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ENERGY COMMISSION

California Energy Commission
Clean Transportation Program

FINAL REPORT

Palo Alto Hydrogen Refueling Station

Prepared for: California Energy Commission
Prepared by: Air Liquide Hydrogen Energy U.S. LLC

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Air Liquide thanks the State of California for the opportunity to participate in this new and exciting effort. The planning, installation, and operation of the Palo Alto Hydrogen Refueling Station could not have occurred without the unwavering support of the California Energy Commission. Air Liquide also acknowledges the efforts of many of the City of Palo Alto inspectors who came out to do inspections at short notice, which led to the opening of the station to the public.

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

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

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance, and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued the solicitation PON-13-607 to develop infrastructure necessary to dispense hydrogen transportation fuel and to support hydrogen refueling operations prior to large-scale roll-out of fuel cell electric vehicles. In response to solicitation PON-13-607, the recipient submitted an application that was proposed for funding in the CEC's notice of proposed awards May 1, 2014, and the agreement was executed as ARV-14-007 on September 12, 2014.

ABSTRACT

Air Liquide requested funding under the solicitation PON-13-607 to construct the Palo Alto hydrogen fueling station and for operation and maintenance grant funds for the station to expand California's fuel cell electric vehicle (FCEV) infrastructure.

Per the terms of agreement ARV-14-007 between the California Energy Commission (CEC) and Air Liquide Hydrogen Energy U.S. LLC (Air Liquide), Air Liquide designed, engineered, permitted, constructed, and commissioned a hydrogen refueling station located at 3601 El Camino Real, Palo Alto, CA 94306. The station consists of modular "C100" units that enclose hydrogen storage, compression, and cooling equipment; a dispenser with two fueling hoses; a customer payment interface; a canopy; and a dedicated fueling position for FCEV drivers.

Keywords: fuel cell electric vehicle, hydrogen, hydrogen refueling station

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EXECUTIVE SUMMARY

Air Liquide requested funding under the solicitation PON-13-607 to construct the Palo Alto hydrogen refueling station and for operation and maintenance grant funds for the station to expand California's fuel cell electric vehicle infrastructure.

Fuel cell electric vehicles are powered by electricity generated in a fuel cell from hydrogen. Hydrogen gas is stored in the vehicle tank in a compressed state.

In March 2012, then-Governor Edmund G. Brown Jr. issued an executive order to accelerate the use of zero-emission vehicles in California. Automakers have been introducing fuel cell electric vehicles to California since 2015, and earlier.

The California Energy Commission funding supported the design review, construction, permitting, and commissioning of the hydrogen refueling station at 3601 El Camino, Palo Alto 94306. This station will give drivers confidence that they can fill up near their homes, jobs, and key destinations throughout Palo Alto and the Silicon Valley area.

CHAPTER 1: Station Design and Installation

Station Design

Air Liquide's modular C100 units are located at the Palo Alto station. They store and dispense hydrogen and are equipped with a medium pressure compressor that maintains a constant inventory of hydrogen in the medium pressure buffer and ground storage tanks. The pressure is 45 mega pascals (MPa). A pascal is a unit of pressure equal to one newton per square meter and one MPa is one million pascals. Here, MPa is used to describe the pressure at which gaseous hydrogen is stored.

From the medium pressure tanks, the hydrogen gas can supply 35 MPa vehicles. This volume is also used to supply a high capacity, high pressure compressor. The compressor, which is housed in a weatherproof container that contains flame and gas detectors, is protected from failure with relief valves, and low and high oil and gas temperature and pressure switches. All these safety systems are wired into the unit's control system and are remotely monitored 24 hours a day.

The medium-pressure buffer consists of 2,000 liters of hydrogen storage at 45 MPa. The buffers are made up of tubes, with relief valves, rated according to American Society of Mechanical Engineers standards. The medium pressure buffer's main purpose is to reduce the compression ratio of the high-pressure compressor, assuring the flow rate from the dispenser meets the project specifications.

The high-pressure compressor boosts the gas from the medium pressure buffers (45 MPa) to 80 MPa. From this point, the hydrogen gas can supply 70 MPa vehicles directly. This volume is also used to fill the high-pressure buffer. The flow capacity of this compressor, paired with the volume in the high-pressure buffers, enables the station to deliver high speed back-to-back fills without the need for long recharge periods.

A mechanical chiller is included in the station design to control the temperature of the hydrogen dispensing process to meet fueling temperatures of T40 (temperature between -40°Celcius to -33°Celcius) and T20 (temperature between -26°Celcius to -17.5°Celcius) fills in accordance with the Society of Automotive Engineers (SAE) International J2601, "Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles."

Station Fueling and Safety Protocols

The Palo Alto hydrogen refueling station is depicted in Figure 1 and shown as a site layout plan in Figure 2. The hydrogen fueling station operation entails vehicle fueling and station recharge. A programmable logic controller (PLC) monitors the fueling and records pressure and temperature in the dispenser and the vehicle fuel tank. The fill stops as soon as the pressure level reaches the equivalent of 70 MPa at 15°C. As the fill ends, the fueling hose is depressurized through a vent valve to avoid the operator having to manipulate the hose under pressure. The station recharge begins when the pressure in the buffer storage (either medium or high pressure) tubes reach a low set point based on the fueling performance specifications. This activates the compressor (either medium or high pressure) for refilling its respective buffer tubes until a high pressure set point on the buffer tube is reached. To ensure safety, a leak test is conducted before each fueling operation. This testing occurs in the dispenser and at the connection between the nozzle and receptacle.

