III.0 Hydrogen Delivery Program Overview

INTRODUCTION

The Hydrogen Delivery program addresses all hydrogen transmission and distribution activities from the point of production to the point of dispensing. Research and development (R&D) activities address challenges to the widespread commercialization of hydrogen technologies in the near-term through development of tube trailer and liquid tanker technologies as well as station compressors, dispensers, and bulk storage; and in the mid- to long-term through development of pipeline and advanced delivery technologies. Technoeconomic analysis is used by the program to identify cost, performance, and market barriers to commercial deployment of hydrogen technologies, and to inform program planning and portfolio development.

GOAL

The goal of this program is to reduce the costs associated with delivering hydrogen to a point at which its use as an energy carrier in fuel cell applications is competitive with alternative transportation and power generation technologies.

OBJECTIVES

The objective of the Hydrogen Delivery program is to reduce the cost of hydrogen dispensed at the pump to a cost that is competitive on a cents-per-mile basis with competing vehicle technologies. Based on current analysis, this translates to a low-volume hydrogen threshold cost of <$7 per gallon gasoline equivalent (gge) (produced, delivered and dispensed, but untaxed) by 2020.[1] To achieve this near-term objective, delivery pathways that can meet a low-volume cost of <$5/gge are needed. To be cost-competitive in the long-term, an ultimate target of <$4/gge (produced, delivered and dispensed, but untaxed) must be met via renewable pathways.[2] This cost target has been apportioned to be <$2/gge for the renewable production and <$2/gge for the delivery and dispensing.[3] The program plans to meet these objectives by developing low-cost, efficient, and safe technologies to deliver hydrogen from the point of production to the point of use in both stationary fuel cells and fuel cell electric vehicles (FCEVs). This objective applies to all of the possible delivery pathways. Key objectives for specific delivery components include:

- **Station Technologies:**
  - Compression: Develop lower-cost, higher-reliability hydrogen compression technology for terminal and station applications.
  - Storage: Develop lower-capital-cost off-board bulk storage technology.
  - Dispensers: Improve the cost, reliability, and accuracy of 700 bar dispensers.
- **Pipeline Technology:** Develop mitigation strategies for combined material fatigue and hydrogen embrittlement in steel pipelines; advance the development and acceptance of alternative composite pipe materials that can reduce installed pipeline costs; and develop lower-cost, higher-reliability compression technology for hydrogen transmission by pipeline.
- **Liquid Hydrogen Technology:** Reduce the capital and operating costs of hydrogen liquefaction facilities.
- **Analysis:** Conduct comprehensive analyses on near- and longer-term hydrogen delivery options to identify the advantages of each and areas for potential improvement.

[1] DOE Hydrogen and Fuel Cells Program Record #15012, Hydrogen Early Market Cost Target, 2015, https://www.hydrogen.energy.gov/pdfs/15012_hydrogen_early_market_cost_target_2015_update.pdf
[2] DOE Hydrogen and Fuel Cells Program Record #11007, Hydrogen Threshold Cost Calculation, 2011, https://www.hydrogen.energy.gov/pdfs/11007_h2_threshold_costs.pdf
[3] DOE Hydrogen and Fuel Cells Program Record #12001, Hydrogen Production and Delivery Cost Apportionment, 2012, https://www.hydrogen.energy.gov/pdfs/12001_h2_pd_cost_apportionment.pdf

FISCAL YEAR (FY) 2016 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

In FY 2016, the Hydrogen Delivery program kicked off nine new projects, competed one Funding Opportunity Announcement (FOA), participated in one workshop, and saw significant progress in research, development, and demonstration (RD&D) activities of existing projects.

Program Level Accomplishments

In FY 2016, significant progress was made by the Hydrogen Delivery program on several important fronts. Several highlights include:

