CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

**FINAL PROJECT REPORT**

# Southern California Hydrogen Fill System, Delivery Trailers, and Fill System Automation

## ARV-10-048 and ARV-12-059

**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 and Chemicals, Inc. also acknowledges the efforts of its engineering and operations teams for their ongoing commitment to safety in the deployment of the system described herein.

# 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 and PON-12-606 to expand California's network of hydrogen refueling stations and to upgrade and automate a central fil system, which produces and distributes hydrogen for transportation applications. 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. 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-12-059 on July 12, 2013.

# ABSTRACT

Air Products and Chemicals, Inc. designed, engineered, constructed, and made operational the Southern California Hydrogen Fill System. The Southern California Hydrogen Fill System is located at an Air Products and Chemicals, Inc. hydrogen production facility in Wilmington/ Carson, California in Los Angeles County. The hydrogen produced at the Southern California Hydrogen Fill System is distributed to stations and the stations fill fuel cell electric vehicles. This report describes two CEC agreements. The first agreement was for the upgrade of the hydrogen production system, built in 2014, and trailers that deliver gaseous hydrogen to the hydrogen refueling stations throughout California. Air Products and Chemicals, Inc. also designed, built, and commissioned hydrogen refueling stations, addressed in other CEC final reports. The second agreement was for automating the trailer fill process at the hydrogen production system. Installation of the automation process began late 2014 and became operational early 2016.

**Keywords**: Air Products and Chemicals, Inc. (APCI or Air Products), fuel cell electric vehicle, hydrogen infrastructure, Southern California Hydrogen Fill System

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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.

Air Products and Chemicals, Inc. designed and built the Southern California Fill System (under agreement ARV-10-048) at the Air Products and Chemicals, Inc. hydrogen production facility in Wilmington/Carson, (Los Angeles County). Parallel with the design, Air Products and Chemicals, Inc. discussed permitting requirements with the South Coast Air Quality Management District. After the company received a permit to build, in 2013, equipment components were installed late December 2014 and the piping pressure tests were performed in January 2015.

Air Products and Chemicals, Inc. installed the equipment for agreement ARV-12-059 (Southern California Fill System Automation) during the same timeframe as the equipment for ARV-10-048. Components for the fill system automation were specified in March 2014 and received in June 2014. All of the components to the fill system automation were installed in December 2014.

The fill system automation for both the analytical and trailer loading systems were installed at the hydrogen production facility in December 2014.

The electrical signoff for initial plant testing was received in February 2015 and pre-service function tests were performed and the filling of the first trailer of hydrogen occurred February 2015, however the oxygen analyzer was not functional. The analyzer was returned to the manufacturer for repair, due to these issues the final installation was delayed until January 2016. The moisture analyzer and oxygen analyzer and the system has been in use since.

