Development of a Natural Gas-to-Hydrogen Fueling System

DOE Hydrogen & Fuel Cell Merit Review

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Gas Technology Institute

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Hydrogen Fueling Systems

Problem Statement/Challenges

> Overall Problem Statement
  – Making hydrogen competitive with gasoline ($/kg or $/vehicle mile traveled)

> Challenges
  – Flexible & efficient fuel processors
  – Fuel purity assurance
  – Long-life compressors
  – Accurate dispensing/complete fills
  – System reliability
  – Safety through appropriate codes & standards and best practices
  – Capital outlay & return on investment
Proposed Solution

> Develop and validate onsite, integrated natural gas-to-hydrogen fueling stations
  – Develop and/or test state-of-the-art subsystems
  – Address integration, operation, maintenance, reliability, and safety considerations
  – Pre-package systems that can be shipped onsite and quickly dispatched

> Leverage compact & efficient hydrogen generation technology

> 40 to 60 kg/day system with nominal 5000 psig dispensing
Project Goals and Objectives

> Quantitative DOE Goals*:
  - Cost: high-pressure hydrogen at $3.00/kg or less by 2005 ($1.50/kg by 2010)
  - Fuel processing efficiency: 72% by 2005 (75% by 2010)
  - Fuel purification: 82% recovery by 2005 (90% by 2010)
  - Compression Energy: 85% by 2005 (88% by 2010)

> Qualitative Goals:
  - Minimize infrastructure investment cost and risk by leveraging existing energy infrastructure
  - Avoid high H₂ delivery costs and logistics problems by using onsite production
  - Provide technology transfer to a spectrum of industry participants and stakeholders

* From Table 3.1.2, *Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year RD&D Plan*
Program Participants

> Gas Technology Institute
  – Program manager, fuel processing subsystem producer, system integrator

> Working with & evaluating range of potential technologies
  – Existing players
    > FuelMaker Corporation, ANGI International, GreenField, Norris Cylinder Co., CPI Industries, General Dynamics/Lincoln, Dynetek, Emerson Process Controls, OPW, others

  – New entrants
    > Several potential technology and subsystem suppliers for compressors, dispensers, fuel purification
# Project Plan Overview

<table>
<thead>
<tr>
<th>Program Duration</th>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
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<tbody>
<tr>
<td>02/02 – 02/05</td>
<td>2/02-9/02</td>
<td>9/02–2/04</td>
<td>3/04–2/05</td>
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- **Phase I** completed
- **Fuel reforming task completed**
- **Fast-Fill characterization completed**
- **Phase II development in process with delays due to technical and budget factors**

Bold and underlined items are completed.

* These task and timing being reschedule due to technical and program funding issues.
Plan & Approach at a Glance

> Task 1: Fuel Reforming
  - Increase efficiency
  - Improve turndown
  - Controls

> Task 2: Fast-Fill Testing
  - Build SOA Test Facility
  - Refine CHARGE thermodynamic model
  - Conduct testing

> Task 3: H2 Dispenser
  - Validate filling algorithm
  - Component availability & cost
  - Metering and fill accuracy
  - Code & safety issues

> Task 4: H2 Compressor
  - Analytical design
  - Tribology & materials
  - Empirical testing
  - Reformer/purifier interface

> Task 5: H2 Purification
  - Adsorbent, membrane strategies
  - Reformer/compressor interface

> Task 6: Design & Economics
  - System design, model, and safety
  - System controls
  - Economic model
Safety Considerations

- GTI has extensive H$_2$ and high-pressure gas experience
  - Specialized engineers & technicians
  - Use best practices for high-pressure lines and fittings
  - Real-time gas monitoring & safety systems
  - Active in codes and standards development
Accomplishments

- Comprehensive subsystem and integrated system design report completed
- Compact fuel processor designed, built, and tested (alpha)
- 2nd generation (beta) fuel processor subsystem built and tested
  - Includes all water treatment and natural gas/sulfur clean-up
  - Fuel processor efficiency exceeds DOE 2005 target
- Full-scale high-pressure hydrogen test facility constructed
- Thermodynamic hydrogen cylinder filling model developed (CHARGEH2)
- Comprehensive set of hydrogen fast-fill tests completed
- H2 dispenser algorithm developed and validated
  - Patent application filed; licensing plans in place
  - Various papers presented
Accomplishments (cont.)

