CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Mountain View Hydrogen Fueling Station

Prepared for: California Energy Commission

Prepared by: Linde LLC

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- California Fuel Cell Partnership
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- First Element
- Toyota

PREFACE

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

The 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 PON-12-606 to develop infrastructure necessary to dispense hydrogen transportation fuel and to support hydrogen refueling operations prior to large-scale roll-out of fuel cell vehicles. In response to PON-12-606, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards April 11, 2013 and the agreement was executed as ARV-12-057 on September 11, 2013.

ABSTRACT

Linde successfully designed, constructed, commissioned and opened the Mountain View Hydrogen Fueling Station which is approved to sell hydrogen by the kilogram by the California Department of Food and Agriculture/Division of Measurement Standards. The Mountain View Hydrogen Fueling Station is open to the public, accepts most major credit cards, and performs refueling of fuel cell electric vehicles in about three to four minutes at both 350 bar and 700 bar hydrogen tank pressures. This final report describes the performance, economic benefits, and local impact of the project and summarizes the operational data collected under Task 5 Data Collection and Analysis.

Keywords: Fuel cell electric vehicle, Mountain View, Linde LLC, California Fuel Cell Partnership, California Assembly Bill 8

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EXECUTIVE SUMMARY

Hydrogen fuel cell electric vehicles and hydrogen refueling stations are expected to play key roles in California as the state transitions to lower-carbon and zero-emission vehicle technologies for light-duty passenger vehicles, transit buses, and truck transport fleets. Numerous government regulations and policy actions identify fuel cell electric vehicles as a vehicle technology that will be available to meet the California Air Resources Board Zero Emission Vehicle Regulation and the Governor's Zero Emission Vehicle Mandate. More specific actions to bring fuel cell electric vehicles to California markets are specified in the Governor's Zero Emission Vehicle Action Plan.

Hydrogen fuel cell electric drive technology offers tremendous potential for the light-duty passenger vehicle market and medium- and heavy-duty truck and bus markets. Fuel cell electric passenger vehicles can drive more than 300 miles on a tank of hydrogen and can be refueled in three to four minutes the way gasoline passenger vehicles are fueled. They have zero tailpipe emissions, while the carbon footprint of these vehicles is nearly the same as plug-in electric vehicles. The technology can be readily scaled up for sport utility vehicles, family passenger vans, pick-up trucks, urban package and beverage delivery trucks, and even heavy-duty trucks and buses. Most auto industry analysts and agencies view fuel cell electric drive technology as a complement to battery electric drive technologies, rather than as a competing technology. Both battery and fuel cell electric vehicle technologies will be needed in California to achieve the zero emission vehicle deployment goals.

In contrast to battery electric and plug-in hybrid electric vehicles that can be charged in home settings, fuel cell electric vehicles require a new network of refueling stations that dispense pressurized hydrogen for consumer use. This has meant that the auto industry and station development industry have had to co-develop two new technologies in parallel: hydrogen refueling infrastructure and hydrogen fuel cell electric vehicles. Fuel cell electric vehicles cannot be widely marketed and sold to consumers without a minimum network of refueling stations available.

Assembly Bill 8 (Assembly Bill 8, Perea, Chapter 401, Statutes of 2013) reauthorized the original Assembly Bill 118 funding program (Núñez, Chapter 750, Statutes of 2007) and created new legal requirements for the California Energy Commission's Clean Transportation Program. The bill directs the California Energy Commission to allocate up to $20 million per year, or up to 20 percent of each fiscal year's available funding, for the development of hydrogen refueling stations "until there are at least 100 publicly available hydrogen-fueling stations in operation in California" (Health and Safety Code 43018.9[e][1]).

