California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

NorCAL ZERO: Zero-Emission Regional and Drayage Operations with Fuel Cell Electric Trucks

Prepared for: California Air Resources Board, California Energy Commission

Prepared by: Center for Transportation and the Environment

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California Energy Commission

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ABOUT CALIFORNIA CLIMATE INVESTMENTS

The Zero-Emission Drayage Truck and Infrastructure Pilot Project is part of **California Climate Investments**, a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy and improving public health and the environment — particularly in disadvantaged communities. Learn more at **caclimateinvestments.ca.gov**.

ABOUT THE CEC'S CLEAN TRANSPORTATION PROGRAM

This project is funded in part by the California Energy Commission's Clean Transportation Program, which invests up to $100 million annually to support California communities, increase access to zero-emission vehicle infrastructure, support innovation, and accelerate the deployment of advanced transportation and fuel technologies.

Additional match for the project was provided by the following organizations:

- Alameda County Transportation Commission
- Bay Area Air District
- FirstElement Fuel, Inc.
- Glovis America, Inc.
- Hyundai Motor Company

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 126 (Reyes, Chapter 319, Statutes of 2023) reauthorizes the funding program through July 1, 2035 and focused the program on zero-emission transportation.

The Clean Transportation Program has an annual budget of approximately $100 million and provides financial support for projects that:

- Produce alternative and renewable low-carbon fuels in California.
- Deploy zero-emission fueling infrastructure, fueling stations, and equipment where feasible and near-zero-emission fuel infrastructure, fueling stations, and equipment elsewhere.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update.

The California Air Resources Board (CARB) approved the Fiscal Year 2019–20 Funding Plan for Clean Transportation Incentives on October 24, 2019, allocating $533 million to accelerate the adoption of zero-emission vehicles and clean transportation technologies. Of this total, $485 million was sourced from cap-and-trade auction proceeds, with the remaining $48 million from the Air Quality Improvement Program. The plan prioritized investments in disadvantaged communities and included a $40 million allocation for Heavy-Duty Advanced Technology Demonstration and Pilot Projects.

The CARB and the CEC issued the Zero-Emission Drayage Truck and Infrastructure Pilot Project solicitation (GFO-20-606), to support large-scale deployments of on-road, zero-emission Class 8 drayage trucks as well as vehicle fueling infrastructure necessary for service operation. In response to GFO-20-606, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards April 5, 2021, and the agreement was executed as ARV-21-017 on August 12, 2021. The agreement with CARB was executed as G19-DRAY-02 on June 2, 2021.

ABSTRACT

This report describes the California Energy Commission and California Air Resources Board-funded Zero-Emission Regional and Drayage Operations with Fuel Cell Electric Trucks (NorCAL ZERO) project. The project deployed 30 fuel cell electric drayage trucks in drayage operations out of the Port of Oakland as well as regional operations throughout the Central Valley and San Francisco Bay Area. The project also established supporting infrastructure, including an Oakland heavy-duty hydrogen fueling station providing 700 bar dispensing and a San Leandro maintenance facility designed to service fuel cell electric vehicles. The project additionally funded comprehensive workforce training, data collection, and community outreach within the Port of Oakland trucking community and West Oakland neighborhood.

Keywords: hydrogen, fuel cell electric trucks, drayage, fueling, zero-emission, heavy-duty

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF ACRONYMS

BIT	Basic Inspection of Terminals
CARB	California Air Resources Board
CEC	California Energy Commission
CTE	Center for Transportation and the Environment
EBMUD	East Bay Municipal Utility District
CalEPA	California Environmental Protection Agency
FCET	fuel cell electric truck
HATCI	Hyundai America Technical Center, Inc.
NFPA	National Fire Protection Association
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
OOS	out of service days
PM	particulate matter
PG&E	Pacific Gas and Electric Company
SOC	state of charge
WOEIP	West Oakland Environmental Indicators Project
ZEV	zero-emission vehicle

EXECUTIVE SUMMARY

The California Air Resources Board and California Energy Commission funded Zero-Emission Regional and Drayage Operations with Fuel Cell Electric Trucks (NorCAL ZERO) with the goal of advancing zero-emission heavy-duty trucking within the State of California. The project paved the way for future commercial fuel cell vehicle deployments, introducing Hyundai Motor Company as a Class 8 fuel cell electric truck original equipment manufacturer (OEM) within the United States and supporting economies of scale for hydrogen technology. The project also directly contributed to the creation of at least 45 partial jobs within the State as well as emissions reductions, including an estimated 1,945 pounds of nitrogen oxides, 100 pounds of particulate matter, 40 pounds of fine particulate matter, and over 696 metric tons of carbon dioxide equivalent greenhouse gases annually based on 2024 data.

The project began in the fall of 2021, led by the Center for Transportation and the Environment. The project supported the deployment of 30 Hyundai XCIENT Fuel Cell Tractors in commercial operation by Glovis America through subsidiaries Global Expedited Transportation Freight (GET Freight) and Extreme Auto Transport (Extreme) in Northern California. These trucks performed both regional deliveries and drayage operations out of the Port of Oakland, hauling a combination of containerized cargo and light-duty vehicles via car hauler trailers. FirstElement Fuel built and operated a hydrogen refueling station in West Oakland capable of supporting the 30-truck deployment at 700 bar pressure. The project also funded hydrogen technology-specific upgrades to Papé’s San Leandro maintenance facility, vehicle parts and equipment, and maintenance labor.

The project team additionally conducted a comprehensive workforce training program establishing Papé Group as the premier zero-emission maintenance and support provider in the greater Bay Area; led outreach activities within the West Oakland community; and collected and analyzed project data detailing vehicle performance, maintenance and repair, fueling infrastructure, and operations in support of future deployments.

CHAPTER 1: Introduction

Project Background

California has set aggressive targets for reducing greenhouse gas emissions and improving air quality, particularly in areas with high concentrations of freight and logistics operations. In late 2020, the California Energy Commission (CEC) and California Air Resources Board (CARB) announced the availability of $44.1 million in funds to support large-scale deployments of on-road, zero-emission Class 8 drayage trucks as well as vehicle fueling infrastructure. Funds provided through the solicitation included $20.1 million from CEC's Clean Transportation Program and $24 million for projects eligible under CARB's fiscal year 2019-20 Funding Plan for Clean Transportation Incentives.

The goals of the solicitation were as follows:

> "(1) advance zero-emission technology for Class 8 on-road trucks with a focus on regional haul or drayage service;
>
> (2) understand fleet dynamics when deploying a large number of zero-emission trucks and supporting infrastructure, including assessing the ability of fleets to recharge or refuel large numbers of trucks on a daily basis – sometimes multiple times per day;
>
> (3) support zero-emission, on-road heavy-duty truck manufacturers to realize economies of scale that come with larger production volumes;
>
> (4) holistically reduce greenhouse gas …, criteria pollutant, and toxic air contaminant emissions in and around ports and freight facilities;
>
> and (5) provide economic, environmental, and public health benefits to disadvantaged and low-income communities." [1]

The Center for Transportation and the Environment (CTE) began developing the NorCAL ZERO project years prior to the solicitation release, with the idea of collaborating with the East Bay Municipal Utility District (EBMUD) to site a hydrogen fueling station adjacent to the Port of Oakland to fuel Class 8 fuel cell electric trucks (FCETs). CTE assembled a core group of established companies and organizations and raised additional funding through $7 million of cost share grants from the Alameda County Transportation Commission and the Bay Area Air District, as well as numerous endorsements from elected officials and industry representatives.

In 2021, CTE submitted a grant application to the CARB and the CEC proposing to deploy 30 FCETs at the Port of Oakland in Northern California, otherwise known as the NorCAL ZERO project. As it was proposed, the NorCAL ZERO project would constitute the largest commercial deployment of Class 8 FCETs in North America. In August of that year, the California Air

[1] https://www.grants.ca.gov/grants/gfo-20-606-zero-emission-drayage-truck-and-infrastructure-pilot-project/.

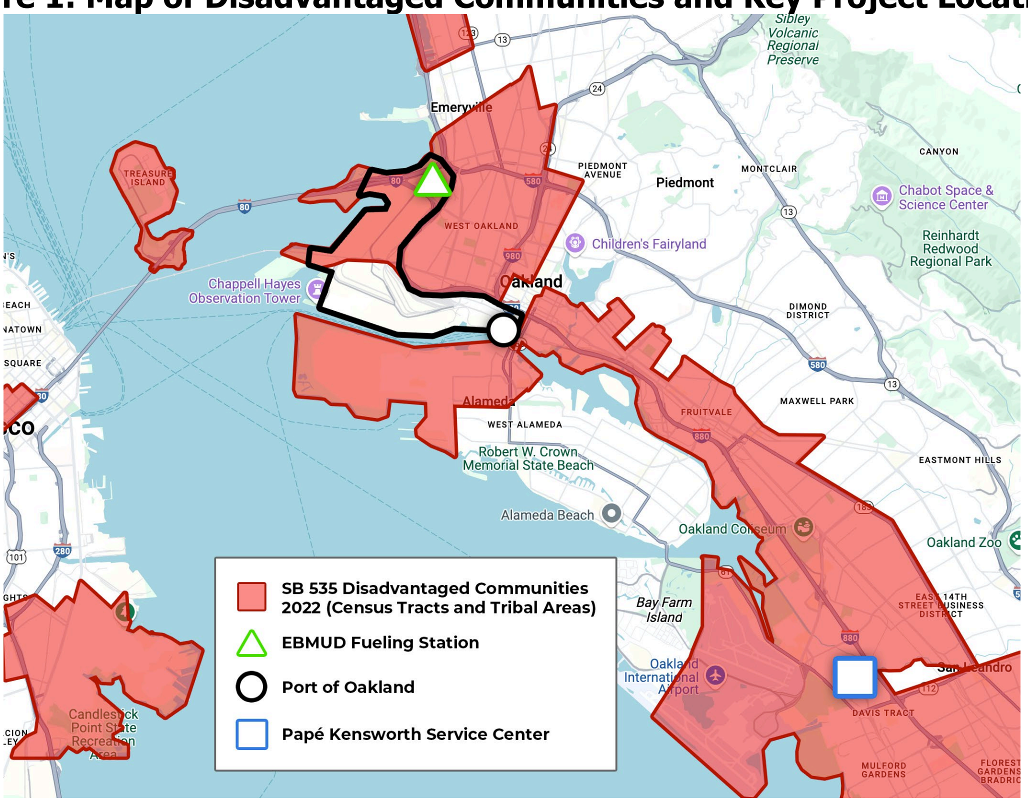
Resources Board and the California Energy Commission awarded CTE as the prime recipient and project manager of grants for Zero-Emission Regional and Drayage Operations with Fuel Cell Electric Trucks (NorCAL ZERO).

Project Goals

The NorCAL ZERO project aimed to advance zero-emission Class 8 on-road technology and an understanding of fleet dynamics when deploying many zero-emission trucks and supporting infrastructure. The CEC agreement funded the construction of a hydrogen refueling station capable of dispensing fuel at 700 bar pressure as well as workforce development and training activities to support the successful deployment of a commercial fleet of 30 fuel cell electric Class 8 trucks in Northern California funded under a separate agreement from CARB. The project aimed to significantly reduce greenhouse gas and criteria air pollutants associated with internal combustion engine vehicle operations and provide economic and public health benefits to the West Oakland disadvantaged community.

Figure 1 uses CalEPA's CalEnviroScreen tool to show the economic and air quality burdens experienced by communities located adjacent to the Port of Oakland and the I-80/I-580/I-880 Interchange. West Oakland is a historically marginalized and under-resourced community that is disproportionately impacted by diesel particulate matter (PM) and other key criteria air pollutants. The map also shows the fueling station and service center locations located within disadvantaged communities as part of the project's commitment to reducing emissions and providing local economic benefits.

Figure 1: Map of Disadvantaged Communities and Key Project Locations



Source: CTE

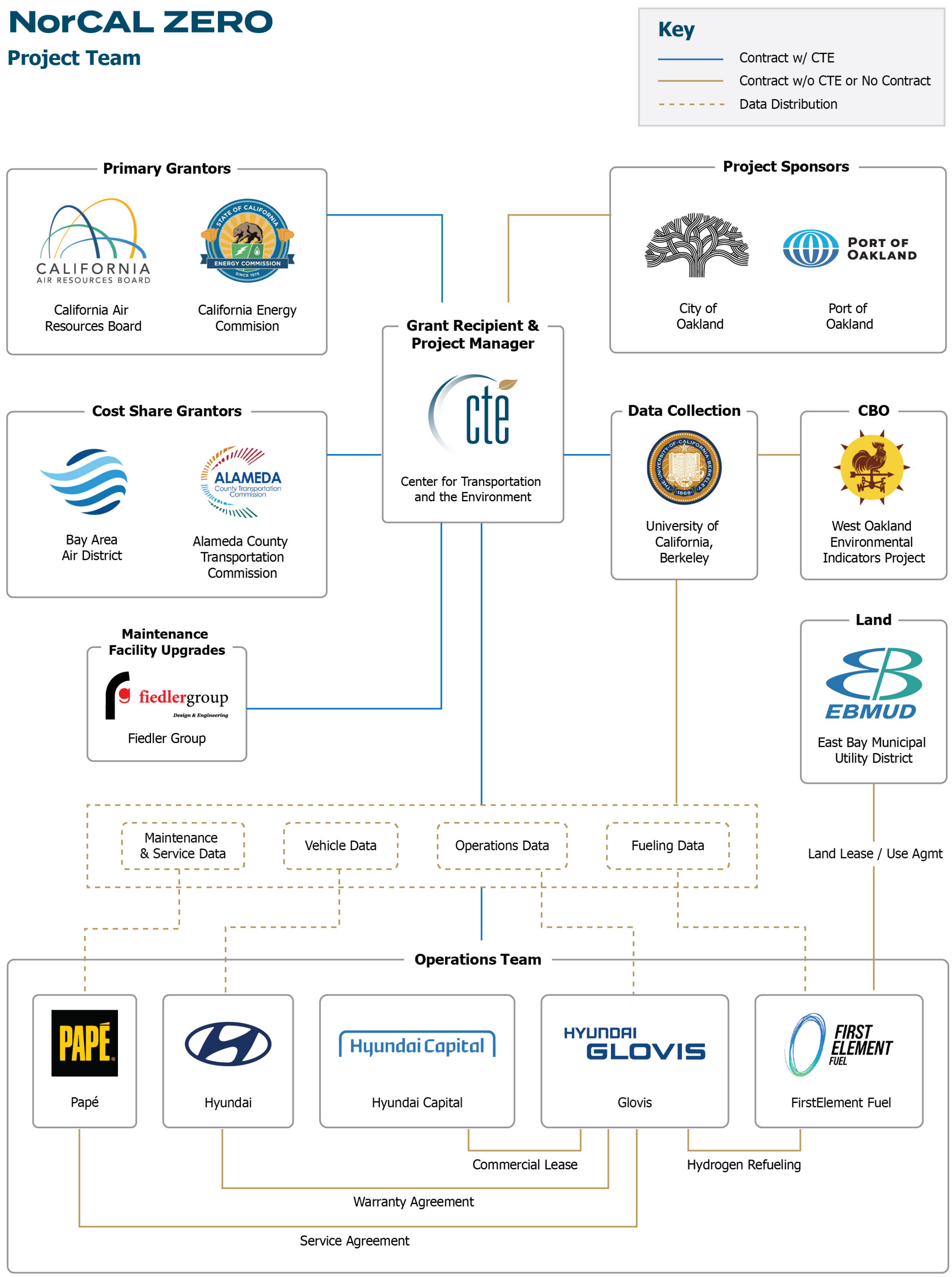
Specific objectives of the CARB and CEC grant agreements included:

1. Introducing Hyundai as another competitive commercial vehicle OEM into the California and United States zero-emission markets, a necessary step to reduce cost and to commercialize zero-emission Class 8 trucks.
2. Operating 30 Hyundai XCIENT Fuel Cell trucks in commercial operation in Northern California for a period of at least six years, offering competitive performance to diesel trucks with respect to total cost of ownership, operating range, capacity, cargo volume, refueling speed, reliability, and longevity.
3. Demonstrating economies of scale for future fuel cell electric truck deployments.
4. Building and operating a hydrogen refueling station capable of supporting a 30-truck deployment at 700-bar pressure, enabling expansion of the operation of fuel cell electric vehicles in the face of growing freight operations in Northern California.
5. Conducting a workforce training program and demonstrating benefits to local employment, particularly within the San Francisco Bay Area.
6. Collecting and analyzing project data detailing vehicle performance, maintenance and repair, fueling infrastructure, and operations. This is a critical step in understanding the current state of zero-emission equipment and steering the industry toward more rapid commercial deployments.

Project Stakeholders

Figure 2 provides a visual representation of the core project team. Both these stakeholders and additional organizations are described in further detail within the following section.

Figure 2: Project Stakeholders



Source: CTE

Project Grantors

Alameda County Transportation Commission plans and funds transportation programs within Alameda County.[2] Alameda County Transportation Commission served as a cost share grantor for the NorCAL ZERO project.

Bay Area Air District, formerly known as Bay Area Air Quality Management District, regulates air pollution in nine Bay Area counties, including Alameda County where the FirstElement Fuel station was constructed.[3] Bay Area Air District served as a cost share grantor for the NorCAL ZERO project.

California Air Resources Board (CARB) oversees California's air pollution controls, including setting vehicle emissions standards.[4] CARB provided funding for vehicle production, vehicle deployment planning, and vehicle operations associated with the NorCAL ZERO project.

California Energy Commission (CEC) leads energy planning and policy efforts for the State of California.[5] CEC provided funding for hydrogen station development, maintenance facility upgrades, community outreach, and workforce development activities associated with the NorCAL ZERO project.

Project Sponsors

The **City of Oakland** is a major port city within the State of California, containing the ninth busiest container port in the United States.[6] The City of Oakland provided guidance to the NorCAL ZERO project team regarding navigating the City's permitting processes and as served as a staunch advocate for the project.

The **Port of Oakland** is a major seaport and logistics hub on the West Coast, handling cargo shipments and serving as a key gateway for international trade, particularly in containerized goods. The Port of Oakland provided invaluable assistance to the NorCAL ZERO project team including, but not limited to, housing an interim hydrogen refueler, expediating permit approvals, and hosting community events in support of the project and the zero-emission trucking industry.

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[2] https://www.alamedactc.org/

[3] https://www.baaqmd.gov/about-the-air-district

[4] https://ww2.arb.ca.gov/about

[5] https://www.energy.ca.gov/about

[6] https://www.oaklandca.gov/Planning-Building/General-Plan-Neighborhood-Plans/City-of-Oakland-Current-General-Plan-Elements/Oakland-2045-General-Plan-Update/General-Plan-Update-Phase-2/GPU-Options-for-How-We-Stabilize-and-Grow/Options-Chapter-4

Project Team

The **Center for Transportation and the Environment (CTE)** is a 501(c)(3) nonprofit that collaborates with federal, state, and local governments; fleets; and vehicle technology manufacturers to advance clean transportation and energy technologies. Since its founding in 1993, CTE has managed a portfolio of more than $4.3 billion in research, development, demonstration, planning, and deployment projects funded by federal and state organizations.[7] CTE served as the prime recipient and project manager for NorCAL ZERO, overseeing the project in its entirety.

East Bay Municipal Utility District (EBMUD) provides water and wastewater services to the East Bay region of Northern California. EBMUD leased the land for the hydrogen refueling infrastructure and supported compliance processes at the site.

Fiedler Group is a California-based design and engineering firm specializing in alternative fuels.[8] Fiedler Group provided a third-party assessment of the existing maintenance facility to determine what modifications would be necessary to bring the building into compliance with current hydrogen codes and standards.

FirstElement Fuel, Inc. a California-based company that operates in the retail hydrogen ecosystem, aiming to build the world's most extensive network of hydrogen fueling stations—a True Zero network—to accelerate the widespread adoption of hydrogen as a vehicle fuel and create a clean energy future.[9] FirstElement Fuel was responsible for building a high capacity and high throughput liquid fueling station and sourcing hydrogen for the fleet.

Glovis America (Glovis) provides third-party vehicle and parts logistics across the United States, serving numerous automotive OEMs including Hyundai, Kia, Tesla, Lucid, Ford, General Motors, Honda, Volkswagen, and BMW. Glovis owns multiple trucking subsidiaries including GET Freight (short haul and drayage), and Extreme Auto Transport (finished vehicles). Glovis was responsible for recruiting prospective customers and operating the 30 XCIENT Fuel Cell Tractors through GET Freight and Extreme.

Hyundai America Technical Center, Inc. (HATCI) is the technology, design, and engineering center for North American vehicle models produced by Hyundai Motor Group.[10] HATCI supported vehicle development, testing, and training for the NorCAL ZERO project.

Hyundai Capital America is a subsidiary of Hyundai Motor Group that supports Hyundai vehicle financing within the United States.[11] Hyundai Capital served as the XCIENT Fuel Cell Tractor owner and lessor for the NorCAL ZERO project.

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[7] https://cte.tv/mission

[8] https://www.fiedlergroup.com/sectors-of-expertise/alternative-fuels/

[9] https://www.firstelementfuel.com/

[10] https://www.hatci.com/about/

[11] https://www.hyundaicapitalamerica.com/

Hyundai Motor Company (Hyundai) is a multinational vehicle manufacturer that has been developing fuel cell technology for more than 25 years, including investments in both heavy-duty and light-duty applications.[12] Hyundai was responsible for designing, testing, manufacturing, and delivering 30 Class 8 FCETs to the United States. Hyundai was additionally responsible for providing training on truck service and maintenance to vehicle technicians program and guaranteeing a six-year bumper-to-bumper warranty for the XCIENT Fuel Cell Tractors.

