CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

Clean Transportation Program

FINAL PROJECT REPORT

WEST SACRAMENTO HYDROGEN STATION

Prepared for: California Energy Commission

Prepared by: Linde LLC

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California Energy Commission

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- Hyundai
- Linde ATZ
- Nissan
- Ramos Oil
- 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 Program Opportunity Notice (PON)-09-608 to provide funding opportunities under the Clean Transportation Program for high-performance hydrogen retail refueling stations. In response to PON-09-608, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards November 17, 2010 and the agreement was executed as ARV-10-038 on March 21, 2012.

ABSTRACT

Linde LLC designed, constructed, and opened a hydrogen refueling station located at 1515 South River Road, West Sacramento (Yolo County). The station is approved to sell hydrogen by the kilogram by the California Department of Food and Agriculture/Division of Measurement Standards. This station is fully open to the public, accepts most major credit cards, and performs refueling of fuel cell electric vehicles in three 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 six months of data collected on station performance.

Keywords: Linde LLC, hydrogen refueling station, hydrogen infrastructure, fuel cell electric vehicles.

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EXECUTIVE SUMMARY

Hydrogen fuel cell electric vehicles (FCEVs) 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 FCEVs as a vehicle technology that will be available to meet the California Air Resources Board's zero emission vehicle regulation and the specific actions to bring FCEVs to California markets 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. FCEV 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 FCEV 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, FCEVs 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 FCEVs and hydrogen refueling infrastructure. FCEVs cannot be widely marketed and sold to consumers without a minimum network of refueling stations available.

Assembly Bill 8 (AB 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 Alternative and Renewable Fuel and Vehicle Technology Program. The bill directs the 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- refueling stations in operation in California" (Health and Safety Code 43018.9[e][1]).

The California Energy Commission funded $1,871,063 of the total $2,494,751 cost to design, engineer, permit, construct, and commission the West Sacramento station.

Linde LLC has demonstrated its ATZ IC90 ionic compressor system in the West Sacramento hydrogen station, which can perform fast cold fills for both 350 bar and 700 bar light duty hydrogen vehicles with up to 7 kilograms of onboard hydrogen storage. This station stores liquid hydrogen on site and utilizes the Linde LLC ATZ IC90 ionic high throughput hydrogen compressor, contributing to the opportunity to increase the scale of the station to meet increased hydrogen demand from the growing light duty FCEV market.

The Linde LLC West Sacramento station achieved the first "Open" status as defined by the new standards set by the California Fuel Cell Partnership and is the first liquid hydrogen station to become operational in California. During the six-month data collection period the Linde LLC West Sacramento station has shown a high uptime of 95 percent as measured by the Station Operational Status System. The Linde LLC liquid hydrogen source is extremely pure due to the low temperature cryogenic process that liquefies and removes impurities.

CHAPTER 1: Station Design and Construction

The West Sacramento station was originally designed to use Linde LLC's (Linde) MF90 compressor. Linde supplied the improved ATZ IC90 ionic compressor (IC90) instead to allow for increased capacity and to standardize on new technology planned for future stations. This allowed for uniform training of maintenance personnel and improved reliability for Linde's network of refueling stations.

Table 1 shows the timetable milestones and target dates listed in the original proposal alongside the actual milestone completion dates. The completion dates diverged from the original schedule because of an extended contract establishment period and a site change. The equipment was also tested for an extended period to ensure safety and reliability which resulted in further delays. The second half of the project (construction and commissioning) proceeded according to the original estimates following the extended start-up period.

