Yard Tractor Average Energy Charged Each Hour, Summer and Winter



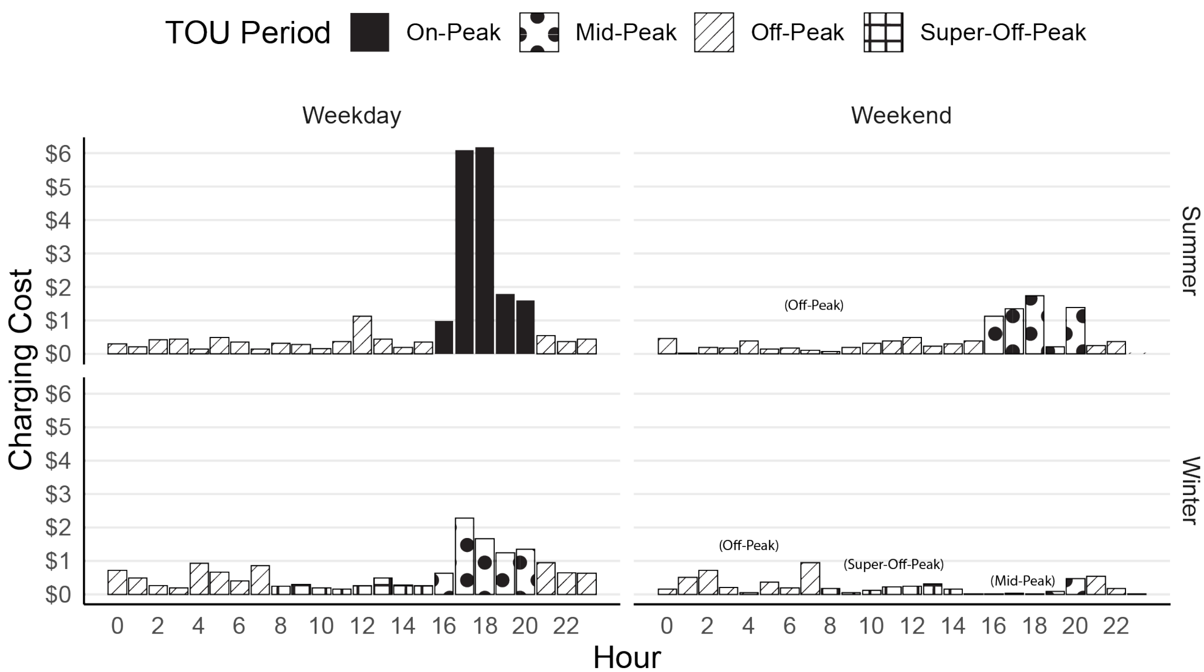
Cost

NFI's electric yard tractor could increase efficiency by 0.6 kWh per mile by excluding idling in its duty cycle. Although it is not practical for yard tractors to avoid idling, NFI's yard tractors can still reduce energy consumption and operational costs from any improvement in efficiency. Using an average utility rate—improving efficiency by 0.3 kWh per mile and avoiding half of the idling—NFI would save $0.089 per mile for each yard tractor. With 600 miles driven monthly on average, NFI could save $640 for each yard tractor per year. If 75% of idling were avoided, annual savings could reach $960 per yard tractor. Therefore, managing idling of yard tractors can benefit the operational costs for fleets.

NFI changed the times for charging yard tractors in May 2021, which impacted the charging cost. Between December 2020 and April 2021, energy was drawn evenly across 24 hours a day. But between May 2021 and August 2021, most energy was charged during on-peak hours or at noon. Each yard tractor charged a similar amount of energy in April and May—153 kWh charged for April and $163 kWh for May. However, April rates were $0.167 per kWh and May rates were $0.217 per kWh, a 30% increase due to different charging strategies.

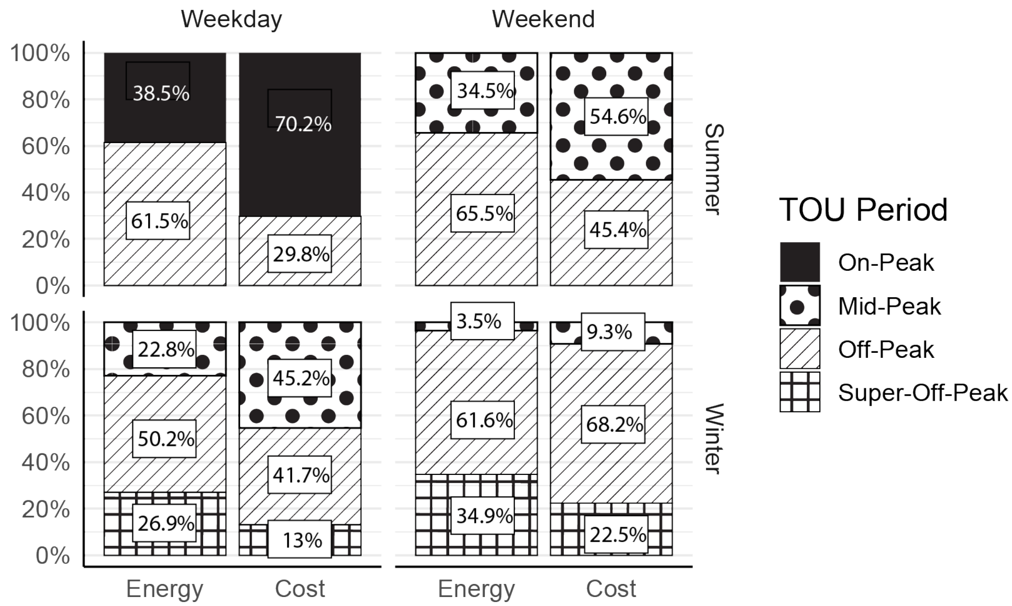
The difference in hourly average costs by season from charging in on-peak and off-peak hours was noticeable. The highest energy consumption took place between 5 p.m. and 7 p.m. in summer on weekdays. Charging cost exceeded $6 per hour per yard tractor, nearly triple the next highest cost per hour. Energy consumption between 4 p.m. and 9 p.m. was less expensive on weekends. In winter, charging costs during super-off-peak hours (8 a.m. to 3 p.m.) barely exceeded $0.50 per hour, making it an ideal time to charge standby electric trucks. If energy charging was evenly distributed throughout the day, NFI could potentially save $5.5 daily per yard tractor on weekdays, or about 23% of daily utility costs. Figure 42 compares charging costs for each hour of the day and each TOU period.

Figure 42: NFI Electric Yard Tractor Average Hourly Charging Cost



Overall, about 45% of yard tractor charging costs were generated during the five-hour window of on-peak or mid-peak charging (4 p.m. to 9 p.m.). During summer weekdays, on-peak charging incurred up to 70% of total utility costs despite consuming only 40% of the energy charged. Significant cost savings could be made by shifting away from on-peak charging. Figure 43 compares energy consumption and costs incurred over each TOU period.

Figure 43: NFI Electric Yard Tractor Proportion of Energy Charged and Utility Cost by TOU Peak Type



According to conversations with NFI, shifting the yard tractors' charging times was not prioritized due to the shift schedule and business needs. The fleet's top priority was keeping vehicles in service; with NFI's 24/7 shift schedule, yard tractors had to take advantage of all opportunity charges, even during on-peak hours. The fleet manager suggested that with more flexibility—more electric yard tractors or larger battery capacities—NFI could try adjusting charging times, but keeping the vehicle charged and in service would always be the top priority.

An alternative solution in the long term would be to deploy solar panels and ESSs to mitigate costs associated with charging during on-peak hours. NFI was deploying solar panels, but the project could not collect data and quantify their impact during the project's timeline. Nearly 60% of utility costs were generated from energy charged between 6 a.m. and 7 p.m., when solar panels would generate electricity. NFI can expect significant charging cost savings once it fully integrates solar into vehicle charging.

This analysis considered a yard tractor duty cycle of 3,000 hours per year, close to what was observed. Fueling costs for the electric yard tractors were calculated based on SCE's TOU-EV-8 and totaled about $7,400 per year, compared with $11,500 for the diesel yard tractors. With LCFS credits included, an electric yard tractor would save NFI about $10,400 per year on fueling. NFI planned to keep its diesel yard tractors in service for five years and the electric yard tractors in service for eight years. Table 76 compares the cost of operating diesel and electric yard tractors.

Table 76: NFI Diesel and Electric Yard Tractor Operating Costs Comparison

Cost Parameter	Diesel	Electric
Annual Time in Operation (hours)	3,000	3,000
Estimated Time in Service (years)	5	8
Annual Fuel Cost	$11,571	$7,426
Annual Fuel Cost with LCFS	$11,571	$1,204
Cost per Hour	$3.86	$2.48
Cost per Hour with LCFS	$3.86	$0.40

Other factors beyond fueling costs were analyzed to estimate TCO values for the different yard tractors. The capital costs were estimated at $120,000 for diesel and $300,000 for electric, plus $20,000 to install a 75-kW charger. Funding from CORE can cover the cost of charging infrastructure, so this amount was excluded under scenarios using CORE funding. NFI provided maintenance costs for both the diesel and electric yard tractors. The tables below list the cost inputs used in the TCO.

Table 77: NFI Diesel and Electric Yard Tractor TCO Parameters - Capital Cost ($)

TCO Parameter	Diesel	Electric (176 kWh)
Total Purchase Price	120,000	300,000
Charging Infrastructure	-	20,000
CORE	-	-143,600
Total Capital Cost	120,000	320,000
Total Capital Cost with CORE	120,000	143,600

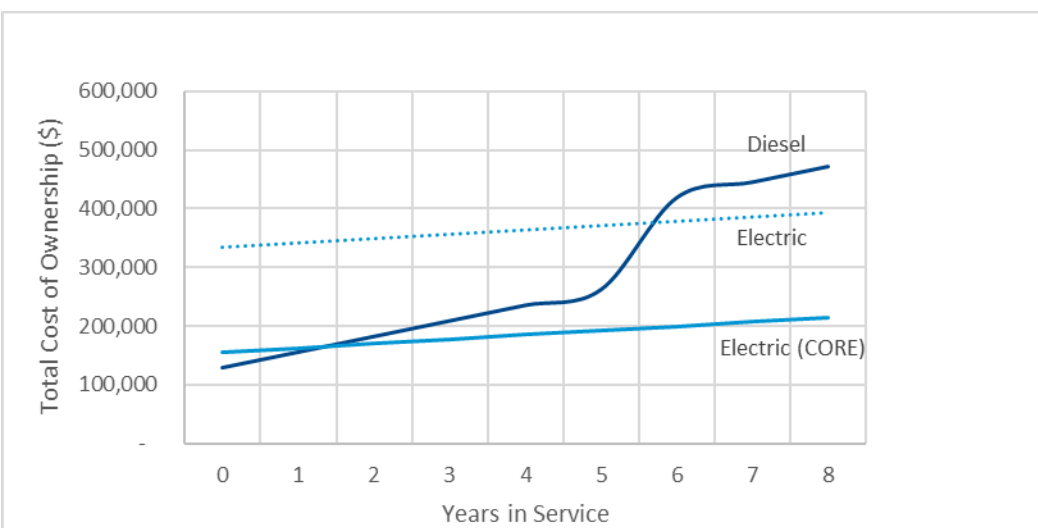
Table 78: NFI Diesel and Electric Yard Tractor TCO Parameters - Operating Costs ($)

TCO Parameter	Diesel	Electric (176 kWh)
Annual Fueling Cost	11,571	7,426
LCFS	-	-3,958
Annual Maintenance Cost	14,910	3,208
Total Annual Operating Cost	30,561	18,676

Electric yard tractors achieved cost parity both with and without CORE funding. NFI plans to keep its diesel yard tractors in service for five years and the electric yard tractors in service for eight years. Figure 44 accounts for this by adding the cost of a second diesel yard tractor in Year 6. With CORE, the electric yard tractor achieves cost parity before Year 2 and would save NFI over $210,000 by the end of Year 8. Thus, a yard tractor with CORE funding would save the fleet more than the cost of buying one diesel yard tractor.

Even without CORE funding, the electric yard tractor would be expected to achieve cost parity by Year 7. The fleet is expected to save about $10,000 per year on fueling and $11,000 per year on maintenance. Figure 41 examines yard tractor TCO with and without CORE funding over the life of the vehicle.

Figure 44: NFI Diesel and Electric Yard Tractor TCO, With and Without CORE Funding



Like DHE, NFI assumed yard tractors were most suited for electrification due to duty cycle. NFI had four diesel yard tractors in addition to 27 electric yard tractors in California overall. Two electric yard tractors were deployed through Volvo LIGHTS and the other 25 received HVIP or CORE funding. NFI planned to continue investing in electric yard tractors and become fully electric in California over the next two to three years. The transition timeline would depend on the incentives available. With incentives like LCFS and CORE for both vehicles and infrastructure, NFI estimated an ROI at 24 months or less. Even without incentives, this analysis showed that electric yard tractors could be economically beneficial within their expected lifetimes.

Emissions Offset

Emissions offsets were estimated based on tailpipe emissions. Tailpipe emissions of baseline propane forklifts were measured through PEMS testing by UCR (see ZEV Assessment under Section I. Project Overview). The tables below present the hourly, annual, and lifetime emissions produced by NFI's propane forklifts assuming 3,000 hours in use per year and an eight-year lifetime.

Table 79: NFI Diesel Yard Tractor Hourly Tailpipe Emissions per Hour

Tailpipe Emission	Grams per Hour
CO2	7,220
NOx	20.99
PM	0.07

Table 80: NFI Diesel Yard Tractor Annual Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	21,661
NOx	63
PM	0.21

Table 81: NFI Diesel Yard Tractor Eight-Year Lifetime Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	173,291
NOx	504
PM	1.68

With zero tailpipe emissions, an electric yard tractor will offset 173 metric tons of CO2, 504 kg of NOx, and 1.7 kg of PM in its lifetime. Both yard tractors deployed through this project together will offset 346 metric tons of CO2, 1 metric ton of NOx, and 3.36 kg of PM over their lifetime. The total amount of CO2 offset is equivalent to:

- 14,730 trash bags of waste;
- 870,960 miles traveled in an average passenger vehicle;
- Annual energy use of 42 homes; or
- 5,719 tree seedlings sequestering carbon for 10 years.[17]

Class 8 Tractor

Class 8 Tractor Introduction and Deployment Process

NFI deployed one Class 8 Volvo truck-tractor in early 2021 (Figure 45). Geotab loggers collected more than 120 days of data on this truck and a comparable baseline vehicle. The CE–CERT team conducted additional in-depth analysis on the electric Class 7 box truck and Class 8 tractors—both the vehicles operating at DHE and NFI as well as other Volvo electric trucks in operation—in their "Volvo LIGHTS Emissions and Activity Results" report expected to be released to the public in 2022. For additional insights on performance, duty cycle, and charging, refer to that report. Table 82 describes the specifications for NFI's electric and diesel Class 8 tractors.

[17] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table 82: NFI Electric and Diesel Class 8 Tractor Specifications

Specifications	Electric	Baseline
Fuel Type	Lithium-ion Electric	Diesel
Model Year	2021	2014-2019
Manufacturer	Volvo	Detroit
Model Name	VNR Class 8 Tractor	-
GVWR (lbs.)	82,000	80,000
Battery Capacity (kWh)	264	-

Figure 45: Class 8 Volvo Truck-Tractor

The vehicle charged on a 150-kW ABB charger and operated on NFI's drayage routes. Diesel trucks on these routes drove 40,000 to 50,000 miles per year; the electric tractor averaged slightly less than 20,000 miles per year. Like the tractors operated by DHE, range limitations and charging times were the key reasons for fewer miles traveled. Still, user satisfaction was positive, and NFI believed that with strategic routes and charging, more electric tractors can be integrated into NFI's operations.

Duty Cycle and Performance

The tractors were used on drayage routes to deliver freight to and from the San Pedro Bay Ports. NFI's diesel tractors generally operate two shifts per day, but the electric tractors were limited to one shift per day to allow time for charging. As of the writing of this report, NFI plans to soon begin operating new Gen 2 electric tractors for two shifts per day. NFI operates their tractors six or seven days per week.

In April, May, and June, the tractors operated nearly every day. The fleet did not experience any major issues or downtime with the Class 8 tractors, and drivers reported positive experiences operating the new trucks. NFI operated its electric tractor about 100 miles per day, with a maximum of 202 miles in a single day. This amounted to about 1,400 miles per month or nearly 18,000 miles per year. NFI's diesel tractors operating regional routes (NFI's shortest routes), driving 40,000 to 50,000 miles per year. While the electric tractors performed well on their routes, range limitations and charging time resulted in half as many miles traveled as diesel. Longer ranges or quicker charging would be necessary to integrate into NFI's regional routes without changing operational patterns. Table 83 lists the daily and monthly distance driven and key on time.

Table 83: NFI Electric Class 8 Tractor Daily and Monthly Distance Driven and Key on Time

Timeframe	Average Distance Driven (mi)	Average Key on Time (hours)
Daily	108	4.9
Monthly	1,369	62

Energy Consumption

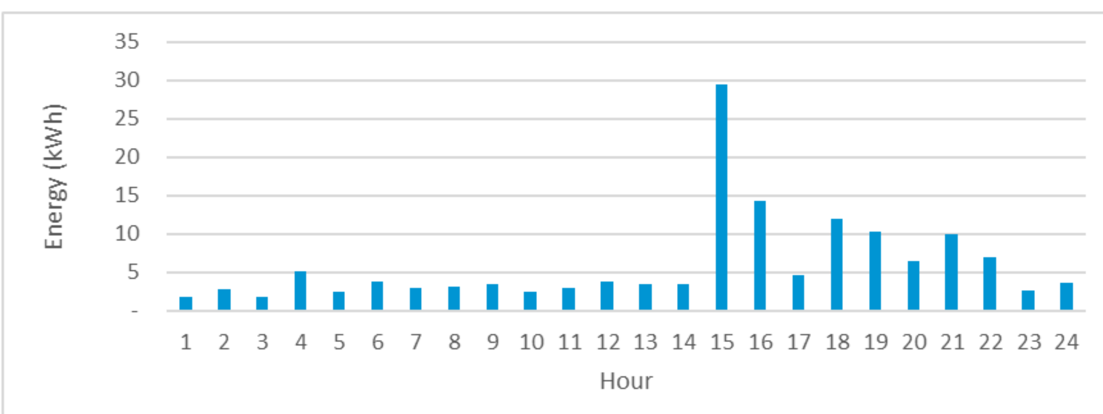
The tractor was charged about 144 kWh per day for a monthly average of 4,386 kWh. The tractor started routes with SOC around 85% and ended around 47%, for a daily discharge of 38%. The minimum SOC recorded was 14%. The energy efficiency of the tractor was calculated to be 2.16 kWh per mile, close to the 2.21 kWh per mile value calculated for DHE's electric Class 8 tractors. Table 84 summarizes the energy consumed, SOC, and energy efficiency metrics.

Table 84: NFI Electric Class 8 Tractor Key Energy Parameters

Energy Parameter	Measured Result
Daily Energy Charged (kWh)	145
Monthly Energy Charged (kWh)	4,386
Avg. Start SOC (%)	85
Avg. End SOC (%)	47
Energy Efficiency (kWh/mile)	2.16

The tractor usually operated a morning shift and returned around 3 p.m. to begin charging (Figure 46). As a result, the maximum average energy draw occurred around 3 p.m. to 4 p.m. and decreased over the evening. The tractor was on SCE's TOU-EV-8 rate plan, which had the highest charging rates between 4 p.m. to 9 p.m. Waiting until 9 p.m. to plug in the tractor would have avoided these high charging fees. NFI's evening staff could begin plugging in the tractor, or smart charging could be utilized to automatically begin charging at 9 p.m. Filling the battery should take less than two hours, so delaying charging would not likely impact operating schedules. Alternatively, the charge rate could be capped for this high-cost period, allowing limited energy transfer that could increase after 9 p.m.

Figure 46: NFI Electric Class 8 Tractor Average Daily Energy Charged



Cost

Charging data was only reliable in October and November where the overlap between charger data and vehicle data was reasonable. To extrapolate annual costs, the average energy charged during each hour of the day for those two months was applied to the tractor's rate plan. Over a year, the tractor was estimated to consume 52,633 kWh of energy for a total cost of $12,950. Only summer months experience on-peak charging rates (4 p.m. to 9 p.m. on weekdays). Table 85 shows energy consumption and cost values.

Table 85: NFI Electric Class 8 Tractor Energy Consumption and Charging Costs on SCE's TOU-EV-8

Rate	Summer (kWh)	Winter (kWh)	Summer ($)	Winter ($)
On-peak	5,564	-	3,312	-
Mid-peak	241	11,611	87	4,650
Off-peak	11,739	10,730	1,856	1,800
Super-off-peak	-	12,748	-	1,246
Total	17,544	35,089	5,254	7,696

During the summer, on-peak charging accounts for twice as much of the total cost compared with the proportion of energy charged. If charging were shifted from 4 p.m. to 9 p.m. on weeknights, NFI could see significant cost savings. Similarly, a disproportionate amount of energy in winter came from mid-peak charging, which also occurred from 4 p.m. to 9 p.m., so shifting the charging schedule would lead to savings year-round. Avoiding on-peak charging completely could save the fleet an estimated $6,000, nearly 50% of their annual charging costs. Figure 47 and Table 86 helps display the difference between the percent energy consumption and costs that occurred during each of the four TOU periods.

Figure 47: NFI Electric Class 8 Tractor Percent of Energy Charged and Costs Accumulated during TOU Periods

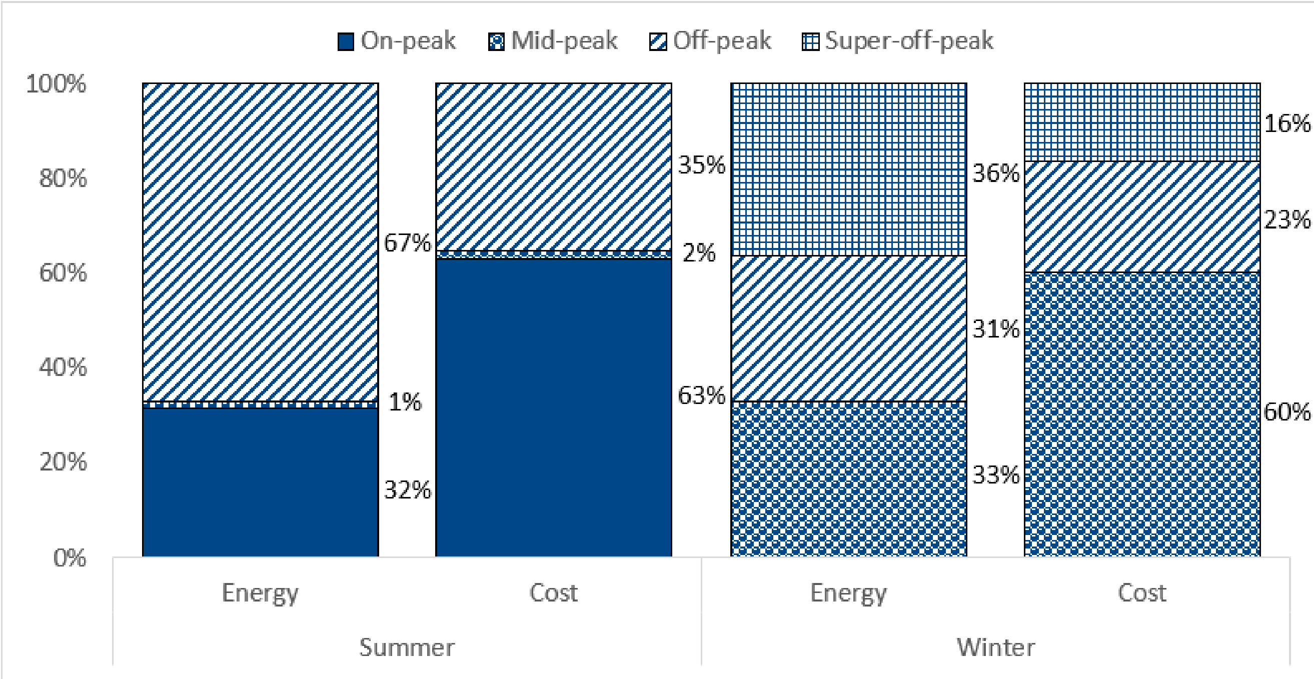


Table 86: NFI Electric Class 8 Tractor Data for Energy Charged and Costs Accumulated

TOU Rate	Summer Energy	Summer Cost	Winter Energy	Winter Cost
On-peak	32%	63%	-	-
Mid-peak	1%	2%	33%	60%
Off-peak	67%	35%	31%	23%
Super-off-peak	-	-	36%	16%

In addition to eliminating charging from 4 p.m. to 9 p.m., minimizing charging costs means avoiding demand charges. SCE temporarily paused all demand charges but plans to phase them back in beginning in 2024. Fleets would be advised to have a system in place to mitigate the huge energy draws that can occur with unrestricted charging. More than one truck charging at the same time multiplies this peak demand. To avoid multiple trucks charging at the same time, fleets can ensure trucks charge in sequence with smart charging or manually time plug-in events, or it could invest in energy storage to shave peak energy demand.