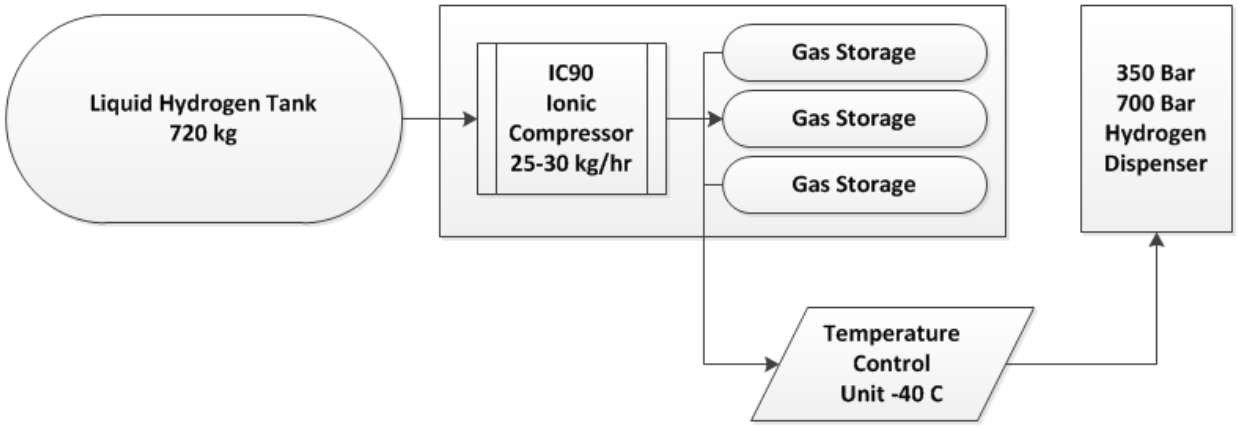
Linde proved at the Mountain View Hydrogen Fueling Station that the Linde IC90 compressor system is capable of performing fast cold fills for both 350 bar and 700 bar light duty hydrogen vehicles with up to five kilograms of onboard hydrogen storage. This station stores liquid hydrogen on site and utilizes the Linde IC90 high throughput hydrogen compressor, which has the capability to scale with the growing light duty fuel cell electric vehicle market. The dual hose dispenser allows for filling of both 350 bar and 700 bar class hydrogen vehicles with tanks less than ten kilograms.

Linde also proved the station's capability of accurately dispensing hydrogen by being approved to sell hydrogen by the kilogram by the California Department of Food and Agriculture/Division of Measurement Standards.

CHAPTER 1:
Station Design and Construction

Linde utilized the IC90 ionic compressor for hydrogen compression for increased capacity and efficiency. This is the Linde standard technology for future stations. The Linde hydrogen fueling station stores 720 kilograms of liquid hydrogen on site and dispenses the hydrogen via high pressure storage tubes which are supplied from the IC90 compressor as shown in Figure 1.

Figure 1: Simplified Block Diagram of the Mountain View Hydrogen Fueling Station



Source: Linde LLC

1.1 Timeline

The project execution timetable is shown below in Table 1. The technical aspects of the project proceeded on time while the site license agreement and local jurisdiction approval took longer than anticipated. The City of Mountain View requested an indemnity and deed restriction be signed by Linde and the property owner which required not only legal input from all parties, but also resulted in re-negotiation of terms between Linde and the property owner. Additionally, securing the Provisional Use Permit and Development Review Permit also required extra time. The City of Mountain View had concerns about locating a hydrogen refueling station in the city. On multiple occasions, technical experts from within Linde, as well as the California Fuel Cell Partnership, third party consultants, and Governor's Office of Business and Economic Development, were brought in to answer questions about technology and safety. It took time to allay concerns and gain acceptance.

Another factor that extended the permitting duration was the station look and feel. Architectural design of the station was important to the city and although professional architects were engaged, numerous iterations for the design of the station and landscaping were required before approval was granted.

