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ENERGY COMMISSION**



California Energy Commission
Clean Transportation Program

FINAL PROJECT REPORT

BLUEPRINT FOR IMPLEMENTATION OF HEAVY-DUTY ZERO- EMISSION VEHICLES IN THE TIMBER AND BIOMASS HAULING SECTOR

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Volvo Trucks North America
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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 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to \$20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Budget Act of 2021 (AB 128, Ting, Chapter 21, Statutes of 2021, as amended by Senate Bill (SB) 129, Skinner, Chapter 69, Statutes of 2021 and SB 170, Skinner, Chapter 240, Budget Act of 2021) appropriated \$785,000,000 from the General Fund to support infrastructure deployments and manufacturing projects for zero-emission light-, medium-, and heavy-duty vehicles.

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

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- 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 CEC issued GFO-20-601 to fund planning "blueprints" that will identify actions and milestones needed for the implementation of medium- and heavy-duty (MDHD) zero-emission vehicles (ZEVs) and the related electric charging and/or hydrogen refueling infrastructure. In response to GFO-20-601, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards August 16, 2021 and the agreement was executed as ZVI-21-013 on February 8, 2022.

ABSTRACT

California’s logging and biomass hauling sector depends almost entirely on diesel-powered heavy-duty trucks, yet it is central to forest management, wildfire risk reduction, and statewide climate objectives. As forest management activities expand, decarbonizing this sector becomes increasingly important. This project developed a Blueprint to evaluate the technical and economic feasibility of deploying zero-emission vehicles (ZEVs) in logging and biomass hauling applications, with a focus on Class 8 trucks operating in Northern California.

The project established baseline vehicle specifications, duty cycles, operating patterns, and cost structures through stakeholder interviews and fleet data analysis. Available and near-market technologies, including hydrogen fuel cell electric trucks (FCETs), battery-electric trucks (BETs), and natural gas engine trucks, were assessed against the operational requirements of logging and biomass hauling. The analysis considered vehicle performance, range, payload capacity, refueling or charging needs, infrastructure requirements, and comparative operating costs relative to diesel vehicles.

The evaluation found that most current Class 8 BETs lack the range and charging flexibility needed for logging operations, though some may be suitable for limited fixed-route biomass hauling. Natural gas engine trucks offer emissions reductions and fuel cost advantages but are constrained by fueling infrastructure availability in the studied region. Class 8 FCETs were identified as the most technically viable ZEV option for logging due to their range, rapid refueling capability, and ability to meet payload requirements.

Based on these findings, the final Blueprint proposes a phased pilot and demonstration project utilizing FCET logging trucks supported by on-site hydrogen production via electrolysis at a Northern California sawmill. The Blueprint outlines infrastructure needs, permitting considerations, emissions impacts, and financing approaches to inform future deployment and replication in California’s logging and other heavy-duty sectors.

Keywords: Logging, Biomass Hauling, Sawmill, Hydrogen Refueling, Forest Management

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EXECUTIVE SUMMARY

Log and related biomass hauling is an important sector of California's heavy-duty trucking fleet and one that needs to scale up significantly to manage California's wildfire crisis and address the state's climate change goals. To scale forest management to meet these needs, significant growth in the forest management sector will be necessary, resulting inevitably in a significant increase in the number of heavy-duty trucks for hauling logs and biomass (i.e., wood chips) that traditionally are diesel-fueled. In order to support this growth and support the state's climate goals, zero-emission vehicles (ZEVs) will ultimately need to be adopted in this sector. Decarbonization of the sector can, in turn, generate a multitude of benefits, from reducing use of diesel with related economic and environmental benefits, to promoting environmentally appropriate forest management practices by reducing the costs of managing low-value forest biomass, to alleviating forest fire risk. Yet to do so, proof that ZEVs are viable and can meet the needs of industry, and do so economically, is critical.

The goal of this project is to demonstrate the technical and economic viability of heavy-duty ZEVs in the logging/timber sector through the development of a Blueprint planning document that will, in turn, ultimately drive adoption of ZEV solutions that could meaningfully serve the sector. The development of this Blueprint was built upon in-depth analyses consisting of both technical specifications of ZEV solutions that could viably serve the logging and biomass sector and of the underlying economics of the proposed solutions versus existing diesel-fueled vehicles and infrastructure. Stakeholders within the sector were engaged to both define the use-cases within the sector as well as to develop the minimum required technical specifications for heavy-duty ZEVs in order to meet the challenging workloads. Next, analysis was performed on in-market or near-market ZEV options across a range of manufacturers and technologies, including hydrogen fuel cell electric trucks (FCETs) and battery-electric trucks (BETs), as well as natural gas engine trucks (NGETs), to determine which options would be best suited to meet the specifications required for logging and biomass hauling trucks.

Finally, the economics of the proposed versus existing solutions for both heavy-duty vehicles and related infrastructure was examined. With the completion of this project, the project team is confident that through the developed Blueprint, the logging and biomass sector, as well as potentially other heavy-duty sectors like mining, have the technical specifications of a ZEV and supporting infrastructure solution that could viably serve the sector.

CHAPTER 1:

Project Purpose and Approach

Purpose

The goal of this project is to demonstrate the technical and economic viability of heavy-duty ZEVs in the logging/timber sector through the development of a Blueprint planning document that will, in turn, ultimately drive adoption of ZEV solutions that could meaningfully serve the sector. Log and related biomass hauling is an important sector of California's heavy-duty trucking fleet and one that needs to scale up significantly to manage California's wildfire crisis and address the state's climate change goals. To scale forest management to meet these needs, significant growth in the forest management sector will be necessary, resulting inevitably in a significant increase in the number of heavy-duty trucks for hauling logs and biomass (i.e., wood chips) that traditionally are diesel-fueled.

In order to support this growth and also support the state's climate goals, ZEVs need to be adopted in the logging and biomass sector, yet to date, the sector has not entertained the possibility of ZEVs and there are no existing examples or models of how ZEVs could be utilized. Based on interviews with stakeholders throughout the sector, the leading impression is that ZEV adoption would be financially unfeasible and that the technical challenges ZEVs face in serving the logging and biomass sector are significant.

In order to assess the economic and technical potential of adopting heavy-duty ZEVs in this industry, a baseline understanding of the requirements of ZEVs for the logging and biomass sector needed to be developed and the available ZEV technologies needed to be evaluated to see which ZEVs are capable of meeting the requirements for these use cases. With this foundational understanding in place, a "Blueprint" for a pilot fleet of ZEVs in the logging industry, including the necessary related infrastructure and services, was developed by working in tandem with industry players, local and state officials, community members and financial institutions, to demonstrate the technical and economic viability of ZEVs in this sector and potentially others (e.g., mining). The Blueprint focused on Shasta County and the surrounding region. The logging and biomass sector is an important economic driver in the region and many of the state's largest operators are located there, making it an ideal location from which to initiate this process.

General Barriers

The logging and biomass hauling sector in California is highly dependent upon diesel-powered heavy-duty vehicles, particularly logging trucks to haul logs and biomass hauling trucks to haul chipped material. These vehicles in many cases must deal with significant logistical challenges, traveling relatively long distances from a variety of locations on challenging roads, though generally delivered to a central location like a

sawmill or a biomass power plant. Beyond these logistical challenges, diesel trucks face operational challenges including fluctuating and increasingly high diesel prices, and relatively high maintenance costs. Private truck operators are also challenged to meet increasingly stringent emissions requirements.

Skepticism about the ability of ZEVs to address these challenging conditions can only be addressed through a pilot test where such vehicles are operated in those environments. Proof that ZEVs can meet the needs of the logging and biomass sector and are viable solutions economically is critical to scaling the adoption of ZEVs and decarbonizing the sector. Decarbonization of the sector can, in turn, generate a multitude of benefits, from reducing use of diesel with related economic and environmental benefits, to promoting environmentally appropriate forest management practices by reducing the costs of managing low value forest biomass. As a result, ZEVs could address multiple key elements of California's effort to address climate change as well as alleviate forest fire risk.

Objectives of the Blueprint

The objectives of the Blueprint are to investigate the potential for the use of heavy-duty ZEVs in the logging/biomass transport industry by:

1. developing the technical specifications a vehicle would need to address the logging/timber industry's needs, as well as the related infrastructure needed for ZEVs and their operators to support their activities;
2. determining if there is a ZEV solution that could viably serve the sector; then
3. outlining one or more pilot projects that can demonstrate the costs and benefits of utilizing ZEVs in the sector; and
4. presenting the resulting plan to the industry and community to build support for the adoption of ZEVs in the logging/timber sector.

Approach to Achieve Project Purpose

The approach to achieve the project's goals and objectives included in-depth data gathering through in-person interviews and researching publicly available data from ZEV manufacturers to establish a baseline understanding of the use-case requirements and vehicle specifications currently supported by existing, diesel-powered infrastructure for this sector. Existing and near-future ZEVs, and their associated infrastructure requirements, were analyzed to determine which ZEVs would best address the requirements and specifications of the sector, as well as build the business case for how ZEV adoption could be economically viable versus diesel-fueled vehicles. Utilizing these baseline understandings, a Blueprint model for a pilot operation utilizing a ZEV solution to demonstrate the suitability of the technology within the sector was completed to promote adoption and replication of the ZEV pilots within the sector and across the state.

CHAPTER 2:

Project Activities Performed

The project activities performed for this Blueprint included developing baseline data on the typical types of heavy-duty trucks used in the logging/timber sector, assessing the available ZEV options currently available in the market, assessing the related infrastructure requirements for the various ZEVs, and determining which of these options are best suited for a pilot project within the sector.

Establishing a Baseline: Develop Baseline Data on Logging and Biomass Hauling Trucks

To understand the potential for ZEVs in the sector, the first step was to understand the requirements of heavy-duty vehicles utilized as logging and biomass hauling trucks and develop specifications for these vehicles. We also investigated grapple trucks,¹ an important specialty vehicle in the sector, though given the challenges of powering a mechanical grapple, a ZEV option seemed unviable at this time and was not included in further analysis. This work included discussions with leading timber companies, fleet managers, and fleet operations around Northern California (see footnote 3 on the following page).

Assessment of Logging and Biomass Hauling Truck Usage

Overall, we found that usage per day for both logging and biomass hauling trucks was generally consistent in terms of hours operated, as the operators' goals are generally to maximize the use of the vehicle. Average driving times or distances per load were less predictable, particularly for logging operations, as the location of the timber landing where trees were being cut and laid down for loads varies significantly over the course of a logging season. Typically, loggers will work out of a particular landing for a week or two and then shift to a different location when the cutting operations at that site are completed. In the Shasta County region, depending on the location of the timber mill in question, logging trucks may bring in four loads of logs to a mill per day with each round trip taking less than two hours, or one or two loads per day where the round trips are closer to three hours.

Biomass hauling distances and drive times can vary more than logging, as both the site of chipping operations and the final chip drop off locations can differ. Yet, that being said, there are also a number of examples of regular set routes for chip hauling (i.e., from a sawmill to a biomass electricity plant) that are predictable and often relatively

¹ See additional information in the Grapple Truck Specifications section.

short distances. Given the lower value of wood chips and grindings,² chips are rarely hauled for more than an hour one-way, as the cost of hauling is prohibitive. As a result, the incentive to leave chipped material in the woods rather than remove that material is greater.

Fleet Sizes

The largest operator in the Shasta County region, Sierra Pacific Industries, operates 161 logging trucks and 13 chip vans, with monthly mileage ranging from 1,685 to 9,056 miles. The typical annual mileage was consistently between 50,000 to 60,000 miles for logging trucks and chip vans.

The largest logging/timber mill operator on the Northern California coast, California Redwood Company, has significantly fewer trucks, with 18 logging trucks and 3 chip hauling vans. This operation manages with fewer trucks because their mills have less throughput, the distance from the logging sites to their mills is shorter, their classification of drivers as agricultural workers allows them to operate longer hours (up to 15 hours with 12 hours of operations), and they have some dependence on independent contract-based drivers. The typical annual mileage for their vehicles is a bit higher, in the range of 80,000 to 90,000 miles/year.

The largest operator of biomass chip vans in Northern California, Bettendorf Trucking, operates nearly 150 trucks and averages 300–400 miles/day. More of their routes are regular and predictable, such as regular runs from sawmills to biomass electricity plants.

These largest operators are summarized in Table 1.

Table 1: Leading Logging and Chip Hauling Fleets in the North State

	Number of Trucks	Estimated Average Monthly Mileage
Sierra Pacific Industries	161 logging; 13 chip vans	2,000 to 9,000 miles
California Redwood Company	18 logging; 3 chip vans	7,000 miles
Bettendorf Trucking	140-150 chip vans	7,000 miles

Source: *Allotrope Partners, LLC*

Smaller logging operators and individual “gypsy” truckers, many of whom have one to five trucks, have similar varied schedules based on the location of the current job. Consistently, smaller operators have reiterated that their goal is to run the vehicle as much as possible to ensure it is earning money to cover the cost of financing and

² Grindings are a less processed mix of coarse chips of bark and wood fiber.

operations. Typically, they run their vehicles for at least 8 to 10 hours/day.

Truck Specifications

The following section includes the typical vehicle specifications, infrastructure requirements, and costs for logging and biomass hauling trucks. This data was collected and summarized based on various conversations with a variety of logging/timber operators, fleet operators, and dealerships around Northern California and the North Coast.³

Logging Truck Specifications

Logging trucks are considered heavy-duty vehicles, and by law, can only run at a total gross weight of 80,000 pounds (40 tons). For independent loggers who desire trucks that can change trailers to handle both logging and biomass hauling duties by adding a fifth wheel, these trucks have the same specifications as a typical logging truck.

It is important to note that certain essential qualities of the truck were not easily summarized in the specifications, such as the need for a sturdy suspension and a robust chassis and frame that can manage the wear and tear of potentially rough, poorly maintained, unpaved logging roads and the pounding of loading and unloading logs.

Table 2: Logging Truck Specifications

Tare Weight (lbs; chassis and trailer without load)	25,000–28,000
Bare Chassis Weight (lbs)	17,000–22,000
Cargo Capacity (lbs; <80,000 lbs tare weight)	52,000–55,000
Range (miles)	500–550
Mileage (miles per gallon [mpg])	4–6.5
Horsepower	Typically, 550 or higher
Torque	1,850 ft/lbs minimum, most are over 2,000 ft/lbs
Transmission	18-speed (for managing hills both up and down)

³ Fleet operators and dealers included Atlas Tree Service, Bettendorf Trucking, Boyd Trucking, California Redwood Company, Cummins, Inc Freightliner Trucks, International Trucks, JW Bamford Inc, Kenworth Motor Truck Company, Muse Trucking, Peterbilt Motors Company, Sierra Pacific Industries, Volvo Trucks North America and Warner Enterprises. We believe the fleet operators represent a substantial portion, if not a majority, of the large operators in Northern California, although definitive data on the logging and biomass sector in the region is not readily available.

Ground Clearance/Tire Size	24.5” tires, rather than standard 22”, for higher clearance. Some loggers are returning to 22”, so this may not be a requirement.
Tractor Axles	Front Axle: 12,000 lbs
Trailer Axles	Locking double axles on trailer: 40,000 lbs minimum, often up to 44,000–46,000 lbs This allows for better weight distribution and longer life for wheels, brakes, and tires.
Turn Radius	Standard; no limitation identified

Source: *Allotrope Partners, LLC.*

Biomass Hauling Truck Specifications

Larger biomass hauling truck operators with biomass trucks dedicated to highway work will purchase trucks with less horsepower (e.g., in the range of 450 horsepower) and an automatic transmission. Such dedicated biomass hauling trucks tend to have more predictable routes, such as from a wood yard to a biomass energy facility or between company-owned operations.

The type of chip trailer can also impact the ultimate capacity. For example, “walking floor” trailers⁴ that can more easily unload chip loads are likely to be heavier.

Table 3: Dedicated Chip Trucks Specifications

Tare Weight (lbs)	25,000-28,000
Bare Chassis Weight (lbs)	17,000-22,000
Cargo Capacity (lbs; <80,000 lbs tare weight)	52,000-55,000
Range (miles)	500-550
Mileage (mpg)	5-8
Horsepower	450 or higher
Torque	1,850 ft/lbs minimum
Transmission	Manual 10-13-15-18 gear setups or automatic
Ground Clearance/Tire Size	Standard 22”

⁴ A moving floor trailer that is equipped with a hydraulic floor system that can automatically unload bulk loads such as wood chips.

Tractor Axles	Triple Axle: 12,000 lbs Often a set-back front axle allows for more weight on the front and the ability to haul a longer trailer
Trailer Axles (can be somewhat lower than logging truck)	Locking Double Axle (adjustable up to 10"): 40,000 lbs minimum
Turn Radius	Standard; no limitation identified

Source: *Allotrope Partners, LLC*.

Grapple Truck Specifications

Grapple trucks are a relatively new vehicle in the landscape management field and have become more common over the past decade. As a result, they are not as codified or defined as Class A trucks and there is not an established dealer network in place that sells and services them. Thus, we found it challenging to find detailed information (see Table 4 for available specifications about a four-axle configuration).

Grapple trucks have a power take-off device that transfers mechanical power from the engine to the grapple assembly, which are either front-end or rear-end mounted to self-load and unload materials. The power usage at those moments is highly intensive and utilizing batteries or another zero-emission power source to power the grapple assembly may be a challenging aspect of adopting ZEVs for this category of vehicle.

Grapple trucks are primarily used for power line clearing and post-fire cleanup operations and are less likely to be used for forest work. When they are used for forest work, they will typically have biomass material brought near road access points to be loaded. Most trucks drive varied and shorter routes ranging from 50 to 100 miles from their base location.

Grapple trucks vary in size, ranging from two axle to four-axle configurations, but are typically Class B trucks and do not have a separate tractor/trailer setup. Larger trucks can manage larger loads, such as in the 15-ton-range, while smaller three-axle trucks can manage smaller loads in the range of 11 tons.

Table 4: Grapple Truck Specifications (Four-axle Configuration)

Tare Weight (lbs)	28,000-30,000
Cargo Capacity (lbs)	30,000
Range (miles)	~400
Mileage (mpg)	6-8
Transmission	Typically Automatic
Ground Clearance/Tire Size	Standard 22"
Axles	Four axles, one is a lift axle used after the truck is loaded

Source: Allotrope Partners, LLC.

Typical Diesel Truck Operating, Maintenance, and Capital Costs

In addition to truck usage patterns and specifications, understanding operating and capital costs of standard trucking and logging trucks was necessary, as ultimately the economics of existing diesel-based options must be compared to ZEV options as part of understanding the potential for adoption. This data is used in the project analysis to compare operating expenses of ZEVs to existing diesel-truck options.

Independent diesel truck operators and loggers who we interviewed were charging \$125 to \$150/hour for their services. Thus, overall costs are logically higher for logging or biomass materials that are traveling longer distances. In Table 5, the project team estimated diesel truck operating expenses that reflect current high diesel costs and data gathered from fleet operators and independent truckers. Additional assumption information is available in [Appendix A](#).

Table 5: Diesel Truck Hourly Operating Expenses, including Maintenance and Capital Costs

		Assumptions	
		40	miles/hour average speed
		6	mpg
		20	operating days per month
		10	hour workdays
Costs	per hour		
Fuel	\$40.00	\$6.00	per gallon diesel
Driver	\$40.00	\$40.00	per hour, fully loaded
Maintenance/other	\$25.00	\$5,000	per month, per vehicle
Financing Costs	\$29.67	\$300,000	vehicle cost
		6 percent	interest
		5	year loan
Total Operating Expenses per Hour⁵	\$134.67		

⁵ This cost estimate does not include a profit margin to the operator.