In addition, a daily leak test is done on the station to ensure the overall integrity of the installation when the station is in standby mode. The daily leak test is programmed to occur during non-peak operating hours. Also, the pressure level is monitored continuously between the dispenser and hydrogen pad to check pipe integrity and avoid hydrogen release. Other safety features include 24-hour monitoring of the hydrogen flame and leak detection systems, as well as the overall process system (Figures 3 and 4).

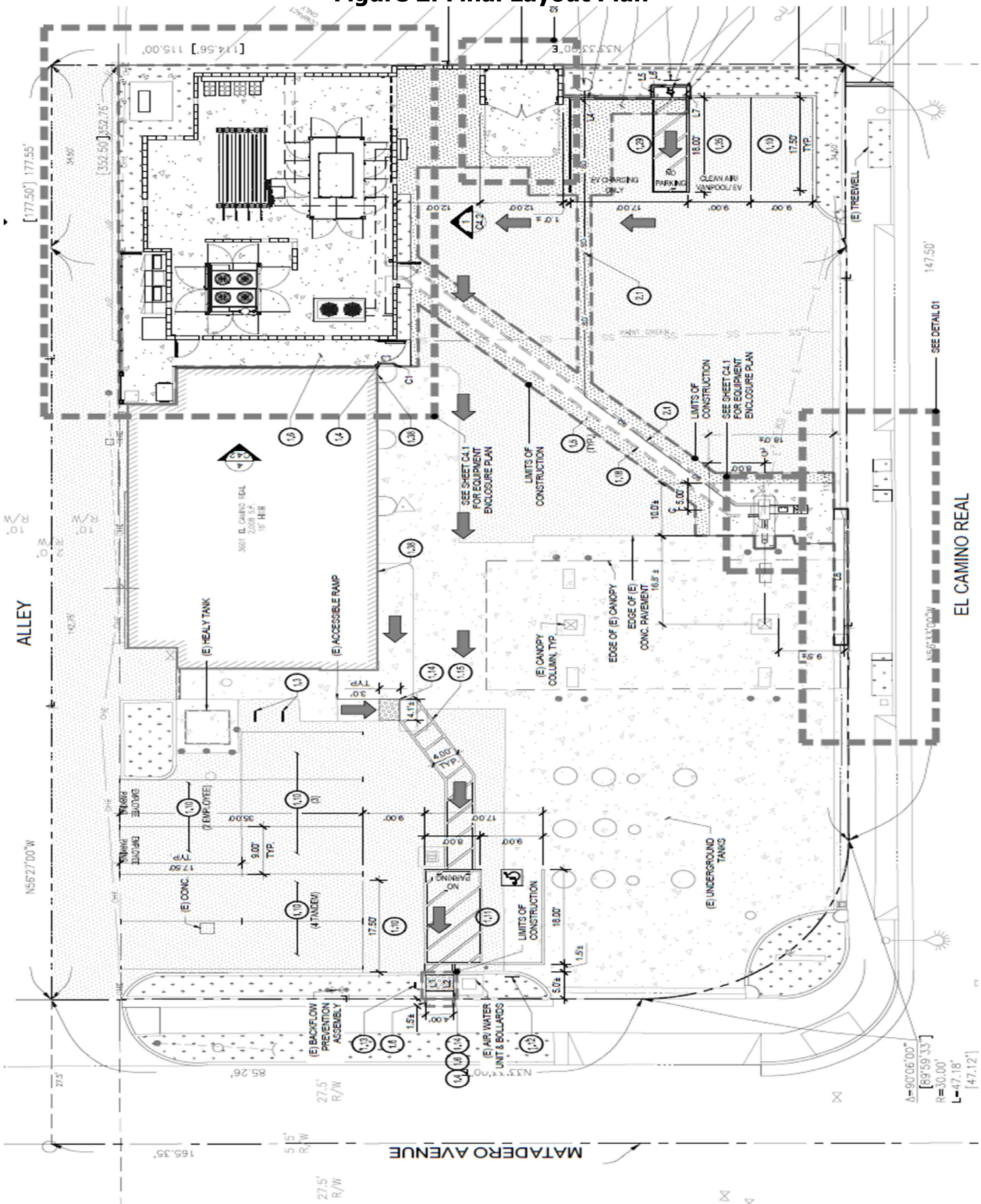
The fuel dispenser is designed to supply hydrogen safely and efficiently to any SAE J2601 compliant vehicle. The dispenser, which is capable of dispensing at fueling speeds in accordance with SAE International J2601, T40 and T20 fills, is built to all National Fire Protection Association (NFPA) "Hydrogen Technologies Code" NFPA 2:2011 standards. This includes dispensing hose breakaway, relief valve, process vent stack, manual shutoff, flame and gas detection, and emergency stop button features. The dispenser will perform a system leak test prior to each fill, and twice during each fill, as well as once per day in between fills. The dispenser contains all the signage required by fire codes. The dispenser also contains standard point of sale equipment.

