Final Report

Frito-Lay Transformative Zero and Near Zero-Emission Freight Facility Project

Prepared for California Air Resources Board

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List of Acronyms

Table 1: List of Acronyms

Acronym	Term
ACF	Advanced Clean Fleets
ACT	Advanced Clean Trucks
BESS	Battery Energy Storage System
CARB	California Air Resources Board
CCS	Combined Charging Standard
CE–CERT	College of Engineering–Center for Environmental Research and Technology
CNG	Compressed natural gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DCFC	Direct Current Fast Charge
DGe	Diesel Gallon Equivalent
EPA	Environmental Protection Agency
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
g	Gram
GHG	Greenhouse Gas
HD	Heavy-Duty
kg	Kilogram

Acronym	Term
KPI	Key Performance Indicator
kW	Kilowatt
kWh	Kilowatt-hour
LA	Lead-acid
lbs	Pounds
LCFS	Low Carbon Fuel Standard
LI	Lithium-ion
LNG	Liquified natural gas
mi	Miles
MHD	Medium- and Heavy-Duty
mpg	Miles Per Gallon
NO_x	Nitrogen Oxides
OEM	Original Equipment Manufacturer
PEMS	Portable Emissions Measurement Systems
PM	Particulate Matter
RNG	Renewable Natural Gas
SOC	State-of-Charge
SJVAPCD	San Joaquin Valley Air Pollution Control District
TCO	Total Cost of Ownership
TOU	Time-of-Use
UCR	University of California at Riverside
ZE	Zero-Emission
ZEV	Zero-Emission Vehicle

Figures and Tables

Figures

Tables

Executive Summary

The Frito-Lay Zero and Near Zero Emission Freight Facility (ZANZEFF) Project was made possible through California Climate Investments and Frito-Lay's investment in sustainable manufacturing, warehousing and distribution throughout their operations. In FY2017-18, the Frito-Lay ZANZEFF Project was awarded $15,382,243, which resulted in a near $30 million investment to deploy zero and near zero technologies throughout Frito-Lay's facility in Modesto, CA. The multi-faceted, phased deployment of medium and heavy-duty ZE technology in this project demonstrated that fleets could adopt ZE technology now. In some cases, the available vehicles will show immediate cost savings; in other cases, fleets can think creatively to deploy ZE technology and still benefit from reducing air pollution and beginning the transition to ZEVs that will be required of all major fleets in the state.

CALSTART's key findings and recommendations to fleets include the following:

- ZEVs have higher upfront costs but lower fueling and maintenance costs. At the Frito-Lay facility, the ZE yard tractors experienced maintenance issues; however, the original equipment manufacturer (OEM) was diligent in fixing issues as they arose, allowing the fleet to avoid prolonged disruptions during operations. Proximity to OEM service shops is essential to maintain efficiency during operations while vehicles are under repair.
- Electric forklifts and yard tractors can meet the required duty cycle when opportunity charging is utilized, and they have a lower, more favorable TCO than conventional baseline equipment.
- Fleets considering upgrading their ZE forklift technology from LA to LI should procure LI-battery packs for the forklifts already in use; using essentially the same forklifts with different battery packs allowed Frito-Lay to minimize operational disruptions by avoiding unnecessary maintenance repairs and costs.
- Installing infrastructure often takes more time than expected. Coordinating the design and permitting, construction, and commissioning of the solar and energy storage systems at the Frito-Lay facility required communication between project managers, subcontractors, utilities, and Frito-Lay employees. CALSTART recommends that fleets begin the infrastructure installation process and engagement of these stakeholders as early as possible during a project.
- Fleets should consider the seasonal variation in solar energy generation during the summer and winter months when calculating their required solar production. Fleets should also account for expected ZEV growth when installing solar; expanding the solar array while the

project is in progress is more costly than installing a larger solar array during the initial installation. Solar arrays cannot be used to offset demand charges, but energy storage can; fleets may want to consider using solar and storage to offset demand charges from ZEV energy draw.

I. Introduction

Project Background

The San Joaquin Valley Air Pollution Control District (SJVAPCD) partnered with Frito-Lay, a division of PepsiCo, for the implementation of the "Frito-Lay Zero- and Near-Zero Emission Project" in Modesto, California; a bold and transformative effort that yielded a world-renowned showcase for economically and environmentally sustainable manufacturing, warehousing, and distribution. This project aimed to completely replace the use of all diesel-powered freight equipment within one of Frito-Lay's largest food production, warehouse and regional distribution facilities. This was accomplished via the use of zero-emission (ZE) technology everywhere feasible, and near-zero emission (NZE) technology and renewable fuels everywhere else. The project integrated an incredible array of commercially available and pre-commercial ZE and NZE technologies in a number of applications, including: 15 heavy-duty Tesla battery-electric tractors; six (6) Peterbilt e220 battery-electric straight trucks; 3 (3) battery-electric BYD yard trucks; 12 lithium-ion battery-electric Crown forklifts; and 38 NZE Volvo tractors fueled with ultra- low carbon renewable natural gas.

In addition to the fleet assets, an on-site renewable energy generation (solar PV) and two energy storage systems from Tesla were installed to better serve the energy needs of the manufacturing facility, warehouses, material handling equipment, heavy-duty electric trucks and light-duty electric vehicles in a more cost-effective manner. This system provides multiple benefits, including: increasing the resiliency of the overall operation; allowing for the self-consumption of renewable energy generated on-site; and reducing demand charges and utility costs for powering the facility and electric trucks. A new dedicated electric utility service was provided to serve the needs of the electric trucks, and state-of-art ZE and NZE fueling facilities were installed to dispense renewable energy via standardized receptacles to all fleet assets, as well as a public-access renewable natural gas fueling station.

This project's objective is to demonstrate the operational, economic and environmental sustainability benefits of ZE and NZE technology at freight facilities and warehouses that can be emulated throughout the state. With the largest private fleet in North America, PepsiCo. will look to apply the lessons learned from this project to other Frito-Lay facilities and within its other food and beverage divisions. Just as Frito-Lay has transformed its North American fleet over the last decade, this project will provide the roadmap on how the company can now continue this transformation via the increased use of ZE and NZE technology. Beyond its own operations, PepsiCo has a pro-active and multi-faceted communications plan that will showcase the results from this project throughout California and beyond. This communication plan will demonstrate how similar companies in the

Central Valley, California, United States, and the world can move freight within regional distribution networks to end-user consumers without the use of diesel, through the use of innovative ZE and NZE vehicles, equipment and renewable/low-carbon energy, thus resulting in significant greenhouse gas (GHG) reductions and air quality improvement, especially along freight corridors and within disadvantaged communities. There is no question that this project will help to accelerate the continued proliferation, commercialization, and use of ZE and NZE goods movement technologies, thereby further magnifying the emissions benefits of this effort on a wide scale.

Frito-Lay's ZE Journey and Commitment

Climate change poses significant risks to Frito-Lay's business and the communities where they operate. The world is already feeling the effects of climate change and faster, bolder action is needed. Frito-Lay not only has an interest in reducing GHG emissions for the benefit of society—it's also crucial to the viability of their business, as they are already experiencing the impacts of climate change directly within their own value chain. Their strategy focuses on the areas in which they have the greatest impact—manufacturing, agriculture, packaging, transportation, and vending and cooling equipment. It requires that Frito-Lay use scalable solutions that are available today, but also acknowledges that achieving net-zero emissions by 2040 will likely require new technologies and mechanisms. Guiding these decisions are several key goals; in January 2021, Frito-Lay more than doubled their science-based climate goal targeting a more than 40% GHG reduction across their value chain by 2030 (Scopes 1 and 2 by 75%; Scope 3 by 40%). In addition, Frito-Lay pledged to achieve net-zero emissions by 2040, one decade earlier than called for in the Paris Agreement.

Project Team

Table 2: Key Project Stakeholders and Their Roles

Logo	Organization	Description and Role
	San Joaquin Valley Air Pollution Control District	The SJVAPCD is the air pollution control agency for approximately 4.3 million people, covering the San Joaquin Valley from San Joaquin County to Kern County. The SJVAPCD assembled the project team and led the grant application effort and the technology implementation plan.
	Frito-Lay, Inc.	Frito-Lay North America is PepsiCo's $23 billion convenient foods division that makes, moves, and sells popular products including Fritos®, Lay's®, Ruffles®, Doritos®, Tostitos®, Cheetos®, PopCorners®, SunChips® and more. Frito-Lay is the project's end-user showcasing transformative economic and environmental sustainability efforts in its newly redesigned 500,000-square-foot Modesto, California, facility.
	CALSTART	CALSTART, North America's leading advanced transportation technologies consortium, is a member-supported nonprofit organization of more than 400 organizations, fleets, and agencies worldwide dedicated to supporting the growth of the high-tech, clean-transportation industry. CALSTART's primary responsibilities included overall project management and data collection and analysis (together with CE-CERT). CALSTART also assisted with the deployment of equipment at the site.
	UC Riverside CE–CERT	CE–CERT is the largest research center at the University of California at Riverside, bringing together researchers from multiple disciplines to address society's most pressing challenges in air quality, climate change, energy, and transportation. They analyzed the electric trucks' performance, developed novel algorithms for dispatching electric vehicles, and modeled the trucks' life-cycle emissions.

Logo	Organization	Description and Role
	Project Clean Air	Project Clean Air, Inc. (PCA) is a 501(c)(3) non-profit that strives to enhance the community by improving air quality through education and collective action throughout the San Joaquin Valley and Eastern Kern County. PCA manages the San Joaquin Valley Clean Cities Coalition, part of the U.S. Department of Energy's Clean Cities Program and has a variety of partnerships and programs benefiting the San Joaquin Valley and beyond. PCA assisted with public outreach and stakeholder engagement.
	Café Coop	Café Coop is a community-based organization that implemented its community outreach plan through public outreach, technology demonstrations, media announcements, and workshops.

II. Technical Overview

The Frito-Lay ZANZEFF Project demonstrated the deployment and performance of ZE and NZE vehicles, equipment, and infrastructure at Frito-Lay's manufacturing, warehousing, and distribution center. At 500,000 square feet, the facility is located in Modesto, California[1] (Figure 1 and Figure 2).

Figure 1: Frito-Lay Modesto Facility

[1] For more information on Frito-Lay's Modesto facility and the ZANZEFF project, visit their website. https://www.fritolay.com/news/frito-lay-cuts-absolute-fleet-greenhouse-gas-emissions-ghg-in-half-reduces-diesel-usage-by-78-percent-at-california-production-site

Figure 2: Frito-Lay Modesto Facility Truck Depot

Technology Deployed

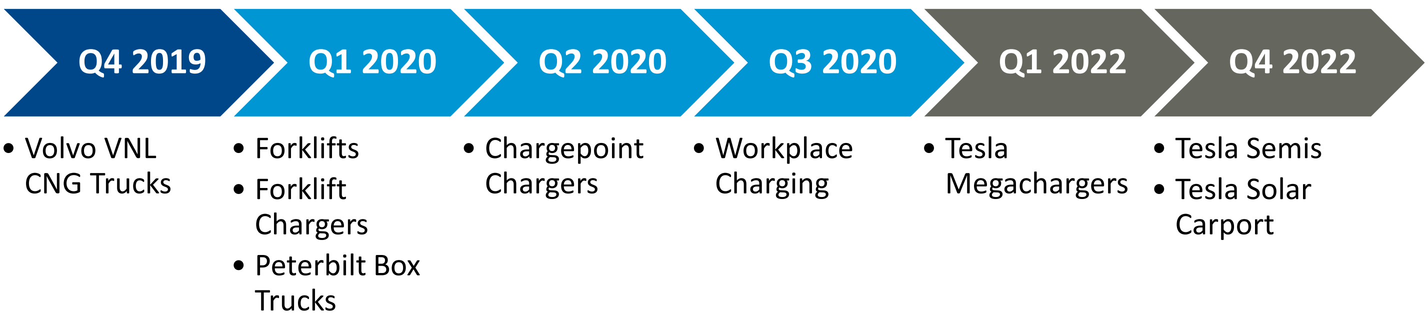
Technology deployed at the facility included forklifts, yard tractors, natural gas and electric trucks, charging and fueling stations as well as solar and battery storage. The project was the first of its kind in deploying vehicles and equipment facility-wide, creating emission reductions onsite and in surrounding communities where Frito-Lay operates. Table 3 includes a comprehensive list of all equipment deployed over the course of the project. Figure 3 demonstrates the overall deployment schedule for all vehicles and associated infrastructure.

Table 3: List of Equipment Deployed

Equipment	Count	OEM
Forklift	12	Crown
Yard Tractor	3	BYD
Class 6 e220 Truck	6	Peterbilt
Class 8 RNG Truck	38	Volvo
Class 8 Electric Semi	15	Tesla
Workplace Charging	5	ChargePoint

Equipment	Count	OEM
Solar	1	Tesla
Battery Energy Storage	2	Tesla

Figure 3 Deployment Schedule



Data Collection and Analysis

In this project, there were many sources of data to collect, store, and analyze to meet CARB's data collection requirements. This data includes both one-time collection of information (e.g., vehicle specifications) and ongoing data streams (e.g., vehicle performance data). The data sources and the applicable technologies are as follows:

- Specifications and cost (vehicles and infrastructure)
- Vehicle performance
- Charging/fueling and electricity use (infrastructure)
- Maintenance (vehicles and infrastructure)
- Operations/payload (vehicles)
- Emissions testing (baseline and conventional vehicles)
- User experience surveys (vehicle operators, fleet managers, maintenance staff)

Data for each vehicle were collected and analyzed to determine whether zero and near-zero equipment could fully replace the fleet's baseline vehicles. The analysis includes a review of performance, energy consumption, costs, and emissions offsets. While the minimum data collection per technology was 90 days, the goal was to collect the maximum amount of data possible. Additionally, freight facility data were collected to understand the benefits of facility improvements and gained efficiencies. This activity included data and analysis on solar, energy storage, and charging infrastructure. Overall, the analyses provide a comprehensive insight into how the project's investments affect operational costs and emissions produced at this facility. The analyses also help demonstrate the effectiveness of several advanced technologies deployed in a large-scale production and distribution facility.

Vehicle data were collected through Geotab, the system Frito-Lay uses to monitor their entire fleet. If data from Geotab were unavailable or insufficient, other methods were used, including proprietary data collection platforms offered by the manufacturers.

Table 4 below provides information on the manufacturer and the platform used to collect data for each equipment type.

Table 4: Sources of Data for Each Type of Equipment and Charger

Equipment Type	Manufacturer	Data Source
Forklifts	Crown	Flux Power
Forklift Chargers	V-Force	Flux Power
Yard Tractors	BYD	Geotab
Class 6 Box Trucks	Peterbilt	ViriCiti
Yard Tractor/Box Truck Chargers	ChargePoint	ChargePoint
Class 8 Tractors	Tesla	Geotab
Class 8 Tractor Chargers	Tesla	Tesla Portal
Class 8 RNG Tractors	Volvo	Geotab
RNG Station	Beyond6	Beyond6
Workplace Chargers	ChargePoint	ChargePoint
Solar Canopy	Tesla	Tesla Portal
Energy Storage Systems	Tesla	Tesla Portal

The following sections will evaluate performance, usage, charging/fueling characteristics, and user acceptance of all equipment deployed in the demonstration project.

III. ZE Forklifts

Frito-Lay purchased 12 LI forklifts to replace preexisting LA battery electric forklifts. From June 2020 to June 2021, data on the LI and LA forklifts were collected by dataloggers that transmitted data from each forklift battery to Flux Power's data portal. While both are ZE, the LI forklifts use more advanced battery technology achieving greater efficiency. The LI forklifts have a battery voltage of 36V and a continuous discharge rate of 350A for a total power rating of 12.6 kW. Overall, the new forklifts performed well and moving forward new forklifts purchased for this site will be LI. They were found to be more energy and cost efficient, and users like them because they have an easy plug-in and charge more quickly while sustaining longer operations.

The deployment process for the LI forklifts was smooth with only a few challenges. Operators adjusted the LI forklift battery settings as they grew accustomed to using them and utilized opportunity charging as much as possible to meet the required duty cycle. They reported few performance issues. Over a year of data on the new forklifts and the baseline LA forklift was collected and analyzed to assess quantitatively how the forklift types performed in comparison to each other. Figure 4 shows the LI forklifts below.

Figure 4: Crown LI Forklifts at Frito-Lay

The forklifts were charged by 12 V-Force chargers inside the facility. Table 5 highlights specifications for the LI and LA forklifts at Frito-Lay.

Specifications

Table 5: Forklift Specifications

Specification	Electric	Baseline
Type	Electric (LI)	Electric (LA)
Model Year	2021	2020
Manufacturer	Flux (battery); Crown (body)	Crown
Model Name	M36	RC 5500 Series[2]
Battery Capacity (kWh)	23.0	27.2, 32.6, and 38.1

Analysis

Data Collection

Data on 12 LI forklifts and one LA forklift were collected by dataloggers that transmitted data from the forklift battery to Flux Power's data portal. It included such parameters as event type (discharging, idling, or charging), start and end time, start and end state of charge (SOC), and start and end energy level (kWh). Data on all forklifts were collected for one year between June 2020 and 2021. Use session data were used to estimate the duty cycle performance and state of charge of forklifts. The lead acid forklift served as the baseline vehicle, including for the duty cycle performance.

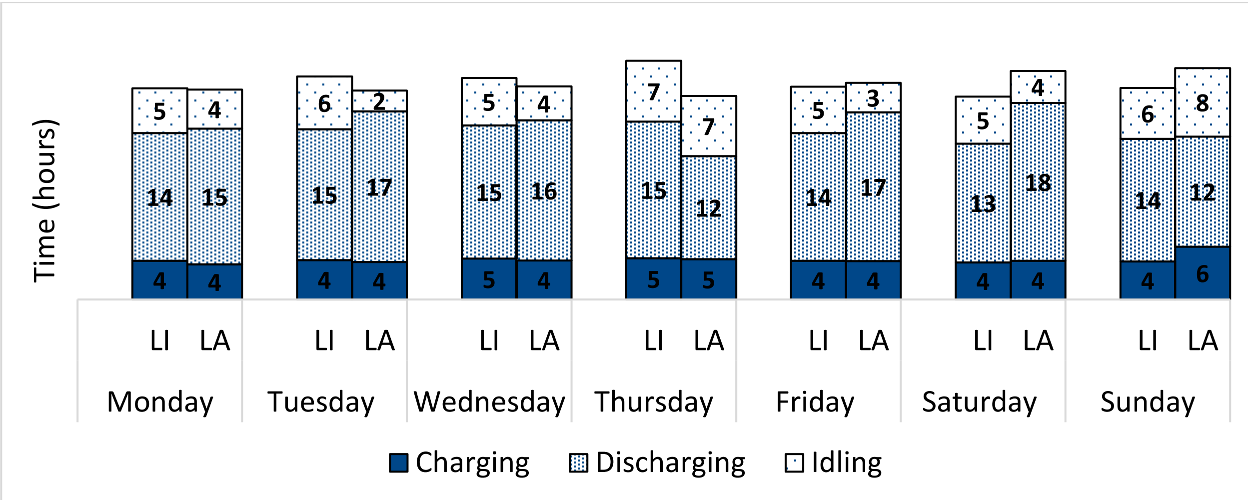
Performance

Frito-Lay used their forklifts to transfer pallets both empty and full of products from manufacturing to the warehouse and to load pallets onto the trailers. Forklifts are critical to fleet operations and are in use around the clock, 7 days a week. The LI forklifts were placed in the same duty cycle as the LA forklifts. Figure 5 shows the average use of both forklift types throughout the week[3].

[2] The LA model specs are for the 5500 series (model numbers: 5510/15-30, 5520/25-30, 5530/35-30) and are associated with three different batteries sizes.

[3] There were some gaps in the operational use data for the fleet's forklifts because they were down and out of service—some for months at a time. Because of these data gaps, some of the averages used in Figure 5 sum to more than 24 hours on some days.