Table 1: Project Timeline

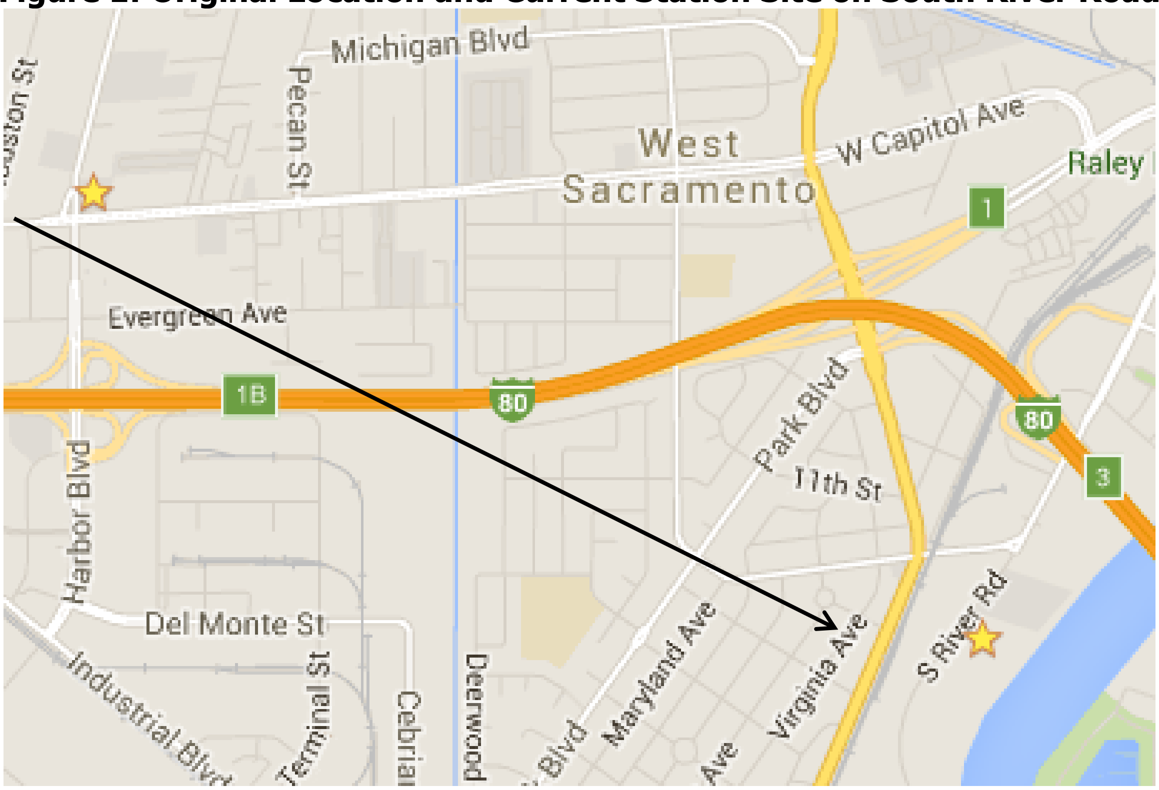
Event/Task	Target Date	Actual Date
Award approval at Energy Commission business meeting	10/1/10	3/23/11
Contract execution	2/1/11	3/21/12
Project kick-off	2/1/11	5/1/12
Order major equipment	3/1/11	8/3/12
Equipment fabrication completed	9/1/11	6/10/13
Equipment released for shipment to site	9/1/11	4/28/14
Begin site work (concrete, electrical and trenching)	10/1/11	6/16/14
Installation of Linde station	11/1/11	8/29/14
Commissioning and testing of station	12/1/11	9/2/14
Operational hydrogen station	2/1/12	9/17/14

Source: Linde LLC.

Station Site Change

The site for the hydrogen refueling station was changed within West Sacramento from the Shell station at 2816 West Capitol Avenue to the Ramos Oil facility at 1515 South River Road. The change in location was required because Linde and the landowner of the original site were not able to agree on the contract terms. In addition, significant concerns about the hydrogen refueling station expressed by the neighbor to the north of the site could have delayed the permitting process. Figure 1 shows the current site location and the originally proposed site marked by stars.

Figure 1: Original Location and Current Station Site on South River Road



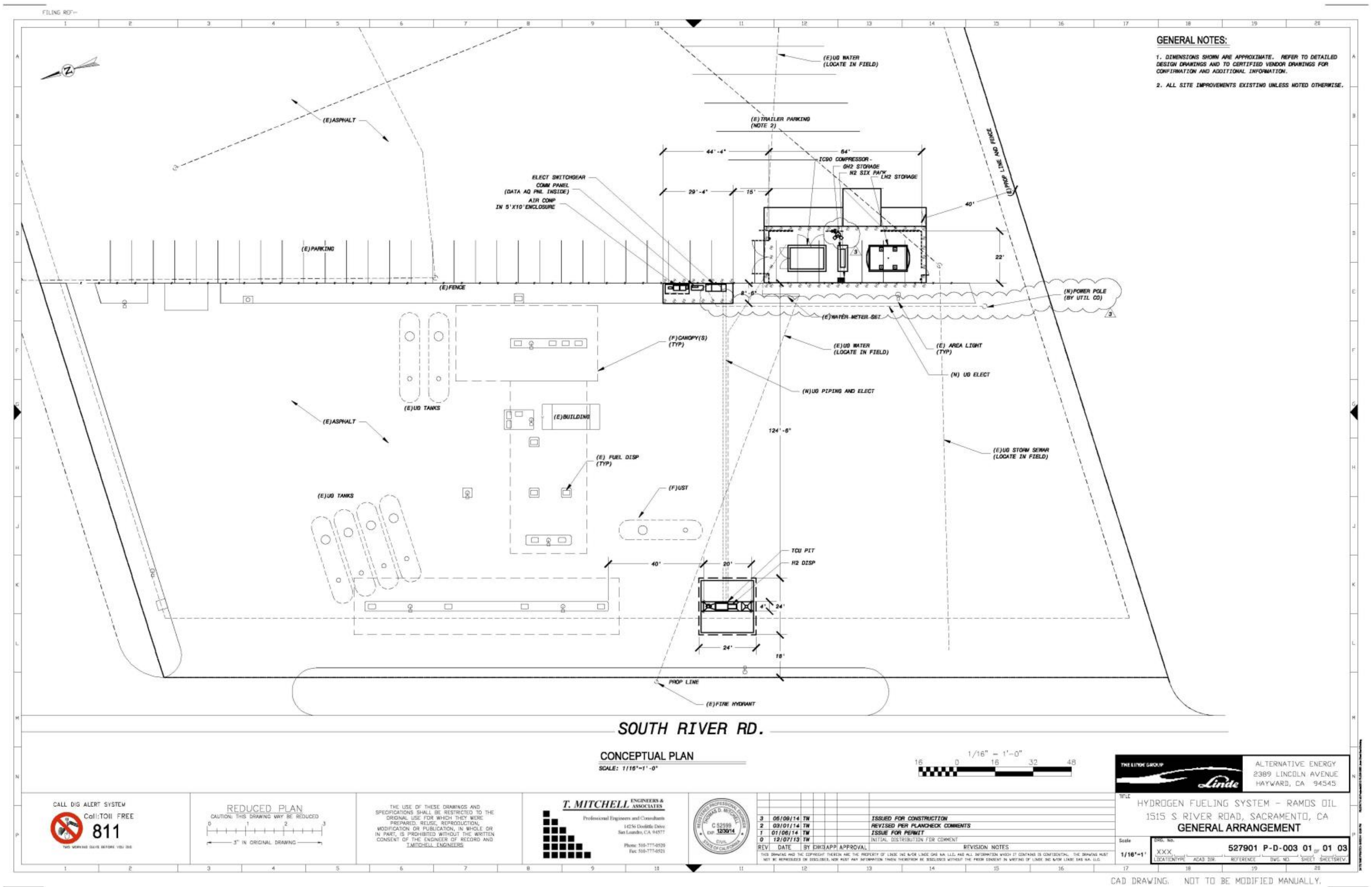
Source: Linde LLC.