Energy and fuel costs were compared under project conditions without demand mitigation techniques. Before LCFS, charging and fueling costs were very similar: $0.64 to $0.69 per mile. With LCFS, charging costs were about a fifth the cost of diesel, equivalent to $0.16 per mile. As noted, avoiding charging between 4 p.m. and 9 p.m. could significantly reduce the annual and per mile cost of charging. NFI kept its diesel tractors in service for five years and planned to keep the electric tractor in service for eight years. Table 87 compiles key cost parameters of NFI's Class 8 tractor and an equivalent baseline driving the same annual mileage.

Table 87: NFI Class 8 Diesel and Electric Tractor Operating Cost Comparison

Operating Cost Metric	Diesel	Electric
Annual Distance Driven (miles)	20,000	20,000
Annual Fuel Cost ($)	12,857	13,827
Annual Fuel Cost with LCFS ($)	12,857	3,300
Cost per Mile ($/mile)	0.64	0.69
Cost per Hour with LCFS ($/mile)	0.64	0.16
Estimated Years in Service	5	8

The tractors' estimated capital costs were $150,000 for diesel and $350,000 for electric. A $30,000 charger of 150 kW was also included in the costs for the electric Class 8 tractors. TCO was calculated with and without HVIP incentive funding ($120,000). Annual diesel fueling costs were calculated at $4.50 per gallon and 7 miles per gallon. The electric charging costs were estimated based on annual kWh charged and considered SCE's TOU-EV-8 rates, which will not include demand charges until 2024. LCFS credits were also incorporated into electric tractor charging at $0.20 per kWh charged. Maintenance costs were based on estimates from TEC, Volvo's maintenance facility. The technicians estimated Class 8 diesel tractor maintenance costs of $5,000 for the first year, increasing to $10,000 by the fifth year. In fact, during the three years TEC staff have been servicing electric tractors, they reported virtually no maintenance costs. This TCO analysis estimated $100 per year in maintenance costs, although more information is needed on electric tractor maintenance rates. Table 88 and Table 89 show the parameters used to calculate TCO for NFI's diesel and electric tractors.

Table 88: NFI Class 8 Diesel and Electric Tractor TCO Parameters - Capital Cost ($)

TCO Parameter	Diesel	Electric
Total Purchase Price	150,000	350,000
Charging Infrastructure	-	30,000
HVIP	-	-120,000
Total Capital Cost	150,000	380,000
Total Capital Cost (HVIP)	150,000	260,000

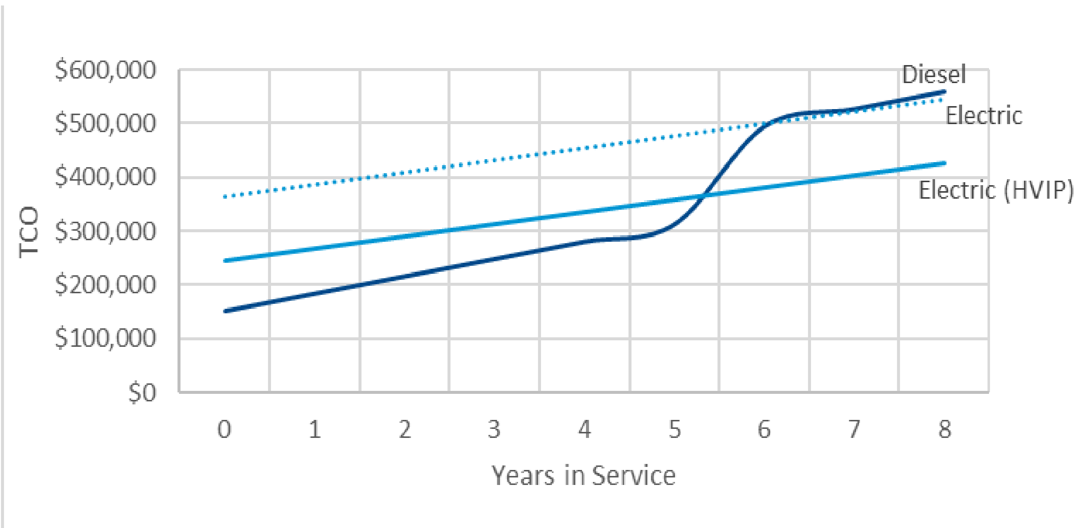
Table 89: NFI Class 8 Diesel and Electric Tractor TCO Parameters - Operating Costs ($)

TCO Parameter	Diesel	Electric
Insurance (5.5%)	8,250	19,250
Annual Fueling Cost per Tractor	12,857	13,827
LCFS	-	-10,527
Annual Maintenance Cost[18]	8,400	100
Total Annual Operating Cost	29,507	22,650

[18] Annual maintenance costs are estimated at $100 based on conversations with TEC maintenance staff. While electric trucks maintenance has proven to cost less, lifetime maintenance data is limited as very few electric trucks have been in service long enough to produce fully representative data.

Because diesel tractors are kept in service for five years, as compared to eight for electric tractors, the cost of a second diesel tractor is included in Year 6. An electric tractor with HVIP funding achieves cost parity by Year 6 and would save the fleet about $95,000 by the end of Year 8. Without HVIP funding, the electric tractor is still $25,000 more expensive than diesel after Year 8. Figure 48 displays the results of the TCO analysis.

Figure 48: NFI Diesel and Electric Class 8 Tractor TCO



As with other EVs, the higher cost of insurance for electric tractors was a key barrier to achieving cost parity. **Insurance cost $11,000 more per year for the electric tractor.** If insurance costs were the same for diesel and electric Class 8 tractors, cost parity would be achieved by Year 6 even without HVIP funding. Subsidies on insurance for EVs could drastically reduce TCO of electric tractors and help fleets see major fueling and maintenance cost savings.

Capital costs of electric tractors were the largest financial barrier. At 2.3 times as expensive as new diesel tractors, the annual insurance cost of 5.5% of the capital cost also meant that the high upfront cost was compounded every year. It should be noted that insurance rates can vary based on the insurance provider and some providers, like Volvo Financial Services, factor in other factors like a fleet's claim history, minimizing the impact of EVs compared to diesel. Upfront cost incentives will be necessary until electric tractor scaling can bring upfront costs down significantly.

Interestingly, the cost of fueling diesel and electric tractors was very similar without LCFS credits. LCFS credits played a major role in helping electric tractors achieve a lower TCO, and receiving LCFS credits should be a discussion point for fleets considering charging at public charging stations. While public charging along a tractor's route may be necessary, fleets likely would not receive LCFS credits from public chargers and should charge at fleet chargers as much as possible. Additionally, with SCE's TOU-EV-8 charging cost of $0.60 per kWh during on-peak hours, actively avoiding charging during these hours can reduce a fleet's charging costs.

Emissions Offset

Electric tractors have zero tailpipe emissions, thereby offsetting the amount that diesel tractors generated. An electric Class 8 tractor will offset 272,892 kg of CO_2, 773 kg of NO_x, and 0.16 kg of PM over its eight-year lifetime with 20,000 annual miles.

The amount of CO_2 emission offset is equivalent to:

- 11,598 trash bags of waste;
- 685,778 miles traveled in an average passenger vehicle;
- Annual energy use of 33 homes; or
- 4,503 tree seedlings sequestering carbon for 10 years.[19]

The tables below summarize the per mile, annual, and lifetime tailpipe emissions produced by diesel Class 8 tractors.

Table 90: NFI Diesel Class 8 Tractors Daily Tailpipe Emissions per Mile

Tailpipe Emission	Grams per Mile
CO2	1,706
NOx	5
PM	0.00

[19] Greenhouse Gas Equivalencies Calculator, EPA. March 2021. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table 91: NFI Diesel Class 8 Tractors Annual Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	34,111
NOx	97
PM	0.02

Table 92: NFI Diesel Class 8 Tractors Eight-Year Lifetime Tailpipe Emissions

Tailpipe Emission	Kilograms
CO2	272,892
NOx	773
PM	0.16

Solar

Solar Introduction and Deployment

NFI chose a 640-kW solar PV Hanwha system for its Chino, California, campus (Figure 49). The system was to be installed on the roof of the main facility and consist of 1,489 Hanwha modules (Table 93) early on in the project, but the need for a roof replacement caused a delay. The facility was under a long-term lease, so NFI worked with the landlord on logistics and costs of the replacement, delaying the process further. The roof replacement was not due for five years, but because the solar life expectancy was closer to 20 years, NFI paid for an earlier roof replacement and extended the lease. This NFI cost was not covered by Volvo LIGHTS. NFI currently owns the solar array but has extended the lease to account for any uncertainties in the event of relocation.

Figure 49: Solar Installation at NFI

The final contract for the roof and solar was finalized in March 2021, and the roof replacement was completed by June 2021. The solar installation began in September 2021. Malfunctioning parts caused installation delays of two to four weeks until the parts were replaced. With solar fully installed in November 2021, the goal was to energize by the end of the year. However, based on communication with SCE, the solar may not be energized until 10 to 12 months after December 2021 and unable to produce solar until the end of 2022. If this happens, it will be a major cost for NFI, which has already paid a significant amount for its portion of the solar and the roof replacement with no ROI in the near future. Battery storage was not part of NFI's scope, though NFI is interested in acquiring it in the future.

Table 93: NFI Solar System in Chino, California

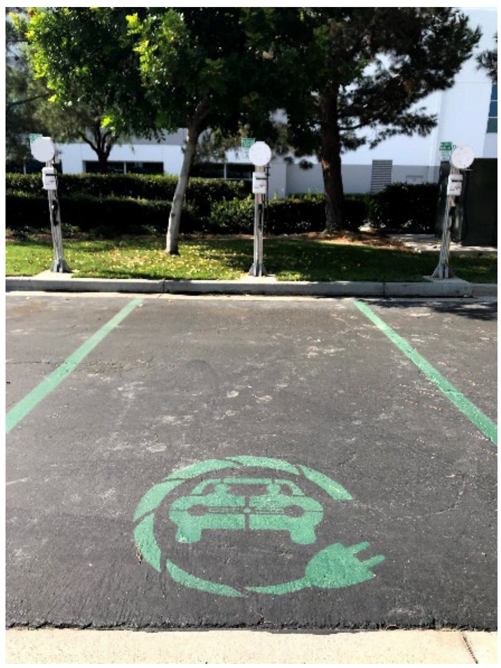
Installation	Solar
Provider	Baker Electric
Manufacturer	Hanwha
Power Rating (kW)	640.27 kW DC
Roof Install Date	July 2021
Solar Install Date	Dec 2021
Deployment Date	TBD

Workplace Charging

Workplace Charging Introduction and Deployment Process

NFI installed five EvoCharge Level 2 charging stations for employees and guests to power personal plug-in EVs (Figure 50). Four stations were 7.2-kW dual-port chargers, and one was a 7.6-kW single-port charger. Charging was provided to employees free of charge; guests paid a small fee charged by the app. Instructions on how to charge and how to set up user accounts through Greenlots were located on the charging stations.

Figure 50: Workplace Charging at NFI



CALSTART developed the workplace charging policy and submitted it to NFI for approval and distribution (see Appendix C). The policy had instructions on charging as well as an honor system time limit of four hours on using the charging space. Before being distributed, the policy went through a strict legal review lasting several months. There was further delay in establishing a helpline, which also extended the policy finalization period. The chargers were not fully utilized until about five months after the installation and energizing of the chargers.

Load Profile and Performance

NFI's workplace charging events primarily began during on-peak hours (Figure 51 and Table 94). Charging began throughout daytime off-peak hours and into the beginning of night shifts from 4 p.m. to 7 p.m.

Figure 51: NFI Workplace Charging Duty Cycle, March 25 to November 1, 2021

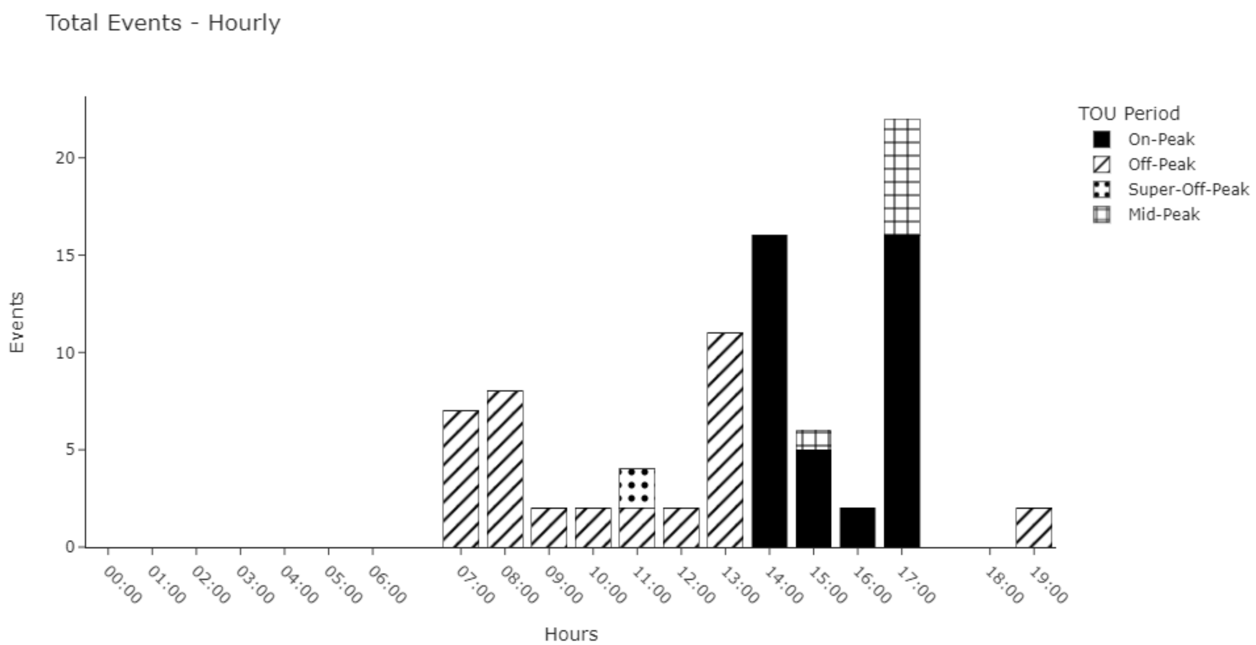


Table 94: Charging Events and Duration for NFI Workplace Charging, March 25 to November 1, 2021

	Charger 1	Charger 2	Charger 3	Charger 4	Charger 5	All Chargers
Charging Events	11	12	36	18	7	84
Average Event Duration (hour)	1.68	2.66	1.22	3.42	0.03	2.25
Max Event Duration (hour)	6.97	6.38	7.04	9.52	0.16	9.52

Based on Greenlots SKY data for charging-session duration, most charging events occurred during on-peak and off-peak TOU periods (Figure 51). Charging during on-peak periods incurs higher costs that could be mitigated by encouraging more off-peak charging. Data regarding each charging event's duration proved valuable in assessing trends for utility costs across TOU periods. However, analysis of Greenlots SKY energy consumption data was found to be unreliable. The recorded consumption on the

Greenlots SKY platform for each charging session was inconsistent with calculated rates of charge for the 7.2-kW and 7.6-kW charging stations and was therefore deemed unreliable.

V. Infrastructure

Forklifts

Table 95: Specifications for Forklift Charging Infrastructure at DHE and NFI

Forklift Infrastructure	DHE	NFI
Forklift OEM (Count)	Yale Chase (14)	Crown (8)
Charger OEM (Count)	Advanced Charging Technologies (8)	V-Force (8)
Charger Model Name	Q6-O36-Y2	V-HFM3
Forklift Battery Capacity (kWh)	26.9	27.5
Charger Power (kW)	11	14.7
Installation Timeline (Weeks)	6	8

DHE installed eight chargers for 14 forklifts, and NFI installed eight chargers for eight forklifts. DHE expressed that, in hindsight, opting for a 1:1 ratio for chargers to forklifts would have simplified their operations, and they will likely do so in the future when installing charging infrastructure. Both fleets' chargers could completely charge a forklift in about two hours, which was considered an acceptable amount of time. NFI's forklift duty cycle only required a few hours of operations per day, allowing ample time each day for forklifts to recharge and rarely needing to opportunity charge. DHE encouraged their operators to opportunity charge whenever possible. Both fleets' forklift SOC seldom dipped below 50%, indicating a balanced duty cycle, charging practice, and charger speed ratio.

Installing forklift charging infrastructure took about two months for both fleets. The fleet managers explained that because a source of electricity was already available from the facility, it was a quick process to install the chargers. One fleet required an electrician to come out and install a panel, while the other fleet was able to install the chargers without help from an electrician. The forklift chargers had some maintenance issues relating to the software compatibility of the chargers and forklifts, but these issues were quickly resolved soon after being energized.

The fleet managers offered several recommendations for other fleets. First, they emphasized that connecting forklifts to the facility's electricity saved significant money and time. If fleets do not already have 480-volt service running to the building in which chargers are housed, installing this service can cost upwards of $10,000. Second, they recommended thinking through the location of the forklift chargers and how operators will interact with them. One fleet manager explained they almost positioned the chargers in a relatively unused location that was far away from most operations; however, they realized that convenience was key for the utilization of opportunity charging and did not want operators to have to walk far before their break. The fleet manager advised installing chargers near "the break room, lunch room, clock in/clock out room, etc. The more convenient you can make it, the more likely operators will be to opportunity charge."[20]

Yard Tractors

Table 96: Specifications for Yard Tractor Charging Infrastructure at DHE and NFI

Yard Tractor Infrastructure	DHE	NFI
Yard Tractor OEM (Count)	Orange EV (2)	Kalmar Ottawa (2)
Charger OEM (Count)	Orange EV (2)	Transpower (4)
Charger Model Name	-	-
Yard Tractor Battery Capacity (kWh)	80 and 160	176
Charger Power (kW)	22	10
Installation Timeline (Days)	10	6 months

The fleets deployed yard tractors with battery capacities between 80–176 kWh, and chargers with charging rates of 10–22 kW. This means it could take over 10 hours to fully charge a depleted yard tractor battery. Still, both fleets expressed that the electric yard tractors were able to meet their required duty cycles, some even operating three shifts

[20] Participant in anonymous fleet feedback surveys and interviews. See Section VII. User Acceptance.

per day. Opportunity charging during each break in operations was crucial to keep the yard tractors running throughout the day. Like the forklifts, yard tractor SOC rarely dipped below 50%, meaning these low charging speeds were still able to keep the yard tractors charged due to effective charging practices.

Moving forward, DHE plans to purchase larger battery-capacity forklifts to allow for longer operations without having to charge. DHE found purchasing larger battery capacities more cost-effective than installing higher-powered chargers. The fleet also aims to charge at low speeds whenever possible to help preserve long-term battery health. With regard to maintenance, both fleets reported little to no maintenance needed on the yard tractor chargers.

The installation timeline for yard tractor chargers ranged from 10 days to six months. The main difference in timeline appears to be how long it took to get an electrician out to the sight and the level of construction. DHE did not have to trench, which saved a significant amount of time. If construction is involved, permits are required; permitting, constructing, and coordinating schedules can all extend the installation timeline. The fleet managers recommended looking at the facility's current power location(s). The further out that power must be moved from the site's current arrangement, the longer and more expensive construction is likely to be. HD equipment to bore underground will add additional costs. NFI reported that permitting and installation cost about $22,000. Closer proximity of chargers to power sources will lead to faster and simpler construction. However, this must be balanced with how users will interact with the chargers, as making opportunity charging convenient will improve operations in the future.

Box Truck and Class 8 Tractors

Table 97: Specifications for Box Truck and Class 8 Tractor Charging Infrastructure at DHE and NFI

Electric Truck Infrastructure	DHE	NFI
Electric Truck OEM (Count)	Volvo (4)	Volvo (2)
Charger OEM (Count)	ABB (2)	ABB (2)
Box Truck Battery Capacity (kWh)	264	-
Class 8 Tractor Battery Capacity (kWh)	264, 396	264
Charger Power (kW)	150	150
Installation Timeline (Months)	22	22

DHE and NFI both installed 150-kW chargers for their 264- and 396-kWh electric trucks. While the fleet managers were content with the slower charger speeds for forklifts, yard tractors, and box trucks—all of which did not require many hours of operation per day—they wanted to charge the electric tractors as quickly as possible. Because the off-road equipment never left the yard, they could opportunity charging as needed. However, the electric tractors could not opportunity charge while enroute. Therefore, leaving for each route with nearly a full charge was a necessity for the electric tractors.

In addition, the Class 8 diesel tractors often operated two shifts per day. Electric tractors were limited to one shift per day since they could not recharge quickly enough between the first and second shift to justify running a second shift in the evening. Moving forward, both fleets showed interest in installing faster chargers alongside future electric tractor deployments. Still, the goal was to have the capability to rapid charge the electric tractors when they returned for 45-minute opportunity charges during lunch breaks, then charge slowly in the evenings to help preserve long-term battery health and mitigate demand charges.

The fleets reported several issues with the tractor chargers. For one, a configuration issue on the charger side limited the 150-kW charger to charge at 130 kW for several months until a solution was identified. In addition, several breakers or circuits failed and had to be replaced. Early into their use, DHE reported two to three charger issues arising per month, leaving some chargers inoperable for weeks. Given that there are few suppliers and service technicians at the time, it took a week for a technician to visit the site. If a part was needed, that took another week to arrive, and the technician may need another week to revisit or order another part. This back and forth caused delays and was experienced "several times – supply chain issues for parts and technicians themselves."[21]

One interesting finding related to charger speed was that when the electric tractor batteries were hot, usually upon returning from a route in warm weather, they were not able to accept charger energy as quickly. The fleet manager found that by waiting until the truck's fans turned off after cooling the battery temperature, they could plug the truck in at a faster charging rate. Since the chargers installed are not smart chargers, meaning they cannot change the charger speed during the charging session, waiting for the battery to cool allowed for maximum charger speed.

Both fleets reported the installation timeline for HD tractor chargers to be nearly two years. According to DHE's fleet manager, the planning for the chargers took about 13 months. Construction for the chargers took an additional nine months, for a total of nearly two years until the chargers were commissioned. In this time, the fleet manager had to wait for city permits, the utility had to install a transformer, and contractors had to trench the length of DHE's site. The manager explained that when DHE's facility was built, the power needs were a fraction of what the electric fleet will require, requiring DHE "to upsize the transformer and lay much more conduit. The process takes time."[22]

Both fleets noted that this project was the first of its kind for SCE, beginning before SCE's Charge Ready Program was announced. DHE and NFI expect the timeline to install charging infrastructure to decrease as utilities streamline their processes. One fleet manager noted that "SCE currently says lead time is one year from the time you pick out a site. That has to go down even more to get mass adoption."[23] One fleet manager recommended contracting a company that can handle the entire process of getting charging infrastructure installed for a fleet, specifically one that has experience working with the fleet's utility. The other fleet manager felt that external consultants simply added more organizations to the equation and preferred to handle infrastructure installations internally moving forward. This manager also shared that charging companies can step in front of the utility and charge fleets more, also claiming the benefits of LCFS credits.

[21] Participant in anonymous fleet feedback surveys and interviews. See Section VII. User Acceptance.
[22] Participant in anonymous fleet feedback surveys and interviews. See Section VII. User Acceptance.
[23] Participant in anonymous fleet feedback surveys and interviews. See Section VII. User Acceptance.

Solar and Storage

Table 98: Specifications for Solar System Infrastructure at DHE and NFI

Solar Infrastructure	DHE	NFI
OEM	Solar Optimum	Hanwha
Max Generation Rate (kW DC)	864	640
Number of Panels	2,367	1,489
Installation Timeline	-	-

Table 99: Specifications for Energy Storage Infrastructure at DHE

Energy Storage Infrastructure	DHE
OEM	CPS
Storage Capacity (kWh)	130
Max Discharge Rate (kW)	60
Installation Timeline	-

DHE's electric vehicle and equipment deployment included installing an 864-kW PV system and a 130-kWh ESS. Solar arrays were installed in two locations: DHE's main facility roof and newly constructed carports (Figure 22). The carports were constructed to increase the available footprint for solar, while also providing shade for employee parking and equipment.

The solar array and ESS were energized in December 2020, but the solar began generating in May 2021 and the ESS in July 2021. DHE's ESS was not fully operational until September 2021 due to a part malfunction, which required ordering and installing the malfunctioning parts. Their ESS took longer to come online because it was initially connected to solar but had to be separated for additional safety tests to ensure safe transfer of energy to the grid. The solar and storage providers had to develop these tests in conjunction with being assessed and approved by SCE. The system testing, verification, and coordination among many stakeholders led to a five- or six-month delay between installation and operation. Even once the solar and storage systems came online, the fleet reported continued problems with slow timelines to resolve the issues due to limited parts and technicians.

