CALIFORNIA
ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

University of California, Irvine SmartFuel® Hydrogen Station

Prepared for: California Energy Commission

Prepared by: Air Products and Chemicals, Inc.

Gavin Newsom, Governor

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California Energy Commission

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- The California Energy Commission
- The Governor's Office of Business and Economic Development (thanks to Tyson Eckerle for his efforts)
- South Coast Air Quality Management District

Air Products also acknowledges the efforts of its engineering and operations teams for their ongoing commitment to safety in the deployment of this hydrogen fueling station.

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 PON-09-608 to provide funding opportunities under the ARFVTP for projects which expand the network of publicly accessible hydrogen fueling stations to serve the current population of fuel cell electric vehicles and to accommodate the planned large-scale roll-out of fuel cell vehicle commencing in 2015. 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-10-048 on December 21, 2011.

ABSTRACT

Air Products and Chemicals, Inc. designed, engineered, permitted, constructed and made operational a hydrogen refueling station at 19172 Jamboree Road Irvine, California. The UC Irvine SmartFuel® hydrogen station was approved for construction on February 12, 2015, and began public fueling in November 2015. The station receives gaseous hydrogen delivered at elevated pressure from an Air Products production facility in southern California. The station is comprised of compression, cooling, and a two-hose dispenser with a customer payment interface are used to refill fuel cell electric vehicles.

Keywords: Air Products and Chemicals, Inc., fuel cell electric vehicles, hydrogen infrastructure, hydrogen refueling station, UC Irvine.

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EXECUTIVE SUMMARY

Hydrogen fuel cell electric vehicles, hydrogen refueling stations, and the production and distribution of hydrogen to the 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. An equally important role is that of the central fill system for hydrogen production and distribution as covered in this report.

The site selected for this project is 19172 Jamboree Road, Irvine, California (Orange County). A hydrogen refueling station at this location will serve fuel cell electric vehicles in the area. The project consisted of the upgrade of an existing hydrogen fueling station located on the campus of the University of California, Irvine.

Air Products developed the site configuration and design, and S. Gordin Structural Design and Engineering Services, Inc. performed the detailed engineering design. Given the site improvements from the existing hydrogen station, a site layout was developed to take advantage of the existing foundations. Structural and electrical designs were also initiated. The initial submittal to University of California, Irvine (who serves as their authority having jurisdiction for campus activities) was made on May 16, 2014. The final approval for the station design was received from the campus Fire Marshal on February 12, 2015.

Construction of the station upgrade started on July 9, 2015, with compression, cooling, and dispensing equipment delivered to the site on July 15, 2015. Completion of construction took place on August 31, 2015.

The process of making the University of California, Irvine SmartFuel® hydrogen station operational began on September 1, 2015 and was completed on October 14, 2015. Approval of the hydrogen dispenser for retail operations by the California Department of Measurements and Standards was received on October 9, 2015. Initial use of the University of California, Irvine SmartFuel® hydrogen station by retail customers occurred on November 13, 2015.

The environmental benefits of operating fuel cell electric vehicles are that they offer long term greenhouse gas and petroleum reduction, unlike gasoline vehicles. The University of California, Irvine SmartFuel® hydrogen station can dispense 180 kilograms per day with daily deliveries. The station has the potential to reduce over 1,100 metric tons of greenhouse gas emissions and 66,000 gallons of gasoline consumption annually.

