Technology Acceleration and Hydrogen Infrastructure R&D Overview

INTRODUCTION

Technology Acceleration and Hydrogen Infrastructure R&D focuses on accelerating the transition of early-stage hydrogen and fuel cell research to subsequent stages of development and leveraging the private sector to enable commercialization and deployment. Examples include integration of hydrogen production technologies with the electricity grid, lowering the cost of manufacturing hydrogen and fuel cell technologies, reducing the cost of hydrogen transport and distribution, and reducing the cost and improving reliability of hydrogen fueling stations and the supporting infrastructure component supply chain. Key focus areas of early-stage R&D include (1) enabling hybrid energy systems that integrate nuclear power with hydrogen production, (2) evaluating and improving the long-term durability of megawatt-scale electrolyzer and fuel cell technologies, (3) reducing the costs of manufacturing electrolyzers and fuel cells through innovations in membrane synthesis and coating, as well as novel methods of quality control and assurance during the manufacturing process, (4) developing novel approaches to enhance efficiency and scalability of hydrogen liquefaction, (5) developing affordable, efficient, and reliable methods of hydrogen compression (such as non-mechanical methods), (6) improving the accuracy and reliability of hydrogen fueling station technologies, and (7) enhancing materials compatibility to improve durability and lower cost of key components of hydrogen infrastructure (e.g., pipelines, dispensing hoses, and storage vessels). Techno-economic analysis is used to identify drivers of hydrogen cost and barriers to widespread growth, which inform Program planning and portfolio development.

In fiscal year (FY) 2018, Technology Acceleration and Hydrogen Infrastructure R&D accomplishments included advances in hydrogen compression and liquefaction, and in hydrogen fueling for medium- and heavy-duty applications. For example, the National Renewable Energy Laboratory (NREL) completed experimental validation of the innovative pressure consolidation strategy developed by Argonne National Laboratory (ANL). Pressure consolidation is an approach to optimize the operation of hydrogen fueling stations that are supplied by tube trailers, such that the capital cost of compression at the station can be reduced by up to 40%.[1] Additionally, R&D projects in the formerly named Technology Validation subprogram portfolio completed more than 15,000 hours of durability testing of low-temperature electrolyzer technologies and collected data on 27 fuel cell electric buses, demonstrating that fuel cell buses have exceeded the DOE and U.S. Department of Transportation durability targets.

In August 2018, the Program hosted the H2@Scale End Use Applications Fuel Cell Truck Powertrain R&D Activities and Target Review with subject matter experts and stakeholders to assess the status, challenges, and opportunities for fuel cell truck applications. This meeting was used to inform technical targets for the use of hydrogen and fuel cells in medium- and heavy-duty transportation. Additionally, in September 2018, the Program hosted the annual International Hydrogen Infrastructure Workshop to identify the current status of technology and key R&D challenges through feedback from key industry and government stakeholders in the United States, Japan, Germany, and Scandinavia. Feedback from these meetings and workshops is being used to guide Program strategy in FY 2019.

OBJECTIVES

Key objectives for Technology Acceleration and Hydrogen Infrastructure R&D include the following.

- By 2019, achieve compression of hydrogen to 875 bar using electrochemical cells and metal hydride materials at $\leq$4 kWh/kg.

[1] For more information, please see: https://www.energy.gov/sites/prod/files/2017/11/f46/fcto_nov17_h2_scale_session_elgowainy.pdf

- By 2020, establish the potential for magnetocaloric technologies to liquefy hydrogen at twice the energy efficiency of conventional liquefaction plants.
- By 2020, develop manufacturing techniques to reduce the cost of automotive fuel cell stacks at high volume (500,000 units/year) to $20/kW (from the 2008 value of $38/kW).
- By 2025, conduct early-stage R&D to enable technologies that reduce the cost of hydrogen delivery and dispensing to $7/kg.

