III.3 Hydrogen Regional Infrastructure Program in Pennsylvania*

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- Air Products and Chemicals, Inc., Allentown, PA
- Resource Dynamics Corporation, Vienna, VA

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*Congressionally directed project

Objectives

Analysis of Hydrogen Energy Stations for Initial Hydrogen Infrastructure in Northeastern States along the I-95 Corridor

- Assess the feasibility of a hydrogen infrastructure based on the concept of hydrogen energy stations along the northeastern I-95 corridor states.

Hydrogen Sensors

- Advance current hydrogen-specific sensors and sensor technologies to ensure reliable operation and performance in hydrogen applications.

Technical Barriers

This project was executed to address the following technical barriers from the Hydrogen Delivery section (3.2.4) [1] of the DOE's Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan (MYRDDP):

(A) Lack of Hydrogen/Carrier and Infrastructure Options Analysis
(K) Safety, Codes and Standards, Permitting
(I) Hydrogen Leakage and Sensors
(J) Other Refueling Site/Terminal Operations

Technical Targets

The Hydrogen Regional Infrastructure Program in Pennsylvania project was established to conduct research in multiple areas. Insights gained from these studies are being used to address the following technical targets detailed in the Hydrogen Delivery section of the MYRD&DP:

Hydrogen Energy Stations for Initial Hydrogen Infrastructure in Northeastern States along the I-95 Corridor

- DOE's 2015 target of \$2.00–\$3.00/gge (delivered, untaxed) at the pump for hydrogen

Hydrogen Sensors

- Hydrogen leakage (% of hydrogen leakage from pipeline): <0.5% (2017)

Accomplishments

The following items are accomplishments to date for the Hydrogen Regional Infrastructure Program in Pennsylvania project:

Analysis of Hydrogen Energy Stations for Initial Hydrogen Infrastructure in Northeastern States along the I-95 Corridor

- Analyzed using lighthouse projects that could serve as an anchor for various hydrogen fueling stations. Focused on hydrogen energy stations, landfill gas and anaerobic digestion gas, and coke oven gas.
- Gathered site-specific and state-specific data, including actual costs for natural gas and electricity.

Hydrogen Sensors

- Achieved successful integration of the hydrogen sensor into a complete sensor package.

Section 1. Pennsylvania Hydrogen Delivery and the I-95 Corridor

Introduction

Hydrogen is expensive to produce and distribute in small volumes, relative to gasoline costs. Phase II work showed that for the 1 percent demand scenario, the costs required to produce and deliver hydrogen from a central plant were over \$9/kg. Distributed production produces hydrogen in smaller quantities with natural gas directly at the fueling stations, and avoids the costs of delivery. Using this method, hydrogen costs were lower, around \$7/kg (Figure 1). These costs are significantly higher than the DOE goal of \$3/kg, and current gasoline prices. Eventually, as demand builds to more modest levels, delivered costs approach the \$3/kg DOE goal and compare with current gasoline prices.

The I-95 corridor from Washington, DC to Boston, Massachusetts is an important market for hydrogen and hydrogen analysis because it contains 10 closely-tied metropolitan statistical areas (MSAs)[1], with four of the nation's largest cities, as well as a variety of potential feedstocks and delivery infrastructures. This places an importance on establishing hydrogen infrastructure within this key transportation corridor as it is reflective of many of the challenges the nation faces in moving towards a hydrogen economy.

Approach

The analysis of hydrogen energy stations (HESs) illustrates the benefits of investing in infrastructure that serves a dual purpose, providing heat and power to its host site while also furnishing a modest amount of hydrogen for refueling purposes.

Results

The results of the analysis show that investment in HESs (Figure 1, Tables 1, 2, 3 and 4), in part due to existing state and federal incentives, can provide attractive return on investment in states such as New Jersey and Connecticut, and provide lighthouse projects upon which the I-95 hydrogen economy can be grown. Similar incentives may be needed in other states, to provide a clustering of refueling sites, until hydrogen demand can be built high enough to attract dedicated hydrogen refueling and lower production and delivery costs are realized with increased demand scenarios and combined MSAs.

