# Blueprint for Implementation of Heavy-Duty Zero-Emission Vehicles in the Timber and Biomass Hauling Sector

*Agreement Number: ZVI-21-013*

Final Blueprint Report

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Air Liquide Global Markets and Technologies
Alternative Fuel Systems
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California Redwood Company
Clean Energy Fuels
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Kenworth Motor Truck Company
Muse Trucking
Nikola Corporation
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Peterbilt Motors Company
Shasta College
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Sierra Pacific Industries
Tesla, Inc.
Volvo Trucks North America
Warner Enterprises

## Preface

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.

On July 14, 2020, the California Energy Commission (CEC) released Grant Funding Opportunity, GFO-20-601 entitled "Blueprints for Medium- and Heavy-Duty Zero-Emission Vehicle Infrastructure." This competitive grant solicitation was 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 a proposal that was proposed for funding in the CEC's Notice of Proposed Awards on August 16, 2021 and the agreement was executed as ZVI-21-013 on February 8, 2022.

## 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 also support the state's climate goals, 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 the industry, and do so economically, is critical.

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.

A summary of the analysis performed in the development of this Blueprint resulted in the following learnings.

- **Specifications:** Logging trucks in particular were found to require a long-range capacity because day-to-day travel distances vary. Logging trucks are also required to be very rugged so that they can hold a full load of timber and also manage challenging conditions and terrains. Biomass hauling trucks required less rugged builds and less horsepower because of generally easier, more predictable highway-based routes.

- **ZEV technologies and their abilities to meet the use-case specifications:** The project team found that heavy-duty BETs would be challenged to meet most requirements for logging or biomass hauling, especially in terms of range and weight limitations. FCETs generally meet the more rigorous specifications of a logging truck, although there were concerns about whether some models could meet the range requirements. FCETs will be able to meet the specifications of biomass hauling trucks. While not considered zero-emission, NGETs are worth considering as an alternative as they reduce emissions significantly, and when utilizing renewable natural gas from biowaste, they achieve a carbon negative footprint. It appears that NGETs, particularly with new larger engines that are soon to be released, could serve the sector for both logging and biomass hauling.

- **Confirmation of FCET and related infrastructure can viably serve the sector:** Based on the ZEV technology analysis, FCETs utilized for logging trucks were selected for further analysis, including determining what related infrastructure would further demonstrate the viability of ZEV adoption throughout the logging and biomass sector. It was determined that an electrolyzer that could produce hydrogen on-site as well as a modular system for hydrogen compression, storage, and refueling would be the recommended accompanying infrastructure.
- **Two-phased approach:** Ultimately, the Blueprint project design outlined in this document includes two phases: a pilot project consisting of 2 FCETs utilized as logging trucks and then a demonstration project with 10 FCETs. While proving the functional viability of the FCETs through a pilot project is important, combining that with a demonstration project that proves the economic viability of FCETs with on-site hydrogen production is even more impactful and can catalyze adoption of ZEVs in this sector and others. The economic analysis suggested that at a scale of 10 FCETs, a demonstration project should have operating costs (which reflect both capital costs for trucks and infrastructure) that are competitive with diesel operating costs, particularly at today's high diesel prices. Proving the viability of these solutions would be a "game changer" for the adoption of FCETs.
- **Future technologies:** Longer term potential technologies, such as biomass-to-hydrogen production, could drive hydrogen costs significantly lower and ultimately drive the adoption of ZEVs not only in the logging industry but across other heavy industries as well.

This Blueprint plan will demonstrate the technical and economic viability of utilizing heavy-duty ZEVs for the logging and biomass sector in Shasta County and surrounding areas of Northern California, a key center of forestry management in California, with the goal of ultimately driving adoption of ZEVs in this sector. The Blueprint project was designed in partnership with Sierra Pacific Industries, who cooperated in the early stages of the Blueprint development process by offering assistance in the truck specifications process and then agreed to allow us to use their headquarters in Anderson, California as a location for the design of the pilot and demonstration projects. A pilot project at Sierra Pacific Industries would be ideal, as their headquarters includes key infrastructure for the projects and because of the size and scale of their operations. Additionally, their high-profile within the sector would lend credibility to further the adoption of ZEVs in the sector assuming successful demonstrations.

## Introduction to the Blueprint

### Project Background: The Challenges Facing the Logging/Biomass 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. 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 delivering 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.

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. After analyzing the ZEV manufacturers' options, the range and weight limitations faced by BETs are key considerations that may limit their suitability to serve this sector. While FCETs may address those issues, ZEVs as a whole are still unproven technologies in this sector, one that demands that vehicles operate in challenging conditions, such as narrow and/or steep logging roads, and with range requirements that would need to accommodate varying travel distances day-to-day.