Hyundai Translead, owned by Hyundai Motor Company, is a manufacturer of heavy-duty trucking equipment for the North American market. Hyundai Translead was responsible for importing the XCIENT Fuel Cell Tractors into North America and ensuring a successful delivery to the customer at the Port of Oakland.

Papé supplies medium- and heavy-duty equipment, including zero-emission trucks, to operators throughout the Western United States. Papé was responsible for providing maintenance and support to the 30 XCIENT Fuel Cell Tractors. NorCal Kenworth, the original maintenance partner for NorCAL ZERO, was acquired by Papé in December 2022.

University of California, Berkeley (UC Berkeley) is a leading public research university located in Alameda County. The NorCAL ZERO project engaged faculty from UC Berkeley's Transportation Sustainability Research Center, which leads advanced transportation technology research projects at the university, and the Goldman School of Public Policy. UC Berkeley supported both community outreach activities and data collection and reporting for the project.

The **West Oakland Environmental Indicators Project (WOEIP)** is an environmental justice-focused community-based organization serving West Oakland, California. Alongside UC Berkeley, WOEIP led community outreach efforts for the NorCAL ZERO project, harnessing its existing relationships with West Oakland organizations to connect project stakeholders and community members.

Other Participants

Air Liquide, a multinational supplier of industrial gases and associated fueling infrastructure, served as the fuel supplier for the FirstElement Fuel station.

Global Expedited Transportation Freight (GET Freight) and **Extreme Auto Transport (Extreme)** are fleet operators and wholly owned subsidiaries of Glovis based in California. GET Freight operated XCIENT Fuel Cell Tractors delivering containerized loads for the NorCAL ZERO project while Extreme operated five XCIENTs used as light-duty car haulers.

Hyundai Mobis (Mobis) was the primary parts supplier for the project.

I&D Consulting Services is a consultancy specializing in commercial real estate development. A subcontractor to FirstElement Fuel, I&D Consulting Services was responsible for entitlements and permitting for the project.

[12] https://ecv.hyundai.com/global/en/newsroom/insights/the-history-of-hydrogen-and-hyundais-25years-of-progress-BL00200512

Macquarie Equipment Capital Inc. **(Macquarie)**, a subsidiary of Macquarie Group, was the planned truck owner and lessor expected to execute a structured asset finance agreement with the project's end user, Glovis. Macquarie was highly engaged with the project prior to Glovis' decision to instead lease the vehicles from Hyundai Capital in July 2023.

Motive served as the electronic logging device provider for the NorCAL ZERO project, supporting data collection and interpretation through GET Freight.

CHAPTER 2: Administration

Objectives

Key objectives of the Administration task included establishing lines of communication and procedures for implementing the project; providing regular opportunities for CARB and CEC to evaluate project progress and make modifications to the project's tasks, schedule, and budget as needed; obtaining match funds; obtaining permits; establishing necessary subcontracts to carry out the project's overarching objectives; and managing risks, including conflicts and changes to the original project proposal.

Activities

CTE led the administration of the NorCAL ZERO project, which began with leading the project kickoff meeting in September of 2021. CTE held regular administrative meetings with project stakeholders throughout the project's lifecycle, working to align diverse partners and providing regular updates to CARB and CEC regarding timeline and delivery status. These updates included Quarterly Progress Reports, Critical Project Review Meetings and associated reports, as well as regular monthly calls between CARB, CEC, and CTE.

CTE was responsible for coordinating match funds and identifying and executing applicable subcontracts, including managing changes to the project team and associated agreements over the course of the project. CTE managed the project budget and invoicing processes, documenting match funding and continuously monitoring project spending. CTE also documented permitting efforts and managed the schedule for tasks and products throughout the project lifecycle, monitoring and working to mitigate project risks. Critically, CTE provided oversight and guidance throughout the process of HATCI obtaining an executive order from CARB to sell the XCIENT Fuel Cell Tractors within the State of California. As risk managers, CTE played a lead role in addressing changes in plans, budget, schedule, and team members, and helping to resolve conflicts to ensure the successful execution of the project.

Timeline

The project consisted of the following 10 tasks:

- Administration: September 2021–March 2026
- Truck Procurement: November 2021–August 2023
- Hydrogen Station Development: October 2021–August 2024
- Maintenance Facility Upgrades: November 2021–August 2023
- Community Outreach: June 2022–March 2025
- Zero-Emission Vehicle (ZEV) Workforce Plan: March 2023–May 2024
- Vehicle Deployment Planning: November 2021–May 2023
- Vehicle Operation: July 2023–March 2026
- Data Collection and Analysis: October 2022–September 2025

Project Subteams

To enhance communication and collaboration, CTE organized project partners into the seven subteams outlined below. These teams met regularly during relevant phases of the project.

Administrative Subteam – all members

Truck Build and Deployment Subteam

Activities: Discussed vehicle build progress and the build schedule, truck performance metrics, and interfacing between the trucks and fueling station.

Members:

- **CTE**: Project Manager
- **Glovis**: Fleet Operator
- **FirstElement Fuel**: Hydrogen Station Owner
- **HATCI**: Truck Testing and Technical Support
- **Hyundai**: Truck OEM and Research and Development
- **Hyundai Capital America**: Truck Owner and Lessor
- **UC Berkeley**: Project Evaluation and Outreach

Customer Base Development Subteam

Activities: Discussed Glovis' customer base.

Members:

- **CTE**: Project Manager
- **Glovis**: Fleet Operator
- **Hyundai**: Truck OEM
- **Hyundai Capital America**: Truck Owner and Lessor

Station Development Subteam

Activities: Discussed station planning, build progress, and fueling operations.

Members:

- **Air Liquide**: Fuel Provider
- **CTE**: Project Manager
- **EBMUD**: Station Site Owner and Prospective Biogas Supplier
- **FirstElement Fuel**: Hydrogen Station Owner
- **I&D Consulting Services**: Permitting and Entitlements Consultant

Maintenance Facility Upgrades Subteam

Activities: Discussed facility planning and upgrade progress.

Members:

CTE: Project Manager

Fiedler Group: Architecture and Engineering Firm

Papé: Maintenance Services and Repair Provider

Workforce Training Development Subteam

Activities: Discussed the Zero-Emission Workforce Training and Development Plan and its implementation.

Members:

CTE: Project Manager

Glovis: Fleet Operator

Hyundai: Truck OEM

Papé: Maintenance Services and Repair Provider

Community Engagement Subteam

Activities: Discussed outreach planning and developed outreach materials.

Members:

CTE: Project Manager

UC Berkeley: Project Outreach

WOEIP: Community Outreach

Data Collection Subteam

Activities: Discussed data collection and evaluation relating to the fleet and station.

Members:

CTE: Project Manager

FirstElement Fuel: Hydrogen Station Owner

Glovis: Fleet Operator

HATCI: Truck Testing and Technical Support

Hyundai: Truck OEM

Papé: Maintenance Services and Repair Provider

UC Berkeley: Project Evaluation

Lessons Learned

Match Funding: The project team experienced cost-savings resulting from a reduction in expected import taxes. This cost reduction resulted in an overall project savings but necessitated that the project team seek alternative sources of match funding to meet requirements set forth in the grant agreement. Future project managers should ensure projects have match sources in excess of the required match funding to account for unexpected project savings.

Property Insurance: Insurance requirements for the trucks proved to be a problem. The insurance industry is not familiar with the risk factors of advanced technology. Their conservative approach to assessing risk was to charge exorbitantly high rates for property insurance to cover very expensive vehicles. While liability insurance is legally required and affordable, because the trucks were principally funded by public agencies for demonstration purposes, they allowed the project to proceed without having to secure property insurance. Larger deployments of these vehicles with private funding may require the state in the early stages of vehicle adoption to establish an insurance pool with reduced rates for excess coverage.

Total Cost of Ownership (TCO): Commercialization of this technology requires a TCO nearly on par with conventional diesel technology. Key factors which contribute to TCO parity are capital cost of the trucks[13], taxes and license fees, maintenance and warranty service, insurance, and fuel costs. NorCAL ZERO included significant subsidies for capital and operating expenses in order to allow the fleet operator to price their services competitively with other fleets operating conventional technology vehicles.

Permitting: Stakeholders must dedicate significant resources towards navigating local regulations and permitting processes in California. Due to the novelty of many hydrogen technologies, organizations developing associated infrastructure should engage in education and awareness-building with permitting agencies to ensure that these agencies are aware of recent updates to codes and standards, such as National Fire Protection Association (NFPA) 2, Hydrogen Technologies Code, that are unique to hydrogen projects. Early engagement with local officials, public agencies, and impacted stakeholders is beneficial to the project development process and minimizes risks during project implementation.

First-Responders: Regulatory stakeholders such as local fire departments were engaged in development and training activities and remain key partners critical to the success of zero-emission infrastructure projects. The project team recommends investing in engagement with permitting stakeholders and first responders regarding zero-emission technology as a critical step towards widespread adoption.

[13] The residual value of the truck will factor into the purchase price of lease agreement. It is still too early to know what the value will be after first-life of the trucks (five to eight years), which means the OEM will have to project a residual value until such time as a truly commercial market for this technology has been established.

CHAPTER 3: Truck Design, Manufacturing, and Procurement

Objectives

The primary objectives for this task were twofold. First, Hyundai Motor Company was to manufacture and deliver 30 FCETs to Glovis America for deployment into commercial operation. Secondly, a gap funding financier was to develop and execute commercial leasing terms required for Glovis America to operate 30 fuel cell electric trucks under a monthly lease for a period of six years.

Activities

The NorCAL ZERO project introduced Hyundai's XCIENT Class 8 FCET to the United States market following the commercial release of a similar truck in Europe. To collect data on North American duty-cycles, two 6x2 FCETs[14] were deployed in Southern California beginning in June 2021 by HATCI, Hyundai's United States research and development subsidiary. The trucks pulled non-cargo weight, also known as "dummy loads," on various duty cycles, some of which included strenuous routes such as Tejon Pass (otherwise known as the Grapevine) on Interstate 5 north of Los Angeles, and ambient temperatures up to 110°F. Results from the tests were transmitted to Hyundai's Korean research and development center to ensure optimal performance of the vehicles to-be-deployed under the scope of this project.

Hyundai's North American 6x4 fuel cell tractor departed from the 6x2 Fuel Cell straight truck designed for the European market, with onboard capacity increased to support more strenuous North American duty-cycles. The North American model stores 70 kilograms (kg) of hydrogen at 700 bar pressure, whereas the 6x2 European straight truck carries 31 kg at 350 bar pressure. Hyundai also made significant investments in compliance with Federal Motor Vehicle Safety Standards, developing a new braking system and certifying the vehicles for the United States market. CARB's New Vehicle and Engine Programs Branch is responsible for the certification of new engines, vehicles, powertrains, aerodynamic devices and other new certifications. In May 2022, Hyundai received approval via a CARB executive order to sell the XCIENT Fuel Cell Tractors in California. **Table 1** provides an overview of the technical specifications for the Hyundai XCIENT Fuel Cell Tractors manufactured for this project. **Figure 3** depicts two XCIENTs at the True Zero hydrogen fueling station.

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[14] A "6×2" or six-by-two is a vehicle with three axles, with a drivetrain delivering power to wheels at the end of one of the axles. A "6×4" or six-by-four is a vehicle with three axles, with a drivetrain delivering power to wheels at the end of the two rear axles.

Table 1: Hyundai XCIENT Fuel Cell Tractor Specifications

Specification	Description
Fuel Cell System	2 fuel cell power units for a total of 170 kilowatts (kW) of net power output
Battery Pack	72 kilowatt-hours (kWh)
Vehicle Range	Up to 450 miles (target, depending on duty cycle)
Onboard H2 Storage	70 kg overall system (68.6 kg usable hydrogen)
Hydrogen Tank Pressure	700 bar (10,000 psi)
Motor Type	Single, centrally mounted
Motor Power (max/continuous)	350 kW
Curb Weight	28,400 lb

Source: Hyundai

Figure 3: XCIENT Fuel Cell Tractors

Source: Tyler Jacobsen

Once Hyundai collected sufficient data to define vehicle specifications, Hyundai produced a Master Truck to serve as a blueprint for subsequent manufacturing of the 30 trucks included in the scope of this project. Hyundai also provided CARB and CEC with a Vehicle Production Plan in April 2022, which included details such as the expected timeline for vehicle build, validation, and delivery, customer acceptance requirements, and vehicle warranty and service expectations. After the vehicles were deployed into commercial operation with the fleet operator, each vehicle was backed by a bumper-to-bumper warranty that lasts six years or 300,000 miles, whichever comes first. As of the writing of this report, no vehicles in the fleet have reached the 300,000-mile threshold.

In October 2022, CTE and Papé attended a trip to Korea to review the truck design and build progress. The team visited Hyundai's Research and Development Center to review vehicle validation procedures, Dangjin integrated steelworks (Hyundai Steel's mill supplying vehicle steel), the new-vehicle manufacturing facility, and Hyundai's workforce training center.

During the first quarter of 2023, Hyundai completed production of all 30 trucks according to the master schedule without delay and began preparing them for shipment to the United States. Hyundai shipped the first 10 trucks in April 2023. Hyundai Translead was the import cosigner, and Glovis America was responsible for import logistics. The trucks arrived at the Port of San Francisco after clearing customs in May 2023. Papé picked up the 10 trucks from the Port and relocated them to Papé's San Leandro facility, where Papé then completed post-delivery inspections. In June 2023, the trucks were used during driver and technician training.

Macquarie was initially selected as the project's gap funding financier. As a novel technology with limited data regarding vehicle residual values, the XCIENT Fuel Cell Tractors are costlier to insure than traditional diesel trucks. Glovis and Macquarie participated in extensive negotiations, however, Macquarie was unwilling to lease the XCIENT Fuel Cell Tractors to Glovis without cost-prohibitive insurance covering physical damages. As a result, Glovis elected to replace Macquarie with Hyundai Capital as the gap funding financier to secure more favorable leasing terms and executed a lease agreement with Hyundai Capital for the first 10 units in July of 2023. Glovis satisfied all other state and federal insurance requirements for commercial operations but elected not to purchase insurance for physical damages.

By July 2023, Papé had the first 10 vehicles registered with the California Department of Motor Vehicles, and the vehicles began operating out of the Port of Oakland. Hyundai waited to ship the remaining 20 vehicles until August 2023 to allow additional time for FirstElement Fuel to complete construction and commissioning on the permanent hydrogen refueling station. Once all 30 vehicles entered commercial operations, this task was considered complete.

Lessons Learned

Due to their novel nature, heavy-duty zero-emission vehicles are currently significantly more costly to insure than internal combustion engine vehicles, increasing the financial burden on both fleet operator lessees and vehicle owner lessors. Flexibility in insurance requirements and partners with significant capital resources and willingness to invest in the success of zero-emission technology were critical to resolving challenges associated with the high cost of physical damage insurance. Several regulatory steps have been or are being taken to address the high cost of insurance for zero-emission vehicles (ZEVs). Assembly Bill 844 (Gibson), which was approved by the Governor in October 2023, directed CARB to collect and publish data regarding the availability of insurance for ZEV heavy-duty truck fleets.[15] CARB is additionally considering creating a used truck voucher program to support the collection of ZEV residual value data at scale.

Due to grant payment timelines, there was a multi-month gap between vehicle production and the receipt of funds. This led to vehicle production costs being financed and interest accumulating, contributing to unanticipated project costs. Future project managers should account for the possible impacts of extended invoicing processes on project budgets and payment schedules.

[15] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202320240AB844

CHAPTER 4: Hydrogen Station Development

Objectives

The primary objective of this task was to develop, construct, and commission a heavy-duty hydrogen refueling station on property owned by East Bay Municipal Utility District (EBMUD) to be used by the Hyundai XCIENT Fuel Cell Tractors while in commercial service operations. To support 30 Class 8 trucks, it was essential that the fueling station provide high-throughput, high-capacity, back-to-back fueling. FirstElement Fuel and the project team collaborated to establish a Hydrogen Safety Plan, ensuring that hydrogen safety was incorporated into project planning and execution and that procedures were established to safely operate hydrogen technologies.

Activities

In the third quarter of 2021, FirstElement Fuel signed a lease agreement with EBMUD to locate the planned heavy-duty refueling station at 2450 Engineer Road in Oakland, CA, kickstarting development activities including design and permitting. The land, as leased, housed military buildings.

Many development activities occurred in parallel. The station was fully opened to the public on August 30, 2024, taking approximately three years to complete from lease agreement signing to the full public opening. **Table 2** provides a high-level overview of the time to complete each major development step:

Table 2: Development Timeline Overview

Phase	Start Date	End Date
Engineering Design	October 2021	March 2023
Permitting	November 2021	August 2024
Procurement	January 2022	September 2023
Demolition	June 2022	September 2022
Construction	May 2023	May 2024
Commissioning	December 2023	August 2024

Source: CTE

Engineering Design

Engineering design work began in October 2021 and concluded in March 2023. **Table 3** provides an overview of key station components.

Table 3: FirstElement Fuel Station Components

Component	Description
Liquid Hydrogen Storage	16,500 gallon vertically mounted tank that cools and stores up to 4,430 kilograms of liquid hydrogen
Three Booster Pumps	Pressurizes liquid hydrogen from the primary storage tank at a rate of 6.16 cubic meters per hour
Three High-Pressure Reciprocating Pumps	Support a 250 kilogram per hour flow rate
Thermal Management System	Contains three heat exchangers, one for each pump. The station's brine system harnesses the extreme cold of liquid hydrogen and boil-off gas to manage fill temperatures, outputting gas at -40° Celsius
Gaseous Hydrogen Storage	Stores 243.6 kilograms of gaseous hydrogen at varying pressures in multiple tanks
Heavy-duty Dispensers	Two dispensers with two fueling nozzles each. Can supports up to 200 truck fills per day (60 kg fills)[16]
Boil-Off Gas Compressor	Pressurizes and moves gas produced by liquid tank boil-off into gaseous hydrogen storage to reduce fuel losses
Safety System	Includes hydrogen gas and flame detection as well as an emergency shutdown system

Source: FirstElement Fuel

Permitting

The project team took a proactive approach in coordinating with local authorities having jurisdiction and utilities regarding station development. By November of 2021, I&D Consulting Services, FirstElement Fuel's entitlements and permitting consultant, had notified PG&E of planned power upgrades at the station and informed the Oakland Fire Department of the project. In January 2022, I&D Consulting Services conducted initial meetings with the Oakland Fire Department and the City of Oakland regarding permitting.

Regulatory requirements and permits included:

- Entitlements
- Demolition Permit
- Pothole Permit
- Mechanical Permit
- Electrical Permit
- Utility Excavation Permit

[16] After the station has been upgraded with the FirstElement Fuel/Bosch Rexroth next-generation pump.

- Power Purchase Agreement
- Encroachment Permit
- Grading Permit
- Building and Fire Permit
- Boring Permit
- Hydrogen Safety Plan Review
- Hazardous Materials Business Plan
- Mobile Refueler Permit
- Asbestos Abatement Permit
- Risk Management Plan
- Planning/Zoning Permit

Permitting proved to be a major challenge throughout the duration of station development, beginning with obtaining land entitlements. The Alameda County Department of Environmental Health, acting as the County's Certified Unified Program Agency, originally claimed jurisdiction over entitlements for the site because of the Department's understanding of the Occupational Safety and Health Administration's General Duty Clause. The project team eventually determined that since the amount of onsite hydrogen storage will not exceed 10,000 pounds, the Alameda County Department of Environmental Health had no jurisdictional oversight of the station build. To resolve this issue, CTE engaged several regulatory stakeholders including CalEPA, which required several months of review. By March 2022—three months later than originally anticipated—FirstElement Fuel's entitlements were approved by both the City of Oakland and the Port of Oakland.

By April 2022, the station building plans were submitted to the City of Oakland and the utility excavation permit was issued. The project team also submitted updated utility excavation plans to EBMUD. FirstElement Fuel received the demolition permit, began asbestos abatement, and initiated an amendment to the lease agreement with EBMUD to include the area for conduit trenching necessary to bring power to the station. Asbestos abatement was completed in May 2022 along with the biological survey conducted in compliance with EBMUD's California Environmental Quality Act Environmental Impact Report, allowing FirstElement Fuel to proceed with demolition. By September 2022, demolition was completed at the station site.

In June 2022, the first building permit was submitted to the City of Oakland, the Offsite Consequence Analysis and Process Hazard Analysis were completed, and the PG&E power design was finalized. FirstElement Fuel also led the Infrastructure Development 50% Completion Progress Review attended by CARB, CEC, CTE, EBMUD, and I&D Consulting Services. The progress review included an overview of station specifications, utility connections, the station site plan, permitting status, timeline, and fueling protocols. The planning/zoning permit was submitted to the City of Oakland the following month.

In August 2022, FirstElement Fuel discovered unexpected piers on the site that required additional excavations. This led to additional onsite work as well as delays due to approvals from the Department of Toxic Substances Control. Grading and utility trenching plans were approved by the Department of Toxic Substances Control, and FirstElement Fuel identified the need to hire a contractor to create a plan for removing train tracks from the station site. FirstElement Fuel additionally submitted the Hydrogen Safety Plan to the Hydrogen Safety Panel, which detailed the station design, applicable codes and standards, internal safety protocols, and risk mitigation strategies.