The states with the most attractive economics for renewable gas (biogas from landfills and wastewater treatment plants) and natural gas-based HES applications along the I-95 Corridor are Connecticut, New Jersey, New York and Pennsylvania. All of these states contain numerous sites in close proximity to the I-95 Corridor. With these HES installations at strategic locations in these states, a hydrogen economy with vehicle refueling stations would begin to emerge.

[1] From South to North: Washington, D.C., Baltimore, Philadelphia, Trenton, New York, Bridgeport, New Haven, Hartford, Providence, and Boston

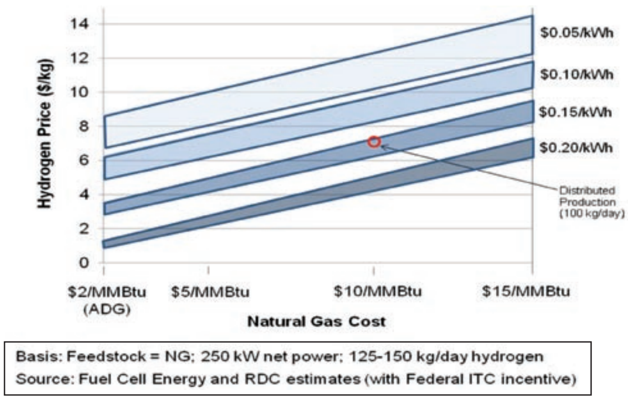

FIGURE 1. Cost of Producing Hydrogen with HES for Prevailing Electricity and Natural Gas Costs

While the HES 300 is seen as a good starting point for potential HES projects, the larger HES 1500 and HES 1600 systems provide better economics under current market conditions, provided that all of the heat and power can be utilized on-site. Several states have sites that are offering estimated payback periods of shorter than three years, with most sites offering paybacks in the 3–4 year range, for the renewable HES. However, only Connecticut and New York show three-year payback potential for the natural-gas HES, with all industrial sectors in Connecticut having payback periods less than three years.

Table 4 provides results from the various sites that were used as case studies, and suggests ways to improve project economics. For the case studies, only the HES 300 and HES 1500 are considered, as these options reflect HES that have been engineered as a system. While this analysis confirms that sites with positive economics are available, those with attractive (less than three-year payback) economics are not so easily found, but do exist.

There are four of the 19 active domestic coke plants in Western Pennsylvania near Pittsburgh. The waste gas streams from these coke ovens provide not only the most cost-effective, but also the most environmentally-green feedstock for hydrogen production. This production pathway would be the most likely to witness beneficial results for a hydrogen economy in the near-term. The price differential between hydrogen and natural gas offers enough financial benefits to coke producers to make the entire stock available for hydrogen production as long as there are sufficient market demands. This region shows a huge potential for a wide-spread deployment of hydrogen-powered fuel cells for light-duty vehicles and power generation stations and is well-positioned to benefit from the readily accessible coke plants.

TABLE 1. Hydrogen Energy Station Configurations

HES Configuration	HES 300	HES 1500	HES 400	HES 1600
Fuel Cell Module	DFC 300	DFC 1500	Purcell 400	4 x Purecell 400
Electrical output (kW)	300	1350	380	1520
Hydrogen output (kg/day)	125	125	27	108
Thermal output (kW)	75	300	480	1900
Notes	Employs a custom-designed hydrogen purification unit developed by Air Products. Electrical, thermal and hydrogen output provided by Fuel Cell Energy.		Employs an off-the-shelf hydrogen purification unit developed by H2Gen. Thermal and hydrogen output estimated by RDC from product literature based on 5 percent of reformer output diverted from fuel cell.	