# CHAPTER 1:
# Design and Construction

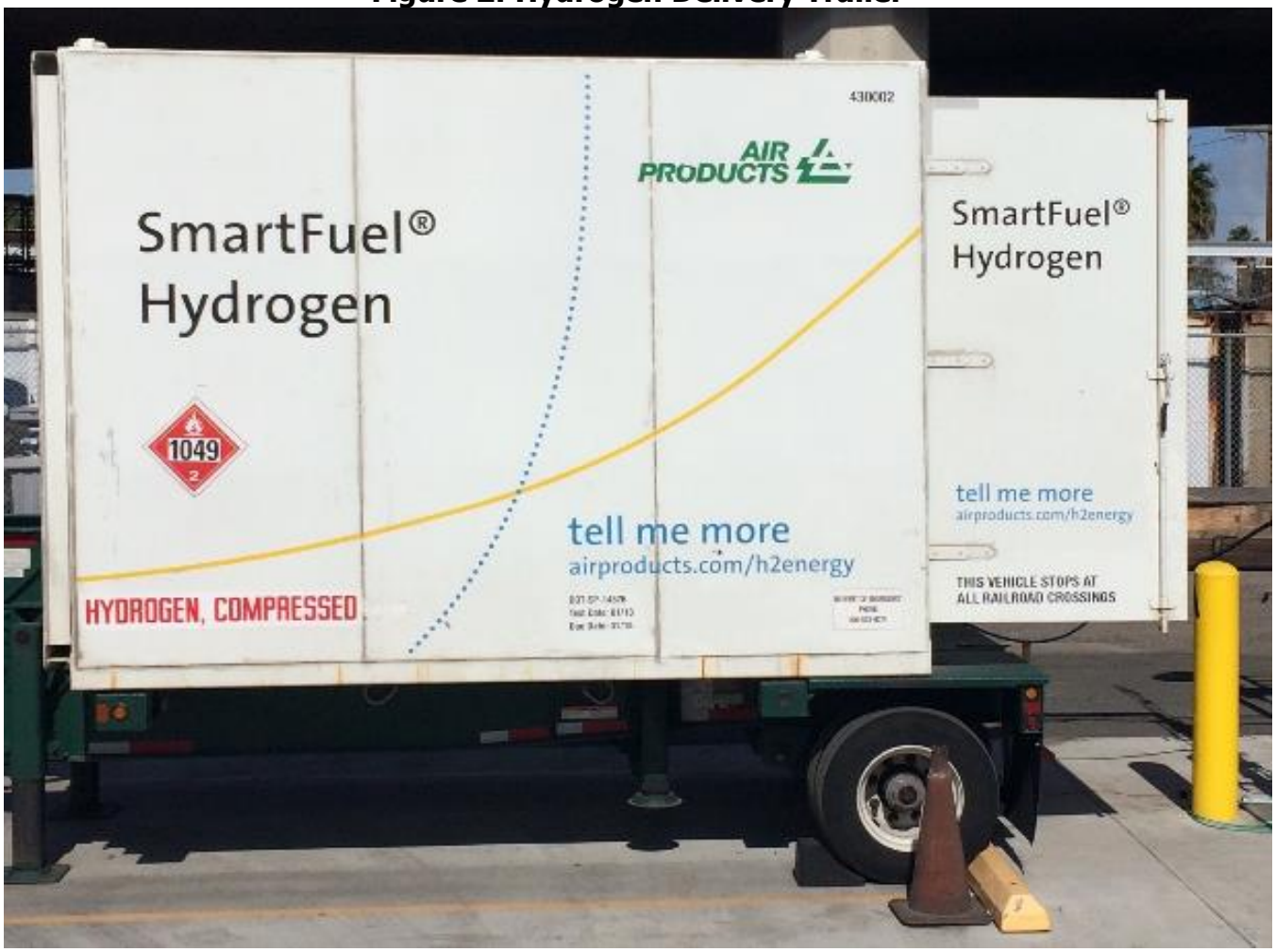
This section highlights the most critical items related to the three distinct projects relate to as the fill system, delivery trailers and the automation of the fill system. This report provides detail on each project, and states the timing required for each step for this particular site. The Air Products and Chemicals, Inc. (APCI or Air Products) facility is located in Wilmington/Carson, California. The hydrogen central fill system is used to facilitate transportation of the fuel for retail sale and is shown in Figure 1.

**Figure 1: Fill System at Southern California Facility**


Source: Google Maps

Figure 2 shows an Air Products hydrogen delivery trailer filled at the plant, one of 12 funded under ARV-10-048. Air Products proposed additional hardware to automate the trailer filling under PON-12-606 and agreement ARV-12-059. Following startup of the Southern California Hydrogen Fill System, Air Products delivered the first trailer of hydrogen from the System to the Diamond Bar, California station.

**Figure 2: Hydrogen Delivery Trailer**




Source: Air Products and Chemicals, Inc.

## 1.1 Design of the Plant and Permitting (ARV-10-048)

Following the kick-off of CEC agreement ARV-10-048, Air Products began the design process for the Southern California Hydrogen Fill System. The tie-ins to the existing production facility at Wilmington/Carson were complete in January 2012. This work coincided with a scheduled plant outage.

During summer 2012, Air Products determined that a change in the hydrogen purification process would result in greater operating flexibility for the plant. This determination considered compliance with the provisions of Society of Automotive Engineering International Standard J2719 for purity.[1] The change in the hydrogen purification system also reduced the hydrogen losses typically diverted to the plant's fuel system. The design began in September 2012 and Air Products ordered the component with the longest lead-time, the compressor, in October 2012.

Process design was completed in April 2013 and electrical, mechanical, civil, and structural design activities commenced. Fabrication of the compression skids was complete in January

[1] Society of Automotive Engineering International, Detroit, Michigan. Society of Automotive Engineering J2719 Hydrogen Fuel Quality for Fuel Cell Vehicles: 2015.

2014 and checkout of the compressors was performed July through August 2014. Following changes resulting from pipe stress calculations and from piping interferences, Air Product completed the skid fabrication in October 2014.

In parallel with design, Air Products began discussions with South Coast Air Quality Management District regarding the permit requirements. Given the time required to prepare the application and to complete the review, Air Products identified an alternate means to the Southern California Hydrogen Fill System that could supply hydrogen fueling stations in advance of the on-stream date. Information on this supply chain was provided to South Coast Air Quality Management District in December 2012. The application was submitted to South Coast Air Quality Management District in February. The application was approved the following summer.

Air Products prepared the pipes and conduits in August 2014, with full construction started after major components were delivered and the foundation was laid in December 2014. Air Products began piping pressure tests in January 2015. The electrical signoff for initial testing was received in February 2015 with the final electrical inspection taking place on March 26, 2015.