Figure 5: LI Forklift Duty Cycle



On average, the forklifts spent 12 to 18 hours per day in service, 3 to 7 hours idling, and 4 to 6 hours charging. On weekends, the LA forklifts were required to spend time equalizing, a process in which the forklift is plugged into the charger for 6 to 14 hours to remove built-up sulfates in the battery and balance cell voltages[4]. While it is not explicitly visible in the figure above, the LA forklifts did spend several hours on weekends equalizing. Sixty-four percent of LA forklift charging events with a duration over 6 hours occurred on weekends and there were several instances where the LA forklifts were equalizing for up to 20 hours on weekends. This is another indirect efficiency gain; the newer, LI models can spend more time in use since they do not require equalization.

Energy Consumption

The LA forklift was used for more hours and consumed more energy than the average LI forklift. While energy consumed from LA forklifts was only slightly higher, lower conversion efficiencies from the grid to the battery and the battery to the forklift resulted in much more energy from the grid being wasted on the LA forklifts.

Table 6: Energy Use Comparisons between LI and LA Forklifts

Forklift	Hours in Use (h)	Energy Used from the Grid (kWh)	Energy Charged (kWh)	Energy Consumed (kWh)
LI	4,776	13,192	12,268	11,815
LA	5,309	20,117	16,295	13,525

The LI forklift charger efficiency was higher by 12% and the battery efficiency was higher by 13%. The

[4] How Often Should You Equalize a Forklift Battery. Battery Tools. https://batterytools.net/how-often-should-you-equalize-a-forklift-battery/

LA inefficiencies compound, resulting in the LI forklifts being more energy efficient than the LA forklifts by 23%. Therefore, the LA forklifts require much more energy than LI forklifts to do the same work, meaning higher operating costs for the fleet. Table 7 shows the LI and LA forklift efficiencies.

Table 7: Efficiency Comparisons between LI and LA Forklifts

Forklift	Charger Efficiency	Battery Efficiency	Overall Energy Efficiency
LI	93%	96%	90%
LA	81%	83%	67%

The LI forklifts used about 33% less energy per hour than the LA forklifts. In addition to lower charger and battery efficiencies,

Overall, the LI forklifts were found to perform equally as well or better than the baseline LA forklifts while using less energy. Fleet management staff proudly reported that the LI forklifts are more energy and cost efficient and that drivers like them. The fleet plans to continue adopting and operating LI forklifts moving forward.

Maintenance

According to some of the fleet's forklift operators, the LI forklifts had little to no downtime associated with service requests, but rather, time spent undergoing routine inspections. The fleet performed preventative maintenance checks on each forklift every 250 hours. Frito-Lay's service shop technicians ran through an internal maintenance checklist during their inspections of the forklifts and made replacements if necessary.

Infrastructure

Frito-Lay installed 12 chargers, each with a 12.6-kW power rating, for their fleet of 12 LI forklifts, opting for a 1:1 ratio between the vehicles and charging equipment. Operators spent a maximum of 6 hours each day charging the LI forklifts with the new chargers, though the chargers could bring the forklifts' SOC to 100% in as little as 4 hours on some days. Previously, the fleet spent up to 18 hours per week equalizing their baseline LA forklifts, a process in which operators plug the forklift into the charger for 6 to 14 hours to remove built-up sulfates in the battery and balance cell voltages. Additionally, operators must top off the LA batteries with deionized water before resuming operations. The new, LI forklifts did not require the 18-hour per week equalization process like the LA forklifts, marking a considerable contrast in uptime between the 2 ZE forklift types. Fleet managers deemed the maximum charging time of 6 hours as an acceptable amount of time to charge given the fleet's continuous use of the LI forklifts. Because LA and LI forklifts use many of the same parts, operators found the transition between the 2 technology types to be seamless.

User Acceptance

The fleet's LI forklift operators had an overall positive experience using the new technology. Operators appreciated that they did not need to spend extra time during their shift topping off the LA forklift batteries with deionized water as they previously did before, after they used the LI forklifts. Though LI forklift operators were, at times, prevented from starting their routes due to a low charge, once they began utilizing opportunity charging between work shifts, the LI forklifts were able to meet the required duty cycle with few performance issues, increasing the fleet's confidence in the new forklifts.

IV. Yard Tractors

Yard tractors are used at Frito-Lay's Modesto facility to move trailers from loading zones to semi-trucks for delivery. Historically, Frito-Lay exclusively used diesel yard tractors for its operations in Modesto. At the start of the deployment process, Frito-Lay had five diesel yard tractors which operate continuously at the facility. This project saw the deployment of three ZE yard tractors. Table 8 below shows the specifications for the diesel and ZE yard tractors.

Specifications

Table 8: ZE and Diesel Yard Tractor Specifications

Data Type	ZE Yard Tractor	Diesel Yard Tractor
Manufacturer Name	BYD	Capacity
Model Name	Q1M	Sabre On Road 4x2
Max Power (HP)	201	200
Runtime (hours)	10+	10+
Battery Capacity	217.6 kWh	--
Max Charge Rate	DC120 kw/ AC33 kw	--
GCVWR	102,000 lbs	Up to 81,000 lbs

Figure 6: Customized Frito-Lay ZE Yard Tractor and Diesel Yard Tractor

Analysis

Data Collection

CALSTART collected data on a diesel yard tractor from October 2020 through September 2021. This was the baseline vehicle used to compare performance with the ZE version. Over this period, the yard tractor recorded 6,642 distinct trips.

For the ZE yard tractors in this study, data were collected from October 2020 to September 2021, creating an analysis window of one full year. Geotab data loggers were used to collect performance data for the ZE yard tractors. These loggers activate once the vehicle is "keyed on" and continue to collect data as the vehicle operates. Data were downloaded directly from the Geotab API using JavaScript and saved in CSV files. All variables were collected on a trip level, meaning each row represents what happened on a single key on to key off event (a trip). The trip level yard tractor data gave fine-grained details on how the vehicles are used over the course of a day and months. After removing data discrepancies from trip driving and trip idling energy, the original 38,337 rows of data were reduced to 22,917 rows of trip data.

Performance

Each yard tractor shift is 10 hours long with two 15-minute breaks and a 30-minute lunch break. There is also a break between shifts of about one hour. The yard tractors operate throughout the day, seven days a week except for major holidays. Based on conversations with the fleet management staff, yard tractors move on average 175 trailers per day.

Table 9: Daily Duty Cycle for 3 ZE Yard Tractors and a Diesel Yard Tractor

Yard Tractor Type	Distance Travelled (miles)	Time Driven (hours)	Idle Time (hours)	Charging Time (hours)
3 ZE Yard Tractors (average)	41.7	10.6	5.1	2.0
Diesel Yard Tractor	34.6	10.9	2.4	N/A

The ZE yard tractor performed the same duty cycle as the diesel yard tractor. There was a slight decrease in time driven and an increase in distance driven and time idled by the ZEVs. The ZE yard tractors drove a similar amount of time each day compared to their diesel counterparts but covered more distance. It is possible that there were some efficiency gains thanks to the better acceleration at low speed offered by ZEVs. If less time was spent getting up to speed, slightly more trailer movements could occur and this effect over time could add up to the differences observed.

The idle time of the ZE yard tractor was more than double (112% more) that of the diesel vehicle. ZE yard tractors, like all ZEVs, make less noise when operating and especially when idling. It is possible that in some situations, for example while waiting for a trailer, the ZE yard tractors were simply left on and idling whereas a diesel would be turned off. If so, tracking this and establishing norms for vehicle shutoff could possibly save time and energy.

The yard tractors drove for ten to twelve hours per day with little difference between vehicle types. While both tractors were operating in typical duty cycles, they idled roughly 20 to 30% of total operating time. This idling occurred between raising and hooking trailers.

Energy Consumption

The ZE yard tractors achieved an impressive 97% efficiency which shows that the battery used almost all the energy it received from charging. The overall efficiency value was 81%. This means that 81% of the energy consumed from the grid ends up powering the vehicle. This high battery efficiency was consistent with other ZEV analysis but in stark contrast to diesel engines, which convert less than half of their energy into work[5].

Table 10: ZE Yard Tractor Efficiency

Battery Metric	Value	Metric	% Efficiency
Energy Charged (kWh)	104,816	Charger Efficiency	83%
Energy Retained (kWh)	87,049	Battery Efficiency	97%
Energy Consumed (kWh)	84,088	Overall Efficiency	81%

For the month of December, the average efficiency value was 10.4 kWh/hour whereas in the hotter month of May it was 8.8 kWh/hour which shows that batteries are less efficient in the winter months as they use more energy[6].

[5] Based on an audit of a USEPA 2010 compliant, heavy-duty diesel engine conducted by the Center for Alternative Fuels, Engines & Emissions at West Virginia University, 39% of the total input fuel energy on average is converted to useful work and 34% of the fuel energy on average is rejected as exhaust gas. https://theicct.org/sites/default/files/publications/HDV_engine-efficiency-eval_WVU-rpt_oct2014.pdf

[6] In their analysis of medium- and heavy-duty EV performance in various U.S. cities with different climates, traffic congestion levels, and hilliness, Qiu et al. found that colder temperatures had the strongest impact on the operational range of electric transit buses. http://evs36.com/wp-content/uploads/finalpapers/FinalPaper_Qiu_Yin_Dobbelaere_Cristina.pdf

Table 11: Yard Tractor Energy Consumption Comparison

Yard Tractor Type	Energy Used per Hour (DGE/hour)	Efficiency (kWh/hour)	Efficiency (kWh/mile)
ZE	0.23	9.3	3.5
Diesel	1.54	62.8	19.2

Across all three metrics, the ZEV used substantially less energy per unit of time or distance. The energy used by the ZEV was six times less than the diesel model on the per hour metric and over five times more efficient on the per mile metric.

Maintenance

Yard tractor maintenance data only included maintenance that was not performed under warranty. Therefore, although the cost of maintenance to the fleet was present in the dataset, the amount and kind of maintenance performed was unable to be fully assessed.

Infrastructure

Frito-Lay deployed six, 125 kW dual-port DC fast chargers to charge the fleet's yard tractors and box trucks deployed in the program as well as an additional ZE box truck outside the scope of this project. The chargers were delivered to the facility in January 2020, and the construction and installation process lasted about three months. The fleet experienced a few challenges coordinating logistics with the utility and charger supplier, which delayed the installation process. Additionally, adjusting to the new charging equipment and software took more time than expected for the fleet, which had the charger and vehicle OEMs on call to resolve issues as they arose as quickly as possible. About five months after installation, the DCFC chargers were fully operational in August 2020. The specifications of these chargers are described in Table 12.

Table 12: Specifications for Yard Tractor and Class 6 Box Truck Charging Infrastructure

Charging Infrastructure	Frito-Lay
Charger OEM (Count)	ChargePoint (12)
Charger Model Name	Express CPE250
Charger Power (kW)	Single Port - 125
Charger Voltage (V)	480
Installation Timeline (Months)	8

The dual-port chargers are equipped with a single Combined Charging Standard (CCS) and a single CHAdeMO plug[7]. Due to thermal inefficiencies and electrical resistance, real-world observations place the total maximum charger power around 108 kW.

Simultaneous charging of multiple vehicles resulted in a peak demand of over 400 kW, which incurred a monthly fee of nearly $4,000. Fleet managers implemented power controls through the smart charging software provided by ChargePoint. The fleet implemented demand management strategies that limited box truck and yard tractor charge rates. The fleet's first power demand limit swiftly reduced the peak demand and associated fees and saved the fleet over $24,000 annually. The proportion of the total cost from demand charges dropped from 54% to 38%.

User Acceptance

According to a Frito-Lay fleet manager, the deployment process was relatively smooth. The vehicle operators were trained on the new equipment and their feedback incorporated to improve the rollout of the new vehicles. Overall, the reliability of these vehicles was noted to be good and the fewer moving parts on the ZEV versus the diesel was seen as an immediate advantage.

According to survey results, most of the fleet's yard truck drivers gave neutral to negative responses to the new ZE yard tractors. Though drivers found some of the new yard tractors' features favorable to diesel yard tractors, many had initial difficulty adapting to the technology. CALSTART gathered more insights on how the fleet adapted to the new ZE technology from fleet manager interviews. According to one of the managers, challenges arose from the ZE yard tractors' regenerative braking, which put torque on the tires in the opposite direction, reducing the tread on the tires significantly. This led to the more frequent replacement of the yard tractors' tires, which are typically replaced once a year on a diesel yard tractor; the tires on the ZE yard tractors were replaced every four to six months. Drivers shared that more throttle control would help reduce the amount of torque on the tires and the need for frequent tire replacement. Additionally, the fleet had to replace the switches on the ZE yard tractors' dashboard three to four times a year.

The operators' experience adapting to the technology provides valuable takeaways for fleets that are considering electrification and demonstrates that more collaboration between manufacturers and fleets in the ZEV industry is necessary to ensure the success of future deployments.

[7] CHAdeMO is the name of the DC charging technology and the organization that develops it. The CHAdeMO technology is a DC charging standard for ZEVs that enables communication between the car and the charger. Learn more about CHAdeMO here. https://www.chademo.com/about-us/what-is-chademo

V. Class 6 Trucks

Frito-Lay used Class 8 trucks for all on-road transportation prior to Frito-Lay's participation in the ZANZEFF project. The new Class 6 box trucks represent an operational shift for the fleet with newly implemented duty cycles. Following the delivery of the 6 electric box trucks in August 2020, the fleet had to determine how best to utilize these vehicles, which have a shorter range and a smaller payload capacity, for Modesto facility's local, retail delivery operations. Given their novelty, there was no baseline internal combustion engine vehicle to directly compare performance. The efficiency of vehicles that use different energy sources was compared using miles per diesel gallon equivalent (MPDGe).

The box trucks were primarily used for local deliveries near Modesto, driving to retailers and unloading products for roughly 30 minutes at each stop. After unloading, the driver loaded the empty carts back onto the truck and continued to the next stop. The exact operations varied between the trucks, with each having a different route and hours of operation. However, all the box trucks had one daily shift from midnight to 10 AM. After completing this shift, the box trucks returned to the fleet depot to charge, with most charging events occurring between 10 and 11 AM. The box trucks were available for charging from the end of one shift to the beginning of the next.

Figure 7: ZE Class 6 Box Truck Deployed at Frito-Lay

The model 220EV Class 6 Peterbilt trucks were made by Peterbilt with a Meritor powertrain. Further specifications are described in Table 13 below.

Specifications

Table 13: Class 6 Truck Specifications

Data Type	ZE Box Truck
Manufacturer Name	Peterbilt
Model Name	Model 220eV
Max Power (HP)	355 hp (or 265 kW)
Runtime (hours)	5+
Battery Capacity	148 kWh
Max Charge Rate	DC120 kw/ AC33 kw
GVWR	26,000 lbs.

Analysis

Data Collection

Peterbilt used a data logger provided by ViriCiti which was hard-wired into each truck's controller area network (CAN) bus. The CAN bus allows electronic control units in vehicles to communicate with each other using a message-based protocol. CALSTART obtained access to this data and analyzed it for the Class 6 ZE trucks from the period of October 1, 2020, to September 30, 2021. ViriCiti aggregates data at the daily. During the data collection period of 365 days, 336 days of data were recorded.

Performance

The maximum range for the ZEVs was listed as 150 miles. Due to multiple variables that can impact range, including weather, geography, speed, driver, etc., the fleet reported the longest usable range to be 120 miles to maintain operational resilience on any given day. The original routes were adjusted to be within the truck's usable route length once analysis was completed.

Table 14: ZE Class 6 Truck Duty Cycle

Vehicle Type	Daily Miles	Daily Drive Time (hours)	Daily Idle Time (hours)	Average Driving Speed (mph)
Class 6	48.4	1.5	5.5	33.4

Though some of the box trucks were put on routes about 100 miles long, the average daily mileage was approximately 48 miles per day—less than half the vehicle's operating range. The box plot below helps visualize the distribution of daily miles driven. The daily driving distance for Class 6 ZEVs median mileage per day is 49.2 miles which corresponds to a local delivery radius for a fleet.

Most days the truck drove between 40 to 60 miles—roughly the length of the box trucks' restructured routes. Although the daily mileage is low compared to the potential range, as the fleet establishes more confidence in the reliability of these ZEVs, they may be able to put the trucks on a more intense duty cycle with longer daily mileage.

The trucks still completed a full shift each day, operating for about 7.1 hours on average. Additionally, drivers maintained an average speed of about 33 miles per hour, indicative of urban driving scenarios. The trucks spent more than 5.5 hours idling per day, which may be due to drivers leaving the truck on during the loading and unloading of goods while parked. Due to the silent operation of these trucks, it is easy to inadvertently leave them running whereas a conventional vehicle might be turned off because it makes more noise when idling. It is possible that this frequent idling could have reduced the box truck's range.

Energy Consumption

The box trucks' battery efficiency, calculated as the ratio of energy consumed to energy charged, was 93%. This high battery efficiency percentage, typical of ZEVs, demonstrates that the vehicle's battery processed the charged energy well.

As mentioned previously, there was no baseline vehicle at the facility for comparison. Instead, the energy consumption was compared to a standard Class 6 diesel truck, with a fuel economy of 8.21 MPDG. In comparison, the ZE box truck achieved a 26.2 MPDGe charged, approximately 3.2 times more efficient.

Table 15: ZE Class 6 Box Truck Energy Consumption Comparison

Fuel Type	Energy Used per Hour (DGE/hour)	Efficiency (kWh/mi)	MPDGE[8] Charged	Energy Efficiency Ratio
Class 6 ZE	0.23	1.32	26.2	3.2

Maintenance

During the first few months of the data collection period, the vehicles received larger quantities of relatively inexpensive repairs, mostly initial adjustments and software updates which caused little to no downtime. After this point, work orders became less numerous, but there was still a peak in maintenance cost during the summer of 2021. This secondary peak was partially caused by a few one-off issues with individual trucks, but mostly due to proactive maintenance campaigns carried out by the fleet.

[8] Miles per diesel gallon equivalent is a commonly used measurement for fuel economy comparisons involving electric vehicles.

Figure 8: Class 6 Electric Box Trucks Average Maintenance Cost per Mile by Month

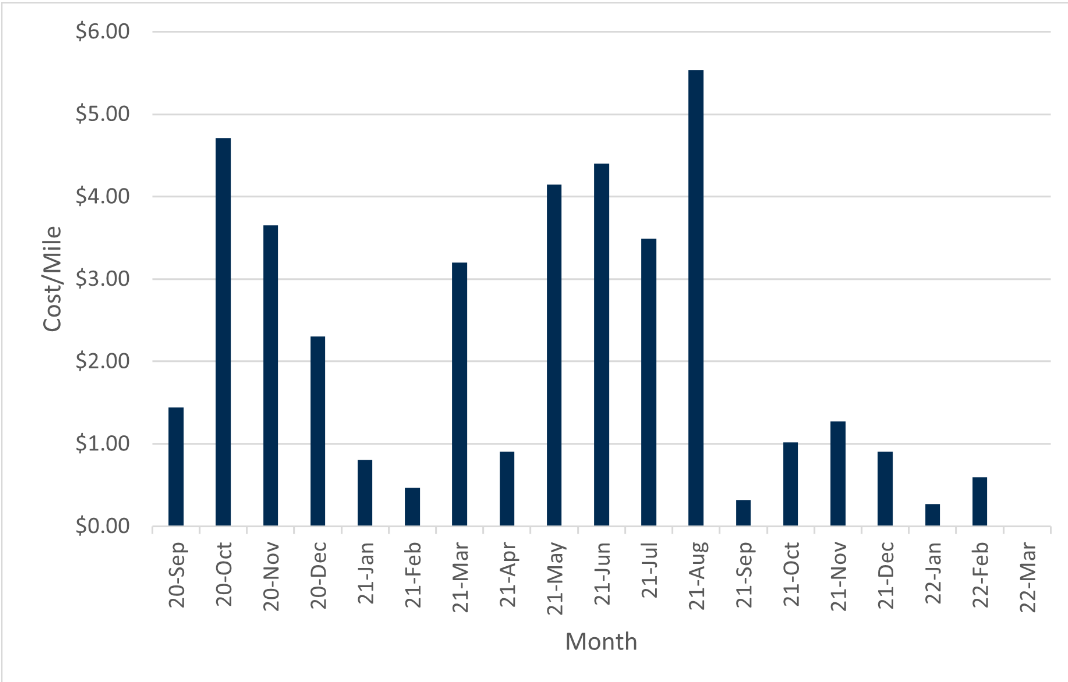


Figure 8 shows the average maintenance cost per mile per month for the Class 6 box trucks. Their maintenance cost peaked in the early months of deployment and then peaked again around month 11, but the final 7 months of data show a marked decrease.