FY 2018 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

In FY 2018, Technology Acceleration and Hydrogen Infrastructure R&D made significant progress to advance cost-competitive hydrogen production and delivery technologies and establish the viability of hydrogen use in emerging applications. The current cost of hydrogen production and delivery ranges from $13–$16/gge (gallon of gasoline equivalent, approximately equal to 1 kg of hydrogen on a lower heating value basis).[2] The Fuel Cell Technologies Office's target for the cost of hydrogen production and delivery is $7/gge by 2025.[3] The targeted cost of hydrogen production is $2/gge,[4] and the target cost of hydrogen delivery and dispensing therefore is $5/gge. In support of this target, Program R&D focused on enabling hydrogen production within hybrid energy systems and improving the reliability and lowering the footprint of hydrogen fueling station technologies. The Program also completed an analysis identifying one R&D pathway to achieving the Program's target for the cost of hydrogen production and delivery by 2025 (see Figure 1).[5]

A key focus of the DOE's H2@Scale initiative is advancing technologies that can be used in hybrid energy systems, wherein hydrogen production is integrated with electricity generators and transmission to lower cost and support grid resiliency. Previous accomplishments in this area have included technology acceleration R&D that established the ability of electrolyzers to meet the performance requirements for responsive load and ancillary services on the grid. In 2018, R&D focus areas were broadened to include development of test capabilities for emerging high-temperature electrolysis technologies that can monetize process heat from nuclear power plants. Integration of high-temperature electrolysis with nuclear power can increase the capacity factors of nuclear power generators and reduce the electrical energy consumption of electrolysis by up to 25%.[6] Another key R&D focus was to enable manufacturing technologies that can reduce the capital cost of electrolyzers at the scales needed for emerging applications. While electrolyzers are commonly manufactured at kilowatt scales for small-scale (<100 kg/day) consumers of hydrogen, megawatt-scale units are required in emerging applications, such as the integration of electrolyzers with the grid (i.e., "power-to-gas") and hydrogen fueling stations. An additional R&D focus area was to lower the costs of hydrogen distribution and fueling infrastructure. Project goals included improving the reliability of hydrogen compression and dispensing, improving the accuracy of hydrogen meters, and reducing the footprint of hydrogen fueling stations.

[2] https://www.hydrogen.energy.gov/pdfs/15011_low_volume_production_delivery_cost.pdf
[3] https://www.hydrogen.energy.gov/pdfs/15012_hydrogen_early_market_cost_target_2015_update.pdf
[4] https://www.hydrogen.energy.gov/pdfs/12001_h2_pd_cost_apportionment.pdf
[5] This analysis is documented in Hydrogen and Fuel Cells Program Record 18003: https://www.hydrogen.energy.gov/pdfs/18003_current_status_hydrogen_delivery_dispensing_costs.pdf
[6] For more information on the electrical energy consumption of low- and high-temperature electrolysis, please see the H2A case studies available here: https://www.nrel.gov/hydrogen/h2a-production-case-studies.html