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.

### Project Goals

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.

### 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.

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

To understand the potential for ZEVs in the sector, a first step was to understand the requirements of heavy-duty vehicles utilized as logging and biomass hauling trucks and develop specifications for these vehicles.[1] This work included discussions with leading timber companies, fleet managers, and fleet operations around the state (see footnote 3 on 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 drive 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.

[1] We also investigated grapple trucks, an important specialty vehicle in the sector, though given the challenges of powering a mechanical grapple, a ZEV option seemed unviable at this time.

Chip 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 short distances. Given the lower value of wood chips and grindings,[2] wood chips are rarely hauled 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.

## 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 1:** 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) |
| **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 |

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

[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.

| | |
|---|---|
| **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 |

***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" trailers[4] that can more easily unload chip loads are likely to be heavier.

**Table 2:** 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" |
| **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[5]** | Locking Double Axle (adjustable up to 10"): 40,000 lbs minimum |
| **Turn Radius** | Standard; no limitation identified |

## 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.[6] FCET and BET

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

[5] Can be somewhat lower than a logging truck.

[6] 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 has changed over the last 12-18 months. We have, where possible, updated the truck availability data.

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 vehicles 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 A (FCETs), Appendix B (BETs), and Appendix C (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.

We identified five primary companies developing Class 8 FCETs (see Appendix A 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

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 the 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 B 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 pose 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

We concluded that a number of these options have sufficient range to potentially serve fixed-route biomass hauling applications but none of the existing battery-electric options have the combination of range 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.[7]

***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

[7] The benefits of regenerative braking should apply to FCETs as well.

natural gas vehicles—not liquified natural gas (LNG)—as these vehicles meet the specifications of a logging truck and can be supported by significantly lower cost infrastructure.[8]

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 C 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% 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 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 D and Appendix E 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.

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[8] 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.

## 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 battery-electric trucks 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

***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 EVs as they gain speed as electromagnetic frequencies develop and erode performance at higher speeds.[9] 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 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.

[9] Automotive 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.

- **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.[10] 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.[11]

- **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.

- **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.[12]

## Two-Phased Pilot Project Model

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 are capable of doing 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 of these questions must be addressed. Thus, in order 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

[10] FCETs utilize electric powertrains and thus are essentially EVs but utilize a different energy source.
[11] North American Council for Freight Efficiency. "Hydrogen Trucks: Long-Haul's Future?" Electric Trucks, https://nacfe.org/research/electric-trucks/#hydrogen. Accessed 9 November 2023.
[12] Sickels, David, and Tess Lovrak. "Electric truck tire tips." Fleet Equipment Magazine, https://www.fleetequipmentmag.com/electric-truck-tire-tips/. Accessed 3 November 2023.

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: Class 8 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.

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. While a number of potential pilot options were examined, they were deemed too challenging and not worthy of pursuing with additional time and capital at this time.

In addition, while this project was not scoped to include an assessment of NGETs, Class 8 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 if located in a region where natural gas fueling infrastructure already exists, and could count on strong support from industry natural gas fuel players. There is presently no existing natural gas fueling infrastructure north of Chico. Thus, a pilot in Shasta County, which was the anticipated geographic location of the pilot in the initial grant proposal, would require installation of some kind of refueling infrastructure. For these reasons, a pilot or demonstration project for NGETs would be better located further south, nearer in proximity to natural gas fueling infrastructure.