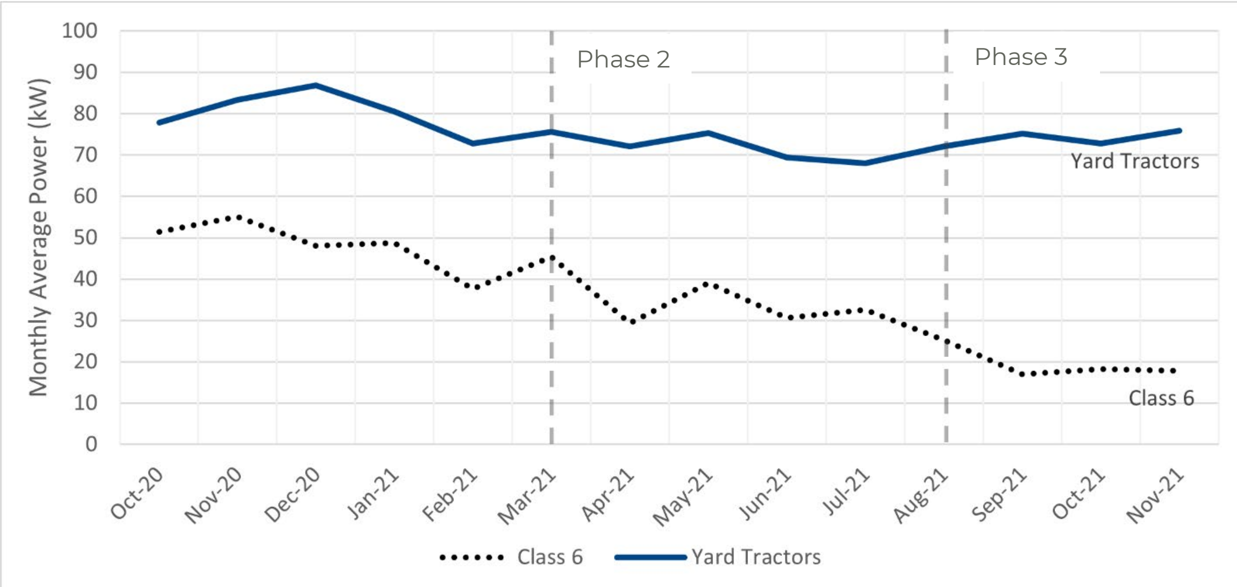
Infrastructure

Overall, the box trucks followed a strongly unimodal distribution in terms of their charging. Drivers plugged in the trucks at the end of their shift that began early in the morning and did not initiate much charging activity outside the 9 am to 11 am window. One interesting insight was that the fleet does not charge these trucks every single day. For instance, all the trucks operated for 336 distinct days over the one-year observation period and charged on 314 distinct days over that period. Overall, this truck charged 75% of working days.

The fleet predictably and consistently charged between 36% and 61% SOC per session, with an average of 49% (equating to roughly 81 kwh). This indicates the duty cycle most often used between one and two-thirds of the battery capacity before recharging. This finding is encouraging for fleets that want to switch to ZEV technology. Being able to use the battery and then only need to charge it up halfway means that the vehicle is serving the duty cycle requirement.

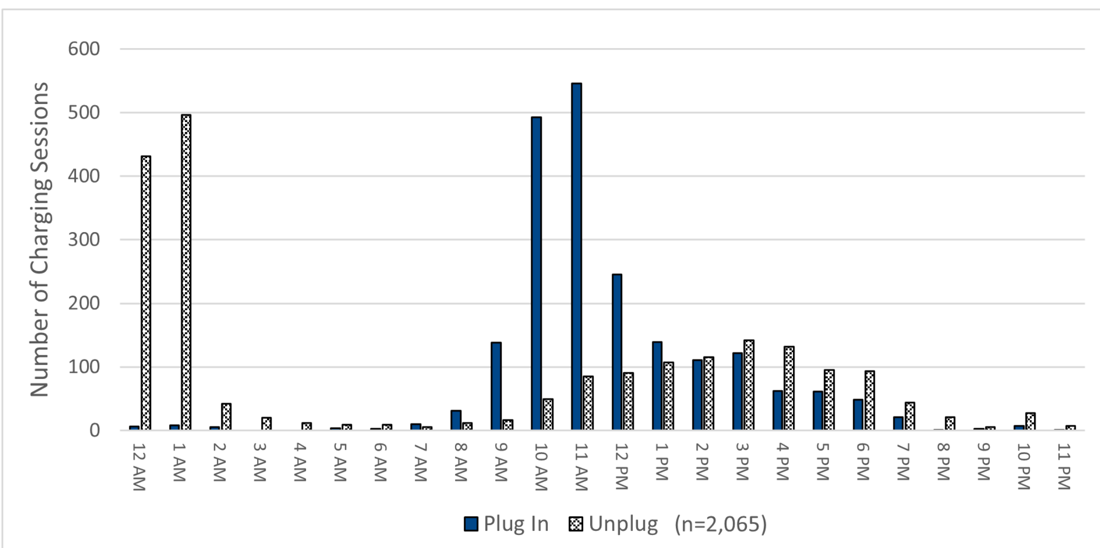
Monthly energy consumption and power demand data were collected for a year from December 2020 to December 2021. The box trucks shared ChargePoint charging infrastructure with the yard tractors. Figure 9 below demonstrates how the fleet's strategies impacted the ChargePoint system's overall power demand.

Figure 9: ZE Yard Tractor and Class 6 Truck Monthly Average Charging Power



The Class 6 box truck has a distinct charging pattern. Figure 10 shows that there is a sharp increase in un-plug events from 12 AM to 1 AM, indicating the beginning of a shift. Conversely, there is a sharp increase in plug-in events from 10 AM to 11 AM, indicating the end of a shift. Because the Class 6 box trucks are used less intensively than the yard tractors, the fleet may have more flexibility to alter the box trucks' plug and unplug schedules to reduce overall energy consumption.

Figure 10: Class 6 Box Truck Plug-In and Unplug Schedules from October 2020 to November 2021



User Acceptance

Most of the drivers had an overall positive experience with the ZEVs. Neutral to favorable responses from the administered surveys included fueling vs charging, coasting, maneuverability, training, and vehicle impacts to daily schedules.

VI. Class 8 RNG and ZEV Trucks

Frito-Lay deployed 38 Volvo RNG trucks and 15 Tesla ZE trucks in this project and monitored 10 diesel trucks for comparison. Data on the diesel and RNG trucks were collected using Geotab data loggers from October 2020 to May 2021, while data on the ZE trucks were provided by the fleet for the period covering December 2022 to March 2023. The specifications of the Class 8 trucks deployed are listed in Table 16 below.

Specifications

Table 16: RNG, Diesel, and Electric Class 8 Truck Specifications

Model Year	Fuel Type	Horsepower	Nominal Range
2022	Battery Electric	1,000 (or ~746 kW)	500 miles
2020-2021	RNG	425	750+ miles
2015-2017	Diesel	425	2,000 miles

Analysis

Data Collection

Battery Electric

The first deployment of the Tesla Semi battery-electric Class 8 tractor occurred at Frito-Lay's Modesto plant under the ZANZEFF project. The fleet received 15 of the Tesla Semis starting in December 2022. The first ZEV received was deployed on its first trip on December 1st, and the fifteenth ZEV was deployed on its first trip on December 22nd. In this dataset, there are 115 unique days from December 1st to March 29th, 2023, with 5,449 trips recorded in total.

Drivers were excited to test the new trucks and were supported by Tesla's service technicians who are onsite at the Modesto facility for 6 to 12 months after the trucks' deployment. Tesla provided both the vehicle and charger equipment, which streamlined interoperability between the trucks and their 750 kW chargers. According to fleet managers, the deployment went smoothly.

Figure 11: Class 8 ZE Truck Deployed at Frito-Lay

Renewable Natural Gas

The deployment of the new RNG trucks went smoothly due to the fleet's familiarity with the vehicle manufacturer and the RNG fuel reliability. Project partner Beyond6 constructed an RNG fueling station under the scope of this project to provide the fleet with a more locally accessible source of fuel. The fleet received 10 of the RNG trucks in 2019 before the station's construction was completed, so managers trained drivers on fueling the new vehicles using remote sources of fuel for approximately 4 to 5 months. During the training process, drivers noted that the RNG trucks had slightly less power than their diesel counterparts but were equally as capable of completing their duty cycle.

Frito-Lay has 2 sets of Class 8 Volvo RNG trucks: model year 2020 VNL64T300 trucks and model year 2021 VNL64T300 trucks. One of the fleet's RNG trucks fueling at Frito-Lay's RNG station is pictured below in Figure 12.

Figure 12: Class 8 RNG Truck Deployed at Frito-Lay

Performance

The fleet's Class 8 tractors run 350 to 400 miles per day, and drivers go out on their routes twice a day. The fleet's Class 8 trucks were used to transport manufactured goods regionally to wholesale distribution centers and retail stores. Because the fleet's Class 6 box trucks handled short-range, local deliveries, the fleet's Class 8 trucks could be prioritized to handle longer routes. The fleet's overall average length of haul for Class 8 on-road travel has been reported to be about 425 miles[9]. The duty cycles of the ZE, RNG, and diesel trucks are documented in Table 17.

Table 17: Class 8 Trucks Duty Cycle

Vehicle	Total Hours in Use (hours)	Miles per Day	Max Miles per Day	Drive Time per Day (hours)	Idle Time per Day (hours)	Average Speed (mph)
RNG Truck	1,325	299.6	855.3	7.2	0.3	41.6
Diesel Truck	1,693	299.8	1311.1	6.4	0.2	46.8
ZE Truck	644	182.0	556.8	5.2	1.0	31.6
ZE Truck Max (Top 10% of Days)	509	361.7	556.8	9.1	1.2	39.8

Each diesel and RNG truck operated a full shift of 6 to 7 hours on most days, though operators drove

[9] Mike O'Connell, the PepsiCo Vice President of Supply Chain, shared insights on the fleet's integration of the Tesla Semi in their operations. https://www.youtube.com/watch?v=l-BVM673pDs

the RNG trucks for a slightly longer time per day compared to the baseline diesel truck. The ZE trucks operated roughly 5 hours per day. Their idle time was also comparatively longer, at one hour per day versus the roughly 15 minutes of the conventional vehicles. This is a common result in ZE demonstration projects and is likely explained by the fact that idling electric vehicles do not make noise.

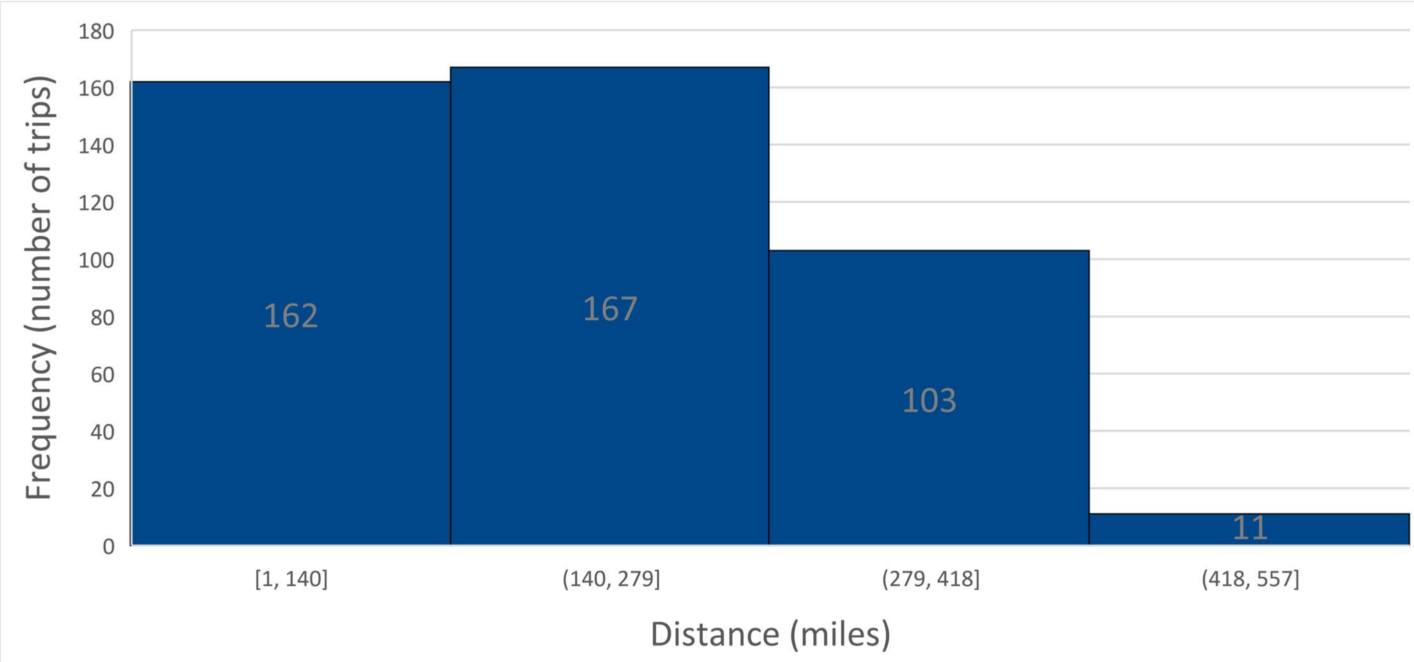
The RNG truck can reliably complete the duty cycle of the diesel truck. Based on the data, the first 3 months of deployment may be too early to make a similarly definitive statement for the ZE trucks on average. However, the fleet staff reported that all RNG and ZE Class 8 tractors could travel the same assigned routes without significant challenges during operation.

The RNG truck performed the same duty cycle as the fleet's baseline diesel trucks. Both trucks traveled almost exactly 300 miles per day on average. The diesel trucks drove slightly faster than the RNG trucks by about 5 miles per hour. There was a marginal increase in idle time for the RNG trucks compared to the diesel trucks, though operators idled for less than 20 minutes each day on average for both trucks. For the duration of the data collection period, however, operators utilized the RNG truck about 360 hours and 20,000 miles less than the diesel truck.

Both combustion Class 8 trucks had a consistent duty cycle throughout the week, with a slight amount of variation in driving time. The similar duty cycles show that the RNG truck is a suitable replacement for a traditional diesel truck.

Figure 13 demonstrates a histogram representing the frequency in which the ZEVs drove varying daily trip distances. The x-axis shows the minimum and maximum distance traveled by the ZEVs; the minimum daily distance was recorded at one mile, and the maximum daily distance was recorded at 557 miles. The range of values in the x-axis are grouped into 4 intervals. The y-axis shows the frequency at which the ZEVs drove a certain distance within these intervals. On nearly 75% of active days the trucks covered more than 140 miles.

Figure 13: Frequency of Daily Travel Distances



On the day that the maximum daily driving distance was recorded, the ZE truck took 15 distinct trips beginning at 4 AM and ending at 10 PM. Out of the 15 trips, 3 were longer than 100 miles. The longest single trip in the dataset was 320.4 miles over 8.4 hours of driving and 0.97 hours of idling—a huge breakthrough for this technology.

A further analysis can be done of days with greater than 250 miles travelled, which was previously a typical maximum daily range for a Class 8 ZEV. There are over 139 days in the dataset where a ZE truck was able to drive this distance in a single day. The duty cycle metrics for days in which more than 250 miles were driven—more comparable to a diesel Class 8 truck—is shown in Table 18 below.

Table 18: ZE Semi Duty Cycle for Days with Greater than 250 Miles

Duty Cycle Metric	ZE Semi
Count of days	139
Average miles per day	331.1
Drive time per day (hours)	7.4
Idle time per day (hours	1.2

The data above suggest that the Tesla Semi is capable of completing the same 300 miles per day without opportunity charging consistent with the average daily mileage of the conventional Class 8 tractors at this fleet.

Energy Consumption

Energy consumption data were collected and analyzed over the one-year analysis window to compare the efficiencies of each Class 8 truck deployed. The fleet's diesel and RNG trucks consumed liquid and gaseous fuels, respectively; the efficiencies of these vehicles were compared by analyzing the volume of fuel consumed in diesel gallon equivalents (DGE) and by analyzing the number of miles traveled per diesel gallon equivalent (MPDGE). The ZE trucks, on the other hand, consumed electricity measured in kWh as fuel. The energy consumed and the energy charged by the ZE trucks were converted to DGE to calculate their fuel efficiency in MPDGE to compare the efficiencies of all 3 truck types on equal footing.

RNG truck operators fueled their trucks at the one-lane, fast-fill Beyond6 RNG Station. Typically, the fueling rate from fast-fill dispensers increases the temperature of the RNG molecules that are stored in the truck's tank, which decreases the density and the energy per volume of the RNG fuel[10]; however, fueling equipment at RNG stations can be equipped with a temperature compensation feature that helps maintain temperatures at industry conditions to maximize fuel storage capacity. Additionally, high ambient temperatures can increase the temperature of the RNG molecules inside the tank, which decreases the energy per volume of fuel. Diesel, on the other hand, is dispensed as a liquid fuel, which can maintain its volume under a wide range of temperatures. Table 19 below documents the volume of fuel consumed by the fleet's Class 8 trucks, the energy efficiency of each vehicle type in MPDGE, and the energy efficiency ratios of the ZE and RNG trucks compared to the baseline diesel tractors.

[10] Slower fueling rates and lower ambient temperatures allow the RNG molecules to remain in a dense state, which prevents the decrease in energy per volume of fuel and maximizes fuel storage capacity. https://afdc.energy.gov/vehicles/natural_gas_filling_tanks.html

Table 19: Class 8 Truck Energy Consumption

Truck Fuel Type	Diesel Gallon Equivalent Consumed (DGE)	Miles per Diesel Gallon Equivalent (MPDGE)	Energy Efficiency Ratio to Baseline
Battery Electric	3,965	19.5	2.4
RNG	6,026	8.8	1.1
Diesel	7,646	8.1	1.0

The volume of fuel consumed by the RNG truck was significantly lower than the volume of fuel consumed by the fleet's baseline diesel truck. Despite the difference in the volume of fuel consumed, however, the RNG truck fuel efficiency was about 1.1 times higher than the diesel trucks. Furthermore, the fleet's RNG truck fuel efficiency exceeded the average Class 8 truck fuel economy in California, which is 5.85 miles per gallon[11] (MPG), as well as the national average of all Class 8 tractors at 6.24 MPG[12]. The ZEs, on the other hand, had the highest fuel efficiency out of all the fleet's Class 8 trucks at 19.5 MPDGE, which is about 2.4 times more efficient than the diesel truck's fuel efficiency and 2.2 times higher than the RNG truck's fuel efficiency.

Battery Electric Driving Energy Consumption

The data produced by the ZE truck tells a story about their efficiency and offers insight into electric drivetrains in general. The table below demonstrates the total distance traveled and the total energy consumed by the fleet's ZE trucks. Below, Table 20 shows what the annual usage of a ZE truck would be given the usage observed in this deployment.

Table 20: ZE Class 8 Truck Energy Consumption

Energy Consumption Metric	ZE Class 8 Trucks
Total Distance (mi)	34,090
Energy Consumed (kWh)	56,678
Energy Efficiency (kWh/mi)	1.6

The 1.6 kWh per mile value listed in the table above is in line with what Tesla reported about the vehicle's efficiency in the initial deployment, which is lower and thus more efficient than other Class

[11] A sample of 31,170 Class 7 and Class 8 trucks with mixed make and models were equipped with a Geotab GO telematics device for one year from June 2016 to June 2017 to track the fuel economy of trucks traveling in the continental U.S. and Canada. https://www.geotab.com/truck-mpg-benchmark/#rol

[12] According to the North American Council for Freight Efficiency (NACFE) in their Annual Fleet Fuel Study report, the national average equipment efficiency for all Class 8 tractor-trailers in 2020 was 6.24 MPG, though participating fleets in the study achieved a fleet-wide fuel economy of 7.23 MPG. http://www.truckingefficiency.org/annual-fleet-fuel-studies

8 ZE tractor data reported to date. Frito-Lay continues to measure the Tesla Semis' operational efficiency post the initial collection period and has observed a rolling-average efficiency below 1.4 kWh/mile. The data provided was insufficient to calculate charging efficiency and battery efficiency on board the vehicle. Table 21 demonstrates key fleet characteristics for trips completed by the Tesla Semis.