Solar Optimum also installed an 864-kW solar PV system comprised of 2,367 Astronergy panels at NFI's facility. The process took about 24 months, preventing any data from being collected as of the writing of this report. Both fleets recommended involving the utility from the beginning of the project to help minimize the installation and energizing timeline. DHE and NFI also noted that supply chain issues can delay infrastructure installations for all equipment types, further emphasizing the importance of early utility engagement.

Workplace Charging

Table 100: DHE and NFI Workplace Charging Infrastructure

Workplace Charging Infrastructure	DHE	NFI
Charger OEM (Count)	EvoCharge	EvoCharge
Charger Model Name	Level 2	Level 2
Charge Power (kW)	Dual Port - 7.2 Single Port - 7.68	Dual Port - 7.2 Single Port - 7.68
Installation Timeline (Months)	22	22

DHE and NFI both installed five workplace chargers. The fleet managers seemed satisfied with the number of chargers and charger rate of about 7 kW. At DHE, there were only three regular users and occasional guests who would use the chargers. Because there were always free chargers, no one ever had to run out and unplug their car, which DHE's fleet manager appreciated. They were planning to wait for more employees to adopt EVs before considering installing more. The workplace chargers had no issues that required maintenance as of the writing of this report.

VI. Maintenance and Safety

Introduction

Maintenance and safety are key factors that fleets consider in transitions to ZE operations. Baseline and EV maintenance costs and causes for days out of service were compared throughout the project by drawing on information from DHE, NFI, and TEC maintenance logs; numerous interviews with fleet managers and maintenance staff; and in-person discussions with equipment operators and maintenance technicians.

Cost data for the forklifts and yard tractors came from fleet maintenance logs. Maintenance costs for Class 7 box trucks and Class 8 tractors came from TEC maintenance logs and interviews with TEC EV-Certified Master Technicians who maintain both diesel and electric trucks. Information on vehicle safety came from interviews with fleet operators who operated both baseline and EV equipment. Because the maintenance records from different sources had differing start and end dates, the costs were averaged to compare baseline and EV maintenance costs over one year. When available, the causes for vehicle downtime were included and supplemented with anecdotes from fleet managers and maintenance staff.

Forklifts

The lithium-ion electric forklifts showed significant maintenance benefits over baseline propane forklifts. Under the same duty cycles, EVs showed lower costs, less downtime, and safer operations. DHE maintenance costs were reduced 65% by switching to electric forklifts. For all 14 forklifts, this represented an annual savings of $67,000 per year. The propane forklifts had been in use for over five years and, according to DHE's fleet manager, were overdue for replacement. As a result, DHE noted higher maintenance repair costs and more intensive repairs on the propane forklifts. These intensive repairs included issues with transmissions, cylinders, cooling systems, and axels that put forklifts out of service for days or weeks at a time. Table 101 compares maintenance costs for DHE's propane and electric forklifts.

Table 101: DHE Propane and Electric Forklifts Maintenance Cost Comparison

DHE	Propane	Electric
Number of Forklifts	14	14
Maintenance Records Timeline	Jan 1, 2019–Jun 24, 2020	Jul 6, 2020–Nov 1, 2021
Total Annual Cost	$103,915	$36,964
Per Forklift Annual Cost	$7,423	$2,640
Average Cost per Day	$20.30	$7.20

The fleet manager noted two main reasons for the electric forklifts' low maintenance costs compared with the propane forklifts. First, the electric forklifts' powertrains had fewer moving parts. Second, fewer maintenance repairs were expected given that these EVs were new. While the maintenance required by the electric forklifts over time remains to be seen, they are expected to continue requiring minimal maintenance over an eight-year lifetime.

With less maintenance came less downtime. Having spent less time in the repair shop, the electric forklifts operated more days per year. The electric forklifts were also found to be safer than propane forklifts; injuries can occur when moving propane tanks, but EVs only require plugging in the charger to refuel.

Operators listed numerous benefits of the electric forklifts. They appreciated the smog-free operations. With propane forklifts, operators expressed that they had to bathe after each shift due to diesel exhaust residue. They also described the propane forklifts as noisy and appreciated the silent operation of the electric forklifts (aside from safety beeping when backing up). Operators found braking to be much smoother and safer on electric forklifts, in addition to a tighter turn radius.

DHE's forklift operators had driven lead-acid forklifts as well, but these forklifts were much bulkier and had a wider turn radius and lower acceleration. A wheel sometimes came off the ground while turning. They felt the lithium-ion forklifts were vastly superior, followed by propane and then lead-acid.

Overall, operators reported three cons to the lithium-ion forklifts. First, the reverse toggle worked differently than on propane forklifts, and this took some adjustment. Second, they initially found it difficult to pick up low pallets with the electric forklifts; it took time to learn how to do so. While operators did miss the warmth emitted the propane forklifts on cold days, overall DHE's forklift operators' experience with the lithium-ion forklifts was very positive.

Both propane and electric forklift costs at NFI were significantly lower than DHE's, primarily because they were operated about 85% fewer hours. The electric forklifts at NFI showed a 96% decrease in maintenance costs compared with the propane forklifts. Notably, NFI's propane forklifts were relatively new, and its EVs still showed significant maintenance savings. Overall, electric forklifts at DHE and NFI showed 65% to 96% maintenance cost savings, less downtime reported by the fleets, and safer working conditions. Table 102 compares propane and electric forklift maintenance costs at NFI.

Table 102: NFI Propane and Electric Forklifts' Maintenance Cost Comparison

NFI	Propane	Electric
Number of Forklifts	1	1
Maintenance Records Timeline	Jan 1, 2019–Jun 24, 2020	Jul 6, 2020– Nov 1, 2021
Annual Cost	$1,829	$82
Average Cost per Day	$5.00	$0.20

Yard Tractors

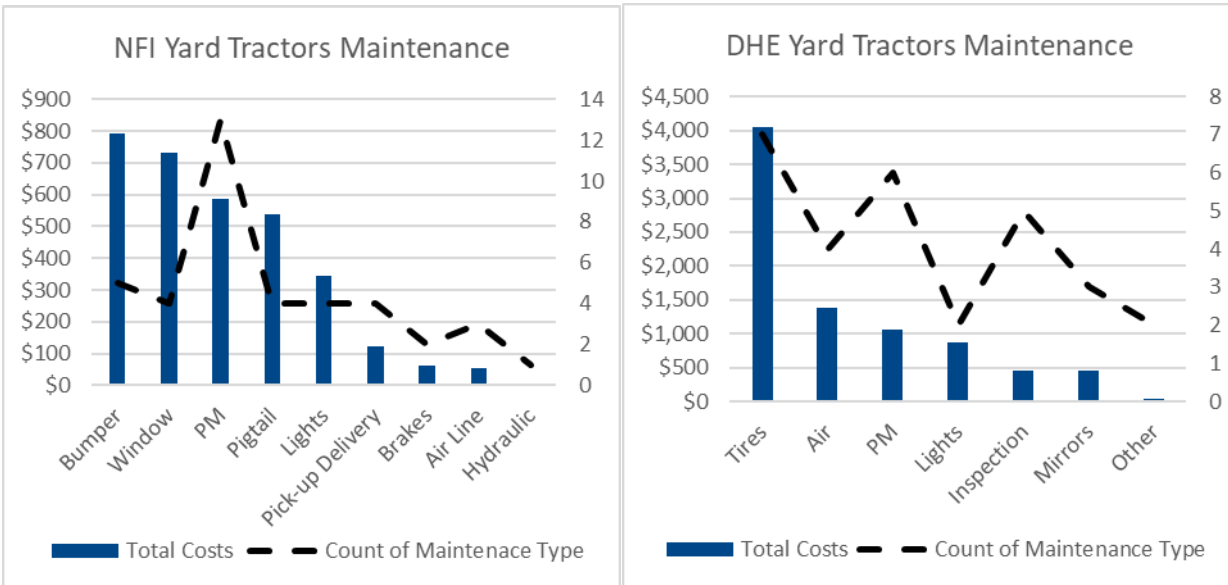
Similar to the electric forklifts, electric yard tractors saved the fleets thousands of dollars in maintenance costs and reduced downtime. Electric yard tractors cost 75% less than diesel in terms of maintenance. Over the 13-year lifetime of the electric yard tractors at DHE, the vehicles were expected to save the fleet $158,000 in maintenance costs. According to the fleet manager, emissions control was the main reason for maintenance on diesel yard tractors. To abide by CARB emissions mandates, the vehicles were equipped with emissions systems originally designed for on-road trucks driving over 50 miles per hour. Because yard tractors drive much slower in comparison, pollutants get trapped in emissions systems, and technicians must clean them out manually or issues arise. As a result, the diesel yard tractors experience much more downtime than the electric yard tractors. Table 103 compares DHE diesel and electric yard tractor maintenance costs.

Table 103: DHE Diesel and Electric Yard Tractors' Comparison of Maintenance Costs

DHE	Diesel	Electric
Number of Yard Tractors	2	2
Maintenance Records Timeline	Jan 1, 2019– Sep 1, 2019	Mar 4, 2020–Mar 10, 2021
Annual Cost	$32,429	$8,164
Number of Yard Tractors	1	1
Annual Cost	$16,215	$4,082
Average Cost per Day	$44.40	$11.20

The fleet manager noted that the electric yard tractors initially had sensor-related issues, but the yard tractors' OEM fixed those quickly. In addition, a DHE operator caused one issue, and the fleet had to wait a few days for a part. DHE's fleet manager, however, was not alarmed by this issue and reported that DHE is in the process of buying two more electric yard tractors for a different facility. The top maintenance reasons were related to tires, bumpers, windows, and preventative maintenance—all components unrelated to the electric drivetrain. Figure 52 shows maintenance performed and associated costs on DHE and NFI's electric yard tractors. NFI's electric yard tractors were frequently out for service due to transmission issues covered by manufacturer warranty and are therefore not included in Figure 52.

Figure 52: DHE and NFI Electric Yard Tractors' Maintenance Causes and Costs



Box Trucks

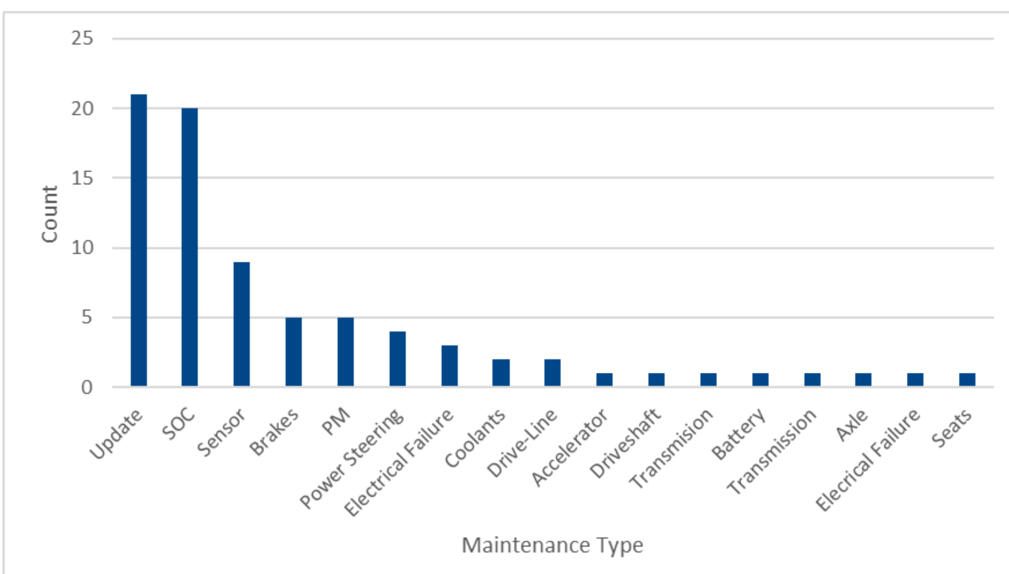
DHE deployed one electric box truck to join its fleet of diesel box trucks. These trucks were primarily used for local deliveries. While performing the same duty cycle, the electric box truck showed significant cost savings over diesel box trucks. Over five years of maintenance logs, the diesel box trucks averaged about $2,300 in maintenance costs. The cost of maintaining a diesel box truck increased over time (as expected) and could range between $900 and $3,500 annually. Maintenance cost data were not available for the electric box truck, which is under a general maintenance agreement with TEC. Instead, cost data came from in-depth conversations with TEC's EV-Certified Master Technicians. These mechanics, who maintained both diesel and electric box trucks, reported that EV maintenance was minimal and less expensive than for diesel. Table 104 shows the maintenance costs of DHE diesel and electric box trucks.

Table 104: DHE Diesel and Electric Box Truck's Maintenance Costs

DHE	Diesel	Electric
Number of Box Trucks	1	1
Maintenance Records Timeline	Aug 16, 2016–Apr 26, 2021	TEC Maintenance Technician Interviews
Annual Cost	$2,263	$100
Average Cost per Day	$5.00	$0.27

According to the technicians, the most common EV maintenance was updating software, which often could be performed remotely. TEC expected maintenance to be performed remotely more regularly in the future. Over the two to three years that TEC performed maintenance on this project's EVs, the technicians reported minimal and inexpensive maintenance. They quoted maintenance costs of $500 over five years. At this rate, the fleet would save about $8,500 over five years or $17,000 over 10 years by switching from diesel to electric, though whether these low maintenance costs remain will become apparent as the vehicles age. Figure 53 lists the main causes of maintenance on DHE's electric box truck.

Figure 53: DHE Electric Box Truck's Causes of Maintenance



DHE's electric box truck operators expressed positive experiences with the electric box trucks, particularly with respect to performance and the silent, smooth operations. One area for improvement, though, was the electric box truck's cargo weight of 8,500 lbs., compared with 15,000 lbs. for diesel. However, DHE trucks were usually limited by volume rather than weight. The next-generation electric box truck is expected to have a cargo weight of 12,500 lbs., narrowing the gap between electric and diesel.

Class 8 Tractors

Both fleets deployed Class 8 electric tractors to deliver trailers on shorter routes. While maintenance cost information was unavailable, conversations with TEC technicians and the fleets alike expressed significant savings with the electric tractors. Table 105 shows the maintenance costs of diesel and electric tractors, according to TEC maintenance technicians maintaining both types of vehicles.

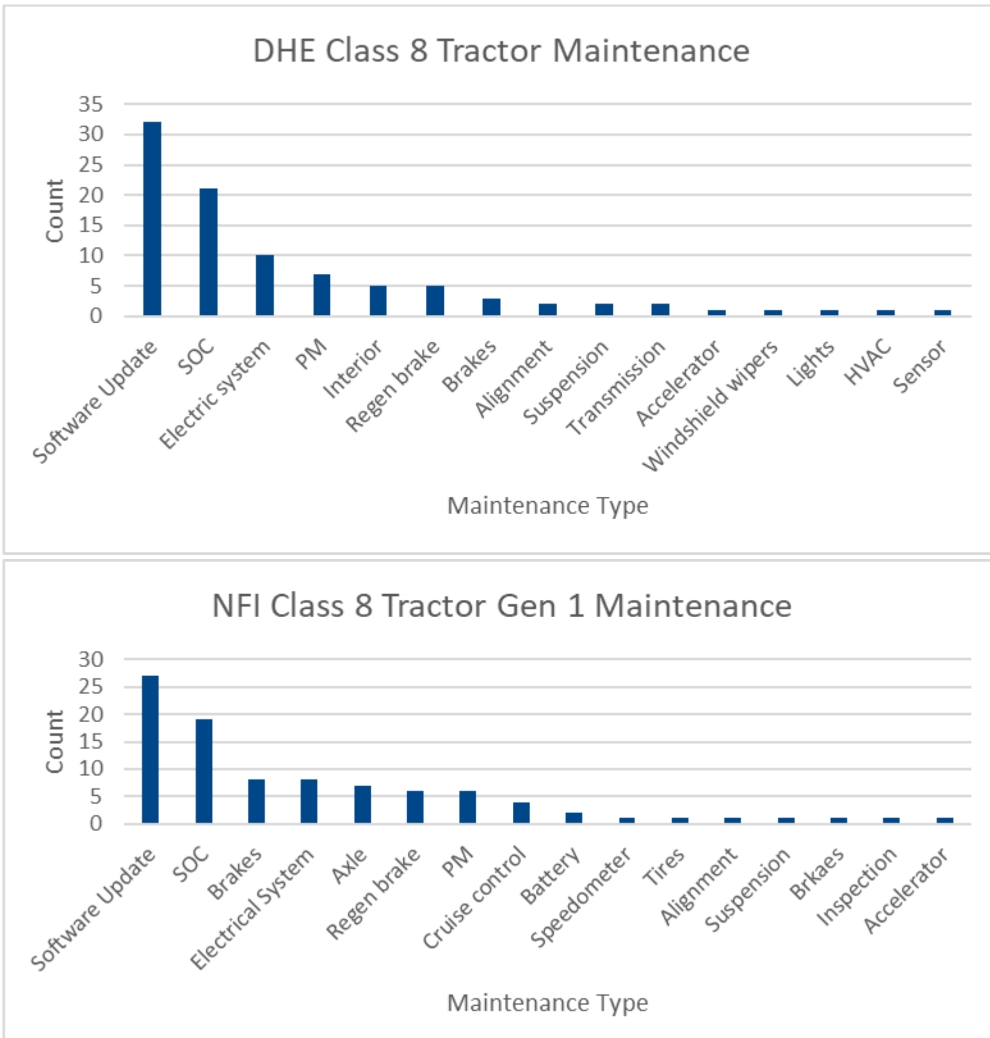
Table 105: DHE and NFI Diesel and Electric Class 8 Tractors' Comparison of Maintenance Costs

DHE and NFI	Diesel	Electric
Number of Class 8 Tractors	1	1
Annual Cost	$8,400	$100
Average Cost per Day	$23	$0.27

According to TEC technicians, diesel tractors cost around $6,000 in maintenance in Year 1 of deployment, increasing to about $11,000 by Year 5. This averages out to about $8,400 per year. For the two or three years after the electric Class 8 tractors went on the road, the technicians reported virtually no maintenance costs on them and estimated about $100 per year. Importantly, NFI reported higher maintenance costs for the electric vehicles they operated. While they saw lower maintenance costs for electric trucks, they expect to pay about two thirds the cost on electric truck maintenance compared to diesel trucks. Moving forward, a value similar to two thirds of the maintenance price of diesel trucks is likely to be incorporated into the upfront warranty cost of electric trucks.

The fleet noted that there are several variables that can impact the maintenance cost of electric trucks. These are confounded by the fact that the trucks operated in the Volvo LIGHTS Project were pre-production, meaning they are not fully representative of the issues that fully commercial models will experience. Also, these pre-production trucks were new, and no maintenance data were recorded on issues that arise after three to five years of operations. Still, the fleet noted that which party performs maintenance can have a massive impact on maintenance costs. In-house maintenance can cost half as much per hour as maintenance performed by a vendor. Maintenance warranties will likely standardize the costs of electric truck maintenance, but cost values from OEMs are very limited at this time. Figure 54 lists the causes of maintenance for DHE and NFI's Class 8 tractors.

Figure 54: DHE and NFI Class 8 Tractors' Causes of Maintenance



Software updates were the most common reason for maintenance on the Class 8 tractors, followed by updates in SOC. When DHE first deployed the pilot tractor, the vehicle ran out of battery and had to be towed. Volvo recalibrated the percent of battery capacity that was accessible to the truck from 70% to 80%, and this issue did not reoccur. Vehicle operators also noted a need for caution when driving on hills as the battery could scrape the road; in addition, the fans needed to cool the batteries when the trucks were first turned on were loud. DHE's fleet manager noted that the electric outlet on the pilot tractor was installed incorrectly, causing the line to short and the truck to malfunction four or five times until the issue was identified and fixed. This issue never occurred on the leased tractors. Lastly, DHE's Service Center Manager noted several issues with the electric tractors upon delivery: SOC would drop from 45% to zero, and one driver broke down three times, leading to an expressed desire to return to diesel vehicles. However, these issues appear to have been largely fixed with Gen 2.

Under a general maintenance agreement, DHE could call TEC whenever issues occurred either at the yard or on a route. TEC would tow the truck back to its facility, deliver a temporary replacement truck for the fleet while performing repairs, then return the truck once repaired. This arrangement suited DHE's needs and was used for both diesel and electric tractors.

Large fleets like DHE often have in-house maintenance staff working on vehicles. According to both DHE and TEC, they foresee dealerships like DHE playing a bigger role in maintenance as fleets transition to EVs. It takes years of training to become a certified Master Technician, and additional training is required to become EV-Certified to work on electric trucks. For the next several years, TEC predicts, all electric truck maintenance will take place at dealerships like TEC until training courses are created for the general public, like a fleet's maintenance staff. Even then, dealerships will play a much larger role in maintenance, and more maintenance will be performed remotely. The electric Class 8 tractors at DHE and NFI showed that software updates were more common than physical maintenance. TEC expects to perform more of these updates remotely moving forward, minimizing costs and downtime compared with diesel tractors.

VII. User Acceptance

Introduction

To evaluate the practical application and adoption of EVs deployed at DHE and NFI, CALSTART conducted surveys to receive direct fleet feedback from vehicle operators and managers. The purpose was to obtain qualitative information in addition to the quantitative data collected from the technology, improving the overall understanding of the new vehicles' performance and fit within operations.

Surveys were distributed to vehicle operators and fleet managers at both locations, with different surveys for different vehicle types. Eliciting feedback from operators was integral because of their detailed knowledge of each vehicle's strengths and weaknesses. Fleet managers' feedback was also important to understand how each vehicle performed within operations. Due to the surveys' small sample size, CALSTART dug deeper by interviewing operators and mangers directly. Face-to-face interviews provided the opportunity for the fleet to elicit feedback not addressed in the surveys, clarify responses, and gain information through open dialogue.

Methodology

Surveys were administered in two rounds—one at the beginning of the demonstration and one near the end—as paper copies so most participants could fill them out without accessing a computer. This approach was more equitable given that most vehicle operators did not use or have access to a computer as part of their daily duties.

Initially, forklift surveys were developed and distributed in October 2020. It was later established that the scope of work for CALSTART also included the yard tractors, and surveys for these vehicles were developed and distributed in February 2021. Per request from the fleet manager, forklift surveys were also created in Spanish at NFI to increase accessibility and the response rate. VNR truck surveys were administered by Volvo; CALSTART was not involved in that process, nor did CALSTART distribute any additional surveys to limit the time and resources each fleet needed to spend to complete.

The second round of forklift surveys and yard tractor surveys was distributed in October 2021. Collecting feedback at least six months apart allowed for testing time of this technology. Additionally, the two rounds of surveys aided in capturing improvements or challenges in using each vehicle over time, as well as any changes in operator or manager perceptions.

Table 106: Number of Survey Respondents at DHE and NFI - Round 1

Vehicle Type	Operators	Managers
DHE Forklifts	8	1
DHE Yard Tractors	2	2
NFI Forklifts	8	1
NFI Yard Tractors	5	1

Table 107: Number of Survey Respondents at DHE and NFI - Round 2

Vehicle Type	Operators	Managers
DHE Forklifts	10	1
DHE Yard Tractors	1	1
NFI Forklifts	5	1
NFI Yard Tractors	1	1

The sample size for the vehicle operators and fleet managers was small (Table 106 and Table 107). Interviews were conducted to supplement the survey data and obtain more detailed and holistic information regarding the daily operation of the new battery EVs. Interviews, which were conversational to elicit open feedback, were held in August 2021 at NFI and September 2021 at DHE. Fleets were assured that results from the interviews and surveys would be anonymous to encourage direct and honest feedback.