### 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:

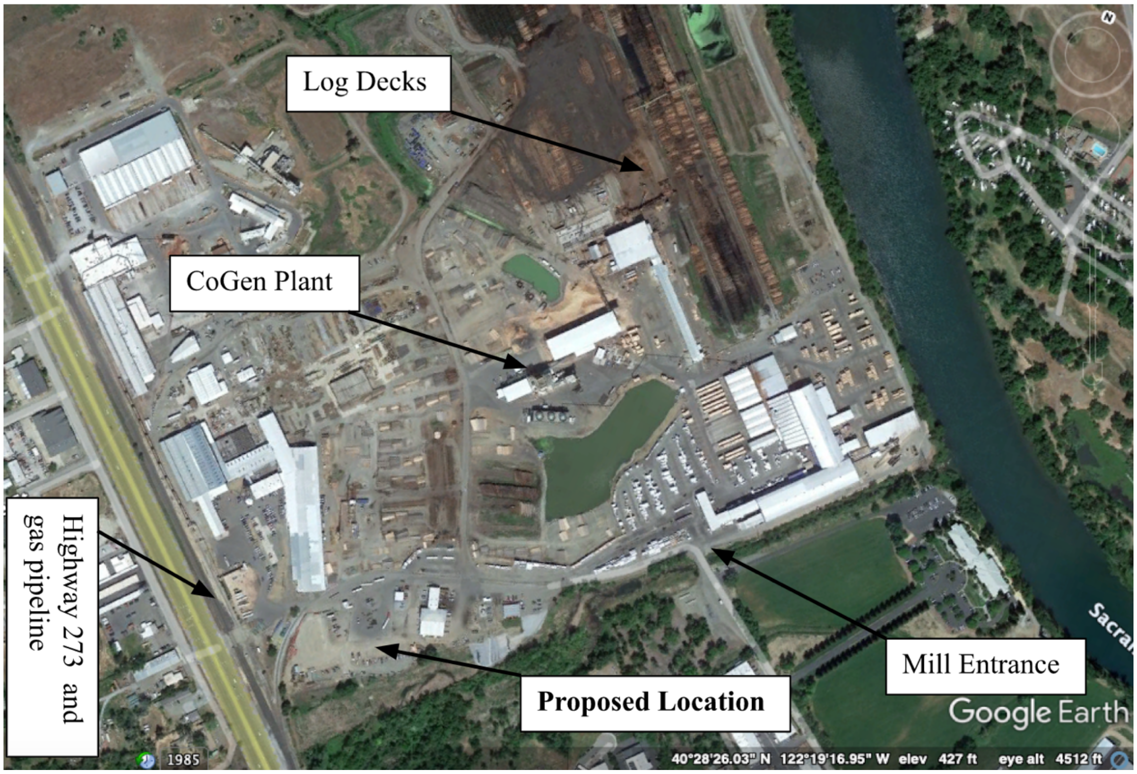
- **A high-profile local partner.** SPI operates six sawmills around the state of California, as well as two in Oregon and four in Washington. They are the largest private landowner in the state and thus are indisputably the most important logging and sawmill operator in California. A successful pilot 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 schematic site plan (Appendix F) lays out a proposed location of the hydrogen production, storage infrastructure, and the refueling site. The proposed location is adjacent to the existing diesel fuel tank and refueling site, which assures 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 1.** Map of SPI's Anderson mill site




## Determination of Preferred Hydrogen Infrastructure

A fully on-site hydrogen production system includes the following equipment:

- A hydrogen production solution (unless delivery is selected)
- Hydrogen compression and pumping
- Bulk hydrogen storage
- High-pressure buffer storage
- Pre-cooling unit
- Dispensers/fueling infrastructure

### *Hydrogen Production Options*

A single FCET requires between 50-60 kg of hydrogen per refuel (assuming a 70 kg tank). While a hydrogen delivery solution could be considered for a small pilot, we concluded that such an approach could prove the efficacy of the vehicle but that on-site hydrogen production is critical to proving the overall concept and driving adoption of ZEVs in the sector and beyond.

We identified three types of potential hydrogen production infrastructure: an electrolyzer, a steam methane reformer (SMR), or a biomass-to-hydrogen solution. 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 number of trucks supported, and the anticipated refueling timeline required.

- **Electrolyzers** are likely to be a favored option for hydrogen production moving forward, because if they use renewable electricity during production, they produce "green" hydrogen[13] with the required low-carbon intensity necessary to receive the maximum credits available through the Inflation Reduction Act (IRA). 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 more than 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).

- **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 ($m^3$) of methane to produce 1 kg of hydrogen. To support 250 kg of hydrogen/day, 1,125 $m^3$ of natural gas or renewable natural gas would be required, which at 26.8 $m^3$/million British thermal units (MMBTU) converts to roughly 42 MMBTUs/day.

- **Biomass-to-hydrogen production** 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 and too large in scale to be used at the pilot stage, 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 these 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 bone dry tons[14]/year, could produce enough hydrogen annually to support a fleet of roughly

[13] 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).
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.

[14] Bone dry tons is a unit of weight equal to 2,000 lbs of woody material at zero percent moisture content and is generally used by the biomass industry to manage for moisture content in delivered materials, which can vary widely depending on the type of material and time of year.

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.

***Additional Hydrogen Infrastructure Options***

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.[15] 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.[16] 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. An engineering group in Germany, Wrystrach, has designed a mobile hydrogen refueling station that has a discharging capacity of 360 kg/day,[17] which could support the initial pilot phase with 2 FCETs.[18] Another solution, provided by Air Liquid, is also modularized and the technology is transported and installed in standard 40-foot shipping containers.[19] The GA-M-70 unit can manage up to 1,000 kg/day of hydrogen A smaller Air Liquide unit is also available, which has a 300 kg/day capacity, at 70% the cost of the larger unit. Following discussions with the AirLiquide representatives, the project team concluded that the larger unit, which is larger than necessary for a smaller pilot project, but could also support the larger demonstration project as well, was the better option.