The Ramos Oil site provided sufficient space to meet the setback requirements for liquid hydrogen and high pressure gas storage.

Figure 2 shows the layout plan for the West Sacramento Station.

The basic equipment layout at the West Sacramento hydrogen station is now a standard design for future Linde sites with along with a few improvements discovered during the course of the project.

Figure 2: West Sacramento Hydrogen Refueling Station Layout Plan



Source: Linde LLC. Original figure is higher resolution.

Finished Hydrogen Refueling Station

Figure 3 shows the completed refueling station. The liquid hydrogen tank and IC90 compressor are behind the bollards and fencing inside the Ramos Oil parking lot while the public use dispenser is under the canopy in front of the station and easily viewed from the street.

Figure 3: The West Sacramento Hydrogen Refueling Station

Source: Linde LLC.

There were design improvements made during the commissioning of the West Sacramento Linde station including the installation of a second cold fill heat exchanger at the dispenser because the hydrogen dispensed during station commissioning was not cold enough.

The most significant change is that the high pressure storage between the IC90 and liquid tank are planned to be integrated into the IC90 container, which will reduce the overall footprint. Also, the IC90 control system will be installed in a remotely located panel to reduce the air purge requirements. In addition, changes in air purge equipment selection and software set points were needed to optimize performance and reliability.

During the final inspection, the Fire Marshal for the City of West Sacramento requested flame detectors. This requirement was not noted during the permitting process. Linde installed flame detectors at the dispenser and the hydrogen equipment pad after construction was complete.

Project Costs and Funding Received from the ARFVTP

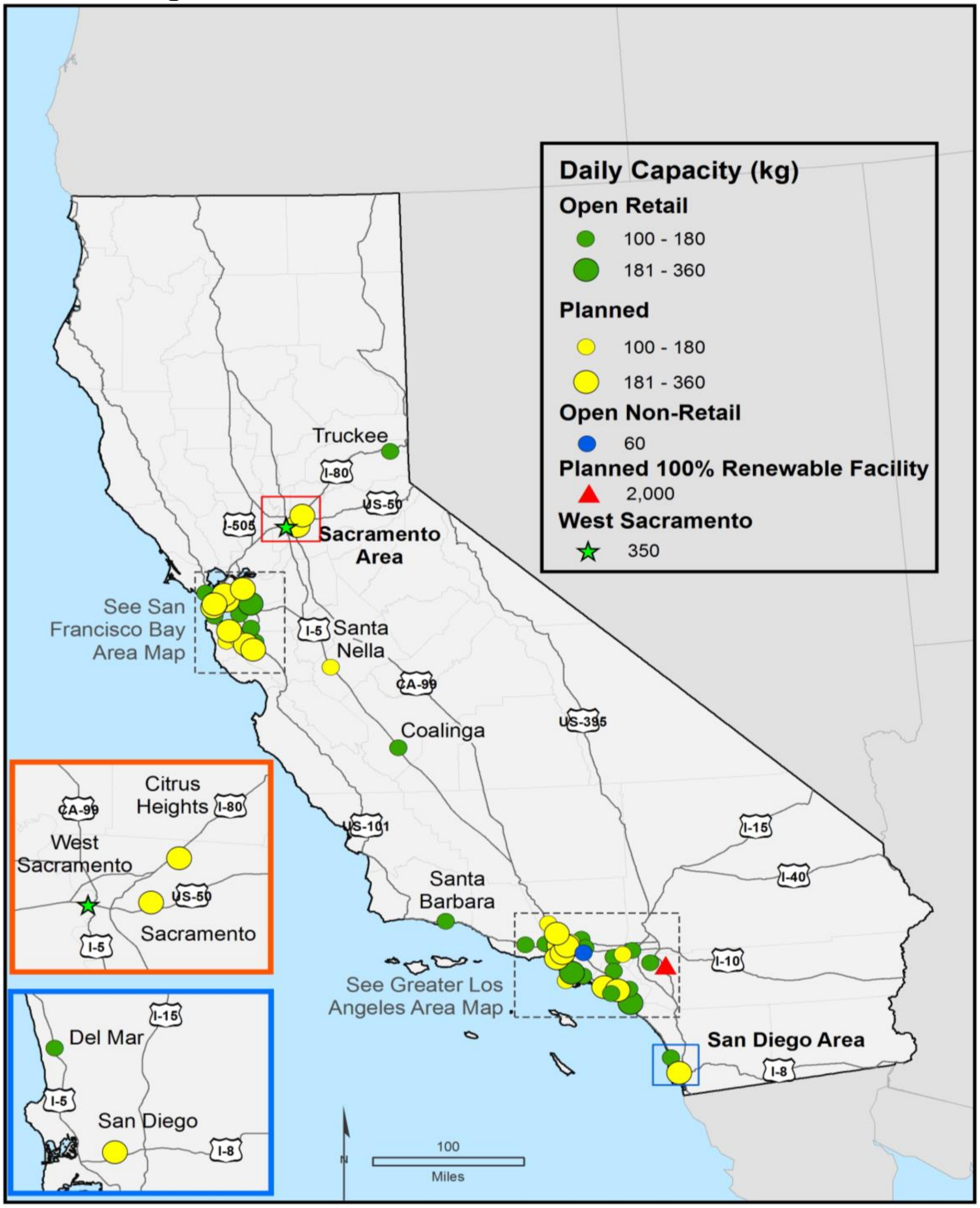
The project was executed within the budget allocated. The total cost of the project was $2,494,751. The Linde match share was $623,688 (25 percent) and Energy Commission share was $1,871,063 (75 percent).