Table 21: Class 8 ZE Energy Consumption

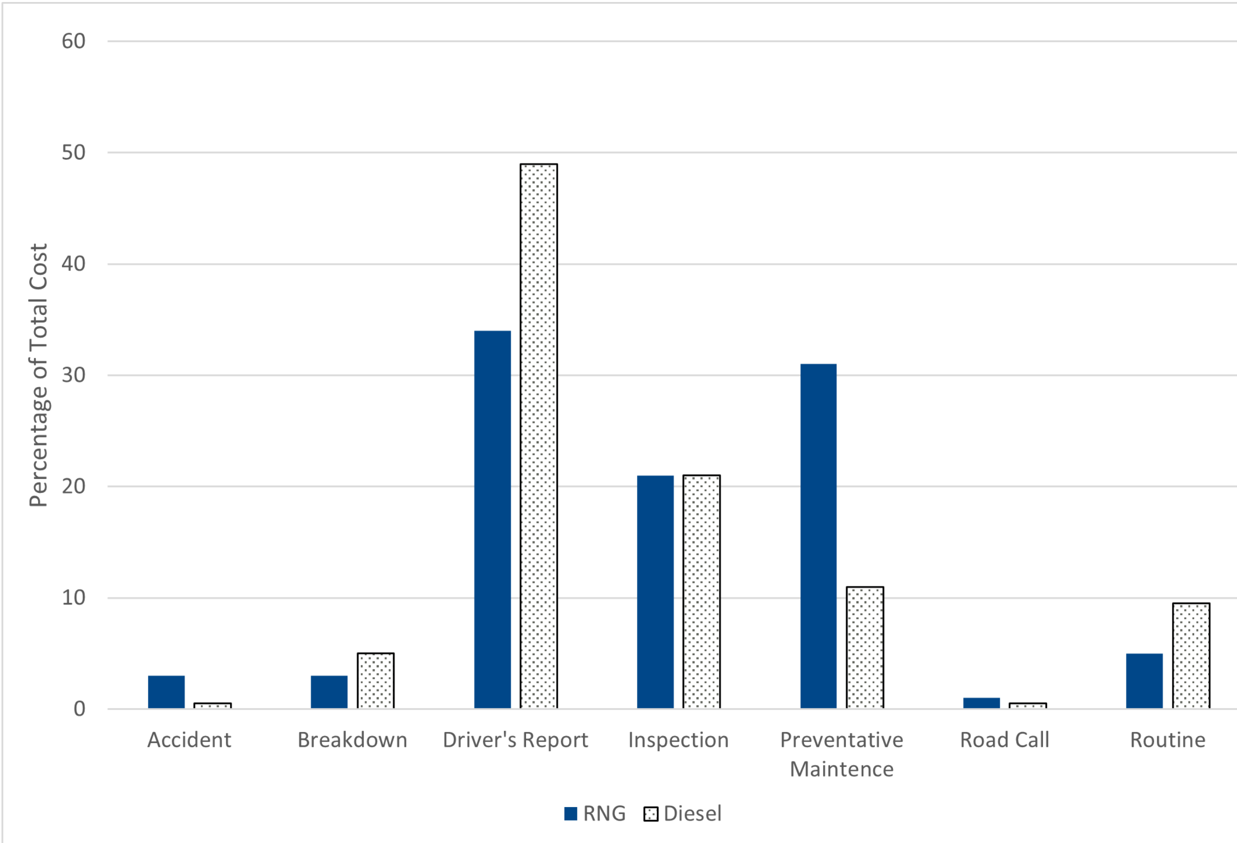
Energy Consumption Metric	Avg for All Trips	Max Trip
Energy Consumed per trip	233.7 kWh	573.6 kWh
Energy Driven per Trip	228.8 kWh	568.8 kWh
Energy Idled per Trip	3.9 kWh	4.6 kWh
Efficiency	1.6 kWh/mi	1.8 kWh/mi
MPDGE	23.0 MPDGE	18.7 MPDGE

Maintenance

Of the 39 RNG vehicles deployed, many began their deployment in different months, ranging from May 2019 to February 2020. In some cases, maintenance cost data were analyzed for vehicles as old as a decade to compare maintenance cost by month of operation. These older maintenance data have been adjusted for inflation to 2020 dollars (19% increase).

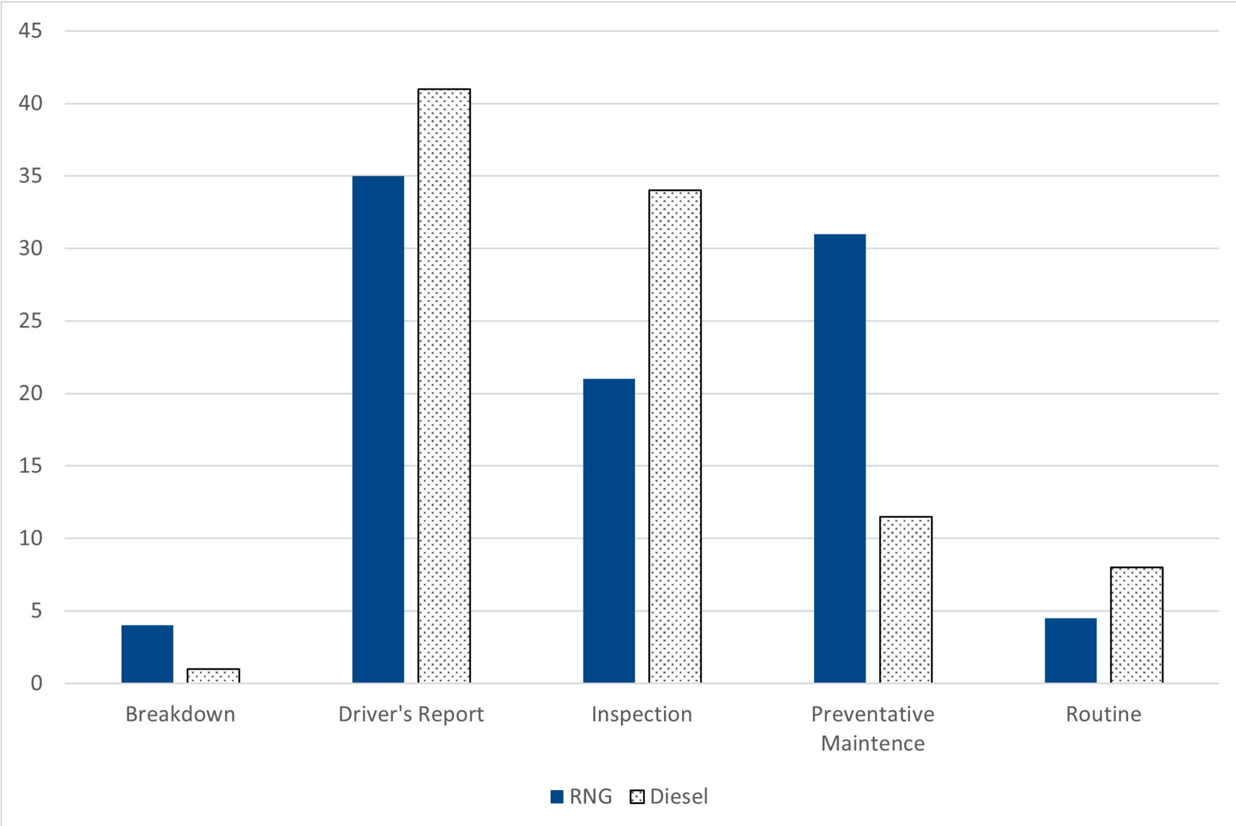
Work orders in the maintenance dataset were categorized into one of the above categories. Preventative Maintenance and Routine both refer to scheduled or planned maintenance activities, while the Driver's Report and Breakdown categories refer to unscheduled or unexpected maintenance.

Figure 14: Class 8 Trucks Percent of Total Cost by Maintenance Type



The percentage of total cost spent on unexpected repairs in the Breakdown and Driver's Report categories was lower for the RNG vehicles, while the percentage of total cost spent on scheduled repairs in the Routine and Preventive Maintenance categories was higher for the RNG vehicles. The fleet discovered one of the RNG vehicles had software update issues, so they repaired the truck and inspected all the other trucks for the same issue, repairing them as needed; this may have contributed to the higher RNG preventative maintenance cost. The RNG vehicles were more reliable during the data collection period and less likely to have unexpected issues than the diesel vehicles. To eliminate the compounding factor of vehicle age, the same analysis was performed on data from the first 20 months of operation for both vehicle types. Figure 15 below shoes the percent of total cost by maintenance type for the first 20 months of operation for the Class 8 trucks deployed by the fleet.

Figure 15: Class 8 Trucks Percent of Total Cost by Maintenance Type – First 20 Months of Operation



The overall cost of maintenance for the Class 8 RNG trucks is lower than diesel. Maintenance data for the Tesla Semis was not collected given their later deployment in the project.

Infrastructure

Beyond6 RNG Station

The Beyond6 RNG station, previously named American Natural Gas, fully operational as of May 2020, is a three-lane, fast-fill RNG station located at 4283 Leckron Rd[13]. According to Beyond6, their fuel is 100% renewable and is sourced from organic matter collected from landfill gas, wastewater, food waste, and agricultural waste[14]. Beyond6 previously dispensed natural gas with a carbon intensity (CI) value of 41 grams of carbon dioxide equivalent per megajoule of energy produced (g CO2e/MJ). CI is the measure of GHG emissions from the complete life cycle assessment of a fuel, including its extraction, production, transportation, and consumption. CO_2e is a measure of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another GHG—

[13] ANG Kicks off Construction on Modesto RNG Station. NGT News. https://ngtnews.com/ang-kicks-off-construction-on-modesto-CNG-station

[14] The molecules of natural gas that the fleet used to fuel their trucks may not always be derived from renewable organic matter; rather, ANG produces a volume of RNG equivalent to the volume of natural gas used by Frito-Lay. Learn more about ANG's RNG fuel here. https://americannaturalgas.com/rng/

RNG in this case[15]. However, in September 2020, the station switched to RNG with a CI value of -240 g CO_2e/MJ[16]. The negative CI value means that it takes out more carbon from the air than it produces. For reference, diesel fuel has a CI value of about 69 g CO2e/MJ.

86% of the fuel consumed at the RNG station goes to Frito-Lay vehicles. The 38 Frito-Lay trucks each fuel about 22 times per month. The frequency of fueling stops by Frito-Lay trucks is regular. Non-Frito-Lay vehicles consume less fuel on average.

750 kW Tesla Chargers

Frito-Lay installed 4, 750 kW Tesla fast chargers to charge its fleet of 15 ZE Tesla Semi Trucks. The units were coupled with a battery energy storage system (BESS) with a capacity of 2.7 MWh. The 750 kW chargers worked seamlessly in conjunction with the ZE Class 8 tractors. The fleet set limits set on charging and monitored demand closely.

Table 22: Specifications for ZE Class 8 Truck Infrastructure

ZE Class 8 Trucks Infrastructure	-
Trucks (Count)	Tesla (15)
Charger Ports (Count)	Tesla (4)
BESS Capacity (MWh)	2.7
Charger Power (kW)	750
Installation Timeline (Months)	>12

CALSTART collected 4 months of charging data from the 750 kW Tesla chargers. The data collection period began November 30, 2022, and ended on March 26, 2023, with a total of 469 sessions across all vehicles and 4 chargers. Summarized data of relevant parameters for 429 sessions can be found in Table 23.

[15] Learn more about CI here. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/rlcf006_-_carbon_intensity_records.pdf

[16] Emissions for RNG transport to station not reflected.

Table 23: ZE Class 8 Truck Charging Session Metrics

Energy Metrics	Avg	Max
Energy Charged (kwh)	326.8	767.0
Charging Power (kw)	268.6	814.2
Charging Duration (hrs)	1.2	3.2
Session Duration (hrs)	9.9	77.2

The average and maximum values are promising, denoting high-powered fast charging. However, the amount of time the vehicles were plugged in without actively charging may indicate that more efficient use of the limited number of chargers could be achieved.

The fifteen ZE Class 8 Tesla Semi trucks operated several times per week and charged regularly using the 4 chargers. In general, the Tesla Semis were commonly plugged in in the early morning and late evening and most often unplugged in the early afternoon. Apart from the 7 am to noon time window, plug and unplug events occurred throughout the day. While most charging sessions were plugged in in the very early morning and unplugged in the early afternoon, this pattern is not very distinct. For the Class 8 trucks, charging sessions overnight were predominant.

Figure 16: Average Daily Maximum Power Demand

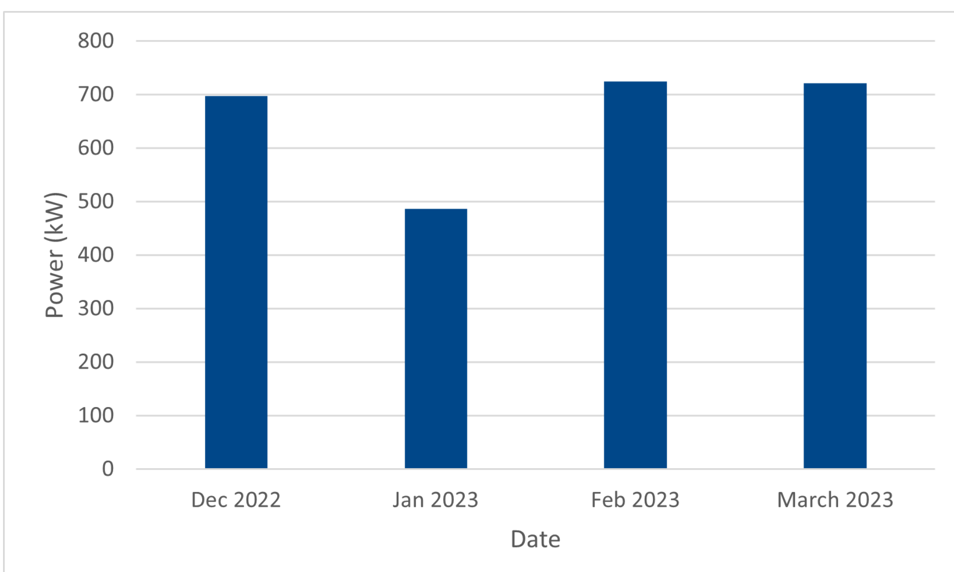


Figure 16 above shows the average daily maximum power demanded by the chargers for each month of the data collection period. During the months of December, February, and March, the chargers' daily average maximum was above 700 kW, while in January, the daily average maximum was less than 500 kW. Table 24 shows the charger energy use metrics below.

Table 24: Charger Energy Use Metrics

Energy Use Metrics	Value
Time Charged (hr)	1,315.9
Time Plugged In (hr)	10,603.0
Energy Use Metrics	**Value**
Average Percent of Session Spent Charging (%)	12.4%
Average Energy Dispensed per Charge (kWh)	313.3
Average Number of Charging Sessions per Day Overall	5.2

Table 25 below describes the total energy charged, in kWh per session, by the Class 8 tractors throughout the data collection period. On average, the vehicles charged 327 kWh per charging session, but were able to charge at a maximum of 90.2% SOC in a single session.

Table 25: Class 8 ZEV Energy Charged (kWh) per Session

Energy Consumption Metric	Class 8 ZEV
Average Energy Charged per Session (kWh)	327
Maximum Energy Charged per Session (kWh)	767
Maximum SOC Gained (%)	90.2

The average time to charge was 1.2 hours for the Tesla Semis.

The battery size for these vehicles was not provided. CALSTART noted that the vehicles charged between 15.4% SOC and 56.9% SOC in the median 50% of charges. On average these charges were completed in 1.24 hours, meaning that the Class 8 ZEVs were able to charge extremely quickly.

Long session duration can be attributed to several factors, but mainly due to the ZEVs being plugged in overnight or over a long weekend and only being unplugged when workers return to work. This is not inherently a problem; however, it suggests that the ZEVs do not need to be charged so quickly when they are left to charge overnight or over the weekend. This may be an area where the fleet can cut some costs.

User Acceptance

> [OPERATORS] FOUND THAT THE TIME SPENT CHARGING THE ZE TRACTORS IMPACTED THEIR DAILY SCHEDULE SIMILARLY AS FUELING A DIESEL TRACTOR WOULD.
> On site surveys and interviews

According to Frito-Lay's analysis, the fleet's RNG truck drivers had trouble operating the new trucks on their routes for standard operations. The drivers gave positive feedback on the RNG tractor training and found the comfort, cab interior noise reduction, and layout of the vehicles to be favorable. Despite these benefits, the RNG truck drivers reported that fueling their vehicles significantly impacted their daily schedule and that there was limited fueling access. Additionally, half of the RNG truck drivers surveyed had trouble in maneuvering the new trucks, and all the RNG truck drivers surveyed had unfavorable experiences with the acceleration on the new RNG trucks. Overall, nearly all the fleet's drivers preferred the baseline diesel trucks to the new RNG trucks deployed in this project—an interesting insight given comparable performance findings.

The fleet's Tesla Semi operators acclimated well to the technology with the assistance of Tesla's technicians onsite and gave positive feedback according to the analysis provided by Frito-Lay. Most operators found the ZE Semi to be a better alternative than the baseline diesel tractors and the new RNG tractors. They found that the **time spent charging the ZE tractors impacted their daily schedule similarly as fueling a diesel tractor would**, with over 80% answering that charging had a similar impact or was an improvement. This is an encouraging and surprising result given that long charge times (together with limited range) have been noted as a limiting factor for Class 8 ZEV deployments. Though there was favorable feedback on the ZE truck capabilities and layout, few operators found the reliability to be better than the baseline diesel vehicles.

VII. Workplace Charging

The workplace charging system at the facility consists of 5 Level 2 chargers made available for staff. The chargers are not accessible to visitors without permission from staff on the ground, who access the chargers with their employee badges. Facility staff did not implement a charging policy for employees or a charge management strategy as it was not a concern. The specifications of the equipment are detailed in Table 26 below.

Specifications

Table 26: Frito-Lay Workplace Charging Infrastructure

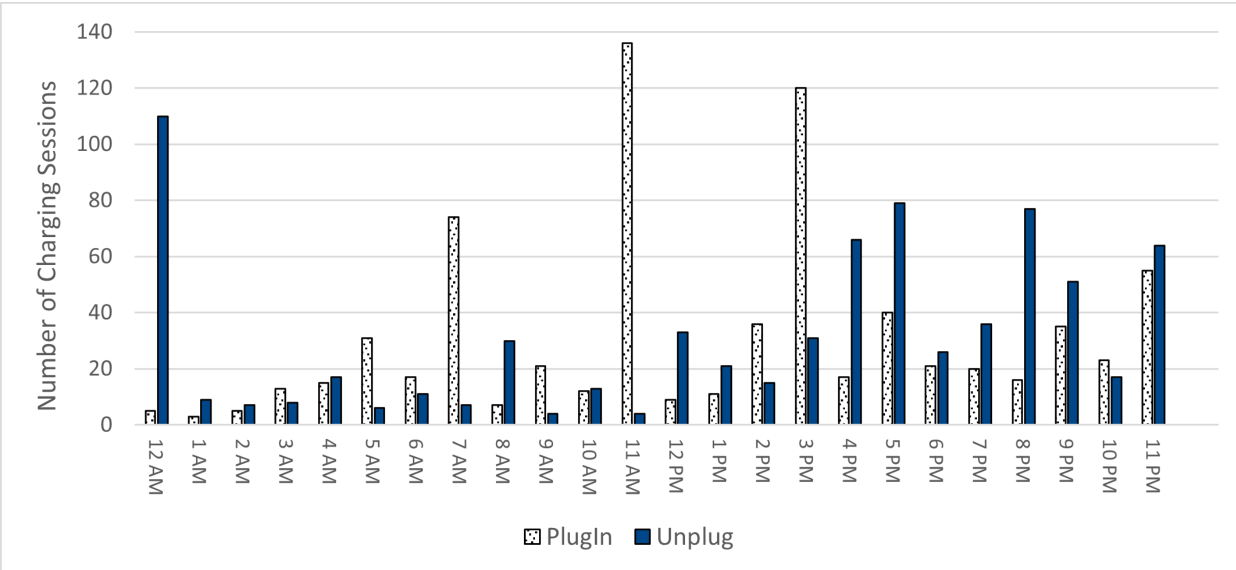
Specification	Workplace Chargers
OEM	ChargePoint
Model Name	CT4000
Connector	J1772
Max Charge Rate (kW)	7.2
Voltage	240
Amperage	30
Installation Timeline (weeks)	~8

Analysis

Performance

Figure 17 displays the plug-in and unplug schedules over the one-year data collection period; most plug-ins occurred at 11 am, 3 pm, and 7 am, respectively, with unplug events more spread out between the hours of 4 pm and midnight.