The transportation costs for hauling logs and biomass are limiting factors for how far away the materials can be hauled while still being economical.⁶ For logging, transportation costs equates to adding \$5-6/green ton/hour to the cost of the delivered logs for every hour of driving, which assumes 25 tons of green wood⁷ per load.⁸ At those costs, rarely is it economical to transport logs from a logging site more than two hours away because the hourly operating expenses reduce the profit margins. Similarly, hauling wood chips (at roughly 15 bone dry tons (BDT)⁹ per load) over one-hour becomes cost prohibitive, as the cost of hauling can equate to \$8-10/BDT/hour.¹⁰ Presently, there are few markets for wood chips and it would be challenging to find buyers at more than \$40/BDT, though it is seasonal and chip prices tend to be highest in the late winter when timber harvesting activity is at its lowest.

Most drivers and/or operators maintained eight-hour shifts in efforts to keep hourly labor wage expenses to a minimum.¹¹ Where longer operating hours are in effect, the challenges of adopting ZEVs that require time to recharge are compounded. Even for standard eight-hour shifts, on days where longer round trips are the requirement, range is a key consideration to the potential of ZEVs and refueling/charging issues may become significant.

Maintenance support is critical and most companies have their own shops and their own mechanics. For example, one North Coast timber mill operator, California Redwood Company, has seven full-time mechanics on staff managing their fleet at two mills.¹²

⁶ Average load sizes for logs and biomass were provided by logging operators and drivers interviewed.

⁷ Green wood is wood that has been recently cut and therefore has not had an opportunity to season (dry) by evaporation of the internal moisture. Green wood is thus heavier on a volume basis than wood that has been left to dry for some time before being transported.

⁸ This calculation assumes the hourly operating costs cited above of between \$125-150 per hour divided by 25 green tons per truck load. Average load size was provided by logging operators.

⁹ BDT is a unit of weight equal to 2,000 pounds of woody material at zero percent moisture content and is generally used by the biomass industry to manage for moisture content in delivered material, which can vary widely depending upon the type of material and time of year. Average load size was provided by logging operators.

¹⁰ This calculation assumes the hourly operating costs cited above of between \$125-150 per hour divided by 15 BDT per truck load. Average load size was provided by logging/biomass operators.

¹¹ One operator uses the California agricultural exemption. While still limiting drivers to 12 hours of operating during a work period of not more than 16 hours on-duty, for one period of 28 days or two periods totaling no more than 28 days during the calendar year, driving time is not restricted by a cumulative 8-day on-duty limit.

<https://www.chp.ca.gov/CommercialVehicleSectionSite/Documents/IB%20Agricultural%20Commodities%20Intra%20vs%20Interstate%20Hours-of-Service%20Exceptions.pdf>

¹² We are unable to share specific names of operators along with certain information. Operators are named where possible.

Their maintenance programs included oil changes for logging trucks every 10,000 miles and for biomass hauling trucks every 15,000 miles. They estimate that maintenance, including tire replacements, amounts to \$15/hour of operation. We believe that with labor, this number amounts to \$5,000/month, or \$25/hour. A quick turn-around to get parts is vital to keeping trucks in service. Similarly concerns about the need for quick turnaround and utilization need to be addressed if any non-diesel vehicle solutions are to be viable.

In terms of capital costs for the diesel trucks, the cost for the truck alone, not including the bunk and trailer, has a base price ranging from \$175,000 to \$200,000. The cost of bunk and trailer is in the range of \$70,000 to \$80,000. The total cost with taxes included is roughly \$300,000, especially with recent price increases. The Federal Excise Tax (FET) is 12 percent. The typical lead time for a purchase is approximately one year.

Assessing ZEV Options Relative to the Needs of the Sector

We gathered data from various ZEV manufacturers, both through interviews and through publicly available data to supplement that information when needed. This project's Final Report includes a deep-dive discussion and comparative analysis based on manufacturer interviews and publicly available specifications for three types of heavy-duty Class 8 trucks.¹³ FCET and BET Class 8 truck options were included as the leading ZEV options. In addition, NGETs were also included even though they are not considered ZEV, because they can offer significant emissions reductions.

We endeavored to gather standardized data that would allow for proper comparisons among manufacturers, as well as an assessment of how well the vehicle performance characteristics compared to the logging and biomass hauling use cases. We faced some challenges in this work as certain performance data was not uniformly available and certain data points, in particular torque, are not comparable between diesel vehicles and ZEVs. Available information is summarized in [Appendix B](#) (FCETs), [Appendix C](#) (BETs), and [Appendix D](#) (NGETs).

Summary of Analysis of ZEV Manufacturers

Class 8 FCETs

FCETs are essentially electric vehicles (EVs) where the fuel cell acts as a charging mechanism supporting a smaller battery than is required in an all-electric vehicle. The larger batteries of an EV are replaced with hydrogen tanks and a fuel cell. Thus, the driving experience of both types of vehicles are relatively similar but capacity, range, and relative costs do differ.

¹³ These interviews were largely completed in Spring 2022. We believe that data gathered regarding truck capabilities remain accurate but previous indications of when trucks would come to market have almost certainly changed over the last 12-18 months. We have, where possible, updated the truck availability data.

We identified five primary companies developing Class 8 FCETs (see [Appendix B](#) for available information). Discussions with these manufacturers suggest that FCETs can meet the cargo capacity and recharging time requirements to make them viable for both biomass hauling and logging trucks that have more stringent requirements. There were some concerns about range, though with an extra hydrogen tank, this would address the issue. These FCET manufacturers aim to achieve cost parity with heavy-duty diesel trucks, though they are each taking different approaches to achieve that goal.

The following Class 8 FCET manufacturers were identified and investigated with interviews where possible and public information:

- Hyzon
- Hyundai
- Nikola
- Volvo
- Kenworth

Hyzon (<https://www.hyzonmotors.com>)

Hyzon's approach to developing FCET technology is to build its technology on top of existing trucking equipment and infrastructure. For example, they started with a Freightliner Cascadia 126 cab, removed the internal combustion engine, and replaced it with an electric drivetrain and fuel cell. Then they converted the sleeper cab space into storage for 10 hydrogen storage tanks that allow for a range of 350 miles. They can also add two additional tanks to extend to a range of 420 miles. They are also developing a liquid hydrogen version that would allow for a range of 800 miles.

The tare weight of the truck is 21,000 lbs, which means that the truck should be able to haul a logging trailer and 25 tons of logs or other cargo. Hyzon's base model utilizes a 100-kilowatt (kW) powertrain, which may not provide sufficient power for a logging truck. An anticipated, more powerful 200 kW model would likely suffice, though it is not clear yet how that model might impact the range and weight.

Given there is 350 miles of range with 10 hydrogen tanks, each tank provides a range of 35 miles. Hyzon estimates that fuel cells can fuel 7 miles/kilogram (kg) of hydrogen, thus each tank contains 5 kg of hydrogen, and each truck will require 50 to 60 kg of hydrogen per refueling, depending on the range.

Hyzon is working with a number of steam methane reformer (SMR) producers that use NG or renewable NG gas to produce hydrogen. Smaller SMRs can produce 100 kg hydrogen/day and larger producers can produce up to 1,000 kg/day. Hyzon plans to build hydrogen hubs in Bakersfield and Los Angeles to support fleets in that region, but any pilots or activity in Northern California would need to be supported by local infrastructure.

Nikola (<https://www.nikolamotor.com>)

Nikola is building a wholly proprietary Class 8 FCET and are offering these vehicles as a full “solution”: they plan to lease the trucks as well as to supply the hydrogen to the fleets that they partner with.

In September 2023, Nikola commercially launched their Class 8 FCET that has a range of up to 500 miles and an estimated fueling time as low as 20 minutes (dependent on fueling solutions).⁵ The trucks are designed with a day-cab configuration, a unique design with seats over the front wheels. Some drivers have expressed concerns, as it’s more difficult to climb into the cab than a traditional truck. The truck’s ground clearance will be 10 inches, which is low, though they may heighten it with the Canadian model (discussed below). The trucks will also have bigger tires than normal, which might benefit the logging and biomass use cases being discussed.

Nikola is developing a “Canadian” version of their FCET for 2024 that is designed with an oil and gas clientele in mind and can handle a rugged environment similar to that of logging and biomass hauling. The vehicle will be a bit heavier, but they believe it should be able to manage a full load of 25 tons. The model is intended to have a range of 500 miles and 645 horsepower.

Nikola has not fully disclosed pricing or the economics of their offering. They will sell to fleets on a bundled lease basis along defined “hydrogen highway” corridors where they will develop refueling infrastructure. Nikola trucks are eligible for the California Air Resources Board Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, opening up access to incentives starting at \$120,000 and ranging up to \$288,000/truck. Additionally, the recently reopened Innovative Small e-Fleet program in Calif. offers incentives to small fleets starting at \$240,000 and ranging up to \$408,000/vehicle. Nikola customers will also benefit from a \$40,000 clean commercial vehicle tax credit per vehicle from the federal government due to the passage of the Inflation Reduction Act. Nikola customers will also benefit from a \$40,000 clean commercial vehicle tax credit per vehicle from the federal government due to the passage of the Inflation Reduction Act. Their stated goal is to achieve parity with diesel-powered trucks after incentives.

Volvo Trucks (<https://www.volvotrucks.com>)

Volvo is exploring three options to reduce truck emissions: FCETs, BETs (discussed below), and renewable fuels such as biogas. In 2022, Volvo unveiled its first fuel cell trucks with a claimed 600-mile-range and a 15-minute refueling time. They also claim a 65-ton hauling capacity, which is well beyond typical highway cargo weights, implying that they could be used for off-road mining and other heavy industrial uses. According to a Volvo press release, the truck uses two onboard fuel cells with a 300-kW combined capacity supplied by Cellcentric, a joint venture between Volvo Group and Daimler AG. Volvo said customer pilots will start in a few years, with commercialization later in the decade.

According to Volvo, the slow pace is in part due to the lack of refueling infrastructure and green hydrogen. Only green hydrogen, which is produced using renewable energy, provides an emissions benefit. Other production methods can still be quite carbon intensive.

Kenworth (<https://www.kenworth.com>)

Kenworth has announced a Class 8 FCET, and while there is some limited published information on the vehicle, local salespeople were not yet familiar with the truck. While not broadly available, there are currently 10 units utilizing Toyota fuel cells that are being tested at the Port of Long Beach/Los Angeles. Kenworth announced they are beginning production with initial customer deliveries planned for 2024, and they are now accepting deposits for serial production in 2025. They have a range of roughly 450 miles, which is slightly limited for their utility for logging, though quick refueling could address that issue in areas where there is sufficient fueling infrastructure. While previous data suggested that there were weight limitations, the version coming to market meets industry standards.

Hyundai (<https://www.hyundaiusa.com>)

Hyundai has a Class 8 FCET presently in the market. The range appears to be a bit limited at roughly 250 miles for addressing the needs of the sector but has an interesting technology that uses a complementary battery pack that allows for higher power when needed and regenerative braking that extends its range.

Conclusion for Class 8 FCETs

We concluded that Class 8 FCETs hold promise in applications where long-range and the ability to carry full loads of 25 tons in rugged environments are required, assuming that economics and pricing can match or improve upon existing diesel-powered options. As of November 2023, there are currently two FCET models on the market (Hyundai and Hyzon). Nikola anticipated entering the market during this quarter (Q4 2023), Volvo's model is expected to enter the market in 2025, and Kenworth's model is expected to be delivered in 2026.

Class 8 BETs

There are numerous manufacturers developing electric-only battery-powered Class 8 trucks, of which the project team analyzed options from six manufacturers (see [Appendix C](#) for available information). Most of these vehicles have range limitations and are designed to be as lightweight as possible to improve on their limited ranges. As such, use cases for these vehicles tend to involve shorter hauls and lighter cargo loads. Additionally, the longer charging times poses a challenge for these trucks.

Like FCET solutions, many models are still in development and only a few manufacturers have vehicles that have reached the market at this point. That being said, high-level data about numerous models is available. In many cases, we interviewed individuals at these manufacturers, though in some cases, we were only able to garner information from publicly available sources and marketing data.

The following Class 8 BET manufacturers were identified and investigated with interviews where noted below and public information:

- Freightliner
- Kenworth/Peterbilt
- Tesla
- Nikola
- BYD
- Volvo

Freightliner (<https://www.freightliner.com>)

Freightliner, which is owned by Daimler Truck (the largest truck manufacturer in the world), is developing the eCascadia. eCascadia deliveries for highway use began in 2022. Presently, they intend to offer 3 configurations with ranges of 155, 200, and 230 miles. These vehicles should attain an 80 percent recharge in 90 minutes. The eCascadia range estimates assume a gradually diminishing load, consistent usage of regenerative braking, and starting routes on a full charge. Therefore, some of these assumptions will not hold in the scenarios we anticipate.

The tare weights for the eCascadia varies. The 4x2 configuration (light-duty) with the standard-range is 16,350 lbs. The 4x2 long-range model is 18,750 lbs. The 6x4 model, the most heavy-duty model, has a tare weight of 21,800 lbs and should be able to carry a full load of logs, although the limited range will restrict its utility. The 4x2 models, meanwhile, may be viable for hauling biomass.

Kenworth/Peterbilt (<https://www.kenworth.com/trucks>)

Kenworth and Peterbilt are both owned by Paccar and are seen as essentially a single vendor, particularly in regard to their EVs. The Kenworth T680E Class 8 light-duty BET model has an estimated operating range of 150 miles (depending on the application) and a recharge time of 3 hours. There are also medium-duty Kenworth K270E and K370E BETs that are also available to order currently. While commercially available, the limited range of these vehicles makes them an unlikely fit for logging and only short biomass hauls would be viable with such limited range and long recharge times.

Tesla (<https://www.tesla.com/semi>)

Tesla's Class 8 BET model advertises impressive performance. At a fully loaded 82,000 lbs gross combination weight, it can accelerate from 0-to-60 mph in 20 seconds. Without a payload, the semi quad-motor can accelerate like a mid-range sports car. There will be two battery versions made available in both trimotor and quad-motor variants: one that provides 300 miles of range and one that delivers 500 miles of range. The first trucks were scheduled to be delivered beginning in 2023, but delivery to customers has not been confirmed to date.

The advertised economics of Tesla trucks is compelling. The two battery models claim low energy consumption with mileages of 1.7 kilowatt-hours kWh/mile. When assuming energy consumption of 2 kWh/mile and Tesla's advertised \$0.07/kWh cost for electricity, the resulting fuel cost would be \$0.12/mile. This is a savings of roughly 85 percent over the roughly \$1.00/mile cost of diesel (assuming \$6.00/gallon fuel cost). Tesla claims the semi can recharge up to 70 percent of its range in 30 minutes using Tesla's Semi Chargers. Tesla's semi, like other electric trucks, should also have lower overall maintenance costs due to having no engine and not requiring standard maintenance like oil changes.

Tesla's core semi-truck model is an "over-the-highway" offering that emphasizes simplification, is lightweight, and non-ruggedized, which makes it unsuitable for the rugged applications we are investigating. Once production ramps up, the company may then look at other applications. Tesla has engaged in discussions with the mining sector that would also require ruggedization but gave no indication of timing. While Tesla's marketing material stresses mileage range and relatively rapid recharging, it does not specify cargo capacity nor power.

Nikola (<https://www.nikolamotor.com>)

Along with the FCET discussed above, Nikola has also introduced a BET with an expected price of \$400,000. This Class 8 truck has an attractive range of 350 miles. Yet, that longer range results in a heavier vehicle, with a tare weight of 29,500 lbs, which limits its cargo weight. Its 6x2 configuration also makes it an unlikely fit for logging, even if the cargo weight was sufficient.

BYD (<https://en.byd.com/truck>)

BYD, a Chinese company with a California-based subsidiary, offers a full line of medium- and heavy-duty BETs that are assembled in Lancaster, CA by unionized workers. At present, they use an iron phosphate battery technology with an advertised range of 125 miles. Thus, BYD trucks are an unlikely fit even for biomass hauling, much less logging.

BYD is apparently exploring battery swapping options, which would allow for rapid recharging. The battery pack is located in a container right behind the cabin, making for easy swapping in less than 10 minutes. Charging is relatively fast because BYD has developed a dual-charging port solution that can charge the dual batteries simultaneously in under two hours.

Volvo (<https://www.volvotrucks.us/trucks/vnr-electric>)

Volvo's VNR Electric (VNR-E) series of Class 8 BETs have seen significant market interest, including a 110-truck order from Maersk in March 2022. The VNR-E advertises a range of 275 miles and a recharge rate of 80 percent within 90 minutes. They offer multiple configurations, including a 6x4 version that may be suitable for logging or biomass hauling, though the range may limit its viability in the logging sector.

Conclusion for Class 8 BETs

We concluded that a number of these options have sufficient range to potentially serve fixed-route biomass hauling applications but none of the existing BET options have the combination of range, charging time, and cargo capacity to successfully serve as a logging truck.

If options emerge for battery swapping or other ways to rapidly recharge, BET options may become viable. Further research might also help determine if the benefits of regenerative braking, which could assist in recharging a logging truck as it descends with a full load of logs (and more often climbs hills empty), could ultimately extend the range of BETs used for logging in a meaningful manner.¹⁴

Class 8 NGETs

While not considered zero-emission, NGETs are worth considering as an alternative as they reduce emissions significantly, and when utilizing renewable natural gas derived from biowaste, they achieve a carbon negative footprint. In addition, on a diesel gallon equivalent (DGE) basis, fuel costs can be considerably lower than diesel. This discussion only focuses on compressed natural gas vehicles (CNG), not liquified natural gas (LNG), as these vehicles meet the specifications of a logging truck and can be supported by significantly lower cost infrastructure.¹⁵

Presently Cummins (<https://www.cummins.com>) is the primary vendor of natural gas engines (NGEs), which are then integrated into traditional Class 8 chassis and tractors (see [Appendix D](#) for available information). The existing Cummins NGE is a 12-liter engine and there are concerns that an engine that size is not capable of heavy-duty use cases like logging. Some of these concerns were due to inappropriate gearing and transmissions that were not ideal for that use case. Newer 12-liter trucks with different gearing appear capable of performing to the required specifications for the logging use case. In addition, Cummins has announced a 15-liter NGE that should be available in 2025. Estimated costs are in the range of \$225,000 more than existing diesel solutions, but with significant incentives offsetting those costs. Maintenance costs are understood to be very similar to existing diesel vehicles.

NGETs can be engineered to have roughly an 850-mile-range when using a 171 DGE tank. With “fast fill” infrastructure, these tanks can be filled to 80 percent capacity at a rate of 10 DGEs/minute, allowing for a 700-mile-range with a refill time of under 20 minutes. Alternatively, “time fill” infrastructure can increase the range to 850 miles by

¹⁴ The benefits of regenerative braking should apply to FCETs as well.

¹⁵ Because of LNG's relatively high production cost, as well as the need to store it in expensive cryogenic, double-walled, vacuum insulated tanks, the fuel's use in commercial applications has been limited to fixed routes and corridors where necessary infrastructure can support a significant number of vehicles. Because of this, LNG was not considered for this project.