The total budget remained unchanged throughout the project. However, several budget reallocations were made between budget categories. These changes were necessary due to the site change, varying costs due to the long duration of the project, and the change in compressor technology.

West Sacramento Station in the Network

The Sacramento area is anticipated to evolve with numerous hydrogen refueling stations along the I-5, I-50, I-80, and I-99 corridors. Figure 4 shows the location of the West Sacramento hydrogen refueling station in relation to other stations in California

Figure 4: West Sacramento Station in the Network

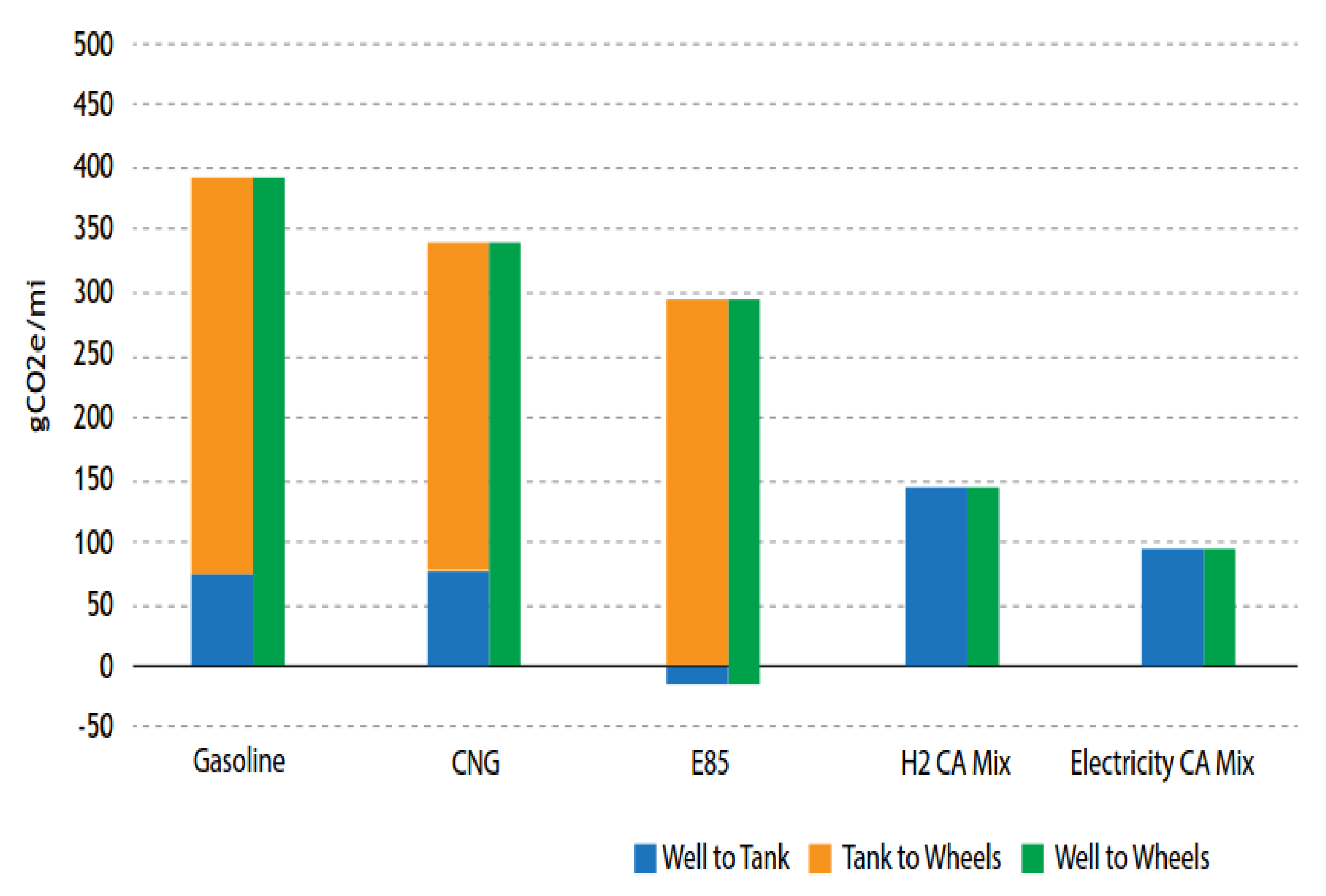


Source: Energy Commission Staff.

Environmental Impacts

From October 1, 2014, to April 28, 2015, the station has dispensed 584.5 kilograms (kg) of hydrogen and reduced greenhouse gas (GHG) emissions by 8.4 metric tons, assuming that an FCEV delivers 60 miles per kilogram of hydrogen. The California Fuel Cell Partnership report, *Air