Figure 17: Level 2 Plug-In and Unplug Schedules from December 2020 to December 2021



According to the MID GS-3 time period structure, most plug-in events occur during the partial-peak period or the on-peak period, depending on the season. Charging during these periods is more costly for the fleet, particularly during the summer months when rates are the highest. Conversely, most unplug events occur during the off-peak period, which is the least costly period to consume energy.

Workplace charging was used regularly throughout the period with more during the summer of 2021. Since 2021 corresponded with the lowest COVID caseload, it is assumed that more employees and guests used their personal ZEVs to drive to work. Workplace charging only averaged about 2 sessions a day. The average SOC gained per day was about 19% per day.

User Acceptance

Conversations with fleet staff in 2023 revealed that employee EV adoption and workplace charging has increased since the data collection period from 2020 to 2021.

VIII. Solar and Storage

The 1.098 MW DC Tesla Solar Carport went live in December 2020 and is made up of 9 solar canopies consisting of approximately 5,600 panels covering 247,000 square feet. The Solar Carport generates energy from the sun while also providing shade for employee parking.

One of the battery storage systems, known as the Tesla Powerpack, is a 696-kWh battery able to store energy generated by the Solar Carport and from the grid. The Powerpack uses Tesla's demand management optimization system called Opticaster to optimize energy distribution. The Powerpack also went live in December 2020. The second battery storage system, a 2.7 MWh battery, will draw energy from the grid to charge the Tesla Semis.

The solar array contributes energy to the facility, Tesla Powerpack battery storage system, and the ChargePoint Level 2 workplace chargers. It does not contribute to the ChargePoint chargers for the Peterbilt trucks or BYD yard tractors. The grid also powers the facility and ZEV infrastructure, including the trucks and yard tractors. The Tesla Powerpack is charged by the solar array and supplies energy to the workplace chargers and the facility. Table 27 lists the solar infrastructure specifications below.

Specifications

Table 27: Specifications for Solar System Infrastructure at Frito-Lay

Solar Infrastructure Metric	Value
OEM	Tesla
Max Generation Rate (MW)	1.098
Number of Panels	5,600
Installation Timeline (weeks)	8

In coordinating the construction and commissioning of the solar system and the BESS, Frito-Lay encountered several roadblocks. Due to the COVID-19 pandemic, Tesla was delayed in providing the design for the Solar Carport and the BESS. Furthermore, the fleet had to collaborate with MID to ensure that the designs for this equipment met the utility's requirements. The biggest barrier, however, was coordinating the construction of the Solar Carport and the Powerpack storage system. Frito-Lay periodically closed and opened areas in the facility parking lot to finish construction. In total, the fleet went through 6 cycles closing off different sections of the parking lot, which entailed cumbersome coordination with employees on where they could park during the closures. This build pattern was necessary to ensure that employees could work as normal, and the plant could maintain production. Despite these delays, the construction process went smoothly on account of the highly skilled and experienced construction team Tesla subcontracted for the fleet. As a result, both the Solar Carport and the 696-kWh storage system went live in December 2020 after 6 months of construction, which includes the parking lot and additional renovations. According to conversations with Frito-Lay, roadblocks should be expected in any construction project; however, it takes a reliable team with expertise to overcome them.

The second battery storage system, a 2.7-MWh battery, draws energy from the grid to charge the Tesla Semis. This goal is for this battery to “peak shave”, meaning it slowly charges up from the grid so that it can deliver energy when a Tesla truck plugs in and begins charging at a high rate. Thus, the “peak” power demand is shaved down to a lower amount. This is important because utilities charge industrial customers not only on the total amount of energy they use, but on the peak demand rate as well, thereby incentivizing conservation of energy and a more even use of the grid’s power over time. In fact, demand charges are so high they can constitute the majority of a site’s electricity cost.

Analysis

Data Collection

Figure 18: Solar Carports and BESS Deployed at Frito-Lay

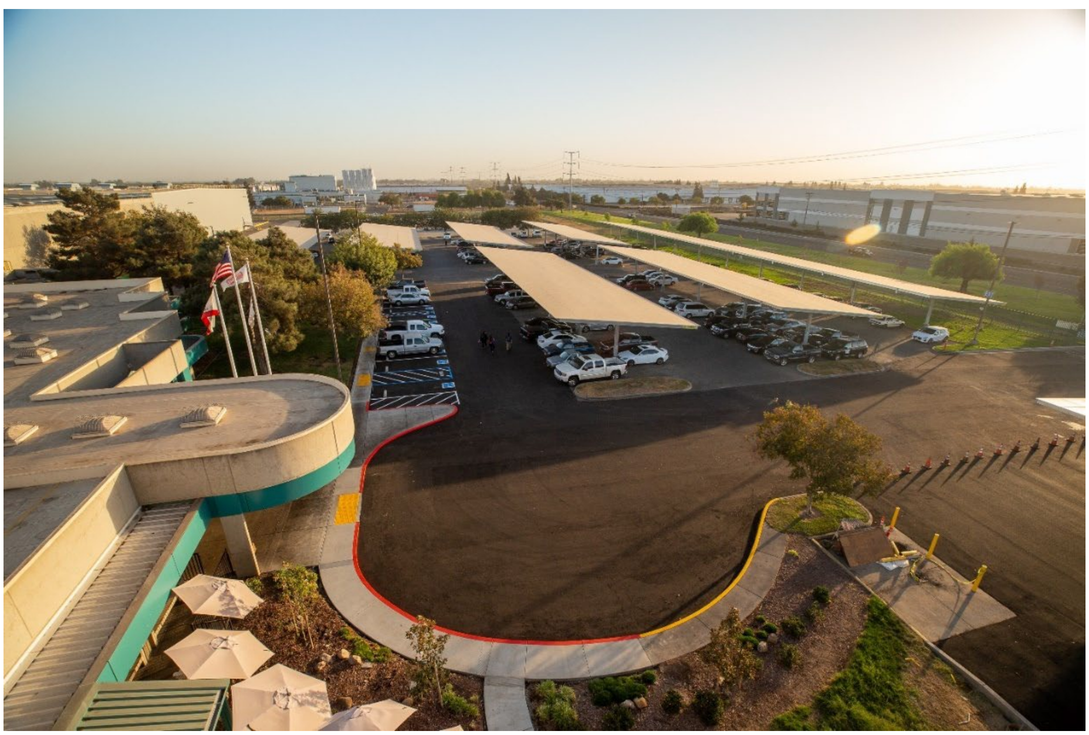
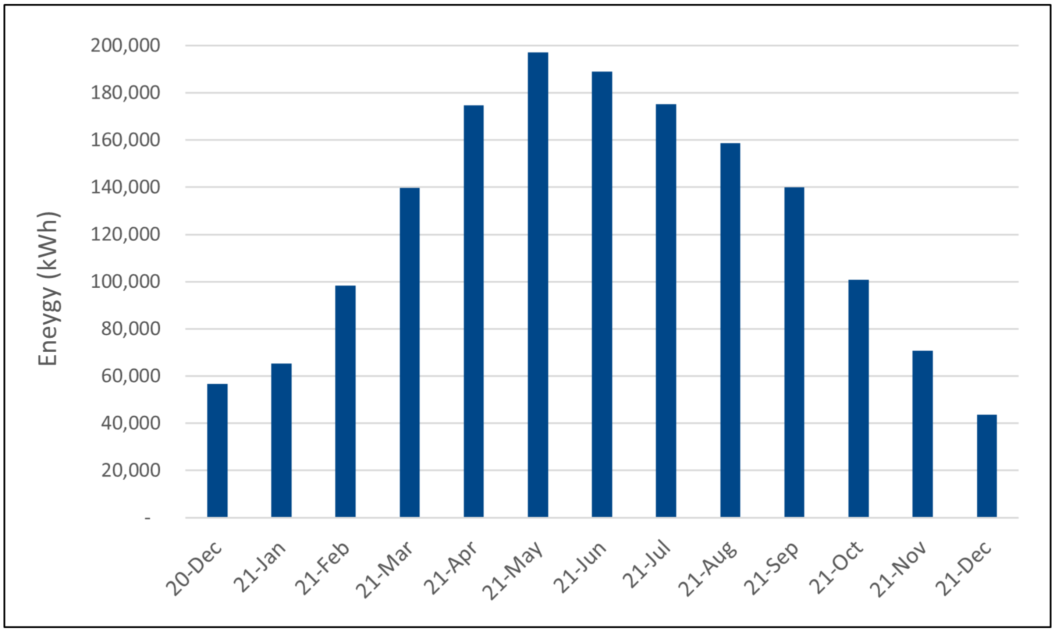


Figure 18 above depicts the facility’s solar carports. Solar and grid data were reviewed for completeness prior to analysis. Solar data was used from December 2020 to end of June 2022. Grid data are used beginning from January 2022. There are gaps in grid data from July to December 2021.

Performance

Data on the solar panels were collected between December 2020 and December 2021 through Tesla's Powerhub platform. Figure 19 below demonstrates the fleet's monthly solar energy production.

Figure 19: Monthly Solar Energy Production



Solar production ranges between 43,000 kWh per month in the winter to 194,000 kWh per month in the summer, which is nearly a five-fold difference. The facility's solar generation began around 8 AM, peaked around 2 PM., and ended around 6 PM. During the summer of 2021, solar energy production reached a maximum of 6,742 kWh on June 10^{th}, where production peaked at 749 kW around 12 PM. The hours that solar generation begins, peaks, and ends vary throughout the year, as does the peak magnitude. Because of the seasonal variation in solar energy, fleets installing solar panels should consider the minimum generation needed during winter months to sustain their intended generation. **In total, the solar production was much greater than all the energy consumed by the ZEVs at this facility combined, as shown in the figure below.**

Figure 20: Annual ZEV Energy Consumption Compared to Annual Solar Energy Production

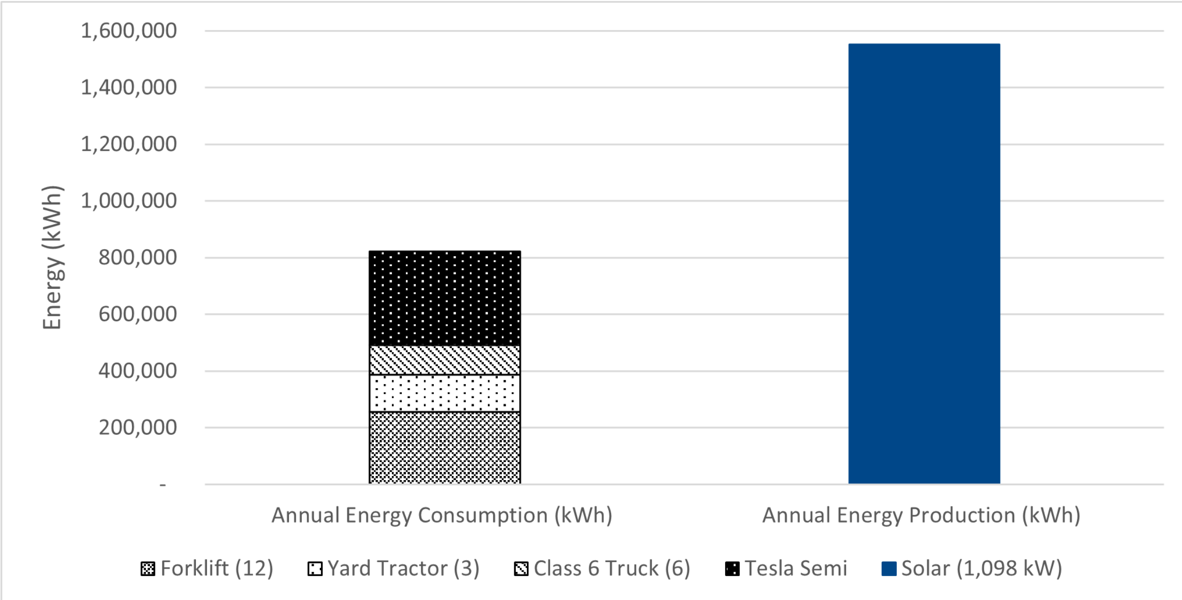


Figure 20 shows that current solar production was almost twice as large than what was consumed by the new technology deployed.

MONTHLY SOLAR ENERGY PRODUCTION CAN BE NEARLY FIVE TIMES HIGHER IN THE SUMMER THAN THE WINTER.

A few conclusions can be drawn from the solar analysis. For one, monthly solar energy production can be nearly five times higher in the summer than the winter. Fleets should consider this seasonal variation when calculating their required solar production. Fleets should also account for expected ZEV growth when installing solar, as installing a larger solar array during the initial installation can save money over expanding the array later. Because solar arrays generate power based on the sun's rise and fall, it is difficult to use solar power to offset demand charges unless peak demand happens to coincide with peak generation. Instead, solar energy is more often used for net metering – generating energy and providing it to the grid to offset the energy consumed on site (with the fleet only paying for the "net" energy used). Energy storage, because it can be charged and discharged on demand, is much better suited for peak shaving demand charges. This concept will be explored more in the following section.

696-kWh BESS Usage and Performance

The 696-kWh battery storage system drew energy from the Solar Carport and dispensed it to the facility or the grid. Table 28 summarizes the daily performance of the battery.

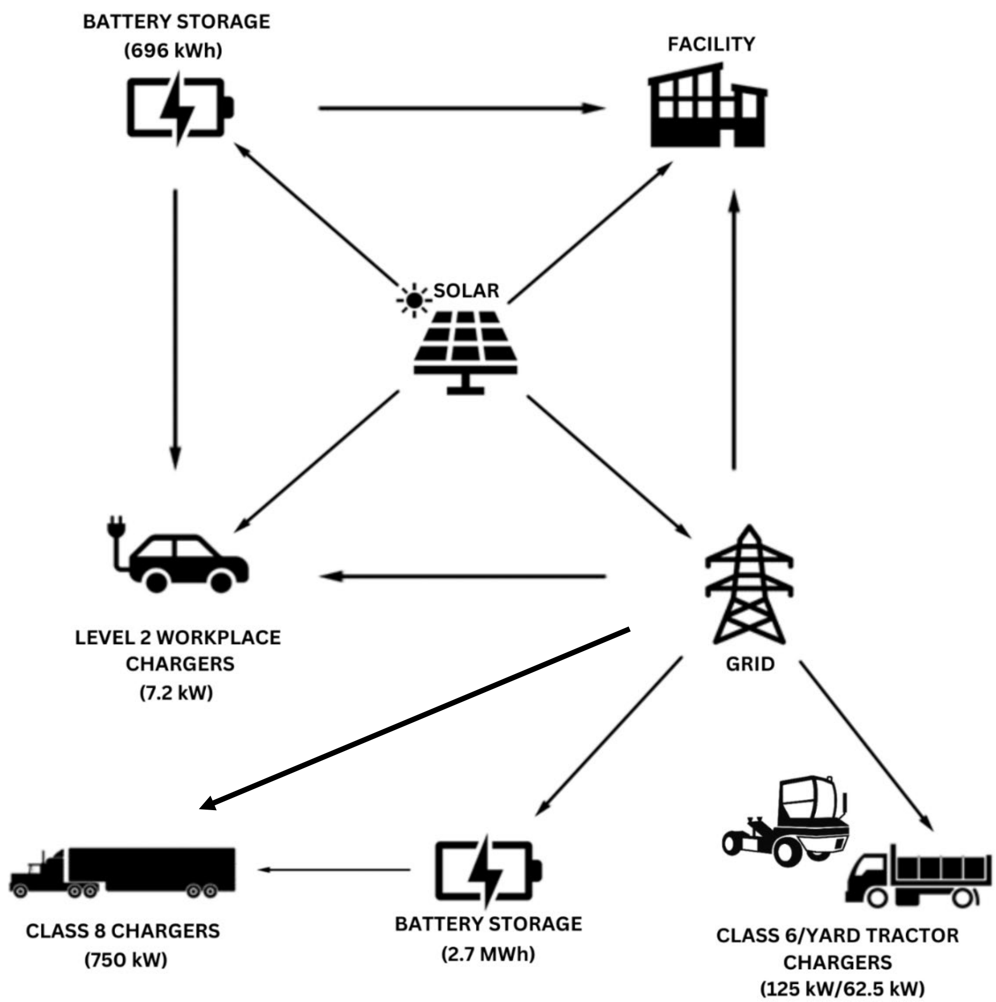
Table 28: Daily Storage Energy Flow

	Daily Energy In (kWh)	Daily Energy Out (kWh)
Average Daily Energy (kWh)	(91)	77
Max Daily Energy (kWh)	(756)	678

The parentheses surrounding the values in Table 28 above are used to indicate the amount of energy consumed by the battery—a negative value of energy in kWh; conversely, the amount of energy dispensed by the battery is represented in the table without parentheses. On average, the battery consumed 91 kWh of energy and expended 77 kWh. Over the course of one day in March, the battery consumed 756 kWh—60 kWh larger than the capacity of the battery—and expended 678 kWh.

Figure 21 below demonstrates the energy flow at the facility.

Figure 21: Frito-Lay Energy Flow Diagram



2.7 MWh BESS

The larger battery energy storage system, rated at a capacity of 2.7 MWh, was designed to support the charging infrastructure for the Tesla Semis. This system was installed in 2022 with the 4 750-kW chargers. Ideally, the BESS provides energy to the vehicles during high peak times and refuel when expended. Given limited data was collected from the first 115 days of truck operation, the larger BESS did not produce conclusive results to inform its efficiency, usage, or performance.

IX. Environmental Impact/Emissions Offsets

Freight movement accounts for approximately 25% of all transport emissions in California[17]. Transportation contributes 50% of all earth-warming air pollution in the state, with higher percentage contributions in specific areas such as nitrogen oxide[18]. For decades, California's Central Valley has had some of the worst air quality in the nation. The San Joaquin Valley's challenges in meeting national ambient air quality standards are unmatched anywhere in the nation due to the region's unique geography, meteorology, and topography, with the Valley being designated as nonattainment for the federal fine particulate matter (PM2.5) and Ozone standards. Through ongoing efforts by the San Joaquin Valley Air Pollution Control District (SJVAPCD) and CARB, nitrogen oxide (NOx) emissions across the Valley have been reduced by over 75%, while stationary source emissions under the district's jurisdiction have been reduced by over 93% since 1980.

Although significant progress has been made, substantial additional emissions reductions are still needed to meet the federal PM2.5 and ozone standards, as the population across the region continues to grow, bringing additional vehicle emissions, goods movement emissions, and other emissions. Notably, the largest 3 sources of controllable NOx emissions—the primary precursor to both ozone and PM2.5 formation—in the Valley are farm equipment, heavy-duty trucks, and off-road equipment[19]. With the majority of the Valley's remaining ozone and PM2.5 precursor emissions now coming from mobile sources, additional reductions from heavy-duty trucks and other mobile sources are needed for the Valley to reach federal air quality standards.

Exposure to pollutants such as PM 2.5 damages organs and is linked to decreased lung function and increased risk of asthma, heart attack, stroke, and preterm birth. These health impacts shorten the lifespan of those exposed, which, in the Central Valley, are largely underserved and low-income communities.

Forklifts

Both forklift types studied were battery-electric-powered, meaning they charged from the grid and did not produce tailpipe emissions. However, energy produced from fossil fuel combustion is contributed to the grid; thus, the electric forklifts produced carbon emissions as they consumed energy. The LI forklifts provided emissions benefits because they consumed about 23% less energy per hour of use. Over one year of operation, a LI forklift can save 1,308 kg CO_2 compared to a LA

[17] Ports and Freights. Coalition for Clean Air. https://www.ccair.org/advocacy/ports-freight/

[18] Transforming Transportation. California Energy Commission. https://www.energy.ca.gov/sites/default/files/2019-07/TRAN-TransformingTransportation_1.pdf.