CHAPTER 1:
Station Design, Permitting, Construction, and Commissioning

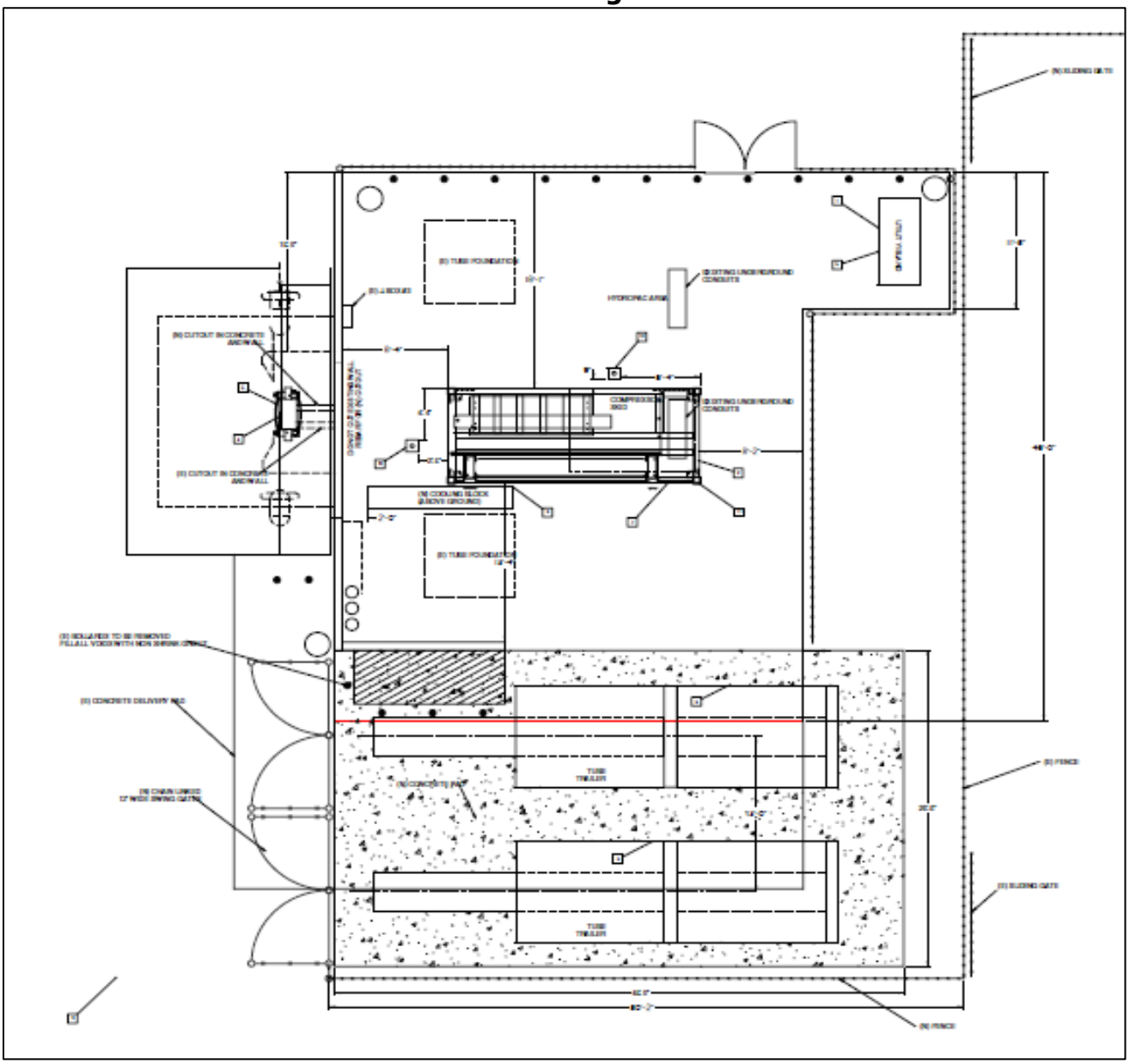
The project consisted of the upgrade of an existing hydrogen fueling station located on the campus of the University of California, Irvine (UC Irvine). UC Irvine would also serve as the operator of the stations. Following the kick-off of Grant Agreement ARV-10-048, Air Products and Chemicals, Inc. (Air Products) began discussions with UC Irvine regarding the lease of station equipment and site access for the hydrogen station project. Negotiations were completed on January 27, 2014 and the agreement was executed on February 17, 2014.

1.1 Site Design and Engineering

Air Products selected S. Gordin Structural Design and Engineering Services, Inc. to provide design engineering services for the UC Irvine station. The companies executed a subcontract for design engineering services on February 3, 2014.

Given the site improvements from the existing hydrogen station, a site layout was developed to take advantage of the existing foundations. Figure 1 provides an initial equipment arrangement drawing. Structural and electrical designs were also initiated. The initial submittal to UC Irvine (who serves as their authority having jurisdiction for campus activities) was made on May 16, 2014.

Figure 1: UC Irvine SmartFuel® Hydrogen Station Initial Equipment Arrangement Drawing



Source: Air Products and Chemicals, Inc.

1.2 Equipment Procurement

Immediately after execution of the Grant Agreement, Air Products began the equipment design and procurement activities for the eight sets of SmartFuel® hydrogen station equipment that would be deployed as part of the overall project. A draft scope of work for the equipment design efforts was prepared in April of 2012. Purchase orders for long-lead items began to be issued in the summer of 2012, and the design team to fabricate a prototype of several of the key containerized components; any lessons learned from this effort could then be used in the design and fabrication of the remaining units.

The component with the longest lead time was the high-pressure storage vessels which are critical components to the hydrogen fueling process. At the time of project execution, only one

vendor could provide these tubes. The first set of vessels was delivered to Air Products in June of 2013, and the remaining tubes were shipped beginning in April of 2014.

UC Irvine requested that the SmartFuel® hydrogen station have the capability to fill fuel cell buses in addition to fuel cell electric vehicles (FCEVs). Changes were made to the dispenser to accommodate this request.

1.3 Permit Process

The permitting process for the UC Irvine SmartFuel® hydrogen station was an iterative review which coincided with continued development of the detailed design for the station. An updated design package which corresponded to a 70 percent design completion status was submitted on June 27, 2014. Work was suspended during August of 2014 to resolve questions on the design basis for the station.

The plan check for structural and architectural designs were completed in October of 2014. The electrical design was changed by UC Irvine which allowed for the existing switchgear to be utilized. Updated plans were prepared and submitted in December of 2014.