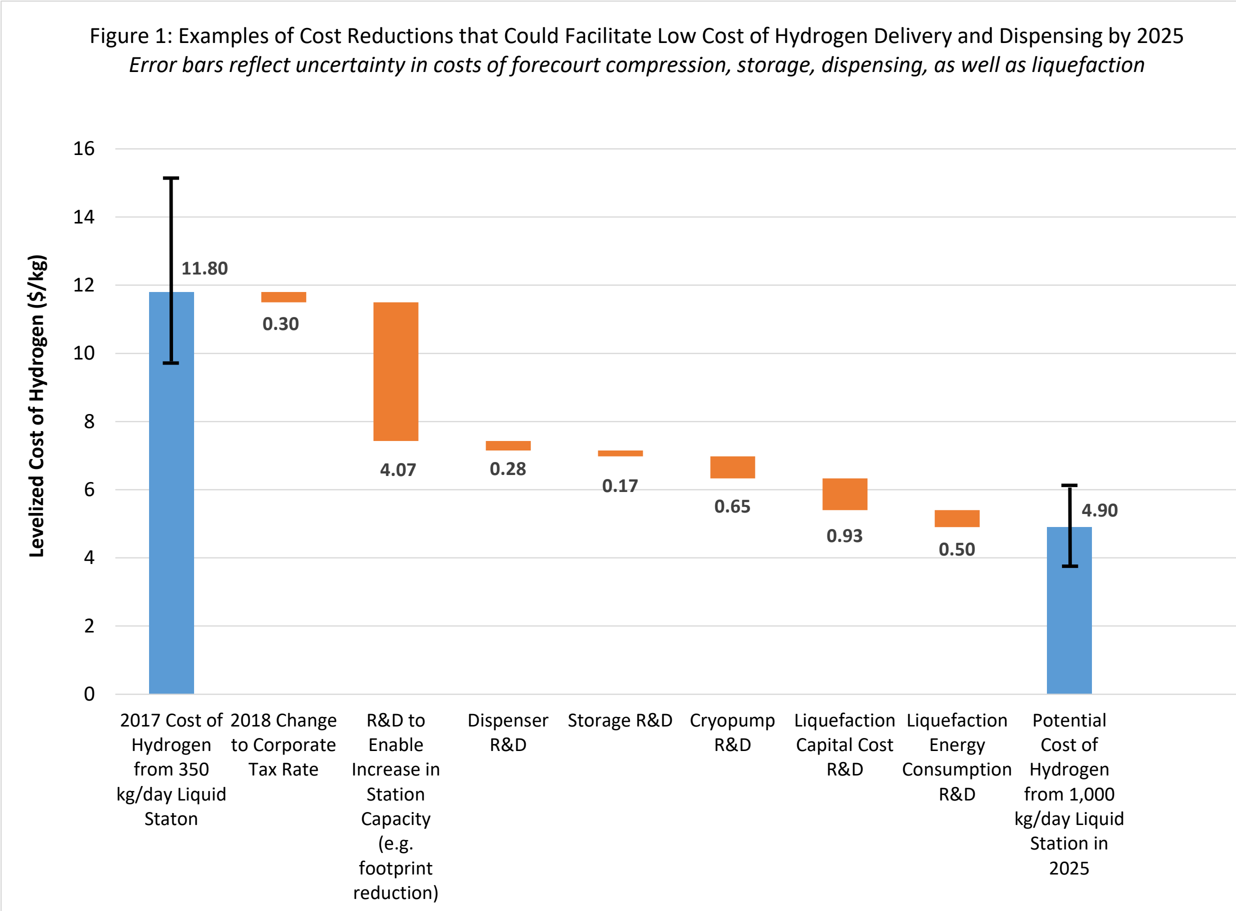

Figure 1. Examples of R&D that can reduce the cost of hydrogen delivery and dispensing to $5/kg by 2025, from the 2017 projected cost of $11.80/kg from a 350 kg/day station supplied by liquid hydrogen. Detailed information is included in the DOE Hydrogen and Fuel Cells Program Record 18003.

ACCOMPLISHMENTS

Technology Acceleration and Hydrogen Infrastructure R&D accomplishments in FY 2018 include the following.

- The Program awarded three new projects through the Small Business Innovation Research program, focused on developing novel membranes with sufficient durability for 875-bar electrochemical hydrogen compression, and non-destructive evaluation technologies for stationary pressure vessels.

- In collaboration with the Hydrogen Fuel R&D and Fuel Cell R&D subprograms and with industry input, the Program developed technical targets for the cost and performance of medium- and heavy-duty vehicles powered by fuel cells. Key metrics included fuel cell costs, vehicle fill time, storage cycle life, and fuel cell life.

- In collaboration with the Safety, Codes and Standards and Hydrogen Fuel R&D subprograms, the Program initiated activities to launch the Hydrogen Materials Compatibility (H-Mat) national laboratory consortium. H-Mat will conduct materials research to reduce the costs and enhance the durability of steels and polymers in hydrogen service.

- One of the 27 prototype fuel cell electric buses undergoing performance evaluation by NREL exceeded DOE's ultimate target for fuel cell durability of 25,000 hours. Twelve have exceeded 19,000 hours to date. NREL has been collecting data on bus maintenance costs and hydrogen consumption and completed its annual report on status versus targets.[7]

Key project-level accomplishments in FY 2018 include the following.

Station Technologies

- GVD Corporation determined that its novel coatings for hydrogen compressor seals reduce seal erosion by 70%. GVD's coatings comprise polymeric and inorganic layers that enhance seal flexibility and lubricity and are expected to reduce hydrogen permeation by 10-fold.
- Giner ELX achieved the highest known efficiency of 350-bar electrochemical hydrogen compression: 4 kWh/kg, at an inlet pressure of 100 bar and outlet pressure of 350 bar. Giner's compressor concept relies on novel aromatic membranes that achieve 30% less drag than conventional perfluorosulfonic acid membranes and 50% less back diffusion.
- Ivys Energy Solutions established that its approach to wireless communication between vehicles and fueling stations, using digital short-range communication, can exceed the requirements of the SAE International J2799 standard. Ivys also established that its novel metering technology, based on Coriolis meters, can achieve an accuracy of at least 2%.