Table 1: Project Timeline

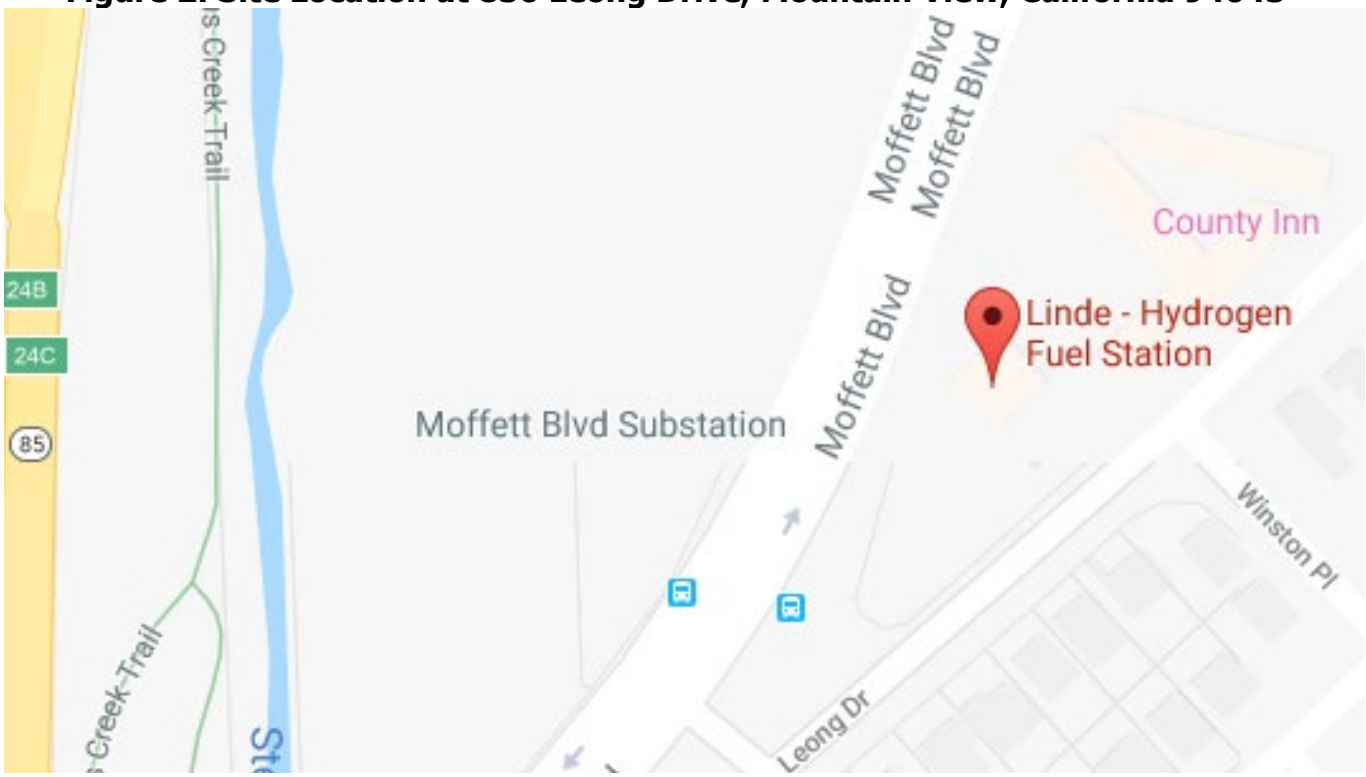
Event	Completion Date
Award Approval at CEC	April 2013
Project Kick Off	October 2014
Execute Site License Agreement	April 2015
Equipment Released for Shipment to Site	June 2015
Secure City Planning Approval	May 2016
Secure Building Permits	June 2017
Begin Site Work (Concrete, Trenching, Excavation)	July 2017
Substantial Completion	November 2017
Commissioning	January 2018
Division of Measurement Standards/Hystep	February 2018
Open	February 2018

Source: Linde LLC

1.2 Location

The Mountain View Hydrogen Fueling Station is located at 830 Leong Drive, shown in Figure 2.