***Selected Hydrogen Production and Filling Infrastructure***

Please see Appendix G 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

[15] 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.
[16] 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.
[17] https://www.wystrach.gmbh/en/products/wyrefueler
[18] 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.
[19] https://energies.airliquide.com

for the pilot could be scaled up to support a follow-on, longer-term demonstration site by adding a number of additional electrolyzers. We 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 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 would require 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 when 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 this industrial 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.

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 H. 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 FCETs[20] (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 **Air Liquide**'s GA-M-70 as the proposed **integrated modular hydrogen refueling solution** (see Appendix I 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 AirLiquide system has fast fill 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. Given that the compressors and refilling

[20] 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.

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% of the capital costs of the units.[21]

### *Analysis of Additional Services and Infrastructure Needed*

#### 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.[22] 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".[23] 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 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,[24] 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.[25]

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[21] 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.

[22] 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.

[23] CalStart.

[24] CEC. "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.

[25] 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.

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.
- 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***

Working with SDS, a local civil engineering firm, the project 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.[26] 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 J).

### *Nitrogen oxide (NOx) Emissions*

According to the International Council on Clean Transportation (ICCT) analysis "Current State of Nitrogen oxide (NOx) Emissions from In-Use Heavy-Duty Diesel Vehicles in the United States", NOx emissions are impacted by driving speeds. The study estimated that typical heavy-duty, diesel-powered vehicles travels at 0-25 mph for 43% of the time and over 50 mph for 46% of the time, with a relatively small share of travel (11%) at the mid-range of 25-50 mph.[27] 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% of the time traveling at the mid-range and higher speed ranges, and 30% of time traveling at the slower speeds (see Table 3 below, column "Estimated % of driving time (logging truck)").[28] According to the ICCT study, NOx emissions per mile are substantially higher when moving at slower speeds in urban settings (see Table 3). Given this mix, the average truck emits 3.55 grams of NOx per mile of operations in urban settings.[29] 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 NOx per mile of operations.

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[26] 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.

[27] ICCT. "Current state of NOx 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.

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

[29] ICCT, 2019.

**Table 3.** Estimated NOx emissions from the ICCT study applied to the logging scenario

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

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 NOx calculated above, we also adjusted these numbers to reflect that logging trucks drive less miles annually (an average of 81,250 miles per year[31]). With these adjustments, **we estimated that diesel logging trucks emit approximately 564 lbs (0.28 tons) of NOx/year**.

### *Carbon Dioxide ($CO_2$) Emissions*

According to the U.S. Energy Information Administration (EIA), 22.5 pounds of $CO_2$ are emitted per gallon of diesel fuel consumed.[32] 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 $CO_2$ emissions/truck/year.[33] 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 $CO_2$ emissions involved in the production of the vehicle), is approximately 3.6 million lbs of $CO_2$, or 1,800 tons.[34] 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 $CO_2$, or 1,127 tons (see Table 5 and calculations in Appendix J).

### *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.[35] 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 $CO_2$ emissions.[36] Because emissions

[30] ICCT, 2019.
[31] This is an average based on data provided from operators using diesel trucks.
[32] 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.
[33] Fuel efficiency and mileage estimates were provided from logging truck drivers and operators. See calculation in Appendix J.
[34] 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.
[35] 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.
[36] 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 J for details on adjustments.

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 $CO_2$ emissions and 2.1 tons of NOx over the lifetime of the vehicles as opposed to diesel trucks (see Table 4 below and Appendix J for assumptions and calculations).

**Table 4.** Lifetime diesel truck emissions compared to ZEV lifetime emissions reductions (assuming 600,000 lifetime miles)[37]

| | Implied Savings Compared to Diesel | Tons of $CO_2$ | Tons of NOx |
|---|---|---|---|
| **Diesel Trucks** | NA | 1,127 | 2.1 |
| **BETs** | 21.5% | 884 | 0 |
| **FCETs** | 78.2% | 193 | 0 |
| **Implied reduction from FCET compared to Diesel** | | 934 | 2.1 |

### *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 5 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.[38]

**Table 5.** 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 |

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% of the total miles and fuel used, these emission

[37] The CO2 calculations include the footprint of the entire truck and fuel production process. Source: American Transportation Research Institute, 2022. The NOx calculations assume no NOx emissions from production and were calculated by the project team (see Appendix J).
[38] 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.

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 Pilot: 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 anticipated 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 K). 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 (FEED) 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 6 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.[39] The Ohmium

[39] From the specification sheet provided by the vendor, see Appendix H, as well as supported by a number of other literature sources.

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.[40] 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.

**Table 6.** 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 |

### ***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

[40] The final design may require additional bulk hydrogen storage tanks.