The Southern California Hydrogen Fill System includes:

- A methanator system to purify up to 4,000 kilogram/day of hydrogen. This system includes:
    - 1 skid, including reactor vessel with catalyst, electric heater and economizer
    - 1 surge tank
    - 1 dryer skid for moisture removal
    - piping, valves, instrumentation/control and electrical subsystems
    - manual sampling and analytical equipment
- 2 hydrogen compression systems capable of delivering 2,000 kilograms per day, each, of hydrogen while achieving the required pressure of 7,500 pounds per square inch in the delivery trailers. These systems include:
    - All associated piping, valving, instrumentation/control and electrical subsystems
    - Stanchions for filling delivery trailers
- Lighting and area monitoring systems to meet safety and operability requirements

## 1.2 Automation of Truck Fills (ARV-12-059)

Air Products installed the equipment for ARV-12-059 during the same timeframe as the equipment for ARV-10-048. The oxygen and water analyzers were specified and ordered in March 2014. A cabinet for the analyzers and controls was designed and a shelter to house the cabinet, along with the associated calibration gases and trailer controls, was specified. All of the components to automate the analyzer system at the Southern California Hydrogen Fill System were delivered to site in December 2014.

The systems to automate the trailer loading system were installed at the Southern California Hydrogen Fill System in December 2014. Sample lines for the two analyzers, along with other piping, sample tubing, and wiring were also installed in December 2014 and construction activities were completed in February 2015. Figure 3 shows the completed automation system housing, electrical infrastructure and components.

**Figure 3: Southern California Fill System – Automation Components**

Source: Air Products and Chemicals, Inc.

# CHAPTER 2:
# Milestones for the Southern California Hydrogen Fill System (ARV-10-048)

Following completion of the construction and operational readiness inspection, Air Products then performed a series of pre-service function tests at the Southern California Fill System:

- February 13, 2015 – Completed operation of the two compressors in recycle mode on nitrogen.
- February 16, 2015 – Completed operation of the system's electric heater on nitrogen.
- February 16, 2015 – Completed operation of the two compressors in recycle mode on hydrogen.
- February 17, 2015 – Switched over the full system to hydrogen service.
- February 17, 2015 – Completed the calibration and function test of analytical system. The carbon monoxide and moisture analyzers were successfully commissioned, but the oxygen analyzer was not functional. Commissioning and start-up of the System continued while the oxygen analyzer was returned to the manufacturer for repair.

Air Products also performed initial fills of delivery trailers and other operational tests:

- February 18, 2015 – Completed the fill of a delivery trailer that was 50% full at the start of the process.
- February 18, 2015 – Performed additional operating tests involving both compressors.
- February 18, 2015 – Demonstrated the ability to stop and start the delivery trailer fill process without disruption to other operations at the hydrogen production facility.
- February 19, 2015 – Successfully tested the automatic swap between fill stanchions upon successful completion of a fill of a delivery trailer.
- February 19, 2015 – Competed the first complete fill of a delivery trailer. Key milestones of this test include:
    - The flowrate met the system design requirements.
    - The pressure in the trailer exceeded the minimum acceptance level of 7,000 pounds per square inch.
    - The carbon monoxide and moisture levels were less than the maximum allowable concentrations permitted in Society of Automotive Engineering J-2719.
- February 20, 2015 – Completed tests to demonstrate the ability to top off a delivery trailer.
- February 20, 2015 – Completed tests of shutdown and hot restart procedures.

# CHAPTER 3:
# Milestones for the Automation System (ARV-12-059)

Air Products performed initial function tests for the Southern California Hydrogen Fill System, calibrated, and tested the moisture and oxygen analyzers in February 2015. Following the February 2015 start-up, the moisture analyzer was commissioned and placed online, but the oxygen analyzer was not functional. The oxygen analyzer was returned to the manufacturer for repair. Automation of the Southern California Hydrogen Fill System was tested through the start-up period.

Due to ongoing maintenance and system enhancements throughout 2015, the final installation and testing of the oxygen analyzer was delayed and ultimately completed in January 2016. Re-installation of the oxygen analyzer was completed on January 20, 2016. The oxygen analyzer's functionality was checked and initial calibration was performed on January 21, 2016.

# CHAPTER 4:
# Budgets for ARV-10-048 and ARV-12-059

Table 1 shows a high-level budget for ARV-10-048.

**Table 1: Budget for ARV-10-048**

| Budget Category | Cost |
|---|---|
| California Energy Commission Grant | $2,674,760 |
| Air Products Cost Share | $1,038,778 |
| Southern California Hydrogen Fill System Automation | $3,713,538 |
| Total Budget | $3,713,538 |
| Total California Energy Commission cost share | 72% |

Source: Air Products and Chemicals, Inc.

Table 2 shows a high-level budget for ARV-12-059.