- The Hydrogen Delivery Cost Projection Record was updated. The publicly available record now provides details to support the modeled cost of delivering hydrogen from a centralized production facility and dispensing to FCEVs. These modeled costs cover a range of gaseous and liquid hydrogen delivery options using current (2015) technologies projected at economies of scale.
- The Hydrogen Delivery Scenario Analysis Model (HDSAM) 3.0 was released. This release includes updated assumptions of the costs of key delivery equipment, allows users to simulate the impact of technology maturity on hydrogen cost, and allows users to simulate the effects of varying station utilization rates over a 30-year analysis period.
- A solicitation for research on advanced compression technologies was released as part of the Fuel Cell Technologies Office's 2016 office-wide FOA.
- Through the Hydrogen Fueling and Infrastructure Research and Station Technology (H2FIRST) project, DOE and several original equipment manufacturers have developed, tested, and validated the Hydrogen Station Equipment Performance Device (HyStEP). Since December 2015, the device has already been used to commission multiple stations in California.
- The H-Prize competition (H2 Refuel) finalist (SimpleFuel) was announced. The team has begun working on their on-site refueling solution. This $1 million competition challenges America's innovators to deploy an onsite hydrogen generation system to fuel hydrogen-powered vehicles. The system may use electricity or natural gas and can be sited in homes, community centers, small businesses, or similar locations.

Project Level Accomplishments

During FY 2016, progress was made by existing projects in several key areas, including:

Station Technologies

Station technologies, in particular compression, onsite storage, and dispensing, are a key area of focus for the program. Efforts in this area aim to improve the reliability and reduce the cost of the technologies.

- The automated dispensing hose testing apparatus at the National Renewable Energy Laboratory (NREL) completed more than 3,100 test cycles of commercial dispensing hoses. The test cycles simulated various fills of hydrogen at 700 bar and -40°C, per the the SAE J2601 fueling protocol. The apparatus and fueling station at NREL were upgraded in April with additional compression and storage capacity. The apparatus is now capable of up to 1,500 autonomous cycles per week.
- A project to create a U.S. supplier for metal-free 700-bar hydrogen dispensing hoses made significant progress in FY 2016. The small business, NanoSonic, has developed a polymer matrix resin with ultra-low hydrogen permeance before and after being subected to the harsh 180-degree triple fold, cold flex test, conducted at -50°C. In FY 2016, NanoSonic demonstrated effective use of a ceramer to prevent the hose from pulling out of fittings at high pressures, and developed a novel proprietary fiber reinforcement expected to enhance burst strength. (NanoSonic)
- Fuel station precooling analysis identified major drivers for precooling capacity/cost and performance. The analysis also acquired performance data at different ambient temperatures for a typical hydrogen refueling station precooling system and developed an algorithm to optimize the size of precooling equipment and heat exchanger for lowest precooling cost. (Argonne National Laboratory)

- The HyStEP testing device was successfully deployed in California with the California Air Resources Board (CARB), including execution of a contract between Sandia National Laboratories (SNL) and CARB for the loan of the device to collect the data needed to validate stations in California as part of the H2FIRST project. Additionally, all relevant designs and control software for the duplication of the device have been made publically available through the H2Tools website. (SNL, NREL)
- An 875-bar stationary pressure vessel design has been approved by the American Society of Mechanical Engineers (ASME). The vessel is manufactured by autofrettaging commercially available steel liners and then wrapping them with high-strength wire. The vessel design is expected to cost 50% less than vessels currently on the market. (Wiretough)

Pipeline Technologies

Pipelines are an attractive delivery pathway for mature market scenarios. Advances in both pipeline compression and fiber-reinforced polymer pipelines continue to improve the economics of the scenario, while work on hydrogen embrittlement of steel continues to improve the understanding of the performance of traditional pipeline materials for the hydrogen pipeline transmission and distribution network.

- Fatigue analysis showed that X100A base metal exhibited comparable hydrogen-accelerated fatigue crack growth rates to lower-strength base metals. Future experimentation will identify high-strength steel microstructures with acceptable hydrogen-accelerated fatigue crack growth performance. (SNL)

Liquid Hydrogen Technologies

Liquefaction represents over 50% of the cost of hydrogen delivered via the liquid pathway, due largely to energy consumption.