Figure 2: Site Location at 830 Leong Drive, Mountain View, California 94043

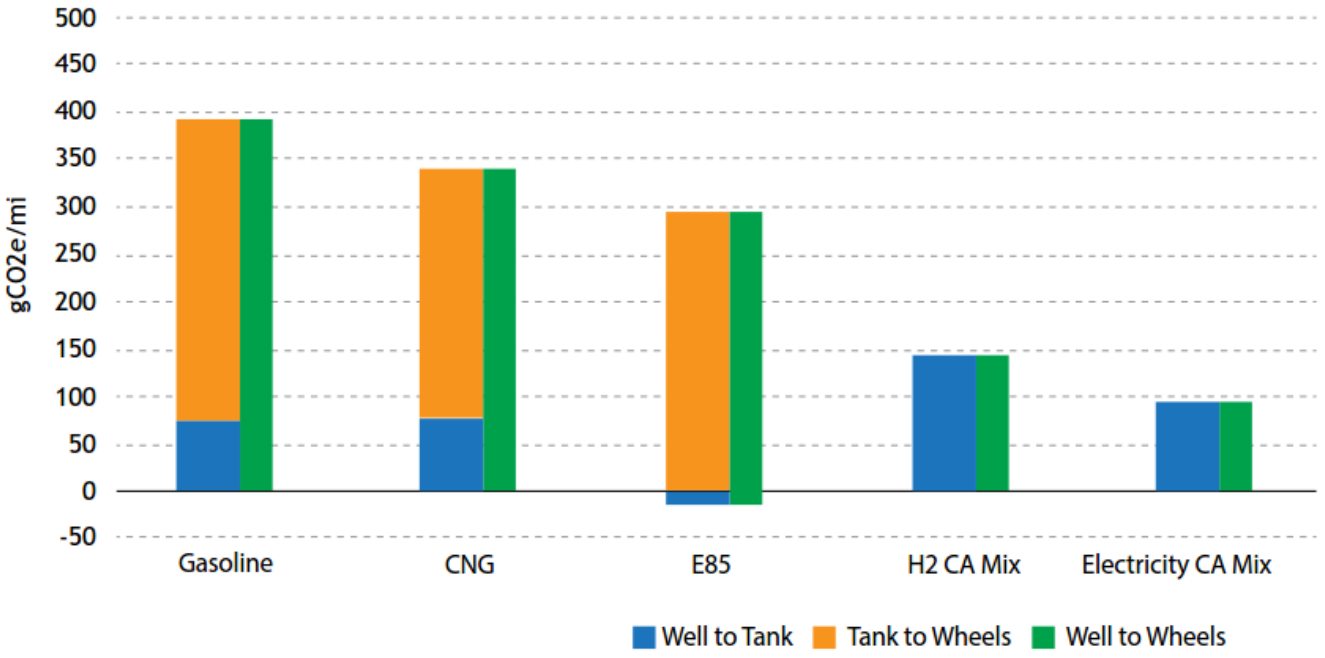


Source: Linde LLC

1.3 Environmental Impacts

From station construction through the first six months of operation since the Mountain View Hydrogen Fueling Station was commissioned, there have been zero incidents that have negatively impacted the environment. From station opening to the end of August 2018, 10,685 kilograms of hydrogen was dispensed. Assuming a fuel cell electric vehicle delivers 60 miles/kilogram of hydrogen, there was a greenhouse gas emission reduction of 154 metric tons. This assumes the difference in emission between gasoline and hydrogen is 240 grams of carbon dioxide equivalent/mile, as taken from the California Fuel Cell Partnership report based on the Argonne National Lab Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies V1-2013 model shown in Figure 3. These results show a reduced impact on the environment.

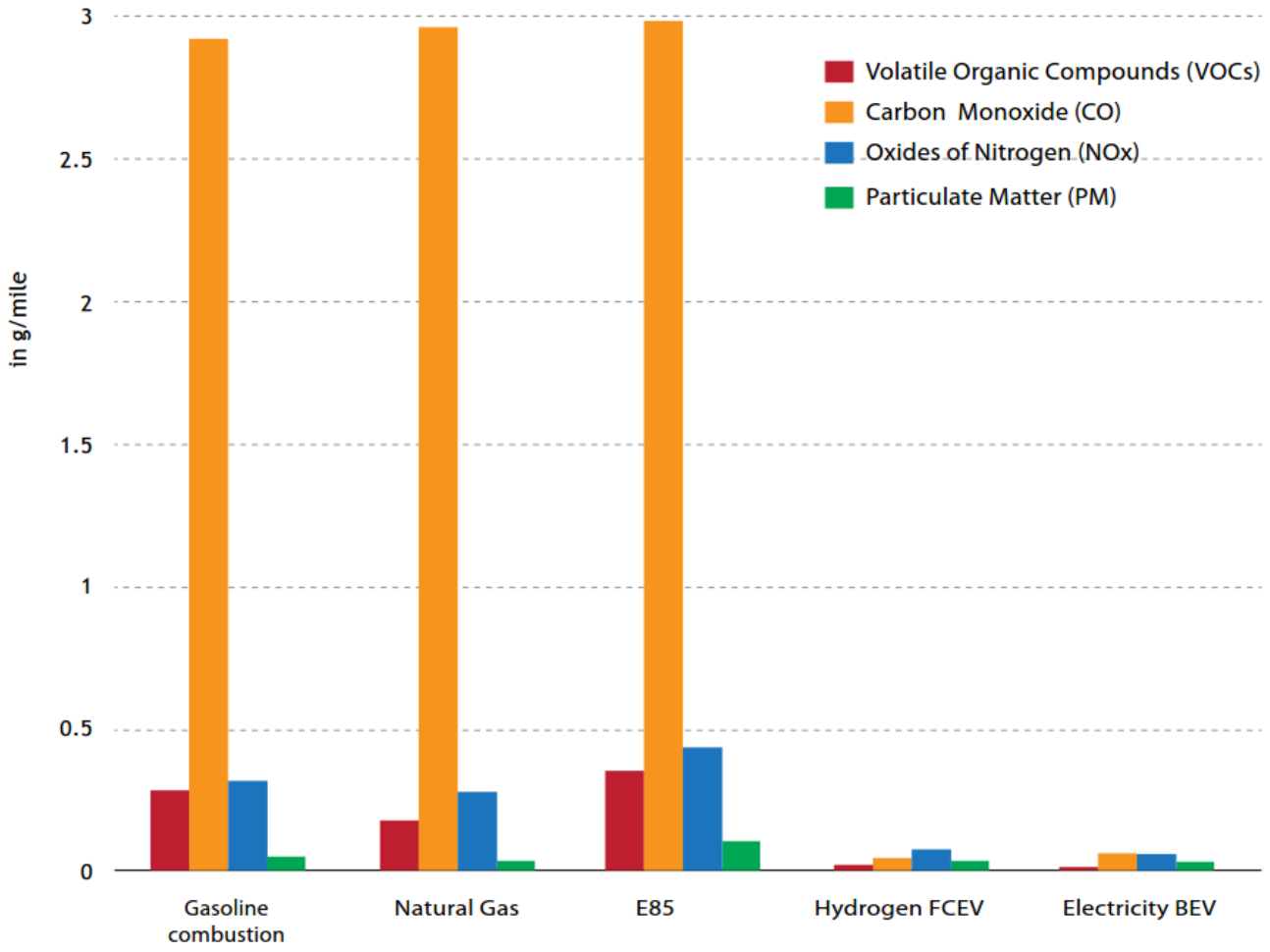
Figure 3: Greenhouse Gas Emissions by Fuel Type