During November 2022, FirstElement Fuel and EBMUD submitted grading and paving permits to the Department of Toxic Substances Control and FirstElement Fuel's safety plans were presented to EBMUD leadership. That month, FirstElement Fuel notified CTE of a cash flow problem that caused a stop work order from FirstElement Fuel executives. The project team worked to streamline payment processes, and the order was eventually lifted.

By the end of 2022, it became apparent to the project team that the permanent station might be delayed beyond expected arrival of the trucks. To mitigate delays, FirstElement Fuel identified temporary fueling solutions to fuel vehicles prior to the start of commissioning. See **CHAPTER 10: Hydrogen Station Operation** for more information regarding the mobile refueler.

In December 2022, FirstElement Fuel and its subcontractor were able to drastically reduce the projected year-long onsite transformer lead time by switching from a pole-mounted transformer to pad-mounted transformer. FirstElement Fuel worked to secure a change order for the modification the following month and began work to replace the transformer in March 2023. That month, FirstElement Fuel worked with the City of Oakland and the Oakland Bulk and Oversized Terminal to secure an easement allowing PG&E to bring power to the lease site.

The dispensers and two pumps were shipped to FirstElement Fuel's Santa Ana warehouse in March while two additional pumps underwent factory acceptance testing. The liquid hydrogen tank and pressure vessels were completed by May 2023.

During the second quarter of 2023, FirstElement Fuel's subcontractor received approval for and completed most grading work at the station site. FirstElement Fuel also began drilling under Engineer Road to complete the offsite utility trenching necessary for PG&E to pull its conductors from a nearby substation to the project site.

A global microchip shortage and other unanticipated supply chain disruptions contributed to extended lead times for many station components. Due to delays associated with FirstElement Fuel's motor control center (the controller that operates the station) resulting from these disruptions, FirstElement Fuel elected to manufacture its own motor control center. The FirstElement Fuel motor control center passed multiple third-party inspections spanning from July to September 2023, and FirstElement Fuel began welding and pressure testing vacuum jacketed piping in November 2023. FirstElement Fuel conducted its first hydrogen offload and purity tests in December 2023, and Glovis was subsequently able to fuel the vehicles using gaseous buffer storage at the permanent station.

By January 2024, FirstElement Fuel received local approvals for adjustments to its Stormwater Management Plan and conducted an excavation to locate and remove unnecessary sewer laterals, which was completed in February. FirstElement Fuel installed multiple onsite manholes and completed the station bioswale in March of 2024. FirstElement Fuel also worked with its component manufacturer to commission the station pumps, conducting test fills multiple days a week. The station passed final fire and electrical inspections in April, and paving and grading were completed at the site throughout March and April. FirstElement Fuel and EBMUD identified the need for modifications to the station's curb design in May.

FirstElement Fuel subsequently completed commissioning for both heavy-duty and light-duty dispensing at the station, and CTE delivered the notification of hydrogen station commissioning to CARB and CEC in July of 2024. Following commissioning, FirstElement Fuel opened the light-duty dispensers to the public and offered heavy-duty fueling by appointment while continuing to work to automate the heavy-duty system and complete additional civil work for the curb and gutter throughout July, which delayed the final inspection by the City of Oakland. Final grading and planning/zoning permits were approved after the completion of curb and gutter work.

After successfully automating the station, FirstElement Fuel opened the heavy-duty station for 24/7 public heavy-duty fueling in August of 2024. The station has two heavy-duty and four light-duty fueling positions, supporting the refueling of passenger cars, gaseous hydrogen tube trailers, and multiple heavy-duty truck models, including the 30 XCIENT Fuel Cell Tractor. **Figure 4** depicts the station.

Figure 4: West Oakland True Zero Station

Source: Tyler Jacobsen

Lessons Learned

The hydrogen station developed for the NorCAL ZERO Project is the first-of-its kind in its ability to serve large quantities of heavy-duty vehicles. To ensure success, FirstElement Fuel designed and developed the station with numerous redundancies, including three sets of liquid hydrogen pumps. The station also serves as a test-site to gain valuable experience operating new equipment. This includes installing a boil-off gas compressor, retrofitting the liquid hydrogen tank inlets to accept Air Liquide's novel Advanced Delivery System, and in the future will be retrofit to deploy and test Bosch Rexroth's new CryoPump. The cost of station development far exceeded the funding provided by the grant, requiring FirstElement Fuel to invest significant funds beyond required match funding in order to make the project a success.

Stakeholders must also dedicate significant resources towards navigating local regulations and permitting processes in California. Due to the novelty of many hydrogen technologies, organizations developing associated infrastructure should engage in education and awareness-building with permitting agencies to ensure that these agencies are aware of recent updates to codes and standards, such as NFPA 2, that are unique to hydrogen projects. Early engagement with local officials, public agencies, and impacted stakeholders is beneficial to the project development process and minimizes delays during project implementation.

Changes during construction, including revisions to curbing requirements along the station lot lines, contributed to significant project cost overruns and delays. Alignment and understanding between infrastructure OEMs and land partners will be critical to the success of future CARB and CEC-funded hydrogen fueling projects. When possible, project stakeholders should seek to partner with organizations that have existing experience with hydrogen technology and/or fueling logistics due to their responsiveness to project needs.

To mitigate supply chain disruptions and keep projects on schedule, project stakeholders should account for extended lead times when purchasing parts and engage in supplier oversight to ensure that components adhere to the quality standards of the project. In the case of NorCAL ZERO, FirstElement Fuel was able to reduce lead times by manufacturing certain critical components, such as the motor control center, in-house. Not every project developer will have resources necessary to manufacture critical subsystems in-house to reduce lead times.

Finally, there is a shortage of highly skilled welders capable of repairing or reworking on vacuum-jacketed piping in the State of California. Future projects should ensure they have adequate skilled labor on-call in case a highly technical repair is needed.

CHAPTER 5: Maintenance Facility Upgrades

Objectives

The primary objective of this task was to bring Papé's San Leandro maintenance facility into compliance for hydrogen vehicle service and operation. The maintenance facility formerly belonged to NorCal Kenworth but became the property of Papé following NorCal Kenworth's acquisition by Papé, after which Papé became the maintenance partner for the project.

Activities

Engineering and design efforts for upgrades to Papé's maintenance facilities were led by Fiedler Group. The Maintenance Facility Upgrades Subteam had its first meeting in November of 2021, which was attended by Fiedler Group, NorCal Kenworth, the building subcontractor, the architect, and CTE. Major activities included third-party assessment and planning as well as upgrades to existing monitoring and alarm systems, ventilation, and electrical equipment.

Fiedler Group met with NorCal Kenworth's building contractor virtually during November 2021 and issued the draft Preliminary Facilities Assessment Report to CTE in December of 2021, which included electrical load and ventilation analyses and a cost estimate which was above the project budget. Fiedler Group reviewed the scope to identify potential cost savings and identified that bay doors were not necessary to achieve hydrogen compliance for the facility, but a firewall, hydrogen detection system, and passive gravity ventilation were still necessary to meet building code and operational requirements. In February of 2022, Fiedler Group shared a new estimate for hydrogen detection and ventilation equipment and revised the Facilities Assessment Report accordingly.

Following the completion of planning activities, NorCal Kenworth's building contractor began work at the maintenance facility. The installation of a firewall was completed by October of 2022 and Fiedler Group submitted a permitting package for hydrogen detection and ventilation systems to the City of San Leandro.

In December 2022, Papé purchased the San Leandro building and other NorCal Kenworth assets, and the original contract was amended to reallocate project funds originally allocated to NorCal Kenworth to Papé instead. In January 2023, Papé discovered that the planned gas detection system had been placed on a production hold and worked with Fiedler Group to determine an alternative gas detection system, receiving approval from the City of San Leandro to use the alternative system that month.

Final maintenance facility upgrades were completed by May 2023. Initial inspections were conducted in June, after which the project team made slight modifications to the onsite detection systems and met with the San Leandro Environmental Health Department for additional approvals. The compliance of completed facility upgrades was verified in August 2023.

Lessons Learned

The project team highly recommends engaging with local authorities having jurisdiction prior to beginning engineering and design work for hydrogen infrastructure projects. Doing so helps teams to identify challenges early on and establish strong working relationships with individuals responsible for code enforcement.

The project team recommends working with an architecture and engineering firm experienced with hydrogen facility retrofits and code compliance. Fiedler Group's extensive experience allowed the team to identify ways to reduce costs while complying with applicable codes and standards.

CHAPTER 6: Community Outreach

Objectives

Conduct public outreach regarding the benefits of the NorCAL ZERO project, including emissions reductions, local economic benefits, and commercial goals.

Activities

Community outreach activities for the NorCAL ZERO project consisted of a joint effort between the Center for Transportation and the Environment (CTE), West Oakland Environmental Indicators Project (WOEIP), and the University of California, Berkeley's Transportation Sustainability Research Center and Goldman School of Public Policy to provide educational resources to members of the public regarding hydrogen fuel cell technologies.

The Community Outreach Subteam identified two target groups for the outreach program: the West Oakland community and truck drivers that operate out of the Port of Oakland. The team aspired to shed light on both the benefits and challenges of zero-emission technology. Benefits discussed included reduced greenhouse gas and criteria air pollutant emissions, improved vehicle efficiencies, local workforce benefits, and reduced noise and vibrations in the vehicle cabin. Challenges discussed included high costs, fuel supply reliability, fuel leakage, and limitations in payload capacity and range for first generation vehicles. The team also worked to address community safety concerns and common hydrogen misperceptions—many perceive hydrogen to be less safe than conventional fossil fuels because of lack of education on hydrogen and incidents such as the Hindenburg Airship Disaster.

The first task for the Community Outreach Subteam was to develop a Community Outreach and Engagement Plan. This plan included outreach materials describing the project and its technology benefits, pathways to engage with WOEIP to disseminate outreach materials to local community groups and leaders, and a schedule for outreach and engagement activities. Outreach materials included the Project Fact Sheet, which summarizes the NorCAL ZERO project's goals, accomplishments, team members, and funding sources; a one-pager describing CARB's Advanced Clean Fleets Regulation; and a slide deck describing the project, explaining fuel cell technology, and debunking common misconceptions regarding hydrogen.

The Outreach Subteam also continuously engaged with local elected officials to raise awareness of and support for zero emission technologies. The project team began outreach activities in August 2021 by coordinating interviews with key project stakeholders for use in Hyundai's "Road to Zero Emissions"[17] promotional video for the XCIENT Fuel Cell Tractor. Stakeholders interviewed included:

- Liane Randolph - Chair, CARB
- Patty Monahan - Commissioner, CEC
- Rebecca Kaplan - Vice Mayor, Oakland
- Nancy Skinner - California State Senator, District 9

[17] https://www.youtube.com/watch?v=IdJOzRRZgXo

- Jack Broadbent - Chair, Bay Area Air Quality Management District
- Pauline Cutter - Chair, Alameda County Transportation Commission
- John Bauters - Vice Chair, Alameda County Transportation Commission

The project team began attending and hosting events to promote the project, including the following:

- **East Bay Innovation Awards Block Party**: CTE, Hyundai, Port of Oakland, and WOEIP representatives attended on June 16, 2022. The project team brought a truck to the event to engage with officials and community members.
- **Port of Oakland Technical Working Group**:
  - CTE presented on August 2, 2022.
  - CTE presented on April 11, 2023.
- **Port of Oakland Truckers Working Group**:
  - CTE and Glovis attended on January 30, 2023, discussing gate operations and land leasing with industry stakeholders.
  - CTE presented on May 15, 2023.
  - WOEIP presented regarding the project and hydrogen as a fuel source on March 18, 2024. Glovis supported the event with an XCIENT Fuel Cell Tractor.
- **WOEIP Town Hall Meeting:** CTE and Glovis attended on December 6, 2023. Two GET Freight drivers and a truck were present to engage with the public, and an informational table was available for community members to ask questions about the project.
- **Zero Emissions Oakland Symposium Driving Innovation:** CTE, WOEIP, and Glovis attended the Zero Emissions Oakland Symposium Driving Innovation on February 7, 2024. CTE presented and Glovis supported the event with an XCIENT Fuel Cell Tractor.
- **Georgia Delegation:** CTE hosted officials from the state of Georgia at the station on February 27, 2024.
- **Unity Council:** CTE, WOEIP, and UC Berkeley visited the Unity Council on March 19, 2024 to discuss potential collaboration opportunities.
- **WBUR Interviews:** A WBUR *Here & Now* reporter conducted interviews with CTE, WOEIP, and UC Berkeley representatives for the "Battery-powered Big Rigs Could Haul the Future of Trucking"[18] podcast on March 27, 2024. FirstElement Fuel leaders were also interviewed regarding hydrogen fueling technology. WBUR is Boston's National Public Radio station.
- **ARCHES launch celebration**: Attended by Governor Gavin Newsom, Under Secretary of Infrastructure David Crane and Senator Alex Padilla (D-Calif.) and featured a tour of the hydrogen NorCAL ZERO refueling station. CTE, Hyundai, FirstElement Fuel, amongst others attended on August 30, 2024.
- **CALSTART's Zero-Emissions Showcase and Ride & Drive**: CTE attended on

[18] https://www.wbur.org/hereandnow/2024/04/21/trucking-electric-hydrogen

August 14, 2024.

- **Harbor Trucking Association Zero Emission Ride & Drive:** CTE, Glovis, and GET Freight coordinated the presence of a Hyundai truck and driver on September 20, 2024.
- **Government of India Station Visit**: CTE and FirstElement Fuel hosted a delegation of senior officials from India's Ministry of Road Transport and Highways, Ministry of Power, and Bureau of Energy Efficiency at the station on December 3, 2024, in partnership with the United States Department of State, CARB, and UC Davis. Glovis and GET Freight provided truck and driver support for the visit.
- **Chamber of Commerce and Industry Elbe-Weser Station Visit**: CTE and FirstElement Fuel hosted a delegation of German professionals investing in renewable energy technologies at the FirstElement Fuel station with truck and driver support from Glovis and GET Freight on January 24, 2025
- *What does hydrogen mean for West Oakland?* **Webinar:** CTE and WOEIP co-hosted a webinar on May 28, 2025 to provide the local community with a live forum to learn about the project and ask questions of various project experts. The panel included CTE, WOEIP, a driver from GET Freight, a master technician from Papé, a local fleet operator, and an industry analyst.

Project Dedication

CTE hosted a project dedication event at the FirstElement Fuel station on May 2, 2024. The event, depicted in **Figure 5**, hosted over 100 attendees, comprising NorCal ZERO partners, sponsors, local elected officials, media representatives, and affiliates. The event featured both a station tour and a fueling demonstration, allowing attendees to explore the facility's infrastructure. WOEIP advertised the event to community members through its newsletter.

Speakers included:

- Rebecca Kaplan – Councilmember at Large, City of Oakland
- Jim Park – Senior Vice President, Commercial Vehicle and Hydrogen Business Development, Hyundai Motor North America
- Dr. Matt Miyasato – Chief Public Policy & Programs Officer, FirstElement Fuel
- Jorden Papé – President and CEO, Papé
- Liane Randolph – Chair, CARB
- Patty Monahan – Commissioner, CEC
- John Bauters – Councilmember, City of Emeryville & Chair, Alameda County Transportation Commission
- Dr. Philip Fine – Executive Officer, Bay Area Air Quality Management District
- Tyson Eckerle – Senior Advisor for Clean Infrastructure and Mobility, Governor's Office of Business and Economic Development
- Danny Wan – Executive Director, Port of Oakland
- Doug Linney – Board Director, EBMUD
- Brian Beveridge – Co-Executive Director, WOEIP
- Dan Raudebaugh – Executive Director, CTE

Figure 5: NorCAL ZERO Dedication

Source: Tyler Jacobsen

West Oakland Community Feedback

Outreach activities provided the project team with a better understanding of community concerns regarding hydrogen technologies. Residents were most concerned about the emissions associated with hydrogen production and the impact of these emissions on local populations. Most hydrogen produced today is made via steam methane reforming, and the NorCAL ZERO project purchases environmental attributes to offset emissions resulting from its fuel production. Community members understood the need for vehicle deployments to generate demand for hydrogen produced using renewable electricity over time. However, community members were concerned about the possibility of an extended period during which hydrogen fueled technology develops and zero-emission hydrogen production does not, contributing to a heightened demand for hydrogen produced using natural gas. Community members also raised the possibility of an increase in costs for consumer goods due to increased costs associated with zero-emission transportation before technologies reach economies of scale.

Outreach activities also provided the project team with insights into the aspects of hydrogen technology that community members are excited about. Members of the West Oakland community were generally very favorable towards fuel cell technology, the reductions in noise pollution associated with operating zero-emission vehicles as opposed to internal combustion engine vehicles, and elimination of criteria air pollutants within the West Oakland neighborhood.

Trucking Community Feedback

Outreach activities also provided the project team with the opportunity to engage extensively with local truckers. In particular, the project team hosted and attended multiple events which allowed truckers the opportunity to ride and drive the XCIENT Fuel Cell Tractor, giving them firsthand experience with zero-emissions vehicles.

Members of the University of California, Berkeley's Goldman School of Public Policy surveyed 11 drivers employed by GET Freight in May 2024. Driver sentiment toward the project vehicles was overwhelmingly positive, with most drivers surveyed ranking the XCIENT Fuel Cell Tractor's lack of exhausts, ride quality, dashboard, and quietness of the vehicles as excellent. Drivers also positively ranked the vehicles' vibration harshness, reliability, handling, and associated training conducted by Hyundai.

Drivers ranked the vehicles less favorably for ease of access and identified the occasional need to recharge onboard batteries when traversing steep, prolonged grades. Results from the survey additionally suggested that drivers may be more familiar with conventional bonneted or long nose trucks rather than cab-over-engine vehicles like the XCIENT Fuel Cell Tractor. Long nose trucks house their engines in front of the cab, whereas cab-over-engine trucks house their engines (or, in this case, onboard fuel cell systems) beneath the cab. This means that operators are seated closer to the front of the vehicle when driving a cab-over-engine vehicle.

Lessons Learned

There is significant industry interest in community outreach regarding hydrogen as a fuel for zero-emission vehicles. As a result, the project team attended many events, but did not host as many events as was originally anticipated. The project team found attending third-party events to be an effective strategy because it allowed the project team to capitalize on existing networks and marketing resources and recommends that future project managers emphasize third-party events in their outreach. The project team found Ride and Drive events to be a particularly effective form of trucker engagement and recommends bringing vehicles to as many events as possible to allow truckers to become familiar with zero-emission technologies.

The project team hosted a successful dedication event bringing community members including West Oakland residents, truckers, project partners, academics, elected officials, and grantors together to celebrate and learn from the project. This event was not included in the scope of work and was a CTE-led initiative made possible through the generous sponsorship of project partners. The project team recommends planning for similar events for future projects to allow teams to engage with elected officials and celebrate successes in a challenging industry.

Regulatory stakeholders such as local fire departments were not specifically identified within the community outreach task for this project but were engaged in development and training activities and remain key partners critical to the success of zero-emission infrastructure projects. The project team recommends investing in engagement with permitting stakeholders and first responders regarding zero-emission technology as a critical step towards widespread adoption.

CHAPTER 7: Zero Emission Vehicle (ZEV) Workforce Plan and Training

Objectives

The primary objective of this task was to develop and implement a Zero-Emission Workforce Training and Development Plan.

Activities

The Workforce Training Development Subteam consisted of CTE, Glovis, Hyundai, and NorCal Kenworth/Papé. The first task for this subteam was to develop a ZEV Workforce Plan for curricula development and training of maintenance and operations staff for both the fuel cell vehicles and refueling process. Some training activities took place prior to the creation of the ZEV Workforce Plan. In June 2022, NorCal Kenworth hosted a truck at NorCal Kenworth Zero-Emissions Day, during which HATCI staff conducted an informal orientation with NorCal Kenworth technicians. **Table 4** provides an overview of key dates relating to operator and maintenance trainings.

Table 4: Training Timeline

Month	Milestone
June 2023	Initial maintenance, service, and driver training
July 2023	Initial 10 trucks enter service
September 2023	Additional 20 trucks enter service
October 2023	Additional driver training
February 2024	Fuel cell diagnostic training
April 2024	Fueling training

Source: CTE

Training responsibilities were shared by Hyundai, HATCI, and FirstElement Fuel. Hyundai led the development of training materials associated with the operations and maintenance of the XCIENT Fuel Cell Tractors. Maintenance training for Papé was provided by Hyundai's Global Channel Training Team, with technicians receiving four full days of maintenance and service training beginning in June 2023. Papé technicians and Glovis drivers both received driver training during the same month. Glovis trained additional operators using a train-the-trainer program in which experienced drivers provided training to newly hired drivers. HATCI conducted additional training with Glovis drivers in October 2023.

During the initial deployment in the summer of 2023, Hyundai assigned a member of its service and support team to work at Papé's facility to support vehicle repairs and conduct follow-up training as needed. Hyundai led training on advanced fuel cell theory and diagnosis training, including both classroom and hands-on components, with eight technicians at Papé's facilities in San Leandro in February 2024. Hyundai provided additional in-person service support during the spring of 2024.

FirstElement Fuel led training sessions associated with hydrogen refueling and emergency response for the refueling station. In April 2024, FirstElement Fuel provided Glovis with fueling cards and spent two weeks conducting refueling training with Glovis' operators. The training included instructions on how to use the fueling cards and dispensers.

