DEVELOPMENT OF A NATURAL GAS TO HYDROGEN FUEL STATION

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Abstract

The development of a hydrogen-fueling infrastructure is a critical element to the introduction of fuel cell-powered vehicles. The importance of direct hydrogen delivery—either as a high-pressure, medium-pressure gas, or liquid—recognizes the technical and economic hurdles facing on-board liquid fuel reforming. This program leverages efforts to develop natural gas reformers for stationary PEM fuel cell power generation as well as various technologies and products for compressed natural gas vehicles. The integrated natural gas-to-hydrogen system includes a high efficiency fuel reformer, appliance-quality hydrogen compressor, hydrogen purification, and advanced fuel dispenser.

Project Goals and Objectives:

The overall project objective is development of cost-competitive technology for high-pressure, hydrogen-based fueling systems. Specific goals include:

- Fast-fill natural gas-to-hydrogen fueling system with 40-60 kg/day delivery capacities.
- Hydrogen at costs of $2.50/kg or less.

The system looks to introduce innovative, compact natural gas steam reforming system and appliance quality hydrogen compressor technologies. Key technical challenges include:

- Flexible fuel reformers.
- Ensuring high level of fuel quality (water, CO_2, CO, and trace contaminants)
- Long-life oil free compressor design.
- Accurate hydrogen dispensing with underfill compensation.
- Ensuring future investors can achieve good returns on investment.

Figure 1 shows a block diagram representation of the proposed system that uses natural gas and water, leading to the production of a purified and distributed hydrogen fuel station capability.

Keys to the system success include cost reduction in system components, reduction in energy losses, and overall system integration for efficient operation of the unit.

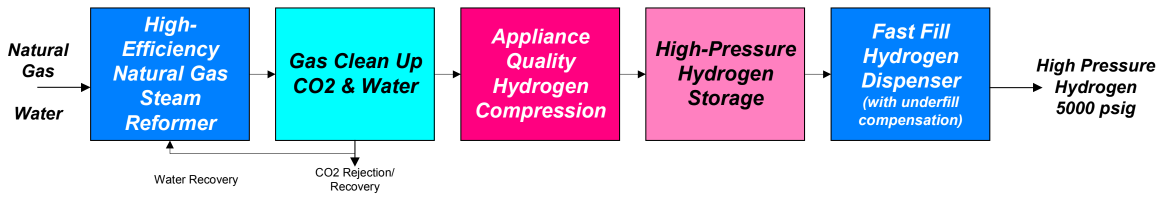

Figure 1: Natural Gas-to-Hydrogen Fuel Station

Project Plan

The approach used in this program is to focus on addressing subsystem and ultimately system level design improvements that lead to achieving market requirements for cost-effectiveness, reliability, and durability.

A three-phase program is being pursued:

- Phase I – Design
- Phase II – Development and Lab Testing
- Phase III – Field Testing and Development

Six individual tasks were identified to develop robust subsystems and a complete integrated system. These six tasks and the approach or issues to be addressed in each include:

- Task 1: Fuel Reforming
  - Efficiency
  - Turndown
  - Compressor/purifier interface
- Task 2: Fast-Fill Characterization
  - Build Test Facility
  - Refine CHARGE thermodynamic fill model
  - Develop AccuFill underfill compensation algorithm
- Task 3: Dispenser
  - Component availability & cost
  - Code & safety issues
- Task 4 Hydrogen Compressor
  - Analytical design
  - Tribology & materials
  - Empirical testing
  - Reformer/purifier interface
- Task 5: Hydrogen Purification
  - Assess adsorbent, membrane purification strategies
  - Reformer/compressor interface
- Task 6: Design & Economics
  - System & subsystem design and model
  - Cascade storage and integrationSystem controlsEconomic model

This program is based on leveraging of developments in the stationary PEM fuel cell and compressed natural gas vehicle market sectors. GTI has been developing high-efficiency steam methane reformers and fuel processing technology for stationary fuel cells, including design approaches to achieve compact size, reduced cost, and simplified control and operation. Modification of this reformer—as a hydrogen generator—will comprise a core element of this system.

In addition, GTI is building upon its experience with high-pressure natural gas fueling systems and working with key partners to develop hydrogen capable and compatible versions of their fueling products—including compressors, dispensers, and cascade storage vessels. GTI sees this strategy of product line extension as a near-term pathway for achieving cost reduction and product availability to support early establishment of a hydrogen-fueling infrastructure.

In this regard, GTI is working with FuelMaker Corporation to develop a high-pressure hydrogen version of their vehicle refueling appliance (VRA). The FuelMaker VRA is a high-quality appliance-like compression unit that is completely oil free—an important consideration for contaminant sensitive PEM stacks.

Results

The program officially began in February 2002, with a focus on subsystem and system design. Accomplishments to date include:

- Development of a comprehensive model 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.
- Prepared and presented paper on hydrogen fueling system economics to World Hydrogen Energy Conference.
- Constructed a state-of-the-art high-pressure hydrogen testing environmental chamber. System contains a full-size hydrogen three-bank storage cascade that can be run from –45°C to 85°C.
- Developed a first-principle model for understanding the fast-fill behavior of hydrogen and the effects of temperature rise on cylinder fill performance.