Source: California Fuel Cell Partnership

Additionally, there is a reduction in volatile organic compounds, carbon monoxide, oxides of nitrogen, and particulate matter with the displacement of gasoline (Figure 4).

Figure 4: Criteria Pollutants by Energy Source

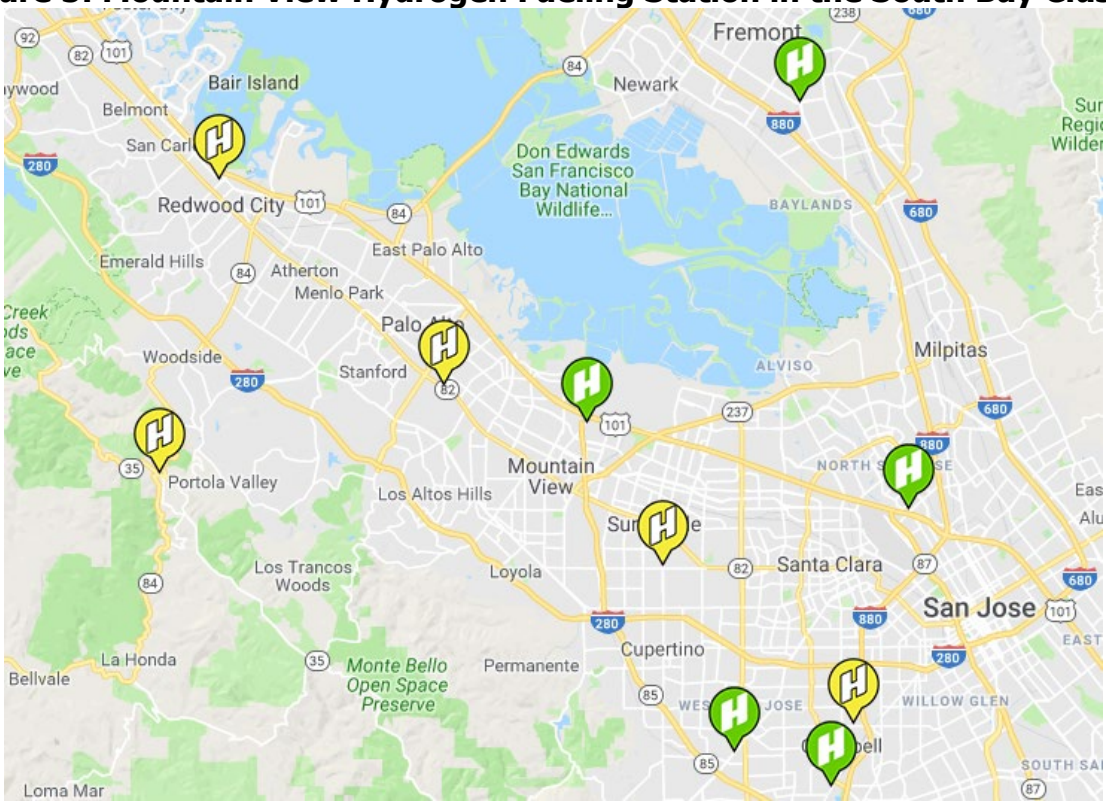


Source: California Fuel Cell Partnership

1.4 The Station's Location in the Fueling Network

The Mountain View Hydrogen Fueling Station is located off Highway United States-101 and Highway California-85 in Santa Clara County. This location is in the cluster of fuel stations in the South Bay and is used by commuters to the area. The location is shown on the California Fuel Cell Partnership website (http://cafcp.org/stationmap) in Figure 5.