**Table 2: Budget for ARV-12-059**

| Budget Category | Cost |
|---|---|
| California Energy Commission Grant | $490,349 |
| Air Products Cost Share | $264,034 |
| Southern California Hydrogen Fill System | $754,383 |
| Total Budget | $754,383 |
| Total California Energy Commission cost share | 65% |

Source: Air Products and Chemicals, Inc.

# CHAPTER 5:
# Trailers

Under ARV-10-048, Air Products built and deployed the 12 trailers listed in Table 3. Some trailers are used to deliver hydrogen to the refueling stations while others are stationary and provide storage at particular stations.

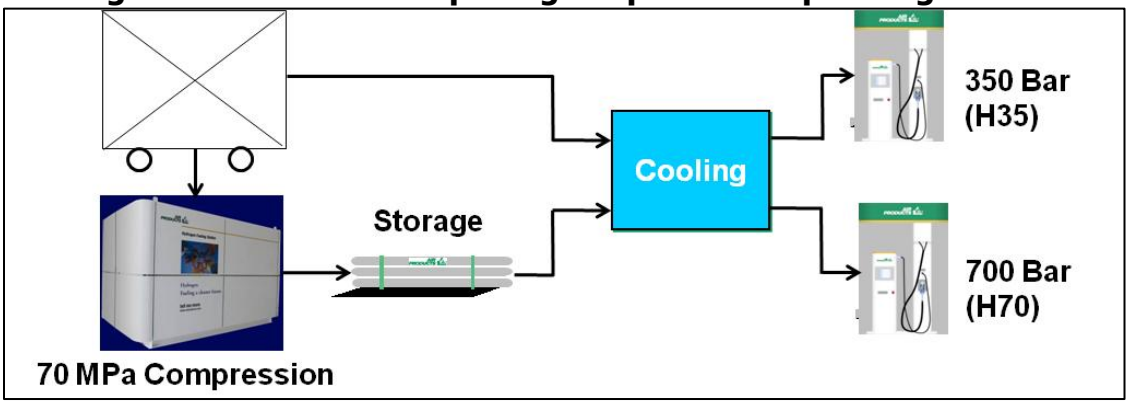
**Table 3: Trailers and Location**

| Trailer Identification Number | Trailer Location As Reported by APCI |
|---|---|
| 430001 | Delivers hydrogen to multiple stations |
| 430002 | Delivers hydrogen to multiple stations |
| 430003 | Delivers hydrogen to multiple stations |
| 430004 | Delivers hydrogen to multiple stations |
| 430005 | Delivers hydrogen to multiple stations |
| 430006 | Delivers hydrogen to multiple stations |
| 430007 | Delivers hydrogen to multiple stations |
| 430008 | Delivers hydrogen to multiple stations |
| 430009 | Storage at Fairfax Los Angeles station |
| 430010 | Storage at Woodland Hills station |
| 430011 | Storage at Lawndale station |
| 430012 | Delivers hydrogen to multiple stations |

Source: Air Products and Chemicals, Inc.

Air Products' 12 delivery trailers, when delivered to a hydrogen fueling station, would serve as the source of fuel for the refueling process. The trailers would utilize high-pressure composite storage tubes manufactured by Worthington Industries which allow for transport of a total of 250 kilograms of hydrogen at a maximum pressure of 51.7 megapascals. Trailers then are dropped and swapped to replenish the station. Figure 4 depicts an overview of the components that make up a SmartFuel® hydrogen station for this configuration.

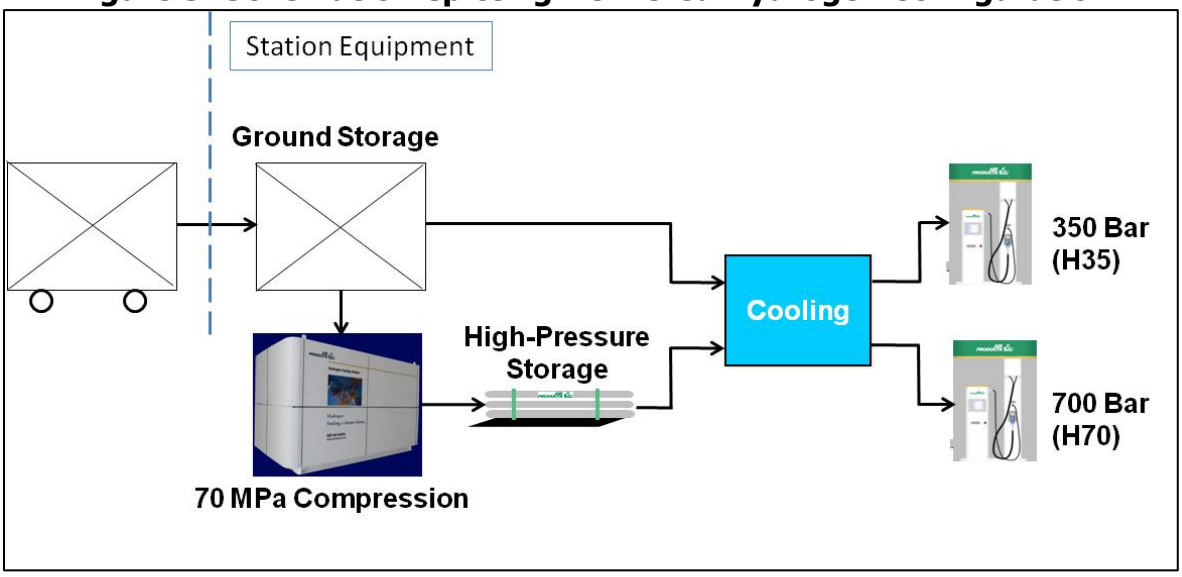
**Figure 4: Schematic Depicting Drop-and-Swap Configuration**