Materials Compatibility

- Researchers at Sandia National Laboratories, Oak Ridge National Laboratory, and the National Institute of Standards and Technology completed fatigue testing of X100 base metal and welds in 210-bar hydrogen. The data generated can be used to enable use of X100 steels in hydrogen pipelines, which could reduce initial capital cost by more than 40% relative to conventional X52 steels. The team's analyses also identified microstructural features of steel, such as high-angle grain boundaries, that may reduce crack growth rates by 4–5 times.

Liquid Hydrogen Technologies

- Pacific Northwest National Laboratory designed an approach to integrate variable diversion flow valves with a regenerator for magnetocaloric materials that will ultimately be used to liquefy hydrogen at twice the efficiency of conventional liquefaction. Variable diversion flow valves enable optimization of the amount of heat transfer fluid that passes through each layer of materials. Each layer achieves a different temperature when the regenerator is operating and experiences different amounts of heat transfer from the layers above and below. The ability to precisely control the amount of fluid that each layer experiences is therefore essential to the concept's success.

Manufacturing R&D

- NREL and Gore scanned two rolls of fuel cell membrane material on a web-line optical research apparatus at NREL to obtain a 2-dimensional thickness map (at ~1 mm spatial resolution). This map can be easily analyzed to locate where thickness is above or below defined thresholds for quality control. In-line mapping of thickness will help enable high-volume manufacturing and cost reduction of membranes for fuel cells and electrolyzers. Preliminary discussions to perform a more extensive study of membrane thickness distributions have begun.
- NREL used roll-to-roll coating to develop gas diffusion electrodes approximately 200 times faster and with superior performance compared to spray-coated electrodes. Electrodes manufactured with roll-to-roll techniques, unlike spray coating, do not require an ionomer film to be sprayed onto the catalyst layer

[7] The report summarizing data on fuel cell bus performance is available here: https://www.nrel.gov/docs/fy19osti/72208.pdf

to maximize performance, which eliminates additional material costs (no need for extra ionomer and solvents) and reduces manufacturing time (fewer processes).

- Mainstream Engineering, NREL, and the Georgia Institute of Technology deployed prototype optical systems using cross-polarized light to monitor membrane films continuously for simultaneous film thickness mapping and defect detection at speeds up to 300 ft/min on polyethylene terephthalate. This technique provides real-time automated in-line defect and thickness mapping and will help improve the manufacturing process by providing real time feedback, increasing reproducibility, and reducing labor costs.

Fuel Cell Technology Validation

- ANL completed performance evaluation of the Toyota Mirai under varying conditions, including outside temperature (-7°C to 35°C). A final report from the project has been published here: https://publications.anl.gov/anlpubs/2018/06/144774.pdf.

Hybrid Energy Systems R&D

- Idaho National Laboratory completed installation of a test stand for 25-kW high-temperature electrolyzers. High-temperature electrolyzers have the potential to utilize heat from nuclear power plants to produce hydrogen with up to 30% less electricity than low-temperature electrolysis. Key metrics that must be validated include long-term durability, particularly when energy supply is variable.

- Significant innovations were incorporated into the development and operation of a hydrogen fueling station operated by the Natural Energy Laboratory Hawaii Authority (NELHA). For instance, the Hawaii Natural Energy Institute developed a tool to simulate electrolyzer performance as a function of key parameters (e.g., operating pressure and temperature, current density, membrane thickness, hydration factor) and developed another tool that simulates grid integration of electrolysis. The team also integrated a booster compressor with NELHA's fueling station that can recover up to 90% of the hydrogen in 450-bar tube trailers, reducing delivery costs by up to 50%.

New Project Selections

In FY 2018, the Program added the following new projects through a funding opportunity announcement (FOA).

- Four projects will focus on integration of electrolyzers with renewable energy and hydrogen distribution infrastructure, electrolysis of wastewater, production of synthetic fuels, and autonomous fueling of vehicles.[8] (Equilon Enterprises, dba Shell Oil Products US; Plug Power; Giner, Inc; Skyre, Inc.)

- Four projects will conduct R&D that reduces the costs of manufacturing electrolyzer components, using advanced techniques such as additive manufacturing. (3M Company; University of Tennessee Space Institute; University of Connecticut; Clemson University)

- One project will develop innovative concepts to improve efficiency and reduce the capital cost of hydrogen liquefaction, using a vortex tube concept. (Washington State University)

- Two projects will develop innovative cryocooler concepts to reduce the footprint of hydrogen fueling stations. (NREL; Gas Technologies Institute).