The dispenser provides operational instructions to the fuel cell electric vehicle (FCEV) driver. The dispenser software requires all first-time users to view the operational instructions.

Figure 1: A Depiction of the Station Site

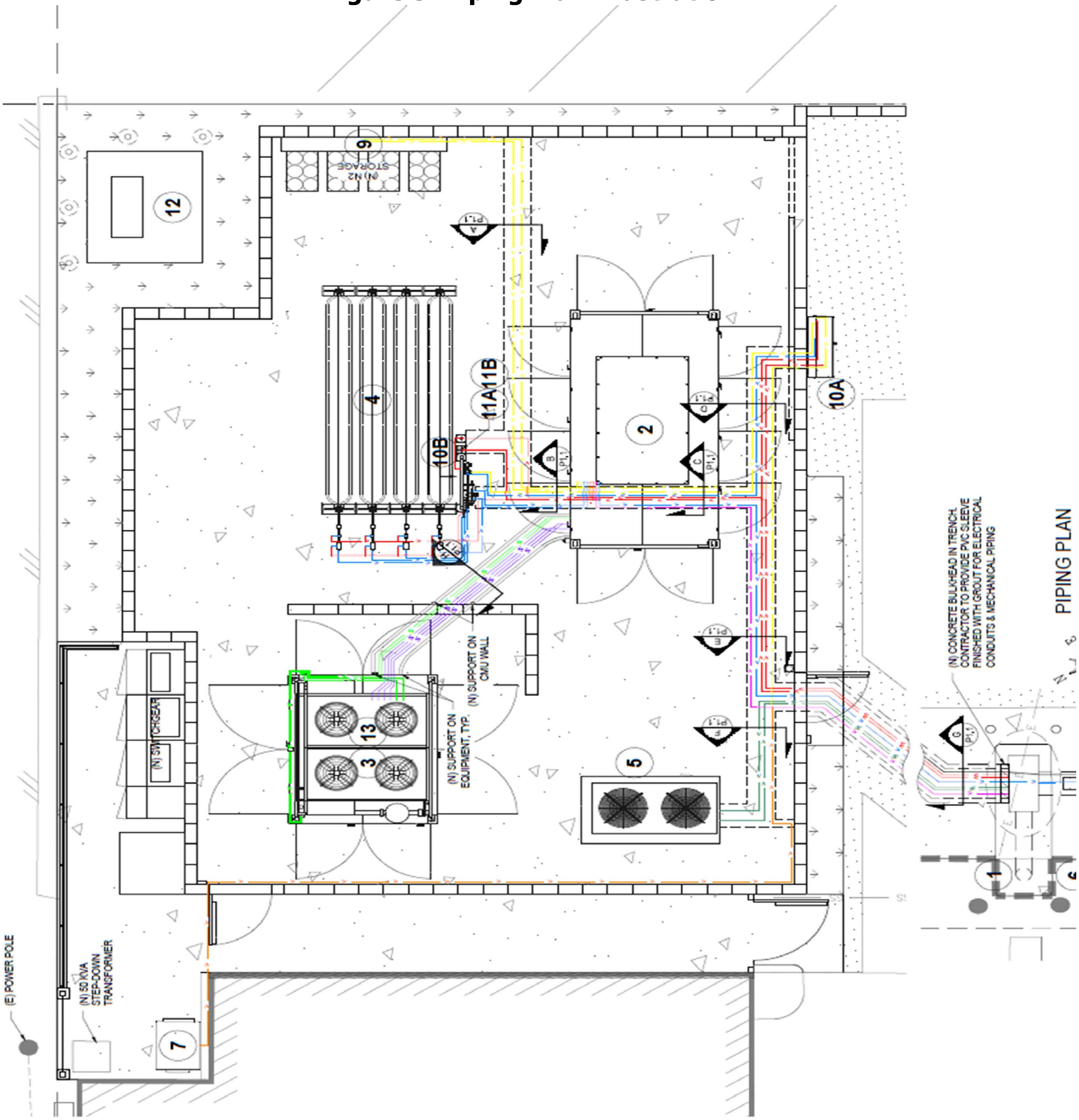
The above photo depicts the station site. Air Liquide submitted the photo to the Palo Alto Planning Department. All new landscaping and irrigation systems were incorporated into the design and delivered at completion.
Source: Air Liquide