GTI has developed a comprehensive model for hydrogen fueling system economics that takes into account all capital, operating, and maintenance cost elements. The model can also be used to assess the effects of factors such as grants and tax incentives. The output, among other dimensions, is the levelized cost for hydrogen.

Figure 2 shows conclusions from a preliminary assessment of system costs. GTI currently sees capital and energy costs (including the cost of natural gas consumed in the steam reformer and electricity for compression) as the dominant cost factors. The cost of “processed gas”—that is, the gas reformed into hydrogen—is less than 20% of the cost of production.

Using Monte Carlo techniques to account for uncertainty and variability for individual cost elements—an important facet given the nascent nature of this technology—Figure 3 shows the model results for probability-based expected cost. Levelized hydrogen costs are estimated at around $3.70/kg with a fair degree of uncertainty. Further work will be undertaken during the design phase to review these cost factors and revise the model.

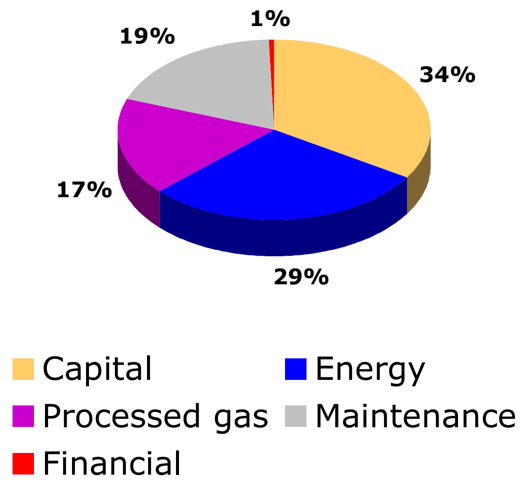

Figure 2: Hydrogen Fuel System Cost Breakout

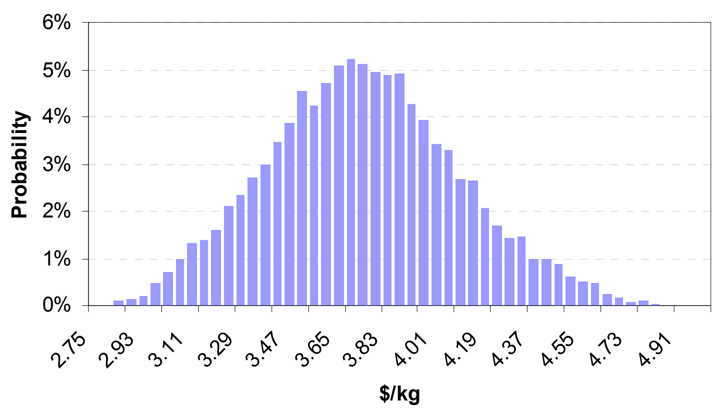

Figure 3: Hydrogen Fuel Cost Distribution

GTI is also developing analytical and empirical information on the filling behavior of hydrogen under fast-fill conditions. Work has shown that hydrogen experiences a significant temperature rise under these conditions. GTI has developed a first-principle model called CHARGEH2 that can be used as a predictive tool for this phenomenon. Figure 4 shows early results in comparing this model with empirical data. The model shows good agreement with the empirical data. Of note is the nearly 55^{o}C temperature rise during cylinder filling. This phenomenon reduces gas density, energy content, and ultimately can result in reduced vehicle driving range. GTI will conduct a comprehensive testing program under a variety of conditions to document this behavior. To counteract this effect, GTI will develop a dispenser control algorithm to more accurately fill cylinders.

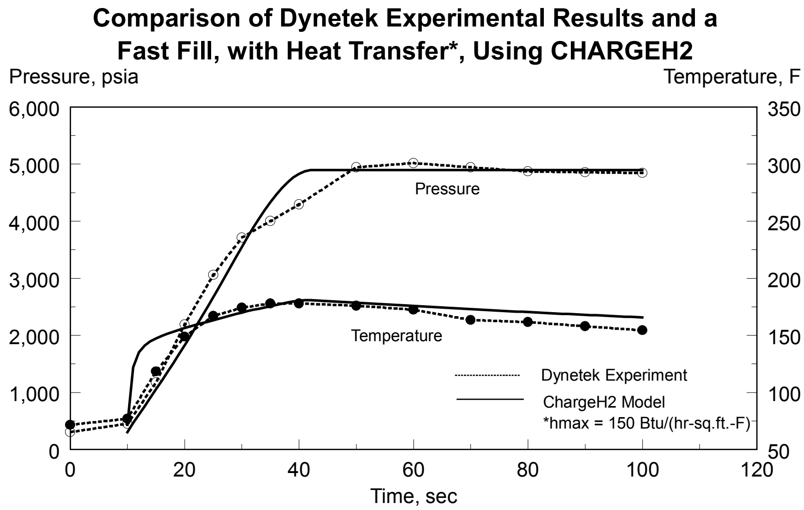

Figure 4: Hydrogen Temperature Rise During Filling

To conduct this unique hydrogen testing, GTI has constructed a state-of-the-art high-pressure hydrogen environmental chamber (Figure 5). This system contains a full-size hydrogen three-bank storage cascade that can be run from –45°C to 85°C (see photo). The chamber is fully instrumented and connected to a high-speed data acquisition system. Fast-fill hydrogen tests will be run over wide range of temperature and pressure conditions using cylinders constructed with steel, aluminum, and plastic liners.