FirstElement Fuel additionally conducted various first responder training with the Oakland Fire Department and East Bay Municipal Utility District (EBMUD), pictured in **Figure 6.** The training took place over several days between late April and early May and consisted of an orientation to the fueling station components, review of emergency response procedures, review of normal and abnormal station sounds, and a joint drill with FirstElement Fuel, the Oakland Fire Department, and EBMUD.

Figure 6: Oakland Fire Department Training with XCIENT Fuel Cell Tractors

Source: CTE

The ZEV Workforce Findings and Recommendations Report created by the project team provided additional details regarding the project's training approach and evaluated the training program as detailed in the ZEV Workforce Plan.

Driver and Technician Training Surveys

CTE administered driver and technician surveys following initial training activities during the summer of 2023 to gauge participant comfort with FCET technology. Responses suggest that the training was overwhelmingly successful. 100 percent of drivers surveyed indicated that they were very or extremely comfortable operating the XCIENT Fuel Cell Tractor, and more than 80 percent of Papé technicians indicated that they felt extremely comfortable conducting maintenance on the vehicles.

Job Creation

CTE and project partners reported job creation over the course of the project through the California Climate Investments Reporting and Tracking System. The majority of jobs created by

NorCAL ZERO were linked to Glovis and GET Freight. Two administrative employees were hired to manage the fleet and deployment alongside the 30 drivers hired to operate the vehicles, including some drivers who operated specialized car hauler trailers through Extreme. FirstElement Fuel hired 10 additional personnel to support station development. UC Berkeley hired at least one staff member involved in data collection and reporting. CTE hired two staff members to support project management efforts. In total this project directly contributed to the development of at least 45 partial jobs within the State of California.

Lessons Learned

Papé indicated the most significant maintenance and support challenge was working with the truck's diagnostic software. Papé and Hyundai are working to make the software more user-friendly for this and future deployments. In some circumstances, Papé also had to use spare components to isolate and troubleshoot component faults. Future projects may consider budgeting for a set of test components that can be stored onsite and used for diagnostic purposes as needed. The project team additionally recommends including printed materials for drivers to keep in their vehicles as part of future training activities for zero-emission fleets.

When leading projects with international stakeholders, project managers should consider the possible impacts that time differences may have on operational needs. Sometimes Papé would staff FCET technicians during the evenings due to the discrepancy in time zones with Korea-based Hyundai maintenance and support staff, allowing for improved collaboration. Hyundai also staffed training personnel at Papé's facilities to enhance communication and complete ad-hoc training. Hyundai has established maintenance and service functions at its United States regional headquarters in Fountain Valley, California, which provides active maintenance training and diagnostic support to Papé.

Without sufficient fueling to support a full fleet due to delays to the station build schedule, Glovis was unable to provide continuous work for the 30 XCIENT drivers that Glovis had initially hired to operate the vehicles. This led Glovis to incur loss of business opportunities as well as additional costs to rehire and retrain staff. Careful timing of infrastructure and vehicle operations is critical to ensuring the success of ZEV workforce activities and stable employment for ZEV operators.

Although operating car hauler trailers was outside the scope of the project's ZEV-specific workforce development activities, future projects may wish to consider investing in training that can allow FCETs to be utilized in more niche applications, such as hauling light-duty vehicles, for which the project team observed significant demand.

CHAPTER 8: Vehicle Deployment Planning

Objectives

The primary objective of this task was to prepare for the safe and successful operation of the Hyundai XCIENT Fuel Cell Tractors and hydrogen refueling infrastructure.

Activities

Key vehicle deployment planning activities included developing a Vehicle Operating Manual, preparing for maintenance and support of the vehicles and infrastructure by developing a Maintenance and Support Plan, conducting training for operations and maintenance personnel (described in ZEV Workforce Plan and Training), and notifying local first responders of hydrogen operations. The team also spent considerable effort establishing yard storage space for tractors, trailers, and containers, seeking priority access to terminals, and supporting Glovis in its customer base development.

The Vehicle Operating Manual was created by Hyundai, and the Maintenance and Support Plan was developed in collaboration between CTE, Glovis, Hyundai, and Papé. The Maintenance and Support plan included processes for reporting issues with vehicles and refueling infrastructure, assignment of maintenance and support responsibilities, communication procedures between members of the project team, emergency events and procedures, and a preventative maintenance schedule for vehicle and infrastructure components.

As part of the vehicle deployment planning process, Hyundai signed a service and maintenance contract with Papé to serve as the service provider for the NorCAL ZERO project. Papé provides both regular and unscheduled maintenance for the vehicle fleet. Warranty service was provided by Hyundai through Papé. Glovis is responsible for all service and maintenance costs that do not qualify under the warranty agreement. This includes service work such as routine preventative maintenance (e.g. regularly scheduled changes of coolant). The NorCAL ZERO project funds approximately two years of non-warranty service and maintenance work, after which Glovis is responsible for service and maintenance costs.

Glovis was responsible for hiring drivers to operate the XCIENT Fuel Cell Tractors as well as identifying customers for its services. CTE assisted Glovis in connecting with potential drivers during the first months of the project.

Customer Base Development

Glovis, Hyundai, Macquarie, and CTE met regularly as the Customer Base Development Subteam throughout the first year of the project. GET Freight was not established at the Port with existing Oakland customers before this project, which added complexity to the process of obtaining customers for a zero-emission fleet with unique operational constraints. Customer base development efforts were led by Glovis.

To support Glovis, CTE helped create a certificate of acknowledgement for customers and FirstElement Fuel provided carbon intensity information to Glovis in support of customer development. By December 2021, Glovis had signed a memorandum of understanding with its first customer, however, delays in determining the cost of insurance, parking, availability of parts, and leasing costs posed a challenge to Glovis' customer development throughout the project.

To respond to market demands and recruit additional customers, five of the XCIENT Fuel Cell Trucks were retrofitted to carry car hauler trailers for operation by Glovis' subsidiary Extreme. This allowed for more varied cargo options and helped attract additional customers for these vehicles.

Parking

Securing parking was a significant challenge for the project team. The Port of Oakland had and continues to have limited land availability and a long waitlist to secure container parking. The project team worked to secure parking space for the trucks, chassis (trailers), and containers near the Port for over a year to maximize the operating range of the vehicles. CTE worked to identify six possible yards and provided information regarding the yards' operating hours, availability, and whether yards could store a mobile fueler, tractors, chassis, and containers.

CTE and Glovis attended the Port of Oakland's Bimonthly Truckers Working Group in January 2023, where the project team discussed land leasing with industry stakeholders in support of Glovis' entry into the Port of Oakland market. By February 2023, Glovis had begun the process of negotiating a lease to collocate trucks, chassis, and containers, eventually signing a lease agreement for yard space on 189 Burma Road in July 2023. Having container parking close to the Port was critical in allowing Glovis to improve its operational efficiency by pulling containers out of the terminals at night.

Priority Access

Glovis worked throughout the project to secure priority gate access and minimize staff labor time lost to idling in port queues. During September 2022, CTE, Glovis, and Alameda County Transportation Commission met to discuss priority access for zero-emission trucks at the port to mitigate long wait times at the terminals and the gates. Glovis and CTE also met with the Port of Oakland in December of 2022 to discuss priority access. A "Green Lane" has already been implemented at the Port of Los Angeles by APM Terminals Pier 400, which allows zero-emission vehicles to bypass extended queues.[19] Glovis continues to pursue the possibility of a zero-emission priority lane, but there has been no resolution at the time of the writing of this report. Other local initiatives aim to address minimize idling and associated emissions by other means. Alameda County Transportation Commission's Freight Intelligent Transportation System project hopes to reduce congestion allowing drivers to monitor traffic at the Port of Oakland.[20]

[19] https://www.linkedin.com/posts/forum-mobility_forget-the-red-carpetelectric-trucks-get-activity-7321208288639885312-TK4s

[20] https://www.alamedactc.org/programs-projects/goport-program

Lessons Learned

Parking availability is a key factor in successful drayage operations planning. Glovis was not an established fleet operator at the Port of Oakland prior to the NorCAL ZERO project and the Port of Oakland is significantly space constrained, leading to challenges associated with securing parking. Future project teams should pay careful attention to container, chassis, and tractor parking availability when selecting locations for future zero-emission Class 8 truck deployments.

Having strong support from local port authorities is essential to the success of zero-emission drayage projects. The Port of Oakland was a key partner to the project team, providing a location to stage the temporary fueler and supporting Glovis in identifying parking and engaging with local stakeholders regarding issues such as priority access.

Timing infrastructure commissioning is critical to the success of zero-emission fleets. The hydrogen refueling station was completed later than anticipated during deployment planning, leading to the need to continue planning activities while operating some vehicles. The associated uncertainty surrounding the availability of fuel made it more challenging for Glovis to recruit customers. Deployment project schedules should seek to mitigate delays to vehicle operations by prioritizing the completion of critical fueling infrastructure prior to vehicle delivery, including accounting for delays in permitting and supply chain disruptions.

Total cost of ownership continues to challenge the commercial competitiveness of zero-emission trucks compared to internal combustion engine trucks. While zero-emission trucks offer significant environmental, noise, and vibration benefits, their initial purchase price, ongoing maintenance costs, and fuel expenses are higher than that of internal combustion engine trucks. These costs are expected to decrease as this technology becomes more widely adopted, but state and local investment remains crucial to incentivizing fleet operators and customers to use zero-emission vehicles in the interim.

Chapter 9: Vehicle Operation

Objectives

The primary objective of this task was to operate 30 fuel cell electric Class 8 trucks in revenue service for a period of at least 12 months during the grant term. The vehicles are expected to continue operating beyond the grant term for a total period of six years.

Activities

Vehicle operation was led by Glovis America through subsidiaries GET Freight and Extreme. This section provides a narrative overview of some key turning points for fleet operation, particularly in relation to vehicle fueling. More detailed information regarding the vehicles' duty cycles and service events throughout the project can be found in the data report contained within **APPENDIX A: Data Report.**

Due to delays in the development of the permanent station, the project team chose to postpone the full shipment of vehicles as discussed in **CHAPTER 3: Truck Design, Manufacturing, and Procurement**. Glovis begin operating 10 trucks using a mobile refueler provided by FirstElement Fuel in June of 2023.

By September of 2023, Glovis hauled approximately 40 loads per week, and began rotating the second batch of 20 trucks into routine service using FirstElement Fuel's temporary refueler while FirstElement Fuel continued to work on completing the permanent station. Glovis executed an agreement for additional container loads to be delivered by all 30 trucks during the third quarter of 2023 and began to slowly increase the number of orders received as Glovis' access to fueling improved over time.

CTE provided CARB with a notification of vehicle operations in October 2023 after all 30 vehicles had been received by Glovis. That month, Glovis' subsidiaries were able to fuel 6–12 trucks weekly with the mobile refueler, however, drivers sometimes waited up to 3 hours before fueling began due to troubleshooting between the trucks and refueler, which incurred unanticipated operator labor costs.

By January 2024, Glovis was rotating all 30 trucks in-and-out of service and fueling by appointment at the permanent station site using the gaseous buffer storage tubes and a tube trailer. At the time, the permanent station was able to support full fills for a small number of vehicles. In March 2024, Extreme began operating XCIENTs that had been retrofitted to haul light-duty cars using car hauler trailers. Throughout the second quarter of 2024, Glovis' subsidiaries delivered cargo to Oakland, Lathrop, Richmond, Tracy, Hayward, and Stockton.

Glovis was able to increase its vehicle utilization significantly following the full opening of the heavy-duty station in August 2024, which allowed Glovis' operators to fuel at any time without appointment. Fleet mileage increased following station commissioning, which also contributed to increased fuel consumption.

Vehicles spent significant time idling in port queues, a factor that contributes to increased fuel consumption and negatively impacts fuel economy without increasing vehicle mileage. Further information regarding fleet mileage and the relationship between idle time and fuel consumption per mile driven for the NorCAL ZERO fleet can be found in **APPENDIX A: Data Report.**

Beginning in the fourth quarter of 2024, FirstElement Fuel experienced periodic technical challenges that resulted in increased dwell and fill times and the closure of one heavy-duty dispenser. These technical complications at the station led GET Freight to pay for unexpected overtime and, in some cases, fill at FirstElement Fuel's Oakland Foothill station that was not designed for heavy-duty vehicles.[21] When these challenges occurred, FirstElement Fuel worked to resolve the issues quickly, but station downtime impacted Glovis' subsidiaries' ability to fuel and operate these vehicles.

Long-haul Testing

In November 2024, Extreme conducted a test of a long-haul trip from Oakland to Southern California using one of the XCIENT Fuel Cell Tractors. A diesel truck accompanied the fuel cell truck throughout its journey. The XCIENT drove from Oakland to Wilmington without a trailer attached and fueled at a public hydrogen station. The XCIENT was subsequently connected to a car hauler trailer that was loaded with vehicles in Long Beach. It then delivered the vehicles to San Diego, returned to the station in Wilmington, and continued to Oakland. The trailer was detached and transferred from the XCIENT to the diesel truck between Fort Tejon and Oxnard.

The XCIENT drove Interstate 5 over the Grapevine[22] in both directions. The XCIENT experienced no challenges without the trailer attached but was unable to complete the journey from Long Beach to Oakland with the trailer attached due to inclines along the route. When testing the prototype vehicles, HATCI was able to complete hauls from Northern California to Southern California. Variations in performance may be attributable to the vehicle operator's level of training. Long-haul testing is discussed in further detail in **APPENDIX A: Data Report**.

Lessons Learned

Fueling station availability had a significant impact on vehicle operations. Delays in the construction of the permanent station led Glovis to delay its receipt of 20 of the XCIENT Fuel Cell Tractors and incur additional costs associated with slower fuel times. Limited access to fueling made it difficult for Glovis to meet its operational mileage goal, contributing to decreased emissions reductions during the original project term. It is critical that fueling infrastructure is commissioned in advance of the deployment of fuel cell vehicles to ensure efficient operations.

Investment in hydrogen refueling networks is critical to the commercial viability of zero-emission drayage operations. Despite significant public investments in infrastructure development, heavy-duty hydrogen refueling stations are currently relatively scarce within California compared to their diesel counterparts, limiting the range of fuel cell vehicle deliveries.

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[21] https://h2stationmaps.com/content/oakland-foothill

[22] A section of Interstate 5 that runs through Tejon Pass and is notable for its steep grades.

Light-duty stations are more common but are designed to fill vehicles with significantly reduced onboard storage capacity. As a result, heavy-duty vehicles can quickly deplete available gaseous buffer storage at stations intended to serve light-duty vehicles. When more heavy-duty stations exist, zero-emission vehicles will be able to fuel more reliably along their routes, increasing their range and the number of locations that they can serve. This will increase their ability to compete commercially with diesel vehicles.

Other infrastructure considerations, including roadway weight limitations, can pose barriers to FCET operations. Because fuel cell trucks generally weigh more than traditional internal combustion engine trucks, fuel cell truck operators may be forced to invest additional time in selecting containers, carry less cargo than internal combustion engine competitors, and/or find alternative routes to delivery points, potentially increasing fuel consumption.

Operators mentioned that the heavier weight of the tractor compared to diesel trucks can also pose a challenge for hauling cars by placing disproportionate strain on the drive axle and reducing the total number of vehicles that can be hauled by a single truck. Existing policy efforts have been made to address challenges associated with the increased weight of zero-emission vehicles, including increasing regulatory limitations on maximum gross vehicle weight by 2,000 lbs compared to diesel vehicles, however, vehicle weight continues to limit the commercial competitiveness of zero-emission trucking operations.[23]

Currently, fuel cell power output is a limiting factor on XCIENT Fuel Cell Tractors' performance, leading to the depletion of the onboard battery when the fuel cell cannot recharge the battery quickly enough to keep up with the demand on the motor from climbing long, steep grades with heavy payloads. This means that drivers, at times, need to pull over and allow time for the fuel cell to recharge the battery. A higher-powered fuel cell may be able to address this challenge, along with driver training specific to adjusting uphill speeds and battery charging before beginning a trip.

Even when fully utilized, the vehicles spent significant time in port queues, increasing labor costs, consuming fuel, and limiting the vehicles' ability to accumulate mileage as projected. To improve logistics for future zero-emission truck rollouts, terminals could consider creating a priority lane for zero-emission vehicles if not space-constrained.

According to project partner Papé, the XCIENTs have been comparable in unscheduled downtime compared to their diesel counterparts. The powertrain/aftertreatment in an internal combustion engine vehicle is typically the largest source of downtime for a standard diesel fleet. Fuel Cell Tractors traded that system for the hydrogen fuel powertrain and have experienced relatively few unscheduled service events. The most common unscheduled service events pertain to the cab/chassis and are comparable to what a diesel fleet would experience such as taillights, tires, body damage, etc. A large subset of those events is caused by driver-related errors and the rough nature of drayage operations. Detailed service and support data can be found in **APPENDIX A: Data Report**.

The specialized nature of fuel cell technology impacts the availability of parts and maintenance services. The project uses tires designed to European, rather than American, standards, contributing to extended shipping times compared to domestic tires. The project team

[23] https://dot.ca.gov/programs/traffic-operations/legal-truck-access/ex-zero-emission-vehicle

recommends that vehicles use domestically available parts when possible. Additionally, the primary parts supplier for the fleet was Hyundai Mobis, which is based in Korea, contributing to extended shipping times for parts. Storage space is limited within Papé's facility, making it difficult to stock up on parts in advance. Future projects may consider accounting for parts storage when planning if resources permit.

CHAPTER 10: Hydrogen Station Operation

Objectives

The primary objectives of this task were to operate the proposed hydrogen refueling station at the Port of Oakland for the XCIENT Fuel Cell Tractors in commercial service operations, report data for 12 months as required for Data Collection and Analysis and then continue to provide hydrogen for these trucks for a total of six years in operation. Fueling data is included in **APPENDIX A: Data Report.**

Activities

FirstElement Fuel was responsible for operating the hydrogen refueling station, providing a hydrogen supply with zero carbon intensity to the 30-vehicle fleet, completing maintenance and service work in response to unplanned station downtime, and providing technical support to ensure station reliability and operator satisfaction.

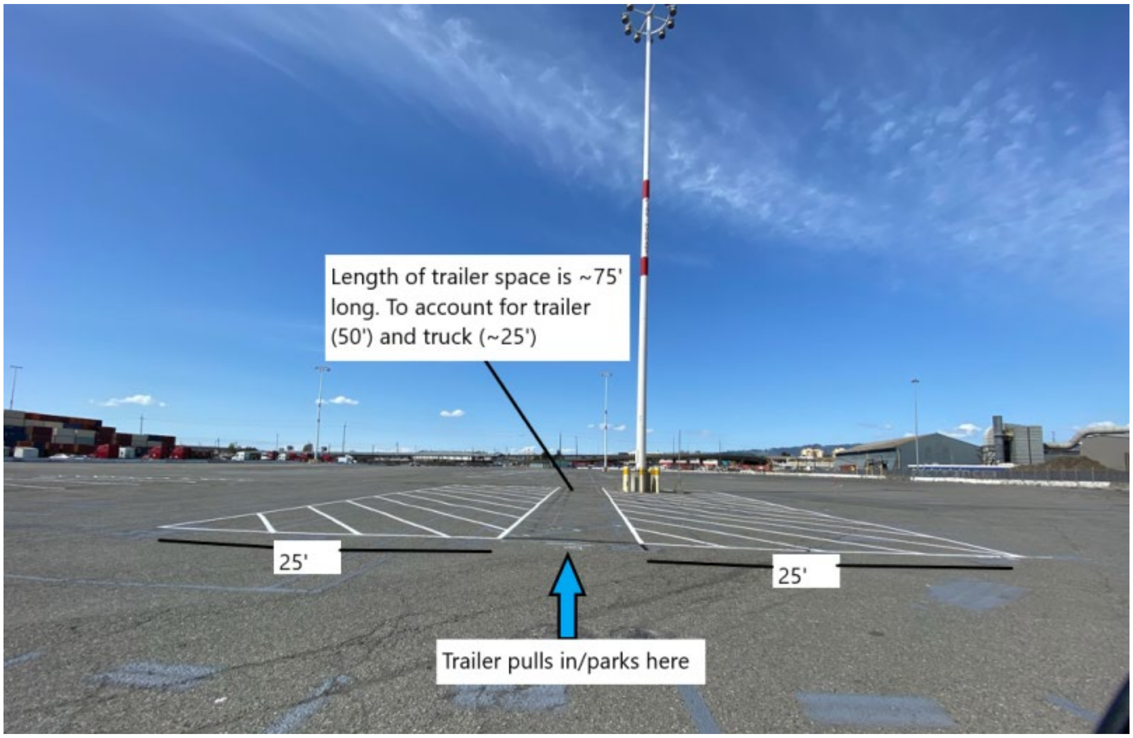
Mobile Refueler

Due to unanticipated delays in station development discussed previously, FirstElement Fuel began investigating alternative fueling solutions to prepare for the initial shipment of 10 trucks during the second quarter of 2023. Glovis provided the project team with mock routes that were representative of its anticipated operations and the project team calculated expected hydrogen demand based on these routes. FirstElement Fuel then drafted a preliminary proposal to meet Glovis' anticipated needs, providing a mobile refueler with the ability to fuel approximately 10 trucks per day.

CTE, FirstElement Fuel, and Glovis secured a space to stage the mobile refueler on Port of Oakland property. The City of Oakland approved the permit necessary to install the mobile refueler in May 2023, and FirstElement Fuel and the Port began working to establish electrical ground at the site.

Figure 7 provides a visual overview of space requirements and setbacks required by the California Fire Code.