Figure 2: Final Layout Plan



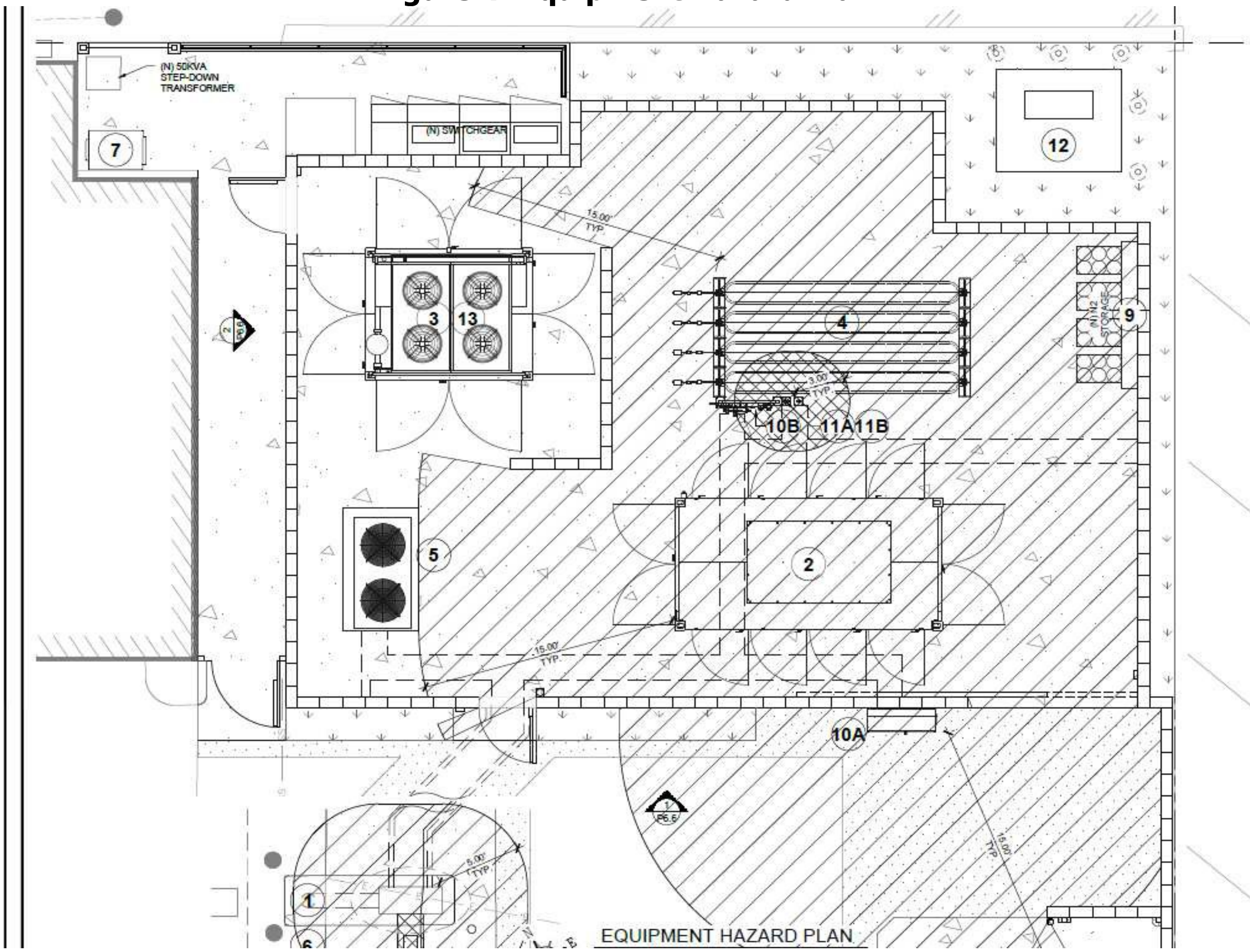
Source: Air Liquide

Figure 3: Piping Plan Illustration



Source: Air Liquide

Figure 4: Equipment Hazard Plan



Source: Air Liquide

Air Liquide submitted the diagrams in Figures 2, 3, and 4 to the City of Palo Alto for planning and permit approval. Air Liquide's project team submitted the building permit application to the City of Palo Alto on August 7, 2017, and the city approved and issued the building permit on April 3, 2018. The construction team broken ground at the site a week later, after mandatory pre-construction meetings with the city. The construction team completed final grading for the equipment enclosure and the excavation for equipment pads and footers, including footings for the block wall, on April 26, 2018.

The construction team then set the groundwork for the installation of underground mechanical piping and electrical and control conduits. The team completed this work on May 3, 2018. For each construction milestone, Air Liquide invited the city inspectors, including the fire department, when applicable, to come to the site and sign off. The required authorities inspected and signed off on the underground mechanical and electrical infrastructure on May 10, 2018. The next milestone, achieved on May 17, 2018, included backfilling and compacting the trenches. Then the team set and anchored all major equipment, including the main electrical switch gears. This construction work and the installed equipment is depicted in Figures 5 through 12. The team finished equipment installation on May 30, 2018.

A part of the project scope as determined by the City of Palo Alto was to install new landscaping irrigation and an electric vehicle charging station. These were all done to the satisfaction of the city.

Figure 5: Crane Setting Skids into Position

Source: Air Liquide

Figure 6: Equipment Being Placed into Position

Source: Air Liquide

Figure 7: Ground Storage Installed

Source: Air Liquide

Figure 8: High Pressure Compressor Skid Installed

Source: Air Liquide

Figure 9: Nitrogen Supply Installed

Source: Air Liquide

Figure 10: Hydrogen Cooling Unit Installed

Source: Air Liquide

Figure 11: Electrical and Control System Skid Installed

Source: Air Liquide

Figure 12: Hydrogen Delivery Panel Installed

Source: Air Liquide

CHAPTER 2: Commissioning Process

The station was declared operational on August 14, 2018.