The final approval for the station design was received from the campus Fire Marshal on February 12, 2015.

UC Irvine did not require a zoning review of the upgrade of the hydrogen fueling station.

1.4 Construction Process

Following a bid process, Air Products selected Fueling and Service Technology, Inc. (FASTECH) to provide construction services for the UC Irvine SmartFuel® hydrogen station. FASTECH has an excellent safety record and had prior experience in hydrogen station construction, including work performed for Air Products under Grant Agreement ARV-10-048. Following execution of the hydrogen supply agreement with UC Irvine, Air Products and FASTECH executed the construction subcontract on April 23, 2015. In order to better coordinate with the shutdown and decommissioning of the existing hydrogen station, construction of the station upgrade started on July 9, 2015, with compression, cooling, and dispensing equipment delivered to the site on July 15, 2015. Completion of construction took place on August 31, 2015.

1.4.1 Commissioning of the Station

Following the completion of construction, commissioning activities were undertaken by Air Products' engineering and operations staff. Initial equipment operation, hydrogen sampling, and test fills into both an Air Products test tank and automaker test vehicles were performed during this time.

Notification that the UC Irvine SmartFuel® station was ready for retail operation was provided by Air Products to the Governor's Office of Business and Economic Development on November 12, 2015.

1.4.2 Division of Measurement Standards Certification

The California Department of Food and Agriculture's Division of Measurement Standards (DMS) is responsible for enforcing California weights and measures laws and regulations and must certify any device used for metering the sale of commercial items within California. The permanent DMS approval was received for the UC Irvine SmartFuel® hydrogen station on

October 9, 2015. Figure 2 provides a photograph of the dispenser with the DMS stickers in place.

Figure 2: UC Irvine SmartFuel® Dispenser with DMS Certification

Source: Air Products and Chemicals, Inc.

1.4.3 Customer Usage

The first public customer fueled at the UC Irvine SmartFuel® station in mid-November of 2015, and the station has been used regularly since then. Dispensed volumes totaled 1,072 kilograms in February of 2016, 1,160 kilograms in March of 2016, and 1,259 kilograms in April of 2016. A photograph of a Toyota FCEV fueling at the UC Irvine SmartFuel® hydrogen station is provided in Figure 3.

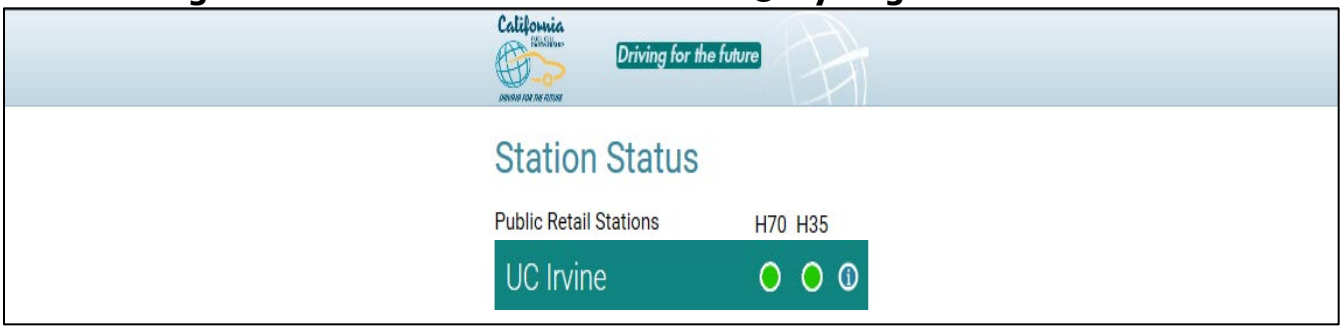
Figure 3: UC Irvine SmartFuel® Hydrogen Station

Source: Air Products and Chemicals, Inc.

1.4.4 Station Online Status System Activated

The California Fuel Cell Partnership (CaFCP) station online status system provides regularly updated station status information to fuel cell vehicle drivers. Air Products has provided CaFCP station status information regarding its stations since the inception of station online status system. The UC Irvine station was added to station online status system on November 13, 2015. A screenshot of the station online status system network that includes the UC Irvine SmartFuel® hydrogen station is shown in Figure 4.

Figure 4: CaFCP UC Irvine SmartFuel® Hydrogen Station Status



Source: Air Products and Chemicals, Inc.

The station is open and active.

1.5 Environmental Impacts

Hydrogen is stored as a compressed gas in an above-ground tank concealed behind a wall at this station. Hydrogen is nontoxic, colorless, and odorless, so hydrogen station equipment is outfitted with appropriate sensors to provide immediate notification in case a leak occurs. No solid or liquid waste will be produced at this site.

There was no additional landscaping added for the construction of the hydrogen refueling station, and, therefore, no additional irrigation water will be consumed.