[19] CARB's California Emission Projection Analysis Model (CEPAM) was created to support air quality modeling efforts and to forecast emissions for point and area sources using the most current growth and control data available at the time of the development of the model version. 2022 Emissions Projects using model Version 1.00 were referenced. For the most current version, visit CARB's website here.

forklift[20], which is equivalent to about one third of the emissions produced by a passenger car. Altogether, replacing 12 LA forklifts is therefore comparable to removing 4 cars from the roads per year.

Yard Tractors

Table 29 shows the emissions generated by a diesel yard tractor in the setting that was observed. The fleet's ZE yard tractors generated no direct emissions from their operation; however, they produced carbon emissions as they consumed energy produced from fossil fuel combustion. These grid emissions were not included in the calculations below.

The values in the table represent emissions savings from replacing a single diesel yard tractor with a single ZE yard tractor. The savings can be scaled up directly as more ZE yard tractors are added and diesel yard tractors are displaced. Using a single electric yard tractor offsets 23,570 kg of CO_2, 93.8 kg of NO_x, and a staggering 850 gram of PM in one year of service for 2,500 hours total[21]. The total amount of CO_2 offset by only one electric yard tractor is equivalent to:

- 5.2 gasoline-powered vehicles for one year, or
- 60,422.9 miles driven by a gasoline-powered car, or
- 2,971 homes' energy use for a year, or
- 389,732 tree seedlings sequestering carbon for 10 years.

Table 29: ZE Yard Tractor Emissions Offset

Pollutants	Emissions (g/hr)	Annual Emissions (kg/yr)	Lifetime Emissions (kg/8 yr)
CO^2	9,428	23,570	188,650
NO_x	37.5	93.8	750
PM	0.2	850	6,800

Class 6 Trucks

The fleet's ZE box trucks did not generate direct emissions from their operation; however, they produced carbon emissions as they consumed energy produced from fossil fuel combustion. These grid emissions were not included in the calculations below.

The emissions savings calculated here are the expected results from replacing a single diesel Class 6

[20] These calculations used 2020 CI values for electricity as a transportation fuel published by CARB in their Low Carbon Fuel Standard Annual Updates to Lookup Table Pathways. CARB published 2023 CI values for electricity as transportation fuel with an average of 81.00 gCO2e/MJ. For more information, visit CARB's publication here.

[21] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results

truck with a single electric Class 6 truck. The savings can be scaled up directly as more ZE Class 6 trucks are added.

The total amount of CO_2 offset by one Class 6 electric truck that traveled 12,970 miles annually (11,508 kilograms) is equivalent to:

- 2.5 gasoline-powered vehicles for one year, or
- 28,565 miles driven by a gasoline-powered car, or
- 2.2 homes' energy use for a year, or
- 190 tree seedlings sequestering carbon for 10 years.[22]

Table 30 below estimates the tailpipe emissions generated by a diesel Class 6 box truck operating a duty cycle similar to Frito-Lay's.

Table 30: ZE Class 6 Trucks Emissions Offset

Pollutant	Emissions (g/mi)	Annual Emissions (kg/yr)	Lifetime Emissions (kg/10 yr)
CO^2	887	11,508	138,100
NO_x	0.92	11.97	143.67
PM	0.09	0.12	1.41

Class 8 Trucks

Portable emissions measurement system (PEMS) testing was carried out on the baseline vehicles involved in this project in order to accurately quantify in-use emissions and the corresponding reductions resulting from the deployment of ZEVs.

Table 31 below summarizes the tailpipe emissions generated by the fleet's Class 8 RNG and diesel trucks during their operation.

[22] The EPA's Greenhouse Gas Equivalencies Calculator was used to convert the emissions and energy data from conventional, fossil-fuel-powered vehicles to the equivalent amount of CO_2 emissions from cars, households, and power plants. These values represent the number of emissions offset by the ZEVs deployed under this project. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results

Table 31: Tailpipe Emissions from Class 8 RNG and Diesel Trucks

RNG	Emissions (g/mi)	Annual Emissions (kg/yr)	Annual Emissions Offset from ZEV Operation (kg/yr)
CO_2	1,161	92,880	39,474
NO_x	0.006	0.48	0.20
PM	0.004	0.32	0.14
Diesel	**Emissions (g/mi)**	**Annual Emissions (kg/yr)**	**Annual Emissions Offset from ZEV Operation (kg/yr)**
CO_2	1,082	86,560	36,788
NO_x	2.01	160.80	68.34
PM	0.01	0.80	0.34

Both the RNG and diesel trucks were standardized to 80,000 miles annually for the purposes of these calculations.

Each RNG truck emitted slightly more tailpipe CO2 than its diesel counterpart but provided significant savings in NOx and Particulate Matter (PM). However, the RNG station dispensed fuel with a carbon intensity (CI) value of -240 g CO2e/MJ. 23 A negative CI value indicates the fuel is carbon negative because the natural gas used to power the vehicle is taken from sources that would otherwise simply disperse into the atmosphere. Given this CI value, while the RNG vehicles produce more tailpipe CO2 than the diesel vehicle during operation, use of the RNG station rather than a traditional compressed natural gas (CNG) station represents a net reduction of carbon emissions.

Like the fleet's other ZE equipment, the ZE Semis did not generate tailpipe carbon emissions; however, they produced carbon emissions as they consumed energy produced from fossil fuel combustion. These grid emissions were not included in the emissions calculations. Not including grid emissions, if a fleet of this size were to completely electrify their Class 8 truck fleet, the reduction in carbon emissions would sum to 1,949,764 kg CO2e per year—the total of carbon emissions generated annually by a diesel fleet of this size.

Solar Generation and Storage

To calculate the emissions offset by the solar system, Modesto Irrigation District (MID), the utility provider for the facility, provided a grid energy mix. According to MID, in 2022 the grid had a carbon intensity (CI) of 434 lb CO_2 per MWh, which is lower than the California state average of 466 lb CO_2

[23] Carbon dioxide equivalent per Mega Joule

per MWh. Because the solar system produced about 1,552.9 MWh of energy in 2021, it is estimated that the solar system offsets about 673,964 lbs of CO_2 annually. Using ZE energy from the solar system rather than the grid is equivalent to offsetting the emissions from 242 gas-powered vehicles.

Table 32 below demonstrates the annual reduction in CO2 emissions for vehicles and equipment.

Table 32: Annual Facility-Wide Greenhouse Gas Savings

Vehicle/Equipment	Annual CO_2 Emissions Avoided (kg/yr)
Forklifts	1,308
Yard Tractors	23,570
Class 6 Trucks	11,508
Class 8 Trucks	76,262
Solar	305,705
Total	**418,353**

X. Facility Total Cost of Ownership

This project was funded by California Climate investments and resulted in a near $30 million investment between Frito-Lay and the California Air Resources Board to deploy zero and near zero technologies throughout the latest facility. The purpose of the Advanced Technology Demonstration and Pilot Projects is to help accelerate the next generation of advanced technology vehicles, equipment, or emission controls which are not yet commercialized. In FY2017-18, the Frito-Lay Zero and Near Zero Emission Freight Facility Project was awarded $15,382,243.

Below is a cost assessment by technology. All costs are reflective of actual data and consideration must be made of the new nature of the technologies deployed, whether that is reflective of lower maintenance cost due to having new equipment or higher costs due to not maximizing equipment usage.

Forklifts

To calculate the cost of operating each forklift, the electricity rate structure of the local utility was applied to the collected energy data. The actual rate structure is detailed in Figure 22 below.

Figure 22: Modesto Irrigation District's Electricity Rate Schedule GS-324

Summer (May – September)	Winter (October – April)
Fixed Monthly $195.00	Fixed Monthly $195.00
Demand (per kW) $17.78	Demand (per kW) $17.78
Electric Usage (per kWh):	Electric Usage (per kWh):
On Peak $0.1053	On Peak $0.0694
Partial Peak $0.0811	Off Peak $0.0526
Off Peak $0.0526	

Time Periods

Time periods are defined as follows

Winter: (Service from October 1 through April 30)
On Peak: 8:00 a.m. to 11:00 p.m. Monday through Friday, excluding holidays.
Off Peak: All other hours.

Summer: (Service from May 1 through September 30)
On Peak: 1:00 p.m. to 9:00 p.m. Monday through Friday, excluding holidays.
Partial Peak: 8:00 a.m. to 1:00 p.m. and 9:00 p.m. to 11:00 p.m. Monday through Friday, excluding holidays.
Off Peak: All other hours.

Holidays are: New Year's Day, President's Day, Memorial Day, Independence Day, Labor Day, Veterans Day, Thanksgiving Day, and Christmas Day.

Energy is billed based on time-of-use (TOU) rates that vary with season. A fee (demand charge) is also levied for the highest power draw at any time throughout the month. The demand charges were not included in the analysis because they were only one of many sources of energy consumption within Frito-Lay's production facility, so their unique contribution to demand could not be calculated.

The energy output was categorized into the corresponding time period and the results were divided by the number of forklifts in operation to reflect the cost of operating a single forklift of each type. Table 33 below compares charging events, energy charged, cost, and cost per hour for both forklift types for the entire year.

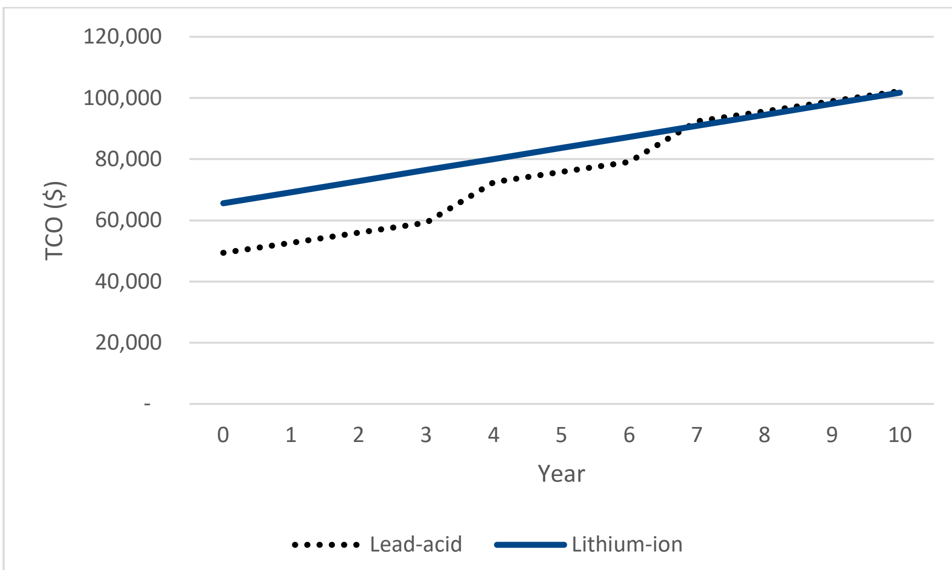
Table 33: Electricity Cost Comparison of LI and LA Forklifts

Total	LI	LA
Hours Charged (h)	1,471	1,588
Number of Charging Events	3,349	3,426
Average Charge Length (h)	0.44	0.46
Energy Charged (kWh)	13,277	20,312
Average Charging Rate (kW)	9.0	12.8
Cost ($)	810	847

Total	LI	LA
Cost per Hour ($/h)	0.55	0.53

The operating cost differential between the two forklift types is attributed to the increased battery and charging efficiency of the LI forklifts. Fleets are encouraged to minimize on-peak charging especially during the summer months when rates are the highest. With their lower efficiencies and greater energy consumption from equalization combined, the LA forklifts incurred an additional, though minimal, demand charge for the facility that is likely higher than reported above in Table 33. By contrast, each LI forklift saved the fleet about $300 in charging costs after normalizing hours in use per year at 4,000 hours. After applying Low Carbon Fuel Standard (LCFS) credits at $0.15 per kWh of electricity charged, the fleet's projected lifetime costs for the LI forklifts exceed the lifetime costs for the LA forklifts until year seven. Figure 23 demonstrates the total cost of ownership (TCO) for both forklift types.

Figure 23: LI and LA Forklift TCO



The upfront cost of the LI forklifts, at approximately $54,000, is significantly higher than the upfront cost of the LA forklifts, which is about $15,000 cheaper. California sales tax of 8% was applied to both the LI and LA forklifts. Charging infrastructure costs ($6,800) and maintenance costs (approximately $4,600) were assumed to be roughly the same amount for both forklift types as well. However, the additional LA forklift maintenance costs from productivity loss associated with equalization could not be calculated. Thus, the LA forklift TCO may be higher than demonstrated here. Additionally, Frito-Lay replaces the LA forklift batteries every 3 and a half years at an approximate cost of $10,000 and replaces the LI forklift batteries every 10 years at an approximate cost of $23,000. Finally, Frito-Lay self-insured their vehicles and did not pay any insurance costs on either forklift type.

Yard Tractors

Next, the cost for operating the ZE yard tractor was directly compared to the diesel yard tractor. The operating cost included fuel, maintenance costs, and insurance. Fuel cost was calculated by taking the sum of energy used over the data collection period and multiplying by the cost of the respective fuel source over time. The fuel cost was then normalized by dividing by the number of hours in operation in order to compare the vehicle types on an equal footing. The cost of electricity fluctuated over time because charging patterns naturally varied over time and efforts were made to moderate peak demand. Table 34 below compares cost to operate the ZE yard tractor and diesel yard tractor.

Table 34: ZE and Diesel Yard Tractor Cost of Fuel Comparison

Metric	ZE Yard Tractor	Diesel Yard Tractor
Fuel Cost Per Hour at Period Start	$2.21[24]	$5.05[25]
Fuel Cost Per Hour at Period End	$2.02[26]	$6.78[27]
Maintenance Cost ($/hour)	$1.07	$9.71
Total Operating Cost ($/hour)	**$3.09**	**$16.49**

Rapid diesel price changes during the COVID-19 pandemic were incorporated in the fuel cost for the diesel yard tractors. The price of diesel over a 12-month period increased 34%—from $5.05 per hour in October of 2020 to $6.78 hour at the end of September 2021[28]. While rising diesel costs contributed to rising operating costs for diesel tractors in this deployment, even with the relatively low diesel prices seen in 2020, electric yard tractors were still less than a third as costly to operate. In contrast, the average electricity price for charging the ZE yard tractors decreased slightly from $0.23 per kWh in October 2020 to $0.21 per kWh in September 2021 as charging patterns were optimized to lessen demand charges. This finding emphasizes the importance of managed charging to decrease costs. Overall, the dollar-per-hour operating cost for the ZE yard tractor was 20% of the cost of the diesel yard tractor.

Maintenance cost was calculated by analyzing the cost of maintenance work orders generated from October 2020 to April 2021. The diesel yard tractor had significantly higher maintenance costs over this time. One consideration is that the diesel equipment was older and more prone to repairs,

[24] Calculated with electricity cost of $0.23/kWh

[25] Calculated with diesel cost per gallon of $3.32

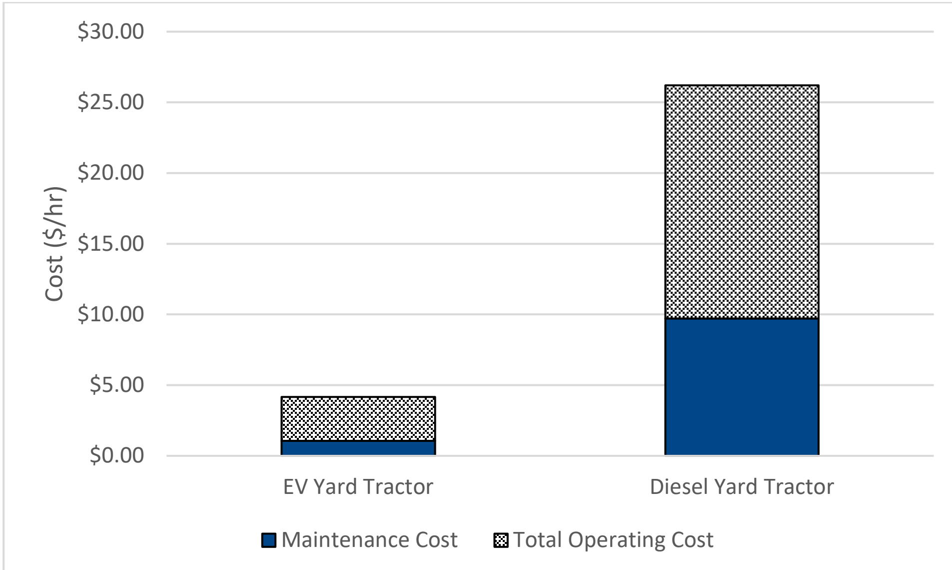
[26] Calculated with electricity Cost of $0.21/kWh

[27] Calculated with diesel cost per gallon of $4.40

[28] US Energy Information Administration. https://www.eia.gov/dnav/pet/PET_PRI_GND_DCUS_SCA_W.htm

whereas the ZE equipment was new.

Figure 24: ZE and Diesel Yard Tractor Maintenance and Total Operating Costs



Lifetime maintenance costs were inherently difficult to establish over one to two years of data collection for a vehicle predicted to last longer than a decade. Some maintenance work was covered under warranty or performed by the OEM at no cost during these projects. However, early analysis showed that ZEV maintenance will likely be significantly lower than diesel vehicles. ZEVs did not require oil changes, frequent brake changes, or other services that contribute to cost and downtime. The disparity between the ZE and diesel yard tractor maintenance costs is likely to grow as the vehicles age as diesel yard tractors become expensive to maintain after about five years. When maintenance, fuel, and incentives are considered, the ZE yard tractor total cost of ownership (TCO) was lower than diesel over their lifetimes. The total cost of ownership for these two types of equipment was directly compared by summing capital costs alongside operating costs. The table below shows these costs.

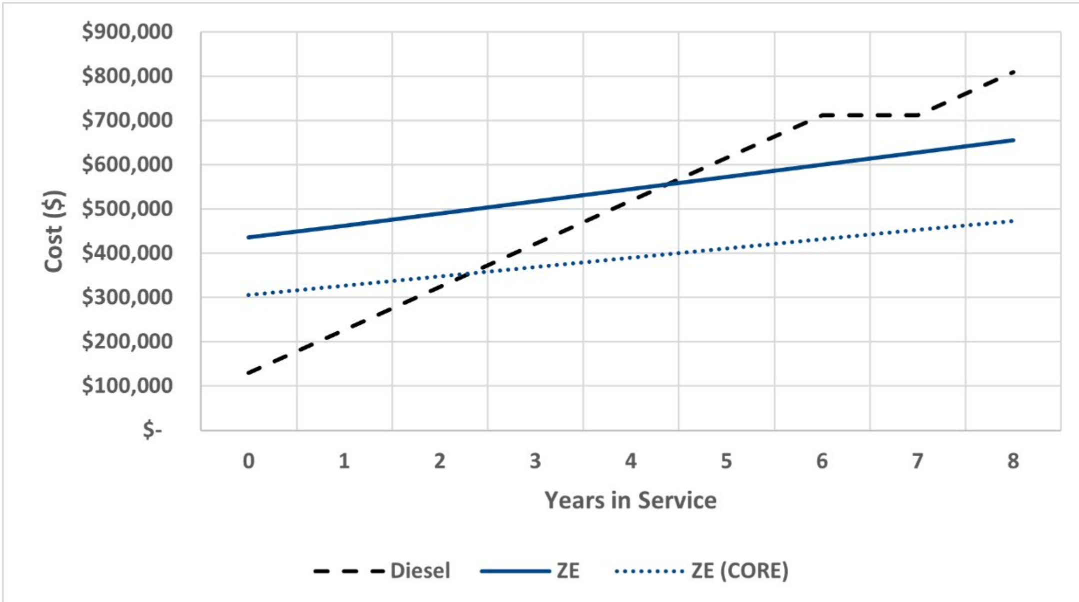
Table 35: Fixed and Operating Costs for Yard Tractors Comparison

Fixed Costs	ZE Yard Tractor	Diesel Yard Tractor
Capital Cost	338,771	120,000
CORE Incentive	-(120,000)	N/A
Sales Tax (8%)	17,502	9,600
Infrastructure Cost	69,324	N/A
Total Capital Cost	305,597	129,600
Operating Costs	**ZE Yard Tractor**	**Diesel Yard Tractor**
Insurance (5.5%)	12,032	6,600
Annual Fueling Costs	12,536	37,898
LCFS	-(8,707)	N/A
Maintenance Costs	5,094	52,644
Total Annual Operating Cost	20,954	97,142

Figure 24 shows the ZE yard tractor purchase price is slightly less than double the cost of the diesel upfront, with the CORE incentive reducing the price significantly.[29] However, on an annual basis the ZEV was seven times cheaper to operate as electricity is cheaper than diesel and the limited maintenance data indicated big savings. Figure 25 shows the total cost of ownership is projected to evolve over time, with and without incentives.