The station met the definition of operational in PON-13-607, including:

- Completing installation of all station/dispenser components.
- Obtaining all required permits from the local jurisdiction.
- Filling the station storage tubes with pressurized hydrogen gas.
- Successfully fueling one fuel cell electric vehicle with hydrogen.
- Being on a site that was open to the public.
- Successfully passing a hydrogen quality test in conformance with SAE J2719, "Hydrogen Fuel Quality for Fuel Cell Vehicles" as shown in Figures 13 and 14.

Hydrogen Purity Testing and Station Certification

The scope of work for this agreement required the station to undergo and pass a hydrogen purity test. This is one of the requirements of that must be met for the station to be considered operational under PON-13-607. Also, purity testing must be completed whenever hydrogen lines are exposed to contamination due to maintenance or other activities.

Hydrogen supply at this station has a minimum purity of 99.995 percent, tested and verified to meet SAE J2719:2011. The charts in Figures 13 and 14 show the results from when SmartChemistry, a testing provider, performed the initial tests at the Palo Alto station on August 3, 2018. The hydrogen purity requirements are incorporated into station procedures, monitoring, and quality control. The purity of hydrogen delivered from central production facilities is verified by chemical analysis to find the types and amount of contamination.

A certificate of compliance is issued when the hydrogen sample passes the requirements of the SAE standard.

Figure 13: Purity Test Results for the Palo Alto Station, Part 1

SUMMARY	Concentration (µmol/mol)
H_2O (ASTM D7649)	< 1
Total Hydrocarbons -C_1 Basis (ASTM D7892)	**0.21**
Methane	0.21
O_2 (ASTM D7649)	< 2
He (ASTM D1946)	< 10
N_2 & Ar (ASTM D7649)	
N_2	**12**
Ar	< 0.4
CO_2 (ASTM D7649)	< 0.05
CO (ASTM D5466)	**0.0017**
Total S (ASTM D7652)	**0.000019**

Source: SmartChemistry

Figure 14: Purity Test Results for the Palo Alto Station, Part 2

SUMMARY	Concentration (µmol/mol)
Formaldehyde (ASTM D7892)	< 0.005
Formic Acid (ASTM D5466)	< 0.0005
Ammonia (ASTM D5466)	< 0.005
Total Halogenates	< 0.01
Cl_2 (ASTM D5466)	< 0.0002
HCl (ASTM D5466)	< 0.001
HBr (ASTM D5466)	< 0.0006
Total Organic Halides (32 compounds in red and bold listed in "Non-Methane Hydrocarbons") (ASTM D7892, Smart Chemistry limit is for each individual organic halide)	< 0.001
H70 Particulate Concentration	**0.056 mg/kg**
H35 Particulate Concentration	**0.091 mg/kg**
H70 Hydrogen Fuel Index	**99.998734%**

Source: Smart Chemistry

The California Department of Food and Agriculture, Division of Measurements Standards (CDFA/DMS), certified correct operation of the dispensing system on August 23, 2018, per SAE J2601, "Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles." The FCEV automakers also conducted testing at the site to verify appropriate hydrogen refueling from the dispenser.

The station now has Division of Measurement Standards certification (Figures 15 and 16) and passed Hydrogen Station Equipment Performance (HyStEP) device testing. Back-to-back fill testing was also completed. This testing met the requirements of SAE International J2601, for T40 and T20 fills.

Figure 15: Weights and Measures Labels Showing Certification

Source: Air Liquide

Figure 16: Dispenser and Canopy Installed

Source: Air Liquide

CHAPTER 3: Station Infrastructure and Hydrogen Supply

The objective of the project's scope of work (SOW) is to give guidance and direction for the station design, procurement of equipment, building, and construction of one hydrogen refueling station located at a predetermined site. Air Liquide is to support and promote California's hydrogen fueling infrastructure, bringing cost competitive hydrogen to the market with a low carbon intensity. Air Liquide's chief executive officer has a stated goal for the company to achieve 50 percent of its hydrogen production for hydrogen energy applications from renewable sources. Air Liquide has constructed this station with this goal in mind.

In terms of direct impacts, this station design, installation, and operation has incorporated sustainability principles to minimize depletion of natural resources, to maximize the reduction of greenhouse gas (GHG) emissions and minimize impacts on local health and the environment.

Environmental impacts will be minimized with the following methods:

- The station site is located at an existing public fueling station with similar zoning and was chosen to avoid any sensitive surroundings per Task 2 of the SOW.
- The system has a small footprint and simple site installation that minimizes construction effects per Task 2 of the SOW.
- Construction and operations include outreach to public and emergency response personnel. This was accomplished to minimize potential impacts and develop plans to mitigate impacts as discussed in the SOW's objectives of the agreement.
- Operation of the station should not result in any additional emissions from passenger vehicles because the new vehicle trips will be from zero-emission FCEVs. However, there are likely to be some additional emissions from hydrogen fuel delivery trucks.

Palo Alto Hydrogen Refueling Station Location

The station provides hydrogen fuel at 70 MPa (also referred to as H70) and 35 MPa (H35) pressures. The station is in Palo Alto on El Camino Real, near Stanford University, U.S. Route 101, and Interstate 280. Figure 17 shows the station location relative to the surrounding communities and major roads in a map.

