III. HYDROGEN DELIVERY

III.0 Hydrogen Delivery Sub-Program Overview

Introduction

Hydrogen must be transported from the production site to a fueling station or stationary power site or produced on-site. It also must be compressed, stored and dispensed at refueling stations or for stationary power generation. Due to its relatively low volumetric energy density, current transportation, storage, and final delivery entail significant costs and inefficiencies for hydrogen as an energy carrier. The Hydrogen Delivery Sub-Program activity focuses on developing technologies to reduce the cost and increase the energy efficiency of hydrogen delivery during the mid-term and long-term use of hydrogen as a major energy carrier.

Three potential delivery pathways are being considered: gaseous hydrogen (trucks or pipelines), liquid hydrogen (trucks), and novel solid or liquid hydrogen carriers (trucks or pipeline). A carrier is a material that stores hydrogen at lower pressures and higher temperatures. Examples of potential hydrogen carriers include metal or chemical hydrides, nanostructures, and liquid hydrocarbons that can be easily dehydrogenated and re-hydrogenated with a round-trip efficiency greater than 60%.

Goal

Develop hydrogen delivery technologies that enable the introduction and long-term viability of hydrogen as an energy carrier for transportation and stationary power.

Objectives

- By 2012, reduce the cost of compression, storage and dispensing at refueling stations and stationary power facilities to <$0.80/gasoline gallon equivalent (gge) of hydrogen (independent of transport). By 2017, reduce this cost to <$0.40/gge.
- By 2014, reduce the cost of hydrogen transport from central and semi-central production facilities to the gate of refueling stations and other end-users to <$0.90/gge of hydrogen. By 2019, reduce this cost to <$0.60/gge.
- By 2019, reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/gge of hydrogen in total.

Fiscal Year 2009 Technology Status

Current costs for the transport of hydrogen range from $3 to $9/gge. This is based on transport by gaseous tube trailers or cryogenic liquid tank trucks and is dependent on the quantity of hydrogen and distance that the hydrogen is transported. Pipeline transport costs are at the lower end of the costs range, and are also dependent on transport distance and quantities. These transport costs do not include the delivery costs associated with compression, storage and dispensing at fueling sites. These additional costs could be as high as $2-3/gge of hydrogen.

In order to achieve the long-term goal of $1/gge for the cost of hydrogen delivery, and to have commercially viable costs during the transition period, significant technology development is needed. Challenges to be overcome include:

- **Pipelines**: resolve hydrogen embrittlement concerns with steel pipelines, reduce capital costs by developing new steel compositions and/or welding and installation techniques, and/or develop viable composite pipeline technology with reduced capital costs.
- **Tube Trailers**: increase gaseous tube trailer capacity and lower trailer costs to reduce overall hydrogen delivery cost, especially during a market transition.
- **Compression**: develop more reliable and lower cost hydrogen compression technology for pipeline transmission and stationary as well as refueling station applications.

- **Storage**: develop lower capital cost off-board storage technology; confirm the technical feasibility and adequate availability geologic storage for hydrogen.
- **Liquefaction**: reduce the capital cost and increase the energy efficiency of hydrogen liquefiers.
- **Carriers**: leverage the National Hydrogen Storage Project for on-board storage applications to determine if a novel solid or liquid carrier might be suitable for hydrogen transport or off-board storage and result in lower delivery costs and higher energy efficiency.
- **Analysis**: comprehensive analysis of the options and trade-offs of hydrogen delivery approaches for the near-term and long-term.