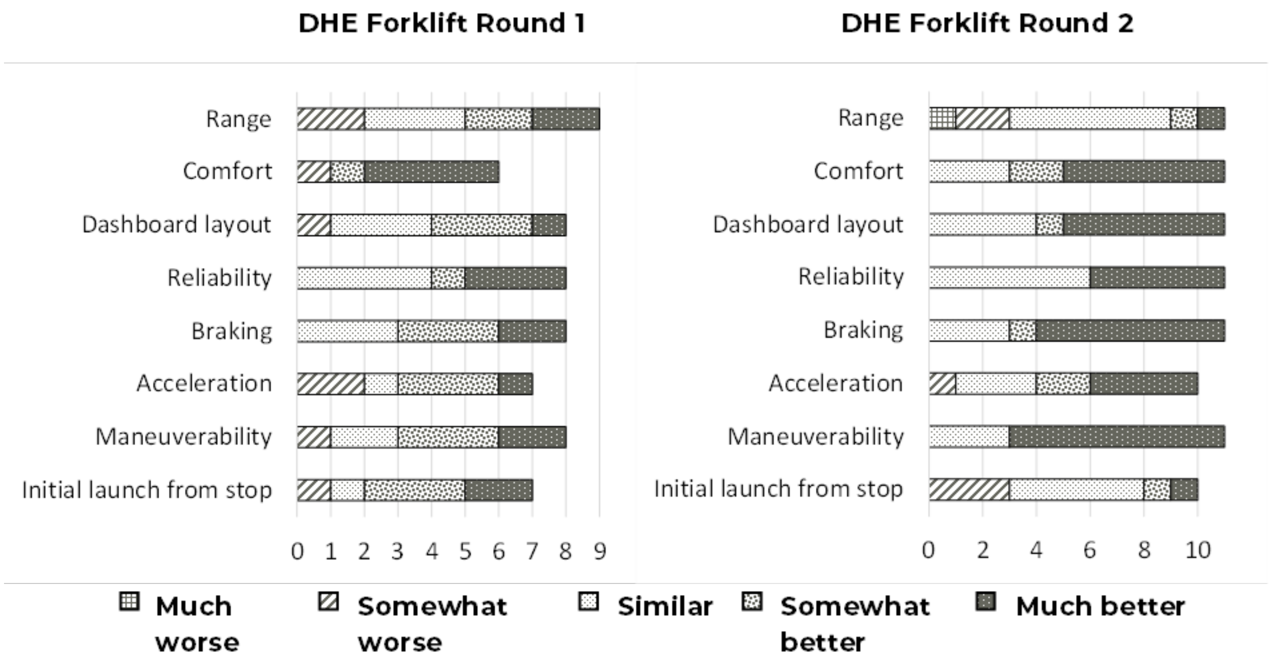
Results

Forklifts—Operators and Managers

DHE Forklift

Acceptance of the battery-electric forklifts changed as operators adjusted to the new technology. After the lithium-ion forklifts were deployed, operators acclimated over time to the regenerative braking, which have little to no coasting. Over time, operators reported the braking to be much safer and smoother than with propane forklifts; respondents rating of overall braking performance increased from 2 to 7 between survey rounds (Figure 55).

Figure 55: DHE Electric Forklift Attributes Round 1 and Round 2 Survey Responses



One disadvantage of the electric forklifts was the initial launch-from-stop compared to propane forklifts. According to operators, the propane forklifts were faster to shift. In interviews, operators noted the quieter operation of the electric forklifts—making for a more comfortable work environment—and their increased center of gravity. Overall rating of the electric forklifts was higher than for the propane forklifts in both rounds of surveys and was also apparent in interview discussions.

The previous propane forklifts required operators to lift heavy propane tanks to refuel forklifts. According to operators, this was often a safety hazard that risked spilling propane and possibly burning oneself or spilling it onto one's clothes. The electric forklifts made refueling simpler and safer. Views of fueling by charging improved from Round 1 to Round 2, likely as operators became more accustomed to charging. Though charging provided a safer refueling method, previous propane fueling required only five minutes whereas charging took about 40 minutes.

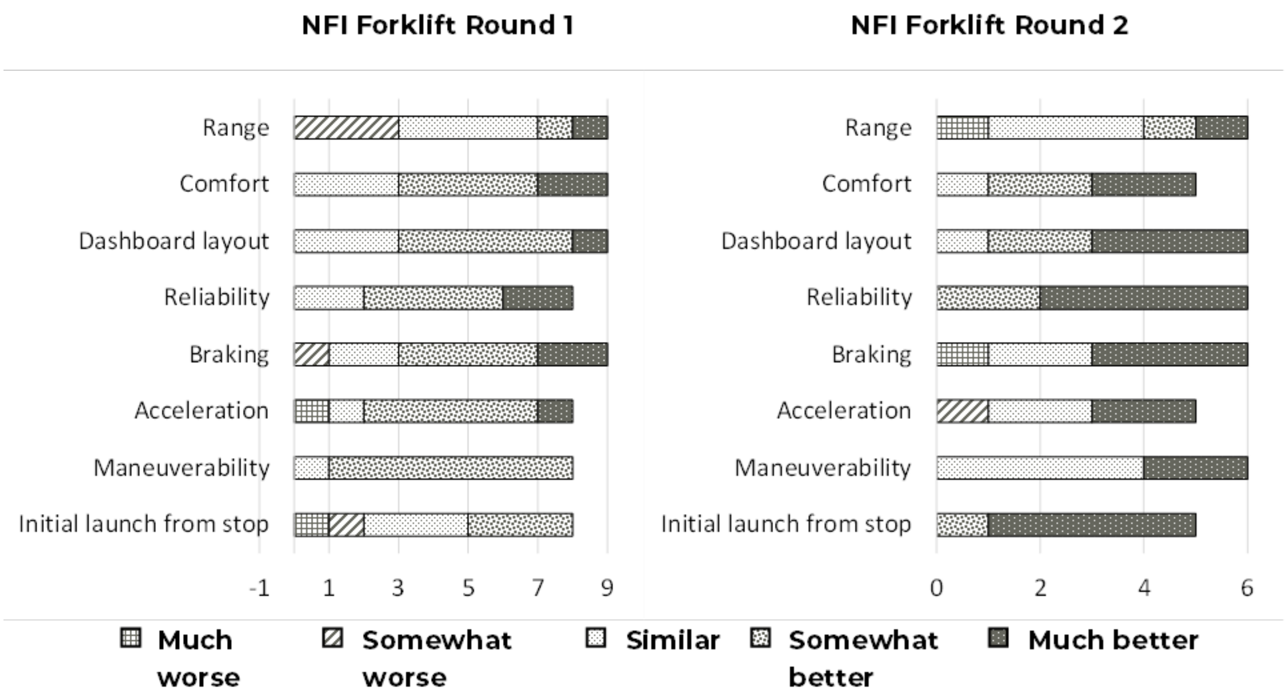
NFI Forklift

At NFI, operators found electric forklifts to be highly favorable to propane alternatives. The propane forklifts required less frequent fueling but required an extra procedure of lifting heavy propane tanks, often leading to spillage. The new electric forklifts could last through a whole shift when charged between shifts during lunch breaks.

One of the most significant advantages of the electric forklifts was mitigating safety risks such as fuel spillage. Further, the loading dock was much quieter; the forklift manager reported the lack of loud revving when maneuvering in the facility. The reduction of propane fumes decreased smell and residue on clothes. Overall, operators and managers reported that the new electric forklifts were an improvement over propane vehicles.

The disadvantages of the electric forklifts included one reported braking glitch that required operators to pump the brake when starting up during morning shifts. A software update resolved this issue. Additionally, it was noted in interviews that the remaining propane forklifts on site needed to be used for lifting heavier loads; the electric forklifts' weight capacity was more limited. Between survey rounds 1 and 2, NFI forklift operators and managers noted improvements across the electric forklift attributes (Figure 56).

Figure 56: NFI Electric Forklift Attributes Round 1 and Round 2 Survey Responses



Yard Tractors—Operators and Managers

DHE Yard Tractors

The performance and favorability of DHE yard tractors improved notably over the previous diesel yard tractors, as shown in both rounds of survey responses (Figure 57). All responses indicated similar or better performance across all surveyed attributes. DHE's fleet manager expressed that the Orange EV yard tractors and compatible charging stations were highly successful. Since the Orange EV yard tractors were so successful at DHE's Ontario facility, DHE utilized CORE funding to get two more for the DHE Los Angeles facility.

Figure 57: DHE Electric Yard Tractor Attributes Round 1 and Round 2 Survey Responses

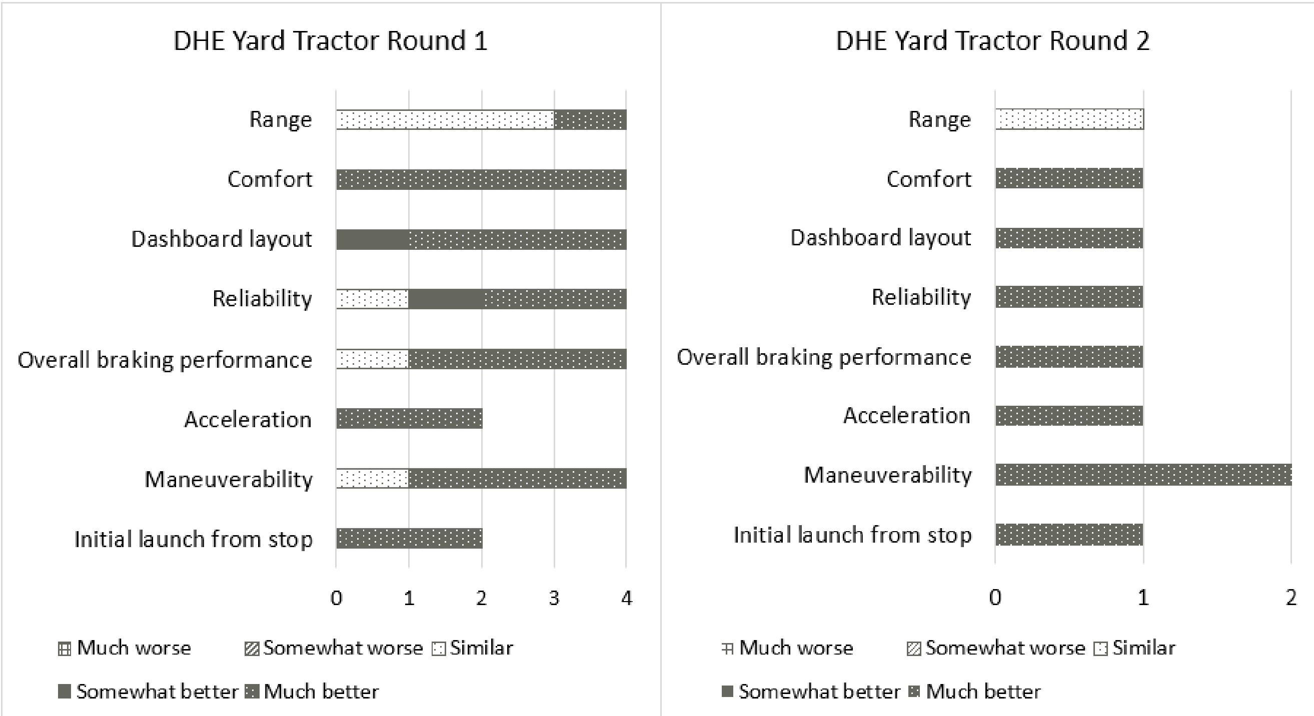
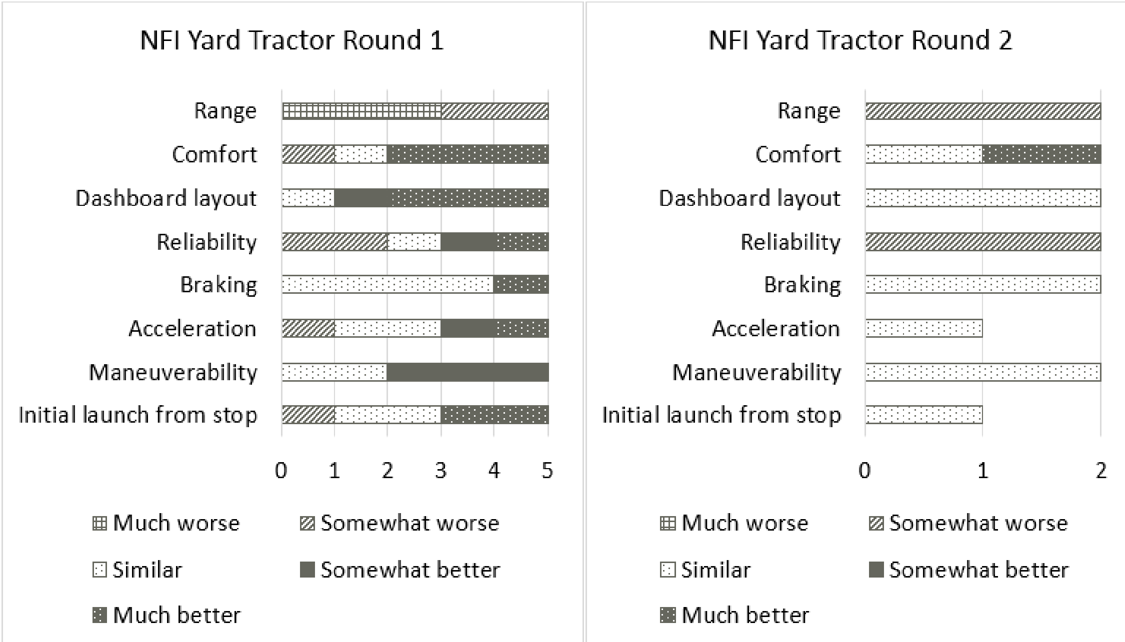


Figure 57 shows the range of DHE electric yard tractors to be similar or better compared to diesels between both survey rounds. This is reasonable because the duty cycle involved moving freight around the yard; extended range is not needed if the electrics can fulfill the diesels' duty cycle. The greatest benefits noted in the interviews and seen in the survey responses were improved comfort and overall environment. The electric yard tractors were much cooler due to their AC system, quieter, and lacked diesel smell, all making for an improved work environment for operators. Between the Round 1 and Round 2 surveys, the only necessary improvements noted in the electric yard tractors were a need for a larger step on the vehicle and one of the yard tractors' heaters was broken.

NFI Yard Tractors

The electric yard tractors at NFI mitigated safety risks and improved work environments. Operators reported the baseline diesel yard tractors had left a smell and residue on their skin and clothes, which was a health hazard. The new electric yard tractors emitted no fumes and created a quieter work environment. Other positives (Figure 58) included improved comfort and dashboard layout. However, key issues with the NFI trucks' charging and reliability were concerns for operators and managers, leading some to request their diesel yard tractors back.

Figure 58: NFI Electric Yard Tractor Attributes Round 1 and Round 2 Survey Responses



Reliability was ranked similarly or somewhat worse between Round 1 and Round 2. Interviews provided insight into how the electric yard tractors often broke down from transmission and braking issues due to quick shifting when connecting to trailers. One operator reported a loud grinding noise when applying hard braking, which would often require repairs.

The NFI charging experience for the electric yard tractors also presented new difficulties for operators and managers. The connector on the Transpower charging station was very large and heavy, making it difficult for some operators to lift and connect to the Kalmar yard tractor regularly (Figure 59). A few operators reported switching back to diesel yard tractors because fueling these vehicles was easier than lifting the heavy connecting port on the electric yard tractor and twisting it in. Additionally, the charging stations were at the edge of the facility, far from employee parking, the break room, and the facility.

Figure 59: Transpower Charging Connector for Kalmar Electric Yard Tractors at NFI

As evident from the low ratings, the NFI charging experience could improve if chargers were closer to the main facility. This is an important lesson for future deployments when planning locations for charging infrastructure.

VIII. Operational Recommendations

Vehicle Improvements

Logistics and Safety

The introduction of ZE technologies normally calls for an evaluation of different approaches to daily operations. Implementation of EVs requires a fleet to plan for vehicle charging and how to best utilize the new vehicles and equipment, with some inherent benefits in such a transition. For DHE and NFI, replacing propane as the primary fuel for the forklifts yielded safety benefits and increased operational efficiencies. As a result of introducing electric chargers, staff did not need to wear gloves to operate a flammable fuel, and spillage concerns and pungent fuel odors disappeared. The fleets also benefitted from time saved because the forklifts did not have to leave the dock for refueling; instead, they were plugged in at the end of shifts.

Similar feedback was collected from yard tractor drivers. Propane forklifts and diesel yard tractors exposed operators to fumes, covering their skin and clothes with a thick residue and smell. The new electric forklifts and yard tractors did not expose operators to fumes, creating a much safer, healthier working environment. Additionally, the electric forklifts and yard tractors were much quieter. Forklift operators reported they could hear one another better while working on the floor, and yard tractor operators noted that the noise reduction made for a more comfortable work environment. Also, the lack of noise made operators more aware of their surroundings.

Deploying the new vehicles and technologies at DHE and NFI led to logistics efficiencies as well as challenges. Staff had to make adjustments and implement additional planning to operate the new vehicles and equipment, although operations mostly continued as usual. According to staff surveys, fueling the propane and diesel-powered vehicles required about five to 10 minutes per vehicle, while charging the electric forklifts, yard tractors, and VNR trucks required 30 to 60 minutes. For yard tractors and forklifts, a fully charged vehicle was generally enough to complete a full shift, but usually a different vehicle was available if needed. For VNR trucks, DHE's fleet manager found that the best way to adjust to longer charging times was to have operators charge during breaks and opportunity charge whenever possible. This was due to a continuing range concern with trucks of that size.

Opportunity charging is recharging a vehicle for short periods whenever convenient throughout the day rather than charging it all at once. For example, the use of DHE's box truck for more local deliveries left it with about a 30% SOC at the end of an average shift. Operators plugged in the box truck immediately after unloading to reduce the time for charging during the next shift. At this point in the technology's development, DHE was still routing the electric trucks locally and using diesels for longer distances. From interviews of dispatchers, they also kept an eye on each battery's SOC to ensure their vehicles could make their next delivery. That way, the electric truck drivers could opportunity charge between the deliveries and easily return to the yard in case of an emergency.

Vehicle operators had overall positive experiences with the forklifts' daily performance. Improvements included smoother braking, a smaller turn radius, and increased acceleration. However, it was noted that the electric forklifts could not lift as heavy a load as the propane forklifts and sometimes were more difficult to maneuver, though this did not appear to cause any major issues with operating the forklifts. The operators at DHE and NFI saw similar performance improvements and an overall smoother ride. NFI yard tractors frequently had issues with braking and transmission systems when loading and unloading, but enough yard tractors were on site to avoid disrupting operations. The electric VNR trucks had notably faster acceleration, but the operators faced challenges in getting accustomed to regenerative braking and often preferred to drive the truck in automatic setting, making them more like the diesel trucks. According to the drivers and the technicians at TEC, the drivers were initially encouraged to use the automatic mode to assist with the transition to an EV, but to start using regenerative driving to maximize performance once they became more comfortable with the practice.

One complication for the electric VNR trucks was range anxiety among drivers, fleet managers, and dispatchers. This was one reason why fleet managers and dispatchers were more mindful of the routes assigned to electric trucks and opportunities for additional charging. For NFI, most pickups were at the port, so routes overall were longer, with little or no opportunity charging available on route. Due to this, one NFI driver used two VNR trucks to fulfill the duty cycle of one diesel truck. The driver made two trips to the port in one shift, using a different electric truck for each trip. While this meant the trucks were not pushed to capacity, the drivers felt more secure about fulfilling a route should unexpected delays occur at the port. At this point in electric truck development, this approach made sense for NFI's operation and for increasing drivers' confidence and willingness to test the relatively new technology. VNR trucks deployed at DHE and NFI had few hardware maintenance issues, according to TEC technicians. The primary maintenance issues were required software updates.

The deployment of new technology raised safety concerns. Vehicle operators expressed a desire to have additional signage for operating different technologies, and they had concerns regarding connecting outdoor charging plugs in inclement weather. CALSTART prepared informational signage to assist with questions and concerns on operating the new technology (see Appendix D). Different signage was prepared for each new vehicle type deployed due to different charging mechanisms and chargers. The goal was to answer the concerns of current drivers and assist new drivers with increasing familiarity and comfort when operating EVs.

By the time the signage was prepared, the vehicle operators and fleet managers appeared to be more comfortable with the technology and did not need the additional signage. Fleet operators seemed more comfortable operating these vehicles because they drove similarly to fossil fuel-powered vehicles. However, more training on the electric component and charging of these vehicles, including additional information on safety, could benefit drivers who have not operated EVs before.

Workforce Training Considerations

The vehicles deployed at DHE and NFI required new skills and knowledge regarding these technologies and respective charging stations. As the EV industry grows and develops, specialized EV training for operating and servicing these vehicles will be needed, as will streamlining the process for certifying electric truck technicians.

Operating/Driving Training

Interviews and surveys indicated that most drivers of forklifts, yard tractors, and VNR trucks were comfortable switching from a fossil fuel-powered vehicle to an electric one. Drivers received short introductions to the vehicles before jumping into hands-on experience. Drivers of VNR trucks expressed discomfort in using regenerative driving, instead driving the electric truck in the automatic setting, which provides the same driving experience as a diesel truck.

Volvo VNR trucks have three driving settings. Automatic resembles driving a diesel truck by turning off regenerative breaking. Second setting is a partial setting, with softer regenerative breaking, and the third setting employs full regenerative braking. In conversations, TEC electric truck technicians suggested that energy savings from full regenerative can be 5% to 10% of total charge, which can be significant over time. Technicians mentioned that upon delivery of some trucks, the drivers were asked to drive in the automatic setting to assist with the initial transition to an EV; this may have led to confusion about or resistance to regenerative driving. One possible solution going forward could be additional education on the energy-saving benefits of an EV and various driving settings.

Maintenance Training

Discussions with DHE and NFI drivers and mechanics showed that maintenance training will play an important role in future electrification efforts. Current fleet staff expressed unease about the consequences of electrification and whether their jobs would become redundant in a few years. The trucks were under warranty and serviced at TEC.

NFI fleet technicians addressed tire and AC issues but nothing relating to the electric components. Staff expressed a desire to learn how to service these trucks before the warranties ran out, preparing them for future electrification and improving their job security.

As of the writing of this report, there were very few EV-certified technicians. Volvo was in the process of developing and finalizing their EV certification training program. Volvo required all technicians to be certified as a Master Technician, which requires close to a year of specialized training, in order to begin EV-certification. Many fleet technicians have not gone through Master Technician training, which may act as a barrier to them becoming EV-certified even once trainings become more available.

Future Pathways for Aspiring Mechanics

The two mechanics interviewed took different initial education paths. One was trained through a specialized technical institute, the other attended a local city college. Both felt they learned more during hands-on experiences. With the emergence of specialized certification programs through city colleges, attending such an institution appears to be the most cost-efficient and practical option. An example is San Bernardino Valley College's designated associate degree training specific to battery-electric HD truck maintenance.[24]

Energy Operations Innovations

EV Fleet and Infrastructure Expansion Scenario Builder Tool

Main Summary

As part of its deliverables for the Volvo LIGHTS Project, CALSTART developed a scenario builder tool to aid fleets in optimizing onsite energy infrastructure and expanding EV deployment. Understanding infrastructure demands and the sizing of renewable energy technologies are concerns expressed not only during this project but across the industry. CALSTART saw this task as an opportunity to develop a tool that fleets involved in ZE deployments and across the industry could use to plan future electrification efforts and expansions. For example, given the opportunities and challenges associated with deploying new technologies, as well as California's overall electrification goals, DHE will need a strong understanding of its site infrastructure if it plans to add more electric VNR trucks. Any fleet may use this scenario builder tool,[25] but it should be noted that since

[24] Heavy/Medium Duty Truck Technology Associate of Science Degree. San Bernardo Valley College. https://catalog.valleycollege.edu/degree-certificate-program-index/hmdt/heavy-medium-duty-truck-technology-as-degree/

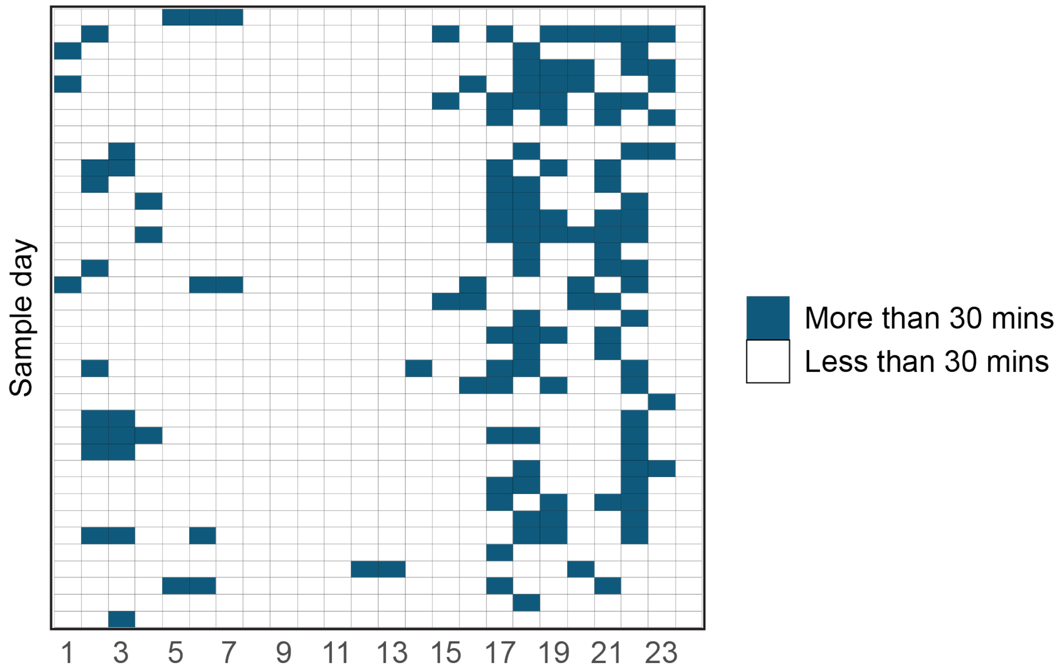
[25] Fleets interested in using the scenario builder tool should reach out to CALSTART for access and guidance at this time.

the installation and electrification of DHE's infrastructure for Volvo LIGHTS was completed in time to collect the necessary data, the tool was developed from DHE's data and lessons learned. All examples discussed below are from DHE's scenario builder results.