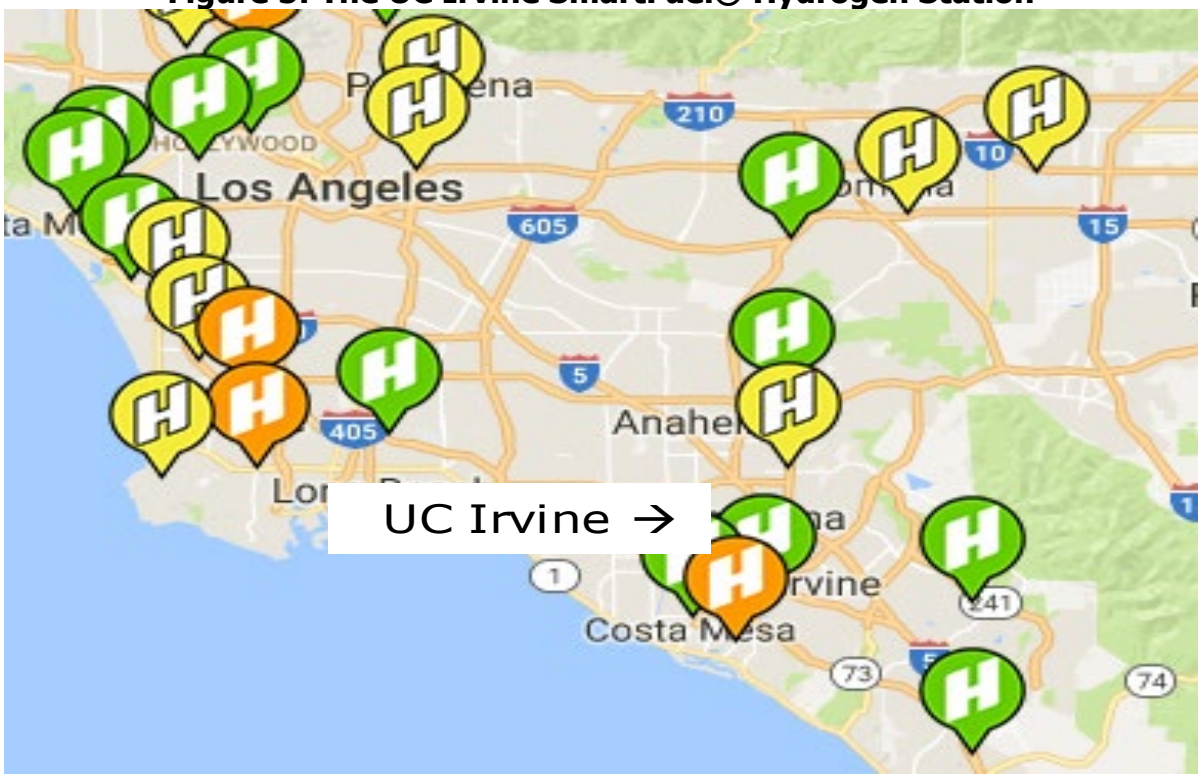
CHAPTER 2:
Location and Schematics of the Station

The hydrogen station at 19172 Jamboree Road, Irvine, California receives gaseous hydrogen delivered at elevated pressure from an Air Products production facility in southern California. The station is comprised of compression, cooling, and a two-hose dispenser with a customer payment interface are used to refill fuel cell electric vehicles.

2.1 UC Irvine SmartFuel® Hydrogen Station in the Network

Figure 5 shows the location of the UC Irvine SmartFuel® hydrogen station at 19172 Jamboree Road in relation to other stations in the Southern California network.

Figure 5: The UC Irvine SmartFuel® Hydrogen Station

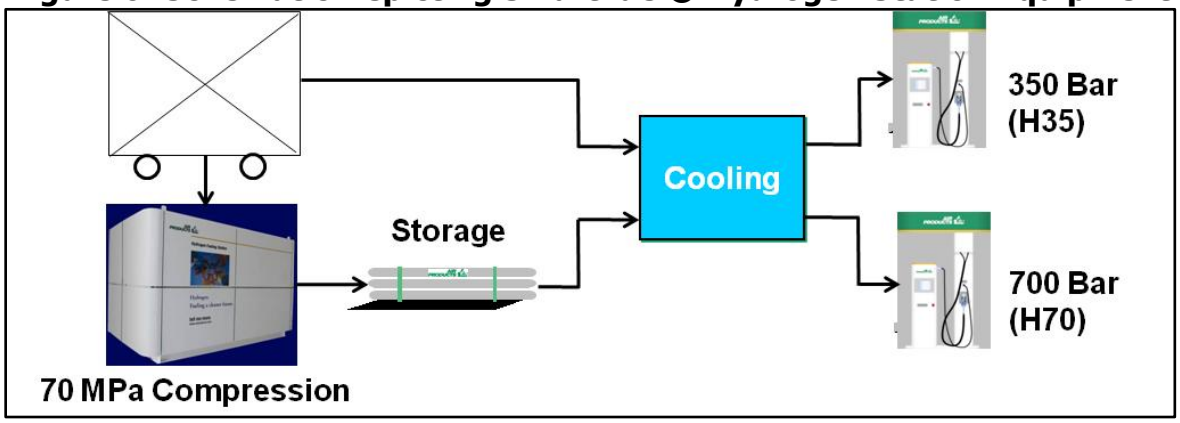


Source: Air Products and Chemicals, Inc.