FY 2009 Accomplishments

- To overcome the embrittlement and capital cost concerns of steel pipeline materials, research is being conducted on fiber reinforced polymer (FRP) pipelines. In FY 2009, researchers at Oak Ridge National Laboratory and Savannah River National Laboratory (SRNL) concluded a testing regimen on a commercially available FRP pipeline material and achieved the following:
  - Hydrogen compatibility tests following eight months of accelerated-aging tests (equivalent to five or more years at room temperature) showed no degradation.
  - Pipeline material passed blow-down testing.
  - The leakage rate for the FRP pipeline was measured to be less than 0.02 percent, compared with the 2017 target leakage rate of less than 0.5 percent.
  - The measured leakage rate of a pipeline joint was approximately 0.5 kg H_2 per year per joint.
- SRNL and the American Society of Mechanical Engineers (ASME) also prepared an action plan that outlines the necessary elements for design and life management of FRP for hydrogen service. Life management is a process for assessing and mitigating pipeline risks in an effort to reduce both the likelihood and consequences of incidents. This paper is the first step towards the development of the necessary ASME codes for FRP hydrogen pipeline delivery.
- Work continued to increase the capacity (currently approximately 300 kg H_2) while reducing the cost of gaseous tube trailers.
  - Lincoln Composites developed the design and manufacturing procedures for the 600 kg H_2 tanks, including large-scale dome molding and tubular welding; filament winding; curing and coating; and proof testing. The tanks passed both burst and penetration (gun fire) testing.
  - Lawrence Livermore National Laboratory continued their work to develop an innovative tube trailer design that would triple the capacity to 1,100 kg H_2 through the use of high-strength, low-cost glass fiber instead of carbon fiber. The researchers demonstrated that the glass fiber strength is 80 percent higher at 140 K versus 300 K. To optimize the strength of the glass fiber, the tube trailer would transport cold or cryo-compressed hydrogen. Glass fiber also has the added benefit of a substantially reduced cost ($6/kg for glass fiber vs. $23/kg for carbon fiber) resulting in a 50 percent trailer cost reduction ($200,000 instead of $400,000) while holding three times as much hydrogen.
- Compression will be needed at various points throughout the hydrogen delivery infrastructure and researchers are making progress on lower cost, higher reliability hydrogen compressors.
  - The use of mass produced components could result in a dramatic cost savings for compressors, especially in early markets. Concepts NREC is developing a centrifugal compressor for hydrogen made from off-the-shelf components designed for natural gas service. Concepts NREC evaluated 30 compressor-gearbox configurations, materials, and compressor-drive options, and determined the best combination of components.
  - FuelCell Energy increased the capability of their compressors from 3,000 psi to 4,500 psi in a single-stage electrochemical compression cell. By decreasing the number of stages required to compress hydrogen, they can lower the capital costs. FuelCell Energy completed over 1,000 pressure cycles without a performance loss. That work may ultimately reduce compressor

maintenance costs and compressor downtime. These two aspects are major contributors to delivery cost and bring the program closer towards the 2017 goal of highly-reliable compressors at both the forecourt and potentially for pipelines.

- Progress was made in lowering the cost of liquefaction.
  - Prometheus is working on an innovative liquefier called the Active Magnetic Regenerative Liquefier. Utilizing magnetic cooling, this could reduce the energy by 50% as compared to conventional gas expander liquefiers, and may reduce the capital costs to liquefy hydrogen by 30%, therefore bringing the program closer to reaching the goal of $1/kg of delivered hydrogen. In 2009, they completed the design for and began construction of their lab-scale magnetic hydrogen liquefier prototype. The prototype will be the first demonstration of the concept.
- A number of accomplishments were also made in hydrogen delivery analysis.
  - Argonne National Laboratory (ANL) added 700 bar fueling and cryo-compressed fueling to the Hydrogen Delivery Scenario Analysis Model (HDSAM). They found, among other things, that 700 bar gaseous hydrogen (GH_2) fueling employing a high pressure cascade system was only 15% more expensive than 350 bar GH_2 fueling. In addition, ANL showed that hydrogen station costs for 700 bar vehicles using booster compressors was 70% higher than the station cost for filling cryo-compressed vehicles with a cryopump.
  - The National Renewable Energy Laboratory designed a preliminary version of the Hydrogen Rail Components Model to be used as an add-on to the HDSAM model. The model allowed them to calculate the costs of delivering hydrogen via the rail network. Rail delivery appears to be a viable low-cost option for long distance transport.

Budget

The President's FY 2010 Hydrogen Delivery budget request was $0 as the program refocuses efforts toward near-term fuel cell technologies that include stationary, portable, and specialty applications, e.g., fork lifts.

2010 Plans

Final reports documenting progress will be issued in FY 2010. The applied research and development program in the Office of Energy Efficiency and Renewable Energy will coordinate with the Office of Science, which plans to include up to $50M of basic research related to hydrogen and fuel cell technologies. Through basic science activities, a fundamental understanding of issues such as hydrogen embrittlement can help address the challenges of hydrogen technologies in the long term. In addition, through the development projects funded by the American Recovery and Reinvestment Act of 2009, lessons learned and best practices related to hydrogen delivery technologies will be determined.

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