The goal of this tool was to provide measurements and estimates to predict how solar, storage, and charging infrastructure could be used to deploy more vehicles while mitigating additional impact on the grid and overall costs. The tool analyzes three main components of electrification planning: energy cost modeling, energy and power demand over time, and duty-cycle modeling. Possible scenarios for altering the sizes and charging times of solar and battery storage systems are compared with a baseline scenario to maximize infrastructure efficiency and cost savings.

What makes this tool unique is its ability to model daily duty cycles for all vehicle deployments and onsite energy infrastructure. This modeling begins with user inputs for average vehicle charging sessions, infrastructure capacities, utility rates, and basic operating costs. A cost calculator estimates average annual costs based on charging and solar generation schedules. Figure 60 shows how each charging event at DHE was analyzed to understand average charging times. Each row represents a sample day, and each column represents a time and hour period. Darker colors represent a longer charging time per event. The charging time was found by calculating the maximum time across the truck charging sessions in a day. Based on this plot, the scenario builder assigns three sample charging sessions: a short session in the early morning around 2 a.m. to 3 a.m., a long session during peak hours, and a medium session after peak time around 10 p.m. to 11 p.m. Energy charged during each peak type is compared with energy generated from solar to determine utility cost with DHE's current solar capacity. Figure 60 shows DHE's average truck charging times, which are then input into the scenario builder. A demand-charge estimator then analyzes baseline demand charges and appraises future demand charges.

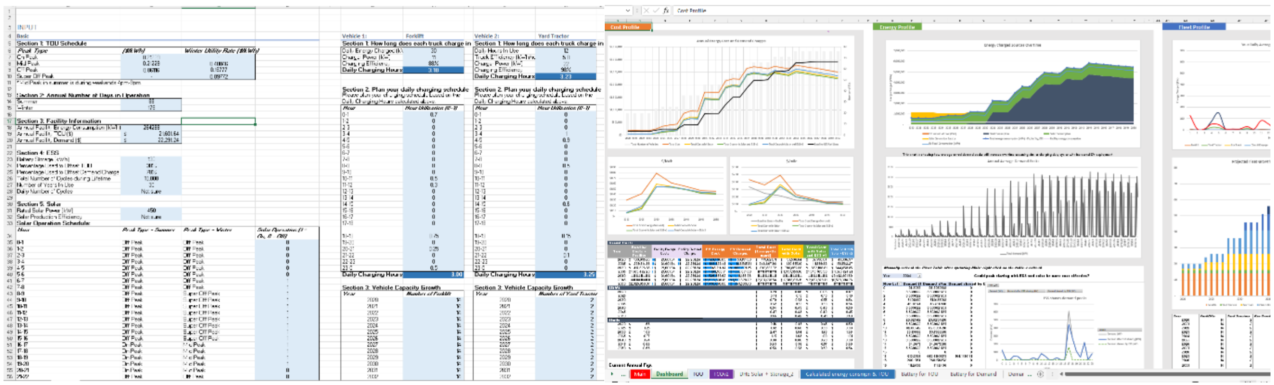
Figure 60: Charging Events



The scenario builder takes user inputs and creates a dashboard estimating operational TCO, dollar per mile, demand estimates over time, and more to aide in EV fleet deployment planning (Figure 61). The tool's dashboard shows annual energy and demand charge cost estimates for the baseline scenario and other possible scenarios:

- Baseline Scenario: Energy and demand costs for internal combustion engine vehicles
- Total Cost Scenario: Energy and demand costs for EVs without any additional energy infrastructure
- Total Cost with Solar: Energy and demand costs with solar generation
- Total Cost with Solar and ESS v1: Energy and demand costs with solar generation mitigating energy costs and ESS mitigating demand costs
- Total Cost with Solar and ESS v2: Energy and demand costs with solar generation and ESS both mitigating demand costs in addition to solar mitigating energy costs

Figure 61: Scenario Builder User Inputs (Left) and Created Dashboard (Right)



The scenario builder also has limitations and requires crucial inputs from fleets to give optimized output. For example, vehicle chargers or solar panels typically do not operate at the suggested operational power from manufacturers. If fleets do not have data collection systems onsite to monitor the rates at which chargers or solar are operating, this may result in incorrect estimates of the amount of energy drawn from the grid or the amount of energy generated by solar—and subsequently inaccurate estimates of operational costs and expansion recommendations. Additionally, different utilities will have different peak rates and other charges associated with energy production and consumption, which must be taken into consideration. For this project, CALSTART worked with SCE and used the values obtained from utility bills and projections provided by the SCE team. Monitoring and validating the energy flow at fleets' facilities will also become increasingly crucial for growth.

In short, fleets will want to use the scenario builder tool with caution. CALSTART encourages fleets to obtain additional consulting services for a more personalized operation and deployment planning.

Main Takeaways

The analyses built into the scenario builder tool clarified certain characteristics and challenges seen throughout DHE's electric vehicle and infrastructure deployment. These characteristics will likely impact similar fleets in future electrification projects and are important lessons for fleets considering electrification.

Optimizing Duty Cycles and Charging Hours

One way that fleets can minimize costs and maximize effectiveness of energy infrastructure is to optimize duty cycle by making designated charging times during more off-peak hours and hours when solar is generating at its peak capacity. Onsite solar can then offset the maximum amount of electricity cost or demand charges from fleet energy consumption. However, many operations may not have the flexibility of changing charging hours.

Duty Cycle and Energy Infrastructure Can Work Together

The scenario builder enables users to create an average duty cycle for each vehicle in their fleet. Establishing this duty cycle is the foundation of the tool, as it expands daily duty-cycle estimates annually until 2050 to calculate expected energy consumption, power demand, and associated costs over time. As seen from the results in this tool, onsite energy infrastructure can mitigate costs to high-demand duty cycles. If possible, fleets may consider determining average duty cycle before deciding the solar and battery storage system's size and capacity. Optimized solar utilization can be increased when deployed in tandem with a battery system. Sizing of both infrastructure systems requires knowledge of a fleet's duty cycle and future expansion plans to achieve the best outcome and create the most savings over time.

The scenario builder tool generates one scenario at a time for varying sizes of solar, storage, and fleet makeup. It is recommended to run this tool multiple times using varying sizes of solar and storage to find the optimal infrastructure capacities for a fleet's duty cycle and vehicle makeup. For DHE, such analysis found that costs could be minimized by increasing both solar and storage capacities simultaneously. If DHE were to increase their battery size from 130 kWh to 2,000 kWh to accommodate future large-scale additions of Class 8 tractors, a larger 3,000-kWh solar capacity would be necessary to both charge the battery and flatten other costs. Solar and battery storage must both be upgraded to support each system without requiring greater grid energy consumption.

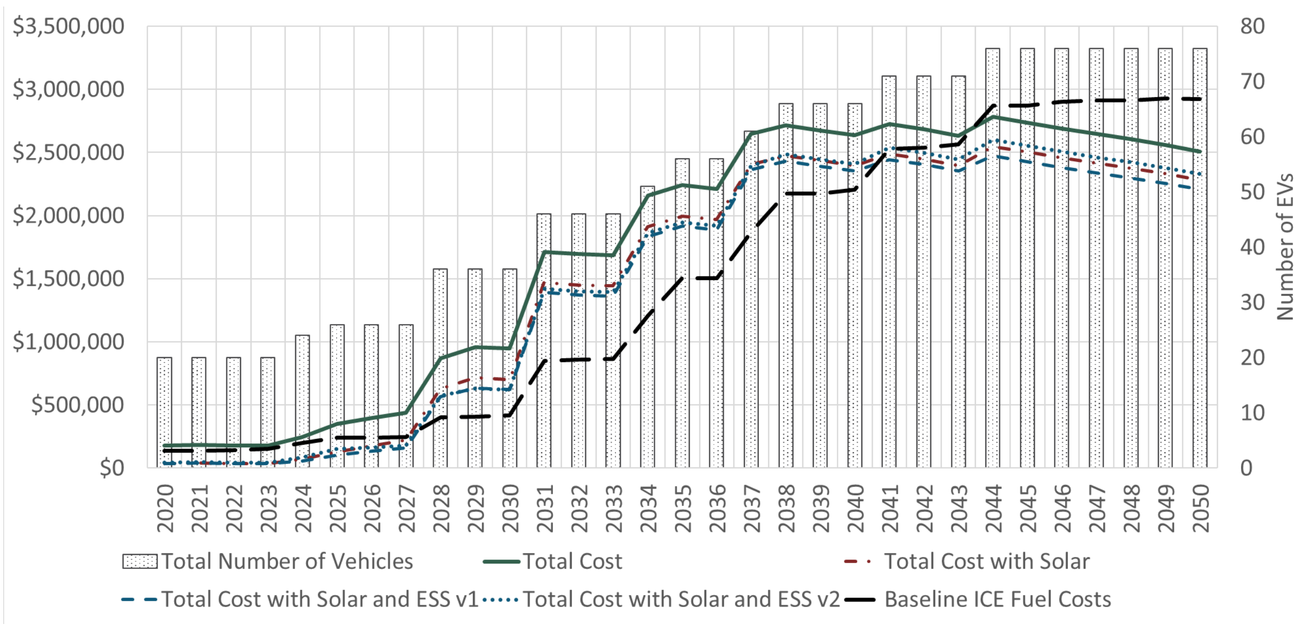
Demand Charge Challenges

One trend apparent throughout the scenario builder tool is that demand charges will be the largest contributor to operating costs over time as more EVs are deployed. Creative solutions through installing energy infrastructure or working with utilities on rate structures will be necessary to mitigate the possibly skyrocketing future demand needs and costs. For mitigating high demand charges, there was no scenario in which batteries could fully offset demand without a large solar array to primarily charge the batteries. Another possible solution could be in different utility rate structures that allow for solar peak shaving accompanying battery peak shaving. However, this solution might sacrifice savings from offsetting electricity costs, meaning multiple iterations should be run through the scenario builder tool to find the best option.

In the cost profile of the scenario builder tool, two scenarios represent operating costs for EV deployments with both solar and battery storage systems. V1 estimates costs based on using solar to mitigate energy costs and energy storage to peak shave demand charges. V2 estimates costs based on using solar and energy storage to shave demand charges in addition to using solar to offset electricity costs. With DHE's current utility rate schedule, solar cannot be used to peak shave demand. The V2 scenario is presented to show how enabling solar peak shaving could influence costs over time. However, the results for this particular case show no greater savings when using solar peak shaving because DHE's greatest demand peaks are outside of solar generating hours. If DHE held more charging sessions within solar generating hours, the solar peak shaving could be a greater demand-charge mitigation tool—but only if the utility allowed for solar peak shaving.

Annual Energy Cost Analysis

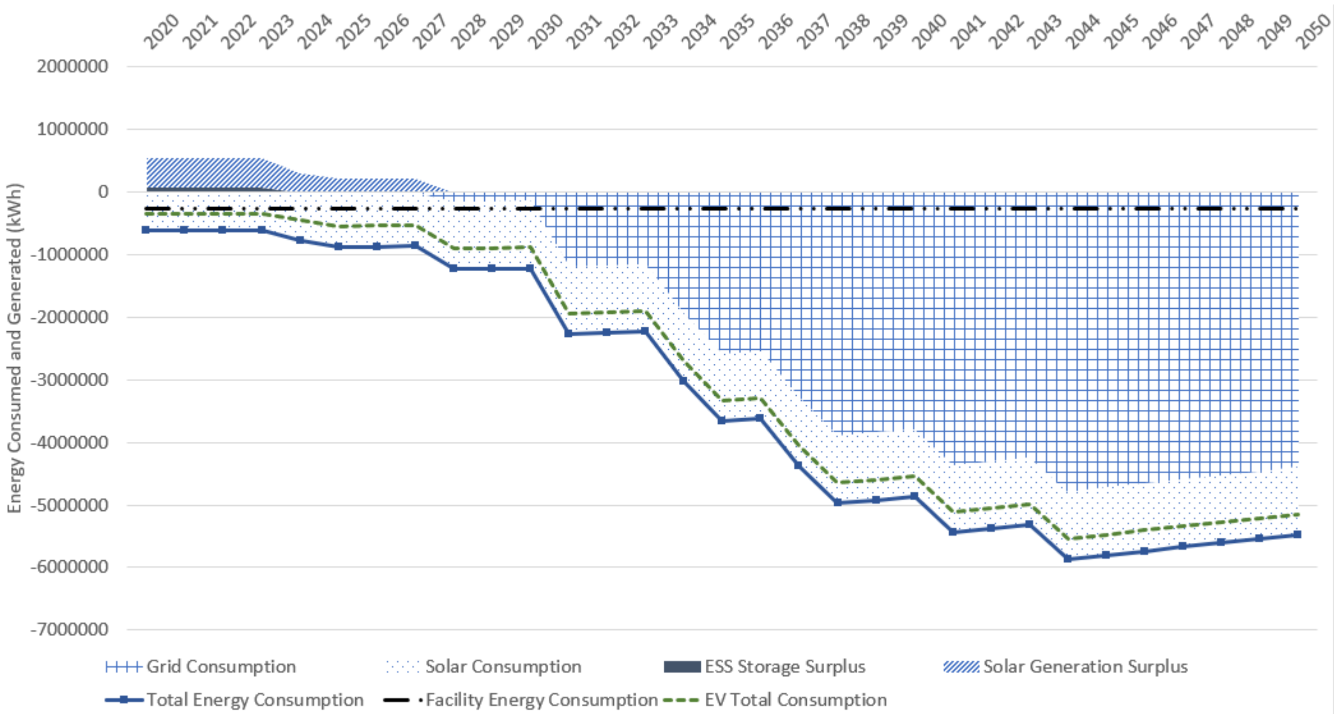
Figure 62: Annual Energy Cost and Demand Charges



The annual energy cost analysis (Figure 62) compares different scenarios of total operating energy costs for a fleet and its facility from 2020–2050. The goal of this analysis is to compare energy costs over time between baseline internal combustion engine vehicles and EV deployments with different infrastructure types, enabling fleets to see the benefits of maximizing energy infrastructure.

Energy Profile Modeling

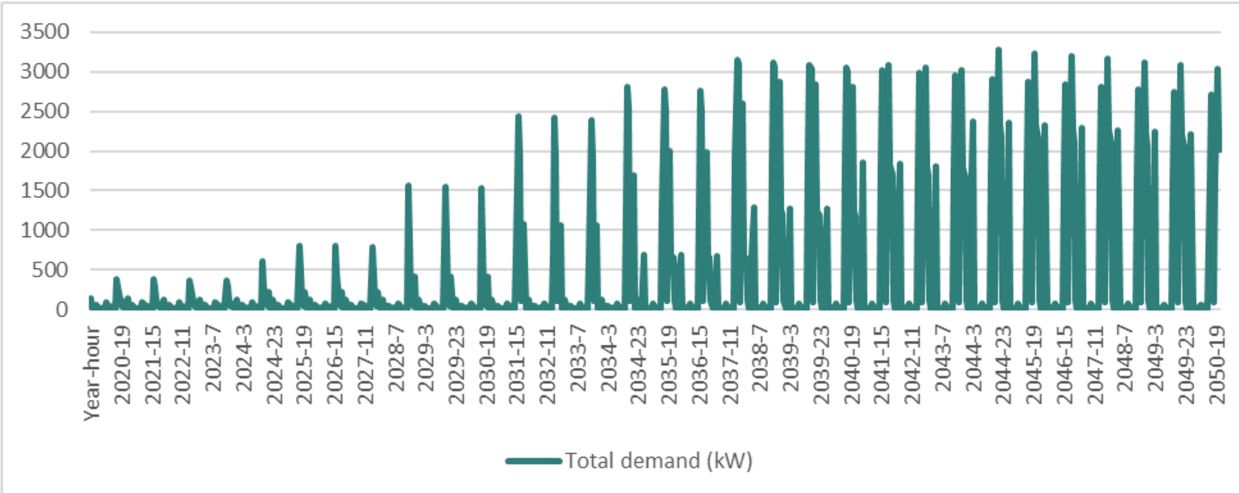
Figure 63: Energy Consumption and Generation Over Time



Energy profile modeling allows fleets to forecast energy consumption makeup, infrastructure capacity, and energy independence over time as electrification expands (Figure 63). High dependency on grid consumption is a signal to high energy costs. In DHE's modeled scenario, upgrading its solar and battery storage system might be needed around 2030 before grid consumption significantly outpaces solar generation. Alternatively, starting with a larger solar system (2,000 kW) might also decrease the need for high grid consumption over the 30-year time span.

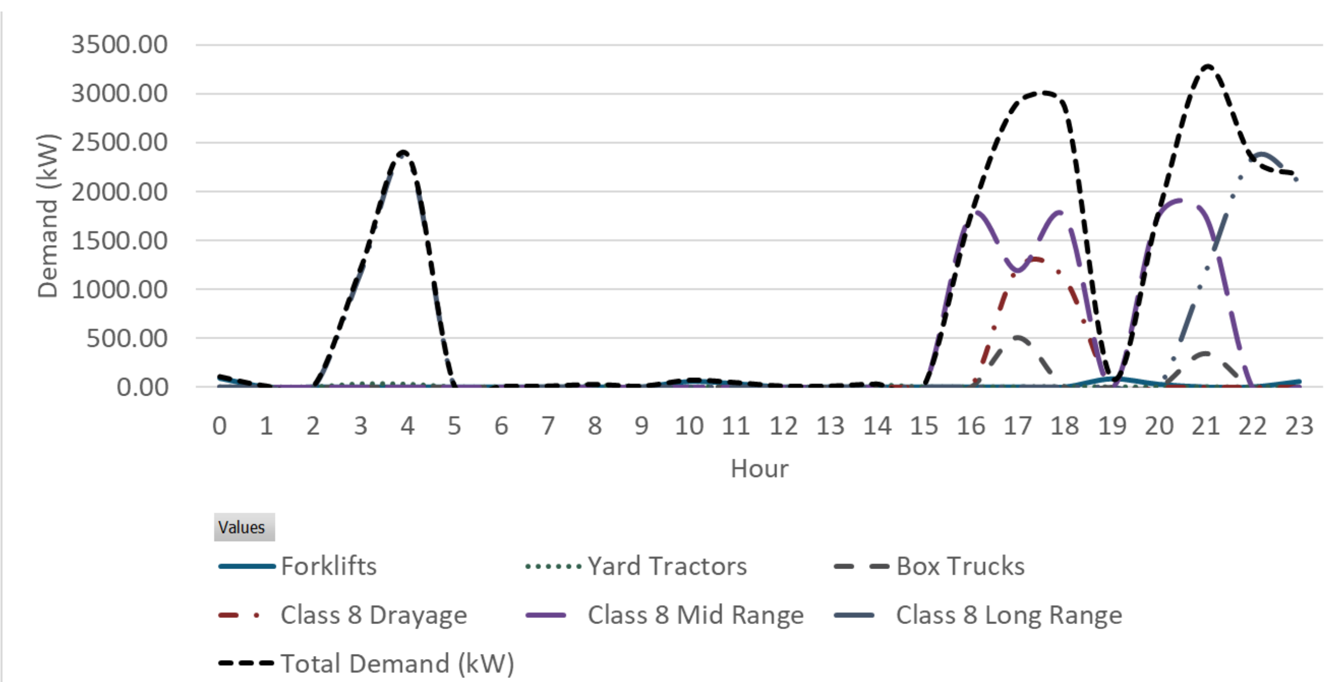
Demand Cycle Modeling

Figure 64: Annual Average Demand Peaks



Based on charging schedule planned in the input section, energy charged is summed for all vehicles in each hour to find the overall demand. Figure 64 shows how average annual demand peaks will increase over time (year-hour) with EV deployment. The scenario builder assumes future vehicles will follow the same duty cycle planned for each type due to restrictions on work schedule. The modeled scenario is more likely to be the maximum demand if charging can be managed to reduce overlap.

Figure 65: Fleet Daily Duty Cycle



Average daily duty cycle (Figure 65) is presented by gathering data inputs on when vehicles charging occurs. Analyses demonstrated in Figure 65 were used to plan for DHE's duty cycle. This chart helps to inform the estimates for TOU costs, demand charges, and overall energy consumption over time. Fleets may refer to the generated figure to adjust planned duty cycle and charging schedule to lower peak demand and to avoid overlap charging and on-peak hours.

Market Analysis

Sustainable Supply Chains

CALSTART acknowledges the private sector's increased goals and plans to create sustainable supply chains and reduce related emissions. To increase sustainability, the current supply chain must be evaluated so that long-term sustainability goals can be created, key performance indicators (KPIs)can be used to measure progress, and partners within the supply chain can work together to ensure success.

When creating long-term sustainability goals, one approach to reducing associated emissions is to replace diesel drayage and regional delivery trucks with ZE alternatives. DHE and NFI have moved forward in starting to obtain these vehicles. As these major companies seek ZE supply-chain solutions, they could provide a catalyst for others to pursue these strategic opportunities.

The United Nations Global Compact defines a sustainable supply chain as one that manages its social, economic, and environmental impacts across goods and services lifecycles, along with maintaining good-governance practices.[26] A sustainable supply chain creates long-term value for stakeholders across the social, economic, and environmental areas of a business. Creating and maintaining a sustainable supply chain will ensure the ability to meet future needs; comply with current and upcoming regulations and laws regarding sustainable business practices; and meet societal and customer expectations for reducing social, economic, and environmental impacts, earning good will. The Global Compact also refers to supply chains as the "engines for today's global economy," making them important for increasing sustainable practices. In the supply chain, sustainability focuses include human rights, labor, good government, and the environment.

Regarding the environmental aspect, sustainability in a supply chain can be increased in a few ways. Writing in Harvard Business Review, Verónica H. Villena and Dennis A.

[26] Supply Chain Sustainability A Practical Guide for Continuous Improvement. United Nations Global Compact. 2015.
https://d306pr3pise04h.cloudfront.net/docs/issues_doc%2Fsupply_chain%2FSupplyChainRep_spread.pdf

Gioia emphasize the importance of creating long-term goals for sustainability.[27] They also suggest that suppliers set sustainability goals of their own. Doing so reiterates the importance of sustainability within the whole supply chain. It also helps ensure that all parts work together to increase sustainability, rather than having one part of the chain implement sustainable practices while another continues unsustainable practices. Thus, dedicated sustainability managers not only manage a company's own internal goals but also help ensure that suppliers have their own sustainability goals. A sustainability manager can track progress toward goals and offer help and support to suppliers working on their own goals.

Another way to drive sustainability within a supply chain is when competitors and major suppliers collaborate to create industry-wide standards. An example is the Responsible Business Alliance.[28] The alliance, which includes Intel, HP, IBM, Dell, Philips, and Apple, focuses on increasing sustainability within global supply chains.

Prologis, a leading real estate, construction, and development logistics solutions and services company, also notes the importance of sustainable supply chain management, as well as corporate social responsibility.[29] Supply chain management creates partnership opportunities, improves productivity, and lowers costs. Companies can save money by making buildings, machinery, and vehicles more efficient.

To implement sustainable supply chain management, Prologis recommends first creating sustainability goals and a plan to reach targets—an approach similar to Villena and Gioia's recommendations mentioned above. Prologis has set goals in three categories: environmental sustainability, social responsibility, and governance. One sustainability goal is to reduce total scope three GHG emissions by 15% of the 2016 baseline. Prologis has a target of reaching this goal by 2025. The progress tracked shows a 37% reduction between 2016 and 2020.[30]

Because supply chains can have a big impact, it is important to include them in overall sustainability goals. It also helps to create a sustainability policy that suppliers follow. The next step is to evaluate the existing supply chain, while monitoring progress on sustainability goals and following through with changes to make the supply chain more sustainable. New options can be utilized as needed, as well as working with partners to use more sustainable practices.

---

[27] A More Sustainable Supply Chain. Harvard Business Review. 2020. https://hbr.org/2020/03/a-more-sustainable-supply-chain
[28] Responsible Business Alliance. http://www.responsiblebusiness.org
[29] The Importance of Sustainability in Supply Chain Management. https://www.prologis.com/what-we-do/resources/sustainability-in-supply-chain-management
[30] Environmental Goals and Accomplishments. Prologis. 2022. https://www.prologis.com/sustainability/sustainability-goals-progress

One way to monitor and maintain sustainability goals and reach planned targets is to report targets and process to CDP, a global nonprofit.[31] CDP has created a disclosure-and-grading system for environmental reporting, and it works with various groups, including cities, states, investors, and companies. The benefits of using CDP's reporting system include identifying unknown environmental risks and opportunities in a supply chain, tracking and benchmarking progress with an annual report, and earning recognition and a score through the program.