- One project will perform metal hydride materials discovery for nonmechanical hydrogen compression, in collaboration with the Hydrogen Materials Advanced Research Consortium. (Greenway Energy)

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[8] Projects were selected to comply with FY 2018 congressional direction.

BUDGET

The FY 2018 budget for Technology Acceleration and Hydrogen Infrastructure R&D projects totaled about $35 million. The funding breakout is shown in Figure 2 and includes $19 million appropriated for Technology Acceleration, which includes $3 million for Manufacturing R&D. Hydrogen delivery R&D funding ($16 million) is included in the breakout below to be consistent with the President's budget request and FY 2019 appropriations, both of which defined a new Hydrogen Infrastructure R&D subprogram line item, which includes hydrogen delivery R&D. The budget emphasized new project selections in the areas of electrolyzer manufacturing, integrated energy systems, hydrogen chillers, compressors, and liquefaction technologies, in support of H2@Scale and congressional direction. In some cases, such as liquefaction and compression, FY 2018 funding is minimal because ongoing projects are being funded by prior year appropriations. The budget also represents launch of the H-Mat consortium on early-stage materials compatibility R&D via a lab call at the end of FY 2018. Finally, the budget included ongoing R&D from FOA selections in previous years in fueling station technologies and fuel cell manufacturing.

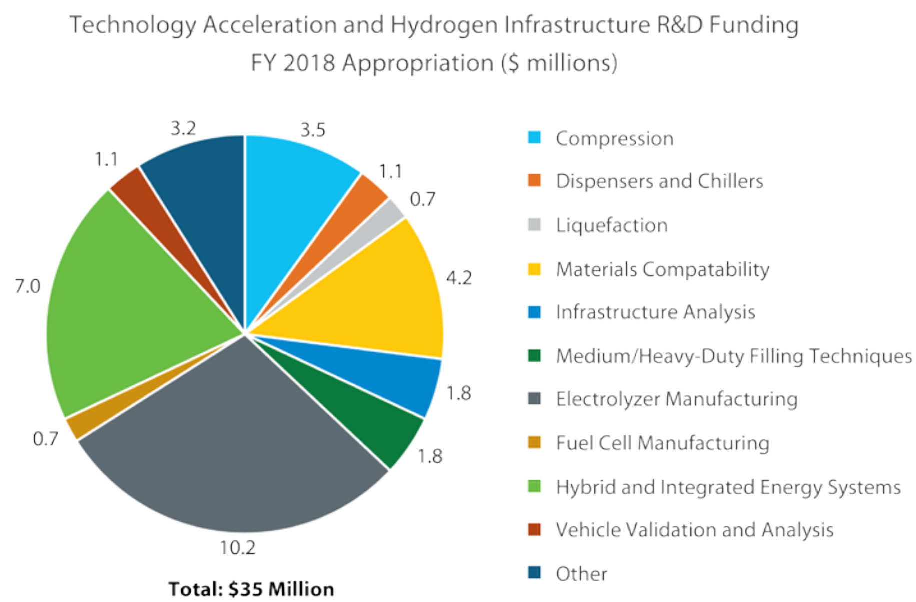

Figure 2. Technology Acceleration and Hydrogen Infrastructure R&D FY 2018 appropriation

UPCOMING ACTIVITIES AND PLANS

The future plans for Technology Acceleration and Hydrogen Infrastructure R&D, pending funding appropriations, include the following.

- Expand early-stage R&D on materials compatibility through the H-Mat Consortium. R&D beginning in FY 2019 focuses on enhancing the toughness of high-strength steels with potential for use in 875-bar pressure vessels, enhancing the durability of polymers used in hydrogen seals, and understanding the effects of water vapor on hydrogen embrittlement in aluminum alloys. A key focus in FY 2019 will be expanding stakeholder engagement with H-Mat.
- Expand R&D on technologies for medium- and heavy-duty hydrogen filling. Efforts in FY 2019 will be guided by technical targets for filling technologies and techniques that were developed in FY 2018 through analysis and stakeholder engagement. R&D will build on filling techniques being investigated in

a cooperative research and development agreement project that was selected for DOE cost match in FY 2018.

- Continue to leverage cross-office and cross-agency R&D opportunities and resources, including expanded collaboration with the National Science Foundation, the DOE Office of Basic Energy Sciences, and Advanced Research Projects Agency-Energy.

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