Figure 7: Mobile Refueler Siting Considerations



Source: FirstElement Fuel

In the interim, FirstElement Fuel completed retrofits on the mobile refueler staged at FirstElement Fuel's Livermore Hub, including adding precooling capabilities. FirstElement Fuel and HATCI tested the mobile refueler using three XCIENTs in June 2023 and Glovis began filling the trucks at the Livermore Hub in July 2023.

The leasing agreement to stage a mobile refueler at the Port of Oakland was executed in August 2023, after which FirstElement Fuel could relocate the unit. The mobile refueler underwent additional testing that month but failed due to system leaks. FirstElement Fuel worked with the mobile refueler OEM to resolve this issue and secured a permit to store a gaseous tube trailer at the station as a backup option.

Figure 8 depicts the mobile refueler used by the NorCAL ZERO fleet. During uninterrupted fueling events, the fueler—which has approximately 800 kg of usable capacity—averaged 22.6 minutes for an average fill quantity of 38.6 kg from September through December 2023.

Figure 8: True Zero Mobile Hydrogen Refueler

Source: CTE

By January 2024, FirstElement Fuel supported fueling from the permanent station site using the gaseous buffer storage tubes and a tube trailer. The heavy-duty station was open for fueling by appointment throughout the third quarter of 2024 and 24/7 beginning in August of 2024.

Fuel Supply

Liquid hydrogen for the FirstElement Fuel station was supplied by Air Liquide's Las Vegas production facility. This facility produces hydrogen via steam methane reformation, which results in some emissions generation. To ensure the fuel provided for the project achieves a carbon intensity of zero with at least 50% renewable content, FirstElement Fuel began procuring Environmental Attributes upon opening the heavy-duty station to 24/7 public fueling. These attributes are certified by CARB's Low Carbon Fuel Standard program.

Challenges

Beginning in the fourth quarter of 2024, FirstElement Fuel experienced periodic technical challenges with their thermal management system that resulted in increased dwell and fill times and the closure of a heavy-duty dispenser to limit throughput demand. FirstElement Fuel worked to resolve these issues quickly when they occurred.

Boil-off, which refers to the loss of hydrogen fuel due to evaporation, is a significant challenge for the cost-effectiveness of liquid hydrogen fueling stations of any scale. Common sources of boil-off include transfer fill losses, storage tank heat leak, and liquid pump priming. Transfer fill losses include losses resulting from the filling of the liquid delivery truck, the transport of fuel to the site, and the transfer of fuel from delivery vehicle to onsite storage. Liquid hydrogen is often transferred to a storage tank from a delivery tanker by pressurizing the tanker and/or lowering the pressure in the storage tank. Those pressure adjustments result in tank venting (boil-off) and lost fuel. Storage tank heat leak losses generally result from the warming of cryogenic fuel as it sits in the storage tank. Liquid pump priming, during which components are cooled to safely handle liquid hydrogen, is often performed using liquid hydrogen, and cooling the pump introduces heat to the liquid tank. When storage becomes pressurized due to boil-off in all three scenarios, gas accumulated in the tank must be vented to keep the pressure within safe levels, leading to loss of fuel.

The FirstElement Fuel station is designed to minimize these losses using multiple strategies. FirstElement Fuel retrofitted the station to accept advanced deliveries to minimize transfer losses by using a pump on board the delivery trailer to move liquid from the delivery trailer to the storage tank. Vaporized liquid hydrogen is processed from the storage tank to on-site gaseous buffer storage using a boil-off gas compressor.

Lessons Learned

Additional regulatory actions are needed to support the long-term commercial viability of public hydrogen refueling infrastructure for station developers and operators. FirstElement Fuel invested significantly in subsidies for fuel supplied by its station and relies on Low Carbon Fuel Standard credits in its financial planning. At the time of the writing of this report, Low Carbon Fuel Standard credits have declined significantly in value since the project's initiation in 2021, reducing opportunities for companies like FirstElement Fuel to offset the capital expenditures and operating expenses involved in hydrogen fueling. This has increased the costs for consumers at the pump. Stabilizing the value of Low Carbon Fuel Standard credits is a critical step in incentivizing early adopters to invest in zero-emission technology. CARB's recently adopted Hydrogen Refueling Infrastructure credits for heavy-duty refueling stations will provide developers with additional incentives to invest in station deployments.

Hydrogen infrastructure benefits greatly from economies of scale. Widespread investment in fostering competition and increasing demand for hydrogen fueling is critical to achieving reductions in operational expenses associated with production, delivery, and dispensing and, by extension, the cost of hydrogen fuel for both heavy-duty fleets and individual light-duty consumers. As the number of stations increases, the equipment required by hydrogen refueling stations will also become more commonplace, and the amount of innovation required by each specific station will be reduced. Some of the components of the FirstElement Fuel station were the first instance of equipment being used, which meant that if a part failed, resolving the issue was more time intensive. In the future, these pieces of equipment can be improved, and maintenance staff can be trained to respond to and resolve failures more quickly.

Due to the high cost of delivered hydrogen, boil-off mitigation is critical to keep operational costs for fuel cell vehicles closer to diesel parity. FirstElement Fuel's current station is designed to minimize losses through multiple strategies. Boil-off losses are expected to decrease as technology advances and companies continue to prioritize boil-off mitigation in station design.

CHAPTER 11: Data Collection and Analysis

Objectives

The primary objective of this task was to collect operational data from the project, to analyze that data for economic and environmental impacts, and to include the data and analysis in the Final Report (contained in **APPENDIX A: Data Report**).

Activities

Data collection and reporting for the NorCAL ZERO project was led by CTE and the University of California, Berkeley's Transportation Sustainability Research Center. The first major stage of data collection and analysis for the project was the development of the Data Collection Test Plan. The Data Collection Test Plan assigned collection responsibilities to partners; defined data to be collected, including units and sources of data; and established methods for collecting, securely storing, and transferring project data.

The project team used multiple strategies to collect data, including vehicle performance data from electronic logging devices and the vehicles' central telematics units, fleet dispatcher-provided operational data such as availability and duty cycles, maintenance data collected by Papé via its service relationship management platform, operator-collected data for the mobile refueler, and telematics data for permanent station including pressure, fill times, and quantities of hydrogen dispensed. CTE was also responsible for collecting job creation and other workforce training data from members of the project team. FirstElement Fuel also completes National Renewable Energy Laboratory (NREL) data collection templates for the station.

The project team used third-party electronic logging devices for vehicle telematics. During the second quarter of 2023, Glovis, Hyundai, HATCI, and Motive, the telematics provider, conducted integration tests on XCIENTs operated by HATCI in Southern California and concluded that Motive's hardware was compatible with the project vehicles. Glovis provided the team with Motive's test data and feedback regarding UC Berkeley's data management plan and ordered 10 electronic logging devices from Motive. During June 2023, Papé and HATCI installed electronic logging devices on the first batch of XCIENTs and UC Berkeley attended mobile refueler testing conducted by FirstElement Fuel and HATCI to review the mobile fueler's data collection capabilities.

The project team conducted biannual data reporting for the XCIENT Fuel Cell Tractors throughout the entirety of 2024. The project team began reporting data for the station beginning in the third quarter of 2024. Additional data for the NorCAL ZERO project can be found in **APPENDIX A: Data Report**.

The project team also calculated fleet-associated emissions reductions using CARB's Benefits Calculator Tool for Advanced Technology Demonstration and Pilot Projects. Annual emissions reductions based on 2024 operational data include an estimated 1,945 pounds of nitrogen oxides, 100 pounds of particular matter (PM10), 40 pounds of fine particulate matter (PM2.5), and 696.08 metric tons of carbon dioxide equivalent greenhouse gases.

Lessons Learned

The amount of time necessary to collect, process, and generate reports from data drawn from multiple organizations was greater than anticipated in initial projections (approximately a three-month process). The project team recommends extending the time between data collection and submission dates for data reporting in future projects. In addition, substantial effort is required upfront to establish data collection capabilities and assign reporting responsibilities. The project team recommends beginning data-collection conversations in parallel with vehicle manufacturing and early-stage station development.

There is industry-wide variability in data reporting for technologies using or dispensing hydrogen fuel. Fuel economy for the project was calculated by dividing miles traveled by kilograms of hydrogen dispensed. Due to station-vehicle communication challenges, some hydrogen dispensed data cannot be attributed to a vehicle or to the NorCAL ZERO fleet. To overcome this, Glovis provided hydrogen dispensed by multiplying the state of charge at the end of each fill by the hydrogen storage capacity onboard the vehicle. This is imperfect because 100 percent state of charge can correspond to variable onboard vehicle tank pressure readings, and—very likely—variable hydrogen onboard the vehicle. Hydrogen dispensed data can be improved for future projects by improving station-vehicle communications or by letting vehicle tank temperature and pressures settle post-fill, so they most accurately represent the true state of charge of the vehicle.

Some data metrics, such as gas precooling temperatures, dispenser ID, and vehicular tank temperature readings were able to be collected but were not automatically recorded until 1Q2025 due to miscommunication between team members. The project team recommends ensuring the gaps between “data can be collected” and “data is recorded” is addressed early in the project. It is critical data collection is automated as much as possible to avoid excessive burden on project partners.

As previously mentioned, the project team was additionally unable to use some of the FirstElement Fuel-supplied data due to repeated communications failures between the dispenser and vehicles. When communications are lost, the dispenser is unable to attribute hydrogen dispensed to specific truck IDs and, by extension, the fleet. The project team recommends that grantors invest in research and technology development to improve the reliability of vehicle-to-dispenser communication systems.

CHAPTER 12: Recommendations for Grantors

The project team recommends that the CEC work to continuously improve invoicing templates and further streamline invoicing processes. This can be achieved by allowing grantees increased abilities to revise the template, specifically allowing grantees to edit the display of values to allow more than two significant figures.

In addition, developing proposals for projects such as NorCAL ZERO takes considerable time and effort. These expenditures are never able to be recovered using a cost-reimbursable contract structure once awarded the grant. This disproportionately impacts small organizations, particularly non-profits with limited capital, as projects awarded under these existing contractual structures guarantee a cradle-to-grave loss at an organizational level. The inability to recuperate labor expended during the project development period and pre-contract period disincentives participation, a key step in developing projects that strive to make zero-emission technology more affordable and scalable. Allowing for milestone billing instead of cost reimbursable billing would help address this issue. Complex invoicing processes are also particularly challenging when funding opportunities limit the percentage of project funding that can be allocated to project administration.

Similarly, although the project team recognizes the benefits of retention as an incentive for partners to complete project objectives, retention can limit the participation of nonprofits like CTE that use labor as a primary source of revenue and hold less cash in reserve than for-profit corporations. Retention was only applicable to some costs under this Grant Funding Opportunity, which was critical in enabling the participation of multiple stakeholders. The project team recommends that CARB and CEC continue to investigate alternate systems for incentivizing project success.

CHAPTER 13: Conclusion

NorCAL ZERO serves as a key step forward in the journey to commercialize zero-emission trucking across the State of California. At the time of the project's dedication, NorCAL ZERO constituted the largest commercial deployment of Class 8 hydrogen-powered fuel cell electric trucks in the United States. The project has enabled containerized cargo deliveries throughout the Bay Area and Central Valley and supported the testing of Hyundai XCIENT Fuel Cell Tractor operations using car hauler trailers on rigorous routes.

NorCAL ZERO has been critical in establishing the supporting infrastructure necessary for zero-emission drayage operations, creating the first Northern California link in a network of heavy-duty stations that will allow deliveries across extended routes comparable to those driven by conventional internal combustion engine vehicles. As of the time of writing, the West Oakland True Zero station is the largest heavy-duty hydrogen refueling station worldwide, with the capacity to support full fills for over 200 trucks daily.

NorCAL ZERO fostered the creation of at least 45 green jobs across clean transportation research, project management, station development, vehicle operation, and fleet management. In addition to creating new jobs, the project has supported workforce development activities necessary to equip Bay Area maintenance professionals with the skills necessary to service fuel cell vehicles. The project has also allowed local first responders to prepare for and safely respond to emergency situations involving hydrogen technologies.

NorCAL ZERO supports improvements to the health of our communities and environment. The fleet's use of zero-carbon intensity hydrogen fuel and zero tailpipe emissions contributes to an estimated annual emissions reduction of 1,945 pounds of nitrogen oxides, 100 pounds of particulate matter, 40 pounds of fine particulate matter and over 696 metric tons of carbon dioxide equivalent greenhouse gases based on operational data collected in 2024. NorCAL ZERO's 30-vehicle fleet is anticipated to continue to operate following project closure for a total period of six years following the vehicles' initial deployment in 2023, providing additional benefits.

NorCAL ZERO is enabling the next generation of fueling stations. The project served as an opportunity for FirstElement Fuel to test new configurations for heavy-duty hydrogen refueling stations using real-world data from a station with public refueling. FirstElement Fuel has already begun optimizing component layouts and integrating equipment to streamline operations for future stations. FirstElement Fuel is partnering with Bosch to develop the next generation of liquid hydrogen pumps and intends to retrofit the West Oakland station in fall 2025. This new pump is expected to significantly reduce boil-off and venting of fuel associated with station operation. FirstElement Fuel also plans to eventually modify the station to support SAE J2601-5, enabling faster fills akin to conventional fuels.

NorCAL ZERO is enabling the next generation of hydrogen fuel cell electric trucks. The first-generation vehicle deployed through this program uses two fuel cell power units for a total of 170 kW of net power output. Hyundai is working on developing a heavy-duty specific fuel cell with increased power output which will improve performance over steep grades. Other future improvements include reducing the cab weight to enable fleet operators to support heavier cargo and eventually plumbing modifications to enable filling according to advanced protocols such as SAE J2601-5.

NorCAL ZERO has paved the way for multiple planned zero-emission trucking initiatives across the State. Among these is ARCHES, which plans to fund the construction of numerous heavy-duty hydrogen fueling stations in support of the deployment of more than 5,000 fuel cell electric trucks.[24] NorCAL ZERO was additionally instrumental to the Port of Oakland's success in securing a $322 million United States Environmental Protection Agency Clean Ports Program grant, through which the Port plans to finance the purchase of both battery-electric and fuel cell electric drayage trucks in addition to zero-emission cargo handling equipment.[25]

[24] https://archesh2.org/arches-officially-launches/

[25] https://www.portofoakland.com/port-of-oakland-awarded-historic-322-million-epa-grant/

GLOSSARY

Air District	A political body responsible for managing air quality on a regional or county basis.
Air pollution	Unwanted particles, mist or gases put into the atmosphere as a result of motor vehicle exhaust, the operation of industrial facilities or other human activity.
Ambient temperature	Surrounding temperature, such as the outdoor air temperature around a building.
California Air Resources Board (CARB)	The "clean air agency" in the government of California, whose main goals include attaining and maintaining healthy air quality; protecting the public from exposure to toxic air contaminants; and providing innovative approaches for complying with air pollution rules and regulations.
California Energy Commission (CEC)	The state's primary energy policy and planning agency. The agency was established by the California Legislature through the Warren-Alquist Act in 1974. It has seven core responsibilities: • Developing renewable energy • Transforming transportation • Increasing energy efficiency • Investing in energy innovation • Advancing state energy policy • Certifying thermal power plants • Preparing for energy emergencies
California Environmental Protection Agency (CalEPA)	A state government agency established in 1991 for unifying environmental activities related to public health protection in the State of California.
Carbon dioxide equivalent	A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential. The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP. MMTCDE = (million metric tons of a gas) * (GWP of the gas) (EPA)
Carbon Intensity (CI)	The amount of carbon by weight emitted per unit of energy consumed.

Center for Transportation and the Environment (CTE)	CTE is a 501(c)(3) non-profit that develops and implements zero-emission vehicles and supporting infrastructure.[26]
Criteria air pollutant	An air pollutant for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set. Examples include: ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, PM10 and PM2.5.
East Bay Municipal Utility District (EBMUD)	EBMUD is a municipally owned provider of water and wastewater services to the East Bay.[27]
Emissions	Released or discharged air contaminants in the ambient air from any source.
Fuel cell	A device or an electrochemical engine with no moving parts that converts the chemical energy of a fuel, such as hydrogen, and an oxidant, such as oxygen, directly into electricity. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes, thus producing electricity.
Fuel cell electric truck (FCET)	A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.
Greenhouse gas	Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs) , ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs). (EPA)
Gross vehicle weight (GVW)	The maximum operating weight/mass of a vehicle as specified by the manufacturer including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers and cargo but excluding that of any trailers.
Hyundai America Technical Center, Inc. (HATCI)	Hyundai Motor Group’s North American design, technology, and engineering division.[28]

[26] https://cte.tv/mission

[27] https://www.ebmud.com/about-us/who-we-are

[28] https://www.hatci.com/

Hydrogen (H2)	A colorless, odorless, highly flammable gas.
Internal combustion engine	An engine in which fuel is burned inside the engine.
Kilogram (kg)	The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1000 cubic centimeters of water at the temperature of its maximum density. One kg of hydrogen is equivalent in energy to one gallon of gasoline, or 0.9 gallons of diesel.[29]
Kilowatt (kW)	A unit of measure of the amount of electricity needed to operate given equipment.
Kilowatt-hour (kWh)	The most commonly used unit of measure telling the amount of electricity consumed over time. It means one kilowatt of electricity supplied for one hour.
Light-duty vehicle	Any motor vehicle with a gross vehicle weight of 6,000 pounds or less.
Low Carbon Fuel Standard (LCFS)	A set of standards designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and therefore, reduce greenhouse gas emissions. The LCFS standards are expressed in terms of the "carbon intensity" (CI) of gasoline and diesel fuel and their respective substitutes. The LCFS is a key part of a comprehensive set of programs in California to cut greenhouse gas emission and other smog-forming and toxic air pollutants by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.
Metric ton	A unit of mass equal to 1000 kilograms.
National Fire Protection Association (NFPA)	A global self-funded nonprofit organization, established in 1896, devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards.
National Renewable Energy Laboratory (NREL)	The National Renewable Energy Laboratory (NREL), located in Golden, Colorado, is the United States' primary laboratory for renewable energy and energy efficiency research and development. NREL is the only Federal laboratory dedicated to the research,

[29] https://afdc.energy.gov/fuels/properties

	development, commercialization, and deployment of renewable energy and energy efficiency technologies.
Nitrogen oxides (NOX)	A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO2) and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO2 is a criteria air pollutant and may result in numerous adverse health effects.
Original equipment manufacturer (OEM)	Refers to the manufacturers of complete vehicles or heavy-duty engines, as contrasted with remanufacturers, converters, retrofitters, up-fitters, and re-powering or rebuilding contractors who are overhauling engines, adapting or converting vehicles or engines obtained from the OEMs, or exchanging or rebuilding engines in existing vehicles.
Out of Service (OOS)	A term used to describe the status of vehicles that cannot be operated due to necessary maintenance activities.
Particulate matter (PM)	Unburned fuel particles that form smoke or soot and stick to lung tissue when inhaled. A chief component of exhaust emissions from heavy-duty diesel engines.
Pacific Gas and Electric Company (PG&E)	An electric and natural gas utility serving the Central and Northern California regions.
PM10	A criteria air pollutant consisting of small particles with an aerodynamic diameter less than or equal to a nominal 10 microns (about 1/7 the diameter of a single human hair). Their small size allows them to make their way to the air sacs deep within the lungs where they may be deposited and result in adverse health effects. PM10 also causes visibility reduction.
PM2.5	Includes tiny particles with an aerodynamic diameter less than or equal to a nominal 2.5 microns. This fraction of particulate matter penetrates most deeply into the lungs.
Site	Any location on which a facility is constructed or is proposed to be constructed.
State of charge (SOC)	The remaining charge in a battery expressed as a percentage of the total capacity. [30] In this report, also

[30] https://www.sciencedirect.com/science/article/abs/pii/S2352152X21001924

	used to refer to the amount of hydrogen remaining within onboard vehicle storage expressed as a percentage of the total capacity.
Storage tank	Any stationary container, reservoir, or tank, used for storage of liquids.
West Oakland Environmental Indicators Project (WOEIP)	A community-based environmental justice organization serving West Oakland, California.
Zero-emission	An engine, motor, process, or other energy source, that emits no waste products that pollute the environment or disrupt the climate.
Zero-emission vehicle (ZEV)	A vehicle which produces no emissions from the on-board source of power (e.g., an electric vehicle).

APPENDIX A:
Data Report

California Energy Commission

Clean Transportation Program

QUARTERLY DATA REPORT

NorCAL ZERO: Zero-Emission Regional and Drayage Operations with Fuel Cell Electric Trucks

Reporting Period: 7/1/2024–12/31/2024

Prepared for: California Energy Commission

Prepared by: Center for Transportation and the Environment

CENTER FOR TRANSPORTATION AND THE ENVIRONMENT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NorCAL Zero Data Report

This report documents the performance and usage of 30 Class 8 Hydrogen Fuel Cell-Electric Trucks (FCETs) manufactured by Hyundai Motor Company and deployed at the Port of Oakland. These zero-emission trucks will be offsetting traditional internal combustion engine diesel trucks on cargo delivery routes within the East Bay and Central Valley regions of Northern California.

Vehicle Specifications

Table 1 provides an overview of the technical specifications for the Hyundai XCIENT Fuel Cell Tractors manufactured for this project.

Table 1: Vehicle Specifications

Hyundai XCIENT Fuel Cell Electric Truck Specifications	
Fuel Cell System	2 fuel cell power units for total 170 kW net power output
Battery Pack	72 kWh
Vehicle Range	Up to 450 miles (target, depending on duty cycle)
Onboard H2 Storage	70 kg overall system (68.6 kg usable hydrogen)
Hydrogen Tank Pressure	700 bar (10,000 psi)
Motor Type	Single, centrally mounted
Motor Power	350 kW
Curb Weight	28,400 lbs.