Source: U.S. Department of Energy. “Natural Gas Fuel Basics.” Alternative Fuels Data Center,

https://afdc.energy.gov/fuels/natural_gas_basics.html. Accessed 2 November 2023.

completely filling the tanks, but overnight filling would be required. Recent price quotes for long-term gas contracts are in the range of \$3.50/DGE particularly in Northern California. These contracts can also amortize the marginal cost of purchasing a NGET rather than a traditional diesel at an additional cost of approximately \$0.85/gallon for five years.

Comparison of Class 8 ZEVs Versus Specifications

Tables in [Appendix E](#) and [Appendix F](#) compare manufacturers' truck specifications for FCETs, BETs, and NGETs against the specifications for logging and biomass hauling trucks, respectively. The variables listed are identified as the critical variables that determine suitability for each use case. While we did not receive complete information from each ZEV manufacturer, we do believe we received sufficient data to support analysis of these critical variables. Where spaces are left blank, data was not available. Capacity and mileage, which is data that we believe is vital to a comparative analysis, was generally available but the costs of the trucks was not consistently available. Additionally, color coding was applied to indicate whether the truck options are able to meet the specifications: green cells indicate that the truck option meets the specifications, yellow cells mean the truck option might meet the specifications, and red cells mean the truck option does not meet the specifications.

Potential for ZEV Logging and Biomass Hauling Trucks

Logging Trucks

Given the limited range of BET options and the longer refueling/charging times, it does not appear that the BETs surveyed are appropriate for logging applications. Tesla's semi model may ultimately be viable with a promising longer range, but the unknown cargo capacity and horsepower at this time make it impossible to qualify them. In addition, it is understood that the Tesla semi model has been designed to be very lightweight, making it likely difficult to adapt it to the rugged needs of logging trucks.

On the other hand, the features of the Class 8 FCETs—most importantly the range, ability to refill rapidly, and the ability to carry a full 25 tons of cargo—make them, at a macro-level, a viable alternative for both logging truck applications and biomass hauling. On a specific, manufacturer-by-manufacturer basis, the Kenworth FCET appears to directly meet the weight specification and is close to achieving the mileage range, being only slightly below the ideal range. Nikola (particularly its Canadian model that is in development) and Hyzon also appear to meet the specifications as well, although Hyzon's proposed range may be a potential limiting factor. Although the Volvo model has a much higher cargo capacity, it appears to be designed for non-highway, heavy-duty use such as mining applications. Thus, it is probably not a fit, because trucks for this project's applications would require highway abilities; additional investigation is merited.

Biomass Hauling Trucks

Given the slightly less vigorous use case for biomass hauling applications, FCETs appear suitable for this application while BETs may work in certain applications. Like logging, only the Kenworth FCET appears to directly meet the weight specification and is close to achieving the mileage range, being only slightly below the ideal range. Nikola (particularly its Canadian model that is in development) and Hyzon also appear to meet the specifications as well, although Hyzon's proposed range may be a potential limiting factor. As discussed above, Volvo's solution requires further investigation (as it's not clear if they are offering a Class 8 vehicle or only off-road mining vehicles).

Where shorter regular hauls are well defined, biomass haulers may find that BETs are a viable option, although operators generally expect to utilize their vehicles more consistently throughout each day and recharging needs may create difficulties. Again, Tesla's advertised range and recharging may make it a promising option, but a lack of data about their cargo capacity and performance/horsepower create uncertainty. Freightliner's eCascadia and Volvo's model may work in those more limited range use cases, as recharging may be viable and range may be acceptable.

NGETs

Class 8 NGETs appear promising for logging and biomass hauling applications, though there may be some concerns whether their horsepower and performance is sufficient for logging. This should almost certainly be addressed when larger 15-liter engines, such as the one under development by Cummins, are introduced in 2025.

ZEVs Operating Costs and Performance

Finding comparable data to assess the performance of diesel versus ZEVs has proven to be challenging. In particular, we believe torque ratings for EVs are only rarely published because they are not truly comparable to torque ratings for diesel trucks. Electric motors provide instant torque the moment they are engaged, thus providing substantial acceleration and impressive 0-to-60 mph performance relative to diesel engines. Torque then dissipates slightly on electric vehicles (EVs) as they gain speed as electromagnetic frequencies develop and erode performance at higher speeds.¹⁶ Diesel torque ratings, on the other hand, appear to be measured at the point when the engine is already running at higher revolutions per minute and indicate force generated at normal operational running rates. As a result, only horsepower will be utilized as a rating for

¹⁶Automotive Training Centre. "How Electric Cars Achieve Instant Torque: An Overview for Grads of Mechanic Schools." How Electric Cars Achieve Instant Torque: An Overview for Grads of Mechanic Schools, <https://www.autotrainingcentre.com/blog/electric-cars-achieve-instant-torque-overview-grads-mechanic-schools>. Accessed 2 November 2023.

performance at this stage. Any pilot project will need to track and assess performance as part of the program.

Fuel Efficiency and Costs

The fuel efficiency and cost issues for the various Class 8 truck manufacturers are summarized below.

- **Class 8 FCETs:** As described in more detail below, if hydrogen can reach a target price of roughly \$6.05/kilogram (kg), the cost of hydrogen fuel will be roughly the same on a per-mile basis as the cost of diesel at its present \$6.00/gallon price (\$1.79/mile for hydrogen versus \$1.76/mile for diesel).
- **Class 8 BETs:** The equivalent cost of fuel (i.e., electricity) for BETs may be significantly cheaper still, though we only have data from Tesla to support this view. Tesla states that its semi-truck can operate at 1.7 kilowatt-hours (kWh)/mile. At \$0.07/kWh electricity prices, which they can offer, fuel costs will amount to \$0.12/mile, which again would be dramatically cheaper than existing diesel equipment.
- **Class 8 NGETs:** As discussed below, recent price quotes for long-term gas contracts in Northern California equate to in the range of \$3.50/DGE, resulting in significant savings over diesel fuel costs.

Other Operational Costs

Other operational costs also appear to favor both FCETs and BETs although hard data is not readily available.¹⁷ According to the North American Council for Freight Efficiency, ZEVs offer the potential for significant operating cost reductions, including the following maintenance benefits, though this may be offset to some extent by additional tire costs.¹⁸

- **Fluids:** ZEVs have no need for regular oil changes, which is a substantial expense for many fleets. Smaller coolant systems and some amount of other lubricants will likely still be required.
- **Emission control systems:** Class 8 FCETs and BETS have zero-emission footprints both in terms of carbon dioxide and criteria pollutants, and thus there is no need for emissions control systems.
- **Brakes:** ZEV trucks have similar air brake systems as other Class 8 tractors, but they are supplemented by regenerative braking that extends the life and service intervals for the friction material on air brake systems.

¹⁷ FCETs utilize electric powertrains and thus are essential electric vehicles but utilize a different energy source.

¹⁸ North American Council for Freight Efficiency. "Hydrogen Trucks: Long-Haul's Future?" Electric Trucks,

[https://nacfe.org/research/electric-](https://nacfe.org/research/electric-trucks/#hydrogen)

[trucks/#hydrogen](https://nacfe.org/research/electric-trucks/#hydrogen). Accessed 9 November 2023.

- **Transmission and drivetrains:** The electric motors that power ZEVs are able to deliver the same torque across nearly all speeds, requiring few—if any—gears. Most ZEV vehicles surveyed had, at most, two-speed transmissions.
- **Tires:** Data is still being collected, but one automotive tire manufacturer stated that tire life tests with EVs showed that EVs can reduce tire life mileage due to the increased weight of the vehicles and the higher torque and resulting acceleration. Tire manufacturers are beginning to offer EV-specific tires to address these challenges.¹⁹

Related Infrastructure Needs for Each ZEV Technology

FCET Truck Infrastructure

A single FCET requires between 50-60 kg of hydrogen per refuel (assuming a 70 kg tank). There are four types hydrogen infrastructure options for having hydrogen on-site for refueling FCETs. The first option is to have hydrogen delivered to the site by truck as well as three on-site hydrogen production infrastructure options: either an electrolyzer, a steam methane reformer (SMR), or biomass-to-hydrogen solutions.

Each type of hydrogen production infrastructure has unique considerations. For an electrolyzer, access to affordable electricity and water will be necessary. For an SMR, access to a natural gas pipeline is a prerequisite, while a heat source is also needed. For a biomass-to-hydrogen solution, sufficient biomass would be needed. The ability to access renewable energy resources for all three of those solutions is also important. Each option was also assessed in the context of the potential site of the pilot, the approximate number of trucks supported, and the anticipated refueling time required.

While a hydrogen delivery solution was considered for analysis, we concluded that on-site hydrogen production is critical to proving the overall concept and driving adoption of ZEVs in the sector and beyond and therefore focused on hydrogen production infrastructure for further analysis.

Electrolyzers

Electrolyzers are likely to be a favored option for hydrogen production moving forward, because if they use renewable electricity during production, they produce “green” hydrogen²⁰ with the required low carbon intensity necessary to receive the maximum credits available through the IRA.

¹⁹ Sickels, David, and Tess Lovrak. “Electric truck tire tips.” Fleet Equipment Magazine,

<https://www.fleetequipmentmag.com/electric-truck-tire-tips/>. Accessed 3 November 2023.

²⁰ Green hydrogen is hydrogen produced through the electrolysis of water with 100 percent or near 100 percent renewable energy with close to zero greenhouse gas emissions (<=1 kg carbon dioxide equivalent per kg hydrogen taken as an average over a 12-month period).

The size of electrolyzers vary from large units of 2-5 MW, that produce over 18 kg of hydrogen/hour/MW, to smaller units that produce only milligrams/minute of hydrogen. We identified an electrolyzer vendor, Ohmium, that produces medium-sized electrolyzers (450 kW/unit) that can produce sufficient hydrogen for a pilot project of 2 vehicles and then, based on their scalable solution, additional units can be added to increase capacity to supply a larger demonstration project of 10 or more vehicles (3 additional units would produce enough hydrogen for 10 FCETs for total of 1.8 MW).

Steam Methane Reformers (SMRs)

SMRs use natural gas or renewable natural gas (i.e., methane), which is put under heat and/or pressure in the presence of a catalyst, to produce hydrogen, carbon monoxide, and a lesser amount of carbon dioxide. It takes 4.5 cubic meters (m³) of methane to produce 1 kg of hydrogen. To support 250 kg of hydrogen/day, 1,125 m³ of natural gas or renewable natural gas would be required, which at 26.8 m³/million British thermal units (MMBTU) converts to roughly 42 MMBTUs/day.

Biomass-to-Hydrogen Production

A number of biomass-to-hydrogen technology development efforts are presently underway in California and a number are receiving significant state support. This potential larger scale hydrogen production option, while still at early stages of technology development, could be an attractive longer-term option for the logging sector. Timber operators often control a significant amount of wood waste that would be necessary as feedstock for such solutions.

High-level discussions with a number of biomass-to-hydrogen project developers suggest that a relatively small amount of biomass, in the range of 35-40,000 BDT/year, could produce enough hydrogen annually to support a fleet of roughly 50-60 trucks. Initial analysis (see detail below) suggests that at this scale, this technology could produce hydrogen at costs significantly lower than the costs of existing diesel solutions.

Supplying Hydrogen by Tanker Truck

Wystrach, an European producer of hydrogen tanker trailers and related storage and fueling infrastructure, was identified as a solution for hydrogen produced at a central location to be transported to remote sites, such as sawmills, where logging trucks could be refueled. Historically, Type 1 hydrogen trailers store hydrogen at 200 bars of pressure, allowing roughly 500 kg of hydrogen/load. This vendor now is offering Type 4 trailers that store at 300-500 bars of pressure and can transport up to 1,000 kg/load.

Additional Hydrogen Infrastructure Options

Source: Green Hydrogen Organisation. "The GH2 Green Hydrogen Standard." Green Hydrogen Organisation, <https://gh2.org/our-initiatives/>

gh2-green-hydrogen-standard. Accessed 2 November 2023.

In addition to hydrogen production, other equipment (i.e., compressors and pumps, bulk storage, high-pressure buffer storage, pre-cooling units, and dispensers/fueling infrastructure) will be necessary to support use of hydrogen on-site.²¹ In the early stages of the project, the project team performed literature reviews on these infrastructure elements that focus on taking hydrogen from production to fueling, but most of these resources focused on solutions for retail automobiles as opposed to solutions for heavy-duty vehicles. Retail automobile solutions are designed to be easy to use and are intended to fill smaller tanks. Dispensers for heavy-duty vehicles are simpler but also require faster fill times to reflect the needs of the larger vehicles. The project team ultimately learned about heavy-duty solutions from direct interviews with vendors in the later stages when the pilot project concept was better defined.²² Based on these discussions and assessments of technologies on the market, modular systems that integrate compressors, storage, and dispensers appear to be optimal in terms of cost saving and installation times.

A number of modular solutions designed by independent engineering firms are available. Wystrach has designed a mobile hydrogen refueling station that has a discharging capacity of 360 kg/day,²³ which could support a small pilot with 2 FCETs.²⁴ This type of smaller solution could potentially be supplied by hydrogen produced off-site and delivered by truck. Another solution, provided by Air Liquide, is also modularized and the technology is transported and installed in standard 40-foot shipping containers.²⁵ Their GA-M-70 unit, which manages up to 1,000 kg/day of hydrogen, would likely be better served with complimentary on-site hydrogen production. A smaller Air Liquide unit is also available, which has a 300 kg/day capacity and at 70 percent the cost of the larger unit, could also potentially be supplied with hydrogen produced off-site.

²¹ CALSTART. Best Practices in Hydrogen Fueling and Maintenance Facilities for Transit Agencies. December 2016, <https://calstart.org/wp-content/uploads/2018/10/Best-Practices-in-Hydrogen.pdf>.

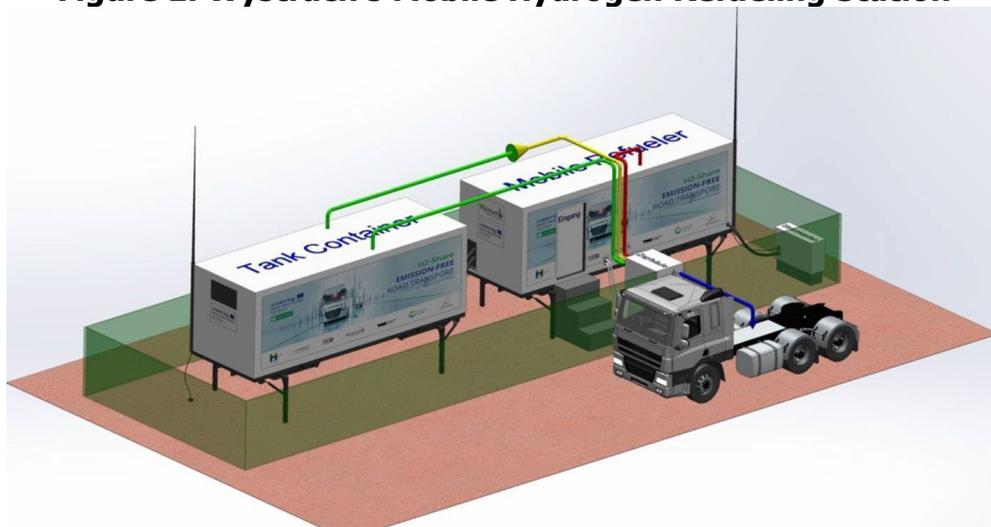
²² These vendors include Air Liquide, Cummins, and a number of engineering firms that are managing hydrogen fueling station projects, such as HTEC and Syringa Energy.

²³ <https://www.wystrach.gmbh/en/products/wyrefueler>

²⁴ At the time of the project team's original assessment of available hydrogen production infrastructure in Spring 2022, this current model was not available; the previous model was only scoped to produce 120 kg/day of hydrogen. Therefore, the project team had moved forward with another possible solution for the Blueprint development.

²⁵ <https://energies.airliquide.com>

Figure 1. Wystrach's Mobile Hydrogen Refueling Station



Source: *Allotrope Partners, LLC*

Battery Electric Truck Infrastructure

There are three general types of recharging units for BETs:

1. Level 1: 110 volts/alternating current (AC)
2. Level 2: 240 volts/AC that can vary in kW, ranging from 50-350 kW levels. Higher kW chargers lower the recharging time, therefore recharge times for Level 2 chargers can range from 15 to 80 miles of range/hour.
3. Direct current fast charging (DCFC): These can range up to a full megawatt (MW), recharging up to 350 miles of range/hour. There are concerns about heat management on larger MW level chargers.

Class 8 BETs in the logging and biomass use cases will need a minimum of a Level 2 charger, most likely in the higher kW range, or a DCFC charger to provide faster charging times that would minimize operating downtime. According to a 2019 study, DCFCs are likely to become a dominant EV charging method for medium and heavy-duty BETs.²⁶

CEC data suggests that the total project costs for a DCFC system is an average of \$112,000, although existing rebates can cover an average of approximately 60 percent of the charger cost.²⁷ DCFC chargers have a more complicated installation that requires

²⁶ U.S. Department of Energy. "Medium- and Heavy-Duty Vehicle Electrification." Medium- and Heavy-Duty Vehicle Electrification, December 2019, <https://info.ornl.gov/sites/publications/Files/Pub136575.pdf>. Accessed 30 November 2023.

²⁷ California Energy Commission. "CALeVIP DC Fast Chargers, Range of Rebate, Unit Cost, and Total Project Cost Per Charger." CALeVIP Cost Data, <https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/california-electric-vehicle/calevip-dc-0>. Accessed 14 November 2023.

coordination with local utilities. Standard Level 2 chargers are significantly less expensive (approximately \$2,800 to \$3,700 depending on the number of connectors),²⁸ although ones with sufficient charging capacity (i.e., higher kW) are significantly more expensive and, like DCFC, are complicated and take time to install as they also require coordination with local utilities.

Natural Gas Truck Infrastructure

Presently, there are no CNG stations in Northern California north of Chico,²⁹ which would make it necessary to install CNG infrastructure if NGETs are going to become a viable option for serving the logging and biomass hauling sector in the Shasta County region. Large CNG stations can cost in the range of \$1.2-\$1.8 million for a full station, with compressors taking up approximately 40 percent of that cost. The exact configuration of a NG filling station depends on the pressure the gas is under at the utility service line being accessed. If the gas line is relatively low pressure, multiple compressors may be necessary to pressurize the gas sufficiently, particularly if a fast-fill station is the goal. For instance, a line with 27 lbs of pressure needs 3 compressors to achieve the pressure necessary for a fast-fill station.³⁰

Alternative options exist but may not yet be feasible or available locally. There are fuel providers, such as Clean Energy Fuels, Inc., that will build stations in return for long-term fuel contracts with fleets. This would require a fleet of 15 vehicles or more with each truck traveling 80,000 miles/year in order to create a large enough fuel contract to justify the investment in a station. In addition, there are portable CNG filling station solutions that we have identified through literature and internet research, but we have not interviewed any manufacturers directly. Such facilities and associated infrastructure appear to cost approximately \$350,000.

²⁸ California Energy Commission. "CALeVIP Level 2, Average Rebate, Unit Cost, and Total Project Cost Per Connector Installed." *CALeVIP Cost Data*, <https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/california-electric-vehicle/calevip-level>. Accessed 14 November 2023.