[29] California CORE Program. https://californiacore.org/equipment-category/terminal-tractors/

Figure 25: ZE and Diesel Yard Tractor TCO



A positive return on investment is indicated when the blue line surpasses the solid and dotted lines along the y-axis. The return-on-investment date with CORE incentives is about 5.5 years. The fleet indicated that they typically replace the diesel yard tractors after only 2.5 years. Even without incentives, the ZE Yard Tractor achieves cost parity with Diesel before Year 5.

The true lifetime of ZE yard tractors is unknown because they are still relatively new to the market. This analysis used a conservative estimate of eight years[30]. It could be substantially longer. One report has suggested a timeline, but it is unclear whether this was based on actual measured data[31]. Even assuming a comparable lifetime for the diesel vehicle, the ZEV would still come out cheaper by the end of its life under this scenario. With or without CORE incentives, the return on investment is positive for the ZEV's lifetime. Upfront purchase incentives clearly played a substantial role. However, even without the incentives and diesel replacement in Year 6, the lifetime cost of the ZEV is $200,000 less than the Diesel indicating that the ZE Yard Tractor is a beneficial investment for a fleet.

[30] Volvo LIGHTS Project: Summary Report. https://calstart.org/volvo-lights-project-summary-report/
[31] Otto, K. et al. Electric Trucks Have Arrived: The Use Case for Terminal Tractors. NACFE. 2022. https://nacfe.org/terminal-tractors/ accessed 2022-4-11

Class 6 Trucks

The upfront cost of the ZEV is almost double an equivalent diesel vehicle. However, the HVIP program offers a significant discount to fleets who receive a voucher to reduce this cost. Along with the price tag of the vehicle, there are California sales tax of 8% and infrastructure costs which together equate to an additional $90,000+ added to the upfront cost[32]. Table 36 shows the fixed costs and operating costs for the fleet's box trucks.

Table 36: ZE Class 6 Truck Fixed and Operating Costs

Fixed Costs	Cost ($)
Capital Cost	282,434
California Sales Tax (8%)	22,594
Infrastructure Cost	69,324
HVIP Incentive	-(85,000)
Total Capital Cost	**289,353**
Operating Costs	**Cost ($)**
Insurance (5.5%)	15,534
Annual Fueling Costs	3,837
LCFS	-(2,741)
Maintenance Costs	15,947
Total Annual Operating Cost	**32,577**

Insurance was estimated to be 5.5% of the upfront cost of the vehicle annually. The higher upfront cost of ZEV means insurance can be more than twice as expensive compared to diesel trucks. This practical aspect has not been considered in many TCO analyses to date. Some insurance organizations also consider several other factors in determining a fleet's insurance rate, including exposure to risk in the driving area, level of driver experience, and other factors which can lessen the difference in insurance rates. Fleets can expect insurance costs to decrease as ZEV production increases and upfront costs correspondingly fall. Incentives will play a key role in supporting

[32] Gordon, J. et al., The Zero-Emission Freight Revolution: California Case Studies , EVS35, 2022, https://cdn.lightsproject.com/downloads/volvo-lights-website-content-news-resource-evs35-zero-emission-freight-revolution-report.pdf, accessed 2022-11-22

production increases and making ZEVs affordable for fleets in the near term.

Next, the operating cost was calculated by analyzing utility bills and calculating the impact of Low Carbon Fuel Standard (LCFS) credits. The cost of electricity was found to be $0.21/kWh based on averaging the cost paid for electricity over several months. The average kWh cost varied from a low of $0.18 per kWh in the spring and only went up as high as $0.24/kWh in the fall. With LCFS credits, the effective cost of electricity in this scenario becomes $0.06/kWh. These values were calculated using CARB's LCFS tool[33].

Table 37: ZE Class 6 Truck Energy Cost

Metric	Amount
Cost without LCFS Credit ($/kWh)	0.21
LCFS Credits ($/kWh)	-(0.15)
Cost with LCFS Credit ($/kWh)	0.06
Energy Charged Per Year (kWh)	18,275
Total Annual Cost (with LCFS) ($)	1,096

Table 37 above shows that a fleet can pay as little as $1,096 to charge a Class 6 truck for a full year. This fueling cost is substantially lower than a comparable diesel vehicle. Since the fleet did not operate any diesel Class 6 trucks prior to the project, there is no baseline to compare fueling costs, but previous estimates have suggested $0.38 per mile, meaning that the EV is about 45% cheaper per mile to fuel even without the LCFS subsidy[34].

Lifetime maintenance costs are inherently difficult to establish over one to 2 years of data collection for a vehicle that will operate longer than a decade. For a new vehicle with no maintenance history and with no baseline vehicle with which to compare, it is even more difficult to estimate maintenance costs. Some maintenance work is covered under warranty or performed by the OEM at no cost during these projects. However, the analysis for yard tractors shows that ZEV maintenance will likely be significantly lower than diesel vehicles. ZEVs do not require oil changes, frequent brake changes, or other service that contributes to cost and downtime. The TCO, estimated for the Class 6 ZE truck's 10-year lifetime, is $532,732.

[33] LCFS Calculator. Pacific Gas & Electric. 2022. https://fleets.pge.com/lcfs/

34 Qiu, Y. et al. Energy Cost Analysis and Operational Range Prediction Based on Medium- and Heavy-Duty Electric Vehicle Real-World Deployments across the United States. World Electric Vehicle Journal. 2023.

Table 38: Lifetime TCO of a Class 6 Vehicle

Vehicle Type	Lifetime TCO $ Amount
Class 6 Electric (without HVIP)	$700,123
Class 6 Electric (with HVIP)	$615,123
Class 6 Diesel	$304,571

Table 38 summarizes the lifetime costs of a ZE Class 6 box truck with and without incentives and the lifetime costs of a diesel box truck. The 10-year lifetime TCO for a Class 6 diesel truck is favorable to the Class 6 EV with or without HVIP incentives. Despite this result, incentive programs like HVIP are still critical as they reduce the upfront cost of these vehicles and drive adoption of this technology, hopefully resulting in lower upfront costs down the line. The major finding is that high upfront cost of the vehicle means that the tax levied on the vehicle is commensurately high—the federal excise tax of 12% adds significantly to the upfront cost. Also, the insurance cost of the vehicle is negatively impacted by the price as 5.5% of the vehicle cost is used to calculate the insurance cost for the vehicle. The Class 6 EV has lower maintenance and fueling costs (the fueling costs are also much more stable). It is also worth mentioning that EV costs are expected to decrease over time.

Class 8 Trucks

The total annual operating cost of each diesel, RNG, and ZE Class 8 truck deployed was calculated by summing the fixed costs and operating costs of each truck during the data collection period. Fixed costs that were analyzed included upfront costs, sales tax, and infrastructure costs; operating costs that were analyzed included insurance rates, fueling costs, and maintenance costs. The operating costs of each truck were analyzed, and the results are listed in Table 39. Maintenance or operating costs for the ZE Semis have not yet been provided.

Table 39: Class 8 Truck Total Operating Costs

Metric	RNG Operating Cost	Diesel Operating Cost	ZE Operating Cost
Fuel Cost at Period Start	$2.69 per gallon[35]	$5.05 per gallon[36]	-
Fuel Cost at Period End	$2.79[37]	$6.78[38]	$0.33 per kWh
Fuel Cost per Mile	$0.36	$0.71	$0.69
Maintenance Cost ($/mile)	$0.32	$0.76	-
Insurance Cost	$0.14	$0.10	$0.24
LCFS/mile	-($0.36)	-	-($0.16)
Total Operating Cost ($/mile)	$0.46	$1.57	$0.77

Diesel Fuel Cost

Diesel fuel costs were by far the most expensive for the fleet due to the fuel's price fluctuation. Unlike electricity and RNG, diesel fuel retail prices vary greatly depending on the cost of crude oil purchased by refineries and the imbalance between diesel fuel supply and demand[39]. Additionally, diesel prices on the West Coast region of the continental U.S., especially in California, are typically higher and vary more than diesel prices in other regions throughout the country due to taxes and supply issues. This was the case for Frito Lay's fleet; at the end of the analysis window, the diesel retail price in California had risen from $3.25 per gallon to $4.02 per gallon–a 24% increase in price[40]. However, the national average diesel fuel retail price in May 2021 was $3.22 per gallon[41].

[35] Calculated with electricity cost of $0.23/kWh

[36] Calculated with diesel cost per gallon of $3.32

[37] Calculated with electricity cost of $0.21/kWh

[38] Calculated with diesel cost per gallon of $4.40

[39] https://www.eia.gov/energyexplained/diesel-fuel/factors-affecting-diesel-prices.php

[40] California diesel prices per gallon in October 2020 and May 2021 were sourced from the U.S. Energy Information Administration. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMD_EPD2D_PTE_SCA_DPG&f=M

[41] National diesel price in May 2021 was sourced from the U.S. Energy Information Administration. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emd_epd2d_pte_nus_dpg&f=m

RNG Fuel Cost

The RNG fuel offered cost savings relative to the baseline diesel trucks. The price of fuel was also more stable over the course of the project, allowing fleets to more readily plan for the future. In addition, due to the renewability of the process by which it is produced, RNG has a negative carbon intensity score and a correspondingly high LCFS subsidy. Though the U.S. Energy Information Administration has predicted that national diesel prices will decline in 2024[42], the price stability of alternate fuels like RNG and electricity can help lower a fleet's total cost of ownership substantially.

ZE Fuel Cost

Electricity prices were even more stable than both diesel and RNG, and as a result, the fleet's ZE trucks were the cheapest to operate per hour. The ZE fuel cost is directly tied to the amount that the fleet pays for electricity. A rough breakdown of ZE fuel cost can be done by looking at a three-month period of electricity bill information. For the period of April – June of 2023, Frito Lay had the following usage of electricity as shown in Table 40.

Table 40: Summer Energy Usage

Metric	Energy Used
On Peak	172,835 kwh
Partial/Off Peak	167,329 kWh
Peak Demand	2,170 kW
Environmental Energy Adj.	91,151 kWh
Capital Infra Adj.	91,151 kWh

Most of the electricity used for charging these vehicles was used for on peak electricity which costs $0.03 more per kWh than off-peak electricity.

[42] According to their Short-Term Energy Outlook, the Energy Information Administration estimates that on-highway diesel prices in the U.S. will decline to $4.23 per gallon in 2023 and $3.70 per gallon in 2024 due to additional refinery capacity in 2022, which contributed to rising diesel fuel supply. https://www.eia.gov/todayinenergy/detail.php?id=55179

Figure 26 below shows the utility rate structure applied to the fleet's ZE Semis, which is more costly than the rate structure applied to the fleet's forklifts. The cost based on the rate structure below for the summer months is calculated by multiplying the associated value with the cost from the utility per unit to give the total cost.

Figure 26: Utility Rate Structure for Class 8 ZE Semis

Summer (May – September)	Winter (October – April)
Fixed Monthly $220.00	Fixed Monthly $220.00
Demand (per kW) $19.28	Demand (per kW) $19.28
Electric Usage (per kWh):	Electric Usage (per kWh):
On Peak $0.11336	On Peak $0.07471
Partial Peak $0.08731	Off Peak $0.05663
Off Peak $0.05663	

Noticeably, the largest cost incurred by the fleet was demand charges. Each kilowatt of demand charge is several orders of magnitude higher than the regular electricity cost. Demand charges occur when excess demand places more instantaneous demand on the grid and the utility has to provide more electricity than normal. Table 41 shows the breakdown of the Class 8 truck electricity cost.

Table 41: Class 8 Electricity Cost Breakdown

Metric	Value
Portion of Electricity Cost from Energy Use	16%
Portion of Electricity Cost from Demand Charge	84%
Average $/kWh with Demand Charge	0.43

The demand charges represent 84% of the total electricity charges paid by the fleet. As a result of the high demand charges, the cost per mile to fuel the ZE truck is comparable with the diesel. If, say, the demand charge could be lowered by half, then the cost per mile would become $0.35 per mile which is half the diesel cost per mile of $0.71.

Maintenance Costs

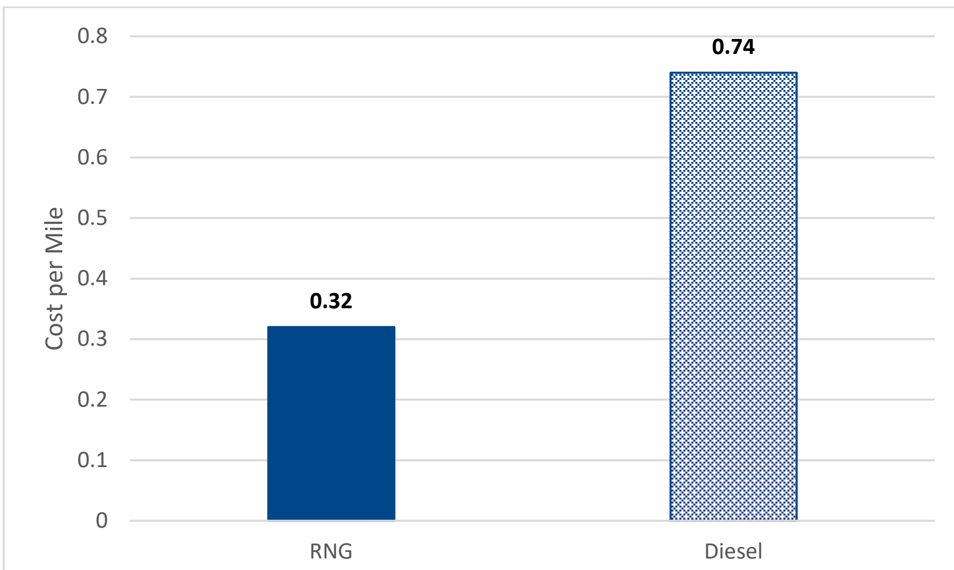
Maintenance costs for the fleet's diesel and RNG trucks were calculated by analyzing the maintenance work orders generated during the data collection period[43]. According to the table

[43] The fleet's diesel truck maintenance costs were calculated from work orders generated from September 2019 to April 2021. The fleet's RNG truck maintenance costs were calculated from work orders generated from July 2019 to April 2021.

above, the diesel trucks' maintenance cost was higher by approximately 15% compared to the maintenance cost of the RNG trucks. Diesel vehicles are often more costly to maintain than other vehicles powered by alternative fuels due to their more complex design. For example, diesel trucks have a more complex emissions control system than RNG trucks, which have passive catalytic converter emissions control systems that require no maintenance[44]. Complex truck design contributes to more expensive maintenance costs per hour. CALSTART was unable to calculate the maintenance cost per mile for the ZE Semis; however, because ZE trucks have a simpler design with fewer moving parts relative to a conventional fuel engine and the shorter operation time for the ZE fleet, the fleet anticipates fewer maintenance issues with the ZE Semis.

Class 8 trucks consume the most fuel and travel the greatest on-road distance, so the operating cost per mile was analyzed for each RNG and diesel truck type. These costs are demonstrated in Figure 27 below.

Figure 27: Class 8 Diesel and RNG Truck Operating Costs per Mile



The operating cost per mile for each truck was calculated by dividing the sum of the fueling and maintenance costs by the total number of miles traveled by each truck. The fleet's diesel Class 8 truck was the most expensive truck to operate at a cost of $0.74 per mile. The RNG Class 8 trucks were much cheaper than the diesel trucks by this cost comparison, as it only cost the fleet $0.32 per mile to operate them.

The fleet's total annual operating costs are documented in Table 42 below. CALSTART will calculate the annual operating cost or the total cost of ownership over a 10-year ZE semi lifetime when all ZE costs are received.

[44] Unlike RNG trucks, diesel trucks use diesel particulate filters and selective catalytic reduction in their emissions control systems which become less effective and requires more expensive maintenance as the truck ages. https://www.freightwaves.com/news/3-reasons-rng-is-decarbonizing-trucking-today

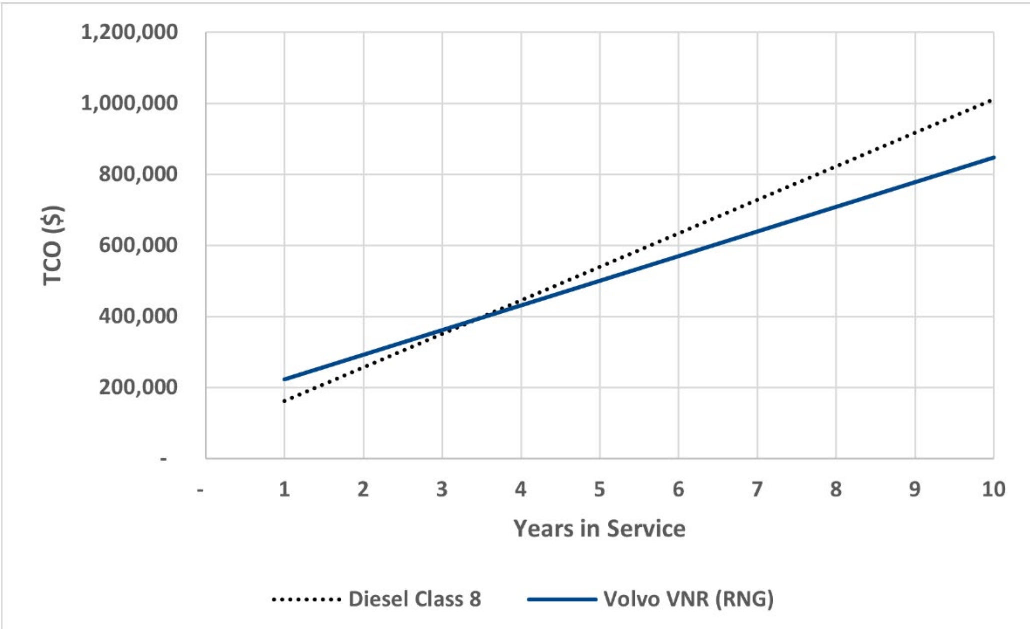
Table 42: Class 8 Trucks Fixed Costs and Total Annual Operating Costs

Fixed Costs	ZE	RNG	Diesel
Capital Cost	$355,494	$206,000	$150,000
HVIP Incentive	-	-	-
Sales Tax (8%)	$28,439	$16,480	$12,000
Infrastructure Cost	-	-	-
Total Capital Cost	$383,933	$222,480	$162,000
Operating Costs	**ZE**	**RNG**	**Diesel**
Insurance (5.5%)	$19,552	$11,330	$8,250
Annual Fueling Costs	$23,460	$46,545	$68,943
LCFS	-($5,440)	-($35,028)	-
Maintenance Costs	-	$11,604	$17,261
Total Annual Operating Cost	$38,472	$34,451	$94,454

A sales tax of 8% was applied to the capital cost of each Class 8 truck. Additionally, there were no incentive funds applied to any of the fleet's Class 8 truck costs. According to the table above, the fleet's diesel trucks had the lowest total capital cost, followed by the RNG and ZE trucks. This is attributed to the diesel truck's lower purchase price, which is typical for well-established, commercialized vehicles. An insurance rate of 5.5% was also applied to the capital cost of each Class 8 truck; thus, the fleet's diesel trucks were also the cheapest to insure each year. Nevertheless, despite the increased cost from insurance and sales tax, the fleet's RNG trucks had a lower total annual operating cost than the fleet's baseline diesel trucks.

The fleet's total cost of ownership was calculated by summing each Class 8 truck's capital and annual operating costs over a 10-year lifetime. The total lifetime costs of each truck are shown Figure 28 below.