Figure 5: Mountain View Hydrogen Fueling Station in the South Bay Cluster



Source: California Fuel Cell Partnership

1.5 Photo of the Finished Mountain View Hydrogen Fueling Station

The following photos show the completed Mountain View Hydrogen Fueling Station below in Figure 6. The Mountain View Hydrogen Fueling Station is open to the public, however the liquid hydrogen tank and IC90 compressor are behind the wall and fence inside the equipment pen. The site is easily viewed from the street.

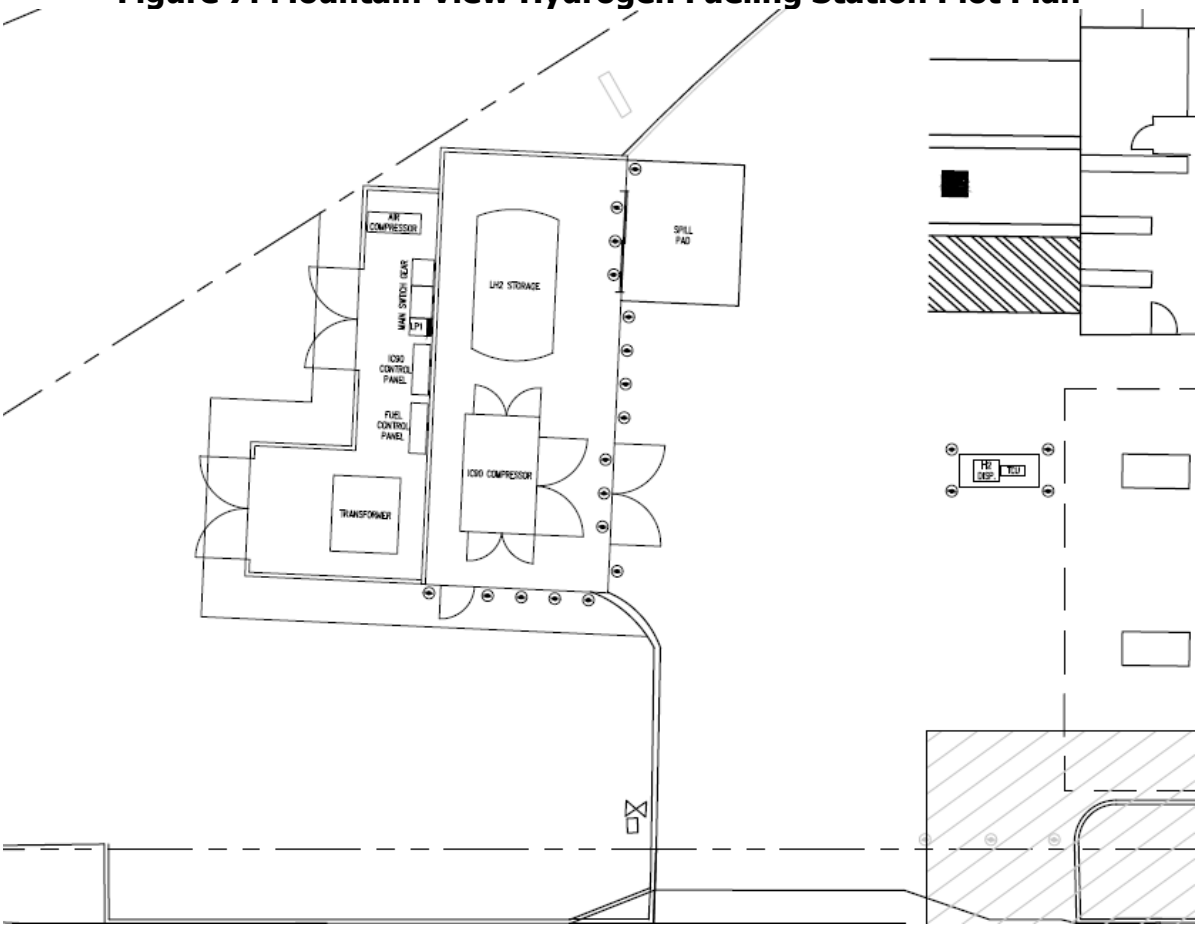
Figure 6: Station Photograph

Source: Linde LLC

1.6 Site Drawings

The plot plan for the Mountain View Hydrogen Fueling Station is shown below in Figure 7. The proper setbacks for liquid hydrogen and high-pressure gas storage fit well on the site. The equipment layout with the IC90 and liquid tank is now a standard design basis for future site selection for Linde.