Best Practices

The Volvo LIGHTS Project has outlined best practices for creating a sustainable supply chain, drawing on common themes found by HBR, Prologis, and iWMS Supply Chain Solutions.[32]

- Map and evaluate the current supply chain: Understanding the supply chain will help reveal where improvements to sustainability could be made and the location of negative impacts on sustainability.
- Create long-term sustainability goals, with a designated sustainability manager to maintain and manage these goals when possible: Even when hiring a designated sustainability manager may not be feasible for a company, it helps to have a stated policy for partners within the supply chain. These policies should align with the company's overall vision and strategy. They also should be shared with stakeholders to encourage their buy-in.
- Create KPIs for sustainability goals: KPIs provide a good way for a sustainability manager to monitor progress toward sustainability goals. KPIs also point to ways a company can improve. In part, companies can track KPIs by leveraging existing technology—for example, a warehouse management system or a transportation management system.
- Work with current partners: This is key to increase the sustainability of a supply chain. It means including other companies both upstream and downstream—such as suppliers, manufacturers, shippers, and more—in the supply-chain strategy and gaining their support. Having each partner create its own sustainability goals will help to achieve a cohesive overall sustainable supply chain.

Business Drivers

Increasing the sustainability of supply chains can yield business benefits (Figure 66). Oracle NetSuite has identified some of these benefits, including lower energy costs in

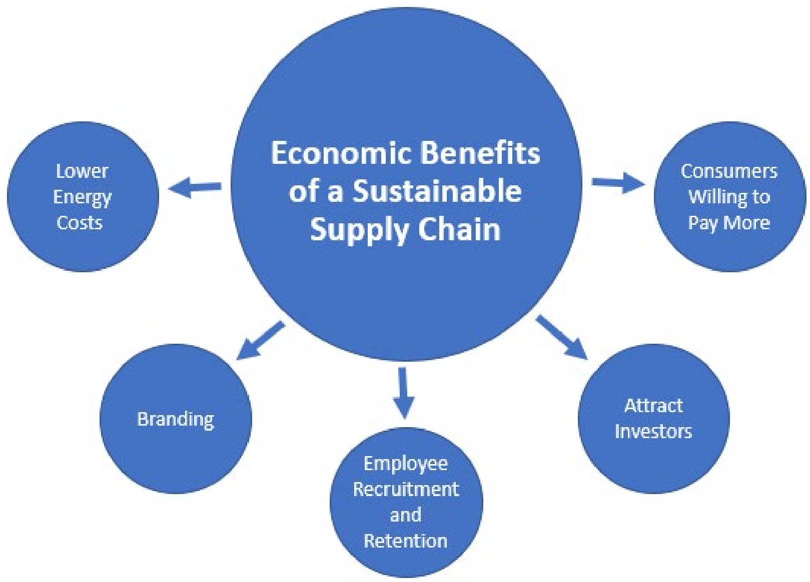
---

[31] CDP Home Page. https://www.cdp.net/en

[32] 6 Best Practices for Supply Chain Sustainability. iWMS Supply Chain Solutions. 2019. https://www.iwmsglobal.co.nz/blog/supply-chain-sustainability

supply-chain operations.[33] Another is branding: consumers will pay more for products made with transparent and sustainable supply chains. Branding for sustainable practice can also help a company recruit and retain employees: people want to work for companies with desirable practices and values. Investors, too, are interested in sustainable investments.

Figure 66: Economic Benefits of a Sustainable Supply Chain



According to SmartWay, an Environmental Protection Agency (EPA) program that helps companies advance supply chain sustainability, using oil and other fossil fuels as energy sources can lead to large operational costs for freight and operations.[34] Using oil and other fossil fuels is also a source of CO2, NOx, and PM, leading to costly environmental and health impacts. Creating and using a sustainable supply chain can help reduce costs and mitigate supply-chain risks and emissions. Consolidating loads, switching to intermodal transport, and working with fleets implementing ZEVs, such as DHE and NFI, can all help to reduce the large operational costs of using fossil fuels as a main energy source as well as reducing the associated emissions. As noted, reporting increases in sustainability and reductions of emissions can help attract investors, stakeholders, and staff.

[33] Supply Chain Sustainability: Why It Is Important & Best Practices. Oracle Netsuite. 2021. https://www.netsuite.com/portal/resource/articles/erp/supply-chain-sustainability.shtml
[34] Introducing Corporate Social Responsibility to Freight and Logistics. EPA. https://www.epa.gov/smartway/introducing-corporate-social-responsibility-freight-and-logistics

A sustainable management system for transportation can be either internally created or purchased. One company that has implemented a sustainable management system is PLS Logistics Services. PLS works with all major freight modes from trucks, rail, barge, and intermodal equaling over 1 million loads per year.[35] PLS works with both shippers and a network of fright carriers to improve and streamline sustainable supply chains.[36] PLS, which has created its own sustainable transportation management system, PLS PRO, describes several business benefits of a sustainable supply chain. Available for purchase, PLS PRO enables PLS to pinpoint not only blind spots but also opportunities to use cleaner types of transportation, consolidate loads, and reduce fuel use. Optimizing routes can also lead to savings and reductions in emissions. Warehouse optimization enables a company to save energy within the warehouse, bringing down energy costs and promoting consolidated loads that reduce fuel usage and avoid excess operations.

California Green Shippers List and Sources

CALSTART has created a list of shippers that either have sustainability goals or have specific transportation goals and may seek to hire fleets working toward ZE and other sustainability goals (see Appendix D: California Green Shippers List). The list draws on four main sources: Business for Social Responsibility (BSR), SmartWay, EV100, and the Zero Emission Transportation Association (ZETA). All four programs have missions to help companies become more sustainable. Companies on this list of shippers with sustainability and transportation goals may be looking to partner with fleets, such as DHE and NFI, that are deploying ZEVs to make the company's supply chain more sustainable.

- BSR's mission focuses on creating a more sustainable and just world through its work with various companies.[37] It also believes in a world where everyone can live well without depleting Earth's natural resources.
- SmartWay, operated by EPA, works to increase supply-chain sustainability across the country.[38] It creates tools to measure, benchmark, and improve the efficiency of freight transportation. SmartWay also maintains a list of "high performers," capturing which companies in the program are the most efficient.
- The mission of EV100, an initiative of The Climate Group, focuses on bringing together companies across the globe that are committed to electrifying their fleets and implementing charging infrastructure for both customers and

---

[35] About PLS. PLS. https://www.plslogistics.com/about-us
[36] 3 Steps For Sustainable Logistics Practices. PLS. https://www.plslogistics.com/blog/3-steps-for-sustainable-logistics-practices
[37] Member List. BSR. https://www.bsr.org/en/membership/member-list
[38] SmartWay. EPA. https://www.epa.gov/SmartWay

employees by 2030.[39] Bringing these companies together will help speed up the market for EVs, thereby increasing affordability and helping encourage widespread adoption.

- ZETA has a goal of reaching 100% EV sales by 2030.[40] ZETA focuses on engaging with advocates, industry, and organizations that share the goal of electrification. The companies brought together by ZETA work on federal advocacy, education, and stakeholder engagement to promote the adoption of EVs.

Sustainable Fleets

CALSTART's Sustainable Fleets program defines clearly what it means to be a sustainable fleet by setting objective, meaningful standards and guidelines.[41] The program was designed by fleets for those interested in setting and reaching clean transportation goals. This program is flexible enough for those seeking to start a sustainable fleet program and those seeking to improve already successful programs. The Sustainable Fleets program will provide resources to fleets to support and achieve their evolving sustainability goals.

CALSTART aims to become the worldwide green standard for recognizing fleet transportation improvements in air quality through reducing emissions, increasing the use of ZE technology, and introducing infrastructure to support ZE fleets. The goal of the Sustainable Fleets program is to accelerate adoption of ZE vehicles and low-carbon fleet operations. There is no one approach to sustainability: fleets set the strategy, and the program measures the results.

What Is a Sustainable Fleet?

CALSTART defines a sustainable fleet as one that reduces net environmental impacts from fleet operations at or ahead of the pace required for environmental need by:

- Improving air quality through reducing emissions;
- Introducing ZE fleet infrastructure; and
- Adopting ZE technology.

The Sustainable Fleets Accreditation Program provides a level playing field by setting standards for all fleets, regardless of industry, size, location, or composition. Every enrolled fleet is assessed on its own progress and real actions.

[39] Making electric transport the new normal by 2030. Climate Group. https://www.theclimategroup.org/ev100
[40] ZETA Home Page. https://www.zeta2030.org/
[41] Sustainable Fleets Program. http://sustainablefleets.org/

The program provides a methodology and tools to help fleet managers measure efficiency, fuel reduction, and emissions reduction while making it possible to track progress. The program serves as a guide to help set a course for continual improvement. For fleets starting sustainability efforts, the program offers easy entry; for fleets with robust sustainability programs, it is sophisticated enough to recognize them for their efforts.

CALSTART is creating a "Sustainable Fleets to Hire" list composed of fleets that go through the sustainable fleet accreditation process and either meet or exceed CARB's Advanced Clean Fleets (ACF) rule, which is in development. A shipping entity will be able to use this list to find fleets with demonstrated sustainability efforts, helping it meet its own sustainability goals.

Earning a high score and a place on the "Sustainable Fleets to Hire" list is one of many benefits to DHE and NFI from joining the Sustainable Fleets program. Others include a fleet report card and feedback specific to their fleets, gaining insight on future fleet planning for increasing sustainability. Accredited sustainable fleets also have access to CALSTART tools and resources to help a fleet progress in its sustainability journey.

Regulatory Drivers

California has two main regulatory drivers for electrifying fleets that are overseen and regulated by CARB: the ACT regulation and ACF regulation.

The ACT regulation focuses more on manufacturers and their ZEV sales.[42] It sets targets that begin in 2024: increasing ZEV sales to 55% of Class 2b–3 trucks, 75% of Class 4–8 straight trucks, and 40% of truck-tractors by 2035. Large fleets, with 50 or more trucks, have a one-time reporting requirement on existing fleet operations to identify strategies that enable them to purchase ZEVs in the future. The ACT regulation helps CARB reach its emissions-reduction goals as outlined in the Sustainable Freight Action Plan, State Implementation Plan, Senate Bill 350, and Assembly Bill 32.

CARB is currently developing the ACF regulation.[43] This regulation targets MD and HD fleets in order to achieve California's goal of ZE truck and bus fleets by 2045 where feasible. CARB also says that last-mile and drayage fleets should achieve zero emissions before 2045. This regulation starts with a focus on fleets considered high priority and fleets that are ideal for early adoption, as well as the entities that hire them and subhaulers. High-priority fleets are those that have a gross annual revenue of over $50 million or a fleet that owns, operates, or dispatches 50 or more vehicles. California and CARB use the ACF regulation to help achieve the goal of transitioning to ZEVs as soon

[42] Advanced Clean Trucks. CARB. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks
[43] Advanced Clean Fleets. CARB. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets/about

as possible by accelerating purchases of MD and HD ZEVs. The ACF regulation's percentage of fleets that must be ZEVs varies by type of vehicle and increases throughout the years (Table 108).

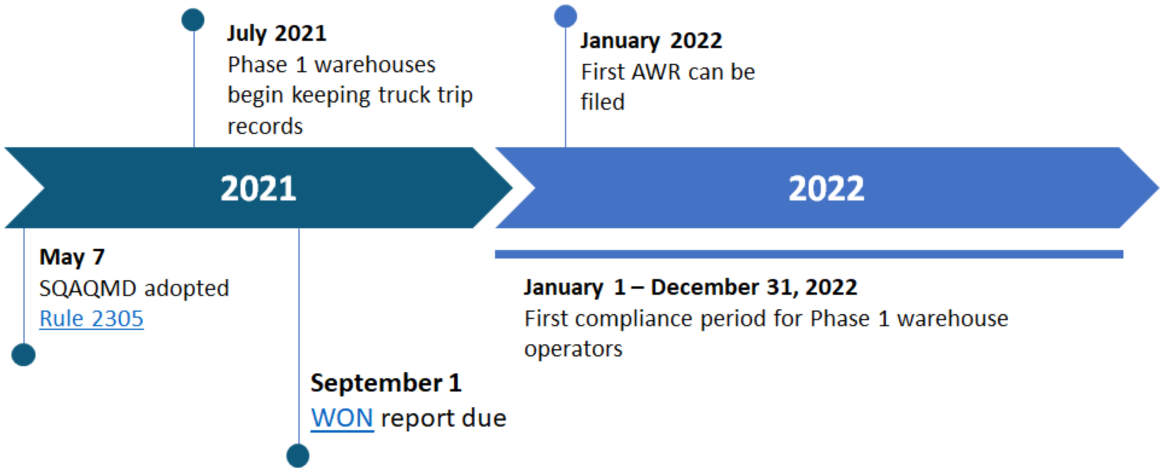
Table 108: ACF Regulation ZEV Percentage Timeline

Percentage of Fleet that must be ZEV	10%	25%	50%	75%	100%
Box trucks, vans, two-axle buses, yard tractors	2025	2028	2031	2033	2035
Work trucks, day cab tractors, three-axle buses	2027	2030	2033	2036	2039
Sleeper cab tractors and specialty vehicles	2030	2033	2036	2039	2042

Another key regulatory driver for California fleets within SCAQMD is Rule 2305, the Warehouse Indirect Source Rule (Figure 67).[44] Rule 2305 establishes the Warehouse Actions and Investments to Reduce Emissions (WAIRE) Program and requires warehouse operators and owners to create emissions-reduction plans. The rule, pertaining to warehouses with more than 100,000 square feet of indoor floor space, requires them to report facility operations and comply with completing WAIRE program actions or pay an annual mitigation fee. The mitigation fee will be used to create incentives for ZE charging, fueling infrastructure, and vehicles in communities surrounding the warehouse paying the mitigation fee. WAIRE is the first regulation of its kind that aims to reduce emissions by placing the liability on the warehouses, incentivized to continue operating and make a profit. This forces facilities to reevaluate not only their own fleets but also partners entering the facility.

[44] WAIRE Program. SCAQMD. http://www.aqmd.gov/home/rules-compliance/compliance/waire-program

Figure 67: Timeline for the Warehouse ISR Rule Roll Out 2021–2022



Rule 2305 was adopted and took affect during the deployments at DHE and NFI. Warehouses over 100,000 square feet were required to collect WAIRE points based on a menu of action items that warehouses could take in electrifying.

DHE and NFI Impact and Feedback

The WAIRE program will not directly affect DHE's Ontario facility due to size, but it will impact the main Los Angeles facility. The feedback received from the fleets was mixed; some fleets expressed uncertainty and frustration in being held responsible for these changes, with potential implications for business operations and additional expenses to already high costs of operating in SCAQMD territory. NFI has mentioned that investing in yard tractors has been one of the most beneficial investments for meeting the rule's requirements. The success of NFI's experience should encourage similar fleets to start electrifying with this type of technology. A benefit of electric yard tractors is a high amount of WAIRE points available for their purchase or onsite use annually (Table 109). Points are available within the WAIRE menu for purchasing one yard tractor and using one for 1,000 hours annually. With the purchase of multiple yard tractors and using them daily, NFI found this a beneficial way to meet the requirements of the Warehouse ISR Rule.

Table 109: Warehouse ISR WAIRE Menu Yard Tractor Items

WAIRE Menu Item	WAIRE Menu Sub-Item	Reporting Metric	Annualized Metric	WAIRE Points	Discounted WAIRE Points for Transfer Rule 2305 Subparagraph (d)(6)(A)
Acquire ZE Yard Tractor	Purchase Yard Tractor ZE	Number of Yard Tractors	1 Truck Purchased	177	177
Use ZE Yard Tractor	Onsite Yard Tractor Use ZE	Hours of Use	1,000	291	51

IX. Lessons Learned

Deployment and Performance

Infrastructure (Chargers, Solar, Storage, and Site Controller)

Figure 68: ABB Charger Cabinet with Three Dispensers

- Clear expectations and communication with contractors can help avoid unnecessary delays: There were several delays related to installation, testing, and permitting of the solar and energy storage systems. Most delays could have been avoided with clearer communication between the project manager, the fleet, the subcontractors, and the utility. Scheduling regular check-ins and setting clear expectations with the project stakeholders can help mitigate communication breakdowns and avoid potential delays.
- Not all chargers are created equal: The DHE facility manager noted that each charger type had unique spacing requirements that are important to understand and consider during the design process. Furthermore, charging frequency and operation can also influence these decisions. Forklifts, for example, are in constant use both day and night, and spacing out the chargers would have allowed multiple forklifts to utilize the same charger. Providing additional spacing, in this case, would not have addressed the need to charge multiple forklifts at once. In addition to space constraints, ABB chargers for the HD trucks could only do sequential charging, meaning only one vehicle could charge per cabinet, despite each cabinet having three dispensers (Figure 68). Smart charging that allows the fleet to charge sequentially or all at once at differing power levels offers significant operational flexibility and cost-saving potential.
- Designing and permitting multiple infrastructure solutions independent of one another may mitigate potential delays: The solar and energy storage systems were coupled and permitted as one system during the original installation. Although coupling the systems together saved administrative time of submitting two different designs and permitting applications, this approach caused further delays. Due to the utility's concern with unexpected battery discharges to the grid and requirement of several system tests, ESS permitting took longer than expected. Because DHE's ESS and solar array were coupled, the solar array could not be

energized, leading to two to four months of lost renewable energy generation. Ultimately, the solar system was decoupled and permitted separately from DHE's ESS so that it could be energized while the ESS battery tests were conducted. DHE's ESS was energized a few months later.

- Operational resilience: EVs are more vulnerable to power/fuel outages than traditional vehicles running on gasoline. At DHE, backup diesel generators are available for use during unexpected power outages. During the project period, DHE had one outage event caused by a person working onsite. The accident did not affect operations, and power returned before an issue arose. Moving forward, the fleet manager is interested in installing more ESSs to collect energy at low-rate periods and distribute it at high-rate periods for both cost and power-backup purposes.
- Data collection platforms: Greenlots' SKY platform was intended to be the primary data collection platform for charging. Due to connectivity issues leading to missing and unreliable data, a combination of vehicle, submeter, and Accuenergy data were used instead. Submetering for VNRs and workplace charging was outside of scope. DHE paid extra to install submetering for VNRs and workplace charging, which assisted in identifying large data gaps between the two platforms. It is therefore recommended, at this point of technology development, to use two points of data collection methods to increase confidence in data and mitigate possible data discrepancies or collection failures.

Vehicles (VNRs, Forklifts, and Yard Tractors)

- EVs may have different load capacities: The current EV models of forklifts and box trucks have less load capacity than their propane and diesel equivalents; while this difference did not impact operations, fleets should be cognizant of the weight loads for electric technologies.
- Low profile battery pack caused limited vehicle accessibility: Drivers of DHE's electric box truck shared a complaint that the battery pack was too low to the ground, making certain terrain and driveways more difficult to navigate. This feedback was communicated to Volvo as a potential improvement for their next generation of box trucks.
- Benefits of regenerative braking: Volvo's VNRs offer three modes of regenerative braking, ranging from zero to 100%. Currently, the majority of VNR drivers do not use full regenerative breaking. Based on the recommendation from the mechanics, it is encouraged to operate vehicles in the max regenerative mode to maximize performance and range. Drivers not using this functionality should be

educated that regenerative braking can add an estimated 5-15% to a vehicle's range.

- Considerations for range: After confidence in the Volvo VNRs durability was established, DHE's dispatcher was advised to place them on longer routes. Even short opportunity charges can have a great impact on range, with operators reporting a 40-minute charge providing 80% SOC. Fleets should expect range capabilities to improve slightly as operators become more familiar with the technology and strategically take advantage of opportunity charging and regenerative braking and learn how driving practices impact SOC. Quick accelerations can be a major drain on the battery.
- Optimizing operations using vehicle data: Using real-world data captured from early EV deployments will allow fleets to optimize EV performance and develop a more robust electrification roll-out plan. As an example, SOC data at DHE suggested that the HD trucks could run slightly longer routes, perhaps reaching daily mileages in the low hundreds and retaining SOC above 25%. Range can be affected by a multitude of factors and therefore it is recommended for fleets to pilot a few vehicles to gather important data and learnings from their specific duty cycles and environment.
- Driving EVs had a variety of performance benefits compared to baseline vehicles: Drivers noted that EVs had a smaller turning radius, improved braking, and lower center of gravity than the baseline vehicles. They also appreciated the quieter operation of EVs in addition to the elimination of emissions and fuel residue, which drivers were typically exposed to while operating baseline vehicles.
- Range is still a significant limitation for an electric HD on-road truck: A maximum range of 90 miles per charge or 150-200 miles including opportunity charges limits the routes electric trucks can run. Returning to base during the operator's lunch break for an opportunity charge helps increase range. Future models are expected to have increased range, lighter battery weight, and lower costs.
- Weight loads: Volvo's pilot box truck has a cargo weight of 8,500 lbs.; its diesel equivalent has a 12,500-lbs. cargo weight. While the trucks were not completely filled, the facility chose to wait for the newer box truck model rated at 11,000 lbs.
- Drivers found it difficult to adapt to regenerative braking: Surveys on braking performance went from "somewhat worse" to "much worse" (by percentage) over the course of the demonstration, with the exception of DHE yard tractors. Unlike conventional vehicles that coast when the accelerator is released, EV breaking mechanisms made the transition to a stop more abrupt, which was new for drivers. Operators suggested adding a braking assist. Braking performance at

DHE was perceived more positively, and Round 2 survey responses noted braking was smoother. Braking was perceived positively for box trucks and Class 8 tractors and attributed to the overall smoother ride, though drivers also needed to become accustomed to regenerative braking.

- Idling management can prevent unnecessary battery drain: Idling consumes energy and should be minimized if possible. Initially, electric yard tractors were left idling while trailers were being loaded. Sometimes, drivers had exited the yard tractor while it was idling. The fleet opted to update the vehicle's programming to shut off automatically after a period of idling, saving energy and charging costs.
- EVs are more efficient and cost less to fuel: Electric box trucks saved approximately $2,000 in fueling costs per year. If LCFS credits were included, a fleet could save up to $7,100 per year per box truck in fueling costs alone.

Charging Practices

- Opportunity charging allowed for more seamless EV integration: Despite DHE's initial concerns regarding how charging would affect operations, opportunity charging between shifts and during breaks allowed for a more seamless EV integration and more available range. Class 8 tractors also fit well into drivers' lunch breaks; dispatchers had to schedule the tractors to return to base so they could charge overnight.
- Managed charging can decrease operating costs: SCE's on-peak rate is nearly 3.8 times the off-peak rate in summer, and the mid-peak rate in winter is three times more than the super-off-peak rate. Managing when vehicles charge can help to ensure charging is primarily done during off-peak hours. In SCE territory, peak hours are 4 p.m. to 9 p.m., so charging before 4 p.m. or after 9 p.m. can result in significant cost savings.
- Importance of mitigating demand charges: Demand charges can significantly raise energy costs when not managed properly. While DHE and NFI both received demand charge exemptions, they will be reintroduced into their EV rate plans starting in 2024, charging fleets based on their max monthly power demand (kW). To minimize demand charges, fleets can (1) stagger charging times for their larger equipment, (2) charge equipment at a lower power if operations permit longer charging times, and (3) consider installing ESSs for peak demand shaving.
- The charge connector matters: Kalmar yard tractors at NFI had significantly long and heavy charging connectors that were difficult to use because of the weight and effort needed to connect. They were also potentially hazardous, being difficult to tuck away and were often left lying on the ground. Charging speeds

over 70 kW can help limit charging times to about two hours (depending on the vehicle's battery capacity), and OEMs are encouraged to ensure chargers are light-weight and easy to use.

- Forklift charging: Charging times were largely driven by work shifts. At DHE, optimized opportunities for charging aligned with an eight- to 12-hour shift. Workers were encouraged to charge during lunch or shorter breaks. However, users found that this was not enough, especially for vehicles like forklifts that took an hour or more to charge. Users then suggested increasing the number of forklifts so that more units would be available to rotate through. However, at NFI, forklifts were used only in the first shift and opportunity charging was not as essential to maximizing operation. These different use cases provided an opportunity to evaluate the varied use of the electric forklifts based on the fleet's individual needs.

Maintenance

- Adequate training for maintenance staff is essential for a smooth rollout: It is important for fleets to provide training and hands-on experience for maintenance staff to safely and competently perform repairs and maintenance on EVs. While the transition for vehicle operators to EVs seemed relatively smooth, feedback suggests that maintenance staff should receive additional training on the high voltage components for these vehicles to prepare for the transition.
- Close proximity to an OEM service shop was invaluable: The proximity and maintenance support provided by TEC Equipment was invaluable to meet the service needs of fleets. The few times the Class 8 tractors broke down and had to be towed to the service center, the process was quick and seamless. TEC could be reached 24/7 to either tow the truck back to the maintenance facility or go to the fleet to perform maintenance. If the electric truck was down for a prolonged amount of time, TEC would deliver a temporary diesel truck for the fleet to operate.
- Less maintenance can lead to significant cost savings: Electric forklift maintenance costs were reduced by 64% compared to the propane forklifts, and electric yard tractor maintenance cost about 75% less than diesel yard tractors. TEC Equipment technicians estimated Class 8 diesel tractor maintenance costs of $5,000 in Year 1 and gradually increase to $10,000 by Year 5. In comparison, they estimated EV maintenance costs at $500 for five years of operation. It should be noted that EVs were compared to older diesel vehicles, and maintenance costs usually increase over the lifetime of a vehicle. As EVs age, time will tell if EV maintenance costs remain considerably lower than baseline vehicles as expected.