$0.87/kW total. In addition, the IRA offers a $0.015/kW production tax credit.[41] 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 cost approximately $0.11/kW and that 55 kW of electricity are 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.[42] 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 searches 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.[43]

### 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% of the cost of the electrolyzer.[44] 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.

[41] Note that the IRA credit could also be used as a 30% investment tax credit on the capital expenditure 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.

[42] 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.

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

[44] Christensen, 2020.

***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% 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 7 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 7.** Operational Costs per kg of Hydrogen Basis [45]

| | Pilot | Demo | Biomass to H |
|---|---|---|---|
| **MW Capacity** | 0.45 | 1.8 | 10 [46] |
| **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 Kilogram** | $11.30 | $6.87 | $2.84 |

***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 L for more details).

[45] See Appendix G 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.

[46] MW Energy Equivalent

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% less than diesel on a per-mile operating basis (Table 8 below and Appendix G for more detail on assumptions).

**Table 8.** 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** |
| ***% Change from Diesel Truck Costs*** | 37.4% | 1.5% | -50.5% |
| | | | |
| **FCET Cost/Mile (excl. infrastructure costs)** | | **$1.54** | |
| ***% Change from Diesel Truck Costs*** | | -6.5% | |

### *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. They indicated an interest in supporting financing arrangements that could support the additional scaling up of infrastructure for the sector, but would need comfort that the equipment is viable and that the 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.[47] 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

[47] 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.

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 the vehicle weight is above 14,000 lbs.[48] This credit is included in the calculations of the FCET costs (see Appendix K).

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% of the cost or 6% 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%, or a metropolitan and non-metropolitan area census tract where the median family income is less than 80% of the state median family income level.[49] If the proposed Blueprint project were to take place at SPI in Anderson, California, it should be

[48] 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.
[49] 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.

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.[50]

### State Grants

There are several active 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 for larger incentives). [51,52] We assumed a grant of $240,000 per FCET in our calculations (see Appendix K). 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 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% 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

[50] 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.

[51] California HVIP. Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, https://californiahvip.org/. Accessed 13 November 2023.

[52] 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.

under the Jump Start requirements.[53] 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 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.[54] 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.

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[53] 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-. Accessed 13 November 2023.

[54] 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.

## Blueprint Conclusions and Recommendations

### Blueprint 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.[55] 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.[56]

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 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 build 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

[55] 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.

[56] SPI already works with Shasta county and CARB on a program that retires older diesel vehicles for newer ones.

firms, are offering "all-in" pricing as long as customers agree to long-term fuel and truck contracts. Again, if adoption of heavy-duty FCETs begins to scale, so too will effective business models.

### Blueprint Recommendations

Full implementation of this Blueprint concept, or one similar to it, is the critical next step in furthering the adoption of ZEVs in the logging sector. A pilot project of two FCETs is important to assess the essential utility of the vehicles and assure that they can, in fact, perform the work required of a logging truck. A full-scale commercial project of 10 FCETs is equally as important because only at scale can the economic viability of FCETs be fully assessed. 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.

# Appendices

# Appendix A. FCET options

**Table 9.** FCET Options for Logging and Biomass Hauling Trucks*

| | *Logging Truck Spec* | *Biomass Hauling Spec* | Hyzon | Hyundai | Nikola | Volvo | Kenworth |
|---|---|---|---|---|---|---|---|
| Cargo Capacity (lbs) | *52,000-55,000* | *52,000* | 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) | *500-550* | *500 but less for certain apps* | 350 - 490 | 450 | 500 | 600 | 450 |
| Capacity (kWh) | *NA* | *NA* | 450 | 350 | | 300 | 310 |
| Mileage (miles/kg) | *4-6.5 mpg* | *4-6.5 mpg* | 7 | 6.7 | 7.1 | | 7.6 |
| Refueling/Charging time (minutes) | *20* | *20* | 15 | 30 | 20 | 15 | 20 |
| Horsepower | *Typically 550 or higher* | *450+* | 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 K

# Appendix B. BET options

**Table 10.** BET Options for Logging and Biomass Hauling*

| | *Logging Truck Spec* | *Biomass Hauling Spec* | Freightliner | Peterbilt/ Kenworth | Tesla | BYD | Volvo | Nikola |
|---|---|---|---|---|---|---|---|---|
| Cargo Capacity (lbs) | *52,000-55,000* | *52,000* | 52,000 | 54,000 | NA | 50,000+ | 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 | 396 | | 563 | 375-565 | 753 |
| Mileage (kWh/mile) | *4-6.5 mpg* | *4-6.5 mpg* | | | <2 | | 1.8-2.4 | |
| Refueling/Charging time | *20* | *20* | 80% in 90 min | 3.5 Hours or 18-36 hrs AC | 70% in 30 minutes | 13.5 hrs AC/4 or 2 hrs DC | 80% 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 |