- As part of the new project to improve liquefaction efficiency using vortex tubes, the first helium-hydrogen-neon liquid phase density measurements for refrigerant mixtures have been completed. (NREL)
- As part of a project to use magnetocaloric materials to liquefy hydrogen, a world record was set in achieving a 100-K temperature span with magnetocaloric materials. These materials were then used to liquefy propane gas from room temperature. Further work increased the system cooling power through the implementation of a bypass loop in an eight-layer magnetocaloric system. (Pacific Northwest National Laboratory)

Workshops

The *Fourth International Workshop on Hydrogen Infrastructure and Transportation*, organized by the New Energy and Industrial Technology Development Organization (NEDO) of Japan, the National Organisation Hydrogen and Fuel Cell Technology (NOW) of Germany, and the DOE and hosted by the European Commission's Joint Research Center, was held in May of 2016 in the Netherlands. The workshop included members of industry, academia, and government from Japan, Germany, the European Union, Scandinavian countries, and the United States. This year representatives from China and Korea were also able to attend. Key takeaways from the workshop are summarized in Table 1 below.

TABLE 1. Key Issues Discussed at 4th International Infrastructure Workshop

Fueling	Germany, Japan, and the United States all have devices in place to collect data for validation of stations against refueling requirements.
Hydrogen Quality	The technical, cost, and time requirements of hydrogen quality monitoring remain common concerns. Several devices are under development to perform inline monitoring for key contaminants.
Metering	Japan has implemented interim meter accuracy targets similar to those adopted in California. Germany has not yet made a decision to adopt such targets. Dispensing error continues to be measured at 4–8% in the field depending on the volume of hydrogen dispensed.
Hardware	Both the reliability and availability of stations continues to be a concern for all participants. While compressor failures are decreasing, the maintenance interval remains a concern. Additionally, dispenser improvements are necessary to improve the user experience.

Publications

In FY 2016, the Delivery program published a program record that provides details to support modeled costs of delivering hydrogen from a centralized production facility and dispensing to FCEVs. The modeled costs range from $3.00/gge to $5.00/gge for 700 bar dispensing, and $2.70/gge to $3.70/gge for 350 bar dispensing. These modeled costs cover a range of gaseous and liquid hydrogen delivery options using current (2015) technologies projected at economies of scale. Prior-year cost estimates were calculated using the H2A Hydrogen Delivery Scenario Analysis Model (HDSAM) V2.3 along with assumptions of the commercial readiness of delivery/dispensing technologies in the respective years. In 2015, HDSAM was updated to Version 3.0 to reflect the then-current status of delivery technologies. Before its release, the model was vetted through comparisons of its projections with the real-world cost estimates provided by station developers in funding applications to the California Energy Commission. The 2015 cost estimates and 2020 projections in this record were made using HDSAM 3.0 along with assumptions about the readiness levels of each technology in the delivery pathway for commercialization.

FY 2016 Funding

The Fuel Cell Technologies Office announced one delivery-focused FOA topic in FY 2016 to fund projects in the area of advanced compression and one Small Business Innovation Research (SBIR) FOA on magnetocaloric materials discovery.

Three *advanced compression* projects were awarded in FY 2016 in the Delivery portfolio and will begin work in FY 2017. The three advanced compression projects are as follows:

- Giner, Inc., Newton, Massachusetts, will demonstrate a cost-effective method for compressing hydrogen while eliminating the need for mechanical compressors, which typically have significant reliability issues.
- Greenway Energy, LLC, Aiken, South Carolina, will combine two novel technologies, Electrochemical Hydrogen Compression and Metal Hydride Compression, into a new hybrid solid state hydrogen compressor, to overcome the reliability issues of mechanical compression and the efficiency challenges of solid state compression technologies.
- Sandia National Laboratories, Livermore, California, will work to investigate and demonstrate a laboratory-scale two-stage metal-hydride-based hydrogen gas compressor.

Two *magnetocaloric materials* SBIR projects were awarded in FY 2016 in the Delivery portfolio. The two SBIR projects are as follows:

- Nanohmics, Inc, Austin, Texas, will design next-generation technologies to cool hydrogen from room temperature by leveraging both the magnetocaloric and magnetoelastic effects in known magnetocaloric materials. The team will leverage their capabilities in nanofabrication to develop and demonstrate materials with geometries that maximize these effects.
- General Engineering & Research, LLC, San Diego, California, aims to develop a low-cost magnetocaloric material for sub-80-K refrigeration applications. Most magnetocaloric materials in use today are high in cost because they use rare earth metals, such as gadolinium. This project will synthesize and characterize novel materials that avoid rare earth metals and have demonstrated potential in previous research.

Additionally, one award was made from the FY 2015 FOA for advanced dispensing technologies.