²⁹ As of time of submission. Source: https://afdc.energy.gov/fuels/natural_gas_locations.html#/find/nearest?fuel=CNG

³⁰ These estimates were summarized by the following report, as well as conversations with several industry experts. Source: U.S. Department of Energy. "Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure." NREL, September 2014, https://afdc.energy.gov/files/u/publication/cng_infrastructure_costs.pdf. Accessed 30 November 2023.

Chapter 3: Project Results - Develop Model of a Pilot Project for One or More ZEV Options

To prove the efficacy of utilizing heavy-duty ZEVs as logging or biomass hauling trucks, a model pilot project needs to be developed that demonstrates that heavy-duty ZEVs can do the work, as well as proving that they can do so economically and with net benefits to the broader community. Our discussions with stakeholders reiterated that both questions must be addressed. Thus, to do so in as timely a manner as possible, we propose a two-phased approach. First, an initial, short-term (three to six months) pilot installation of a hydrogen production and fueling facility for a small number of FCETs (two vehicles) utilized for logging at Sierra Pacific Industries' headquarter mill in Anderson, California would be established. The proposed hydrogen production and fueling facility would include a single on-site electrolyzer (for an initial pilot project) and an integrated modular hydrogen refueling unit that includes compressors, fuel storage, and refueling dispensers (see additional details below). This pilot project, if successful, could then quickly scale up to a longer-term (1-2 year) demonstration project of 10 vehicles with additional electrolyzers. A demonstration project should have operating costs that more closely resembles at-scale economics. Our economic analysis suggests that operational expenses of FCETs at the demonstration project scale are competitive with diesel operating costs, particularly at today's high diesel prices.

Determination of the Vehicle Type for the Pilot

The pilot design process began by analyzing the potential for pilot and demonstration programs for each vehicle type (FCETs, BETs, and NGETs) in the two different use cases (logging and biomass hauling).

Option 1 - Class 8 FCETs

Our assessment concluded that FCETs could be suitable for both logging (with some reservations about range) and less demanding biomass hauling use cases. While a Class 8 FCET would likely meet the needs of the biomass hauling pilot routes described previously, we believe finding a logging truck pilot project would contribute to a more meaningful demonstration to decarbonize industrial processes with direct impacts on forest management and forest carbon throughout the state while also serving as an example for other industries that depend on heavy-duty vehicles.

Option 2 - Class 8 BETs

The assessment concluded that given the limited range of BET options, as well as the longer refueling/charging times, it does not appear that the Class 8 BETs surveyed are suitable for logging applications and a pilot would only be viable in a biomass hauling scenario. Even then, the pilot would have to have a predictable set route that is short enough to assure that multiple circuits could be run per day without recharging to ensure operators are able to maximize the utilization of their vehicles.

Discussions with one large biomass hauling fleet operator in Northern California, Bettendorf Trucking, identified two potential pilot options. The most promising option was a 60-mile route between a sawmill and a biomass power plant. The route would be downhill while carrying the biomass loads, thus offering the opportunity for regenerative braking to recharge the trucks' batteries and extend the range per charge. The fleet operator also has a second route which would require their vehicles to transport biomass from the sawmill to a coastal destination, a 100-mile trip each way. With the exception of the Tesla BET with a 500-mile range, this longer distance would only allow for a single roundtrip in that direction per day without recharging, which is untenable for the fleet operator.

Option 3: Class 8 NGETs

Initially, this project was not scoped to include an assessment of NGETs, therefore earlier discussions with loggers and biomass hauling operators did not include exploring the potential of NGETs, nor the idea of designing a pilot for such vehicles. Conversations with NGET manufacturers, as well as marketers of natural gas suggest that NGETs are a more mature market. While there are some concerns about the performance of the existing 12-liter NGEs, Class NGETs appear suitable for both logging and biomass hauling uses.

While a pilot or a demonstration project is likely still necessary to demonstrate the utility of such vehicles in the logging and biomass hauling sector, designing a demonstration or pilot should not require significant resources and could count on strong support from industry NG fuel players. In addition, the savings in fuel costs relative to diesel would be significant, with our estimates in the range of \$400,000 to \$500,000/year.³¹ It remains to be investigated whether local utilities could supply this amount of natural gas, or preferably renewable natural gas, and whether that amount could scale if the use of NGETs were to increase.

Recommendation and Justification for Choice of the ZEV: FCET Logging Trucks

Our assessment of the technical specifications of potential ZEV options that could viably serve the sector concluded that a pilot project that utilized **FCETs for logging** would provide a valuable demonstration and first step for transitioning to the use of ZEV technology within the logging and biomass sector, as well as other heavy-duty sectors. The technological feasibility, the interest of a major industry partner (Sierra Pacific Industries; described in detail below) to utilize FCETs, and the potential for this pilot to serve as a widespread vehicle decarbonization example suggests that this could be an impactful pilot project if implemented.

³¹ A fleet of 2 trucks (assuming 6 miles/gallon and 7.2 DGE/MMBTU) running 500 miles/day, 300 days/year (for a total of 600,000 miles/year) would require just under 14,000 MMBTUs/year. This estimate assumes a CNG price of \$3.50 per MMBTU versus \$5-6 per gallon diesel. .

The two remaining options—BETs and NGETs—are not recommended for a pilot for several reasons. Class 8 BETs pose too many challenges mainly due to their short range before requiring longer recharging periods. While one promising biomass hauling route did materialize for a potential pilot, there did not appear to be a larger opportunity that a pilot could scale into. Additionally, while a pilot for a NGET using renewable natural gas may also prove promising, we recommend developing such a pilot in a region further south where natural gas refueling infrastructure is already in place.

After choosing to proceed with FCETs, we then further engaged with key stakeholders to identify a potential partner and pilot location within the Shasta County area in order to further define and refine the potential pilot, such as determining the optimal hydrogen refueling infrastructure to have on-site, refining the estimated pricing, and complete the design the pilot.

Determination of Pilot Project Partner and Location: Sierra Pacific Industries (SPI)

SPI is the largest timber operator in the state. SPI provided significant value to earlier tasks in this study, in particular by providing valuable data regarding the specifications required for logging or biomass hauling trucks. During those initial conversations, SPI expressed interest in participating in the process of designing a heavy-duty ZEV pilot at one of their sites. SPI later indicated that their sawmill and headquarters in Anderson, CA would be their preferred location for a pilot design process.

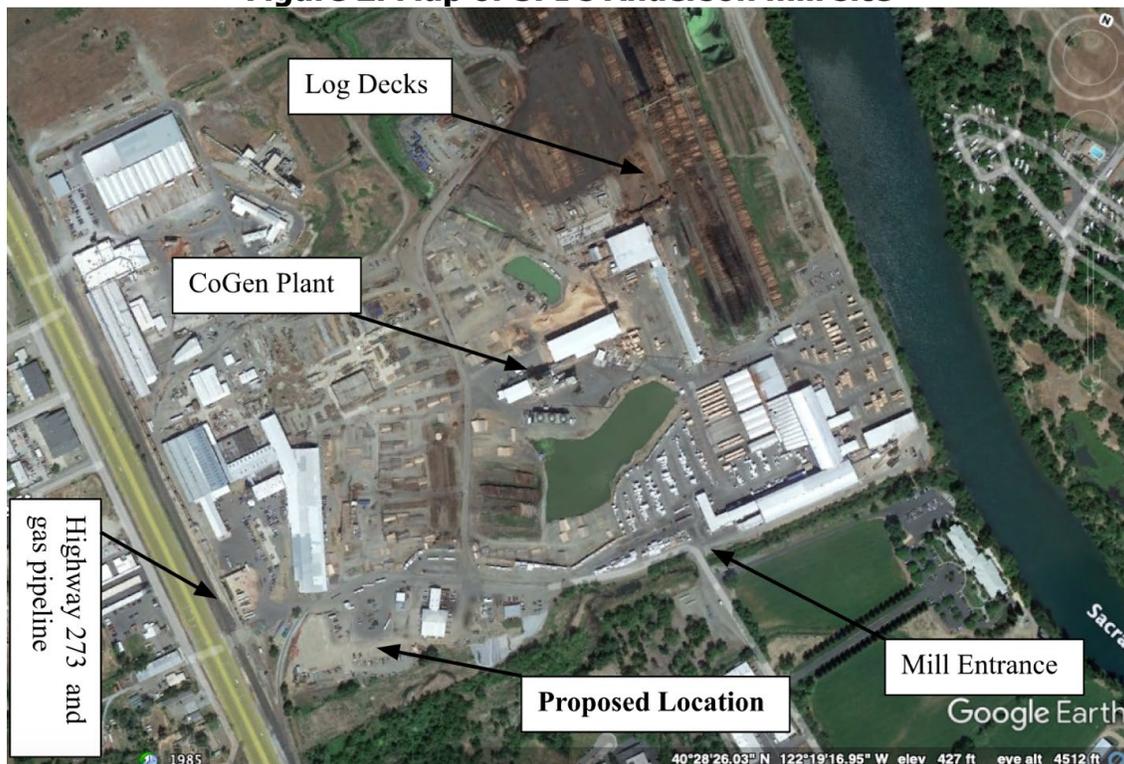
We believe SPI would be a valuable pilot partner and their Anderson location is an ideal location for the pilot project for the following reasons:

- **A high-profile local partner.** SPI operates six sawmills around the state of California, as well as two in Oregon and four in Washington. They are the largest private landowner in the state and thus are indisputably the most important logging and sawmill operator in California. A successful pilot implementation of ZEV logging trucks in partnership with SPI will generate significant exposure and act as a catalyst for generating interest and adoption across the industry as a whole. That said, it is important to stress that the economics of adoption of ZEV vehicles will need to be viable to generate sustained interest in the solution over time. The pilot and demonstration project design will need to demonstrate an economically viable path to implementation and broader adoption if we are to be confident in the industry's long-term support for the effort.
- **SPI's capabilities, size, and heavy-duty truck specifications.** SPI operates a fleet of over 120 logging trucks in California and approximately 100 logging trucks from their Anderson headquarters alone. They require that their logging trucks have a 550-mile-range, which is slightly higher than the existing specifications for most publicly announced heavy-duty FCETs, but otherwise their requirements are met by all the other specifications. Given their large fleet at the Anderson site in particular, they are well positioned to manage and test the

stated capabilities of a relatively small number of FCETs without risking their core operations.

- **Existing infrastructure.** SPI's Anderson headquarters includes a full truck repair and maintenance facility as well as existing diesel fueling infrastructure. SPI also has a cogeneration power plant on-site, which at a minimum can provide access to the electrical grid and can also potentially be accessed directly for the electricity needed for an electrolysis solution to produce hydrogen on-site.
- **Convenient space for a pilot.** Out of three potential sites that were identified for potential on-site hydrogen production and FCET refueling locations, SPI selected a site near their existing truck maintenance facility that is approximately one acre in size (identified in the satellite photo in Figure 1 below). The proposed location is adjacent to the existing diesel fuel tank and refueling site, which ensures that the ZEVs will work within the preexisting flow of traffic on-site and be near their repair shops in case any supporting maintenance is necessary. Key infrastructure, in particular the location of the electrical grid, gas pipelines and water, have also been identified.

Figure 2. Map of SPI's Anderson mill site



Source: Allotrope Partners, LLC

Additional schematics of the proposed project site can be found in the Appendix.

- [Appendix G](#) – Schematic Site Plan: The proposed location of the hydrogen production, storage infrastructure, and the actual refueling site. The proposed location is adjacent to the existing diesel fuel tank and refueling site, which ensures that the ZEVs will work within the preexisting flow of traffic on-site and be near their repair shops in case any supporting maintenance is necessary. Key infrastructure, in particular the location of the electrical grid, gas pipelines and water, has been identified.
- [Appendix H](#) – Vicinity Map: The proposed location in the broader context of the plant and the surrounding road infrastructure. The location is in close proximity to two intersections: Interstate 5 and Highway 273 (a significant secondary route).
- [Appendix I](#) – PG&E Gas Pipeline Vicinity Map: Location of NG pipelines in the area. While there is not a NG pipeline on the SPI property at this stage, pipes do border the property, particularly on Riverside Avenue.

Determination of Infrastructure Needed and Additional Services

Determination of Preferred Hydrogen Infrastructure: Electrolyzers

As described previously, there are a number of hydrogen production or supply options available. The pilot design process explored the possibility of both an electrolysis and a SMR solution on-site, as well as investigated the economics of shipping in hydrogen to the site. Based on the project team’s analysis, it was determined that the use of electrolyzers on-site would be the most ideal option primarily because there is access to the grid, potential usage of electricity produced on-site, and we believe there is an ample supply of water, which are the two primary inputs for an electrolysis unit.

In contrast, using a SMR to produce hydrogen requires natural gas, which is not currently available on site at SPI as it is not utilized in their operations. There is a natural gas line adjacent to the property, but there is not an existing connection to SPI. The cost of installing a new connection to SPI’s site, the related permitting, and the higher carbon intensity of the resulting hydrogen produced via SMR, all make SMR a less attractive option.

In addition, as outlined in the financial analysis below, there is a significant financial reason to pursue electrolysis, particularly using renewable electricity, as it would allow the project to qualify for the maximum tax credits available through the IRA. This credit of \$3/kg of hydrogen produced is quite essential to making the operational model for hydrogen viable relative to operating diesel vehicles.

A biomass-to-hydrogen solution may become a very compelling option for the logging/timber sector given the increasing need to manage biomass in these parts of the state, yet there does not appear to be a commercially available technology on a small scale for a pilot. As acceptance of the ZEV technology increases and larger fleets

consider converting to hydrogen, then higher volumes of hydrogen will be in demand and such facilities may be more appropriate.

For a small pilot, a hydrogen delivery solution could also be considered. While such an approach could prove the efficacy of the vehicle, we believe a pilot that includes on-site hydrogen production is critical to proving the overall concept of the Blueprint and driving adoption.

Please see [Appendix J](#) for the calculations and assumptions that support the development of the pilot project and demonstration project. We believe that a pilot with two trucks in operation for three to six months is an appropriately sized pilot given our understanding of the nature of the supporting infrastructure available. In addition, the core hydrogen production technology for the pilot could be scaled up to support a follow-on, longer-term demonstration site by adding a number of additional electrolyzers.

Determination of Electrolysis System and Supporting Infrastructure

A fully on-site electrolysis system includes the following items:

- An electrolysis unit
- Hydrogen compression and pumping
- Bulk hydrogen storage
- High-pressure buffer storage
- Pre-cooling unit
- Dispensers/fueling infrastructure

We recommend using a polymer electrolyte membrane (PEM) electrolysis unit based on the project team's analysis of a number of these units. We believe that the **Ohmium electrolyzer solution** is suitable for the pilot, as a single unit can support two vehicles and Ohmium units can then easily be added to scale up to a demonstration scale project. A specifications sheet supplied by Ohmium is attached in [Appendix K](#). Upon request, the company provided supporting information that allowed us to model the initial implementation and potential scale up. One Ohmium electrolyzer (with a capacity of 450 kW) can produce sufficient hydrogen for a pilot project of 2 FCETs³² (approximately 148 kg/day) and 4 total electrolyzer units (with a capacity of 1.8 MW) can supply a larger demonstration project of 10 or more FCETs (approximately 720 kg/day).

Increasingly, compressors, cooling units, chillers, high-pressure storage, and related control electronics are being supplied in a single module. The project team recommends

³² We assume that each FCET will need a full fill up of 70 kgs per day, though in fact it is likely that the trucks will not fully empty their tanks very often. It is possible that once regular usage rates are better understood, that an additional FCET could be added to the pilot and additional trucks to the demonstration project.

Air Liquide’s GA-M-70 as the proposed integrated modular hydrogen refueling solution (see [Appendix L](#) for additional details). The unit includes compressors, hydrogen pre-cooling, buffer storage, and refilling capabilities that can manage up to 1,000 kg/day of hydrogen, which can support up to 14 trucks. Additionally, the Air Liquide system has tank storage at 350 bar and fast fills at approximately 7.2 kg/minute, which we believe is required to assure fast refueling time that should not impact SPI’s typical on-site operations. Much of the literature on hydrogen dispensers focuses on solutions for retail automobiles as opposed to solutions for heavy-duty vehicles. Retail automobile solutions are designed to be easy to use and are intended to fill smaller tanks. Dispensers for heavy-duty vehicles are simpler but also require faster fill times to reflect the needs of the larger vehicles.³³

Given that the compressors and refilling requirements are identical for both a smaller pilot and a larger demonstration project, the costs of this unit will be high on a per truck basis for a pilot project but will be reduced at a demonstration scale. Additionally, we found that this solution was less expensive than other engineered solutions that depend on integrating equipment from multiple vendors and building the station on-site, resulting in significantly higher installation costs. This confirmed studies that found that installation of integrated solutions should amount to no more than 5 percent of the capital costs of the units.³⁴

Services and Support Required for On-site Hydrogen Infrastructure

Hydrogen Production and Infrastructure Maintenance

Presently, there is little data on the reliability of hydrogen filling stations that serve Class 8 FCETs and even less on stations that produce their own hydrogen.³⁵ One 2016 study outlines the best practices for hydrogen fueling and maintenance for transit agencies’ buses that more closely resembles the needs of a heavy-duty FCET, yet even this study acknowledges that “maintenance costs are not well documented for transit applications”.³⁶ The data that does exist suggests that dispenser failures are a reasonably common problem, though it is not clear from the data how often dispensing

³³ Along with literature searches, the project team spoke to a number of engineering firms (HTEC and Syringa) as well as Twin Transit, the Oregon-based transit authority building hydrogen fuel infrastructure, and Air Liquide.

³⁴ Hecht, Ethan S., et al. “Comparison of conventional vs. modular hydrogen refueling stations and on-site production vs. delivery.” *U.S. Department of Energy Office of Scientific and Technical Information*, March 2017, <https://h2tools.org/sites/default/files/Reference-Station-Phase-2-1.pdf>. Accessed 30 January 2023.

³⁵ Kurtz, Jennifer M., Sprik, Samuel, Peters, Michael C., and Bradley, Thomas H.. Retail Hydrogen Station Reliability Status and Advances. United States, 2020. Web. doi:10.1016/j.ress.2020.106823.

³⁶ CALSTART.

failures occur. To note, there are dedicated resources available through a current CEC grant solicitation (GFO-23-604, released November 2023) that specifically focuses on developing and improving hydrogen station processes,³⁷ which is indicative of the state of hydrogen adoption in the state and that there exists both a gap in data and implementation experience regarding new hydrogen technology solutions. Regular preventative maintenance checks, leak detectors, and hydrogen gas detectors, as well as monitoring pressure and flow rates, are all methods to perform leak checks. Many dispensers use pressure holds during dispensing operations that check for leaks by monitoring for pressure drops. System controls of the dispensing infrastructure include automated monitoring such as this as well as fail-safe shut-offs and other safety features. Remote monitoring is incorporated into solutions offered by some engineering firms, allowing for staff at a central location at the site to be alerted to any anomalies or problems.³⁸

The Air Liquide solution offers a full set of monitoring and maintenance features that should address maintenance and monitoring requirements, including hydrogen and ultraviolet/infrared flame detection, emergency stop buttons, and process safety limits and parameters. Air Liquide also provides commissioning, start-up services, technical assistance, and training.

