Development of a Natural Gas to Hydrogen Fuel Station

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Subcontractor: FuelMaker Corporation

Objectives

- The overall objective is to develop cost-competitive technology suitable for distributed production of high-pressure hydrogen from natural gas to fuel hydrogen-powered vehicles.
- Design and test a fast-fill natural gas to hydrogen fueling system with 40-60 kg/day delivery capacity.
- Produce high-pressure hydrogen at $2.50/kg or less to meet intermediate cost targets.
- Demonstrate innovative, compact natural gas steam reforming system and appliance-quality hydrogen compressor technologies.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Fuel Processor Capital Costs
- B. Operation and Maintenance (O&M)
- C. Feedstock and Water Issues
- E. Control and Safety
- Z. Catalysts
- AB. Hydrogen Separation and Purification

Approach

- Undertake system design and analysis to identify pathways for meeting cost and performance targets.
- Conduct subsystem development and laboratory testing to confirm unit operation and suitability for complete system application.
- Combine subsystems into an overall integrated system that incorporates system controls and safety features.
- Conduct lab and field experiment testing to validate the complete system for performance, operability, and reliability.

Accomplishments

- Comprehensive subsystem and system design report completed.
- Laboratory prototype fuel processor (alpha unit) subsystem built and tested under a wide range of operating conditions, including start-up, steady-state, turndown, and dynamic response rates.

- Full-scale high-pressure hydrogen cascade and environmental chamber constructed.
- First-principle hydrogen cylinder filling model developed (CHARGE H_2).
- Comprehensive set of hydrogen fast-fill tests conducted on two different types of cylinders, including tests beginning at cold and hot ambient temperatures.
- Documented and reported on degree of in-cylinder temperature rise and spatial variability during fast-filling process.
- Paper presented at National Hydrogen Association (NHA) meeting on fast filling of hydrogen cylinders.
- Advanced hydrogen filling dispenser algorithm developed (H_2 AccuFill).
- All-new, oil-free primary hydrogen compressor designed and built for compressing reformed gases (80% hydrogen/20% carbon dioxide) up to 100 psig.
- Pressure swing adsorption (PSA) test facility constructed.
- PSA tests initiated to evaluate multi-component fuel treatment and removal strategies.
- Comprehensive model developed for analyzing hydrogen-fueling station costs, including capital, operating, and maintenance cost elements. Program includes Monte Carlo techniques to account for uncertainty and variability in cost drivers.
- Paper on hydrogen fueling system economics prepared and presented to World Hydrogen Energy Conference.
- Engaged in various technology transfer and communications efforts, including: display of system design at event for President Bush, presentation at SAE TOPTEC, presentation for SAE Industry-Government meeting, International Energy Agency Forum, and one-on-one meetings with various North American, European, and Asian organizations and companies.

Future Directions

- Complete subsystem testing and evaluation of fuel processor, primary compressor, PSA fuel purification, secondary compressors, and dispenser filling algorithm.
- Continue building of the first-generation integrated natural gas to hydrogen fueling system, beginning with system "front end" that includes fuel processor, water treatment and recovery, and primary compression, followed by the system "back end" including PSA subsystem, secondary compression, storage, and dispenser hardware.
- Work with various parties interested in technology transfer, licensing, and/or testing of core subsystems and overall integrated fueling station.

Introduction

A key impediment to expanded fuel cell vehicle use is fueling infrastructure. The use of distributed hydrogen fueling systems is seen as an intermediate pathway to permit infrastructure development (with future development of a hydrogen pipeline delivery infrastructure). This project aims to leverage the substantial natural gas delivery infrastructure by developing a distributed natural gas to hydrogen fueling system.

Several key technologies are being developed in this project. This includes a highly compact, cost-effective steam methane reformer and fuel-processing technology originally developed by GTI for stationary proton exchange membrane (PEM) fuel cells. This unit has been adapted to serve as a hydrogen generator for fueling stations. Experience with compressed natural gas vehicles is being leveraged through modification and development of intermediate and high-pressure hydrogen compressors with FuelMaker Corporation. An additional core effort is development of a hydrogen dispenser with an advanced filling algorithm that will permit accurate and complete filling of compressed hydrogen vehicles under a range of conditions. These advanced subsystems - reforming, fuel cleanup, compression, storage, and dispensing - will be incorporated into an integrated and cost-competitive small natural gas to hydrogen fueling station that will support hydrogen fueling infrastructure development and expansion.

The specific goals for this project are a fast-fill natural gas to hydrogen fueling system with 40-60 kg/day delivery capacity. DOE goals include providing hydrogen at costs of $2.50/kg or less, as part of an intermediate path to $1.50/kg.