2.2 Schematic Layout of the UC Irvine SmartFuel® Hydrogen Station

As shown below, Figure 6 depicts an overview of the UC Irvine SmartFuel® hydrogen station components. Hydrogen is produced by Air Products at a central fill system located in southern California, and the gas is delivered by a high-pressure tube trailer. Hydrogen is compressed as needed to fill the high-pressure storage tubes that are integral in providing a full fill to fuel cell vehicles that use the H70 nozzle. Gas is taken from storage and cooled based on the dispenser programming that meets the Society of Automotive Engineers J2601 fueling protocol; Air Products has patents which cover elements of the station operation and the dispensing process.

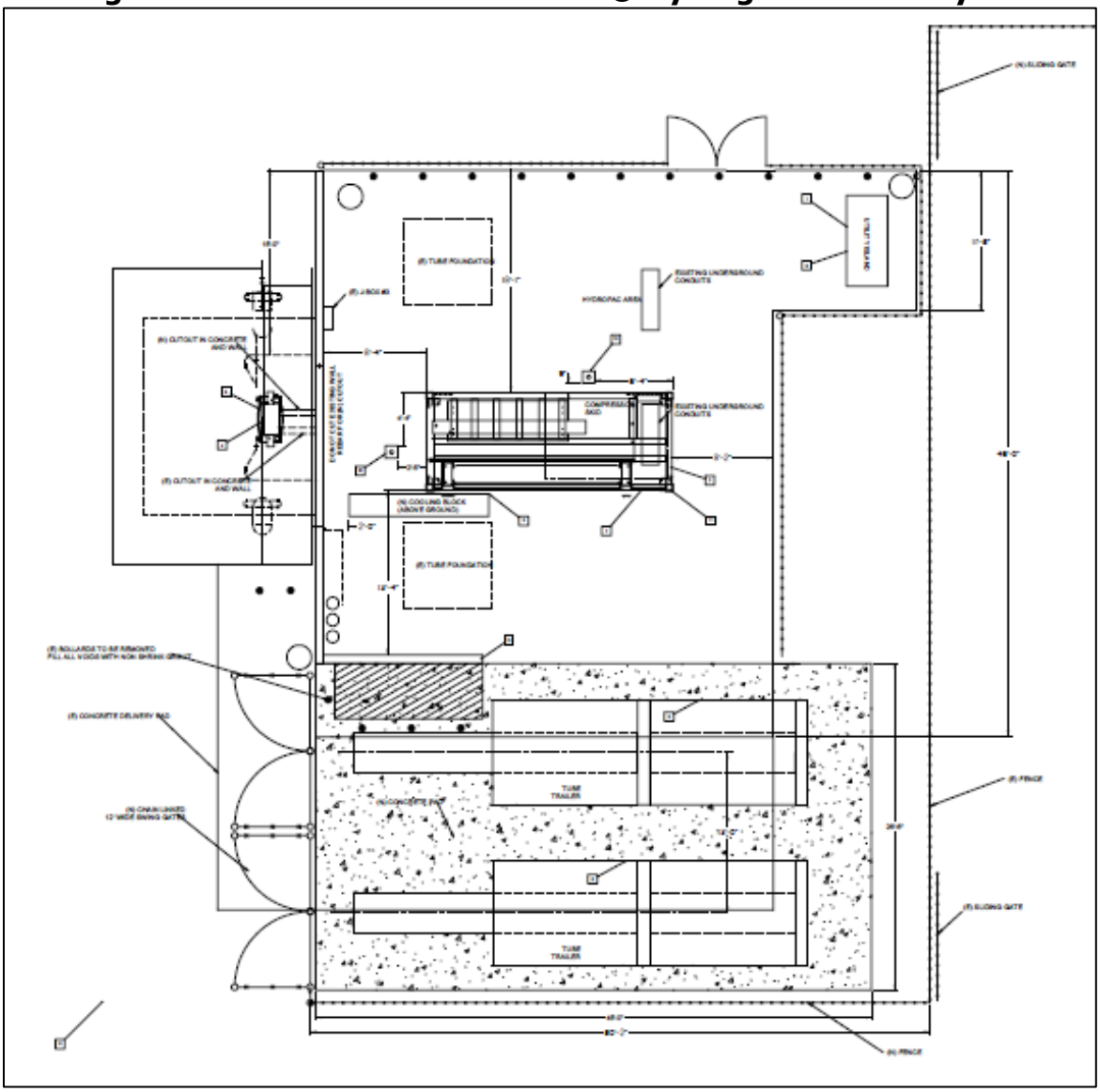
Figure 6: Schematic Depicting SmartFuel® Hydrogen Station Equipment



Source: Air Products and Chemicals, Inc.