Truck Maintenance

Like EVs, heavy-duty FCETs should have significantly lower maintenance needs than traditional heavy-duty diesel trucks. Regular oil changes, a significant part of maintenance costs for diesel trucks, are not necessary for EVs. Yet there is little hard data to support FCET maintenance costs. The project team used estimates from a FCET manufacturer in our modeling and we acknowledge additional analysis will be necessary. That said, some garage/maintenance space would be required as part of the pilot.

There are certain requirements for hydrogen vehicle repair shops if in a closed shop:

- FCETs will be required to be defueled if any welding or open flames are within 18 inches of the vehicles' fuel supply container.
- A gas detection system must be installed in the shop that activates when hydrogen levels exceed the permitted levels.

³⁷ California Energy Commission. "GFO-23-604 - Improvements in Maintenance Processes for Reliable Operations that are Verifiable and Effective for Hydrogen Refueling Stations (IMPROVE for H2)." California Energy Commission, November 2023, <https://www.energy.ca.gov/solicitations/2023-11/gfo-23-604-improvements-maintenance-processes-reliable-operations-are>. Accessed 15 November 2023.

³⁸ Pacific Northwest National Laboratory. "Gaseous (GH₂) and Liquid Hydrogen (LH₂) Fueling Stations." Hydrogen Tools, <https://h2tools.org/bestpractices/gaseous-gh2-and-liquid-hydrogen-lh2-fueling-stations>. Accessed 1 February 2023.

- Open flame heaters with temperatures over 750°F are not permitted in areas where ignitable concentrations of gas are possible.

These requirements should be attainable but will either require some level of retrofitting the maintenance facility at the pilot location or identifying a local facility that can meet these standards.

To note, open air areas are better suited for FCET maintenance, as hydrogen gas rises and dissipates rapidly in open areas, which vastly decreases hazard risks. For a potential pilot to take place in the Anderson area where SPI's headquarters are located and summer days can reach quite extreme temperatures, covered space for truck repair and maintenance is a requirement and matches what SPI has on-site at their existing maintenance facility.

As part of a pilot and demonstration project, maintenance staff with familiarity with FCETs will be necessary. Initial conversations with the local community college, Shasta College, identified their existing diesel vehicle repair and maintenance program as a potential partner in developing those skills. The program is presently unfamiliar with the technology and as part of the pilot, a curriculum would need to be identified or developed.

Analysis of Permitting and Regulatory Needs

Existing County-level Use Permitting and CAL FIRE Considerations

At this time, the preliminary assessment in regard to potential permitting and regulatory needs appears to be positive for the pilot project. Working with Sharrah Dunlap and Sawyer (SDS), a local civil engineering firm, the project team analyzed the permitting, safety, and regulatory requirements that would be necessary to gain local, state and federal approval for the pilot. A pilot located at an existing permitted facility with a similar use case (i.e., the existing diesel fueling station), will be a significant factor in reducing the time and risk associated with obtaining a permit for a hydrogen pilot fueling station. In addition, SDS performed an initial review of a study for a project in Southern California to produce similar gas and liquid hydrogen for distribution to local and regional fueling stations and concluded that the regulatory requirements were manageable. Thus, at this time, the preliminary assessment in regard to potential permitting and regulatory needs appears to be positive for the pilot project.

As part of the Blueprint design, the project team engaged with the Shasta County Planning Department to explore the permitting and regulatory issues that would need to be addressed to implement a pilot at the SPI site. At the Shasta County administrative level, the SPI property's General Plan Designation is Industrial (I) and it is zoned for General Industrial (M). The facility currently operates under the Conditional Use Permit 07-021A. Per Condition 2 of the Use Permit, minor modifications, which includes diesel and fuel storage and fuel pumps, may be approved by the Planning Director.

Presently, SPI fuels over 100 trucks at their existing facility. The hydrogen pilot project is proposed to be located adjacent to the existing fueling facility and the hydrogen

vehicles would be incorporated into the existing diesel vehicle fleet. Per section 17.58.020-B of the Shasta County Zoning Ordinance, “uses accessory to the primary use and contained within the same plant site” are permitted uses. The pilot project will not be a retail operation, and it will not be open to the general public. Therefore, the pilot project will function as an accessory use to the existing lumber facility.

The Planning Department officials were encouraging and agreed that the hydrogen fueling infrastructure should be seen as a minor modification. More detailed site schematics will need to be submitted as part of a more formal permitting process.

The project team also contacted CAL FIRE to discuss the proposed pilot implementation and assure that any requirements they identify are addressed. Initial discussions were positive, but approvals cannot be issued until final detailed plans and specifications are developed for the specific pilot project to be implemented.

State-level Hydrogen Station Permitting

At the state-level, the California Governor’s Office of Business and Economic Development published a “Hydrogen Station Permitting Guidebook” in September 2020, which stated that “the use of hydrogen does not trigger any special California Environmental Quality Act (CEQA) considerations” and that there are several common exemptions for hydrogen stations on existing fueling sites for existing facilities, small structures, and minor alterations to land.³⁹ As such, the project team believes that state-level planning and regulatory issues, in particular CEQA, should not hinder the implementation of this project.

Potential Environmental Impacts of Project and Broader Implementation

Utilizing data made available by various sources, the project team assessed the potential emissions (focusing on nitrogen oxide and carbon dioxide) for heavy-duty diesel trucks to use as a comparison to FCET emissions (all calculations for diesel and FCET emissions are available in [Appendix M](#)).

Nitrogen oxide (NO_x) Emissions

According to the International Council on Clean Transportation (ICCT) analysis “Current State of Nitrogen oxide (NO_x) Emissions from In-Use Heavy-Duty Diesel Vehicles in the United States”, NO_x emissions are impacted by driving speeds. The study estimated that typical heavy-duty, diesel-powered vehicles travels at 0-25 mph for 43 percent of the time and over 50 mph for 46 percent of the time, with a relatively small share of travel

³⁹ California Governor's Office of Business and Economic Development. “Hydrogen Station Permitting Guidebook.” Governor's Office of Business and Economic Development, 1 September 2020, https://business.ca.gov/wp-content/uploads/2019/12/GO-Biz_Hydrogen-Station-Permitting-Guidebook_Sept-2020.pdf. Accessed 12 October 2023.

(11 percent) at the mid-range of 25-50 mph.⁴⁰ Logging trucks have different driving patterns than other heavy-duty trucks in terms of mileage, location of driving, and traveling speeds. While no detailed speed and usage data is available for truck usage in rural logging scenarios, we estimated, based on our interviews with logging fleet operators, that logging trucks traveling on smaller logging roads spend approximately 35 percent of the time traveling at the mid-range and higher speed ranges, and 30 percent of time traveling at the slower speeds (see Table 6 below).⁴¹ According to the ICCT study, NO_x emissions per mile are substantially higher when moving at slower speeds in urban settings (see Table 4). Given this mix, the average truck emits 3.55 grams of NO_x per mile of operations in urban settings.⁴² Using the estimated logging truck estimated driving times we developed, we calculated a somewhat lower overall level of emissions of logging scenarios at approximately 3.15 grams of NO_x per mile of operations.

Table 6: Estimated NO_x emissions from the ICCT study applied to the logging scenario

	Grams of NO_x per mile (g/mile)	Estimated percent of driving time (study)	Estimated percent of driving time (logging truck)
Urban Driving (0-25 mph)	7	43 percent	30 percent
Suburban (25-50 mph)	2.4	11 percent	35 percent
Highway (>50 mph)	0.6	46 percent	35 percent
Resulting blended average of NO_x (g/mile)		3.55	3.15

Source: *Allotrope Partners, LLC*

Using the assumption that each heavy-duty vehicle travels approximately 120,000 miles/year, the ICCT study estimates that each truck emits approximately 833 lbs of NO_x/year. Along with the lower emission profile of 3.15 NO_x calculated above, we also adjusted these numbers to reflect that logging trucks drive less miles annually (an

⁴⁰ ICCT. "Current state of NO_x emissions from in-use heavy-duty diesel vehicles in the United States." International Council on Clean Transportation, 25 November 2019, https://theicct.org/sites/default/files/publications/NOx_Emissions_In_Use_HDV_US_20191125.pdf. Accessed 13 March 2023.

⁴¹ The project team took into account feedback from logging truck drivers for this estimated breakdown.

⁴² ICCT, 2019.

⁴³ ICCT, 2019.

average of 81,250 miles per year⁴⁴). With these adjustments, **we estimated that diesel logging trucks emit approximately 564 lbs (0.28 tons) of NO_x /year.**

Carbon Dioxide (CO₂) Emissions

According to the U.S. Energy Information Administration (EIA), 22.5 pounds of CO₂ are emitted per gallon of diesel fuel consumed.⁴⁵ Assuming that heavy-duty logging trucks have a fuel efficiency of 6 mpg and travel approximately 81,250 miles/year, this amounts to about 152 tons of CO₂ emissions/truck/year.⁴⁶ The American Transportation Research Institute's (ATRI) estimates that a heavy-duty diesel vehicle's lifetime emissions (assuming a lifetime is equal to 1,000,000 miles and also includes the CO₂ emissions involved in the production of the vehicle), is approximately 3.6 million lbs of CO₂, or 1,800 tons.⁴⁷ The project team adjusted the lifetime miles to 600,000 miles, which interviews with logging fleet operators suggest is more realistic of logging vehicles, and calculated that the lifetime emissions of a diesel logging truck are approximately 2.3 million lbs of CO₂, or 1,127 tons (see Table 7 and calculations in [Appendix M](#)).

FCET Emissions

FCETs are considered zero-emission vehicles because they do not have any greenhouse gas tailpipe emissions, but there are still some emissions that can still be generated in the process of producing, transporting, and dispensing hydrogen fuel.⁴⁸ Using the ATRI analysis, but adjusting for lower lifetime miles (600,000 miles) and assuming the use of "green hydrogen", we estimate that a FCET has an estimated 193 tons of lifetime CO₂ emissions.⁴⁹ Because emissions are related to the production and use of hydrogen, the project team does not believe an FCET logging truck as opposed to other FCET use cases should change this meaningfully. Therefore, utilizing a FCET is expected to result in a reduction of 934 tons of CO₂ emissions and 2.1 tons of NO_x over the lifetime of the vehicles as opposed to diesel trucks (see Table 5 and [Appendix M](#)).

⁴⁴ This is an average based on data provided from operators using diesel trucks.

⁴⁵ EUI. "Carbon Dioxide Emissions Coefficients by Fuel." Carbon Dioxide Emissions Coefficients, https://www.eia.gov/environment/emissions/co2_vol_mass.php. Accessed 13 March 2023.

⁴⁶ Fuel efficiency and mileage estimates were provided from logging truck drivers and operators.

⁴⁷ ATRI. "Understanding the CO₂ Impacts of Zero-Emission Trucks." American Transportation Research Institute, 3 May 2022, <https://truckingresearch.org/2022/05/03/understanding-the-co2-impacts-of-zero-emission-trucks/>. Accessed 13 March 2023.

⁴⁸ U.S. Environmental Protection Agency. "A Glimpse into Hydrogen & Transportation | US EPA." EPA, 22 February 2023, <https://www.epa.gov/greenvehicles/glimpse-hydrogen-transportation>. Accessed 13 March 2023.

⁴⁹ American Transportation Research Institute, 2022. Note: Estimate reflects adjustment from report to reflect use of alkaline electrolysis with renewable power rather than SMR with natural gas and lower lifetime mileage of logging vehicles. See [Appendix M](#) for details on adjustments.

Table 7: Lifetime emissions footprint and reduction (assuming 500,000 miles)⁵⁰

	Implied Savings Compared to Diesel	Tons of CO ₂	Tons of NO _x
Diesel Trucks	NA	1,127	2.1
BETs	21.5 percent	884	0
FCETs	78.2 percent	193	0
Implied reduction from FCET compared to Diesel		934	2.1

Source: *Allotrope Partners, LLC*

Overall Emissions Reductions for the Pilot Project and Beyond

The proposed pilot project assumes two diesel-powered trucks are retired and replaced by FCETs. The assumption is that the hydrogen used for operations will be produced on-site using renewable energy, thus resulting in zero emissions both from the operations but also the production of the fuel used. Table 8 below includes the calculated emissions reductions for a single FCET, for a 2 FCET pilot, for a 10 FCET demonstration project, for fleet-wide conversion at the pilot location of approximately 120 FCETs, and sector-wide conversion for approximately 1,000 FCETs.⁵¹

⁵⁰ The CO₂ calculations include the footprint of the entire truck and fuel production process. Source: American Transportation Research Institute, 2022. The NO_x calculations assume no NO_x emissions from production and were calculated by the project team (see [Appendix M](#)).

⁵¹ While there is no hard data on the logging industry, we believe that there are at least 500-1000 logging vehicles operating in California. In addition, the logging sector could potentially grow as an increase in forest management is anticipated in order to address the State’s climate and forest fire crises.

Table 8: Summary of annual vehicle and lifetime emissions reductions from pilot to sector-wide adoption of FCET logging trucks

	Fleet Size	Annual Emissions Reduction		Lifetime Emissions Reductions	
		Tons of NOx	Tons of CO ₂ /Year	Tons of NOx	Tons of CO ₂
Single Vehicle	1	0.3	152	2.1	934
SPI Pilot	2	0.6	304	4.2	1,868
SPI Demo Project	10	2.8	1,520	20.8	9,341
Total SPI Fleet	120	33.9	18,241	250.0	112,086
Est. Total CA Logging	1,000	282.1	152,005	2,083.4	934,053

Source: *Allotrope Partners, LLC*

Given that the logging sector accounts for a very small percentage of the total number of Class 7 and Class 8 truck fleets in California, and that the estimated vehicle miles and fuel use of that segment amounts to approximately 0.5 percent of the total miles and fuel used, these emission reductions are proportionally quite small as a percentage of the total California truck fleet. Yet, a proof of concept in this sector would prove the viability of heavy-duty ZEVs across a number of other robust use cases and sectors (e.g., mining) where skepticism about the range and durability of such vehicles needs to be addressed.

Approaches to Financing the ZEVs and Infrastructure

Capital Costs of FCETs

In terms of costs, extensive data on FCET costs is not yet available for a majority of models. Importantly, FCETs coming to market in the near future are expected to be able to take advantage of California grants, as well as federal tax credits, that should reduce capital costs of the trucks significantly. As of November 2023, the project team learned that Kenworth, whose FCETs are not anticipated to be in the market until 2026, expects the list price of their vehicle to be roughly \$750,000 (including taxes and other fees) but after grants and credits should be in the range of \$623,000. Hyzon’s model, which is already on the market, has been reported to be \$442,000 after taking into account taxes, grants, and credits (see [Appendix N](#)). For initial modeling, we estimate that each FCET heavy-duty vehicle will cost \$500,000 for a total of \$1 million for a pilot project with 2 FCETs and an additional \$4 million for a demonstration project with 8 additional FCETs.

Capital Costs of Hydrogen Production Infrastructure

Highly accurate costing for the installation of a hydrogen production facility will only be available once an engineering, procurement and construction (EPC) contractor is hired

and a detailed third stage of front-end engineering and design work is completed. Yet, working with key vendors, we were able to create what we believe is a reasonable estimate of the capital costs of the infrastructure required to support a pilot project of 2 FCETs and then an estimate of costs to scale the effort up to a demonstration project of 10 FCETs. In total, we estimate that the capital costs for the infrastructure to support the pilot project will cost \$3.2 million and for the demonstration project an additional \$1.2 million, totaling \$4.4 million (see Table 9 below). The following subsections will provide additional details about the required infrastructure and associated estimated costs.

Electrolyzer Costs

While a number of literature sources cited varying costs ranging from \$500/kW to \$1,500/kW, we were provided an estimate by a number of electrolyzer vendors, including Cummins, at \$1,000/kW of capacity. Ohmium presented a competitive price of approximately \$875/kW. Given a fully loaded efficiency of 55 kW of electricity needed per kg of hydrogen produced, 1 MW of electrolyzer capacity would produce 18 kg/hr or 436 kg/day.⁵² The Ohmium electrolyzer solution with a 450-kW capacity would be sufficient to support a pilot of 2 FCETs each with 70 kg of total tankage capacity. The Ohmium solution is designed so that additional units can be readily added to the core infrastructure, allowing the system to scale up to possible 1.8 MW of capacity, which would be enough to support a 10-vehicle demonstration project.

Storage and Filling Equipment Costs

The leading modular system offered by Air Liquide has an estimated cost of approximately \$2.8 million, which includes most of the additional infrastructure required for compressing, cooling, storage, and filling that will be needed for both the pilot and demonstration projects.⁵³ The differences between Air Liquide's two models, the 360 kg/day and 1,000 kg/day, comes down to a difference in tank sizes and a relatively small change in price, therefore it makes sense to opt for the larger model that will serve both the pilot and demonstration projects.

⁵² From the specification sheet provided by the vendor, see [Appendix K](#), as well as supported by a number of other literature sources.

⁵³ The final design may require additional bulk hydrogen storage tanks.

Table 9: Pricing for Hydrogen Production Infrastructure and Vehicles on a Pilot and Demonstration Scale

	Pilot Only	Additional Costs for Demonstration
Electrolyzer: Ohmium	\$ 407,250	\$ 1,164,150
Compression/Storage/Filling: Air Liquide	\$ 2,800,000	N/A
Total Capital Cost of Infrastructure	\$ 3,207,250	\$ 4,371,150
Cost of Vehicles	\$1,000,000	\$4,000,000
Total Cost Each Stage	\$4,192,250	\$5,164,150
Total Cost of Pilot and Demo Project	-	\$9,371,400

Source: Allotrope Partners, LLC

Operation Costs of Hydrogen Production

The primary cost of hydrogen production is the cost of electricity used to operate the electrolyzer. Other expenses include the cost of compression (which is also energy intensive), the cost of water, and other expenses that are described below.

Electricity Cost Assumptions

Given the significant amount of electricity needed, we believe wholesale electricity rates are appropriate target prices for production. Pricing from the CAISO Around the Clock (ATC) market for 2025, as accessed from Bloomberg market data as of November 10, 2023, was approximately \$0.067/kW. The estimated cost for a renewable energy credit (REC) to assure that the electricity is from a renewable resource is estimated to cost an additional \$0.02/kW, or \$0.87/kW total. In addition, the IRA offers a \$0.015/kW production tax credit.⁵⁴ Thus, we are using an overall cost of \$0.11/kW, which we believe is conservative

The pilot plant location has an operational 30 MW cogeneration plant on-site that could conceivably supply the necessary renewable power for the site, but we understand from SPI that they have an existing power purchase agreement for the power produced from the plant and thus they are unlikely to be able to offer the pilot or demonstration project power from the plant. Therefore, for the purposes of this analysis, we assume that power will need to be purchased from a third-party. Assuming that electricity will

⁵⁴ Note that the IRA credit could also be used as a 30% investment tax credit on the Capex of the project, but we are assuming that you can't take both an investment tax credit and the production tax credit. Thus we are assuming only the production tax credit for this analysis.

cost approximately \$0.11/kW and that 55 kW of electricity is needed to produce 1 kg of hydrogen, the cost of 1 kg of hydrogen is estimated to cost \$6.05 for electrolysis alone.

Compression Cost Assumptions

According to a study of hydrogen fueling station operational costs, total compression costs can cost up to \$1.50/kg of hydrogen compressed.⁵⁵ This study focused on a series of smaller sites around California, leading us to conclude that \$1.50/kg is a conservative estimate, as we believe a larger facility serving heavy-duty vehicles will have some benefits of scale. That said, we acknowledge that this datapoint requires more investigation.