Climate Energy Water Security*[1], states that the difference in GHG emissions between gasoline and hydrogen is about 240 grams of carbon dioxide equivalent per mile on a well-to-wheels basis. The emission reduction is shown in Figure 5 indicates the GHG emissions based on the Argonne National Lab *Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model*[2] V1_2013 (GREET). Due to the slower rollout of FCEVs in Sacramento, the amount of hydrogen dispensed was originally lower than anticipated. Nevertheless, there is still a positive impact to the environment.

Figure 5: GHG Emissions based on the Argonne National Lab GREET V1_2013 Model



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 usage. Using the GREET results shown in Figure 6, the highest reduction is the emission of carbon monoxide which is approximately three grams per mile.

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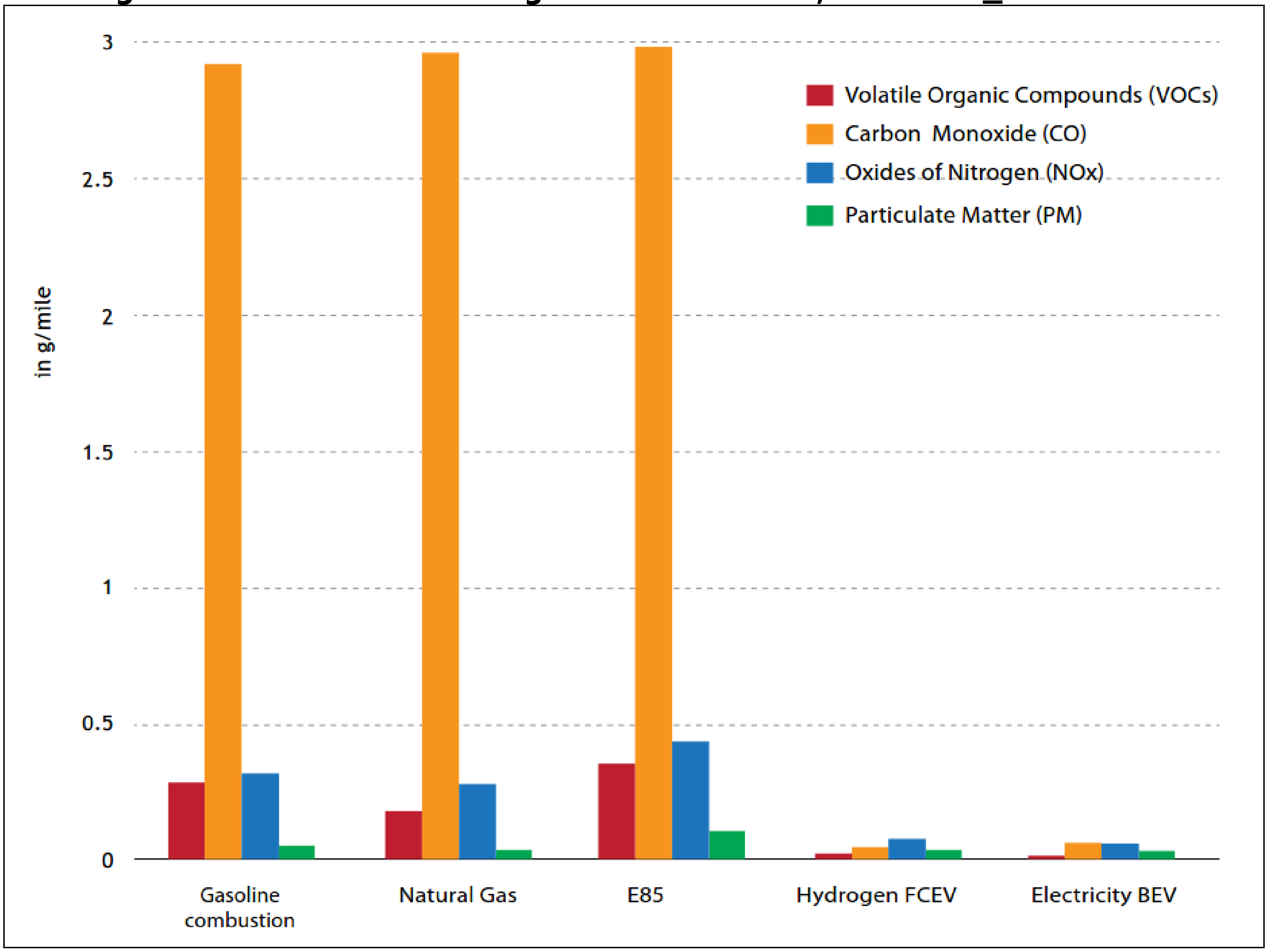
[1] https://cafcp.org/sites/default/files/W2W-2016.pdf