Figure 17: Palo Alto Station Location Shown on Map

Source: Google Maps

Hydrogen Fuel Supply

The Palo Alto station dispenses hydrogen gas delivered by a tube trailer. The main source of this delivered gas comes from re-gasified liquid hydrogen produced by a steam methane reformation (SMR) process. The SMR process converts natural gas and water into hydrogen and carbon dioxide or carbon monoxide. The hydrogen is currently obtained from a production source located in Sacramento, California.

The Palo Alto station has been approved by the California Air Resources Board (CARB) for the Low Carbon Fuel Standard (LCFS) Hydrogen Refueling Infrastructure (HRI) credit program as defined in the 2019 LCFS regulation. The station will be supplied by renewable hydrogen as defined in the LCFS regulation. The station will dispense at least 33 percent renewable hydrogen, and the companywide average across all Air Liquide stations will be at least 40 percent renewable per the HRI program requirements. The renewable content is provided through the purchase of landfill gas (LFG) environmental attributes and using book and claim accounting. One potential source for these credits is Air Liquide's biogas business line.

Air Liquide is working to establish a fuel pathway for the hydrogen dispensed at the Palo Alto station, to be considered for possible approval by CARB. The existing LCFS look-up table pathways named HYBL (liquefied hydrogen produced in California from central steam methane reforming of biomethane from North American landfills) and HYFL (liquefied hydrogen produced in California from central steam methane reforming of North American fossil-based natural gas) have built-in assumptions that do not reflect the current supply chains used in many stations in California. Air Liquide is working with CARB to revise mileage assumptions on LFG plant distance-to-source and liquid hydrogen plant distance-to-stations that are used for these pathways.

CHAPTER 4: Station Operations and Associated Benefits

As of December 2018, the Palo Alto station had passed DMS certification testing and received more than two FCEV automaker letters of support allowing it to be declared officially open. The station is currently in the open retail status and should encourage more FCEV sales in the area. Air Liquide is currently operating the station from 6:00 a.m. to 10:00 p.m. It should be noted that the station does not operate 24 hours a day as a courtesy to nearby residents, reflecting Air Liquide's commitment to maintaining good community relations.

Current and past challenges to operating the Palo Alto station:

- A supply chain disruption in Northern California due to an outage at the Northern California gaseous hydrogen fill plant. To mitigate this disruption, Air Liquide supplied the Palo Alto station from its fill plant in Etiwanda, California.
- The chiller, dispenser, and point of sale system have been main sources of downtime. Air Liquide has worked with the vendors to resolve the issues encountered with these and established a special task that made major progress in improving the availability of the station.

Data Collection and Analysis

Station operation and maintenance data are reported to the California Energy Commission (CEC) via the National Renewable Energy Laboratory (NREL) Data Collection Tool. The quarterly submission of the NREL report is made to the CEC (and NREL) by the 15th of the month following the end of each calendar-year quarter.

As part of this project, Air Liquide developed a plan for data collection. The primary method for NREL data collection comes from a Schneider Electric Inter-Regional Input (iRio) telemetry unit located at each station. The telemetry unit is able to connect to the PLC control system, which consists of station tags used for remote monitoring, alarms, and key performance indicators (KPIs). The station KPI data is collected in various data tables, and a subset of the data is used for NREL reporting purposes. Some examples of the data captured via this iRio telemetry unit for the NREL report include storage pressures, compressor operating hours, compressed hydrogen, electricity usage, downtime events, and fueling logs.

The NREL report maintenance data is collected via the Air Liquide Computerized Maintenance Management System (CMMS). This system tracks all maintenance labor hours and parts costs via work orders. Additional station cost data are collected in accounting systems to determine purchases, charges, utilities, rent, etc., assigned to each station. Station sales reports, developed by the point of sale developer, are another source of data used in the NREL reports. Figure 18 shows a photograph of the iRio hardware.

Figure 18: Inter-Regional Input-Output (iRio) Telemetry Unit

Source: Air Liquide

Station Usage

The usage of the Palo Alto station during 2019 is shown in Table 1. Air Liquide will continue to monitor monthly hydrogen dispensing results and report on the station performance over the next few months.

Table 1: Hydrogen Dispensing Data

Month	Numbers of Fills	Hydrogen Dispensed (kilograms)
Jan 2019	313	905
Feb 2019	436	1,184
Mar 2019	267	676
Apr 2019	343	1,043
May 2019	441	1,318
Jun 2019	542	1,542
Jul 2019	403	1,146
Aug 2019	615	1,736
Sept 2019	444	1,172
Oct 2019	508	1,464
Nov 2019	645	1,873
Dec 2019	706	1,987
Annual Total	**5,663**	**16,046**

Source: Air Liquide H2E Operations team

The performance statistics of the Palo Alto project from December 21, 2018, to January 1, 2020, are shown in Tables 2 and 3. The total hydrogen dispensed in 2019 is 16,046 kilograms, and assuming a FCEV delivers 60 miles of range per kilogram of hydrogen, the associated mileage is 962,760. For 962,760 vehicle miles traveled, the gallons of gasoline equivalent (GGE) displaced is 16,351. GGE is calculated by multiplying the 16,046 kilograms of hydrogen dispensed by 1.019, which is the number of gallons of gasoline per one kilogram of hydrogen.