Approach

The project approach is to develop and test key subsystems (fuel processor, compression, fuel purification, storage, and dispensing) and then integrate these subsystems with controls into an overall cost-effective hydrogen fueling solution. The project approach includes three phases: 1) Design, 2) Development and Lab Testing, and 3) Field Testing. Through these progressive phases, GTI anticipates building a proven small natural gas to hydrogen fueling system that can support the development and expansion of a distributed hydrogen-fueling infrastructure.

This project is leveraging developments in the stationary PEM fuel cell and compressed gas vehicle market sectors. GTI has developed a high-efficiency, compact steam methane reformer and fuel processor for stationary fuel cells. Modification of this fuel processor comprises a core element of this project. GTI is working with FuelMaker Corp. to develop intermediate-pressure (100 psig and less) and high-pressure hydrogen compressors based on experience with their oil-free designs, as well as fuel purification solutions. An advanced filling algorithm is being developed and tested to allow for complete and accurate filling of vehicles.

Results

The project began in February 2002 with a focus on subsystem and system design. A comprehensive design and analysis report was submitted in September 2002. This covered all of the key subsystems as well as a first-generation integrated system design. Figure 1 shows a detailed description of the key subsystems. The footprint for the system (excluding hydrogen storage) is approximately 8' by 14'. This could be made more compact in the future, but the current emphasis is on system functionality over form.

Work has been conducted using the GTI compact fuel processing system. Normally, this unit contains a steam methane reformer, shift conversion system to maximize hydrogen yield, and methanation reactor for CO control. Testing of the complete system indicates the ability to reliably obtain high hydrogen concentrations of 80% with CO levels reliably below 10 ppm.

An additional set of tests was conducted with the methanation reactor removed from the fuel processing system. This testing was to determine CO levels under different conditions so that sizing of the PSA system could be considered for CO control. In this way, there was an effort to look at the capital and operating cost trade-offs between methanation and additional PSA subsystem material used for CO removal. Figure 2 shows one set of results when testing the fuel processor without the methanation step in a repeat test mode. These data are being incorporated into the PSA system design and testing.

GTI completed a comprehensive set of tests on fast-filling of high-pressure hydrogen cylinders under a range of starting ambient temperature conditions, starting pressure levels, varying time of fill, and other key parameters. Figure 3 shows representative test results, with thermocouples placed on the exterior of a Type 4 cylinder and at various

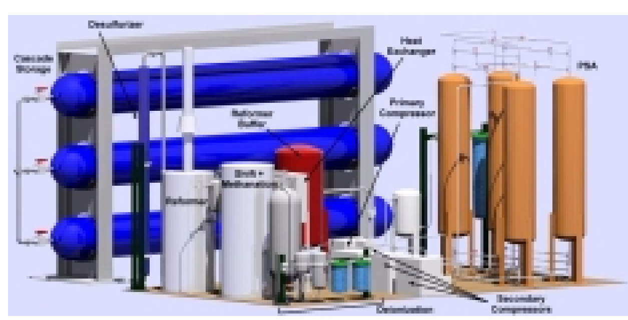

Figure 1. Hydrogen Fueling System Details

points along the internal central axis of the cylinder. The degree of temperature rise in this example is over 140°F. Depending on the point of measurement and time of measurement, there can be substantial differences in temperature within the cylinder. Additional tests were also run on a Type 3 cylinder.

Figure 4 shows a summary of the testing results to date. As a first order, the degree of temperature rise is proportional to the change in pressure from the beginning to the end of the fill process. Secondary factors come into play to result in variations in the degree of temperature rise (e.g., cylinder type, time of fill, etc.).

Testing on hydrogen cylinder filling was conducted at low, moderate, and high ambient temperature conditions using the GTI full-scale environmental chamber equipped with a hydrogen