Water Cost Assumptions

Cummins and literature research both confirm that electrolyzers need 4.5 gallons/kg produced but we are increasing that to 5.0 gallons/kg to be conservative. This water would be available from a well on-site, but it will require deionization/demineralization before it could be used in the electrolyzer (the Ohmium system includes water treatment within their solution). Operating costs for such a system appear to be quite low, but overall, we are modeling a total cost of \$0.02/gallon which amounts to \$0.10/kg.⁵⁶

Other Cost Assumptions

Other costs should include additional ancillary equipment, maintenance, upkeep, and ongoing expenses. The "Assessment of Hydrogen Production Costs from Electrolysis: United States and Europe" study estimates that other expenses to operate an electrolysis facility costs \$40/kW of installed capacity or 1-3 percent of the cost of the electrolyzer.⁵⁷ This would suggest a range between \$0.26 and \$0.19/kg of ongoing operating expenses. To be conservative, we are assuming other costs to be approximately \$0.50/kg.

Based on the specific implementation of the Blueprint project, there are several active federal tax credits and state-level grants that should be considered with the specific context of the project on hand. Several factors, such as the actual location of the project, the chosen ZEV (type and manufacturer), and the chosen infrastructure will influence the financial incentives that the project is able to take advantage of. Several of the top tax credits and state grants are included below, but a full analysis of current

⁵⁵ Christensen, Adam. "Assessment of Hydrogen Production Costs from Electrolysis: United States and Europe." International Council on Clean Transportation, 18 June 2020, https://theicct.org/wp-content/uploads/2021/06/final_icct2020_assessment_of_hydrogen_production_costs-v2.pdf.

⁵⁶ Christensen, 2020. Note: This study uses \$0.08/kg for water in his analysis, but we believe a premium is appropriate in California.

⁵⁷ Christensen, 2020.

offerings with open funding rounds is paramount when implementing project pilots to ensure the project can take advantage of as many incentives as possible.

Financing the Project Expenditures

To generate a full assessment of the costs to support this pilot facility, the capital cost of the vehicles and infrastructure needs to be reflected. These costs are assumed to be financed with a 20-year loan at an 8 percent interest rate. The overall capital cost can ultimately be adjusted to reflect any grants or other cost reductions that may be attainable. As of now, and assuming the full cost of capital of the infrastructure must be reflected (and excluding the costs of the trucks that are added below), the capital costs amount to \$6.15/kg of hydrogen for the pilot project. This capital cost per unit drops to \$1.72/kg for the demonstration projects, due to the higher volume of production and relatively lower incremental additional costs of expanding capacity to the demonstration scale.

Table 10 includes a comparison of the operational costs for hydrogen production for the proposed pilot and demonstration project and also includes a preliminary biomass-to-hydrogen production model to demonstrate that scale can drive down hydrogen costs significantly.

Table 10: Operational Costs per kg of Hydrogen Basis ⁵⁸

	Pilot	Demonstration	Biomass to H
MW Capacity	0.45	1.8	10 ⁵⁹
Trucks Supported	2	10	56
Electricity cost per Kg of H	\$6.05	\$6.05	
Compression Costs	\$1.50	\$1.50	
Other Expenses	\$0.50	\$0.50	
Cost of Water	\$0.10	\$0.10	
Capital Cost Infrastructure	\$6.15	\$1.72	
IRA Credit	-\$3.00	-\$3.00	
Cost per kg	\$11.30	\$6.87	\$2.84

Source: *Allotrope Partners, LLC*

⁵⁸ See [Appendix J](#) for more detail regarding these calculations and the underlying assumptions regarding the pilot and demonstration project level costs of hydrogen per kg produced. Detail regarding biomass-to-hydrogen economics was provided under a non-disclosure agreement and thus we cannot provide additional detail regarding that technology.

⁵⁹ MW Energy Equivalent

Operational Cost Comparison: Heavy-duty FCET versus Diesel Trucks

Given the previously reported estimate of 7 miles/kg of hydrogen, at the pilot stage, it would cost approximately \$2.42/mile to operate a heavy-duty FCET. This estimate includes \$1.61/mile for hydrogen, a capital cost for a single truck (\$0.63/mile) and a truck maintenance expense (\$0.18/mile) based on an estimate provided by a FCET manufacturer.

Diesel vehicles cost on average \$1.76/mile to operate, assuming 6 mpg and \$6.00/gallon cost (and thus \$1.00 per mile), plus a capital cost of \$0.31 (due to lower costs for a diesel truck) and maintenance expense of \$0.45/mile (see [Appendix A](#) for more details).

The capital cost of infrastructure is included in the calculation of the cost of production of hydrogen, but the diesel comparison does not include a cost of supporting diesel infrastructure. Removing the cost of hydrogen infrastructure from the project calculation results in a cost of \$1.54/mile, which would result in the hydrogen option costing nearly 6.5 percent less than diesel on a per-mile operating basis (Table 11 below and [Appendix J](#) for more detail on assumptions).

Table 11: Hydrogen versus Diesel Cost Comparison (Including and Excluding Infrastructure Costs)

	Pilot	Demonstration	Biomass to H
FCET Cost/Mile	\$1.61	\$0.98	
Capital Cost	\$0.63	\$0.63	
Maintenance Costs/Mile	\$0.18	\$0.18	
FCET Cost/Mile (incl. infrastructure costs)	\$2.42	\$1.79	\$1.07
Diesel Operating Cost/Mile	\$1.00	\$1.00	
Capital Costs	\$0.31	\$0.31	
Maintenance Costs/Mile	\$0.45	\$0.45	
Diesel Trucks Cost/Mile	\$1.76	\$1.76	\$1.76
<i>percent Change from Diesel Truck Costs</i>	37.4 percent	1.5 percent	-50.5 percent
FCET Cost/Mile (excl. infrastructure costs)		\$1.54	
<i>percent Change from Diesel Truck Costs</i>		-6.5 percent	

Source: Allotrope Partners, LLC

Financing Options for the ZEV Transition

If the estimated costs of hydrogen and other operating costs prove to be accurate, in particular the at-scale biomass-to-hydrogen projections, then the long-term ability to finance the transition to ZEVs in the logging sector and ultimately other heavy-duty industries should be relatively straightforward. Private industry will aggressively pursue a technology option that reduces fuel costs significantly and capital sources will be willing to lend for/invest in equipment that will make that industrial sector more competitive. In particular, we have discussed the opportunity with a number of lenders/investors focused on investing in equipment and vehicles as part of their mission to expand the forest management sector in the state.⁶⁰ They indicated an interest in supporting financing arrangements that could support additional the scaling up of infrastructure for the sector, but would need comfort that the equipment is viable

⁶⁰ We are unable to name these individual lenders/investors due to non-disclosure agreements.

and that cash flow generated from resulting operations can support interest or lease payments related to such a financing.

In order to prove the viability of FCETs in the sector, initial pilots and demonstration projects will need federal and/or state financial support.⁶¹ It is unlikely that the private sector will directly invest in unproven technologies without grant support, particularly given the higher costs of infrastructure that needs to be included as part of a pilot and/or demonstration project that would not be useful to the operator post-project if they chose not to continue operating the technologies. Some grant offerings, such as the follow-up CEC grant for funding Blueprint projects, require matching funds, whereas others do not require matches. Such funds will need to be found, perhaps from industry partners as well as vendors of the equipment that could recover the equipment at the end of the demonstration project or from other federal and state programs.

Based on the specific implementation of the Blueprint project, there are several active federal tax credits and state-level grants that should be considered with the specific context of the project on hand. Several factors, such as the actual location of the project, the chosen ZEV (type and manufacturer), and the chosen infrastructure will influence the financial incentives that the project is able to take advantage of. Several of the top tax credits and state grants are included below, but a full analysis of current offerings with open funding rounds is paramount when implementing project pilots to ensure the project can take advantage of as many incentives as possible.

Federal Tax Credits

There are several federal-level tax credits available that can be applicable to both FCETs and the related hydrogen production infrastructure. While the exact details of the credits available from the **IRA** are not yet fully defined, it is generally understood that green hydrogen production that utilizes renewable electricity sources is likely to qualify to receive a \$3/kg tax credit. This is driving the increased popularity of electrolyzer solutions for hydrogen production where renewable electricity is available. We believe that power from the on-site cogeneration facility on-site would qualify as renewable electricity for the program or, alternatively, renewable electricity could be procured from the grid. Thus, we are assuming a \$3/kg credit as part of our calculations.

Under the **Commercial Clean Vehicle Credit**, businesses that buy a qualified commercial clean vehicle (BETs and FCETs) may qualify for a clean vehicle tax credit of up to \$40,000. Qualifying vehicles must have at least a 15-kWh battery capacity when

⁶¹ Note that our assumptions about truck pricing (\$500,000 per truck) assumes a \$240,000 grant from California and a \$40,000 federal tax credit from the IRA.

the vehicle weight is above 14,000 lbs⁶² This credit is included in the calculations of the FCET costs (see [Appendix N](#)).

As of January 1, 2023, fueling equipment infrastructure, including hydrogen, is eligible under the **Alternative Fuel Infrastructure Tax Credit** for a tax credit of 30 percent of the cost or 6 percent in the case of property subject to depreciation, not to exceed \$100,000. The qualified equipment must be installed in a census tract that is not an urban area, in a population census tract where the poverty rate is at least 20 percent, or a metropolitan and non-metropolitan area census tract where the median family income is less than 80 percent of the state median family income level.⁶³ If the proposed Blueprint project were to take place at SPI in Anderson, California, it should be eligible for this credit based on its location and 2017-2021 census data. We have not included this tax credit in our cost analysis as we are uncertain if a project can stack multiple credits.

Department of Energy (DOE) Loan Programs Office (LPO)

While not a traditional incentive, the DOE's LPO has a dedicated track to support the deployment of clean hydrogen in the United States in difficult-to-decarbonize sectors by addressing the challenge of a lack of debt financing for commercial deployment. LPO can finance projects spanning hydrogen production and end uses, including advanced transportation that includes fuel cell vehicles in heavy-duty trucking, through several different avenues. The most likely avenue for Blueprint implementers to consider a consultation for additional information based on the specifics of the pilot to be implemented is "Innovative Energy and Innovative Supply Chain Projects (Section 1703)" under the Title 17 Clean Energy Financing Program.⁶⁴

State Grants

There are several active federal and state level grants available that focus on the adoption of ZEVs. California's **Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)** offers first-come, first-served incentives that reduce the incremental cost of MDHD commercial vehicles to accelerate the deployment of zero-emission and plug-in hybrid trucks and buses. Class 8 FCETs are eligible vehicles, but the incentive offered is dependent on fleet size of the purchaser (operators with fleet sizes less than 10 vehicles and are located in disadvantaged communities qualify

⁶² U.S. Internal Revenue Service. "Commercial Clean Vehicle Credit." Commercial Clean Vehicle Credit, 22 June 2023, <https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit>. Accessed 13 November 2023.

⁶³ U.S. Department of Energy. "Hydrogen Laws and Incentives in Federal." Alternative Fuels Data Center, <https://afdc.energy.gov/fuels/laws/HY?state=US>. Accessed 13 November 2023.

⁶⁴ U.S. Department of Energy. "Innovative Energy and Innovative Supply Chain." Department of Energy, <https://www.energy.gov/lpo/innovative-energy-and-innovative-supply-chain>. Accessed 13 November 2023.

for larger incentives).^{65,66} We assumed a grant of \$240,000 per FCET in our calculations (see [Appendix M](#)). California's **Energy Infrastructure Incentives for Zero-Emission (EnergIIZE)** provides incentives for infrastructure (i.e., equipment, extended equipment warranty, network, and charge management software) to support commercial fleets of medium- and heavy-duty ZEVs.

Finally, CEC's GFO-23-603 "Implementation of MDHD Zero-Emission Vehicle Infrastructure Blueprints" would be an excellent opportunity to support the implementation of the infrastructure proposed in the Blueprint, but that will be dependent on if future solicitation windows are opened. The Blueprint Implementation grant could offer incentives of up to \$4 million and up to 75 percent of eligible costs covered because of the hydrogen focus and meeting at least one of the criteria under the "Jump Start" requirements (SPI's headquarters is located in Anderson, which is categorized as a low-income community). If applicants are also participating in the HVIP or other state or federal vehicle programs, that would also help them to qualify under the Jump Start requirements.⁶⁷ Additional opportunities are available through the CEC that warrant additional research for applicability for future implementation.

Present Models to Industry and Community for Feedback Feedback from Partners on Challenges and Strengths of the Project

With the pilot project largely defined, an effort to present the idea to the industry and community has begun with outreach focused on our direct partners and local Shasta County community members, such as local government officials, non-profit and community college staff, at this point. We expect to continue to present the concept to other operators in the sector over the next months and into 2024.

Our direct partner, SPI, has indicated continued interest in the concept, as they acknowledge that there will be increasing regulatory pressure to decarbonize their operations and recognize that their diesel-powered truck fleet is a high-profile source of

⁶⁵ California HVIP. Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, <https://californiahvip.org/>. Accessed 13 November 2023.

⁶⁶ The Clean Off-Road Equipment Voucher Incentive Project (CORE) is another California voucher program that offers the purchase of zero-emission equipment used in off-road applications, which includes a voucher enhancement to offset certain costs associated with the purchase and installation of hydrogen production and storage infrastructure, but it does not appear that the Blueprint's equipment (FCETs which are both on- and off-road and not considered terminal tractors) and use case (non-shore-side) would qualify for this incentive.

⁶⁷ California Energy Commission. "Implementation Manual for Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles Project (EnergIIZE)." EnergIIZE, 21 September 2023, <https://client-calstart-energiize170606-staging.s3.us-west-2.amazonaws.com/public/EnergIIZE-Implementation-Manual-Q4-2023.pdf?X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Content-Sha256=UNSIGNED-PAYLOAD&X-Amz-Credential=ASIASSSISOGM3IVWZA7C%2F20231113%2Fus-west-2>. Accessed 13 November 2023.

emissions that needs to be addressed. That said, they would need further proof of concept, with both operational and financial feasibility confirmed and the technologies proven. Thus, the pilot/demonstration project proposal is an essential next step. In addition, there is also a concern about vehicle availability as it is not clear when FCETs will be available in the market at scale.

Opportunities and Needs as Defined by Broader Community

Discussions with a number of key members of the local community suggest that there is, in theory, interest in the concept. It's not clear how it applies to the local population, as this pilot proposal will focus first on a private company fleet and will have less direct impact on the community at-large.⁶⁸ That said, driving down emissions, finding ways to do so that ultimately are financially viable, and supporting the needs of an important local industry are of interest to the community. In addition, contacts at Shasta College look forward to understanding the skill sets needed to serve a new technology and incorporating those skills into the vocational training programs they oversee.

⁶⁸ Community outreach included Shasta College, Shasta County Economic Development Corporation (meeting with Shasta Supervisor Chris Kelsrom), Associated California Loggers, CAL FIRE, Shasta County Planning Commission, as well as regional logging and fleet operations listed previously. If a shorter list, include names of organizations. But I think Kate would rather see this in an Appendix with more detail like name of persons, name of org, date of meeting(s), overall takeaways.

Chapter 4. Advancements in Science and Technology

This project doesn't center on groundbreaking scientific or technological advances but rather on strategically integrating existing cutting-edge technologies—heavy-duty FCETs, BETs, and NGETs and their infrastructures—into the logging and biomass sector. This serves a dual purpose: addressing the pressing issue of California's wildfire crisis and aligning with the state's climate change goals.

To tackle the challenge of upscaling forestry management for wildfire risk reduction without a dependence on pollution-heavy, diesel-fueled trucks and excessive impacts on the climate, a pragmatic two-phased pilot project approach has been outlined in the Blueprint. This approach aims to demonstrate the feasibility of ZEVs, particularly FCETs, in meeting the technical demands and heavy-duty workloads of the logging and biomass sector in the smaller pilot project, as well as showcasing the economic viability through on-site hydrogen refueling infrastructure in the larger demonstration project to provide a practical model for industry stakeholders. By partnering with the largest operator in the region, SPI,

Beyond its applicability to the logging sector, this Blueprint extends as a potential implementation model for similar industries, like mining, where heavy-duty diesel trucks are prevalent. By illustrating the feasibility and economic viability of ZEVs and related infrastructure, the project team has contributed a foundational model to guide interested parties toward transformative advancements in their respective sectors.

Chapter 5: Project Successes and Observations

Measuring Success of the Project

The goal of this project was to assess and demonstrate the technical and economic viability of heavy-duty ZEVs in the logging/timber sector through the development of a blueprint planning document. The in-depth project activities that deeply analyzed all aspects of ZEVs, potential infrastructure, and made comparisons to diesel-fueled vehicles, all supported the successful development of a “Blueprint for Implementation of Heavy Duty Zero Emission Vehicles in the Timber and Biomass Hauling Sector”.

Achievement of the Project Goal

We believe that the Blueprint document achieves the project goal by identifying and presenting a seemingly viable technological solution that can meet the needs of the industry and laying out a pathway to a pilot project that would act as a proof of concept. If this pilot project can demonstrate that the equipment can serve the needs of industry as well as prove that the financial and operational assumptions are reasonable, then this could, in turn, ultimately drive adoption of ZEV solutions in the sector at scale.

Achievement of Project Objectives

There were four key objectives of the Blueprint as we investigated the potential for the use of heavy-duty ZEVs in the logging/biomass transport industry.

1. **Developing the technical specifications a vehicle would need to address the logging/timber industry’s needs.** We believe we largely met this objective for logging and biomass hauling vehicles. We also investigated grapple trucks, though we made less progress on that front as grapple trucks are a newer category and it was difficult to find useful information on their operations.
2. **Determine if there is a ZEV solution that could viably serve the sector.** We achieved our objective, as our analysis determined that Class 8 FCETs could possibly serve as a logging truck. There are some concerns about the range of such vehicles, but they appear to be manageable, particularly as infrastructure for hydrogen vehicles proliferates. Class 8 BETs seem less likely to fit as logging trucks but might work to haul biomass/wood chips in certain circumstances. Finally, we elected to not pursue the question of a ZEV/grapple truck, as information was difficult to find and it appeared that running a grapple is very energy intensive so a ZEV option was challenging.
3. **Outline one or more pilot projects.** We ultimately focused on one pilot project opportunity, one that focused on the most promising technological solution, Class 8 FCETs for logging, with a most promising pilot partner in SPI.

The pilot project design included an analysis of the capital costs of a pilot and estimates of the operational costs and benefits of utilizing Class 8 FCETs moving forward. The pilot project analysis also included an analysis of the permitting process and environmental impact of the pilot and the at-scale adoption of ZEVs in the sector.

4. **Present the pilot project plan to the logging/timber sector and the local community to build awareness and support for the effort.** Outreach only began in the final stages of this project, and while important findings have already been identified, it is anticipated that this process will be ongoing in the future.

Project Observations

Logging and Biomass Hauling Operators

Operators in the logging and biomass sector consistently were open to discussions about their needs and specifications and were, at a high level, interested in discussions about the potential for ZEVs in the sector, but there was a high level of skepticism about the potential for heavy-duty BETs and limited-to-no knowledge about FCET options.

Given the nature of the logging sector, these businesses tend to be quite conservative about new technologies. Equipment tends to have a high level of utilization, and runs on very tight operating margins. Thus, adoption of a new technology requires strong, verifiable proof of concept and a strong business case.

