Development of a Natural Gas-to-Hydrogen Fueling System

DOE Hydrogen & Fuel Cell Merit Review

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Hydrogen Fueling Systems
Problem Statement & Challenges

> Problem Statement
  – Making hydrogen competitive with gasoline on a $/vehicle mile basis

> Challenges
  – Flexible fuel reformers & systems
  – Fuel purity
  – Long-life compressors
  – Accurate dispensing
  – Capital outlay & return on investment
Goals and Objectives

> Goals:
  – Distributed high-pressure hydrogen delivered at $2.50/kg or less to vehicle users
  – Avoid high costs for over-the-road hydrogen delivery
    > Leverage existing energy infrastructure
  – Leverage CNG technologies, products, and experience to extent practical

> Technical Characteristics:
  – 40-60 kg daily
  – 5000 psig fast fill system
Program Participants

> Participants and Roles
  – Gas Technology Institute
    > Program manager, system integrator, fuel processing subsystem
  – FuelMaker Corporation
    > Maker of high-quality high-pressure compressors and fuel purification systems
    > Commercialization pathway
  – ANGI International
    > In-kind support on hydrogen dispensing
    > Commercialization pathway
> Cofunding from Canadian government
### Project Plan and Approach

<table>
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<tr>
<th>Program Duration</th>
<th>Phase I Design</th>
<th>Phase II Development/Lab Test</th>
<th>Phase III Field Test/Dev.</th>
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- Phase I completed and report submitted
- Fast-Fill characterization completed and reported
- Phase II development in process

Program on schedule
Plan & Approach at a Glance

> Task 1: Fuel Reforming
  – Efficiency & turndown
  – Compressor/purifier interface
> Task 2: Fast-Fill Testing
  – Build SOA Test Facility
  – Refine CHARGE thermodynamic model
  – Conduct testing
> Task 3: H2 Dispenser
  – 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
System Inputs & Outputs

Natural Gas
Water
Electricity

H2 Fuel Station
Reformers
Purifiers
Compressors
Storage
Dispensers

Hydrogen
Output: 40 - 60 kg/day
(12 - 18 scfm)
5000 - 7000 psig

Steam Methane Reformer/Fuel Processor
\[ \text{CH}_4 + 2 \text{H}_2\text{O} \leftrightarrow 4\text{H}_2 + \text{CO}_2 \]
Some Keys to Success

Advanced oil-free high-pressure compressors

Compact fuel processing using efficient steam methane reforming process

Fuel cleanup systems that are cost effective, efficient, and meet fuel purity requirements

Reliable & cost effective hydrogen fueling system
Accomplishments

> Comprehensive subsystem and system design report completed
> Lab prototype fuel processor designed and tested (alpha)
> Full-scale high-pressure hydrogen test facility constructed
> Hydrogen cylinder filling model developed (CHARGEH2)
> Comprehensive set of hydrogen fast-fill tests completed
  – Paper presented at National Hydrogen Assoc. meeting
> H2 dispenser algorithm developed (in test for validation)
> Primary hydrogen compressor designed and built (operate under 100 psig)
> Secondary compressors undergoing materials evaluation and long-term life testing (operate up to 7,000 psig)
  – Critical path item
  – Evaluating advanced metals, ceramics, and coatings
> System economic model developed
  – Paper presented at World Hydrogen Energy Conference
Accomplishments (cont.)

> Pressure Swing Adsorption (PSA) test facility constructed

> PSA tests underway to evaluate multi-component removal effectiveness
  – Documenting trade-offs with fuel processor in areas related to CO and methane

> Phase II Prototype - Alpha Integrated System Build
  – Building “front end” of system (“hydrogen generator”)
    > Test “front end” first, then “back end” with fuel purification and high-pressure compression
  – Steel skid procured and prepped
  – 2nd generation fuel processor subsystem procured (beta) and subsystem assembly underway
  – Natural gas & water treatment systems procured and being installed
  – Primary compressors procured and being installed
  – System controls procured
Natural Gas to Hydrogen Fueling System
Preliminary Natural Gas to H2 Fueling Station Design

Further refinements underway to reduce size & cost
Fuel Processor Testing

Substantial testing done on start-up, ramping, shutdown testing of fuel processor to characterize dynamic response
GTI CHARGEH2 Model

> Characterizes dynamic fast-fill process
> Assess cylinders of different size & construction
> Various starting & ending fill conditions
  – Cylinders
  – Ground storage

Model captures dynamic gas filling effects, gas to cylinder heat transfer, and heat transfer from cylinder to ambient
GTI High-Pressure Hydrogen Test Facility

> Full-scale, three bank, high-pressure hydrogen cascade
  - 7,000 psig
  - Expanding to 12,000 psig

> Wide temperature range
  - -50 to 160°F

> Fully instrumented with data acquisition

> Flexibility to run wide range of conditions

High-Pressure Hydrogen Environmental Chamber
Hydrogen Cylinder Filling

> Substantial temperature variation documented

Type 4 cylinder, 105°F, under 4 minutes
Hydrogen Cylinder Filling Test Summary

![Temperature Change (°F) vs. Pressure Change (psi) graph]

- Temperature Change (°F) on the y-axis, ranging from 40 to 160.
- Pressure Change (psi) on the x-axis, ranging from 2000 to 6000.

The graph shows a linear relationship between temperature change and pressure change, with data points scattered across the range.
Communication & Cooperation

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
  > Specific input to group on vehicle/dispenser interface
> 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 several companies/organizations in U.S., Canada, Japan, China, India, and Europe
> **Presented on this work at various meetings:**
  > World Hydrogen Energy Conference (6/02), NHA Annual Meeting (3/03)
  > SAE TOPTEC (4/03), SAE Gov-Ind Conference (5/03), others

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

**Alpha Unit Implementation**

- Complete build-up and testing of “front end” of alpha system in 2003
  - Fine tune system integration and controls
- Build “back end” of alpha system second half of 2003
- Target tests results from fully integrated alpha system by February 2004
- Identify improvements for Phase III
- Work with potential partners on field testing, commercialization, technology transfer
Conclusions

> Significant thermal effects seen with hydrogen fast filling

> Meaningful variation in gas temperature exist
  – Various factors: cylinder design and materials, time of fill, ambient temperature, cascade pressure and temperature, etc.
  – Data indicate potential for large spatial internal gas temperature variation

> Intelligent pressure-based compensation algorithms are expected to be viable
  – Near 100% fill under most conditions
  – Implementation costs confined to fueling station
  – Compatible with approaches requiring additional vehicular equipment and communication