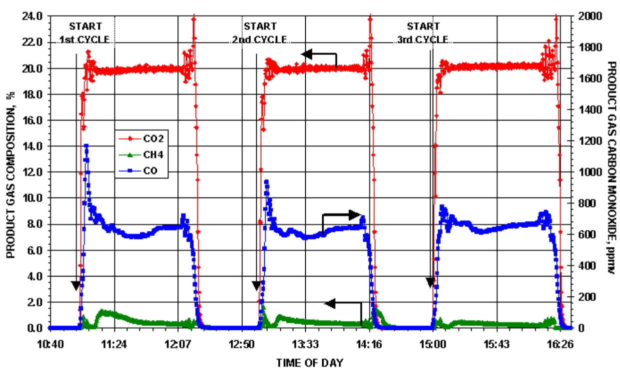

Figure 2. Compact Fuel Processor Testing Without Methanation for CO Control

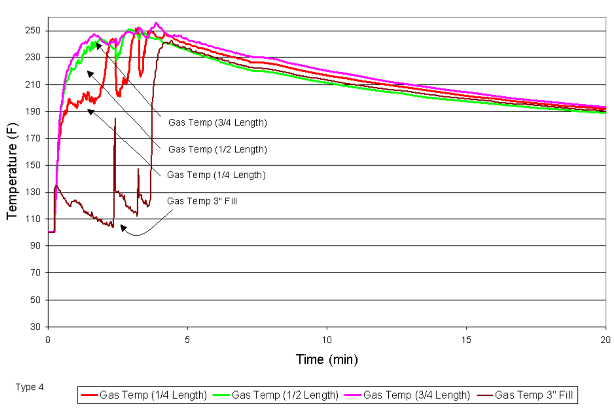

Figure 3. Temperature Measurements During Hydrogen Cylinder Filling

storage cascade (Figure 5). This facility is fully instrumented with data acquisition equipment

GTI has developed a first-principle thermodynamic model of the hydrogen cylinder filling process (a program called CHARGE H2). We are now using this model and empirical data from the testing program to develop a dispenser control algorithm that will enable proper hydrogen cylinder filling. This algorithm is called H2 AccuFill and leverages a GTI patented approach.

A brand new compressor, referred to as a primary compressor, has been designed and built by FuelMaker during the past year. This unit is designed to take reformate gas (H_2/CO_2) from low

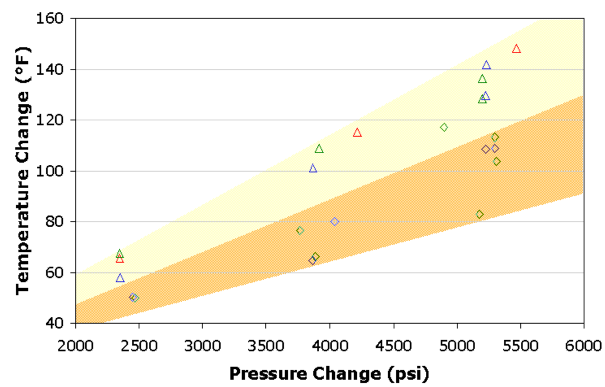

Figure 4. Summary of Hydrogen Fill Tests

Figure 5. GTI Hydrogen Environmental Chamber

pressure to levels of 60-100 psig. The output of the primary compressor is then fed to a PSA system for removal of CO_2 and other trace gases. Figure 6 shows a computer-aided design (CAD) drawing of the primary compressor.

Work is underway in building the first-generation completely integrated natural gas to hydrogen fueling system. An 8’ by 14’ steel skid has been constructed, and the front end of the system (fuel processor, water treatment and recovery, and primary compressor) is being installed and readied for testing. The back end of the system will be installed during the second half of CY 2003.

Conclusion

1. There are challenges with meeting the system cost targets in the near term; a substantial element of the cost target rests on the price of natural gas.

2. The application of a natural gas fuel processing system originally developed for stationary PEM system application has proven successful.

3. Fuel processor start-up time and dynamic response rates are acceptable for fast-fill stations that incorporate high-pressure cascade storage systems.

Figure 6. FuelMaker Primary Compressor Design

4. Fuel processor efficiencies up to 83% are anticipated based on testing and evaluation efforts to date.

5. Preliminary data indicates an optimum cost trade-off for CO control using a combination of shift conversion and PSA system operation.

6. Significant thermal effects are seen with fast filling of high-pressure hydrogen cylinders.

7. Meaningful spatial variations in hydrogen gas temperature occur with a hydrogen cylinder during fast filling.

8. Preliminary results indicate that a dispenser-based filling algorithm should be suitable for achieving a complete cylinder filling under most conditions.

FY 2003 Publications/Presentations

1. Richards, M. and Liss, W., "Reformer-Based Hydrogen Fueling Station Economics," World Hydrogen Energy Conference, June 2002.

2. Liss, W., "Development of Hydrogen Fueling Systems," Presentation to Japan Gas Association, June 2002.

3. Richards, M. and Liss, W., "Natural Gas Reformer-Based Hydrogen Fueling Station Modeling," NGV International Conference 2002, Oct. 2002.

4. Richards, M., Liss, W., and Kountz, K., "Natural Gas Reformer-Based Hydrogen Fueling Station Modeling," GTI Natural Gas Technologies Conference, Oct. 2002.

5. Liss, W., "Distributed Hydrogen Fueling System & Infrastructure Development," Presentation to International Energy Agency Annex XV, Nov. 2002.

6. Richards, M., Liss, W., and Kountz, K., "Modeling and Testing of Fast-Fill Control Algorithms for Hydrogen Fueling," NHA Annual Meeting, March 2003.

7. Liss, W., "Developing a Retail Hydrogen Market," SAE Fuel Cell TOPTEC, April 2003.