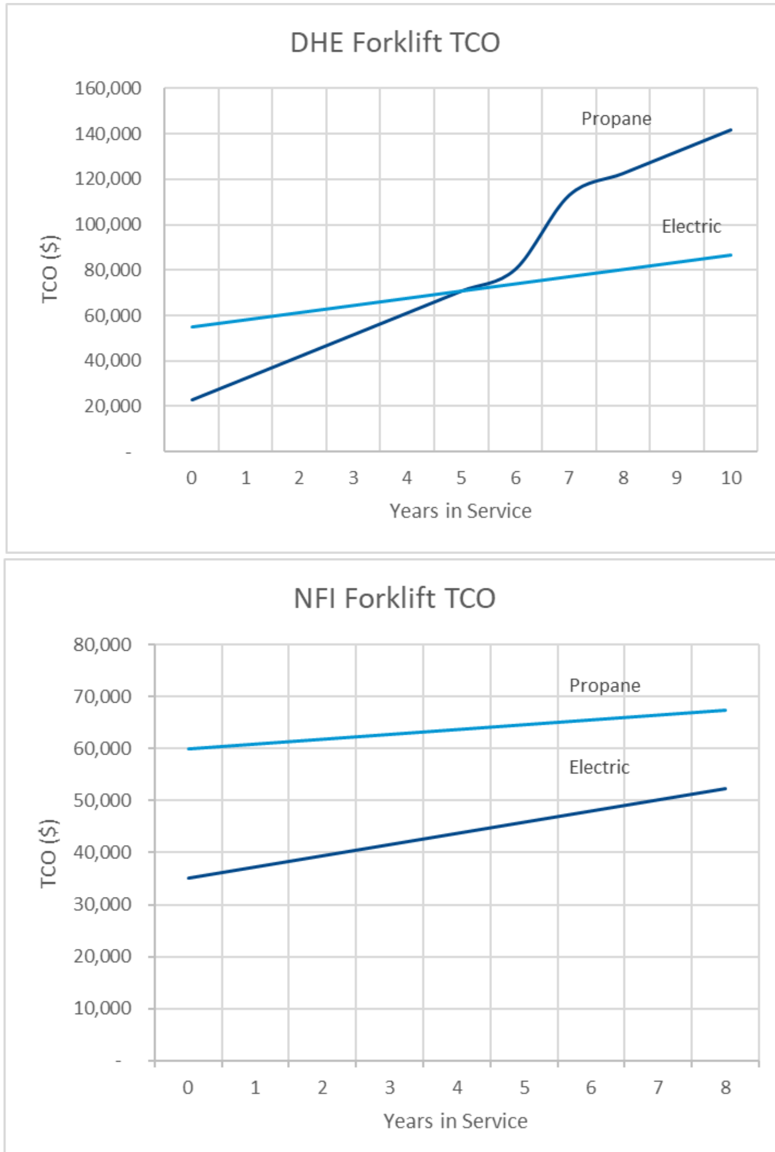
TCO

To compare the lifetime costs of battery-electric and baseline equipment, a TCO analysis was performed. This section pulls together various findings—upfront cost, annual fueling costs, and much more—to estimate the cost of operating electric and baseline equipment performing their real duty cycles at each fleet. A TCO analysis gives a fleet insight regarding the relative costs of different equipment types, helps identify the key sources of costs, and provides recommendations on how to minimize electric costs while planning strategically toward fleet-wide electrification.

Forklifts

- At DHE, it would take an estimated 9,900 hours of operation for electric forklifts to reach cost parity. At NFI, it would take about 6,000 hours of operation. Figure 69 shows TCO for forklifts at each fleet and whether cost parity is achieved.

Figure 69: DHE and NFI Propane and Electric Forklift TCO



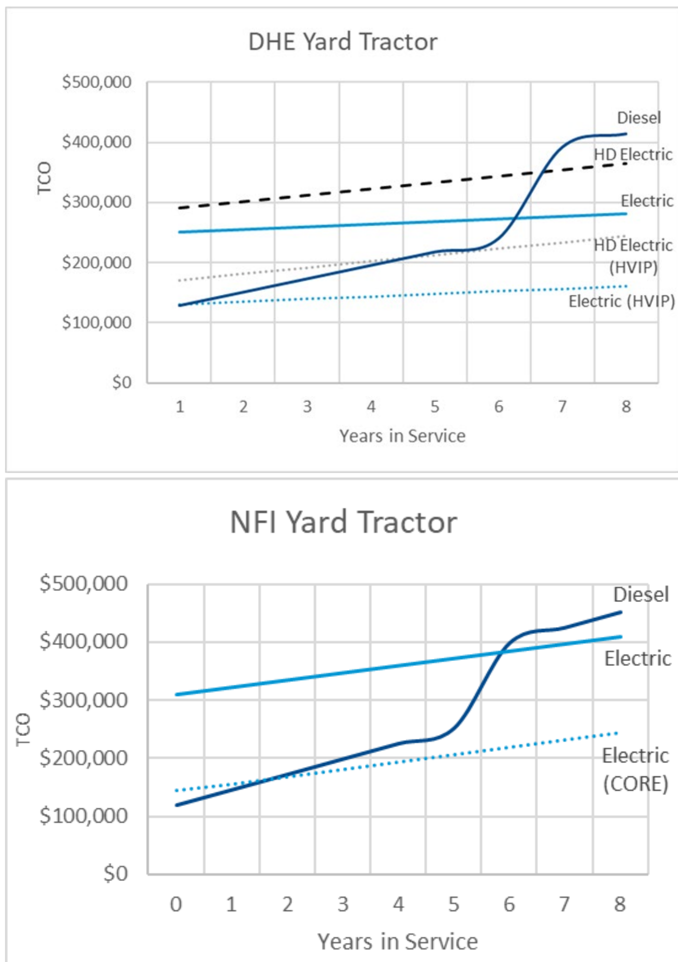
- DHE electric forklifts are expected to achieve cost parity in less than five years. By Year 10, the expected life of DHE's electric forklifts, the fleet will save about $60,000. Having transitioned all 14 forklifts in its fleet to electric, DHE will save an estimated $825,000 over 10 years of operations.
- NFI's electric forklifts are not expected to achieve cost parity over their eight years of service. As stated above, electric forklifts have higher upfront costs and save money during operations, making cost parity a function of hours in service. NFI's forklifts only averaged about 320 hours per year, not allowing them to recoup costs on cheaper fueling and maintenance.

- If highly utilized, electric forklifts can save fleets hundreds of thousands of dollars. If not placed in high-utilization duty cycles, they may always cost more than propane forklifts. Fleets are encouraged to operate electric equipment as much as possible to take advantage of their cheaper operating costs compared with baseline technology.

Yard Tractors

- Electric yard tractors cost about 2 to 2.5 times more than diesel upfront and cost 1.6 to 2.6 times less than diesel yard tractors in annual operations. Figure 70 below shows yard tractor TCO at each fleet.

Figure 70: DHE and NFI Diesel and Electric Yard Tractor TCO



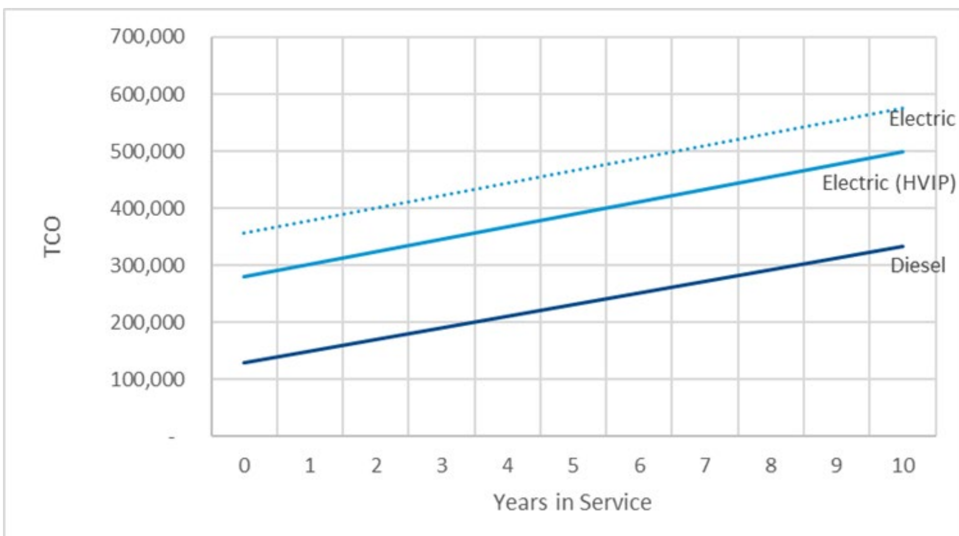
- Under all battery capacities and even without HVIP funding, the electric yard tractors are expected to achieve cost parity with diesel yard tractors. The 80-kWh yard tractor reaches cost parity more quickly than the 160-kWh yard tractor due to its lower upfront cost. HVIP funding has a major impact on TCO.

- Both fleets believe the yard tractors are the best vehicles to electrify, noting significant cost savings, operator satisfaction, and emissions benefits. Additionally, operating at the yard itself allows for easy access to opportunity charging. DHE has already converted its entire Ontario fleet of yard tractors to electric, and NFI plans to do so over the next few years.

Box Trucks

- Annual insurance costs are estimated at 5.5% of the upfront cost of the vehicle. Because the upfront cost of electric trucks is close to three times more than diesel, insurance costs effectively compound this higher cost each year. Despite $9,300 less in fueling and maintenance costs each year, the electric box trucks cost $2,700 more than diesel to operate due to high insurance costs. While 5.5% is a standard estimate, some insurance providers consider many more factors that can minimize the cost of an electric compared to a diesel vehicle. Figure 71 compares electric and diesel box truck TCO at DHE.

Figure 71: DHE Diesel and Electric Box Truck TCO

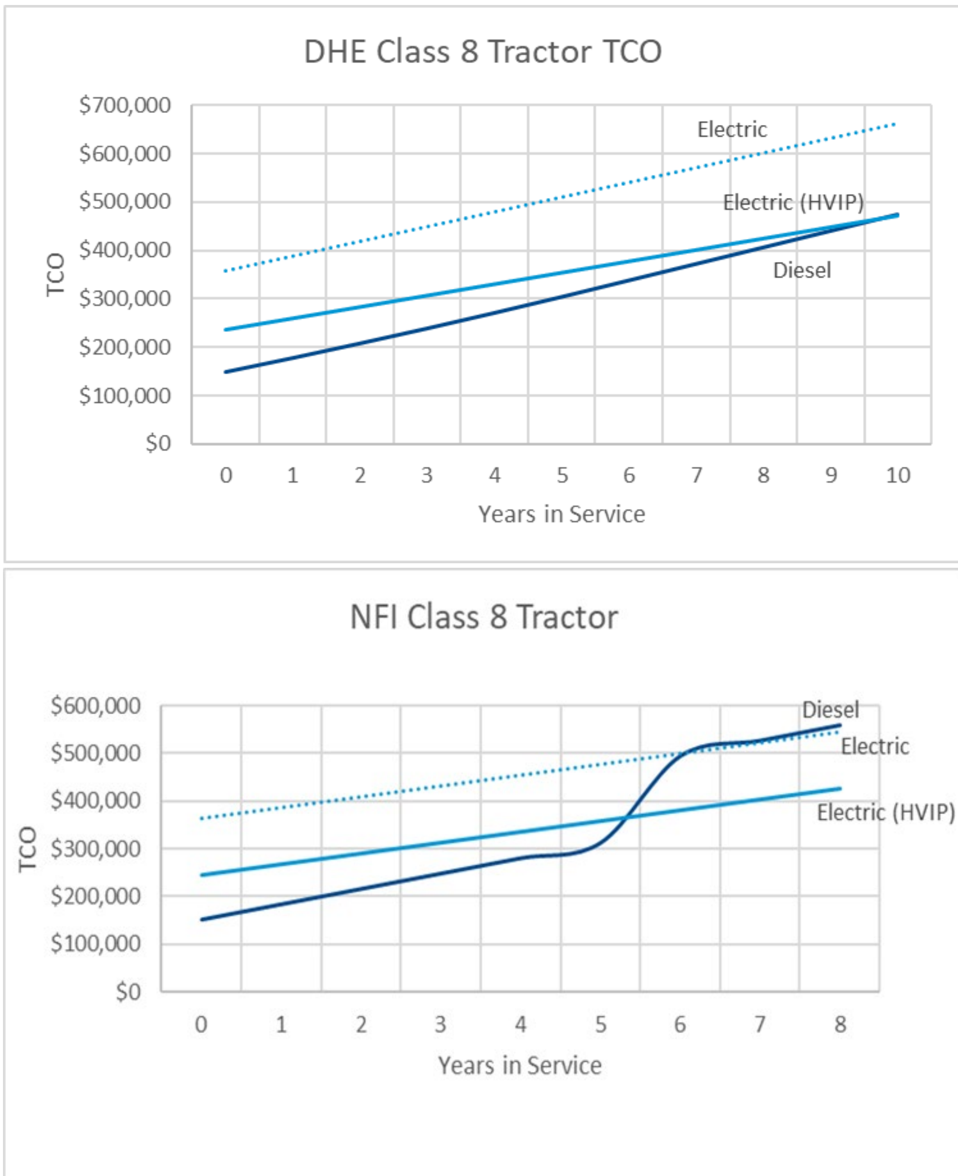


- With higher upfront costs and higher annual operating costs, these electric box trucks are not expected to achieve cost parity at any point. The additional estimate of $12,000 each year for electric box truck insurance impedes any operational cost savings.
- As OEMs scale up their electric trucks and battery technology improves, both upfront costs and insurance costs will fall. The electric box truck cost 4.6 times less to fuel and maintain than the diesel box truck, so significant cost savings can be expected in the coming years as upfront costs drop. DHE is planning to transition all 10 of its box trucks to electric in the coming years.

Class 8 Tractors

- Electric Class 8 tractors also have high annual insurance costs based on an estimated 5.5% of a vehicle's upfront cost. Fueling and maintaining the electric Class 8 tractors ranges between $3,400 and $4,300, compared with about $21,000 for diesel tractors. Insurance costs $11,000 more per year for electric tractors, lowering annual cost savings to about $6,000. Figure 72 examines whether cost parity can be reached by the electric tractors.

Figure 72: DHE and NFI Diesel and Electric Class 8 Tractor TCO

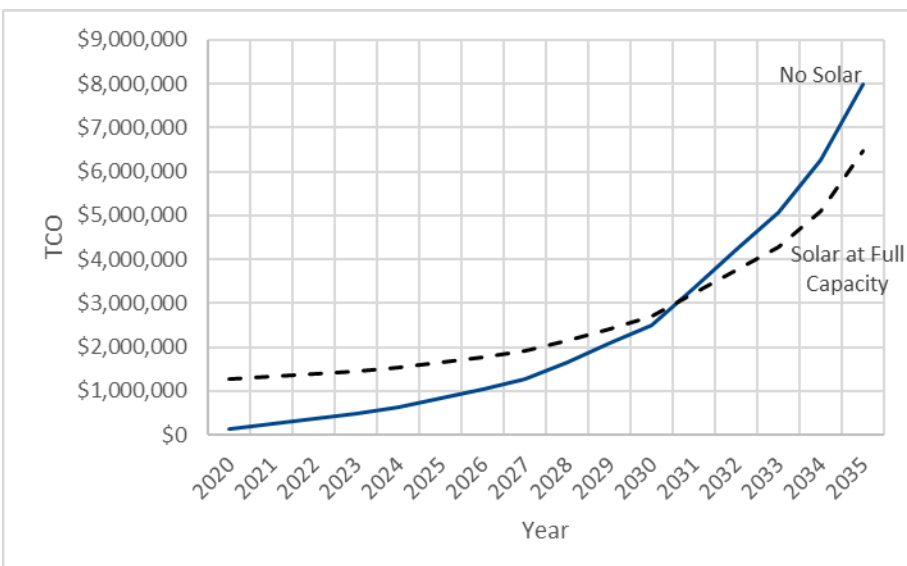


- Under current conditions, DHE's electric tractors will not achieve cost parity. By the end of Year 10, DHE's electric tractors with HVIP funding would still cost $27,000 more than diesel tractors.
- NFI's electric tractors are expected to achieve cost parity by Year 6 with HVIP funding and save the fleet $110,000 by the end of Year 8.
- As with all electric equipment, operating electric tractors as much as possible will help reduce fleet costs due to lower fueling and maintenance costs. Fleets should actively avoid charging between 4 p.m. and 9 p.m., especially because tractors draw the most energy of any equipment type. When demand charges come back online, fleets should also consider how they can minimize peak power consumption by staggering charging times, reducing charging power, or investing in energy storage.
- Fleets can expect upfront and insurance costs to decrease as electric tractors' scale and battery technology improves.

Solar

- Because the solar array produces more energy than DHE consumes, DHE could currently consume much more energy each year than it currently does at no cost. Figure 73 below shows TCO of the solar system at DHE.

Figure 73: DHE Solar and Storage System TCO



- Cost parity for the solar system is expected by the end of 2030 after being in operation for about 10 years. By 2035, the solar system is expected to save the fleet about $1.5 million. As DHE continues to electrify its fleet, both energy consumption and solar savings will increase. By 2050, the model estimates DHE will be able to save as much as $8 million off the solar system.

X. Conclusion

The Volvo LIGHTS Project brought together a diverse team of leaders in the clean transportation space, in partnership with two freight facilities and the first-of-its-kind Volvo dealership, to demonstrate state-of-the-art transitions to ZE operations. The findings in this report highlight three years' worth of interviews, data analysis, and lessons learned on duty cycle and performance, energy consumption, cost, emissions offset, maintenance, and operator experience for ZE forklifts, yard tractors, box trucks, Class 8 tractors, corresponding charging infrastructure, solar and ESSs, and workplace charging.

Across all technology types, operators expressed their pride in leading the transition toward a ZE future and appreciated the EVs' smooth, silent, and odorless operations. The forklifts, yard tractors, and box trucks met the duty cycle of their baseline equivalents. Though not yet capable of offering the same range as diesel tractors, the electric Class 8 tractors reached an encouraging 150 miles per day maximum, including two to three opportunity charges. As the technology continues to advance, new generations of electric trucks will have more range and more carrying capacity at a lower cost. All electric equipment proved less expensive to charge and maintain than diesel counterparts, savings fleets as much as $150,000 compared to baseline models over their expected lifetime.

While the upfront costs for all electric equipment in this project proved to be two to three times more expensive than their baseline equivalents, forklifts and yard tractors are expected to save fleets money over the lifetime of operations. Box trucks and Class 8 tractors are not yet expected to achieve cost parity with diesel trucks, predominantly due to high upfront costs and expensive insurance costs for EVs. Incentives will play a major role in helping electric trucks realize cost parity with diesel trucks. Subsidies for electric truck insurance would also greatly reduce TCO, as insurance can cost two to three times more for EVs.

Optimizing operational cost savings also proved critical for successful deployment of EVs. Avoiding on-peak charging hours (4–9 p.m. in SCE territory), installing solar panels to offset TOU costs, utilizing LCFS credits for equipment charged onsite, and operating EV equipment as much as possible to benefit from their lower operating costs were key lessons learned during this project. SCE will be phasing in demand charges for EVs starting in 2024, and fleets are encouraged to plan ahead to minimize high costs for demanding significant amounts of power at once. Strategies include scattering charging times, especially for the larger equipment like Class 7 box trucks and Class 8 tractors that often charge at high power ratings (kW). Fleets can also lower the speed of their chargers if operations permit, and ESSs can be used to peak shave and lower the maximum demand per month.

Operationally, this project found that opportunity charging during operator breaks and shift changes is important for preserving long-term battery health, avoiding on-peak charging rates, and extending the duty-cycle capabilities of EV technology. Opting to utilize regenerative braking can also extend EV range. It is also good practice to install charging infrastructure before deploying EVs. This project proved that plans for infrastructure installation should include contingencies for delays. Solar and ESSs can take a significant amount of time to be installed and energized by the local utility.

This project shed light on emerging trends: EVs are expected to revolutionize the freight sector as fleets opt to minimize onsite maintenance and instead contract these services to maintenance facilities. The maintenance required by EV technology will typically consist of software updates rather than hardware repairs, which will likely be performed remotely.

The future of freight will be highly dynamic over the coming decades. Motivated by regulations like ACT and ACF, freight-handling fleets will transition to both battery-electric and fuel cell technology. Incentive funding like HVIP, CORE, LCFS, the Volkswagen Mitigation Trust, and Carl Moyer can help lower the total cost of owning EV technology. The Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles (EnergIIZE) Project will also fund a massive expansion of charging and hydrogen infrastructure across California, and the Research Hub for Electric Technologies in Truck Applications (RHETTA) program will help bring EV charging into the megawatt sphere and greatly reduce charging times.

The fleets that lead the transition toward electrification will benefit from incentive funding and will act as a model for other fleets in California and across the world. ZE fleets will benefit communities near freight hubs such as the Ports of Los Angeles and Long Beach. Thanks to the EVs deployed for Volvo LIGHTS, nearly 11,000 kg of NOx and 4.8 million kg of CO2 will be avoided over the next decade. As countless fleets learn from this project and adopt ZE technologies of their own, emissions reductions will grow exponentially. With leaders in freight electrification like DHE and NFI, communities will breathe easier as California, the United States, and the world moves toward a ZE future.

Appendix A: PEMS

Introduction

CALSTART partnered with UCR's CE–CERT to calculate the emissions savings from operating ZE equipment at DHE and NFI. The partners conducted Portable Emissions Measurement System (PEMS) testing, capturing the actual in-use emissions by installing lab-grade PEMS equipment on the baseline diesel and propane vehicles. These vehicles then operated their normal duty cycles.

PEMS testing focused on emissions of CO2, NOx, and PM. In-use emissions from the conventional vehicles were compared with the emissions produced in charging EVs on SCE's grid. The CE–CERT team performed testing on 17 vehicles at DHE and NFI (Table 110).

Table 110: Number of Baseline Forklifts, Yard Tractors, Box Trucks, and Class 8 Tractors PEMS Tested

Vehicle Type	Fuel Type	DHE	NFI	Model Years
Forklift	Propane	2	2	2007, 2014, 2017
Yard Tractor	Diesel	2	2	2014, 2017
Class 8 Box Truck	Diesel	3	-	2017
Class 8 Tractor	Diesel	4	4	2014–2019

Methodology

PEMS testing is normally a two- to three-day process for one unit. PEMS equipment takes about half to a full day to install, a full day to test, and half to a full day to uninstall. To ensure the most accurate results, all PEMS testing occurred on units operating normal duty cycles. The equipment was installed on the tractors, box trucks, yard tractors, and forklifts.

Figure 74: PEMS Equipment Installed on Diesel Class 8 Tractor

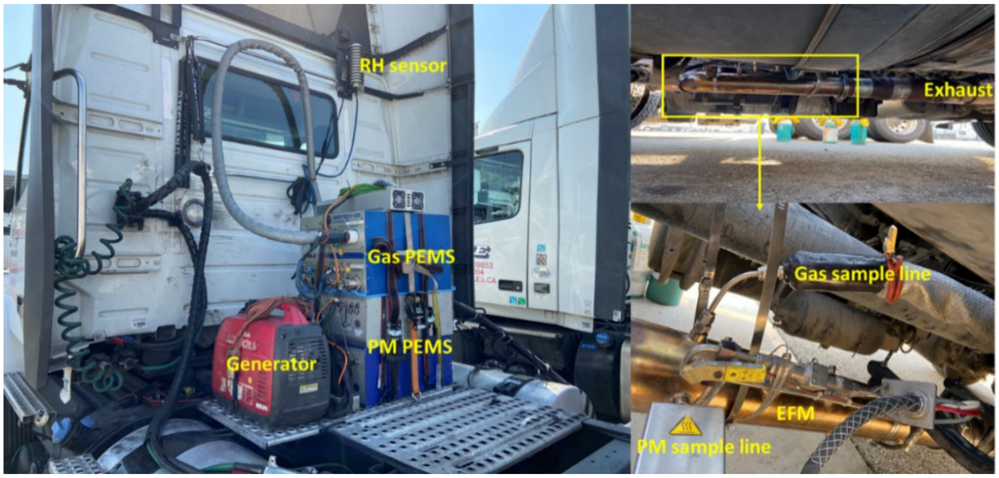


Figure 75: PEMS Equipment Installed on Diesel Box Truck

Figure 76: PEMS Equipment Installed on Diesel Yard Tractor

Figure 77: PEMS Equipment Installed on Propane Forklift

Gaseous PEMS tests used SEMTECH gas-phase analyzers to measure emissions of carbon monoxide (CO), CO_2, total hydrocarbon, and total NOx. PM emissions were measured using an AVL 494 PM system. Exhaust flow was measured with a 40 CFR (Code of Federal Regulations) 1065 capable flow meter connected to the engine tailpipe, allowing calculation of emissions rates in grams per second.