Figure 7: Mountain View Hydrogen Fueling Station Plot Plan



Source: Linde LLC

1.7 Project Costs and Funding Received from the CEC

The total cost for the new station is $2.67 million which is higher than the approved budget of $2.53 million. This was due to extra architectural elements that were required to be integrated into the station design, extensive landscaping requirements, upgrades to the existing site to meet Americans with Disabilities Act requirements, and the extra engineering effort to produce the design for the extra scope.

CHAPTER 2:
Data Collection and Analysis

The goal of this task was to collect at least four months of data on the performance, economic benefits and local impact of the project throughout the term of the project and to analyze the sustainability of the Linde Mountain View Hydrogen Fueling Station. The usage of the station since commercial opening is as follows (Table 2):

Table 2: Mountain View Hydrogen Fueling Station Usage by Date

Month	Kilograms
March 2018	1436
April 2018	1802
May 2018	1852
June 2018	1769
July 2018	1799
August 2018	2027

Source: Linde LLC

2.1 Hydrogen Supply and Performance Statistics

The hydrogen supply for the Mountain View Hydrogen Fueling Station was obtained from a production source located in the Los Angeles area. This same supply was used for the entire funded period of the project and is planned to remain the supply source in the future with potentially additional supply from green sources as discussed in section 2.5 below. The performance statistics of the Mountain View Hydrogen Fueling Station project from March 1, 2018 to August 31, 2018 are shown in Table 3.

Table 3: Mountain View Hydrogen Fueling Station Statistics from Opening (March 1, 2018 to August 31, 2018

Description	Value
Total Kilograms of Hydrogen Dispensed	10,685
Average Kilograms/Day	58
Approximate % of Hydrogen Fuel (70 Megapascals)	99.6%
Approximate % of Hydrogen Fuel (35 Megapascals)	0.4%
Number of Days Vehicles Filled	184
Number of Transactions (~Vehicles Filled)	3119
Average Fill (Kilograms)	3.43
Average Transactions Per Day	17

Description	Value
Total Gallons of Gasoline equivalent displaced, (1 gallon = 0.997 kilograms)	10,717

Source: Linde LLC

2.2 Current and Planned Use of Renewable Energy

The Mountain View Hydrogen Fueling Station is planned to be 33 percent renewable, either by purchasing credits from our landfill gas facility in Altamont, California, delivering renewable hydrogen from our chlor-alkali fed hydrogen plant in Magog, Quebec, or purchase of biofuel renewable identification numbers to meet the 33 percent requirements. The Mountain View Hydrogen Fueling Station currently plans on purchasing credits from the landfill gas facility in California.

2.3 Energy Efficiency

The Linde IC90 has a 73 percent isentropic efficiency. The entire fuel station electrical consumption can vary due to ambient temperature and station utilization. The station requires a base load for the refrigeration system which cycles on and off automatically to maintain the cold fill heat exchangers at -40 Celsius. On a per kilogram basis the refrigeration energy is reduced by taking advantage of the cold temperatures in the liquid hydrogen tank. These cold temperatures cool the cold fill heat exchangers and reduce the refrigeration system load. This is more efficient than using only electricity to maintain the cold temperature.

Linde has also improved site power consumption at the Mountain View Hydrogen Fueling Station by eliminating the need for purged air cabinets by installing the cabinets outside the classified area. The purge air blower would be driven by a seven-horsepower motor. If running at full load, the blower would draw about 125 kilowatt-hours per day. Assuming a conservative ten percent of full load, this translates to about 13 kilowatt-hours or three percent of the monthly power usage for the site.

2.4 Economic Development

During construction, hours worked by contractors were approximately 1400 hours/month for six months. This translates to eight full time jobs during the six months of construction. For operation and maintenance, Linde anticipates 10 to 20 percent of a full time equivalent in the early years growing thereafter based on volume and station utilization. During construction, commissioning, Department of Food and Agriculture/Division of Measurement Standards testing, original equipment manufacturer testing, and public events, significant business has been given to local vendors, labor, hotels and restaurants. Continued economic development would include this station's contribution to a new market supporting local sale of fuel cell electric vehicles.

2.5 Life Cycle Greenhouse Gas Emissions

This project reduces greenhouse gas emissions through the supply of a low carbon fuel, hydrogen, for zero emission vehicles. Hydrogen fuel cell vehicles reduce greenhouse gas emissions up to 40 percent compared to conventional gasoline-powered vehicles on a well-to-wheels basis based on the California Air Resources Board Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies model.