Figure 28: Class 8 Truck Total Cost of Ownership



Despite a higher upfront cost, the cumulative lifetime cost of the RNG trucks is lower than the diesel lifetime cost; the fleet is projected to achieve cost savings after operating the RNG trucks for 4 years. Based on these metrics, an RNG truck would save about $200,000 over its lifetime compared with a diesel truck.

Solar

The solar energy generated at this site is directed by Tesla's Opticaster system. Opticaster utilized machine learning and numerical optimization to perform energy load forecasting, solar generation forecasting, energy dispatch optimization, and energy load management[45]. Based on what Opticaster determined was the best available destination, energy went to either the 696 kWh battery or directly to the Level 2 workplace chargers.

Because MID charged different rates per kWh during different times of day and days of the week, an extensive analysis was conducted to calculate the cost savings of drawing energy from the solar array rather than the grid.

The grid energy cost and the solar energy savings were calculated by categorizing grid energy and solar energy into either the on-peak, mid-peak, or off-peak TOU rate structure. Solar energy savings

[45] More information on Tesla's Opticaster system can be found here. https://www.tesla.com/support/energy/tesla-software/opticaster

represent cost savings that would be charged from consuming an equivalent amount of energy as was generated. In 2021 alone, the solar array saved the fleet $115,461.

As described above, grid energy data were not reported between July and October 2021, and the facility underwent an expansion in December 2021. Before the grid energy data stopped reporting, the solar array was able to provide between 26% to 51% of the facility's energy needs. After the expansion, the solar array provided between 6% and 23% of the facility's energy needs. Between January 2021 and July 2022, the solar facility is estimated to have saved the fleet $174,041 in energy costs.

The energy storage system would be better utilized peak shaving demand from the 125kW chargers used on the yard tractors and Class 6 trucks. This is due to the constant facility load that makes peak shaving not as effective. The vehicle chargers, however, can be peak shaved using a battery to minimize the energy demand placed on the grid at any given time.

According to utility bills provided by the fleet, the 125 kW chargers accrued a cost of $26,258 over the 11 months between January and November 2021. Demand charges were calculated by multiplying $10.31 by the maximum energy draw in kW each month. The demand charge comprised between 32% and 54% of each month's bill. Though the 696-kWh battery was recorded outputting energy at rates as high as 678 kW—a power rating nearly two times greater than the maximum demand charge power draw—the ESS could not effectively peak shave considering its connection to the facility and the Level 2 workplace chargers. Rather, the ESS offset the energy consumed from the grid and did not contribute to any of the fleet's demand charge savings.

XI. Community Involvement

Transforming Modesto Initiative

This project replaced the use of all diesel-powered freight equipment within one of Frito-Lay's largest food production, warehouse and regional distribution facilities. This was accomplished via the use of zero-emission (ZE) technology everywhere feasible, and near-zero emission (NZE) technology and renewable fuels everywhere else. The Frito-Lay ZANZEFF Project was a massive undertaking with an enormous investment equally made by the State of California through Cap-and-Trade dollars from the California Climate Investments initiative and Frito-Lay. A project of this scale spurs many opportunities for education about ZE technologies and high visibility of the facility's many state-of-the-art deployments. As a result, the project included partner coordination with community-based organizations, construction of a Visitor Center, national and local media coverage, and increased community relations.

The milestone project kicked off on October 3, 2019, with a joint Frito-Lay and ZANZEFF launch event. The planned transformation at the Modesto facility directly supported PepsiCo's broader sustainability goals, including a 75% reduction in absolute greenhouse gas emissions across direct operations and a 40% reduction in the indirect value chain by 2030. Ultimately, PepsiCo aims to achieve net-zero emissions by 2040.

After the event, the project team continued to share the impact of the transition. Frito-Lay released "Modesto, California: A Showcase for Sustainability in Freight Operations." In July 2021, Frito-Lay began construction of the visitor center focused on demonstrating the facility's transition to zero emission technologies. Complete with a full timeline displayed on the walls and interactive screens, the visitor center displays the facility's transformation journey and is a visual model of future deployments.

On January 18, 2023, Frito-Lay formally announced the completion of the project at a large press conference and event. The event hosted all project partners, local government leaders, community organizations and both national and local media. The resulting impact was a clear demonstration of feasible ZE and NZE technologies at work. Media outlets noted the transformation at Modesto as a template and catalyst for continued large-scale commercialization of ZE and NZE technologies at freight facilities and warehouses – magnifying emissions reduction benefits on a broad scale.

In April 2023, Frito-Lay announced plans to deploy over 700 electric delivery vehicles in the U.S. by the end of 2023—expected to lower emissions by 7,052 metric tons of GHG emissions annually, equivalent to 1,533 passenger cars removed from the road. Paired with advancements in regenerative agriculture, water saving technology, packaging innovation and more, the announcement reflected the PepsiCo division's significant progress toward its PepsiCo Positive sustainability goals. By the end of 2023, the pledge was met.

Local voices in the community were fundamental to Frito-Lay's journey to significant emission reduction, as their advocacy for improving air quality in the Central Valley was a critical driver of this project.

Engaging the Community

Two local organizations were engaged to share project learnings and build capacity to engage community members on the benefits of zero emission technologies at Frito-Lay. These Community Based Organizations (CBOs) were tasked with amplifying the project's progress and accomplishments with community members and relevant stakeholders.

Community Partners

Project Clean Air, Inc. (PCA) is a 501(c)(3) non-profit that strives to enhance the community by improving air quality through education and collective action throughout the San Joaquin Valley, Eastern Kern County and California's Central Coast. Project Clean Air was created in 1990 with the knowledge that the majority of criteria air pollutants in the region come from mobile sources, which are not regulated by the local air districts. PCA manages the San Joaquin Valley Clean Cities Coalition, part of the U.S. Department of Energy's Clean Cities Program and has a variety of partnerships and programs benefiting the San Joaquin Valley and beyond. PCA assisted with public outreach, community relations, fleet outreach and employee outreach.

PCA is the lead organizer of the "Trucking with Clean Fuels Conference" and focuses on consistently holding this event annually to engage fleets and community members. On Tuesday, August 13, 2019, Project Clean Air, Inc. held a Trucking with Clean Fuels Conference focused on CNG, liquefied natural gas (LNG), and RNG at the Ford Theater in Shafter, California (an AB 617 community). Dealerships and trucking fleets displayed vehicles in the venue parking area (Affinity, Harris Ranch, Pape Kenworth, B&N Trucking, and A-1 Alternative Fuel Systems). Exhibitors included Kern Council of Governments, Central California Asthma Collaborative, California HVIP, California Air Resources Board, San Joaquin Valley Air Pollution Control District, Revolution CNG, Trillium, Biorem Energy, A-1 Alternative Fuel Systems, Dynamic Renewable Solutions, Pape Kenworth, and Project Clean Air.

On Thursday, November 7, 2019, Project Clean Air, Inc. held a Trucking with Clean Fuels Conference. It focused on CNG, LNG, and RNG. It was held in the Gem & Mineral Building at the Big Fresno Fairgrounds, Fresno, California (an AB 617 community). On February 23, 2023, a Trucking with Clean Fuels Conference was held in Bakersfield. The event included a ZEV convoy, Ride N Drive, numerous vendors, and speakers.

PCA also identified a need for first responder training to increase First Responder EV knowledge and safety in the central valley following increased deployments of ZE technology and coordinated training sessions in various cities. EV first responder trainings were held at Moonlight Farms in Reedley and the Modesto County Fire Department's training facility in Ceres. The Modesto training included vehicle operators from 3 companies and 16 firefighters from 4 different departments. Frito Lay provided a Peterbilt box truck and a Tesla semi from the Modesto facility. Captain Womock and AFV Educate provided an excellent training experience for all attendees.

PCA also participated in Frito-Lay's event held on January 2023 and began including PepsiCo messaging in each of their newsletters. These posts included items about the Tesla Semi delivery and sustainability, including the Tesla Semi's being showcased in the Modesto Christmas Parade. These actions signal a significant shift towards greener transportation solutions in the region.

Café Coop is a community-based organization that implemented its community outreach plan through technology demonstrations, media announcements, and workshops.

Cafe Coop has a long-standing relationship with various Community Based Organizations (CBOs) in San Joaquin County as well as statewide. Cafe Coop scheduled integrated meetings with many of the CBOs and stakeholders with whom Cafe Coop partners with and builds community capacity.

Cafe Coop facilitated communication to partner organizations including making announcements at Frito-Lay team and coalition meetings. The organization developed Frito-Lay's Environmental Justice Communities Outreach and Communications List. Cafe Coop engages with CBO partners and coalition members by text messaging, in-person and zoom public meetings, community meetings, service projects and online organizing. While in-person meetings and on-site meetings are preferred to engage the community, the pandemic prevented frequent in-person engagements. Despite COVID restrictions, Café Coop coordinated two in-person CBO meetings over the project term.

The Get Out the Vaccine {GOTV) campaign by Governor Newsom's office and University of California - Los Angeles (UCLA) was one of California's most successful COVID vaccination efforts among Disadvantaged Community (DAC) populations. Cafe Coop collaborated with the Environmental Justice Coalition for Water and Todos Unidos in the GOTV Campaign, where stakeholders and community members showed great interest in the health benefits provided by the new heavy-duty freight equipment and operations Frito-Lay Transformative ZANZEFF Project.

Announcements on the project were shared at partner coalition meetings (i.e. Healthy Neighborhood Collaborative, AB617 Community Steering Committee, Coalition for Environmental Equity and Economics (CEEE), California Justice Coalition (CEJC), iHub San Joaquin, and San Joaquin Partnership.)

Cafe Coop also had significant impact in amplifying Frito-Lay hosted events. They utilized various communication tactics to secure attendance by local CBO and economic development partners (i.e. Catholic Charities, Sierra Club, iHub San Joaquin, and Central Valley New Market Tax Credit) at the project kickoff event. The tactics used by Cafe Coop for promotion and invitation by Cafe Coop ensured the full distribution of event information to key community leaders and advocates who could amplify the ZANZEFF project. The same strategy was applied for the site's Transforming Modesto Celebration Event held on January 18, 2023, where Cafe Coop recruited and secured attendance of regional leaders.

Cafe Coop provides professional and rapid-fire grass roots community communication in the Greater Surrounding San Joaquin Communities. Cafe Coop also produced, in partnership with Kenny McCann Media, short videos that displayed many of the dynamic aspects of this transformative project. Videos include:

- Groundbreaking technical improvements to the Frito-Lay Plant Site in Modesto promoting zero emission equipment.
- Engaging Videos of electric zero emission trucks operating in Modesto
- Video of Frito-Lay electric trucks operating on California's Central Valley freeway, California State Highway 99, the freight workhorse of central California from Bakersfield to Redding. This was to have been the introduction of the animation video. Though not used in the final Frito-Lay project, these videos are still available.

Impact

During the project period, various political leaders visited the Modesto facility to witness Frito-Lay's commitment to sustainability. California Senator Maria Alvarado-Gil (District 4) cited community support, higher education for students, and employee investment. State Assemblymember Juan Alanis (District 22) demonstrated excitement at the facility's manufacturing process and the difference being made through sustainability efforts.

Figure 29 Frito-Lay's Tesla Semi Participates in Local Holiday Parade

A lot of the media attention directed at the Frito-Lay facility in Modesto was generated by media outlets regarding the first deployment of the Tesla Semi trucks at the facility. Deployment of all 15 trucks concluded in January 2023. Independent of this project, the Frito-Lay facility has a considerable community impact. Frito-Lay contributes to Love Stanislaus County, an initiative that oversees city-wide volunteer days (Love Modesto, Love Waterford, Love Oakdale, etc.) in Stanislaus County with the goal of bringing communities together through volunteering community projects. Frito Lay employees also participate in "Bed Build Day" held at Modesto Junior College, where volunteers build bunk beds for children in families in need. The same spirit extends to the ZANZEFF project as well where Frito-Lay featured the Tesla Semi in

Modesto's holiday parade (Figure 29), bringing the vehicle to the community whose curiosity had been augmented since the deployment became public.

XII. Lessons and Recommendations

Deployment and Performance (Vehicles and Infrastructure)

Vehicles/Equipment

ZE LI forklifts are more energy and cost efficient than ZE LA forklifts. Operators found that they charged more quickly, and their batteries sustained a charge longer than the LA forklifts. The similar configurations between the LI and LA forklift models facilitated operators' adoption of the new LI technology. Additionally, the fleet reported that the new LI forklifts outperformed the LA models in maneuverability, acceleration, reliability, and comfort.

ZE yard tractors can meet the required duty cycle of conventional diesel yard tractors while covering more distance in the same amount of time.

ZE Class 8 Semis can successfully drive approximately 320 miles in a single trip, which is a breakthrough for electric Class 8 truck technology. To accomplish this feat, the fleet deployed a single Class 8 Semi before the other 14 vehicles and gradually drove on higher-mileage routes as drivers grew comfortable operating the Semis. Furthermore, the Class 8 Semis can also successfully complete a trip of approximately 300 miles without any opportunity charging. The early deployment demonstrated a lower energy consumption at 1.6 kWh per mile, decreasing with increased use according to Frito-Lay.

Class 6 box trucks have a significantly shorter range and smaller payload than Class 8 trucks, which the fleet previously used for all on-road transportation. Though the fleet expected the box trucks to have a range of 150 miles, operators never progressed beyond 120 miles. Thus, the fleet had to restructure the Class 6 box trucks' routes to reduce the mileage required for travel.

The early deployment of the Class 8 Volvo RNG Trucks during the project yielded many benefits for Frito-Lay's fleet. Drivers gained valuable experience operating and fueling the new RNG trucks for five months before Frito-Lay had fully commissioned and utilized the Beyond6 RNG Station, which made the deployment of the rest of the NZEVs much smoother for the fleet as well.

Infrastructure

Forklift Chargers: Opting for a 1:1 ratio between their forklifts and forklift chargers proved beneficial to the fleet's operations given the intense duty cycle of their forklifts. The convenient placement of the forklift chargers provided operators with an easier plug-in charging process.

125-kW DCFC Chargers: Communication issues between the ChargePoint EVSE and the BYD yard tractors and Peterbilt ZEVs revealed that charger and vehicle OEMs must take initiative and collaborate with each other more efficiently to conduct interoperability testing with their products. OEMs in the ZEV industry must set a standard of partnering with multiple EVSE OEMs without limiting themselves to what equipment can be used in certain locations. These actions will help prevent interoperability issues from delaying future deployments.

RNG Station: Clear communication with project suppliers was critical; the project managers had weekly and biweekly calls to resolve any issues that arose during the design and construction processes. Additionally, having a project manager onsite to resolve these communication issues quickly within the hour or the day—rather than working remotely and responding within the week—proved invaluable to the success of the fleet's vehicle and infrastructure deployments.

Solar and Storage: Installing and commissioning the solar and storage systems at Frito-Lay was a process that generated lessons for future fleets considering these technologies. The construction process revealed that clear communication between fleets and subcontractors is imperative to assure that all design requirements are satisfied before deployment. Fleets considering solar and storage system installation should anticipate a prolonged construction process that takes several phases to complete and should coordinate with their employees sufficiently so there is no confusion or disruption of fleet operations. Additionally, at the Modesto facility, solar production ranges between 43,000 kWh per month in the winter and 194,000 kWh in the summer, a nearly 5-fold difference; fleets should consider this seasonal variation when calculating their required solar production, particularly during the winter. Fleets should also account for expected ZEV growth when installing solar, as installing a larger solar array during the initial installation can save money over expanding the array later. Solar arrays cannot be used to offset demand charges, but energy storage can. The fleet may want to consider using solar and storage to offset demand charges from ZEV energy draw.

Charging Practices

Forklift charging: The lithium-iron-phosphate chemistry of the fleet's new forklifts allowed operators to charge the ZEVs completely in about 4 to 6 hours. Additionally, because the LI batteries did not require equalization—an 18-hour process per week—the fleet was able to increase their forklift uptime significantly. However, forklift operators also reported that setbacks would occur when a low charge prevented them from starting their routes. For future LI forklift deployments, the fleet recommends charging between shifts, or **opportunity charging**, to allow for fully charged forklifts during operation.

Off-road versus on-road equipment: The fleet's ZE off-road equipment was utilized around the clock with few break intervals. The ZE forklifts and yard tractors were plugged in and unplugged practically every hour of the day. Operators aim for a best practice that encourages charging during idle to maintain operational efficiency. However, the fleet's ZE Class 6 box trucks, despite traveling a similar distance per day compared to the ZE yard tractors, had a much shorter duty cycle—about 2 hours per day—and did not need to be charged each day of operation.

Demand management: The deployment of the dual-port, 125-kW chargers revealed that charge management strategies are essential to avoiding exorbitant demand fees. Charging the ZE yard tractors and Class 6 box trucks simultaneously without establishing power limitations cost Frito-Lay about $4,000 each month. After capping demand at 200 kW, however, the fleet saved about $24,000 annually. Limiting demand results in slower charging speeds for all vehicles plugged into the chargers, though one vehicle type can still be prioritized to receive fast charging over another. Yard tractors at Frito-Lay were prioritized because of their 24-hour duty cycle and received the fastest charging speeds. The Class 6 Box trucks were deprioritized and received the slowest charging speeds as a result, though they could accommodate this change due to their shorter duty cycle and fewer charging events.

Maintenance

Forklifts: According to some of the fleet's forklift operators, the LI forklifts were rarely out of service for days at a time due to malfunctions. Rather, most time out of service was spent undergoing routine inspections. The fleet performed preventative maintenance checks on each forklift every 250 hours. Frito-Lay's service shop technicians ran through an internal maintenance checklist during their inspections of the forklifts and made replacements if necessary.

Yard tractors: Yard tractor maintenance data only included maintenance that was not performed under warranty. Therefore, although the cost of maintenance to the fleet was present in the dataset, the amount and kind of maintenance performed was unable to be fully assessed. Additionally, a fleet spokesperson remarked about the electric yard tractors that, although the vehicles experienced a lot of maintenance issues, including frequent tire and dashboard switch replacements, the OEM was very good about fixing issues as they arose. The electric yard tractors' cost per month was consistently lower than the baseline yard tractor. The fleet is very satisfied overall and has continued buying ZE yard tractors.

Class 6 Box Trucks: There was an overall downward trend in the amount and cost of maintenance for Class 6 trucks over the data collection period. During the first few months of the data collection period, the Class 6 trucks received larger quantities of relatively inexpensive repairs, mostly initial adjustments and software updates which caused little to no downtime.

Class 8 RNG Trucks: Of the 39 Class 8 RNG trucks deployed, many began their deployment in different months, ranging from May 2019 to February 2020. Vehicles were compared within their first, second, third etc. month of operation rather than comparing costs within the same calendar month. The percentage of total cost spent on unexpected repairs in the Breakdown and Driver's Report categories was lower for the RNG vehicles, while the percentage of total cost spent on scheduled repairs in the Routine and Preventive Maintenance categories was higher for the RNG vehicles.

VI. Conclusion

The world is already feeling the effects of climate change and fast, bold action is needed. PepsiCo is eager to help lead the way toward net-zero. Not only because climate change threatens the prosperity of people and communities, but also, because it challenges the long-term sustainability of companies like PepsiCo and the millions of jobs it collectively supports. To help mitigate these risks and adapt to new realities, it is essential to build resilience to protect against climate change. That means a reduction in the dependence on fossil fuels, including by investing in sustainable solutions like renewable energy. PepsiCo has set an ambitious goal of achieving net-zero emissions across its entire value chain by 2040 and an interim goal to reduce absolute emissions (Scopes 1, 2, and 3) across the value chain by more than 40% by 2030, which includes a reduction of 75% in Scope 1 and 2 emissions (both goals against a 2015 baseline). PepsiCo always aims to do more to drive progress toward its climate goals and is focusing its climate strategy on the areas where the biggest impact can be made: manufacturing, agriculture, packaging, transportation and vending and cooling equipment.

The coming year continues the transition to a cleaner, advanced, and more efficient fleet increasingly powered by renewable sources. Investments and initiatives will focus on:

- Safety: Leveraging advanced technologies that improve the safety performance of fleet operations;
- Connectivity: Utilizing data and technologies that improve efficiency; and
- Electrification: Increasingly deploying electric vehicles to reduce emissions.

This project sought to demonstrate that the deployment of near-zero and zero emission technologies were not only possible facility-wide, but operated cleaner and more efficiently than their diesel counterparts.