Source: Air Products and Chemicals, Inc.

During the execution of the project, a number of the host sites for the hydrogen fueling stations have been changed, and these replacements locations do not provide the space or access for the trailers to be swapped. In these cases, hydrogen is delivered to the station by a high-pressure tube trailer and pressure-transferred to a ground storage module at the station. Figure 5 provides a schematic of the SmartFuel® hydrogen station for this mode of delivery. In these cases, the "ground storage" module (a total of four units) was fabricated under this project.

**Figure 5: Schematic Depicting Delivered Hydrogen Configuration**




Sources: Air Products and Chemicals, Inc.

Following the kick-off of Grant Agreement ARV-10-048, Air Products began the design process for the hydrogen storage systems. The composite storage tubes were ordered in January 2012. Frames to house the tubes were ordered beginning in August 2012, and the first two frames were completed in January 2013. Production of the chassis for the trailer units began in April 2013. As part of the design of the trailers, consideration was given to a scenario where the chassis might have to be tied onto a permanent anchor which would be incorporated into the foundation design for the hydrogen fueling station.

Air Products decided to complete these two initial units so that lessons learned could be applied to the remaining modules and trailers. This became important as pressure testing of the system revealed issues with leakage through isolation valves on the hydrogen storage

tubes. Air Products worked with the valve supplier and developed a design that would pass the pressure test. Following delivery of the first trailer to California in June 2014, operability upgrades were identified by Air Products' distribution team, and these were able to be implemented prior to deployment in August 2014.

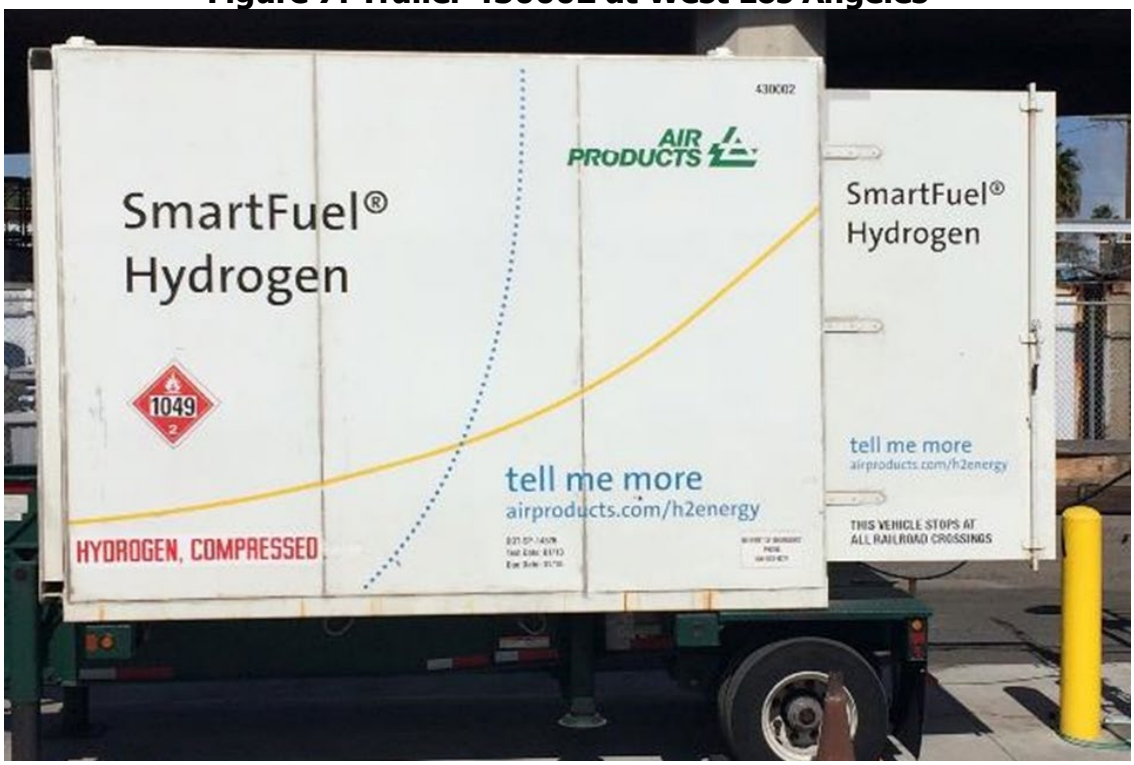
A photograph of the first delivery trailer is shown in Figure 6 in service at the Diamond Bar station (21865 East Copley Drive). Photographs of the other trailers and storage modules are provided in Figures 5 through 14. The final unit completed pressure-testing in September 2015.