Figure 5: GTI Hydrogen Environmental Chamber

On the reformer technology, GTI has independently developed stationary fuel processing technologies for PEM fuel cell systems. The intent is to leverage this design for use as a hydrogen generator for fueling station service. Figure 6 shows two different versions of the GTI compact fuel processing system. Each of these packages includes equipment needed to reform, shift, and control CO levels. In this effort, GTI will work to incorporate this technology separate from a PEM fuel cell. This will entail systems integration and controls development.

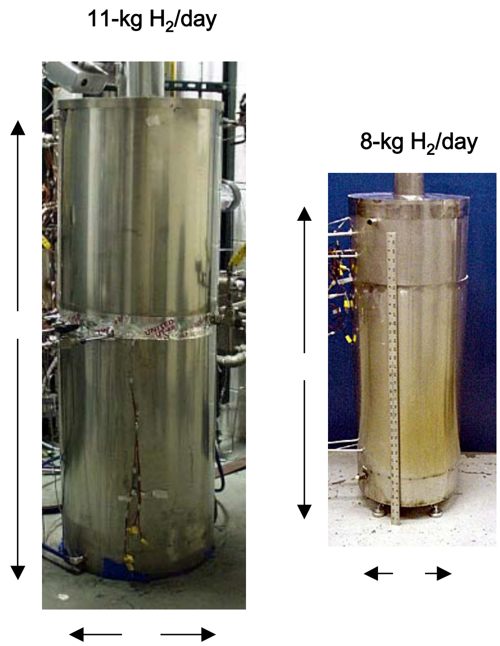

Figure 6: GTI Compact Fuel Processors

GTI is also working with FuelMaker Corporation to develop a high-pressure hydrogen compressor that builds upon their compressed natural gas Vehicle Refueling Appliance (VRA) technology. Natural gas versions of the FuelMaker product have been on the market for nearly 15 years, achieving reliable operation on natural gas at pressures around 3600 psig. This effort seeks to substantially increase the discharge pressure of the compressor when operating on hydrogen. This will entail an in-depth program to develop and test new materials for the compressor piston and liner—especially for the final stage of compression. Figure 7 shows a picture of the core FuelMaker compressor module.

Figure 7: FuelMaker Compressor Module

Conclusions

Work officially began on this program in February 2002. Preliminary indications are that a natural gas to hydrogen fueling system with reduced cost capabilities is possible. Achieving the stated cost targets (i.e., $2.50/kg) in the near term, however, will be a challenge.

The strategy of leveraging developments in PEM reformers and compressed natural gas vehicle technology appears a promising pathway for leveraging technology, experience, and market channels. Work will continue to leverage complementary developments.

References

Richards, M. and Liss, W., "Reformer-based Hydrogen Fueling Station Economics." World Hydrogen Energy Conference, June 11, 2002.

Hydrogen Cooperative Efforts

GTI, through its predecessor organizations (the Institute of Gas Technology and Gas Research Institute), has conducted work on hydrogen energy systems since 1951. During this period, over 200 hydrogen publications were developed by GTI. GTI commitment to Hydrogen Energy Systems follows the vision of a leading voice in this area – Dr. Henry Linden (past president of IGT and GRI). GTI's rich hydrogen history and portfolio include groundbreaking research into:

- Hydrogen Production (thermochemical hydrogen production, gasification processes—including UGAS, RENUGAS, and HYGAS)
- Addressing issues associated with transitioning natural gas to hydrogen
- Various end-use hydrogen applications, including leading-edge work on fuel cell systems (MCFC, PEMFC, SOFC, and PAFC).

GTI is continuing its efforts on hydrogen today, focusing on novel hydrogen production processes, development of hydrogen fueling systems, development of fuel cell technologies and products for stationary and mobile applications. GTI's hydrogen charter includes work on natural gas, coal, and renewable resources such as biomass.

GTI is involved in numerous hydrogen industry support activities, including:

- Member of the National Hydrogen Association (since its inception).
- Secretary for the Society of Automotive Engineers (SAE) Fuel Cell Standards Committee.
- Participant in the International Code Council Ad Hoc Hydrogen Committee.
- Participant in the U.S. Technical Advisory Group to the International Standards Organization Technical Committee (ISO/TC 197) developing hydrogen vehicle cylinder standards (ISO/CD 15869).
- Participant in the International Energy Agency Advanced Motor Fuels Annex—addressing international energy agency coordination on hydrogen fuels for vehicles.
- Participant in the Hydrogen Technical Advisory Panel (HTAP).
- Participant/presenter at the World Hydrogen Energy Conference and other industry-related forums.
- Member of UL Standards Technical Panel 2264, Standard for Gaseous Hydrogen Generation Appliances.