Table 2: Station Usage and Operation Data for 2019

Description	Value
Total Kilograms of Hydrogen Dispensed	16,046
Total Kilograms of H70 Dispensed	14,772
Total Kilograms of H35 Dispensed	1,274
Average Fill Size (in Kilograms)	3.237
Total Gallons of Gasoline Equivalent (GGE) displaced*	16,351

Source: Air Liquide H2E Operations team

*GGE = kilograms of hydrogen dispensed X 1.019

The minimum daily fueling capacity that Air Liquide stated the Palo Alto station would have in its solicitation proposal to PON-13-607 was 180 kilograms. The largest actual amount of fuel dispensed in one day, based on demand, has been 122 kilograms, but the Anaheim station (equivalent to Palo Alto) has dispensed 316 kilograms in one day.

Emissions Reduction Benefits

Table 3 shows the energy sources used to produce the hydrogen that is dispensed into FCEVs at an Air Liquide station, and the energy sources used for gasoline. It also shows the amount of GHG emissions produced (expressed in grams of carbon dioxide equivalent, or gCO2e) by a FCEV and an internal combustion engine (ICE) vehicle per mile of travel. This project reduces GHG emissions through the supply of a low carbon fuel, hydrogen, for zero-emission vehicles. FCEVs reduce GHG emissions up to 40 percent compared to conventional gasoline-powered vehicles on a well-to-wheels basis, based on the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model, 2019 version, from CARB and developed by the Argonne National Laboratory. The hydrogen supplied to FCEVs is among the lowest carbon fuels available for use as a transportation fuel.

Table 3: Performance Statistics

Energy Source	FCEV Fueled at Air Liquide Station	Average ICE Vehicle Fueled by Gasoline
Coal	0.9%	4.0%
Petroleum	2.6%	78.6%
Nuclear	0.6%	0.0%
Natural Gas	62.3%	13.9%
Renewable	33.6%	7.1%
Resulting GHG Emissions	339.61 gCO2e/mile	460.2 gCO2e/mile

Source: Air Liquide H2E Operations team

The total GHG emissions savings attributable to the Palo Alto station for 2019 are calculated by using these GHG emissions values with the annual dispensing data. A total of 16,046 kilograms of hydrogen was dispensed at the Palo Alto station in 2019. Assuming a FCEV delivers 60 miles of range per kilogram of hydrogen, the FCEVs could be driven 962,760 miles with this fuel. As shown in Table 3, there is a GHG emissions reduction of nearly 120 gCO2e (460.2 minus 339.61) per mile driven. But this savings is multiplied by two, to total 240 gCO2e/mile, to account for the energy efficiency differences between gasoline and hydrogen (whereas one kilogram of hydrogen supplies about 60 miles of range, one gallon of gasoline supplies around 30 miles on average). This assumption of 240 gCO2e/mile is consistent with a California Fuel Cell Partnership report based on the GREET V1_2013 model.

The total GHG emissions savings attributable to the Palo Alto station for 2019 are calculated by multiplying the total amount of miles driven (962,760) by the amount of GHG emissions savings per mile driven (240 gCO2e), which is 231,062,400 gCO2e, or 231 metric tons CO2e.

Additionally, there are reductions in volatile organic compounds (VOCs), carbon monoxide (CO), oxides of nitrogen (NOx), and particulate matter (PM10) with the displacement of gasoline by hydrogen. These reductions are shown in Table 4.

To find the total for VOC reduction in 2019, multiply the emissions savings (0.331 grams per mile) times the total number of miles driven (962,760), which is 318,674 grams VOC. Table 4 provides this emission reduction calculation for the other air pollutants.

Table 4: Palo Alto Emissions Reduction Results for VOC, CO, NOx and PM10

Type of Emissions	Emissions from Gasoline (g/mi)	Emissions from Hydrogen* (g/mi)	Emissions Reduction (g/mi)	Total Reduction in 2019 (g/mi)
VOC	0.367	0.036	0.331	318,674
CO	2.778	0.115	2.663	2,563,830
NOx	0.277	0.159	0.118	113,606
PM10	0.038	0.027	0.011	10,590

Source: GREET 2019 model

*These values assume hydrogen is produced via SMR without carbon capture and storage

Table 5 is a result of GREET analysis (Tier 2 – Look Up Table Modified Hydrogen Pathways, December 13, 2019) by ICF. It shows the increased Carbon Intensity (CI) that results from additional mileage of transporting liquid hydrogen from Sacramento to Santa Clara and compressing and delivering the hydrogen in gaseous form via tube trailer to the station. These calculations assume 40 percent renewable hydrogen using purchased biogas.