[2] GREET® Model https://greet.es.anl.gov/

Figure 6: Results from the Argonne National Lab, GREET V1_2013 Model



Source: California Fuel Cell Partnership.

CHAPTER 2: Data Collection and Analysis

The goal of this task was to collect data on the economic benefits and local impacts of the project throughout the term of the project. In addition, analyze that data for project sustainability and collect six-months of throughput, usage, and operational data.

Job Growth and Economic Development

This type of project stimulates the development of high tech, California-based construction jobs and technology firms to build and support these new stations. These new jobs and firms must become well versed in working with high pressure hydrogen, hydrogen compression equipment, cryogenic hydrogen, and hydrogen dispensing technology. The expertise these workers and firms develop during the construction and support of these new stations will be directly transferable (and quite valuable) to other hydrogen refueling station developers in California. The Linde West Sacramento station sells hydrogen by the kilogram since July 7, 2015.

During construction, hours worked by contractors were approximately 820 hours per month for three months. This translates to 4.9 full time jobs during the three months of construction. For operation and maintenance, Linde anticipates 10 - 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 West Sacramento vendors, labor, hotels, and restaurants.

Use of Renewable Energy

The hydrogen dispensed at the West Sacramento station is 33 percent renewable. Linde will meet the 33 percent renewable requirement in one of two ways, either by purchasing credits or by using a certified pathway of delivering renewable hydrogen from a Linde facility from outside the state.

Energy Efficiency

Electrical current transducers installed at the West Sacramento hydrogen refueling station measure the power usage of the IC-90 compressor, the refrigeration system, and the dispenser. The average energy consumed in compression is 5.4 kilowatt hour (kWh) per kilogram of hydrogen compressed. The range is 4.5 kWh/kg to 7.1 kWh/kg. The consumption of electrical energy can vary for a variety of reasons. For example, when ambient temperatures are higher, the refrigeration unit needs more electrical power to keep the filling components within standard operating temperatures. Also, the suction and discharge pressures affect the amount of energy required to compress the gas. Lastly, the refrigeration unit’s compressors run regularly, even when the station is unused, to ensure that any hydrogen dispensed is chilled.

The refrigeration system consumes about 30 to 50 kWh/day in current operations; however, this electrical consumption will not increase dramatically as the station utilization increases. On a per kilogram basis the need for refrigeration is expected to diminish due to the liquid hydrogen cooling off the heat exchangers as it vaporizes and reducing the refrigeration system load.

The station utilizes approximately 100 to 150 kWh/day. This includes the compressor, refrigeration, and balance of plant equipment including lights and instrument air which is used to purge the air from the electrical cabinets due to the close proximity to hydrogen. Linde has identified a potential improvement to energy savings by the reduction of instrument air needs by eliminating the need for the purged cabinets on the instrument air circuit. This upgrade would require major rework for the West Sacramento station and is not practical.

The IC-90 cabinet instrument air blower was originally selected with a larger motor to ensure proper ventilation. The electrical consumption was approximately 2000 watts continuously, which produced warm air when purging the cabinet at higher than necessary pressure. A smaller blower was tested to meet the purge requirements which uses only 200 watts and the original blower was replaced resulting in a small improvement in energy efficiency. This change will also reduce the temperature in the electrical cabinet, which will provide better reliability in the hot summer months.

Boil off, which is the amount of hydrogen that converts to a gas inside of the storage tanks, is a factor in liquid hydrogen systems. The cascade fill tank array has been optimized to control boil off. This improvement was implemented in April of 2015 and future analysis will measure the percent improvement in reduction of boil off losses. This system allows the station to automatically optimize boil off and storage capacity based on station demand. Linde liquid hydrogen tanks are rated for 0.5 percent to 1.0 percent boil off loss per day with zero utilization. The boil off can be eliminated with two cars utilizing the station per day, one in the morning and one in the afternoon.

Life Cycle Greenhouse Gas Emissions

This station 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 California Air Resources Board’s (CARB) modeling.

Hydrogen supplied to FCEVs is among the lowest carbon fuels available for use as transportation fuel. The total carbon reduction potential from the West Sacramento station is significant due to its 350 kg per day capacity. Based on the projected demand by the Original Equipment Manufacturers and using the California Air Resources Board Low Carbon Fuel Standard carbon emission values, the Linde West Sacramento station was projected to reduce GHG emissions by 1,173 metric tons in the first three years and 5,895 metric tons over the equipment’s likely minimum service life of six years. These assumptions are based on projected vehicle demand estimates, not including the additional benefit of 33 percent renewable hydrogen which will reduce the GHG emissions at the point of production.