Figure 7 shows a detailed view of the actual final, as-built configuration of the UC Irvine SmartFuel® hydrogen station.

Figure 7: Final UC Irvine SmartFuel® Hydrogen Station Layout



Source: Air Products and Chemicals, Inc.

Table 1 shows the list of subcontractors and the grant agreement budget under this project.

Table 1: List of Subcontractors and Grant Agreement Budget

Air Products and Chemicals, Inc., Allentown, PA	
H2 station equipment	$1,580,807
FASTECH, Buena Park, CA	
Construction	$315,395
S. Gordin Structural Design & Engineering Services, Inc., Carson City, NV	
Design and permitting services	$31,100
California Energy Commission Grant	$1,252,746
Air Products Cost Share	$674,556
Total Energy Commission cost share	65%
Total Budget	**$1,927,302**

Source: Air Products and Chemicals, Inc.

CHAPTER 3:
Data Collection and Energy Analysis

The UC Irvine SmartFuel® hydrogen refueling station is supplied by hydrogen generated via steam methane reformation that converts methane (CH4) and water (H2O) to hydrogen (H2) and carbon dioxide (CO2) and along with an equilibrium amount of carbon monoxide (CO):

Steam/Methane Reforming Reaction $CH_4 + H2O + Heat \Leftrightarrow CO + 3H2$

Water-Gas Shift Reaction $CO + H2O \Leftrightarrow CO2 + H2 + Heat$

Per California Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006) and PON-09-608, which funded this project, at least one-third of the hydrogen dispensed will be produced from renewable energy sources.

Hydrogen is supplied to the hydrogen fueling station from Air Products' hydrogen production facilities in Wilmington/Carson, California. Renewable biogas is being procured as feedstock for the facilities, resulting in delivered hydrogen product that meets the 33 percent renewable requirements.

Air Products has a contract for sourcing the renewable biogas that meets Public Resources Code Section 2574(b)(1); documentation is provided in Figure 8. Although California has a substantial amount of biogas, local supply cannot be injected into California pipelines under California Health and Safety Cost Section 25420. Air Products' biogas supply for this project is sourced outside California and transported to California with connection to a natural gas pipeline within the Western Electricity Coordinating Council region that delivers gas into California.