**Figure 6: Trailer 430001 at the Diamond Bar station**


Source: Air Products and Chemicals, Inc.

Figure 7 shows trailer 430002 in service at the West Los Angeles station (11261 Santa Monica Blvd).

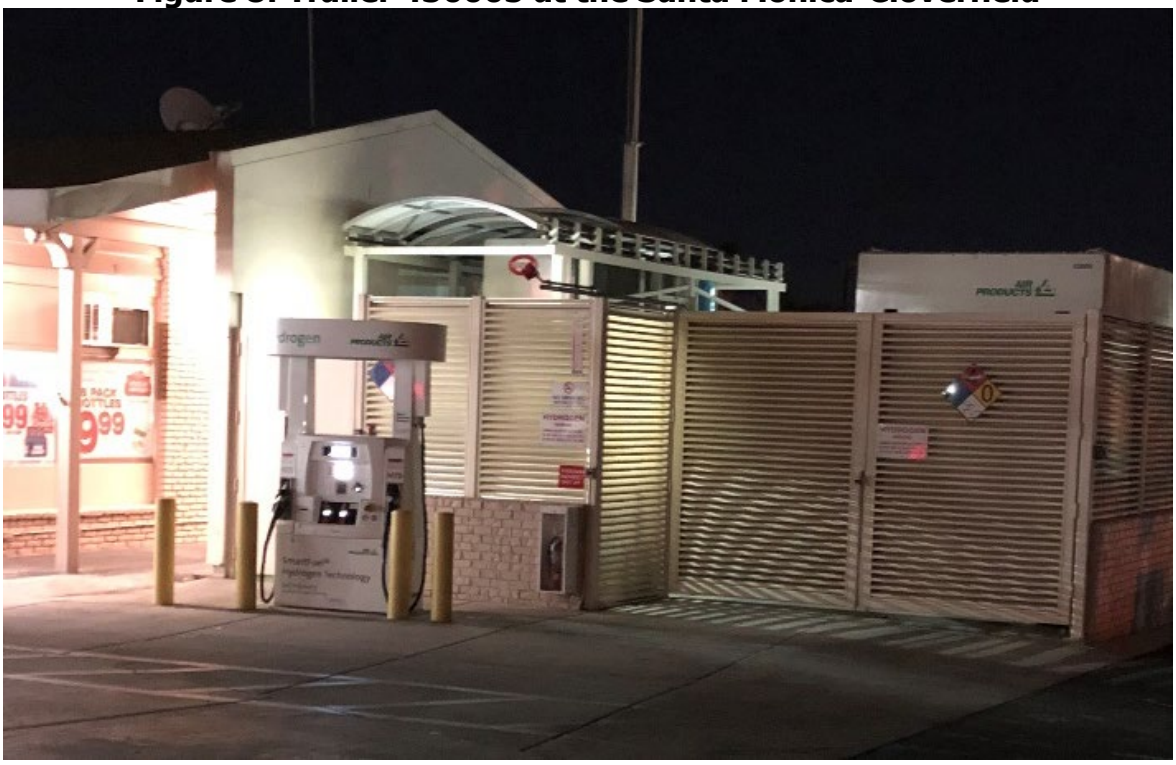
**Figure 7: Trailer 430002 at West Los Angeles**




Source: Air Products and Chemicals, Inc.

Figure 8 displays trailer 430005 in service at the Santa Monica-Cloverfield station.

**Figure 8: Trailer 430005 at the Santa Monica-Cloverfield**



Source: Air Products and Chemicals, Inc.