Results

The tables representing PEMS results from DHE (Table 111) and NFI (Table 112) include both grams per mile and grams per hour for CO_2, NOx, and PM. The report uses these results throughout to extrapolate emissions from the vehicles that were tested.

Table 111: DHE Baseline Equipment Emissions Values from In-Use PEMS Testing

Equipment and Fuel Type	CO2 (g/mile)	CO2 (g/hour)	NOx (g/mile)	NOx (g/hour)	PM (g/mile)	PM (g/hour)
Propane Forklift	-	56,323	-	11.0	-	1.98
Diesel Yard Tractor	6,234	11,223	14.6	22.2	0.025	0.04

Equipment and Fuel Type	CO2 (g/mile)	CO2 (g/hour)	NOx (g/mile)	NOx (g/hour)	PM (g/mile)	PM (g/hour)
Diesel Box Truck	1,603	19,565	0.47	6.70	0.010	0.21
Diesel Class 8 Tractor	1,706	20,290	4.80	52.3	0.001	0.02

Table 112: NFI Baseline Equipment Emissions Values from In-Use PEMS Testing

Equipment and Fuel Type	CO2 (g/mile)	CO2 (g/hour)	NOx (g/mile)	NOx (g/hour)	PM (g/mile)	PM (g/hour)
Propane Forklift	-	7,575	-	17.2	-	0.04
Diesel Yard Tractor	2,745	7,220	8.43	21.0	0.030	0.07
Diesel Class 8 Tractor	1,295	22,846	1.64	29.3	0.001	0.02

It is worth noting that diesel yard tractors emit nearly three times the amount of NOx per hour as diesel box trucks.

Appendix B: Workplace Charging Policies

DHE's Workplace Charging Policy

DHE installed five parking spaces with electric vehicle supply equipment (EVSE) for plug-in electric vehicles (PEV) that are available on a first come, first serve basis for all employees and guest in accordance with the below Use Policy.

Use Policy

- All employee vehicles utilizing the EVSE are required to be registered with DHE and complete all associated paperwork.
- Employees are responsible for their guests using the EVSE equipment.
- EVSE spots are only for use by vehicles that are actively charging. There is no limit on charging time at the present time. As a matter of courtesy, it is important to make room for other PEVs once a vehicle has finished charging. This policy will be reevaluated when the number of employees PEVs exceeds the number of chargers.
- Hours of use will be limited to business hours only: 24 hours, Monday – Friday
- At this time, EVSE use will be free for all employees and guests.
- Employer is not responsible for any cost related to vehicle purchase or repairs for any damage to the vehicle while it is parked at the charging station. Employee is responsible for damage outside of normal wear and tear to the equipment.
- For any additional support with either setting up the account, charging your vehicle or the charging station is not operating properly, please contact operations@greenlots.com or dedicated Volvo Lights program support at hotline 888-665-5051 for assistance.

This policy will be reevaluated annually and is subject to change during this revaluation.

NFI's Workplace Charging Policy

Overview

NFI has created five parking spaces with charging stations for plug-in electric vehicles. This policy governs the use of those spaces.

Compliance

NFI has created five parking spaces for use for charging Plug-in Electric Vehicle (PEV). They are available on a first come, first serve basis, and they may only be used to park actively charging vehicles during business hours. The chargers are available to employee and guest use.

Employee Use

In order for employees to be eligible to use these spots, they must register their cars with NFI and complete all associated registration paperwork. Employees who would like to register their vehicle should contact operations@greenlots.com or dedicated Volvo Lights program support at hotline 888-665-5051.

Employees are expected to move their vehicles to another spot once charging is complete. The average time associated with charging is 45-60 minutes and as a result, no PEV should be in one of these spots for more than 4 hours. Employees who fail to move their vehicles in a timely manner may have their charging privileges revoked.

Guest Use

Guests may also use the charging stations. If a guest would like to use a parking spot with a charging station, then the guest must register their cars with NFI prior to their visit and complete all associated registration paperwork. Employees who have guests who would like to register their vehicle should contact operations@greenlots.com or dedicated Volvo Lights program support at hotline 888-665-5051.

Like employees, guests are expected to move their vehicles to another spot once charging is complete. No PEV should be in one of these spots for more than 4 hours. Guests who fail to move their vehicles in a timely manner may not be permitted to use the charging stations in the future.

At this time, use of the charging stations is free for all guests, but NFI reserves the right to charge employee in the future.

Costs

At this time, use of the charging stations is free for all employees, but NFI reserves the right to charge employee in the future.

When account authorization mode is setup, users will need to contact the local Administrator responsible for this account to get access. Once account access is granted by the site host, the user may use RFID or QR code for activation.

Liability

NFI is not responsible for any cost related to vehicle purchase or repairs for any damage to an employee's vehicle while it is parked at a charging station.

The employee or guest using the charging station will be responsible for any damage sustained by the charging station while in use by their vehicle if the damage sustained by the charging station is outside the normal wear and tear caused by ordinary charging.

Account Creation

- Sign up at charge.greenlots.com.
- Download the free Greenlots app for iPhone or Android.
- Call Greenlot's customer care team at 888-665-5051.

Charging Instructions

STEP 1: To start the charging, the vehicle should be parked in front of the charging stations and completely turned off.

STEP 2: Visually confirm that the indicator light (located to the left side of the screen) on the charger is "solid green".

STEP 3: Open the vehicle charging port cover.

STEP 4: Remove the charging connector and plug in the charging connector into your cars charging port.

STEP 5: Wait until the indicator light turns from "solid green" to blinking "blue" to signal that the charging session has begun.

If you require any additional support with either setting up the account or charging your vehicle, please contact operations@greenlots.com or dedicated Volvo Lights program support at hotline 888-665-5051 for assistance.

Appendix C: Charging Station Signage

Workplace Charging Instructions

Sign Up:

To use this charging station, please set up a Greenlots account at www.charge.greenlots.com and download the free Greenlots app for iPhone or Android.

Charging:

STEP 1: To start charging, the vehicle should be parked in front of the charging stations and completely turned off.

STEP 2: Visually confirm that the indicator light (located to the left side of the screen) on the charger is **solid green**.

STEP 3: Open the vehicle charging port cover.

STEP 4: Remove the charging connector and plug in the charging connector into your car's charging port.

STEP 5: Wait until the indicator light turns from **solid green** to **blinking blue** to signal that the charging session has safely begun.

If you require any additional support with either setting up a Greenlots account or charging your vehicle, please contact operations@greenlots.com or the dedicated Volvo Lights program support at hotline 888-665-5051 for assistance.

NFI Yard Tractor Charging Instructions

Start Charging

1: Make sure the red switch on the truck is on charge mode.

2: Open the charge box and locate the charge socket. Open the cover on the charge cord, hold open and insert the charge cord into the socket, turn right until it stops. Use the 2 lever locks to keep in place.

3: Ensure the red and yellow switch on the charger is on. The green light should illuminate. After approximately 90 seconds the white light will illuminate showing charging is in progress.

Stop Charging

4: Before disconnecting the charge cord, make sure the white lights are off on both boxes. This indicates that there is no power on the charge cord.

5: Push the red button on the bottom of the charge cord to unlock, then unlatch the side locks.

6: Pull the cord off the socket and return cord to the charge station.

Orange EV Yard Tractor Charging Instructions

Start Charging

1: To start charging, locate the charging receptacle and plug in the charging cable.

2: Ensure that the charging cable fits snugly, and you hear a **click.** The click ensures you are safe, even in inclement weather.

3: Pull out the **red stop** button next to the receptacle to begin the charge.

4: The **red light** above the stop button should light up while the truck is charging. Charging progress can be monitored with the display on the dash.

Stop Charging

5: To stop charging, first press in the **red stop** button to the right of the receptacle.

6: Make sure that the **red light** above the stop button is off before continuing.

7: Remove the charging cable by holding down the button on the handle and pulling straight out.

8: Carefully stow the charging cable and close the receptacle cover.

Forklift Charging Instructions

Start Charging

1: Connect the battery to the charger. Once the battery is detected, the charger Auto Start count down will appear on the screen.

2: If the charger is not set to start automatically, start the charge cycle by pushing the **START** button on the screen.

3: The charge cycle begins.

Stop Charging

4: To stop the charge cycle, select the **Stop** button. The options **Resume** or **Exit** will appear.

5: Selecting exit stops the charger completely. Selecting **Resume** resumes the Charge Cycle, and the screen will display the charging operation display.

6: Once the charge cycle has completed, the charger will display **Completed** on the screen.

Table 113: Forklift Charger LED Color Indication

LED Color Meaning	Color Icon
Constant Current or Constant Voltage	
Charge Cycle Completed	
Charger Cycle Interrupted with Fault	
Charger Idle, No Battery Connected	

NFI Forklift Charging Instructions

Start Charging

1: Connect the charger cable to the vehicle.

2: The indicator will light with a red rotating pattern during charge. The display will show the time elapsed, profile stage, cell voltage and charge returned.

3: The indicator will light solid green when the charge is completed.

Stop Charging

4: Press the STOP button before disconnecting the vehicle to interrupt a charge that has not yet completed.

VNR Truck Charging Instructions

Start Charging

1: Park the electric vehicle with the charge inlet within reach of the connector. Turn off the vehicle.

2: Connect the charger's connector to the vehicle's charge inlet.

3: When there is no other vehicle already connected that requires bulk charging the charger will automatically start to charge the vehicle after the preparation phase and will indicate the progress by the LED state.

4: When there is another vehicle connected that is being charged the LED state will turn to **green** and start blinking until the other charge sessions are complete. After completing the other charge sessions, the charger will automatically start to charge the vehicle after the preparation phase and will indicate the progress by the LED state.

Stop Charging

5: The charge session will automatically **stop** after completing the bulk charge mode.

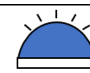
6: If there is another vehicle connected to the charger that requires bulk charging the charger will **stop** the session and automatically switch to the next vehicle in line.

7: The charging session can also be stopped manually by either pushing the **stop** button on the depot charge box or the **stop** button on the vehicle.

8: Take the connector out of the vehicle and put it back in the connector holder on the depot charge box.

If you require any additional support, please contact operations@greenlots.com or the dedicated Volvo Lights program support at hotline **888-665-5051** for assistance.

Table 114: VNR Truck LED Charger Color Indication

Charger Status	LED State	LED Color
Ready to Charge		
Initializing		
Charging		
Error		

Appendix D: California Green Shippers List

Table 115: Shippers that focus on reducing transportation and scope 3 emissions and would benefit from hiring fleets such as DHE and/or NFI

Source	Company	Commitment	Transportation Commitment	City	Revenue
SmartWay EPA	BSH Home Appliances Corporation	Carbon-neutral locations Aim to save 198 GWh of energy by improving energy efficiency by 2030 Increase amount of self-generated green energy through new photovoltaic installations	15% reduction in scope 3 emissions by 2030	Irvine	-
BSR	Mattel Inc	100% recycled, recyclable, or bio-based plastic materials in product and packaging by 2030 Reduce absolute scope 1 and 2 GHG emissions 50% by 2030 vs 2019 baseline Zero manufacturing waste by 2030	99% freight volume transported by SmartWay certified partners	El Segundo	$4.584 Billion

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Google Inc	Carbon free by 2030	Achieved a 33% reduction in total transportation emissions per unit for Made by Google products from 2017 through 2019 Growing number of EVs in our Google-owned and -operated commuter program fleet, with the majority of the nonelectric vehicles using renewable diesel	Mountain View	$181.690 Billion
SmartWay EPA	Apple Inc.	Carbon neutrality by 2030. Use only recycled and renewable materials in our products and packaging, eliminate plastics in our packaging by 2025, minimize the use of freshwater resources in water-stressed locations, eliminate waste sent to landfill from our corporate facilities and our suppliers	Address emissions from transportation with alternative fuels Seeking out technical innovations including alternative fuels and EVs	Cupertino	$274.515 billion

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Levi Strauss & Co	90% absolute reduction in GHG emissions in all owned-and-operated facilities 100% renewable electricity in all owned-and-operated facilities 40% absolute reduction in GHG emissions across our global supply chain	Clean cargo working group 2025 40% reduction in scope 3 emissions	San Francisco	$4.453 Billion
SmartWay EPA	Earth Friendly Products	Carbon neutral across entire operation in 2013 100% renewable energy	Dramatically reduced transportation emissions	Cypress	-
BSR	Unity Technologies	Measuring environmental footprint Purchase carbon offset credits to neutralize environmental impact of essential business travel	Establishing policies and guidelines to operationalize our environmental sustainability goals throughout our value chain	San Francisco	$0.774 Billion
BSR	PayPal	Power all data centers with 100% renewable energy 2023 75% of suppliers by spend adopt science-based targets 2025 Reduce operational GHG emissions by 25% 2025 Net zero GHG emissions across operations and value chain 2040	Evaluating scope 3 emissions including upstream transportation and distribution	Palo Alto	$21.454 Billion

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Autodesk, Inc	Net zero GHG emissions across business and value chain 50% reduction in scope 1 and scope 2 GHG emissions target established by fiscal year 2031 compared with fiscal year 2020	Fund climate technologies that work on electrification of transportation 25% minimum reduction in scope 3 GHG emissions per dollar of gross profit by fiscal year 2031 compared with fiscal year 2020	San Rafael	$3.790 Billion
BSR	WIlliams-Sonoma Inc	100% sustainably sourced cotton by 2021 75% landfill diversion across company by 2021 50% sustainably sourced wood by 2021 50% absolute reduction in scope 1&2 emissions by 2030	Increase direct-to-consumer sales More efficient deliveries 14% absolute reduction in scope 3 emissions by 2030	San Francisco	$6.783 Billion
SmartWay EPA	Callaway Golf	40% energy used at headquarters came from renewable sources	Increased use of SmartWay carriers from 50% to 87% by 2019	Carlsbad	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Cisco Systems, Inc	Reduce total Cisco scope 1 and 2 GHG emissions worldwide by 60% absolute by FY22 (FY07 baseline) Use electricity generated from renewable sources for at least 85% of our global electricity by FY22	Reduce Cisco supply chain-related Scope 3 GHG emissions by 30% absolute by FY30 (FY19 base year). Includes allocated emissions from Cisco's Tier 1 and Tier 2 manufacturing, component, and warehouse suppliers, and calculated emissions associated with transportation emissions managed and paid for by Cisco	San Jose	$49.818 Billion
SmartWay EPA	Epson America, Inc.	Reduce scope 1 and 2 GHG emissions by 19% by FY2025	Reduce scope 3 GHG emissions as a percentage of value added by 44% by FY2025	Long Beach	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR SmartWay High Performer	The Gap Inc	Carbon Neutral value chain 2050 Source 100% renewable electricity for our owned and operated facilities global from 2017 baseline by 2030 Reduce absolute scope 1 and 2 GHG emissions by 90%	Reduce Scope 3 GHG emissions from purchased goods and services by 30%, from a 2017 baseline	San Francisco	$13.800 Billion
BSR	McDonalds Corporation	36% reduction of absolute emissions from offices and restaurants by 2030 from 2015 baseline 31% reduction in supply chain emissions by 2030 from 2015 baseline	Reducing the distances our products travel, moving toward alternative fuels and making product journeys as efficient as possible	San Bernardino	$19.208 Billion
SmartWay EPA	Sony Electronics, Inc.	2040 100% renewable electricity for all business sites 2050 zero environmental footprint	Switching to modes of transport with lower CO_2 emissions Reduce transport distances through revised routes Improving loading efficiency	San Diego	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Trimble	Establishing complete GHG emissions inventory across scopes 1,2,3 Set science-based targets	Up 20% fuel efficiency Reduce carbon emissions Increased fleet utilization up to 30%	Sunnyvale	$3.125 Billion
SmartWay EPA	Rincon Technology	2025 implement renewable energy initiatives at largest energy consuming sites Quantify all scope 3 carbon footprint elements	Use the most carbon efficient transport option within the required time constraints	Santa Barbara	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Avery Dennison Corporation	Reduce our Scope 1 and 2 GHG emissions by 70% from our 2015 baseline with an ambition of net zero by 2050. Source 100% of paper fiber from certified sources focused on a deforestation-free future. Divert 95% of our waste away from landfills, with a minimum of 80% of our waste recycled and the remainder either reused, composted, or sent to energy recovery Deliver a 15% increase in water efficiency at our sites that are located in high or extremely high-risk countries as identified in the WRI Aqueduct Tool. Engage 80% of our spend of LGM's direct suppliers on their environmental and social policies including water, human rights, fair business, forestry, etc.	work with our supply chain to reduce our 2018 baseline Scope 3 GHG emissions by 30%	Glendale	$6.972 Billion

Table 116: Shippers on the path to sustainability, but they are step behind those above and may desire services from DHE and/or NFI in the future

Source	Company	Commitment	Transportation Commitment	City	Revenue
SmartWay EPA	BSH Home Appliances Corporation	Carbon-neutral locations Aim to save 198 GWh of energy by improving energy efficiency by 2030 Increase amount of self-generated green energy through new photovoltaic installations	15% reduction in scope 3 emissions by 2030	Irvine	-
BSR	Mattel Inc	100% recycled, recyclable, or bio-based plastic materials in product and packaging by 2030 Reduce absolute scope 1 and 2 GHG emissions 50% by 2030 vs 2019 baseline Zero manufacturing waste by 2030	99% freight volume transported by SmartWay certified partners	El Segundo	$4.584 Billion

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Google Inc	Carbon free by 2030	Achieved a 33% reduction in total transportation emissions per unit for Made by Google products from 2017 through 2019 Growing number of EVs in our Google-owned and -operated commuter program fleet, with the majority of the nonelectric vehicles using renewable diesel	Mountain View	$181.690 Billion
SmartWay EPA	Apple Inc.	Carbon neutrality by 2030. Use only recycled and renewable materials in our products and packaging, eliminate plastics in our packaging by 2025, minimize the use of freshwater resources in water-stressed locations, eliminate waste sent to landfill from our corporate facilities and our suppliers	Address emissions from transportation with alternative fuels Seeking out technical innovations including alternative fuels and EVs	Cupertino	$274.515 billion

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Levi Strauss & Co	90% absolute reduction in GHG emissions in all owned-and-operated facilities 100% renewable electricity in all owned-and-operated facilities 40% absolute reduction in GHG emissions across our global supply chain	Clean cargo working group 2025 40% reduction in scope 3 emissions	San Francisco	$4.453 Billion
SmartWay EPA	Earth Friendly Products	Carbon neutral across entire operation in 2013 100% renewable energy	Dramatically reduced transportation emissions	Cypress	-
BSR	Unity Technologies	Measuring environmental footprint Purchase carbon offset credits to neutralize environmental impact of essential business travel	Establishing policies and guidelines to operationalize our environmental sustainability goals throughout our value chain	San Francisco	$0.774 Billion
BSR	PayPal	Power all data centers with 100% renewable energy 2023 75% of suppliers by spend adopt science-based targets 2025 Reduce operational GHG emissions by 25% 2025 Net zero GHG emissions across operations and value chain 2040	Evaluating scope 3 emissions including upstream transportation and distribution	Palo Alto	$21.454 Billion

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Autodesk, Inc	Net zero GHG emissions across business and value chain 50% reduction in scope 1 and scope 2 GHG emissions target established by fiscal year 2031 compared with fiscal year 2020	Fund climate technologies that work on electrification of transportation 25% minimum reduction in scope 3 GHG emissions per dollar of gross profit by fiscal year 2031 compared with fiscal year 2020	San Rafael	$3.790 Billion
BSR	WIlliams-Sonoma Inc	100% sustainably sourced cotton by 2021 75% landfill diversion across company by 2021 50% sustainably sourced wood by 2021 50% absolute reduction in scope 1&2 emissions by 2030	Increase direct-to-consumer sales More efficient deliveries 14% absolute reduction in scope 3 emissions by 2030	San Francisco	$6.783 Billion
SmartWay EPA	Callaway Golf	40% energy used at headquarters came from renewable sources	Increased use of SmartWay carriers from 50% to 87% by 2019	Carlsbad	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Cisco Systems, Inc	Reduce total Cisco scope 1 and 2 GHG emissions worldwide by 60% absolute by FY22 (FY07 baseline) Use electricity generated from renewable sources for at least 85% of our global electricity by FY22	Reduce Cisco supply chain-related Scope 3 GHG emissions by 30% absolute by FY30 (FY19 base year). Includes allocated emissions from Cisco's Tier 1 and Tier 2 manufacturing, component, and warehouse suppliers, and calculated emissions associated with transportation emissions managed and paid for by Cisco	San Jose	$49.818 Billion
SmartWay EPA	Epson America, Inc.	Reduce scope 1 and 2 GHG emissions by 19% by FY2025	Reduce scope 3 GHG emissions as a percentage of value added by 44% by FY2025	Long Beach	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR SmartWay High Performer	The Gap Inc	Carbon Neutral value chain 2050 Source 100% renewable electricity for our owned and operated facilities global from 2017 baseline by 2030 Reduce absolute scope 1 and 2 GHG emissions by 90%	Reduce Scope 3 GHG emissions from purchased goods and services by 30%, from a 2017 baseline	San Francisco	$13.800 Billion
BSR	McDonalds Corporation	36% reduction of absolute emissions from offices and restaurants by 2030 from 2015 baseline 31% reduction in supply chain emissions by 2030 from 2015 baseline	Reducing the distances our products travel, moving toward alternative fuels and making product journeys as efficient as possible	San Bernardino	$19.208 Billion
SmartWay EPA	Sony Electronics, Inc.	2040 100% renewable electricity for all business sites 2050 zero environmental footprint	Switching to modes of transport with lower CO_2 emissions Reduce transport distances through revised routes Improving loading efficiency	San Diego	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Trimble	Establishing complete GHG emissions inventory across scopes 1,2,3 Set science-based targets	Up 20% fuel efficiency Reduce carbon emissions Increased fleet utilization up to 30%	Sunnyvale	$3.125 Billion
SmartWay EPA	Rincon Technology	2025 implement renewable energy initiatives at largest energy consuming sites Quantify all scope 3 carbon footprint elements	Use the most carbon efficient transport option within the required time constraints	Santa Barbara	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Avery Dennison Corporation	Reduce our Scope 1 and 2 GHG emissions by 70% from our 2015 baseline with an ambition of net zero by 2050. Source 100% of paper fiber from certified sources focused on a deforestation-free future. Divert 95% of our waste away from landfills, with a minimum of 80% of our waste recycled and the remainder either reused, composted, or sent to energy recovery Deliver a 15% increase in water efficiency at our sites that are located in high or extremely high-risk countries as identified in the WRI Aqueduct Tool. Engage 80% of our spend of LGM's direct suppliers on their environmental and social policies including water, human rights, fair business, forestry, etc.	work with our supply chain to reduce our 2018 baseline Scope 3 GHG emissions by 30%	Glendale	$6.972 Billion

Table 117: Shippers taking their first steps toward creating sustainability and sustainable supply chain goals

Source	Company	Commitment	Transportation Commitment	City	Revenue
BSR	Ambarella Inc	Ambarella is committed to promoting environmental protection and sustainability, from the product design phase, through manufacture, sale and distribution. In addition to complying with applicable environmental laws and regulations, we are committed to reducing our environmental impact. We seek to minimize our environmental impact by eliminating hazardous substances from our products, prioritizing resource conservation and responsibly disposing of our waste; and by encouraging our suppliers to do the same.	-	Santa Clara	$0.223 Billion
SmartWay EPA	Bumble Bee Seafoods	2025 less than 2% of packaging non-recyclable materials Sustainable source for products	-	San Diego	-

Source	Company	Commitment	Transportation Commitment	City	Revenue
SmartWay EPA	Fujitsu Computer Products of America, Inc.	Improve environmental performance of data centers Reduce consumption of energy and other natural resources in business facilities Act as industry/market leaders achieving organic growth through a sustainable and responsible business model Reduce greenhouse gas emissions at Fujitsu sites by 37.8% or more from the base year level	-	Sunnyvale	-
SmartWay EPA	New Leaf Paper Inc.	100% post-consumer recycled fiber for paper 80% less water use than virgin wood fiber paper	-	Walnut Creek	-
SmartWay EPA	Tatung Company of America, Inc.	2030 improve water quality by reducing pollution 2030 increase share of renewable energy 2020 environmentally sound management of chemicals and waste	-	Long Beach	-