Figure 8: Documentation of Biogas Sources

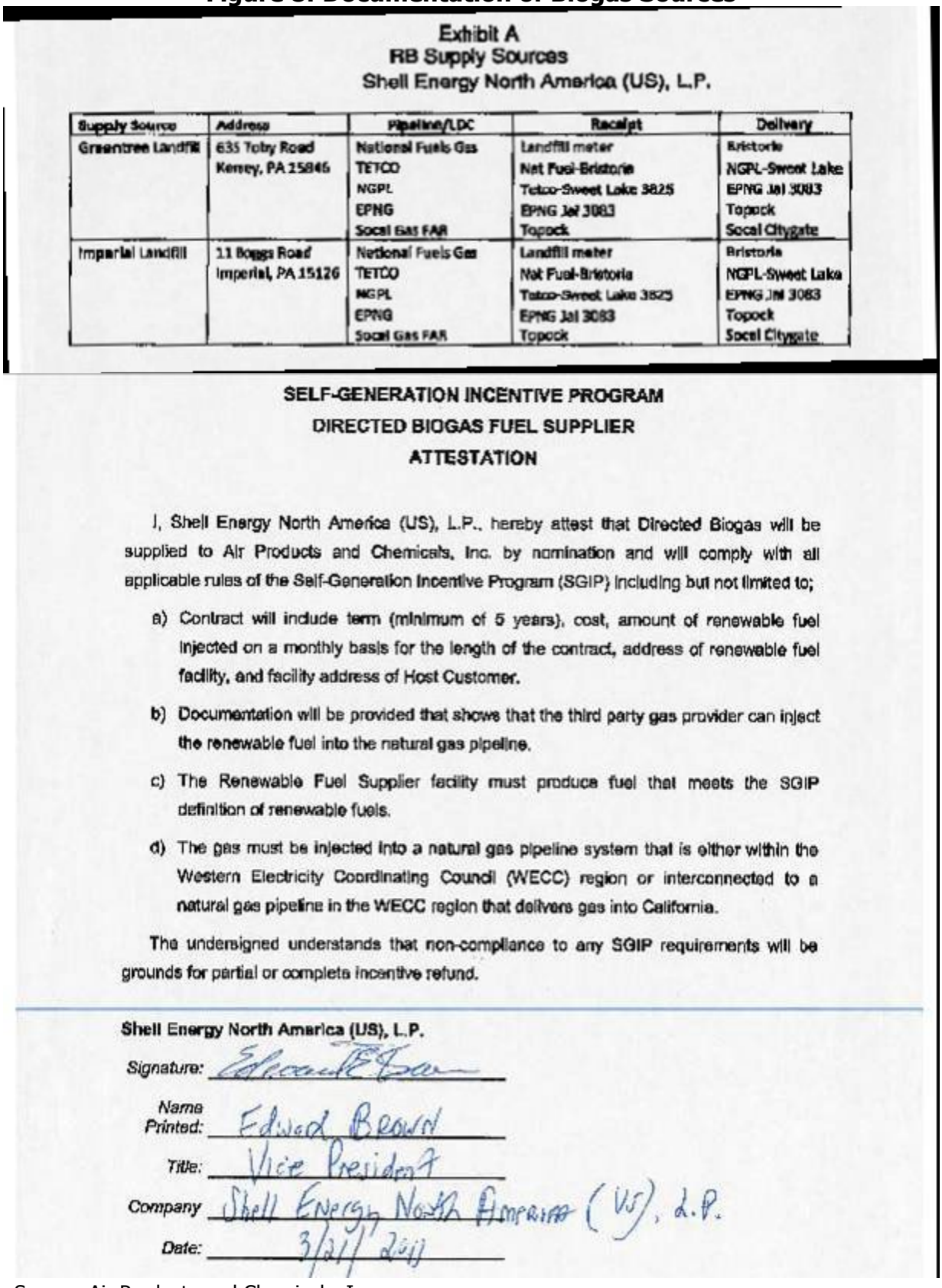


Exhibit A
RB Supply Sources
Shell Energy North America (US), L.P.

Supply Source	Address	Pipeline/LDC	Receipt	Delivery
Greentree Landfill	635 Toby Road Kersey, PA 15846	National Fuels Gas TETCO NGPL EPNG Socal Gas FAR	Landfill meter Nat Fuel-Bristoria Tetco-Sweet Lake 3825 EPNG Jal 3083 Topock	Bristoria NGPL-Sweet Lake EPNG Jal 3083 Topock Socal Citygate
Imperial Landfill	11 Boggs Road Imperial, PA 15126	National Fuels Gas TETCO NGPL EPNG Socal Gas FAR	Landfill meter Nat Fuel-Bristoria Tetco-Sweet Lake 3825 EPNG Jal 3083 Topock	Bristoria NGPL-Sweet Lake EPNG Jal 3083 Topock Socal Citygate

SELF-GENERATION INCENTIVE PROGRAM
DIRECTED BIOGAS FUEL SUPPLIER
ATTESTATION

I, Shell Energy North America (US), L.P., hereby attest that Directed Biogas will be supplied to Air Products and Chemicals, Inc. by nomination and will comply with all applicable rules of the Self-Generation Incentive Program (SGIP) including but not limited to;

a) Contract will include term (minimum of 5 years), cost, amount of renewable fuel injected on a monthly basis for the length of the contract, address of renewable fuel facility, and facility address of Host Customer.

b) Documentation will be provided that shows that the third party gas provider can inject the renewable fuel into the natural gas pipeline.

c) The Renewable Fuel Supplier facility must produce fuel that meets the SGIP definition of renewable fuels.

d) The gas must be injected into a natural gas pipeline system that is either within the Western Electricity Coordinating Council (WECC) region or interconnected to a natural gas pipeline in the WECC region that delivers gas into California.

The undersigned understands that non-compliance to any SGIP requirements will be grounds for partial or complete incentive refund.

Shell Energy North America (US), L.P.

Signature: Edward Beard

Name Printed: Edward Beard

Title: Vice President

Company Shell Energy North America (US), L.P.

Date: 3/21/2011

Source: Air Products and Chemicals, Inc.

Hydrogen is delivered to the UC Irvine SmartFuel® hydrogen refueling station by a Department of Transportation-certified high-pressure delivery trailer.

The environmental benefits of using FCEV were calculated based on the annual reduction in greenhouse gas (GHG) emissions and petroleum consumption. These calculations were compared to California Air Resource Board's (CARB) Low Carbon Fuel Standard (LCFS) lifecycle emissions of light-duty gasoline vehicles. For the analysis on GHG emissions and the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model model; gaseous hydrogen has been appended with calculations to deliver compressed hydrogen gas with 33.3percent renewable energy content from a large central hydrogen production facility to a cluster of fuel cell stations in Southern California. For the hydrogen supply pathway and hydrogen fueling station, the lifecycle emission of hydrogen energy supply is estimated at 75.2 grams of carbon dioxide equivalent (CO2e) per megajoule on a full well-to-wheels basis. CARB's LCFS lifecycle emissions estimate for a similar pathway for compressed hydrogen from central reforming of natural gas (LCFS Pathway HYGN005) is 88.3 grams CO2e/megajoule. In factoring in an Energy Efficiency Ratio of 2.5 for FCEV's established under CA LCFS the resulting emissions performance for FCEVs is 148 grams CO2e/mile. In comparison to a LCFS light-duty gasoline vehicle baseline, the hydrogen supply pathway results in a 62 percent reduction in well-to-wheel greenhouse emissions relative to California gasoline.