The West Sacramento station did not benefit in the early days from this demand curve. Efforts to kick start the Los Angeles and San Francisco area hydrogen station clusters, limited the overall fueling options for potential FCEV buyers in the West Sacramento area and may have slowed local FCEV sales.

Table 2 shows the predicted GHG reduction for the West Sacramento station based on information available in 2010. The station was projected to displace between 188,000 and

961,000 gallons of gasoline once a sufficient number of FCEVs begin using the station near its design capacity of 350 kg/day.

Table 2: Predicted GHG Reduction

GHG Reductions for the West Sacramento Station	Years 1-3	Years 1-6
2012 projected kg dispensed	8,760	8,760
2013 projected kg dispensed	23,725	23,725
2014 projected kg dispensed	42,705	42,705
2015 - 2017 projected kg dispensed based on capacity*	n/a	341,640
Total kg of hydrogen dispensed	75,190	384,345
Total gallons gasoline displaced	187,975	960,862
Avoided carbon dioxide equivalent emission from the displaced gasoline usage (tonnes)	2,126	10,768
Total carbon dioxide emission associated with the hydrogen displaced at the station (tonnes)	953	4,873
Total project life GHG reduction (tonnes)	1,173	5,895
* Based on station capacity of 26 kg/hour for 12 hours, 312 kg/day		

Source: Linde LLC

The reduction in nitrous oxides (NOx) and reactive organic gas are significant as well and come in two forms. First, the well-to-tank emissions reduction by using hydrogen versus gasoline is 50 percent for the West Sacramento station based on California Air Resources Board modeling. Second, the tank-to-wheels emissions reduction by using hydrogen in a FCEV is 100 percent compared to gasoline because water vapor is the only emission from the operation of a FCEV.

On July 7, 2015, the West Sacramento station passed Division of Measurement Standards certification testing and received several Original Equipment Manufacturer letters of support, completing the construction agreement requirements and allowing the hydrogen refueling station to be declared officially open.

The Linde West Sacramento station displaced 595 gallons of gasoline equivalent and filled 603 FCEVs during its first six months of operation (between September 2014 and March 2015).

This station's design and operation comply with the Energy Commission's Program Opportunity Notice requirements and support California Code of Regulations Title 20, Section 3101.5.[3] The goal of California Code of Regulations Title 20 Section 3101.5 is to ensure that funded projects promote sustainable alternative fuels and vehicles by reducing GHG emissions associated with

[3] http://www.energy.ca.gov/2014publications/CEC-140-2014-002/CEC-140-2014-002.pdf

California's transportation system, protecting the environment, and enhancing market and public acceptance of sustainably produced alternative and renewable fuels.

The use of the Linde Ionic Compressor and associated innovative technologies helped achieved the status of the first open hydrogen refueling station in California as defined by the California Fuel Cell Partnership.

Table 3 shows the actual performance statistics of the West Sacramento project from October 1, 2014, to April 28, 2015.

Table 3: Station Statistics From October 1, 2014 to April 28, 2015

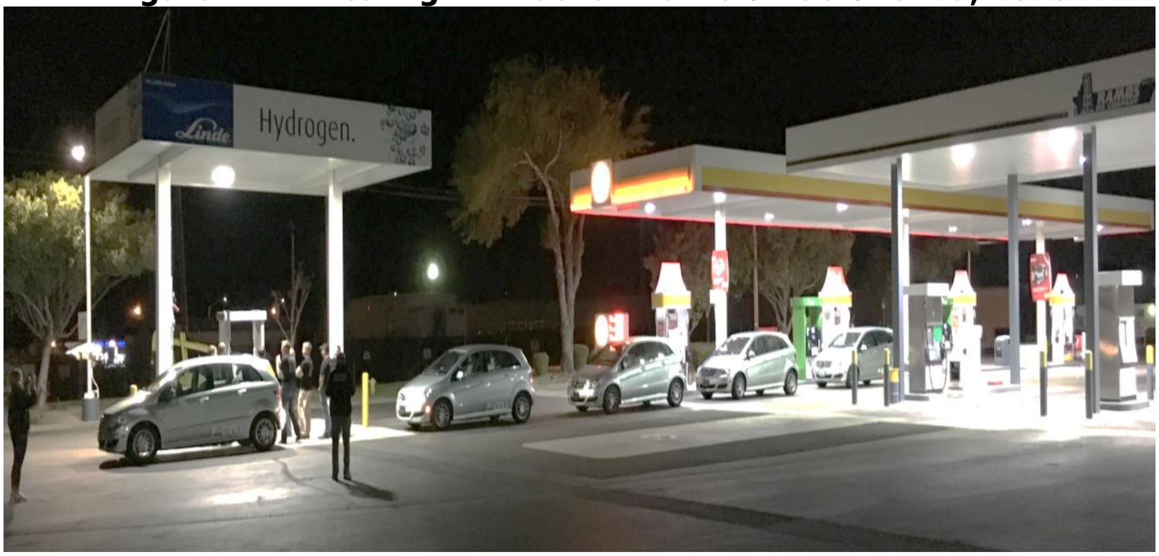
Total hydrogen dispensed	584.5 kg
Average hydrogen dispensed	2.75 kg per day
Proportion of 700 bar fills	63%
Proportion of 350 bar fills	37%
Total sales	$7,792.50
Number of days vehicles filled	87 days
Number of transactions (≈vehicles filled)	603 transactions
Average fill	2.4 kg
Average transactions per day	3 transactions per day
Gasoline equivalent displaced	595.6 gallons

Source: Linde LLC.