- Ivys, Inc., Waltham, Massachusetts, will develop a 700 bar hydrogen dispenser that achieves 2% accuracy and durable operation through the use of wireless dedicated short range communication and advanced Coriolis metering technologies.

Three new projects were also initiated in FY 2016 through a lab call released in FY 2015.

- Pacific Northwest National Laboratory, Richland, Washington, will demonstrate a laboratory-scale hydrogen liquefier with a figure of merit increase from 0.3 up to 0.5 using magnetocaloric materials.
- National Renewable Energy Laboratory, Golden, Colorado, will develop a proof-of-concept small modular hydrogen liquefaction system that utilizes kinetic parahydrogen–orthohydrogen separation and conversion via vortex tubes to provide a pathway to achieving a figure of merit of 0.5.

- Sandia National Laboratories, Livermore, California, will work with National Institute of Standards and Technology and Oak Ridge National Laboratory to identify pathways for developing high-strength pipeline steels by establishing the relationship between microstructure constituents and hydrogen-accelerated fatigue crack growth.

BUDGET

The FY 2016 appropriation provided $25.4 million for the Hydrogen Production and Delivery program, with approximately $11.9 million provided for Delivery RD&D. The estimated budget breakdown for Delivery in FY 2016 and FY 2017 is shown in Figure 1. The request for Hydrogen Production and Delivery in FY 2017 is $28.1 million, with $11.0 million planned for Delivery RD&D, with an emphasis on improving reliability and reducing costs of near-term technologies, such as dispensers and storage at the station, and developing technologies for longer-term pathways, such as liquefaction.

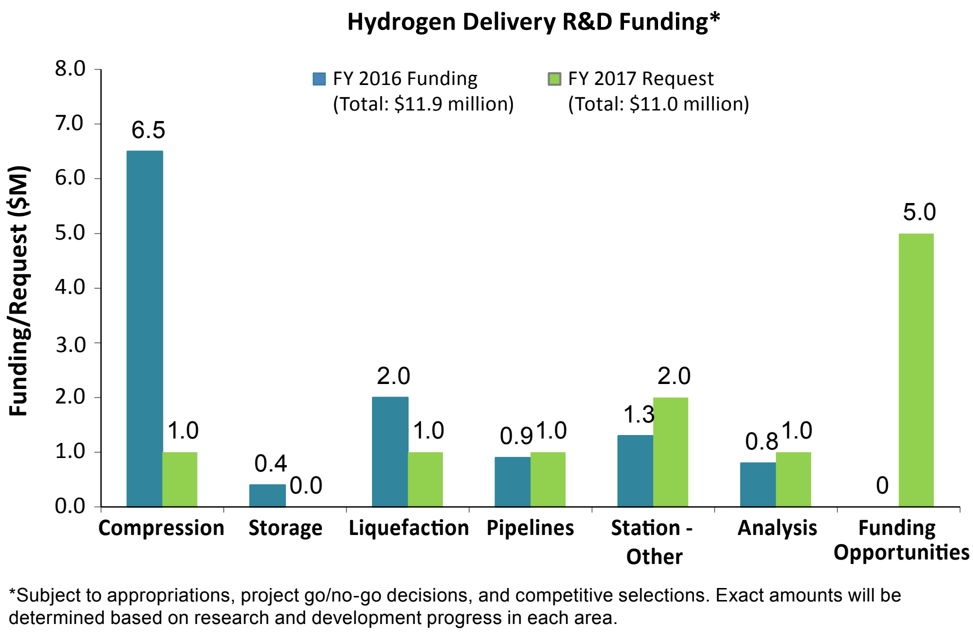

FIGURE 1. Hydrogen delivery budget. Budget amounts for FY 2016 and projected amounts for FY 2017, contingent upon appropriations, are shown broken down by the different delivery pathways. Exact distribution of funds in FY 2017 will not be defined until funds have been appropriated and new projects selected.

FY 2017 PLANS

In FY 2017, the Hydrogen Delivery program will focus on several key efforts, including the following:

- Review the current state of the art in carrier technology and publish the results.
- Focus on improving compressor reliability through new projects focused on advanced compression technologies. (SNL, Giner, and Greenway)
- Continue to address near-term hydrogen station R&D needs through the H2FIRST project, including work on reducing station footprint for urban sites and research to improve dispensing reliability. (NREL and SNL)

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