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

# Appendix C. NGET options

**Table 11.** NGET Options for Logging and Biomass Hauling Trucks*

| | *Logging Truck Spec* | *Biomass Hauling Spec* | **Cummins Natural Gas Engine** |
|---|---|---|---|
| **Cargo Capacity (lbs)** | *52,000-55,000* | *50,000* | 52,000 |
| **Gross Vehicle Weight Rating (lbs)** | *82,000* | *82,000* | 82,000 |
| **Range (miles)** | *500-550* | *500 but less for certain applications* | 700-850 |
| **Mileage** | *4-6.5 mpg* | *4-6.5 mpg* | 4-6.5 DGE |
| **Refueling/Charging time** | *20 min* | *20 min* | 20 min |
| **Horsepower** | *Typically 550 or higher* | *450+* | 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 D. ZEV Analysis by Manufacturer Compared to Logging Truck Specifications

**Table 12.** 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 |

**Table 13.** 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% in 90 min | 3.5 Hours or 18-36 hrs AC | 70% in 30 minutes | 13.5 hrs AC/4 or 2 hrs DC | 80% in 90 min | 2 hours @ 240 kW |
| Horsepower | Typically 550 or higher | 470 | 536-670 peak | Not available | 483 | 455 | 645 |

**Table 14.** 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 |

**Color coding**
Green = meets the specifications
Yellow = maybe meets the specifications
Red = Does not meet the specifications

## Appendix E. ZEV Analysis by Manufacturer Compared to Biomass Specifications

**Table 15.** 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 | NA | 415 |

**Table 16.** 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 | 220 | 150 | 500 | 125 | 275 |
| Refueling/Charging time | 20 min | 80% in 90 min | 3.5 Hours or 18-36 hrs AC | 70% in 30 minutes | 13.5 hrs AC/4 or 2 hrs DC | 80% in 90 min |
| Horsepower | 450+ | 470 | 536-670 peak | Not available | 483 | 455 |

**Table 17.** Suitability of Natural Gas Engine 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 |

**Color Coding**
Green = meets the specifications
Yellow = maybe meets the specifications
Red = Does not meet the specifications

## Appendix F. Schematic Site Plan


# HYDROGEN PILOT PROJECT

SIERRA PACIFIC INDUSTRIES • CALIFORNIA ENERGY COMMISSION

# SCHEMATIC SITE PLAN

JANUARY 2023

SHARRAH DUNLAP SAWYER

JOB. 22.152

# Appendix G. Pilot and Demonstration Production Cost Assumptions

**Hydrogen Production Cost Assumptions - Pilot and Demonstration Projects**

| *Hydrogen Production Costs* | **Pilot Plant** | **Demo Project** | ***Sources/Assumptions*** |
|---|---|---|---|
| Electricity cost per Kwh | $ 0.11 | $ 0.11 | *CAISO Market assumption, wholesale green electrons* |
| Kwhs per Kg of Production | 55.0 | 55.0 | *As per Cummins spec sheet, with Ohmium confirming, as well as other data sources* |
| Electricity cost per Kg of H | $ 6.05 | $ 6.05 | |
| Compression Costs | $1.50 | $1.50 | *Christensen, Adam. "Assessment of Hydrogen Production Costs..." International Council on Clean Transportation, 18 June 2020* |
| Other Expenses | $0.50 | $0.50 | *Ohmium Quote is $0.31 per kg for support and management* |
| Gallons of H20 per Kg Produced | 5.0 | 5.0 | *4.5 as per Cummins spec plus 10%* |
| Cost of Water per gallon | $0.02 | $0.02 | *per gallon cost - local estimate* |
| Cost of Water per Kg | $0.10 | $0.10 | |
| Capital Cost Infrastructure | | | |
| Electrolyzer | $ 407,250 | $ 1,571,400 | *Ohmium Electrolyer and Commissioning Costs for both Pilot and Demo* |
| Compression/Storage/Filling | $ 2,800,000 | $ 2,800,000 | *AirLiquide* |
| Total | $ 3,207,250 | $ 4,371,400 | |

| *Financing Costs* | | | |
|---|---|---|---|
| Life of Loan (years) | 20 | 20 | |
| Interest Rate | 8% | 8% | |
| Annual Payment | $326,665.50 | $445,236.75 | *Payment on 20 year, 8% note* |
| Cost per Kilogram | $6.15 | $1.72 | *divide by total Kgs per year (see below)* |