Source: CTE

Table 2 provides an overview of the components and technical specifications for the FirstElement Fuel heavy-duty station.

Station Specifications

Table 2: Station Specifications

FirstElement Fuel Oakland Heavy-Duty Station Specifications	
Vertical Cryogenic Pressure Vessel	4,430 kg (16,500 gal)
Booster Pumps	6.16 m3/hr
High-Pressure Reciprocating Pumps	250 kg/hr
Gaseous Storage	243.6 kg at varying pressures
Thermal Management (pre-cooling)	T40 (-40 degrees Celsius)
Heavy Duty Dispensers	Two dispensers with two nozzles each, TN1 receptacle
Boil-off Gas Compressor	6.2 kg/hr @ 1.5 barg

Source: CTE

Fleet Mileage and Fuel Consumption

During this reporting period (July – December 2024), the permanent station became fully commissioned and operational as of Friday, August 30, 2024, providing 24/7 fueling access for both heavy- and light-duty vehicles. This marks a significant improvement from the previous reporting period, where fueling was limited to designated appointment-based fills conducted by trained FirstElement Fuel personnel. With the station now operating around the clock with an automated system, drivers can refuel their trucks independently at any time, increasing flexibility and supporting expanded service capabilities.

For this data report, the data team elected to continue using hydrogen consumption data from Glovis. Even though the heavy-duty station is fully commissioned and operational, occasionally there is interference in vehicle-station infrared communication and the station must complete a fill without communication. When this happens, the team loses the ability to attribute a given fill to a given truck, thus relying on data directly from Glovis operators is the most complete method of capturing fuel consumption.

In April 2024, Glovis transferred five trucks (3208, 3212, 3220, 3224, and 3225) from GET Freight to Extreme—another wholly owned subsidiary of Glovis—who retrofitted five XCIENTs to haul light-duty cars. During this reporting period, these collectively traveled 65,831 miles and experienced an average fuel economy of 5.88 mi/kg. The Extreme mileage accumulation represents 37% of all fleet miles traveled during this period.

Table 3 below provides a summary of revenue miles driven, revenue hydrogen used, and calculated fuel efficiency on a biannual basis. **Figure 1** provides a visual representation of the total revenue mileage and hydrogen consumption over the duration of the program.

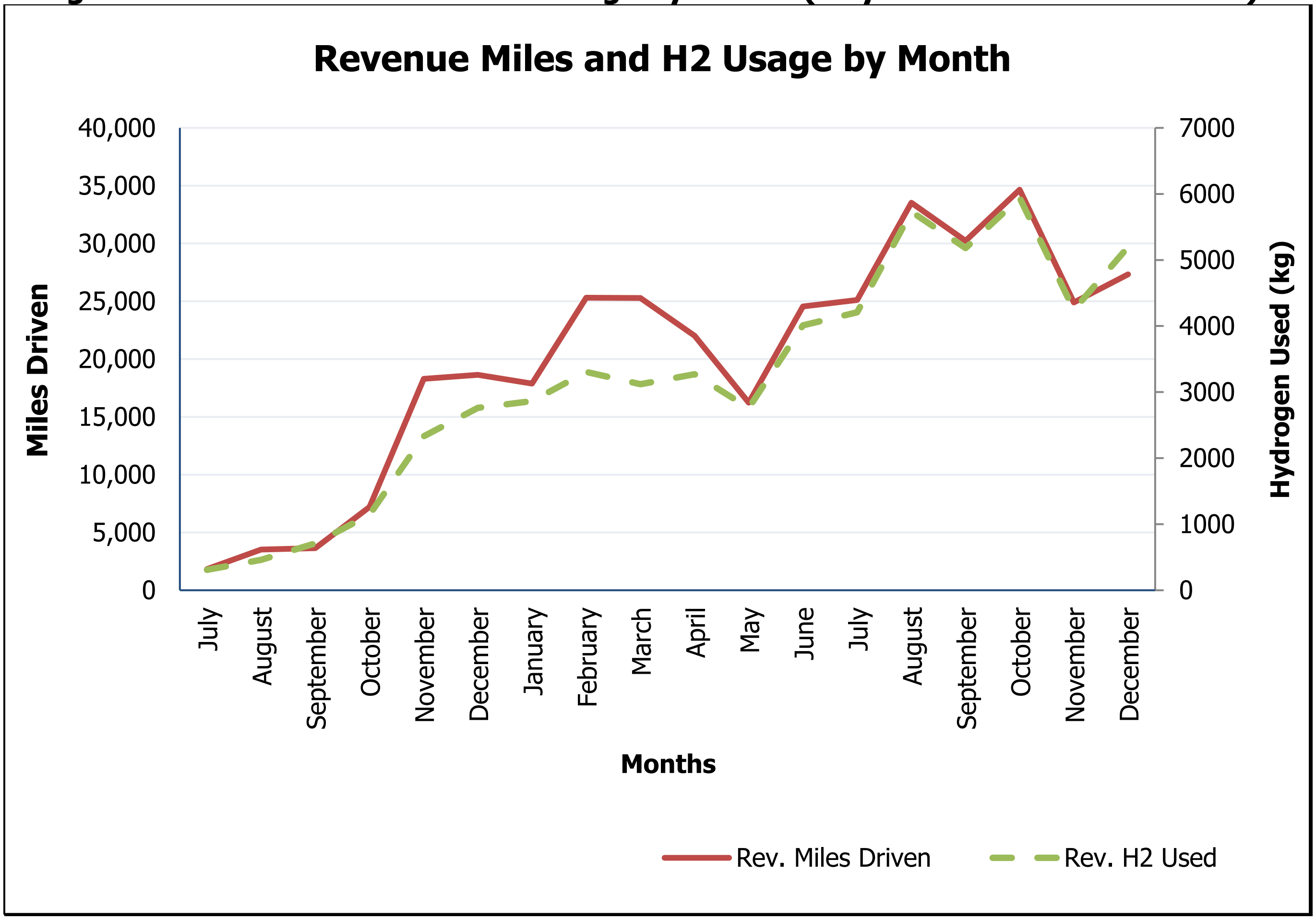
Table 3: Revenue Service Miles and Hydrogen Fuel Used by Reporting Period

	July - Dec. 2023	Jan. – June 2024	July – Dec. 2024	Total
Revenue Miles Driven	53,138	131,261	175,751	360,150
Revenue H_2 Used (kg)	7,718	19,328	30,503[31]	57,549
Revenue Fuel Efficiency (mi/kg)	6.88	6.79	5.76	6.26

Source: CTE

[31] Revenue Hydrogen dispensed and used from four fueling events in Wilmington, Southern California, were excluded due to missing information.

Figure 1: Revenue Miles and H2 Usage by Month (July 2023 – December 2024)



Source: CTE

The July – December 2024 period experienced a 34% increase in mileage[32] accumulation from the last period. The fleet-wide fuel efficiency dropped significantly during the July – December 2024 period. On a monthly basis, the fuel economy has varied from as low as 5.13 mi/kg and as high as 8.10 mi/kg. To understand this variation, the team explored the impact of idle time on vehicle fuel efficiency. This warranted the development of a new metric—idle minutes per mile driven. Idle minutes per mile driven allowed the team to better characterize Glovis' duty cycles and compare monthly periods with dramatically different total mileage. **Table 4** includes miles driven, minutes idled, idle minutes per mile driven, hydrogen dispensed, and fleet-wide fuel economies by month. **Figure 2** below compares idle minutes per mile driven (blue) with vehicle fuel efficiency in mi/kg (orange).

[32] Revenue Mileage is inclusive of all deployment mileage beginning after the FCET made its first customer delivery and is not inclusive of training mileage described in detail in the 3Q2023 and 4Q2023 Data Report.

Table 4: Revenue Service Miles Driven by Month

Month[33]	Rev. Miles Driven	Idle Time (min)	Idle minutes per mile driven	Rev. H_2 Used (kg)	Rev. Fuel Efficiency (mi/kg)
July, 2023	1,830	8,945	4.89	309	5.93
August, 2023	3,529	12,200	3.46	461	7.65
September, 2023	3,647	18,869	5.17	710	5.13
October, 2023	7,202	26,550	3.69	1,144	6.29
November, 2023	18,294	45,569	2.49	2,332	7.84
December, 2023	18,635	36,704	1.97	2,762	6.75
January, 2024	17,875	46,945	2.63	2,863	6.24
February, 2024	25,312	51,632	2.04	3,305	7.66
March, 2024	25,279	50,500	2.00	3,120	8.10
April, 2024	22,007	70,959	3.22	3,271	6.73
May, 2024	16,235	60,061	3.70	2,759	5.88
June, 2024	24,554[34]	85,053	3.46	4,010	6.12
July, 2024	25,106	86,291	3.44	4,207	5.97
August, 2024	33,526	108,606	3.24	5,733	5.85
September, 2024	30,228	106,102	3.51	5,180	5.84
October, 2024	34,652	107,966	3.12	5,942	5.83
November, 2024	24,904	86,447	3.47	4,244	5.87
December, 2024	27,335	119,174	4.36	5,196	5.26
Total	360,150[35]	1,128,573[36]	3.13	57,549	6.26

Source: CTE

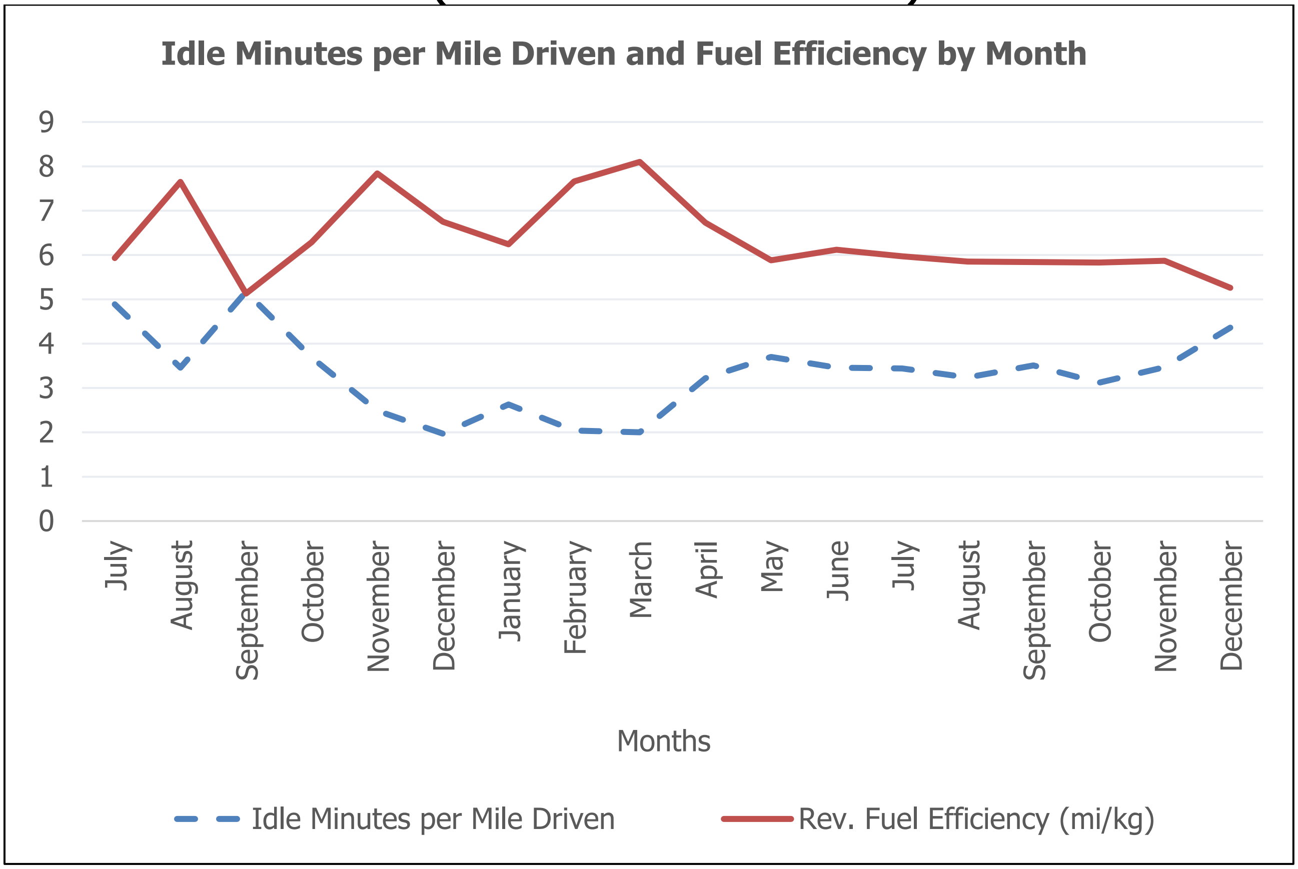
[33] Glovis only had access to 10 trucks between July 2023 to September 2023.

[34] FCET 3210 had a data logger defect beginning in June 2024. Some miles were unable to be recorded, and no fuel data was provided.

[35] This cumulative total does not include "training miles" driven by the vehicles before they began performing revenue generating deliveries. There were 5,275 fleet-wide training miles. Further information on training miles can be found in the 3Q2023 and 4Q2023 Data Report.

[36] The table omits an outlier idle event that lasted 3976 minutes where an FCET was accidentally left on for a sustained period.

Figure 2: Idle Time per Mile and Fuel Economy by Month (June 2023 – December 2024)



Source: CTE

At the conclusion of this investigation, it is clear that idle time significantly impacts vehicle fuel efficiency. As idle minutes per mile driven increases across the periods, fuel economy generally decreases and vice versa, highlighting the negative impact of increased idle time on operations. Reducing idling time can significantly improve fuel economy, making it crucial to implement strategies that minimize idle periods. One effective approach could be establishing priority lanes for zero-emission trucks at port terminals**.** These lanes would save fleet operators money on fuel consumed while idling and improve operational efficiency by reducing delays, ultimately contributing to better fuel economy for zero-emission trucks.

Fuel Consumption While Idling

An internal combustion engine typically runs through a complete cycle to generate power. Each cycle—comprising intake, compression, power, and exhaust strokes—contributes to the overall power output. FCETs instead rely on energy stored in on-board batteries to operate systems like air conditioning and heating. When FCETs are stationary, they can enter a low-energy mode to minimize energy consumption further. To validate this claim, the project team collected data to estimate fuel consumption while idling for the NorCAL ZERO fleet from July 2023 to December 2024.

Many factors impact idling fuel consumption, including ambient conditions, HVAC operation, and current battery state of charge (SOC). The project team worked with the Hyundai-Kia America Technical Center Inc. (HATCI) to determine acceptable idling consumption rates that account for all possible conditions. The range 0.3-0.6 kg/hr was derived from empirical data collected by HATCI on their fleet of XCIENTs operating in Southern California. The predicted diesel fuel consumption while idling is calculated by the third-party telematics installed onto the vehicle.

Table 5 provides monthly idle time and predicted fuel consumption. Under the most strenuous idling consumption (0.6 kg/hr), the FCETs have consumed 1,354,320 MJ of fuel[37] while idling. Under the least strenuous idling consumption scenario (0.3 kg/hr), the FCETs have consumed 677,160 MJ of fuel while idling. A similar diesel truck would have consumed approximately 2,096,010 MJ of fuel while idling. This represents between a 35% and 67% overall reduction in energy consumption while idling compared to a traditional internal combustion engine Class 8 truck.

[37] Assuming hydrogen has an energy density of 120 MJ/kg and diesel has an energy density of 135 MJ/gal.

Table 5: Idle Time by Month

Month	Idle Time (min)	Idle Time (hr)	H2 Used (0.3 kg /hr)	H2 Used (0.6 kg /hr)	Predicted Diesel Used (gal)
July, 2023	8,945	149	45	89	123
August, 2023	12,200	203	61	122	168
September, 2023	18,869	314	94	189	259
October, 2023	26,550	442	133	265	365
November, 2023	45,569	759	228	456	627
December, 2023	36,704	612	184	367	506
January, 2024	46,945	782	235	469	646
February, 2024	51,632	861	258	516	710
March, 2024	50,500	842	252	505	695
April, 2024	70,959	1,183	355	710	976
May, 2024	60,061	1,001	300	601	826
June, 2024	85,053	1,418	425	851	1,170
July, 2024	86,291	1,438	431	863	1,187
August, 2024	108,606	1,810	543	1,086	1,494
September, 2024	106,102	1,768	531	1,061	1,460
October, 2024	107,966	1,799	540	1,080	1,485
November, 2024	86,447	1,441	432	864	1,189
December, 2024	119,174	1,986	596	1,192	1,640
Totals	1,128,573	18,808	5,643	11,286	15,526

Source: CTE

Maintenance and Support

Papé served as the project's service provider and provided all maintenance and support data collected for this report. Service events were divided up by type of service (i.e., road call, scheduled, unscheduled) and then further categorized by vehicle subsystem:

- The **Cab/Chassis** system consists of the FCET's structural base and frame, such as suspension, wheels and tires, fifth wheel connection, frame rails, the cab interior, etc.
- The **Low Voltage Electrical** system includes components using less than 24 volts, like the wiring harness, vehicle control unit and 12-volt batteries.
- The **High Voltage Electrical** system consists of components needing above 24 volts and up to or above 400 volts. Examples in this system would be the traction drive motors and associated inverters, as well as the high-voltage batteries and their associated inverters and converters.
- The **Thermal Management** system consists of the pumps, radiators, and coolants that heat and cool the fuel cell stacks and the high voltage batteries.
- The **Fuel Cell** system is made up of the components that facilitate the operation of the fuel cell stacks like the hydrogen valves, air intake controls, and the fuel cell stack itself.
- The **Hydrogen Storage** system includes the high-pressure hydrogen tanks plus the associated pipes, valves, and solenoids that facilitate hydrogen fueling and flow within the vehicle.
- **Maintenance,** while not a vehicle subsystem, is used to capture service events such as 90-Day Basic Inspection of Terminals[38] required for all commercial motor vehicles driven in the State of California with a gross weight of more than 10,000 lbs.

Downtime is expressed as Out of Service days (OOS days) due to maintenance issues that make a truck unavailable for use. The metric OOS days is used to determine how often and for how long the trucks are out of service. Scheduled service events are a normal, expected part of any piece of equipment's usable life. The downtime related to these events is viewed differently than downtime related to unscheduled service events or road calls, where a recovery vehicle must be dispatched to assist or retrieve the vehicle. OOS days do not count weekends or federally recognized holidays, as the vehicles would not be used in Revenue Service if fully operational. If two service events are completed on the same day, only one OOS day is added to the overall tally. **Table 6** includes unscheduled service events and OOS days experienced by the fleet by reporting period.

[38] The process by which California Highway Patrol inspects truck terminals to ensure that motor carriers safely operate and maintain their vehicles. Inspections can be performed by anyone with experience as a federal or state commercial vehicle inspector or experience as an inspector or mechanic for a commercial vehicle maintenance team.

Table 5: Unscheduled Service, OOS Days, and Road Calls by Vehicle System Type and Type of Service Needed (July 2023 – June 2024)

	Jul – Dec 2023	Jul – Dec 2023	Jul – Dec 2023	Jan– Jun 2024	Jan– Jun 2024	Jan– Jun 2024	Jul- Dec 2024	Jul- Dec 2024	Jul- Dec 2024
System Type	Unscheduled Service	OOS days	Road Calls	Unscheduled Service	OOS days	Road Calls	Unscheduled Service	OOS days	Road Calls
Cab/ Chassis	17	27	1	49	236	0	55	248	0
Fuel Cell System	2	7	0	1	18	0	0	0	0
High Voltage Electrical	1	22	0	1	17	0	1	26	0
Hydrogen Storage	2	21	0	1	0	0	1	14	0
Low Voltage Electrical	14	78	3	18	93	0	7	24	0
Thermal Management	5	36	1	3	7	0	1	6	0
Maintenance	0	0	0	0	0	0	0	0	0
Total	41	191	5	73	371	0	65	318	0

Source: CTE

As shown in the table above, there were no road calls during the entire calendar year of 2024. **Table 7** includes scheduled service events and OOS days experienced by the fleet by reporting period. OOS days decreased by 14% during the current reporting period.