Based on the LCFS lookup tables for CI, and including a modified (increased) trucking distance from the liquid hydrogen source to transfilling facilities, the following CIs, expressed in grams of carbon dioxide equivalent per megajoule (gCO2e/MJ), are determined:

Table 5: Total Carbon Intensity

Hydrogen Pathways	Final CI (gCO2e/MJ)
HYFL*	158.29
HYBL**	136.44

Source: Unchanged data from the CA-GREET 3.0 Technical Support Documentation

*HYFL: Liquefied H2 produced in California from central Steam Methane Reformation (SMR) of North American fossil-based natural gas

**HYBL: Liquefied H2 produced in California from central SMR of biomethane (renewable feedstock) from North American landfills

Energy Saving Features and Economic Benefits

The California Building Standards Code (California Code of Regulations, Title 24, Part 6) requires that all lighting systems in non-residential buildings have switching or control capabilities to turn off when unoccupied. This is accomplished by a scheduled controller with an override capability at the station. The focus of Title 24, Part 6, is to reduce energy usage by limiting light usage and other device usage when the space is not occupied. The Palo Alto station site is open continuously, but the light system at the station automatically turns on at dusk and off at dawn to save energy.

Air Liquide installed an EV charger at the site, which allowed a second alternative fuel at the station.

For operation and maintenance, Air Liquide hired a full-time field service technician to operate and maintain the Palo Alto station. A reliability engineer was hired to monitor and improve the reliability of the station. In addition, a distribution and sourcing manager was employed to organize the hydrogen supply chain. Air Liquide also brought on an operations manager that overviews those three resources. During the project, Air Liquide hired a project manager who became responsible for site selection, permitting, equipment procurement, design, construction, commissioning, lessons learned, and reporting to the CEC. During construction, commissioning, Department of Food and Agriculture/Division of Measurement Standards (DMS) testing, automaker testing, and public events, significant business has been generated for local vendors, labor, hotels, and restaurants.

CHAPTER 5: Budget

Table 6 shows the budget to construct the Palo Alto hydrogen Refueling station. The budget reflects the amount of CEC grant funding provided to the project. Air Liquide provided $940,486.24 in match funding, bringing the total project cost to nearly $2.7 million.

Table 6: Budget Summary

Task Summary	Funding
Engineering, Administration, Procurement	$105,796.86
Equipment Fabrication	$1,154,178.64
Installation & Site Prep	$314,703.97
Start-up & Commissioning	$116,280.21
Data Collection & Reporting	$59,040.32
Total CEC Grant Funding	**$1,750,000.00**

Source: CEC

CHAPTER 6: Findings and Conclusions

There were substantial lessons learned from the Palo Alto station project. This project underscored the importance of community outreach and the consideration of community benefits such as landscaping when planning a hydrogen refueling station project. The project experienced major delays during the permitting phase whereby there were scope changes that Air Liquide had to implement. These delays may have been avoided with more proactive outreach with city and community stakeholders.

Air Liquide had orientation sessions with the Palo Alto Fire Department whereby the first responders were given a tour of the facility. A demonstration of the safety features of the station and of a FCEV were presented. These sessions were well received by the fire department and were a successful component of the project.

Air Liquide also learned from past projects and incorporated those learnings into the Palo Alto station operations plan. Although these are unmanned refueling stations, Air Liquide has found it is good practice to have someone on hand to assist with fueling, especially during the first two weeks of operation. Early interaction with the station customers helps them better understand the filling sequence.

GLOSSARY

American Society of Mechanical Engineers – is an American professional association that promotes the art, science, and practice of multidisciplinary engineering and allied sciences around the globe "via" continuing education, training and professional development, codes and standards.

California Air Resources Board – California's clean air agency whose main goals include attaining and maintaining healthy air quality, protecting the public from exposure to toxic air contaminants, and providing innovative approaches for complying with air pollution rules and regulations.

California Energy Commission - The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are:

- Forecasting future statewide energy needs.
- Licensing power plants sufficient to meet those needs.
- Promoting energy conservation and efficiency measures.
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels.
- Planning for and directing state response to energy emergencies.

Clean Transportation Program – The CEC's fuel and vehicles program that provides funding for hydrogen infrastructure, low or non-carbon producing vehicles, and low or carbon-free fuels in the State of California.

Fuel Cell Electric Vehicle – A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.

GREET model – The Greenhouse gases, Regulated Emissions, and Energy use in Technologies model, developed by Argonne National Laboratory.

HYBL – The name of the LCFS pathway for liquefied hydrogen produced in California from a central SMR of bio methane (renewable feedstock) from North American landfills.

Hydrogen Refueling Station – A physical site that produces and/or accepts hydrogen gas/liquid from an outside source and allows for dispensing of hydrogen into hydrogen fuel cell electric vehicles.

HYFL – The name of the LCFS pathway for liquefied hydrogen produced in California from a central SMR of North American fossil-based natural gas.

Low Carbon Fuel Standard – A set of standards designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and therefore, reduce greenhouse gas emissions. The LCFS standards are expressed in terms of the "carbon intensity" of gasoline and diesel fuel and their respective substitutes. The LCFS is a key part of a comprehensive set of programs in California to cut greenhouse gas emissions and other smog-forming and toxic air pollutants. This is accomplished by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.

Pascal – Unit of pressure equal to one newton per square meter. A mega pascal (MPa) is 1 million pascals.

Steam Methane Reformer – The physical plant that takes methane and water and converts it to a product of hydrogen gas and carbon monoxide.