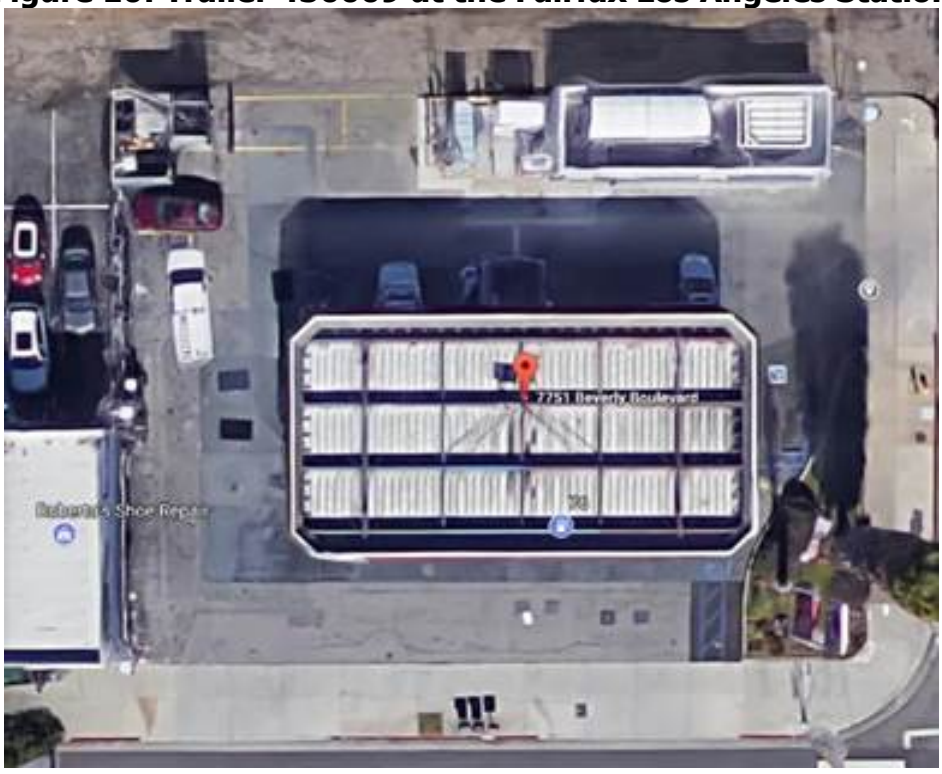
Figure 9 shows trailer 430008 and Figure 8 shows trailer 430009 at the Fairfax Los Angeles Station.

**Figure 9: Trailer 430008 Delivery**


Source: Air Products and Chemicals, Inc.

Figures 10, 11, and 12 show trailer 430009 in service at the Fairfax Los Angeles Station (7751 Beverly Blvd). The module is to the right of the enclosure, next to the compression skid.

**Figure 10: Trailer 430009 at the Fairfax Los Angeles Station**




Source: Air Products and Chemicals, Inc.

**Figure 11: Trailer 430009 at the Fairfax Los Angeles Station**


Source: Air Products and Chemicals, Inc.

**Figure 12: Hydrogen Delivery Trailer 430009**


Source: Air Products and Chemicals, Inc.

Figures 13 shows trailer 430010 in service at the Woodland Hills Station (5314 Topanga Canyon Rd).

**Figure 13: Trailer 430010 at the Woodland Hills Station**


Source: Air Products and Chemicals, Inc.

Figure 14 shows the back opening of trailer 430011.