TABLE 2. Number of Sites Capable of Supporting Renewable HES Projects, by State and Estimated Payback Period

City/State	Payback < 3 Years	Payback 3–5 years	Payback 5–7 years	Total
Connecticut	6	1	3	10
Washington, DC	1	0	0	1
Boston, MA	0	0	1	1
New Jersey	2	16	2	20
New York, NY	11	6	0	17
Philadelphia, PA	3	1	0	4

TABLE 3. Number of Sites Capable of Supporting Natural Gas HES Projects, by State and Estimated Payback Period

City/State	< 3 Years	3–5 Years	5–7 Years	Total Potential NG Sites
Connecticut	900	10,474	722	12,096
Washington, DC	0	0	80	80
Boston, MA	0	0	0	0
New Jersey	0	0	2,450	2,450
New York, NY	0	57	11,574	11,631
Philadelphia, PA	0	0	3,253	3,253

Conclusions and Future Directions

While the prospects for HES in D.C. and Boston do not look promising with current price and performance estimates and market conditions, there appears to be a great deal of potential on the I-95 Corridor from Philadelphia through New Jersey, New York, and Connecticut. The keys are targeting the large renewable sites (landfills and wastewater treatment plants), manufacturing facilities, hospitals, and other commercial sites with positive HES economics along the I-95 Corridor, and identifying uses for the hydrogen produced that will procure hydrogen at the rate of $7/kg. This may include distribution centers with battery-powered forklifts that can be converted to fuel cell-powered units, sales contracts with industrial facilities, or hydrogen refueling stations for fuel cell vehicles. In a developing hydrogen economy, HESs could play a crucial role in implementing an early infrastructure of refueling stations for light duty fuel cell vehicles along the I-95 Corridor.

TABLE 4. HES Case Studies of Individual Sites along the I-95 Corridor

State	Site	HES Option	Est. Payback Period (Yrs.)	Areas to Improve Payback
CT	Hospital	HES 1500	2.4	The 2008 natural gas costs used in the analysis are relatively high – lower costs would lower the payback period.
CT	Travel Center	HES 300	5.3	Facility averages about 180 kW, while HES output is 250 kW – in an average hour, 180 kWh replaces high-price electricity, while 70 kWh is sold at utility's avoided cost – economics improve for larger facilities.
DE	Big Box Distribution Center	HES 1500	8.2	Delaware currently offers no state incentive – a $1 million incentive would lower payback by almost 2 years. Also, little/no thermal demand in summer months.
NJ	Distribution Center	HES 300	9.6	Thermal load is nonexistent in summer months, so excess thermal energy must be dumped – finding an outlet for this energy would improve project economics.
NJ	Hospital Complex	HES 1500	7.2	Electricity and natural gas prices were typical for New Jersey – RECs or other incentives for natural gas fuel cells would help economics.
NJ	Rutgers EcoComplex LFG	HES 300	7.8	LFG availability only 85 percent; facility is too small for HES 300 base load operation, so excess electricity is sold through net metering at the avoided cost rate – a larger facility with more accessible LFG would obtain a better payback.
NY	Big Box Distribution Center	HES 1500	5.4	Little to no thermal demand during the summer months – if excess thermal energy could be utilized, project economics would improve.
		HES 1500 with Fuel Cell Forklifts	3.6	Incorporating the forklift investment to convert fleet to fuel cells creates on-site demand for hydrogen, and improves payback for combined investment. Investment includes additional hydrogen purification.
PA	Grocery Distribution Center	HES 300	18.6	Low electricity prices, high natural gas prices, and low summer thermal demand prevent this site from achieving a desirable payback period.

RECs - renewable energy credits
LFG - landfill gas

To facilitate the early adoption of HESs, the DOE should consider a two-pronged approach. First, there are a number of potential sites in the New York and Connecticut areas that could deploy HES technology economically. Work would have to be done to locate these sites and find a host for the hydrogen output. Potential options other than a vehicle refueling station include distribution centers that could convert to fuel cell forklifts, and industrial or institutional purchasers of hydrogen. Secondly, many of the sites contacted in this project were unaware of HESs and even of the developmental status of stationary fuel cells in general. To accomplish heightened awareness, an educational campaign could also be launched in concert with the states along the I-95 Corridor to provide factual information about fuel cells as well as a vision for the hydrogen economy. Addressing both of these recommendations would remove some of the key barriers to HES adoption, as well as those impeding a hydrogen infrastructure in general.