The only instance during the six-month review period that the system was close to reaching the maximum designed throughput of 26 kg/hour was during a planned back-to-back fill testing of seven FCEVs, which dispensed 20 kg of hydrogen in one hour. This test showed that the IC90 is capable of providing enough flow rate for repeated refueling.

It is noteworthy that in West Sacramento there are several 350 bar cars which use the station regularly. This may not be representative of the entire market as we see 700 bar FCEVs becoming the standard offering. Figure 7 shows the back-to-back refueling test in progress.

Figure 7: Fill Testing with Seven FCEVs on October 19, 2015



Source: Linde LLC.

Actual Vs. Proposed Performance

The station was designed to supply up to 350 kg/day of dispensed hydrogen.

Up to the end of the data collection period there was Original Equipment Manufacturer verification testing and a few local vehicles using the station, but not enough utilization to verify the real world performance in sustained operation.

A key aspect of the Linde design uses low temperature hydrogen from the liquid storage tank to provide part of the cooling required for compression. When the number of FCEVs refueled each day at this station increases, this system will dispense hydrogen at a higher kilogram per day capacity, and a more accurate average kWh/kg dispensed can be verified.

The proposed and actual performance of the West Sacramento hydrogen station is shown in Table 4 and Table 5.

Table 4: Station Performance Minimum Requirements

PON-09-608 Minimum Technical Requirements	Actual
100 kg/day nominal capacity with 20 kg/hour peak refueling capacity	350 kg/day 26 kg/hour peak
350 bar (35 MPa) and 700 bar (70 MPa) dispensing pressures	350 and 700 bar
Compliance with SAE-2799/J-2601/J-2719/2600	compliant
Meet or exceed 33 percent renewable hydrogen content	33%

Source: Linde LLC

Table 5: Station Performance Additional Station Attributes

Additional Station Attributes	
3 back-to-back 700 bar refueling of 7 kg within 45 minutes	Yes
Refueling a 7 kg, 700 bar FCEV in 3 minutes	Yes
Dispense 34 kg hydrogen in one hour	34.67
Dispense 20 kg per hour for a sustained period of time	26 kg/hour
Demonstrate the industry's only 700 bar dry running hydrogen compressor	900 bar
Demonstrate novel hardware in a 20 foot container for 20 kg per hour	14 foot Container, 26 kg/hour
Define the O&M to keep the refueling station operating reliably performance	Yes – in process
Estimated 2.6 kWh/kg electric consumption	4.65 kWh/kg
* 33% renewable plans being researched due to low demand	

Source: Linde LLC

Demand at the Linde West Sacramento station was anticipated to be 20 kg/day in first year, ramping up to 99 kg/day in the sixth year. Additional stations will help increase demand for the Linde station in West Sacramento as station installations are expected to grow along with an increase in the total number of FCEV sales.

CHAPTER 3: Conclusion

The technical aspects (construction and commissioning) of the project proceeded on schedule, although the project development, site selection, and approval by the original equipment manufacturer took longer than anticipated. Nevertheless, the Linde West Sacramento station achieved the first "Open" status as defined by the new standards set by the California Fuel Cell Partnership and was the first liquid hydrogen station to become operational in California. This station stores liquid hydrogen on site and utilizes the Linde IC90 high throughput hydrogen compressor, features which may facilitate increasing the scale of the station to meet increased hydrogen demand from the growing light duty FCEV market.

GLOSSARY

ATZ 1C90 IONIC COMPRESSOR (IC90)— The IC 90 is a highly efficient and powerful compressor with a flexible design. It can handle changing inlet and outlet pressures while keeping energy consumption at a minimum.[4]

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 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.

FUEL CELL ELECTRIC VEHICLE (FCEV)—A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.

GREENHOUSE GAS (GHG)—Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (NOx), halogenated fluorocarbons (HCFCs), ozone (O3), per fluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

GREENHOUSE GASES, REGULATED EMISSIONS, AND ENERGY USE IN TRANSPORTATION (GREET®)—A full lifecycle model sponsored by the Argonne National Laboratory (U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy). GREET® fully evaluates energy and emission impacts of advanced and new transportation fuels, the fuel cycle from well to wheel, and the vehicle cycle through material recovery and vehicle disposal. It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis.

KILOGRAM (kg)—The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1,000 cubic centimeters of water at the temperature of its maximum density.

NITROGEN OXIDES (OXIDES OF NITROGEN, NOx)—A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO2 is a criteria air pollutant and may result in numerous adverse health effects.

[4] PowerPoint-Präsentation (gsv.co.at) https://gsv.co.at/wp-content/uploads/2017%2001%2019%20Adler.pdf