| *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 | *Ohmium single electrolyzer* |
| Hours of Operations | 18 | 22 | *adjusted to hit capacity* |
| Kg Produced | 8.2 | 33 | *per hour - as per Ohimium Quote* |
| 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 | $1.61 | $0.98 | *Cost of H divided by Miles per Kg* |
| Truck Costs | $ 1,000,000 | $ 5,000,000 | *$500K per Truck* |
| Number of Trucks | 2 | 10 | |
| Life of Loan | 20 | 20 | |
| Interest Rate | 8% | 8% | |
| Annual Cost Per Truck | $50,926.10 | $50,926.10 | *Payment on 20 year, 8% note* |
| Capital Cost per Mile | $0.63 | $0.63 | *Assumes 70kg per day for 350 days times 7 miles per kg* |
| Maintenance Cost per Kg | $0.18 | $0.18 | *From Hyzon Interview. There is no hard data and more study of maintenance expenses is needed.* |

| *Truck Operating Costs Summary* | | |
|---|---|---|
| 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 H. Ohmium Tear Sheet

| | | | |
|---|---|---|---|
| Doc.Ref: OHM/TS-01/R0, 10/2022 | | | |

# OhmiumTM Electrolyzer Technical Specification Sheet

| | | | |
|---|---|---|---|
| Customer Name: | | Allorope Partners | |
| Customer Address - Office | | 1301 Clay Street, #71180 Oakland, CA 94612 | |
| Customer Address - Site Location | | Sierra Pacific Industries HQ Sawmill - Anderson CA | |
| Customer contact person - Name & Address | | Robert Hambrecht, Partner | |
| | | rhh@allotropepartners.com 415 608 4581 | |
| | | | |
| Sl.No: | Technical Specifications | Customer Inputs | Remarks |
| 1.0 | Project Details: | | |
| 1.1 | Project / End User Details | Hydrogen Fuel Cell Class 8 Vehicles - Logging Truck Pilot Project. CEC Grant funding to identify appropriate zero emission solution for logging industry and design pilot project "Blueprint" report to be generated will be used to apply for funding to build the pilot project. | |
| 1.2 | Name Plate Capacity in MW DC | 450kw system (should support 2-3 vehicles for pilot) | |
| 1.3 | Usage Application – Upstream and downstream | Hydrogen production support filling station on site which in turn supports Class 8 Vehicles/Logging Trucks. | |
| 1.4 | Electrolyzer Delivery Date at Site | TBD based on funding cycles - likely late 2024 | |
| 1.5 | Expected start date of Hydrogen production | likely late 2024 | |
| 2.0 | Plant Details: | | |
| 2.1 | Plant Availability in hours (continuous or intermittent) | 18? | Perhaps 24 |
| 2.2 | Plant design life in years | pllot for 24 months? | sound good |
| 3.0 | Power: | | |
| 3.1 | Input Power (AC / DC) | Pilot location adjacent to interconnect | maybe add nearby shop |
| 3.2 | Input Power (Voltage) | ?? | |
| 3.3 | Input Power (Phase) | ?? | |
| 3.4 | Power availability (hours per day) | 24 | |
| 3.5 | Renewable Power – Solar / Wind – if already | Biomass energy already being sold via | |
| 3.6 | New Renewable Power - Solar / Wind - | Sourcing green electrons from other | |
| 3.7 | Transformer Capacity in KVa | 30MW cogen plant interconnect should | |
| 4.0 | Hydrogen Details: | | |
| 4.1 | Hourly flow rate in kg/hr | | |
| 4.1a | - Beginning of Life* | | |
| 4.1b | - End of Life* | | |
| 4.2 | Daily flow rate in kg/day | 150 - Truck tanks should be 70kgs, so | |
| 4.3 | Purity in % | | |
| 4.4 | Hydrogen Delivery Pressure in barg | Higher pressure necessary for filling | |
| 5.0 | Utilities: | | |
| 5.1 | Project Land area (dimensions required) | | |
| 5.2 | Water Source - (City, well, etc) | Well water - looking for quality report | |
| 6.0 | Oxygen Details: (If Reqd - Optional) | | |
| 6.1 | Hourly flow rate in kg/hr | NA | |
| 6.2 | Daily flow rate in kg/day | NA | |
| 6.3 | Purity in % | NA | |
| 6.4 | Oxygen Delivery Pressure in barg | NA | |
| 7.0 | Others: | | |
| 7.1 | Internet availability -details | Not sure | |
| 8.0 | Customer additional requirements: | | |

**Note from Ohmium on clause 4.1 a & 4.1 b**

| | |
|---|---|
| * - 4.1a & 4.1b | We would like to discuss with you further to understand whether the project volume is a **"mission critical"** output which must always be delivered (in other words, if hydrogen supply must be consistent from BOL to EOL). In this case, Ohmium will ensure the project includes required margin for all conditions and times in operating life; or alternatively, if the project is driven by "offtake revenue," in which case committed output as a percentage of project potential generation is a more appropriate model. The Ohmium team has experience working with either model. |