Since Pittsburgh is strategically located near four major coke plants, it is recommended that a multi-year feasibility study and demonstration project be pursued at the DTE Shenango coke battery to verify and validate the concept and cost benefits as well as to identify and solve any technical problems associated with practical application of the coke oven gas-to-hydrogen production process.

Section 2. Hydrogen Sensors

Introduction

The objective of the Phase III sensor work was to develop and fabricate a hydrogen sensor unit and install the unit at a hydrogen refueling station. The sensor technology and manufacturer used during the Phase III work was selected previously during the Phase II portion of this project. The hydrogen sensor unit developed also included remote monitoring capabilities. Testing and operation of a completed unit was also included in Phase III.

Approach

During Phase I and Phase II of the Hydrogen Regional Infrastructure Program in Pennsylvania, sensor technology A was selected as the optimum technology to be used in creating a complete H_2 sensor unit in Phase III. As part of Phase III, an actual hydrogen sensor unit was designed and assembled.

Results

Based on the results and work conducted as part of Phases I and II, sensor technology A was selected to be used in Phase III to develop and test a hydrogen sensor unit. This technology was selected for the following reasons:

- The sensor has had at least five years of development, and the microelectronic manufacturing process steps have been well developed in producing other types of sensors by the manufacturer.
- Testing results showed that the sensor had the highest speed of response of all the sensors tested. Fast response time leads to innovative applications.
- Testing results showed that the sensor had no detectable interferences from components found in natural gas systems.
- Of the available palladium-based sensors, this sensor had the lowest power requirements. The benefit is the impact on power sourcing requirements and promotes innovative applications.

During the Phase III efforts, the hydrogen sensor unit was developed and fabricated at an affiliate of Air Products' located in New Mexico. Following the assembly, the unit was laboratory-tested at the manufacturing location and then shipped to Air Products' facility in Allentown, Pennsylvania where further laboratory testing was conducted. The purpose of the laboratory testing was to ensure the unit was operating as expected.

The results of the testing showed that the sensor unit possesses hydrogen-specific response (<0.0500% to >4.000% H_2), no other molecular interferences, high speed response (<0.5 second), wireless (1 mile) and internet protocol communications, and has designed-in adaptability for future expansions such as an internal self-test specific for hydrogen (unique to this system). The results of the laboratory testing were satisfactory and showed the unit was operating as expected. Following this testing, the units were installed at a shuttle bus refueling station that is located on Air Products' Campus in Allentown, Pennsylvania.

Conclusions and Future Directions

The sensors work was completed at the end of Phase III for this project. It is expected that the unit will be operated and tested at this refueling station during a future project.

FY 2009 Publications and Presentations

1. Eileen M. Schmura, Paul L. Lemar, Jr and Sarah Largent, *Northeastern I-95 Corridor and Pennsylvania Indigenous Energy*, NHA Annual Hydrogen Conference 2009, Columbia, SC, (April 2009).

2. Paul L. Lemar Jr. and Eileen Schmura, *Building a Transitional Hydrogen Infrastructure Using Warehouses as Lighthouse Projects*, NHA Annual Hydrogen Conference 2009, Columbia, SC (April 2009).

3. Kevin L. Klug, *The Department of Energy's Pipeline Working Group Round Robin Test Program*, 2008 International Hydrogen Conference, Wyoming, (September 2008).

4. Vladimir M. Shkolnikov, *Fatigue Performance of Composite Overwrapped Pressure Vessels*, NHA Annual Hydrogen Conference 2009, Columbia, SC (April 2009).

References

1. DOE, "Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan," April 27th, 2007.