ZEV Manufacturers

A key concern of industry contacts was the ultimate availability of vehicles. In our initial discussions in June 2022, many of the manufacturers we interviewed suggested that vehicles would be available in 2023. A number of trucks did come to market this year, but a number of pushed release dates into 2024 through 2026. We believe there would be vehicles available on the market for a pilot (i.e., two vehicles) in the later part of 2024 or in 2025, but this would need to be confirmed when funding for the project is obtained. Scaling to a full demonstration project (i.e., eight additional vehicles) may take further time. FCET vendors also may place a priority on meeting the demand for vehicles in larger market sectors than logging.

Infrastructure Providers

In researching and interviewing infrastructure providers we found that there are quite a few companies looking to provide products and services in the emerging sector. We found that producers of hydrogen infrastructure equipment range from large conglomerates like Air Liquide to smaller companies that resemble start-ups. There are also numerous engineering firms of various sizes looking to serve this sector. Given the range of businesses, it is important to assess the capabilities of those potential partners and ensure that they can not only execute but also are in a position to provide ongoing support (such as monitoring and maintenance) for any services or products they offer.

Local Community and Workforce

Discussions with the Shasta County Economic Development Corporation as well as different members of the Shasta College staff that focus on vocational training consistently reflected a strong interest in supporting the adoption of ZEVs generally but also acknowledged that there is only limited understanding of the skills and know-how that needs to be developed and taught to a workforce in the area. These groups expressed interest and support in following the process of a pilot project to learn about the skills that need to be developed. They have expressed concern about the difficulties of expending significant resources to start and scale vocational programs to provide long-term support for these technologies without first knowing that heavy-duty ZEVs are viable in the logging sector and are going to scale.

Chapter 6: Conclusions and Recommendations

Project Conclusions: The Opportunity for ZEVs in the Logging Sector

McKinsey estimates that FCETs will, by 2030, have a lower total cost of ownership than existing diesel technology, a technology that has already dropped down the cost curve given the economies of scale diesel already has in place.⁶⁹ Given a \$3/kg tax credit generated from the IRA, we believe this is feasible and can be achieved relatively soon based on our analysis. Our analysis confirms that with access to \$0.11/kWh for electricity, heavy-duty FCETs appear to operate on a close-to-parity basis with diesel vehicles when operating on a demonstration scale (10 trucks or more). This analysis includes the cost of new hydrogen infrastructure, whereas diesel infrastructure depends on pre-existing, and in many cases, public infrastructure).

If and when hydrogen vehicles begin to penetrate the market, similar economies of scale to diesel will occur and refueling infrastructure will become more readily available. If the cost models of proposed biomass-to-hydrogen solutions are correct, hydrogen could be produced at well below \$3/kg, making FCETs competitive with diesel regardless of IRA credits.

In the meantime, we believe that grants or other financial incentives (such as the IRA but also state-level infrastructure and truck financing programs) will be necessary to fund initial demonstration or Proof of Concept projects, as it is unlikely that industry participants will fund the build out until the operating assumptions of this analysis are proven on the ground. Thus, we believe that a combination of grants, tax credits, and loan programs to fund hydrogen infrastructure and FCET purchases will be necessary to fund the initial capital costs of a pilot project like the one proposed in this Blueprint.⁷⁰

A portion of ongoing operational expenses of a pilot and later a demonstration project could potentially be covered by the operator, particularly if the amount replicates the operational costs of their existing diesel-powered infrastructure. That being said, tracking operational expenses might be a challenge and would require developing an agreed upon system upfront. Any additional expenses that a pilot or demonstration

⁶⁹ McKinsey Center for Future Mobility. "Preparing the world for zero-emission trucks." McKinsey & Company, September 2022, <https://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/preparing%20the%20world%20for%20zero%20emission%20trucks/preparing-the-world-for-zero-emission-trucks-f.pdf>. Accessed September 2023.

⁷⁰ SPI already works with Shasta County and CARB on a program that retires older diesel vehicles for newer ones.

project would generate, including monitoring and maintenance of both the infrastructure and the vehicles, would need to be covered as part of the program.

Longer term, if initial pilots are successful and economies of scale generate price reductions across the hydrogen supply chain, we believe models will emerge that could fund the roll out of heavy-duty FCETs through private funding sources that can capitalize on the long-term tax credits generated by the IRA. In many cases, traditional debt financing can support the building out of infrastructure and vehicles, much like traditional funding for vehicles that exists today. In addition, certain vendors of renewable natural gas fuel, as well as emerging hydrogen trucking firms, are offering “all-in” pricing as long as customers agree to long-term fuel and truck contracts. Again, if the adoption of heavy-duty FCETs begins to scale, so too will effective business models.

Project Recommendations

The project team is confident that the developed Blueprint can demonstrate to the logging and biomass sector, as well as potentially other heavy-duty sectors like mining, that there are ZEV options and supporting infrastructure solutions that can viably serve the sector. The economic analysis suggested that at a scale of 10 FCETs, a demonstration project should have operating costs (which reflect both capital costs for the trucks and infrastructure) that are competitive with diesel operating costs, particularly at today’s high diesel prices. These cost estimates were developed with the best available market data and assumptions developed based on interviews with industry stakeholders including logging operators and drivers, ZEV manufacturers, and infrastructure developers.

Timeline

The full implementation of this Blueprint concept, or one similar to it, is the critical next step in scaling the adoption of ZEVs in the logging and biomass sector. Proving both the functionality and the essential economic viability of ZEVs in a “real world” environment with a high-profile partner is essential to driving adoption not only in the logging sector but in other heavy industries that utilize similar vehicles in challenging environments.

The project team **recommends a two-phased approach** because sector stakeholders, mainly logging company operators and inclusive of the proposed Blueprint partner SPI, need to first see, through a pilot project, that ZEVs can meet the needs of the industry and then, through the demonstration phase, see proof that such vehicles can do so on an economically viable basis. SPI has shared that **a proof of concept is necessary** to ensure that the FCETs can manage the heavy-duty workload of logging prior to committing to a full-blown demonstration level project with 10 FCETs.

Additionally, while the source of hydrogen on-site is not likely to be the paramount concern for the participating operators who could implement this first phase of the project, be that SPI or others, we believe that demonstrating the feasibility and economics of on-site hydrogen production with an electrolyzer and modular refueling station for the demonstration project is an important step to confirm that the operating

costs for hydrogen-based solutions (which reflect both capital costs for the trucks and infrastructure) are competitive with diesel operating costs.

In terms of timeline for implementing a project of this scale and with a focus on technologies that are still coming to the market, **the next steps forward hinge of securing funds** to cover or substantially reduce the costs of the FCETs and on-site hydrogen production infrastructure. There are a number of California grants to explore that could potentially provide substantial funds for both aspects. Notably, CEC's grant funding.

Full funding of a two-phase project must include a more detailed Front End Engineering and Design (FEED) study that confirms the pricing estimates developed as part of this Blueprint process. Ideally, a partner engineering firm will complete a FEED study and then commit to the pricing costs developed therein. Such a commitment/guarantee would greatly reduce the risk of cost overruns and further ensure a successful implementation of the Blueprint plan.

The project team will consider pursuing a smaller grant to fund the FEED study alone, possibly through foundations and other philanthropic organizations focused on addressing and mitigating the impacts of climate change. Continued community outreach, both locally in the Redding/Shasta region and more generally in California, as well as nationally, will continue to support this effort. Yet completing a FEED study without a strong path to full funding already in place carries considerable risk, as the cost estimates in a FEED study tend to be accurate/supported by the engineering firm that developed the study for only a short time before it is considered "stale".

Furthermore, availability (and pricing) of FCETs for the pilot will also have to be confirmed. The project teams' discussions with vendors, both initially in the Summer of 2022 and more recently update calls, leaves us concerned that exact timing of full-scale availability of vehicles is still uncertain and only preliminary pricing of certain vehicles is available to date. As part of any FEED study, commitments for vehicle availability and pricing will have to be gathered from FCET vendors.

GLOSSARY

ALTERNATING CURRENT (AC)—Flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that shifts direction at a rate of 60 times per second.

BATTERY ELECTRIC VEHICLE (BEV)—Also known as an “All-electric” vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source in order to recharge.

CALIFORNIA AIR RESOURCES BOARD (ARB) -- 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 DEPARTMENT OF TRANSPORTATION (Caltrans)—Responsible for the design, construction, maintenance, and operation of the California State Highway System, as well as that portion of the Interstate Highway System within the state's boundaries.

CALIFORNIA ENERGY COMMISSION - 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

CARBON DIOXIDE (CO₂) - A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO₂ is the greenhouse gas whose concentration is being most affected directly by human activities. CO₂ also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent). The major source of CO₂ emissions is fossil fuel combustion. CO₂ emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO₂ have been increasing at a rate of about 0.5% per year and are now about 30% above preindustrial levels. (EPA)

CARBON INTENSITY (CI) -- The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels.

CARL MOYER FUND -- A multi-million dollar incentive grant program designed to encourage reduction of emissions from heavy-duty engines. The grants cover the additional cost of cleaner technologies for on-road, off-road, marine, locomotive and agricultural pump engines, as well as forklifts and airport ground support equipment.

COMPRESSED NATURAL GAS (CNG) - natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

DIRECT CURRENT (DC) - Electricity that flows continuously in the same direction.

ELECTRIC VEHICLES (EV) -- A broad category that includes all vehicles that are fully powered by Electricity or an Electric Motor.

ELECTROLYSIS - Breaking a chemical compound down into its elements by passing a direct current through it. Electrolysis of water, for example, produces hydrogen and oxygen.

ENVIRONMENTAL PROTECTION AGENCY (EPA) - A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting and enforcement activities.

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.

HYDROGEN (H₂) -- A colorless, odorless, highly flammable gas, the chemical element of atomic number 1.

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.

KILOWATT (kW) -- One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon a typical home, with central air conditioning and other equipment in use, might have a demand of four kW each hour.

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. In 1989, a typical California household consumes 534 kWh in an average month.

LIQUID COMPRESSED NATURAL GAS (LCNG) -- The volume of liquefied compressed natural gas is only around 1/600th of the volume of gaseous natural gas. This results in significant advantages where gas transportation is concerned in particular. Following liquefaction and transportation, the liquefied natural gas (LNG) is regasified (converted into CNG) with subsequent forwarding to grid gas companies via pipelines.

MEGAWATT (MW) - One-thousand kilowatts (1,000 kW) or one million (1,000,000) watts. One megawatt is enough electrical capacity to power 1,000 average California homes. (Assuming a loading factor of 0.5 and an average California home having a 2-kilowatt peak capacity.)

MEGAWATT HOUR (MWh) - One-thousand kilowatt-hours, or an amount of electrical energy that would supply 1,370 typical homes in the Western U.S. for one month. (This is a rounding up to 8,760 kWh/year per home based on an average of 8,549 kWh used per household per year [U.S. DOE EIA, 1997 annual per capita electricity consumption figures]).

METHANE - A light hydrocarbon that is the main component of natural gas and marsh gas. It is the product of the anaerobic decomposition of organic matter, enteric fermentation in animals and is one of the greenhouse gases. Chemical formula is CH₄.

NATURAL GAS -- Hydrocarbon gas found in the earth, composed of methane, ethane, butane, propane and other gases.

NATURAL GAS ELECTRIC TRUCKS (NGET) -- vehicles that are powered by compressed or liquefied natural gas.

NITRIC OXIDE (NO) -- A Precursor of ozone, NO₂ and nitrate; nitric oxide is usually emitted from combustion processes. Nitric oxide is converted to nitrogen dioxide (NO₂) in the atmosphere and then becomes involved in the photochemical processes and/or particulate formation.

NITROGEN OXIDES (OXIDES OF NITROGEN, NO_x) -- 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.

OFF-ROAD -- Any non-stationary device, powered by an internal combustion engine or motor, used primarily off the highways to propel, move, or draw persons or property, and used in any of the following applications: marine vessels, construction/farm equipment, locomotives, utility and lawn and garden equipment, off-road motorcycles, and off-highway vehicles.

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.

Appendix A. Diesel Truck Operating Expenses, including Maintenance and Capital Costs

Assumptions		Notes
Miles per gallon	6.0	<i>Sourced from interviews, with fleet operators and truck reps. Range was 5 to 7. Chip Vans probably have better mileage, logging trucks less</i>
Cost of Diesel per Gallon	\$6.00	
Diesel Costs/Mile	\$1.00	<i>Calculation: Cost divided by mileage</i>
Capital Costs	\$0.31	
Maintenance Costs/Mile	\$0.45	<i>Sourced from interviews, with fleet operator on North Coast. https://www.freightwaves.com/news/understanding-total-operating-cost-per-mile study cites \$0.40 per mile.</i>
Cost per mile	\$1.76	
Days of Operations	250	<i>Typical Logging Truck activity, 8 months per year. Chip Vans more miles than logging because operate all year</i>
Average miles	325	<i>Avg 40 mph for 8 hours</i>
Miles per year	81,250	<i>Estimate based on interviews with truck manufacturers, operators and literature - using logging truck example</i>
Capital Costs		
Truck Costs	\$250,000	<i>Estimate based on interviews with truck manufacturers, operators and literature - prices have gone up significantly over the last 18 months.</i>

		<i>Truck costs: Taxes and Trailer Costs push price up significantly Truck costs - Recent Quote: Kenworth T880/W900 Chassis = \$345,000.00 (full taxes and trailer for logging)</i>
Loan Term (years)	20	
Interest Rate	8 percent	
Annual Payment	\$25,463.05	
Cost per mile	\$0.31	<i>Payment divided by Annual Miles driven</i>

Appendix B. FCET options

FCET Options for Logging and Biomass Hauling Trucks*

	<i>Logging Truck Spec</i>	<i>Biomass Hauling Spec</i>	Hyzon	Hyundai	Nikola	Volvo	Kenworth
Cargo Capacity (lbs)	<i>52,000-55,000</i>	<i>52,000</i>	52,000	40,000	52,000	130,000	45,000
Gross Vehicle Weight Rating (lbs)	82,000	82,000	82,000	82,000	82,000		82,000
Range (miles)	<i>500-550</i>	<i>500 but less for certain apps</i>	350	450	500	600	450
Capacity (kW)	<i>NA</i>	<i>NA</i>	450	350		300	310
Mileage (miles/kg)	<i>4-6.5 mpg</i>	<i>4-6.5 mpg</i>	7	6.7	7.1		7.6
Refueling/Charging time (minutes)	<i>20 min</i>	<i>20 min</i>	15	30	20	15	20
Horsepower	<i>Typically 550 or higher</i>	<i>450+</i>	612	483	536		415
Estimated Cost After Incentives	N/A	N/A	\$442,776**		lease model, pricing TBD		\$623,401**

* Cells have intentionally been left blank where information is not readily available at the time of submission.

**Pricing details available in [Appendix L](#)

Appendix C. BET options

BET Options for Logging and Biomass Hauling*

	<i>Logging Truck Spec</i>	<i>Biomass Hauling Spec</i>	Freightliner	Peterbilt/ Kenworth	Tesla	BYD	Volvo	Nikola
Cargo Capacity (lbs)	52,000-55,000	52,000	52,000	54,000	NA	50,000 plus	52,000	"lighter payloads"
Gross Vehicle Weight Rating (lbs)	NA	NA	82,000	82,000	82,000	105,000	82,000	82,000
Range (miles)	500-550	500 but less for certain apps	220	150	500	125	275	350
Capacity (kWh)	NA	NA	438 kWh	396 kWh		563 kWh	375-565 kWh	753 kWh
Mileage	4-6.5 mpg	4-6.5 mpg			<2 kWh per mile		1.8-2.4 kWh per mile	
Refueling/Charging time	20 min	20 min	80 percent in 90 min	3.5 Hours or 18-36 hrs AC	70 percent in 30 minutes	13.5 hrs AC/4 or 2 hrs DC	80 percent in 90 min	2 hours @ 240 kW
Horsepower	Typically 550 or higher	450+	470	536-670		483	455	645

Estimated Cost After Incentives	N/A	N/A		\$510,000	\$180,000			~\$300,000
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* Cells have intentionally been left blank where information is not readily available at the time of submission.

Appendix D. NGET options

NGET Options for Logging and Biomass Hauling Trucks*

	<i>Logging Truck Spec</i>	<i>Biomass Hauling Spec</i>	Cummins NGE
Cargo Capacity (lbs)	<i>52,000-55,000</i>	<i>50,000</i>	52,000
Gross Vehicle Weight Rating (lbs)	<i>82,000</i>	<i>82,000</i>	82,000
Range (miles)	<i>500-550</i>	<i>500 but less for certain applications</i>	700-850
Mileage	<i>4-6.5 mpg</i>	<i>4-6.5 mpg</i>	4-6.5 DGE
Refueling/Charging time	<i>20 min</i>	<i>20 min</i>	20 min
Horsepower	<i>Typically 550 or higher</i>	<i>450+</i>	400-500 (15 L engine)
Estimated Cost After Incentives	N/A	N/A	\$300,000

* Cells have intentionally been left blank where information is not readily available at the time of submission

Appendix E. ZEV Analysis by Manufacturer Compared to Logging Truck Specifications

Suitability of FCETs as Logging Trucks

	Logging Truck Specs	Hyzon	Hyundai	Nikola	Volvo	Kenworth
Cargo Capacity (lbs)	52,000–55,000	52,000	40,000	52,000	130,000	45,000
Range (miles)	500–550	350	450	500	600	450
Refueling/Charging time	20 min	15 min	30 min	20 min	15 min	20 min
Horsepower	Typically 550 or higher	612	483	536	Not available	415

Suitability of BETs as Logging Trucks

	Logging Truck Specs	Freightliner	Peterbilt/ Kenworth	Tesla	BYD	Volvo	Nikola
Cargo Capacity (lbs)	52,000-55,000	52,000	54,000	Not available	50,000 plus	52,000	"lighter payloads"
Range (miles)	500-550	220	150	500	125	275	350
Refueling/ Charging time	20 min	80 percent in 90 min	3.5 Hours or 18-36 hrs AC	70 percent in 30 minutes	13.5 hrs AC/4 or 2 hrs DC	80 percent in 90 min	2 hours @ 240 kW

Horsepower	Typically 550 or higher	470	536-670 peak	Not available	483	455	645
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Suitability of NGETs as Logging Trucks

	Logging Truck Specs	Cummins NGE
Cargo Capacity (lbs)	52,000- 55,000	52,000
Range (miles)	500-550	700-850
Refueling/Charging time	20 min	20 min
Horsepower	550+	400-500

Appendix F. ZEV Analysis by Manufacturer Compared to Biomass Specifications

Suitability of FCETs as Biomass Hauling Trucks

	Biomass Hauling Specs	Hyzon	Hyundai	Nikola	Volvo	Kenworth
Cargo Capacity (lbs)	50,000	52,000	40,000	52,000	130,000	45,000
Range (miles)	500 but less for certain apps	350	450	500	600	450
Refueling/Charging time	20 min	15 min	30 min	20 min	15 min	20 min
Horsepower	450+	612	483	536	Not available	415

Suitability of BETs as Biomass Hauling Trucks

	Biomass Hauling Specs	Freightliner	Peterbilt/ Kenworth	Tesla	BYD	Volvo
Cargo Capacity (lbs)	50,000	52,000	54,000	Not available	50,000 plus	52,000
Range (miles)	500 but less for certain apps	230	150	500	125	275