# Appendix I. Air Liquide Tearsheet

# 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

## 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

**For More information please contact:**

**Jorge Manrique - Business Development Manager, Hydrogen Refueling**
**AIR LIQUIDE GLOBAL MARKETS AND TECHNOLOGIES**
Mobile: + 1 713-444-4901
Email: jorge.manrique@airliquide.com

Air Liquide

# Appendix J. Emissions Calculations and Assumptions

## Emissions Estimates with Assumptions

**Table 3. Estimated NOx emissions for a logging scenario**

**NOx Emissions Estimates from ICCT report**

| | grams of NOx per mile | % Time in Study | |
|---|---|---|---|
| Urban Driving | 7 | 43% | 0-25 MPH |
| Suburban | 2.4 | 11% | 25-50 mph |
| Highway | 0.6 | 46% | >50 mph |
| | | **3.55** | **blended average** |

**Logging Truck Estimate (estimated by project team)**

| % Time in Study | | |
|---|---|---|
| 30% | 0-25 MPH | *Estimates based on conversations with Fleet Operators* |
| 35% | 25-50 mph | *Nature of work is such that not as slow as urban vehicles* |
| 35% | >50 mph | *But not highway speed as much either* |
| **3.15** | **grams of NOx per mile** | |

*Source: "Current State of NOx 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 NOx emitted per year = 3.15 grams * 81,250 miles/year
255937.5 grams NOx /year
(b) Calculation to convert grams to lbs = 255937.5 grams * (1 gram = 0.002204623 lbs)
564.2456991 lbs NOx/year
(c) Calculation to convert lbs to tons = 564.2 lbs / 2000 lbs
**0.2821228495 tons NOx/year**

**Logging Truck CO2 Emissions Estimate**

| | |
|---|---|
| 22.5 | pounds of CO2 per gallon of diesel fuel |
| 6 | miles per gallon |
| 81,250 | miles per year |
| **152.0** | **CO2 emissions tons per year / Diesel Logging Truck** |

*Source: EIA - https://www.eia.gov/environment/emissions/co2_vol_mass.php*

(a) Calculation for CO2 emissions tons per year per truck = ((81,250 miles/year / 6 mpg) * 22.5 lbs CO2 per gallon diesel ) / 2000 lbs

**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% | 2.25 | 1,127 | 2.1 |
| BETs | 21.5% | 1.77 | 884 | 0 |
| FCETs (a) | 78.2% | 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 NOx emissions per year per truck = ((3.15 NOx emissions per mile * 81,250 miles driven annually) / by 907,185 grams per ton) * 7.4 years of operation
*Years of driving = 600,000 lifetime miles/81,125 avg miles per year*

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

| | | **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 driving = 600,000 lifetime miles/81,125 avg miles per year*
* Logging Truck CO2 Emissions Estimate (see above)

## Appendix K. FCET Quotes as of November 2023

## FCET Capital Cost - Two Available Price Quotes

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

*(a) Kenworth Rep has system for calculating taxes and fees. Used pro rata amounts for Hyzon*

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

Diesel Operating Cost Assumptions

| | | | |
|---|---|---|---|
| Miles per gallon | 6.0 | | *Sourced from interviews, with fleet operators and truck reps. Range was 5 to 7. Chip Vans probably have better mileage, logging trucks less* |
| Cost of Diesel per Gallon | $6.00 | | |
| Diesel Cost /Mile | $1.00 | | Cost divided by mileage |
| Capital Costs | $0.31 | | |
| Maintenance Costs/Mile | $0.45 | | *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.* |
| | $1.76 | | |
| Logging Truck Days of Operations | 250 | days | *Typical Logging Truck activity, 8 months per year. Chip Vans more miles than logging bc operate all year* |
| | 325 | miles | *Avg 40 mph for 8 hours* |
| Miles per year | 81,250 | | *Estimate based on interviews with truck manufacturers, operators and literature - using logging truck example* |

| | | | |
|---|---|---|---|
| ***Capital Costs*** | | | |
| Truck Costs | $250,000 | | *Estimate based on interviews with truck manufacturers, operators and literature - prices have gone up significantly over the last 18 months.* |
| Loan Term | 20 | years | *Truck costs: Taxes and Trailer Costs push price up significantly* |
| Interest Rate | 8% | interest rate | *Truck costs - Recent Quote: Kenworth T880/W900 Chassis = $345,000.00 (full taxes and trailer for logging)* |
| Annual Payment | $25,463.05 | | |
| **Cost per mile** | **$0.31** | | ***Payment divided by Annual Miles driven*** |