Hydrogen supplied to fuel cell vehicles is among the lowest carbon fuels available for use as transportation fuel. The total carbon reduction potential from the Mountain View Hydrogen

Fueling Station is significant due to its 350 kilograms per day nameplate capacity. Based on the projected demand by the original equipment manufacturers' and California Air Resources Board's Low Carbon Fuel Standard carbon emission values, the Mountain View Hydrogen Fueling Station was projected to reduce greenhouse gas emissions by 1,872 metric tons in the first three years and 16,216 metric tons over the equipment's likely minimum service life of six years, assuming projected vehicle demand estimates are met, not including the additional benefit of 33 percent renewable hydrogen which will have remotely located reductions in greenhouse gas emissions.

As of February 2018, the Mountain View Hydrogen Fueling Station had passed Division of Measurement Standards certification testing and received original equipment manufacturer letters of support allowing it to be declared officially open. The station is currently in the full open status and should encourage more use of the station and car sales in the area.

2.6 Transition to Alternative Fuels

The Mountain View Hydrogen Fueling Station displaced nearly 11,000 gallons of gasoline equivalent during its first six months in operation. It is estimated that hundreds of people who have now seen the Linde dispenser in use will be more comfortable buying a fuel cell electric vehicle because they know where to fuel. Linde staff regularly had people stopping by to ask about the station while it was under construction and commissioning. They stated that they were interested in buying a fuel cell electric vehicle when they become available because they know they can fill up at the Linde Mountain View Hydrogen Fueling Station. Greater use of fuel cell electric vehicles by local residents, as well as local city and State government offices, will dramatically increase the awareness and transition to hydrogen as an alternative transportation fuel.

2.7 Sustainability Goals 20 California Code of Regulations Section 3101.5

This station's design and operation comply with the California Energy Commission's Program Opportunity Notice requirements and support 20 California Code of Regulations Section 3101.5. The goal of 20 California Code of Regulations Section 3101.5 is to ensure that funded projects promote sustainable alternative fuels and vehicles by reducing greenhouse gas emissions associated with California's transportation system, protecting the environment, and enhancing market and public acceptance of sustainably produced alternative and renewable fuels. The station utilization is key to ensuring financial viability of the station and continued development of future stations for all station developers. A rapid increase in utilization of new fuel cell electric vehicles will be an important step in the grown of the market.

2.8 Actual Versus Proposed Performance

The Mountain View Hydrogen Fueling Station meets or exceeds all the technical requirements from the proposed performance as shown in Table 4.

Table 4: Proposed Technical Performance Requirements

Dispense up to seven kilograms of hydrogen in any fuel cell vehicle, five times in a single hour
350 bar (35 megapascals) and 700 bar (70 megapascals) dispensing pressures
Compliance with Society of Automotive Engineers-2799/J-2601/J-2719/2600

Source: Linde LLC

The Mountain View Hydrogen Fueling Station was estimated in its original business case to see 27 kilograms/day in the first year, ramping up to 180 kilograms/day in the sixth year. This is a developing market. Recently, the demand for the Mountain View Hydrogen Fueling Station increased, and Linde is hopeful that the following year, 2019, will provide additional car sales and station demand. Additional stations in the area will help increase vehicle adoption. Currently, the Mountain View Hydrogen Fueling Station supplies on average 50-60 kilograms/day, well above the estimated 27 kilograms/day in the first year (Table 5).

Table 5: Estimated Demand at the Mountain View Hydrogen Fueling Station

Years Open	**Kilograms/Day**
Year 1	27
Year 2	55
Year 3	90
Year 4	125
Year 5	140
Year 6	180

Source: Linde LLC

CHAPTER 3:
Conclusion

Linde is now operating four, high-capacity, liquid hydrogen based fueling stations to supply light duty vehicles in California in addition to the bus and light duty vehicle fueling stations at alternating current transit in Emeryville and Oakland, California. Linde appreciates the support of the State of California and the entire hydrogen community to develop the hydrogen fuel market. This is a great step forward for the State of California and Linde to lead the nation with hydrogen zero emissions vehicles infrastructure and technology deployment. Linde is looking forward to continuing to develop the hydrogen fuel technology and market with collaboration with the State of California, stakeholders and industry leaders. The support from this project has contributed to the commercialization of the IC90 ionic compressor which is becoming the industry standard for station developers and facilitated real world verification of liquid hydrogen supply, storage and 700 bar gaseous dispensing as a valid hydrogen pathway for this market.

GLOSSARY

CALIFORNIA ENERGY COMMISSION (CEC)—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 California Energy Commission's five major areas of responsibilities are:

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