Refueling/Charging time	20 min	80 percent in 90 min	3.5 Hours or 18-36 hrs AC	70 percent in 30 minutes	13.5 hrs AC/4 or 2 hrs DC	80 percent in 90 min
Horsepower	450+	525	536-670 peak	Not available	483	455

Suitability of NGE in Biomass Hauling Trucks

	Biomass Hauling Specs	Cummins NGE
Cargo Capacity (lbs)	50,000	52,000
Range (miles)	500 but less for certain apps	700-850
Refueling/Charging time	20 min	20 min
Horsepower	450+	400-500

Appendix G. SPI Schematic Site Plan

1. 5,000 Square Foot Pilot Project Area

To Support:

- A.) Electrolyzer On-Site Hydrogen Production
- B.) Liquid or Gaseous Hydrogen Delivery
- C.) Steam Methane Reforming On-Site Hydrogen Production

2. Water

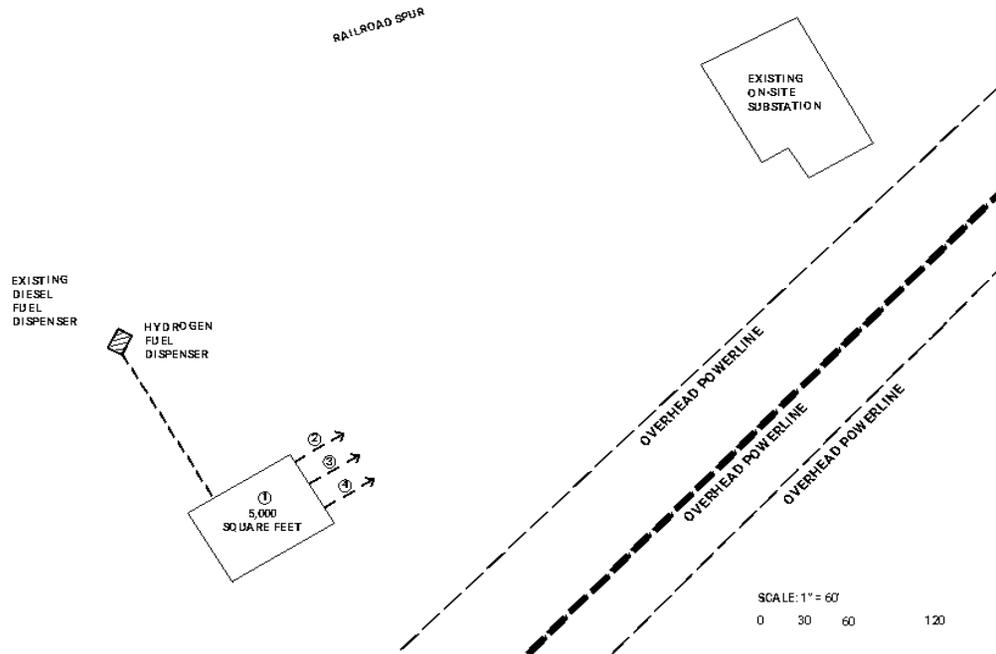
On-Site Connection To Adjacent Building

3. Gas

Connection To Existing Line in Riverside Avenue

4. Electric

Connection To The On-Site Electric Substation



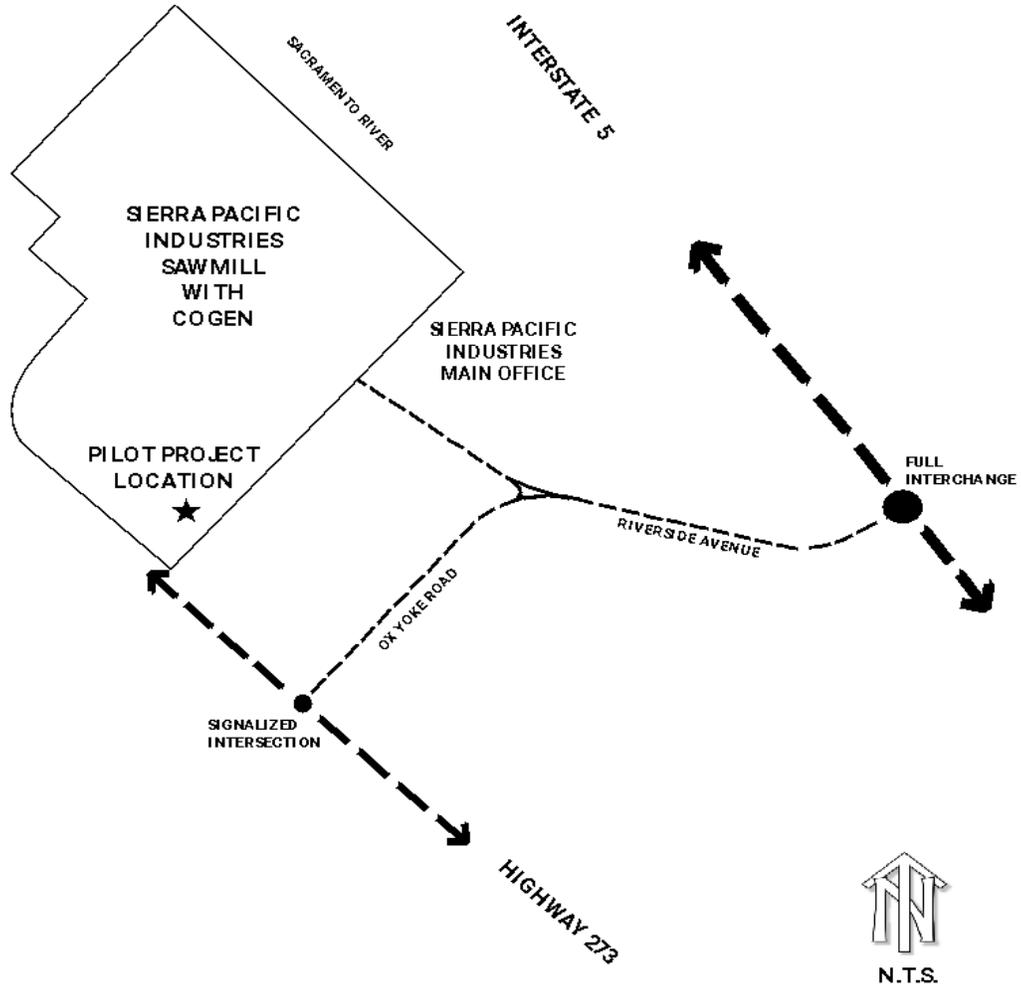
HYDROGEN PILOT PROJECT
 SIERRA PACIFIC INDUSTRIES • CALIFORNIA ENERGY COMMISSION

SCHEMATIC SITE PLAN
 JANUARY 2023

SHARRAH DUNLAP SAWYER
 .JOB. 22.152

Appendix H. SPI Vicinity Map

8



HYDROGEN PILOT PROJECT

SIERRA PACIFIC INDUSTRIES • CALIFORNIA ENERGY COMMISSION

VICINITY MAP

JANUARY 2023

SHARRAH DUNLAP SAWYER 
JOB: 22.182

Appendix I. PG&E Gas Pipeline Vicinity Map at SPI

PILOT PROJECT
LOCATION



Exhibit provided by Pacific Gas and Electric 1/3/23

NOTE:

Yellow lines represent gas distribution lines. The Hydrogen Pilot Project shall be served via the gas line in Riverside Avenue if necessary.

HYDROGEN PILOT PROJECT

SIERRA PACIFIC INDUSTRIES • CALIFORNIA ENERGY COMMISSION

PG&E GASEXHIBIT

JANUARY 2023

Appendix J. Pilot and Demonstration Production Cost Assumptions

Cost Categories	Pilot Plant	Demo Project	Sources/Assumptions
Electricity cost per kWh	\$ 0.11	\$ 0.11	<i>CAISO Market assumption, wholesale green electrons</i>
kWhs per Kg of Production	55.0	55.0	<i>As per Cummins spec sheet, with Ohmium confirming, as well as other data sources</i>
Electricity cost per Kg of H₂	\$ 6.05	\$ 6.05	
Compression Costs	\$ 1.50	\$ 1.50	<i>Christensen, Adam. "Assessment of Hydrogen Production Costs..." International Council on Clean Transportation, 18 June 2020</i>
Other Expenses	\$ 0.50	\$ 0.50	<i>Ohmium Quote is \$0.31 per kg for support and management</i>
Gallons of H ₂ O per Kg Produced	5.0	5.0	<i>4.5 as per Cummins spec plus 10 percent</i>
Cost of Water per gallon	\$ 0.02	\$ 0.02	<i>per gallon cost - local estimate</i>
Cost of Water per Kg	\$ 0.10	\$ 0.10	
Capital Cost Infrastructure			
Electrolyzer	\$ 407,250	\$ 1,571,400	<i>Ohmium Electrolyzer and Commissioning Costs for both Pilot and Demo</i>
Compression/Storage/Filling	\$ 2,800,000	\$ 2,800,000	<i>Air Liquide</i>

Total Capital Cost Infrastructure	\$ 3,207,250	\$ 4,371,400	
Financing Costs			
Life of Loan (years)	20	20	
Interest Rate	8 percent	8 percent	
Annual Payment	\$ 326,665.50	\$ 445,236.75	<i>Payment on 20 year, 8 percent note</i>
Cost per Kilogram	\$ 6.15	\$ 1.72	<i>divide by total Kgs per year (see below)</i>
Summary - Hydrogen Production Costs			
Electricity cost per Kg of H	\$ 6.05	\$ 6.05	
Compression Costs	\$ 1.50	\$ 1.50	
Other Expenses	\$ 0.50	\$ 0.50	
Cost of Water	\$ 0.10	\$ 0.10	
Capital Cost Infrastructure	\$ 6.15	\$ 1.72	
IRA Credit	\$ (3.00)	\$ (3.00)	
Costs of Hydrogen	\$ 11.30	\$ 6.87	
Hydrogen Production Capacity Assumptions			
MW Capacity	0.45	1.8	<i>Ohmium single electrolyzer</i>
Hours of Operations	18	22	<i>adjusted to hit capacity</i>
Kg Produced	8.2	33	<i>per hour - as per Ohmium Quote</i>
Kgs Per Day	147.6	720	
Kgs Per Year	53,136	259,200	
Truck Operating Costs			
Kgs per Truck - Capacity	70	70	

Miles per Kg	7	7	
Cost Per Mile	1.61396066 4	0.981104908 3	<i>Cost of H divided by Miles per Kg</i>
Truck Costs	\$ 1,000,000	\$ 5,000,000	<i>\$500K per Truck</i>
Number of Trucks	2	10	
Life of Loan	20	20	
Interest Rate	8 percent	8 percent	
Annual Cost Per Truck	\$ 50,926.10	\$ 50,926.10	<i>Payment on 20 year, 8 percent note</i>
Capital Cost per Mile	\$ 0.63	\$ 0.63	<i>Assumes 70kg per day for 350 days times 7 miles per kg</i>
Maintenance Cost per Kg	\$ 0.18	\$ 0.18	<i>From Hyzon Interview. There is no hard data and more study of maintenance expenses is needed.</i>
<i>Truck Operating Costs Summary</i>			
Cost Per Mile	\$ 1.61	\$ 0.98	
Capital Cost per Mile	\$ 0.63	\$ 0.63	
Maintenance Cost per Kg	\$ 0.18	\$ 0.18	
Truck Operating Costs Total	\$ 2.42	\$ 1.79	

Appendix L. Air Liquide Tear Sheet



Modular Hydrogen Refueling Station Gaseous or Liquid Series



With more than 185 hydrogen stations delivered and more than 50 in operation all over the world, Air Liquide provides **global hydrogen refueling solutions** from project definition to operation and maintenance support.

The GA-M is part of the **modular refueling station product line** is capable of supporting both light and heavy duty fueling (350 or 700 bar) with increased performance and the ability to accept either a gaseous hydrogen supply chain or a liquid supply chain depending on the station demand.

- Compliant with SAE J2601
- SOC > 95%
- Up to 1,000 kg/day
- Standard Remote Dispenser
- Modularity for easy installation and customization
- Capable of simultaneous filling through two fueling positions

Key figures / Performance

		165 bar gas supply (21.9 m3 storage and 4 kg per fill)	450 bar gas supply (15.3 m3 storage and 4 kg per fill)
Peak time performance (through two fueling positions)	Max. flow dispensed	48 kg/hr	72 kg/hr
	Max. vehicles in one hour	12	18
	Max. back-to-back fills (3 min in between)	4	21
Maximum daily performance	Multiple delivers per day	Up to 154 cars (615 kg)	Up to 260 cars (1040 kg)

Equipment and Features

- Equipment provided by Air Liquide:
 - Hydrogen Offloading panel
 - Hydrogen Refueling Station skid (compression, medium and high pressure storage, cooling)
 - Remote Dispenser (H35 and/or H70) with point-of-sale
- Compatible with the following gaseous hydrogen sources:
 - 165 bar tube trailers
 - High pressure tube trailers (450 bar)
 - Stationary ground storage
 - Onsite Liquid Station (Tank, Pump, and Vaporizer)
 - Onsite Electrolyzer (with additional equipment)



Other Services

- Commissioning and startup
- Technical assistance
- Spare parts
- Training
- Maintenance

For More information please contact:

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Technical Characteristics

Electricity

- 480 V, 3 phases, 60 Hz, 150 kW
- Grounding of station : 25 ohm (max. resistance)

Gas utilities

- Nitrogen for maintenance and instrument gas (approx. 5 SCFH)
- Recommended nitrogen source: Liquid nitrogen dewar (VGL) at 24 bar and gaseous bundle at 165 bar (for backup)

Station to Vehicle Interface:

- Nozzle - Design follows SAE J2600
 - Option for either H70 or H35

Environment:

- Ambient operating temperature: -30°C to + 40°C
- Humidity: Up to 100%

Standard Footprint:

(LxWxH): 28' X 9' 6" x 13' 4" (does not include hydrogen source storage or utility requirements)

Weight (Station skid only):

61,000 lbs

Safety

The following safety features are included with the station:

- Hydrogen detection
- UV/IR Flame detection
- Emergency stop buttons
- Process safety limits and parameters



Appendix M. Emissions Calculations and Assumptions

Table 3. Estimated NO_x emissions for a logging scenario
NO_x Emissions Estimates from ICCT report **Logging Truck Estimate (estimated by project team)**

Driving Scenarios	grams of NO_x per mile	percent Time in Study	Speed Range	percent Time in Study	Speed Range	Notes
Urban Driving	7	43 percent	0-25 mph	30 percent	0-25 mph	<i>Estimates based on conversations with Fleet Operators</i>
Suburban	2.4	11 percent	25-50 mph	35 percent	25-50 mph	<i>Nature of work is such that they are not as slow as urban vehicles.</i>
Highway	0.6	46 percent	>50 mph	35 percent	>50 mph	<i>But, they are also not at highway speed as much either.</i>
Blended average grams of NO_x per mile	3.55			3.15		

Source: "Current State of NO_x Emissions from In-Use Heavy Duty Diesel Vehicles in the United States". Chart on Page ii. The International Council on Clean Transportation, November 2019.

(a) Calculation for grams of NO_x emitted per year
 3.15 grams * 81,250 miles/year = 255937.5 grams NO_x/year

(b) Calculation to convert grams to lbs
 255937.5 grams * (1 gram = 0.002204623 lbs) = 564.2456991 lbs NO_x /year

(c) Calculation to convert lbs to tons =
 564.2 lbs / 2000 lbs = 0.2821228495 tons NO_x /year

Logging Truck CO2 Emissions Estimate

Assumptions

22.5 pounds of CO2 per gallon of diesel fuel (*Source: EIA https://www.eia.gov/environment/emissions/co2_vol_mass.php*)

6 miles per gallon (mpg) for diesel logging truck

81,250 miles driven per year

(a) Calculation for CO2 emissions tons per year per truck =

$((81,250 \text{ miles/year} / 6 \text{ mpg}) * 22.5 \text{ lbs CO}_2 \text{ per gallon diesel}) / 2000 \text{ lbs} = \mathbf{152.0 \text{ tons of CO}_2 \text{ emissions per year / diesel logging truck}}$

Table 4. Lifetime emissions (including production) assuming 600,000 miles

Lifecycle CO2 Emissions, 600,000 miles, including Production CO2 emissions

	Implied Reduction Compared to Diesel	million pounds of CO2	tons of CO2	tons of NOx (b)
Diesel	100 percent	2.25	1,127	2.1
BETs	21.5 percent	1.77	884	0
FCETs (a)	78.2 percent	0.39	193	0
Implied reduction from FCET over diesel		1.87	934	2.1

Source: American Transportation Research Institute, <https://truckingresearch.org/2022/05/03/understanding-the-co2-impacts-of-zero-emission-trucks/>

(a) Estimate based on adjustment from report to reflect use of renewable electricity for alkaline electrolysis hydrogen production, rather than SMR with natural gas (page 36 of report)

(b) Calculation for tons of NO_x emissions per year per truck =

$((3.15 \text{ NO}_x \text{ emissions per mile} * 81,250 \text{ miles driven annually}) / \text{by } 907,185 \text{ grams per ton}) * 7.4 \text{ years of operation}$

Years of operation = $600,000 \text{ lifetime miles} / 81,125 \text{ avg miles per year}$

Table 5: Summary Data of Lifetime Emissions Reductions for FCETs v. Diesel

Scenario	# of Trucks	Annual Emissions Reductions (v. Diesel)		Lifetime Emissions Reduction (v. Diesel)	
		Tons of NOx (a)	Tons of CO2*	Tons Of NOx (b)	Tons of CO2
Single Truck	1	0.3	152	2.1	934
SPI Pilot	2	0.6	304	4.2	1,868
SPI Demo Project	10	2.8	1,520	20.8	9,341
Total SPI Fleet	120	33.9	18,241	250.0	112,086
Est Total Cal Logging	1,000	282.1	152,005	2,083.4	934,053

(a) Calculation: 3.15 NOx emissions per mile * 81,250 miles driven annually / by 907,185 grams per short ton

(b) Calculation: Annual Emissions * 7.4 years of operation

Years of operation = 600,000 lifetime miles/81,125 avg miles per year"

* Logging Truck CO2 Emissions Estimate (see Table 4 above)

Appendix N. FCET Quotes as of November 2023

	Kenworth Quote	Hyzon Quote	Notes
Before taxes and grants	\$750,000.00	\$600,000.00	<i>As per Nov 2023 conversations with Sales Reps (Kenworth phone call and Hyzon via Email)</i>
Fed Excise Tax	\$90,000.00	\$72,000.00	<i>12 percent tax rate</i>
State Taxes (a)	\$58,125.00	\$46,500.00	<i>Hyzon value is prorated</i>
Doc and admin fee (\$75 + \$85)	\$160.00	\$160.00	<i>as per Kenworth Rep</i>
Reg Fees (a)	\$5,098.00	\$4,078.40	<i>Hyzon value is prorated</i>
Tire Fees	\$17.50	\$17.50	<i>as per Kenworth Rep</i>
CA HVIP Credit	-\$240,000.00	-\$240,000.00	<i>Hyzon confirmed online, assuming Kenworth gets same Credit. https://californiahvip.org/</i>
Federal Commercial Clean Vehicle Credit	-\$40,000.00	-\$40,000.00	<i>Source: https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit</i>
Total	\$623,400.50	\$442,755.90	