> Primary (100 psig) hydrogen compressor designed and built
> Secondary compressors (up to 7000 psig) undergoing materials evaluation and life testing
> Pressure Swing Adsorption (PSA) test facility constructed
> PSA tests underway
  – Testing new compact PSA unit as part of a confidential program
> Integrated System Engineering and Construction
  – Steel skid procured and prepped
  – Fuel processor installed
  – Natural gas & water treatment systems installed
  – System controls procured and programming initiated
> Comprehensive system economic model developed
  – Various papers presented
  – Conducted additional analyses for DOE to evaluate size effects
Preliminary Natural Gas to H2 Fueling Station Design

Further refinements underway to reduce size & cost

Evaluate more compact, simpler, lower cost PSA option

Consider options for gas compression

Testing new catalysts to boost output by 20% or more
Hydrogen Fuel Station Costs
Capital, Operating, and Maintenance
Natural Gas Reforming

Source: Gas Technology Institute
Natural gas cost = $4.75/mcf
GTI Compact Fuel Processors

Complete 50 kg/day fuel processor developed

Equipment rated to comply with fire safety codes

50-80 kg/day
H₂ Generator

H₂ Generator Controls
Four-Step Hydrogen AccuFill Development Process

1. **Model**
   - Develop first-principle thermo-dynamic model

2. **Test**
   - Empirical testing under varied conditions

3. **Correlate**
   - Regression analysis using first-principle model

4. **Implement**
   - Code development and dispenser integration
GTI CHARGE H2 Model

- First principle model of dynamic fast-fill process with real gas properties
  - Uses multiple differential equations
  - Filling of cylinders
  - Discharge of ground storage
- Assess cylinders of different size & construction
- Various starting & ending conditions
H₂ Cylinder Filling & H₂ Dispenser Validation

1. Accurate mass flow meter, cascade controls, and instrumentation
2. High-pressure hydrogen three-bank storage cascade in temperature-controlled environmental chamber
3. Ultra-high-precision, intrinsically safe scale for high-pressure H₂ cylinder gravimetric fill ratio validation and meter accuracy testing
Hydrogen Cylinder Filling

- Highly dynamic process with temporal and spatial temperature dependencies

Type 4 cylinder, 105°F, under 4 minutes

Correct temperature?
Hydrogen AccuFill Test Scatter plot

- Pressure Change (MPa)
- Temperature Change (°C)

Types:
- Type 3 cluster
- Type 4 cluster
Hydrogen AccuFill Validation Testing

> Completing test and validation phases
  – Developed code, defined hardware and interface elements

> Over 44 cylinder filling tests
  – Variety of initial pressures and temperatures
  – Single and combinations of cylinders

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<tr>
<th>Group</th>
<th>Avg. Fill %</th>
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<td>All</td>
<td>100.5</td>
<td>2.68</td>
<td>44</td>
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<tr>
<td>&gt; -20°C</td>
<td>99.6</td>
<td>2.19</td>
<td>32</td>
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<td>Type 3 &gt; -20°C</td>
<td>100.8</td>
<td>1.38</td>
<td>20</td>
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<tr>
<td>Type 4 &gt; -20°C</td>
<td>96.9</td>
<td>1.26</td>
<td>7</td>
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Interactions and Collaborations

Gas Technology Institute
> Founding Member - National Hydrogen Association
> Member - U.S. Fuel Cell Council
> DOE Executive Advisory Council for FreedomCAR
> Secretary - SAE Fuel Cell Standards Committee
> International Code Council Ad Hoc Hydrogen Committee
> International Energy Agency Advanced Motor Fuels Annex
> U.S. TAG to ISO/TC 197 (ISO/CD 15869) and ANSI/NGV2 on hydrogen vehicle cylinder standards
> Technology exchange with numerous companies and organizations in U.S., Canada, Japan, China, India, and Europe
> Present on this work at various meetings:
  – World Hydrogen Energy Conference (6/04), NHA Annual Meeting (04/04), others

FuelMaker Corporation
> NFPA committee on hydrogen fueling system fire safety codes
Next Steps

> Complete build-up and testing
  – Initially, fuel processor, primary compressor, and PSA system
  – Secondly, high pressure compressor, storage, dispenser
  – Fine tune system integration and controls

> Target full system test by 1Q/2005

> Work with partners on field testing and filling hydrogen fuel cell vehicles
  – Ongoing discussions with City of Chicago

> Work with potential partners on additional systems
  – Several possible projects being evaluated for follow-on development and demonstration
Conclusions

> Efficient, compact fuel processing feasible
  – 75 to 80% efficiency is practical; up to 85% possible

> Complete fill hydrogen dispenser algorithm developed and validated
  – Simple approach that avoids added cost, complexity
  – Technology transfer through license
  – Additional standards development needed

> Fuel clean-up systems
  – Improved PSA packaging solutions needed
  – Membrane technology advances desired

> Onsite hydrogen stations feasible
  – More cost savings needed over coming years
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