Relating to the Lawndale SmartFuel® hydrogen refueling station, this level of relative GHG reduction to the LCFS 2016 baseline for gasoline vehicles each FCEV deployed in the market will reduce GHG emissions by 4.3 metric tons per year. The station has the potential to contribute to the reduction of 620 metric tons of GHG emissions and greater than 36,500 gallons of gasoline consumption annually. The long-term greenhouse gas and petroleum reduction that could be realized by widespread adoption of FCEVs in the marketplace is enormous.

CHAPTER 4:
Statement of Future Intent

Air Products is working under an extension to December 31, 2017 of the equipment and access agreement with UC Irvine.

Data on the operation of the station will be collected and reported to the Energy Commission throughout the term of operations and maintenance under Grant Agreement ARV-15-027.

As part of its ongoing support to hydrogen fueling stations in California, Air Products has a fully staffed operations department which can address station maintenance and emergency situations. Air Products utilizes a 24-hour Equipment Support Team to monitor for alarms from the hydrogen station (in addition to any local alarms at the point of use). Air Products employs technicians in the Los Angeles Basin area that are trained in the specialized requirements for hydrogen fueling stations.

CHAPTER 5:
Conclusion

The following is a list of important findings from the UC Irvine SmartFuel® hydrogen station project:

- Station upgrades have the potential to require less time for design, permitting and construction when compared with new locations.
- The hydrogen station equipment at UC Irvine has common components to other stations supplied by Air Products. This helps to increase the efficiency of the project management process.

GLOSSARY

AIR PRODUCTS AND CHEMICALS INCORPORATED (APCI or Air Products)—The Company provides industrial gases and related equipment to dozens of industries, including refining, chemical, metals, electronics, manufacturing, and food and beverage. Air Products is also the world's leading supplier of liquefied natural gas process technology and equipment.[1]

CALIFORNIA AIR RESOURCES BOARD (CARB or ARB)—The "clean air agency" in the government of California, whose main goals include attaining and maintaining healthy air quality; protecting the public from exposure to toxic air contaminants; and providing innovative approaches for complying with air pollution rules and regulations.

CALIFORNIA FUEL CELL PARTNERSHIP (CaFCP)—The California Fuel Cell Partnership is an industry/government collaboration aimed at expanding the market for fuel cell electric vehicles powered by hydrogen to help create a cleaner, more energy-diverse future with no-compromises to zero emission vehicles.[2]

CARBON DIOXIDE EQUIVALENT (CO2e)—A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.

CARBON MONOXIDE (CO)—A colorless, odorless, highly poisonous gas made up of carbon and oxygen molecules formed by the incomplete combustion of carbon or carbonaceous material, including gasoline. It is a major air pollutant on the basis of weight.

DIVISION OF MEASUREMENT STANDARDS (DMS)—Enforcement of California weights and measures laws and regulations is the responsibility of the Division of Measurement Standards (DMS). The Division's activities are designed to:

- Ensure the accuracy of commercial weighing and measuring devices.
- Verify the quantity of both bulk and packaged commodities.
- Enforce the quality, advertising and labeling standards for most petroleum products.

The Division works closely with county sealers of weights and measures who, under the supervision and direction of the Secretary of Food and Agriculture, carry out the vast majority of weights and measures enforcement activities at the local level.[3]

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.

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[1] Air Products Company Overview (http://www.airproducts.com/Company/company-overview.aspx)

[2] Fuel Cell and Hydrogen Energy Association Website (http://www.fchea.org/)

[3] California Department of Food and Agriculture Division of Measurement Standards

(https://www.cdfa.ca.gov/dms/)

FUELING AND SERVICE TECHNOLOGY, INC. (FASTECH)—FASTECH is a construction company offering construction maintenance and repairing services.[4]

GREENHOUSE GASES (GHG)—Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

GREENHOUSE GASES, REGULATED EMISSIONS, AND ENERGY USE IN TRANSPORTATION (GREET®)—is a full life-cycle model sponsored by the Argonne National Laboratory (U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy). It 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 need to be considered. It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis.

HYDROGEN (H_2)—A colorless, odorless, highly flammable gas, the chemical element of atomic number 1.

LOW CARBON FUEL STANDARD (LCFS)—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 (GHG) emissions. The LCFS standards are expressed in terms of the "carbon intensity" (CI) 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 emission and other smog-forming and toxic air pollutants by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.

UNIVERSITY OF CALIFORNIA, IRVINE (UC Irvine/UCI)—A public research university located in Irvine, California. It is one of the 10 campuses in the University of California (UC) system.

[4] Fueling and Service Technology, Inc. Website (http://www.fastechus.com/)