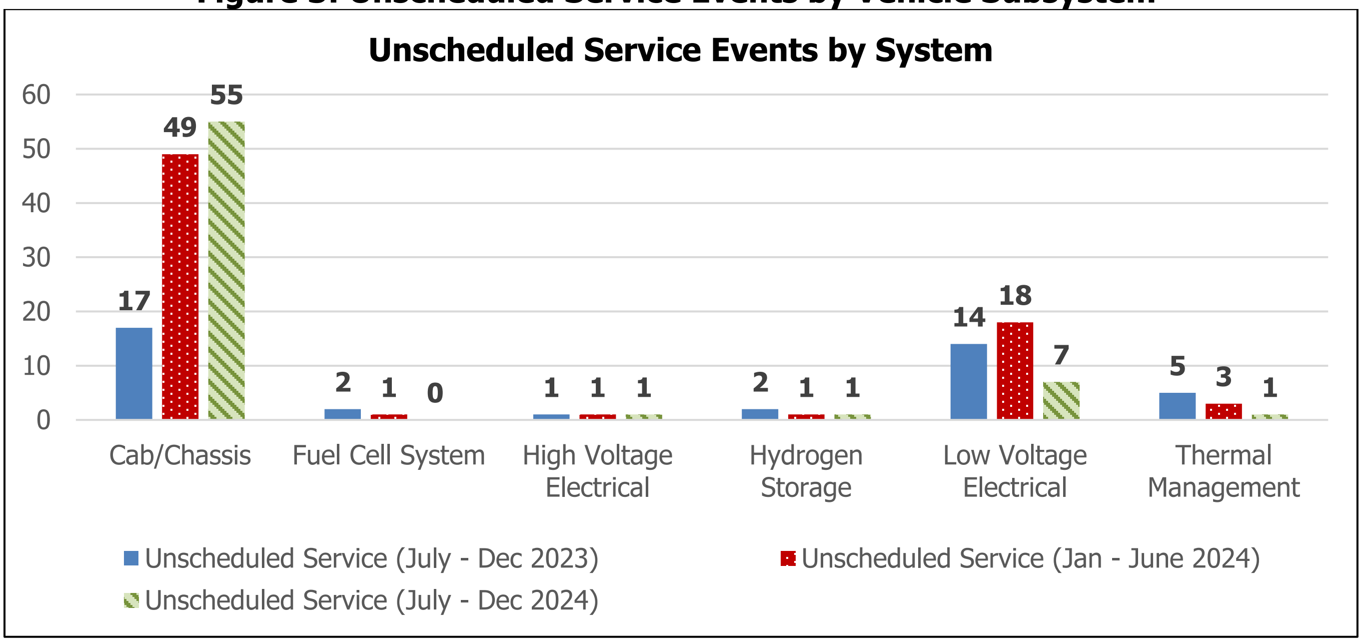
Table 7: Out of Service Days by Vehicle System Type and Type of Service Needed (July 2023 – June 2024)

	Jul – Dec 2023	Jul – Dec 2023	Jan – Jun 2024	Jan – Jun 2024	Jul-Dec 2024	Jul-Dec 2024
System Type	Scheduled Service	OOS days	Scheduled Service	OOS days	Scheduled Service	OOS days
Cab/Chassis	2	1	6	48	1	27
Maintenance	38	17	80	41	67	66
Low Voltage Electrical	1	3	0	0	0	0
Total	41	21	86	89	68	93

Source: CTE

Figure 3 provides a visual representation of total unscheduled service events by vehicle subsystem over the entire deployment. It is important to note, a significant portion of Cab/Chassis OOS days can be attributed to driver-related errors, not functional deficits of the vehicle.

Figure 3: Unscheduled Service Events by Vehicle Subsystem



Source: CTE

According to Papé, the XCIENTs have been comparable in unscheduled downtime compared to their diesel counterparts. The powertrain/aftertreatment in an internal combustion engine vehicle is typically the largest cause of downtime in a standard fleet. FCETs traded that system for the hydrogen fuel powertrain and have experienced relatively few unscheduled service events. Many of the cab/chassis issues correlate to what a diesel fleet would see such as taillights, tires, body damage, etc. As Glovis increases utilization of the fleet, it is normal and expected to see more of those wear and tear items. Alternatively, as they've run more miles and utilized the trucks more, they've seen fewer low voltage and FCET-specific issues.

Utilization

Utilization directly impacts the efficiency, profitability, and sustainability of an operation. A truck is defined as utilized if it carried cargo to or from a destination. Potential workdays exclude weekends and federal holidays. The duration of the trip or the amount of cargo carried did not influence if the truck was considered to perform work on a giving day.

In April 2024, Glovis subleased five trucks from GET to another of their subsidiaries, Extreme. When these trucks were subleased to Extreme, cargo data was no longer recoded for this subset of vehicles. Typically, GET supplies data on days of operation, but in this case, the information remained with Extreme. Since utilization is calculated based on cargo data, and all five subleased trucks recorded zero days of port and delivery operations, they were excluded from the calculation. **Table 8** provides the utilization rate for each month.

Table 8: Monthly Utilization Rate (July 2023 – December 2024)

Month[39]	Vehicle Quantities	Fleet-Wide Utilized Days	Operational Days in Month	Fleet-Wide Operational Days	Utilization Rate
July, 2023	7	11	23	161	6.8%
August, 2023	10	45	23	230	19.6%
September, 2023	18	49	23	414	11.8%
October, 2023	29	44	23	667	6.6%
November, 2023	30	60	23	690	8.7%
December, 2023	30	59	23	690	8.6%
January, 2024	30	171	22	660	25.9%
February, 2024	30	158	20	600	26.3%
March, 2024	30	178	21	630	28.3%
April, 2024	25	288	22	660	52.4%
May, 2024	25	241	23	690	41.9%
June, 2024	25	221	21	630	42.1%
July, 2024	25	262	22	550	47.6%
August, 2024	25	299	22	550	54.4%
September, 2024	25	276	20	500	55.2%
October, 2024	25	309	23	575	53.7%
November, 2024	25	265	20	500	53.0%
December, 2024	25	317	19	475	66.7%
Totals	--	3,253	--	9,872	33.0%

Source: CTE

[39] Due to phased truck deliveries (June and September), driver training, and initial truck testing and servicing, each truck has a unique in-service start date. These in-service dates correspond with the date each truck first handled cargo.

The average utilization during this reporting period experienced a 50% increase from the previous reporting period, rising from an average of 36% utilized to 55% utilized. Referring to **Table 3**, utilization improvements mirrored percentage increase in fuel consumption (57.8%); however, did not mirror percentage increase in mileage (33.9%). This is primarily attributed to GET Freight’s current duty cycle, completing a lot of shuttle-type trips from the Port of Oakland to a nearby Union Pacific rail terminal. These trips consume driver labor and fuel idling, but do not necessarily accumulate high mileage. These trips are most typically handled by diesel drayage trucks, emphasizing the value of port improvement projects as a direct means to reduce vehicular emissions. This could be achieved via a direct railway line that would run inside the port area, allowing cargo containers to be loaded and unloaded directly from ships onto trains without the need for additional truck transport.

Cargo Weight

Cargo weight refers to weight goods being hauled and delivered to the customer. Both FCETs and battery-electric trucks currently have heavier curb weights than a typical diesel tractor, so it is critical to assess the impact cargo weight has on both vehicle fuel efficiency and ability to carry similar loads to a diesel tractor. A typical diesel Class 8 highway tractor can weigh between 18,000-21,000lbs[40]. The first-generation XCIENT FCET has a curb weight of 28,400 lbs. As of 2018, the State of California has allowed zero-emission vehicles a 2,000 lb. weight exemption above the federal limit of 80,000 lbs.

Table 9 includes data on cargo weight delivered by GET Freight throughout the entire duration of the project. Load Weight includes the container, its cargo, and the truck chassis. Total Weight is both the Load Weight and the weight of the FCET itself. This reporting period, Glovis hauled loads well below State gross vehicle weight limits, with an average total weight of 57,817 lbs.

[40] https://www.trucknews.com/features/how-to-load-trailers-and-distribute-weight-trucking-202/

Table 9: Cargo Delivery Weights Per Month

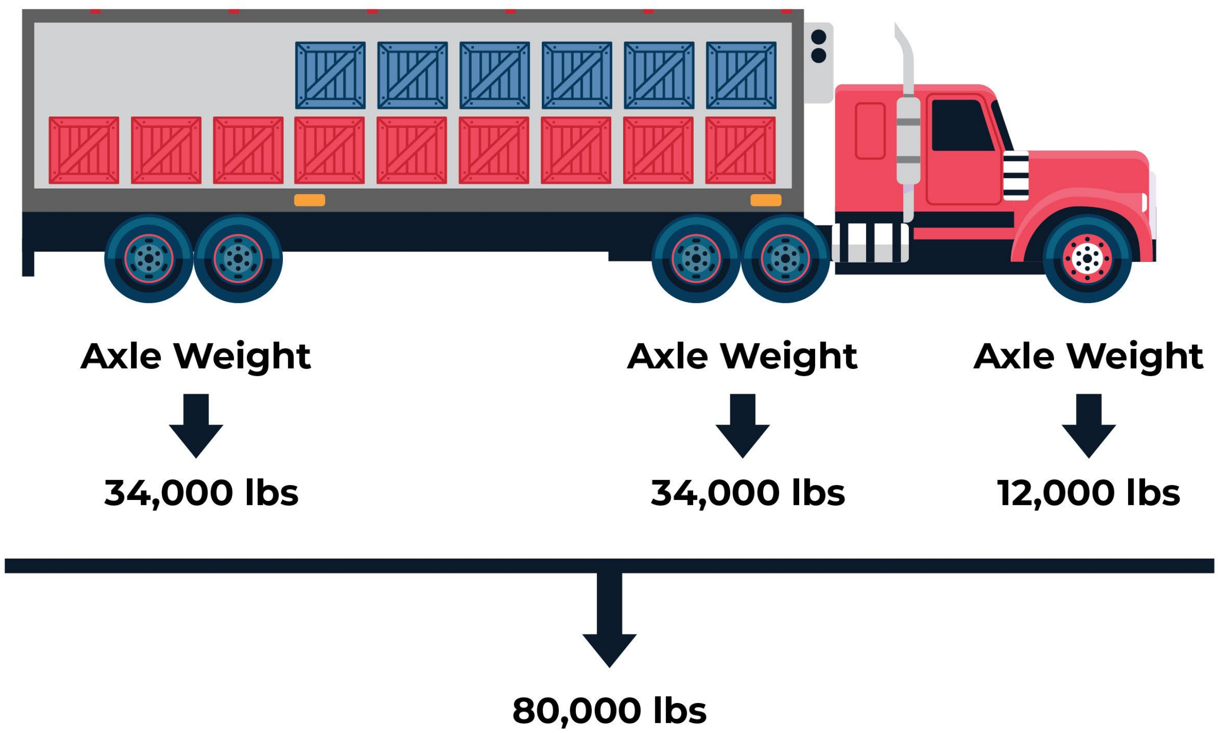
Month	Trips	Avg. Load Weight (lb.)	Avg. Cargo Weight (lb.)	Avg. Total Weight (lb.)
July, 2023	15	35,071	27,498	63,471
August, 2023	48	35,016	27,455	63,416
September, 2023	53	20,718	14,067	49,118
October, 2023	71	21,111	13,819	49,511
November, 2023	75	20,593	13,989	48,992
December, 2023	75	33,764	26,223	62,164
January, 2024	134	28,687	21,152	57,087
February, 2024	140	32,375	25,250	60,775
March, 2024	176	36,163	28,586	64,563
April, 2024	400	31,797	24,406	60,197
May, 2024	340	25,945	18,422	54,345
June, 2024	299	28,610	21,021	57,010
July, 2024	345	26,401	18,881	54,801
August, 2024	419	29,298	21,723	57,698
September, 2024	317	29,441	21,956	57,841
October, 2024	334	20,519	13,037	48,919
November, 2024	307	33,740	26,480	62,140
December, 2024	627	33,767	26,371	62,167
Totals	4,175	29,417	21,983	57,817

Source: CTE

While Extreme was unable to provide detailed cargo weight data, they could provide general cargo weight information. As previously mentioned, Extreme is in the business of hauling light-duty cars. They typically max out their diesel 9-car haulers with 35,000 lbs in cargo. FCETs have a different weight distribution than diesel drayage trucks, requiring careful consideration towards the load on each of the truck's three axles. Extreme maxes out the FCET car haulers at around 23,000 lbs, with the weight limit governed by axle loading, not gross vehicle weight.

Figure 4 below provides a visual representation of American axle load limits for a diesel tractor.

Figure 4: Overview of American axle loading limits[41]



Source: CTE

Because FCETs are heavier than diesel, Extreme can haul fewer cars with each trip, meaning each trip is less profitable than it would otherwise be. Heavier loads naturally will reduce FCET range; however, they allow operators enhanced flexibility if range is not their primary concern. Lawmakers can encourage immediate adoption of zero-emission trucks by working with OEMs to understand the technical limitations of increasing weight limits (i.e. axle limits, suspension limits, tire ratings, etc.) and then further increasing both axle and gross vehicle weight allowances on state roads based on what battery-electric trucks and FCETs can reasonably handle. Once there has been sufficient innovation such that vehicle curb weights are more comparable to diesel, then lawmakers could consider repealing additional weight exemptions.

[41] https://www.trucknews.com/features/how-to-load-trailers-and-distribute-weight-trucking-202/

Cargo Destinations

Tables 10, 11, and **12** include cargo delivery destinations for the 25 trucks operated by GET Freight. From July to December 2023, the most frequently visited cargo delivery destination was a rail yard in Lathrop, California, accounting for nearly half of all revenue-generating trips. In January – June 2024 and July – December 2024, the most common destination shifted to the Union Pacific rail terminal in Oakland, California. During the first half of 2024, more than one-third of all revenue-generating trips went to this location, increasing to more than half of revenue-generating trips in the second half of the year.

Table 10: Cargo Deliveries by Destination (July – December 2024)

Destination	Trips	Gross Load Weight (lbs.)	Gross Cargo Weight (lbs.)	Average Cargo Weight (lbs.)
Lathrop	269	7,359,076	5,585,156	20,763
Escalon	5	41,116	0	0
Port of Oakland	79	683,072	46,480	588
Richmond	147	2,278,731	1,503,409	10,227
Sacramento	93	1,624,474	901,694	9,696
Union Pacific	1412	45,706,066	34,895,349	24,713
Fairfield	13	595,157	487,307	37,485
ONE	172	5,662,158	4,307,366	25,043
Modesto	9	226,586	152,753	16,973
GSC	20	165,942	0	0
Hyundai Merchant Marine	130	4,758,456	3,715,350	28,580
Totals	2349	69,100,834	51,594,863	21,965

Source: CTE

Table 11: Cargo Deliveries by Destination (January – June 2024)

Destination	Trips	Load Weight (lb.)	Cargo Weight (lb.)	Avg Cargo Wt.
Lathrop	268	8,908,078	7,018,132	26,187
SIEMENS (Sac)	3	100,438	75,372	25,124
Port of Oakland	169	3,838,874	2,523,015	14,929
Richmond	96	1,487,389	930,550	9,693
Sacramento	17	259,039	124,499	7,323
Union Pacific	594	21,752,389	17,159,647	28,888
Tracy	19	501,534	344,554	18,134
Hayward	1	33,329	24,820	24,820
ONE	163	5,488,097	4,167,292	25,566
CMA CGM Group	55	888,864	590,601	10,738
GSC National Transportation	68	546,367	7,275	107
ITG	2	16,535	0	0
Oakland International Container Terminal	1	8,157	0	0
Zinus	1	23,551	15,383	15,383
SIMWON AMERICA	3	112,875	87,169	29,056
Hyundai Merchant Marine (HMM)	29	870,248	643,172	22,178
Totals	1,489	44,835,766	33,711,482	22,640

Source: CTE

Table 12: Cargo Deliveries by Destination (July – December 2023)

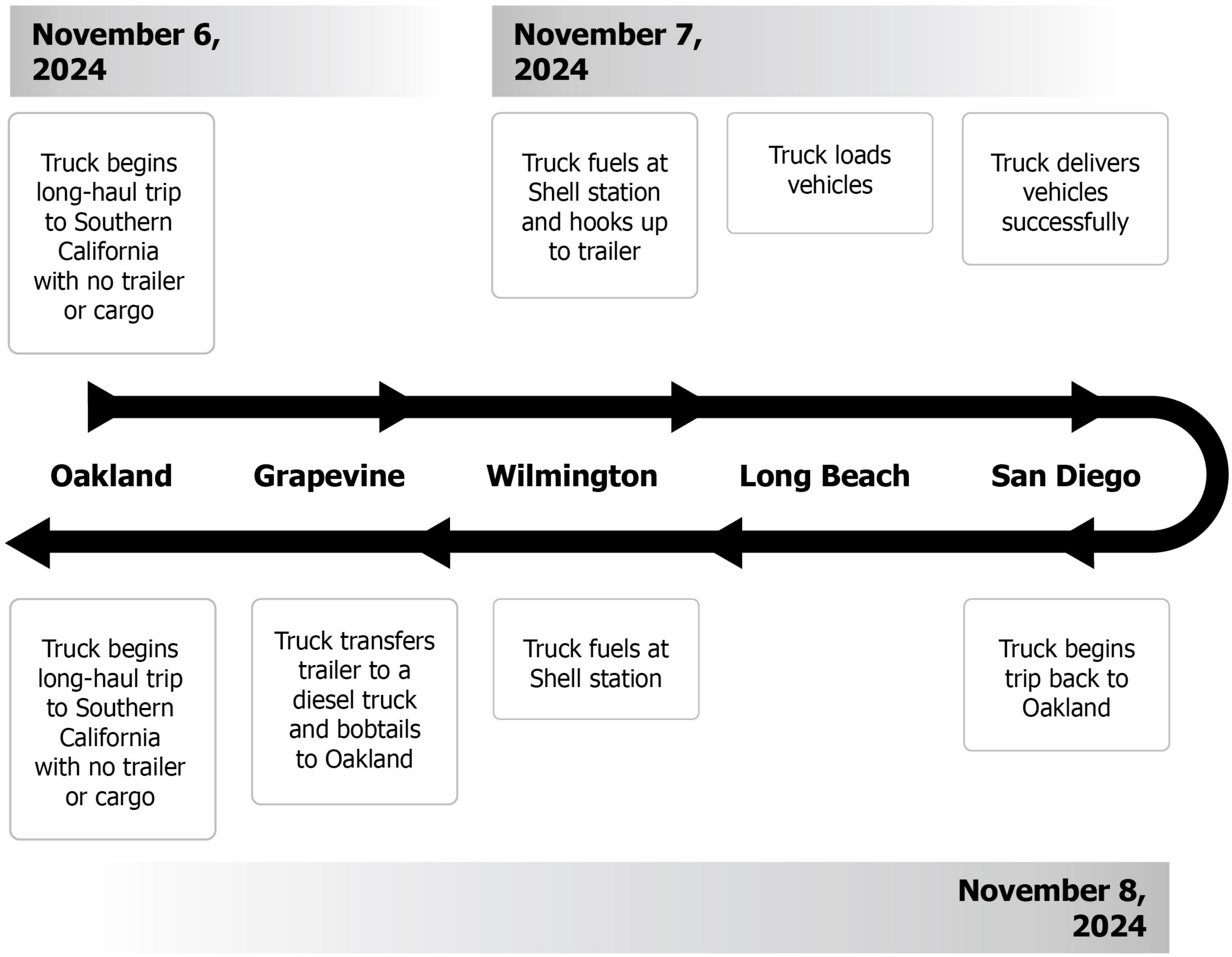
Destination	Trips	Load Weight (lb.)	Cargo Weight (lb.)	Avg Cargo Wt.
Yard to Lathrop	168	4,552,244	3,410,055	20,298
Lathrop to Yard	3	41,810	24,394	8,131
Port	35	909,409	623,562	17,816
Richmond	60	1,172,922	769,403	12,823
Yard to Port	3	17,417	0	0
Union Pacific	51	1,812,753	1,393,984	27,333
Tracy	4	113,765	80,463	20,116
Hayward	7	219,013	161,101	23,014
Port; Ret. empty	5	26,720	0	0
Stockton	1	14,541	9,911	9,911
Totals	337	8,880,593	6,472,872	19,207

Source: CTE

Extreme Long-Haul Trip to Southern California

In November 2024, Extreme tested a long-haul trip from Oakland to Southern California. **Figure 5** provides a graphical representation of the timeline of the trip.

Figure 5: Timeline for Long-Haul Trip from Oakland to Southern California



Source: CTE

On November 6, the FCET bobtailed[42] from Oakland towards Southern California, but ran out of driver hours on the way to Wilmington due to the limits set by the Federal Motor Carrier Safety Administration, which restricts how many hours a driver can operate a vehicle in a day to ensure safety.

The next day, the FCET completed the trip to Wilmington, refueled at the Shell station, hooked up to the trailer, and successfully loaded vehicles in Long Beach for delivery to San Diego. After completing the delivery, the truck returned from San Diego to Wilmington, refueled

[42] Bobtailed" refers to a truck operating without a trailer or cargo. In this context, it means the truck was driving without its usual load or trailer attached, typically only carrying the truck's chassis.

again, and began hauling the trailer north. However, halfway back to the Grapevine[43] from Oxnard, the driver determined the truck would not be able to complete the journey back to Oakland, and the diesel backup truck transported the trailer the rest of the way. The total trip covered 868 miles.

While fueling data is available for fills at the FirstElement Fuel station, the team lacks records from the refueling events at the Shell station in Wilmington. Without this data, it was not possible to calculate a trip-specific fuel economy.

This test highlighted specific challenges. While the FCET successfully bobtailed over Interstate 5's Grapevine, the driver felt most comfortable transferring the fully loaded trailer to a diesel tractor on the way back. Future FCET models could improve by increasing the fuel cell power output to more quickly recharge batteries depleted by steep grades like the Interstate 5 Grapevine, while also incorporating weight reductions to enhance efficiency.

[43] Interstate 5 between Santa Clarita and the San Joaquin Valley is commonly referred to as "The Grapevine" by locals and traffic reporters

Average Speed

Some short trips, such as port trips, often involved the handling and repositioning of cargo containers for future deliveries. These routine runs experience low average speeds and should not be aggregated with the average speed when performing deliveries in revenue service. If a trip was greater than one mile but less than five miles, it was considered to be a short trip and evaluated separately from regular delivery trips. **Table 13** includes a breakdown of average speed under different trip length conditions. In the second two quarters of 2024, there were 152 trips with an average speed of over 50 mph. These 152 trips totaled 8,818 miles and demonstrate that the FCETs are fully capable of hauling cargo at speeds up to allowable legal limits (55 mph for commercial trucks on most California highways).