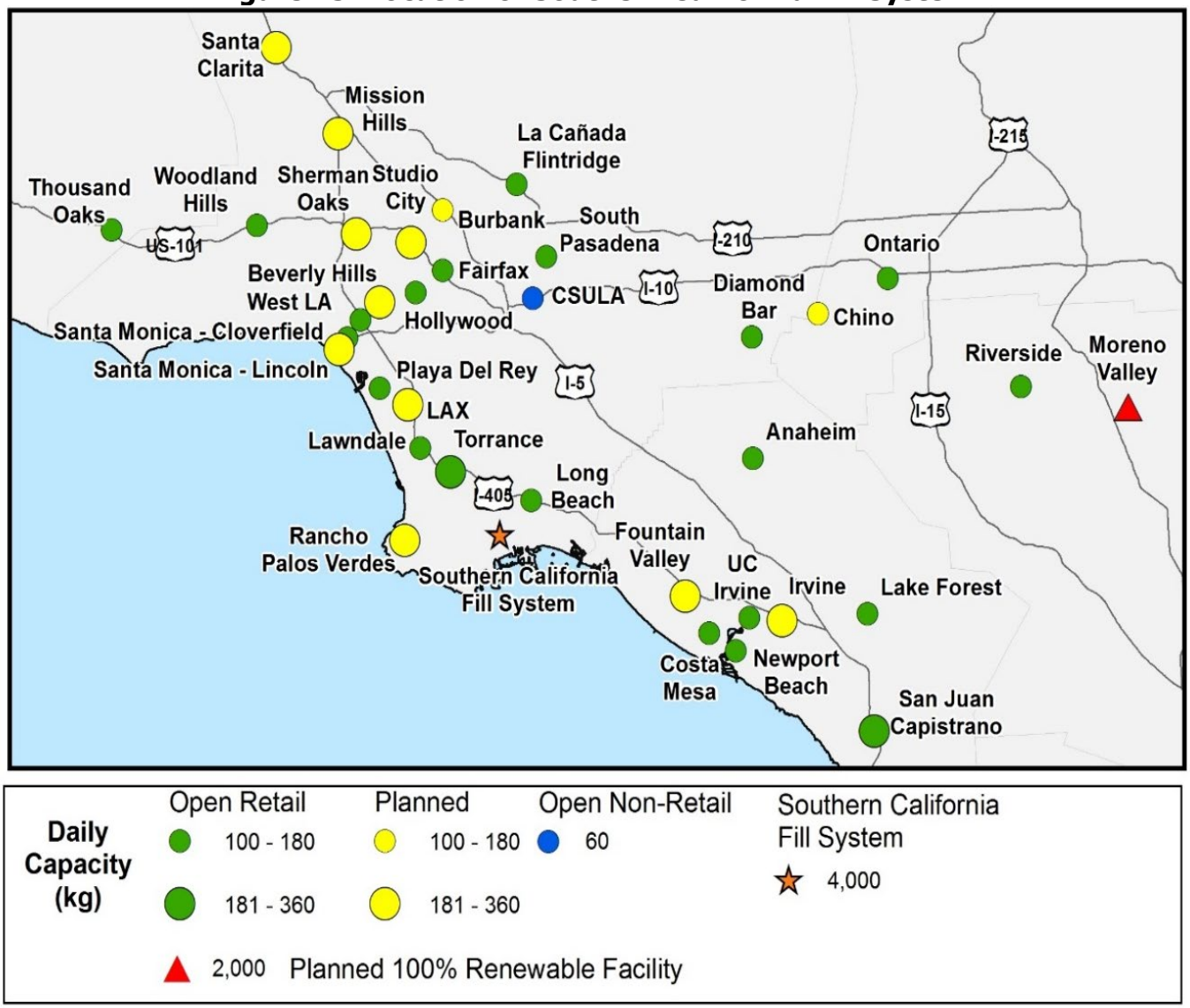
**Figure 14: Trailer 430011**


Source: Air Products and Chemicals, Inc.

# CHAPTER 6:
# Future Activities

The Southern California Hydrogen Fill System is in a facility owned and operated by Air Products. The Southern California Hydrogen Fill System is located near hydrogen refueling stations in Southern California, as shown in Figure 15. The red star connotes the location of the facility.

**Figure 15: Location of Southern California Fill System**




Source: California Energy Commission Staff

Under ARV-10-048 air products designed, built, and commissioned the hydrogen refueling station listed in Table 4.

**Table 4: List of Stations under ARV-10-048**

| Project Stations | Location |
|---|---|
| Diamond Bar SmartFuel® Hydrogen Station | 21865 E. Copley Dr.<br>APCI |
| West Los Angeles SmartFuel® Hydrogen Station | 11261 Santa Monica Blvd.<br>APCI |
| University of California Irvine SmartFuel® Hydrogen Station | 19172 Jamboree Rd.<br>APCI Upgrade |
| Santa Monica SmartFuel® Hydrogen Station | 1819 Cloverfield Blvd.<br>APCI |
| Fairfax Los Angeles SmartFuel® Hydrogen Station | 7751 Beverly Blvd.<br>APCI |
| Lawndale SmartFuel® Hydrogen Station | 15606 Inglewood Ave.<br>APCI |
| Will not be completed by the time this report is published | 24551 Lyons Ave.<br>APCI |
| Will not be completed by the time this report is published | 28103 Hawthorne Blvd.<br>APCI |

Source: California Energy Commission Staff

# CHAPTER 7:
# Conclusions

The following is a list of findings from the Southern California Hydrogen Fill System, the delivery trailers and the automation of the fill system:

- Design, building, and commissioning a Southern California Hydrogen Fill System required significant investment.
- Process improvement in areas such as purification is integral to the Southern California Hydrogen Fill System.
- Analyses and monitoring of moisture and oxygen content are integral and the grant recipient prioritized these activities.
- Milestones for the design, building, and commissioning of the Southern California Hydrogen Fill System were integrated with the system that automated the truck fills.
- When fabricating a number of duplicate items, the fabrication of prototype units can generate lessons learned which can yield benefits during the production of the follow-on units.
- Development of cost-effective means to purify and compress hydrogen are critical to the successful rollout of fuel cell electric vehicles.
- Management of design changes is key to the implementation of cutting-edge technologies.
- Analytical systems are an important part of the overall process for assuring the purity of hydrogen delivered to refueling stations.
- Automation of key subsystems allows for greater efficiency in filling delivery trailers and lowering the cost of hydrogen.

# GLOSSARY

AIR PRODUCTS AND CHEMICALS INCORPORATED (APCI or Air Products)—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.

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 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.

Funding for the CEC's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account, and other sources.