Table 13: Average Speed Per Trip Type (July 2023 – December 2024)

Trip Distance	Total Dist. (mi)	Total Time (hr.)	Avg mph	% Total Dist.	% Total Time
July – December 2023					
All Trips	53,584	1,949	27.5	100.0%	100.0%
Trips > 5 miles	48,154	1,342	35.9	89.9%	68.8%
Trips > 1 mile and < 5 miles	4,801	477	10.1	9.0%	24.5%
January – June 2024					
All Trips	132,127	5,115	25.8	100.0%	100.0%
Trips > 5 miles	116,697	3,324	35.1	88.3%	65.0%
Trips > 1 mile and < 5 miles	13,100	1,403	9.3	9.9%	27.4%
July – December 2024					
All Trips	174,098	7,213	24.1	100.0%	100.0%
Trips > 5 miles	149,862	4,553	32.9	86.1%	63.1%
Trips > 1 mile and < 5 miles	20,782	2,104	9.9	11.9%	29.2%

Source: CTE

Hydrogen Fuel Station Data Overview

During this reporting period, the permanent station, which is located next to East Bay Municipal Utility District's (EBMUD's) wastewater treatment facility, became fully commissioned and operational. The station has been providing 24/7 fueling access for both heavy- and light-duty vehicles and was recently retrofitted to accept low-loss liquid hydrogen delivery technology by Air Liquide. Due to its location just outside of the Port of Oakland, the station is essential to expanding the operation of fuel cell electric vehicles in the face of a growing influx of freight in Northern California.

Since the station is now fully commissioned, the project team has collected and analyzed fuel log data. The available data provides insight into fueling activity, including timestamps, fuel quantity dispensed, and system pressure readings. This allows for a comprehensive evaluation of station performance and fueling efficiency. However, there are notable gaps in the data that limit certain analyses, such as dispenser-specific performance, descriptions of station maintenance service events, and detailed temperature readings that could affect fueling behavior.

Below is an overview of the data and its associated availability during this reporting period:

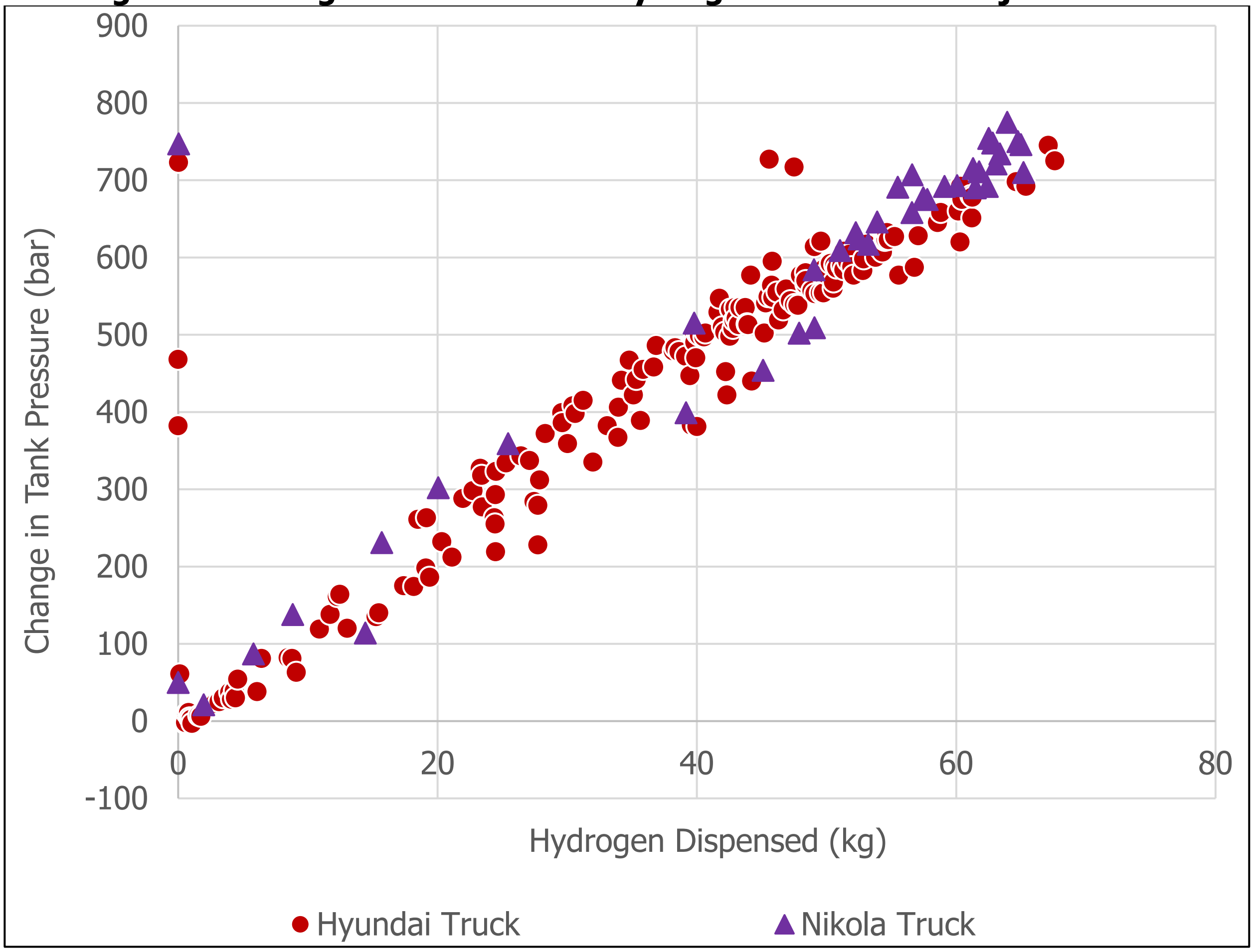
- **Start of Fill Date/Time**: Complete data for all fill entries.
- **H2 Filled (kg)**: Captured for all fills, including incomplete attempts.
- **Fill Time (s)**: Recorded for every entry, though very short times (e.g., incomplete fills) appear in some cases.
- **Start and Final Pressure (bar)**: Detailed for all fills.
- **Final SOC (%)**: Available for successful fills where communication systems functioned.
- **Fill Communications**: Differentiates between communication and non-communication fills, where data transmission between the station and the vehicle was lost. Information appears reliable for communication fills.
- **Fill Rate (kg/min)**: Calculated for all fills where H2 dispensed and fill time are available.
- **Dispenser ID**: Unavailable. This prevents the analysis of specific dispenser performance.
- **Ambient Temperature**: Not recorded, which hinders the ability to analyze the environmental impacts on fueling efficiency.
- **Pre-Cooling Temperature**: Unavailable. This is critical for assessing pre-cooling system performance, as temperature fluctuations during fueling can impact system performance.
- **Tank Temperature**: Unavailable. Tank temperature data is used to understand how much heat is introduced to the system under different filling conditions.
- **Description of Station Maintenance Service**: Unavailable. This limits the ability to assess maintenance events and their potential impact on system performance.

- **Final SOC for Non-Communication Fills**: Although the station records final pressure and H2 dispensed, the reliability of these values is questionable when communication between the station and the vehicle was lost. These fills require further validation before they can be considered for accurate analysis. As a result, most analysis in this section excludes these fills.
- **Vehicle Name or Type**: Partially available. While some entries include vehicle names (e.g., "Hyundai Truck"), many others are labeled as "Unknown." This limits the ability to analyze fueling behavior based on vehicle-specific characteristics.

Final Fill Pressure and Hydrogen Dispensed

Figure 6 represents hydrogen dispensed versus change in tank pressure for fueling sessions that did not experience communication losses. The data includes fills from two different FCET models that have been filling at the station—the Hyundai XCIENT FCETs funded under this grant program and the Nikola FCETs. The team conjoined any fill data with small interruptions[44] to be able to evaluate each fill as a singular event. The conjoining approach allows for more accurate representation on the relationship between hydrogen dispensed and change in tank pressure. The results demonstrate a highly linear relationship between hydrogen dispensed and final fill pressure, as expected.

Figure 6: Change in Pressure vs. Hydrogen Added for Conjoined Fills



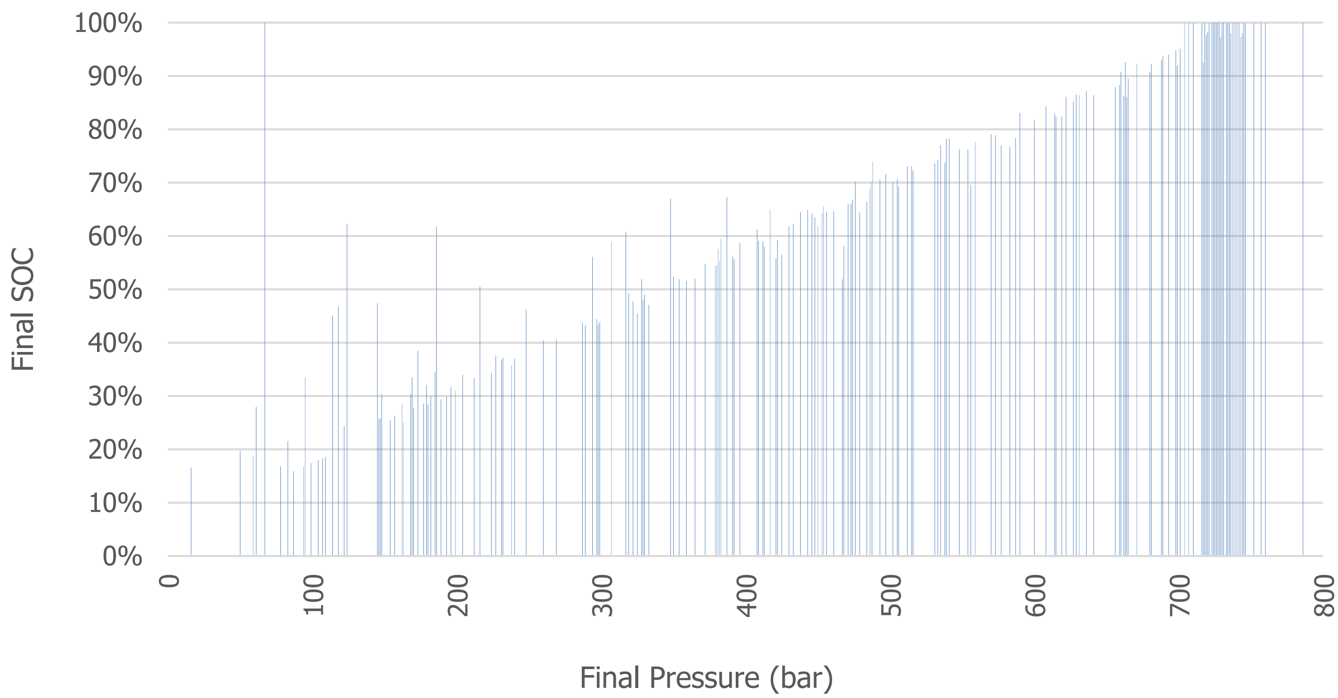
Source: CTE

[44] To ensure a more accurate representation of fueling sessions, fills that were interrupted have been conjoined into a single session where appropriate. This approach minimizes the number of partial fills in the dataset and provides a clearer picture of the complete hydrogen dispensing process. Fills were only conjoined if communication was not lost, they belonged to the same vehicle, with the end pressure of one row matching or being within 25 bar of the start pressure of the next row, and if the start and end times were within two minutes of each other.

Final Fill Pressure and Vehicle State of Charge (SOC)

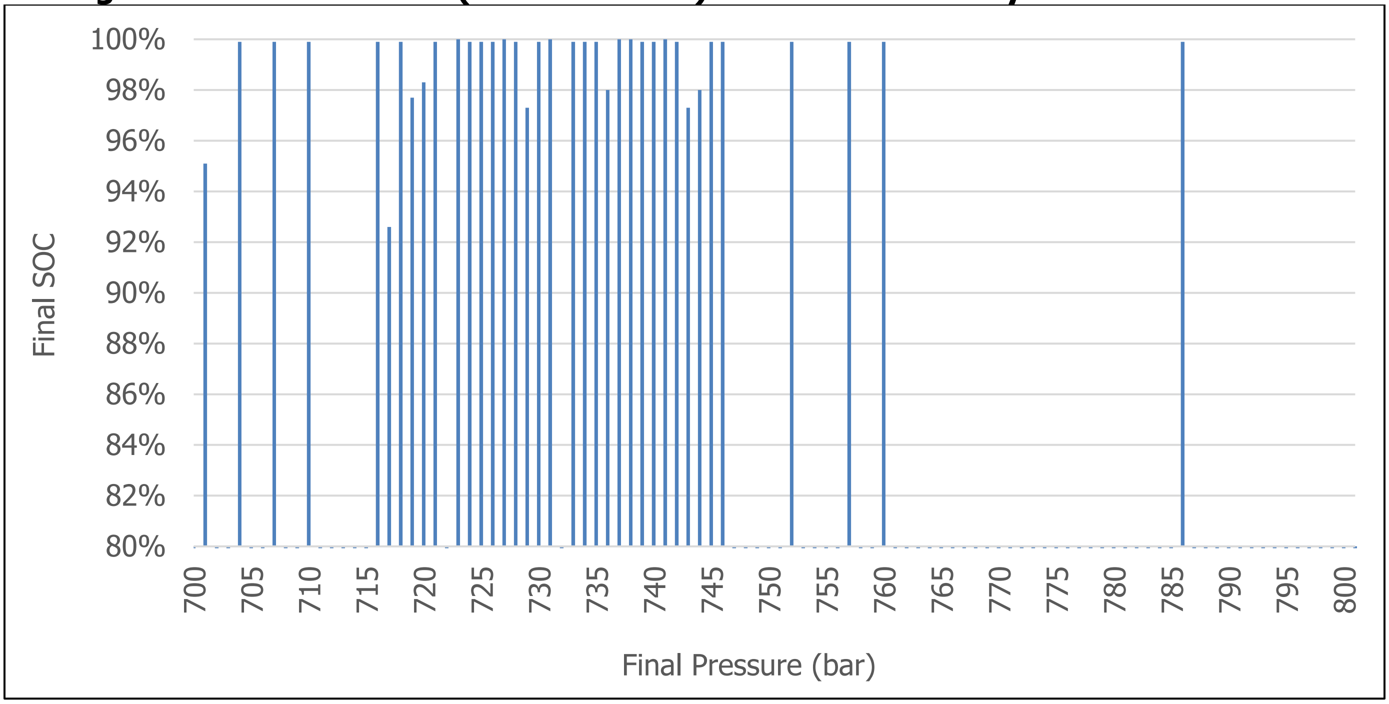
Vehicle SOC is on the FCET dashboard and serves as the primary indicator to the driver on how much fuel is remaining onboard the vehicle. **Figure 7** provides a visual representation of the immediate final fill pressure recorded at the hydrogen station for various state of charge (SOC) values for Hyundai FCETs. The data only includes fills where communication was not lost and does not conjoin partial fills. **Figure 8** iterated on **Figure 7** to "zoom in" on final pressures between 700 and 800 bar and demonstrates that while final fill pressure generally follows a linear trend with SOC, a 100% SOC can correspond to a wide range of final fill pressures.

Figure 7: Final Pressure vs Final SOC for Hyundai Truck Fills



Source: CTE

Figure 8: Final Pressure (700 – 800 bar) vs Final SOC for Hyundai Truck Fills



Source: CTE

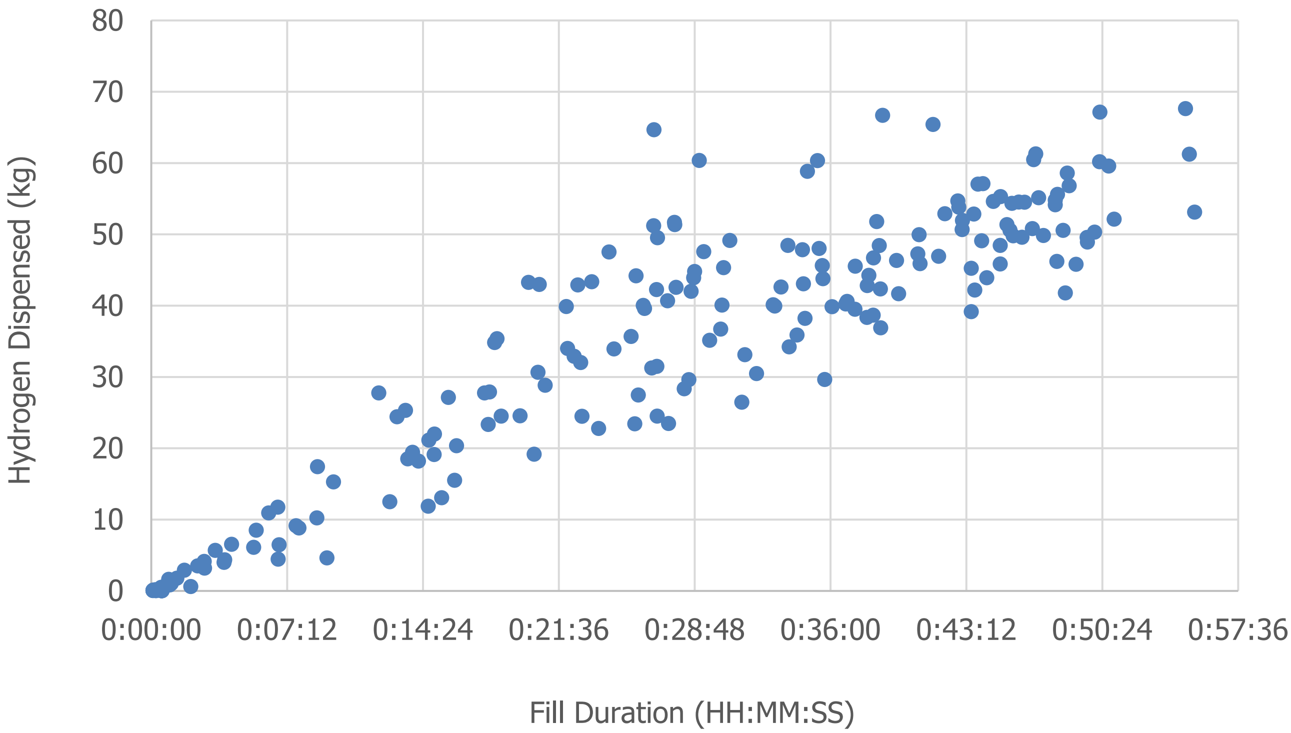
CTE expects the wide variation in final pressure for the same or similar SOC is due to SOC being a calculated value that depends on multiple raw inputs, including tank temperature. **Figure 6** validates that final fill pressure and hydrogen dispensed follow a linear trend. Lower final pressures that correspond to 100% SOC may simply be fills with warmer gas within the vehicle tank.

In the fourth quarter of 2024, the station began making improvements on its pre-cooling system. This means that before the improvements are complete, the temperature of the gas being used to fill the trucks may have been highly variable, corresponding to the wide array of final fill pressures associated 100% SOC. If the driver leaves for a delivery immediately after filling and before tank temperature has a chance to equilibrate and recalibrate SOC, they may experience variable ranges on the same delivery route with the same weight of load. Having consistent SOC readings is critical to build driver trust in vehicle capabilities and emphasizes the importance of consistent pre-cooling capabilities at hydrogen refueling stations.

Fill Duration

Figure 9 illustrates the relationship between fill duration and hydrogen dispensed for conjoined fills for Hyundai FCETs only. The data for this graph includes instances where communication was lost during the fill process. Initially, using only fills with communication led to discrepancies in the start and end times of the data, resulting in inaccurate duration measurements. By incorporating fills where communication was lost, the team was able to accurately identify and analyze both the duration and the amount of hydrogen dispensed. While there is some variability in the hydrogen dispensed as fueling time increases, the data generally follows a linear trend. The maximum hydrogen dispensed is limited to just under 70 kg, which closely matches the tank size.

Figure 9: Fill Duration vs. Hydrogen Added for Conjoined Fills



Source: CTE

The data in **Figure 9** reveals a slower fill rate than original anticipated when developing the grant program (approximately 1-2 kg/min). Fill rates are likely to improve once pre-cooling improvements are complete. Future development work on implementing H70 high flow fueling protocol (J2601-5) on both vehicles and infrastructure could also improve fill speeds, achieving a more comparable fill time to a typical diesel Class 8 truck.

Data Challenges

There are data elements listed in *GFO-20-606 Attachment 20: Data Collection Requirements,* which the project team cannot either collect or disclose. The project team is unable to collect Fuel Cell Degradation, which cannot be accurately measured onboard the vehicles with existing monitoring equipment and is also considered proprietary by Hyundai Motor Company and not available for public dissemination.

The fuel price paid by Glovis is strictly confidential and significantly subsidized and cannot be included in this data report.

The project team faced several data challenges that impacted the ability to fully assess hydrogen station performance. Missing or unavailable data, such as ambient temperatures and vehicle tank temperatures, hindered analysis of fueling efficiency. Station maintenance records were also not provided, making it difficult to evaluate the impact of servicing activities on refueling availability. This data will begin becoming available in 2025. Non-communication fills presented another issue, as some key fueling data could not always be validated and had to be excluded from the analysis. To enhance future deployments, OEMs and station developers can improve station-to-vehicle communication, expand data logging, and automate station maintenance tracking to maximize the utility of collected information.