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

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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

Program Duration 02/02 – 02/05	Phase I Design	Phase II Development/ Lab Test	Phase III Field Test/Dev.
	2/02-9/02	9/02–2/04	3/04–2/05
Fuel Reforming	8/2002	2/2004	2/2005
Fast Fill Testing	8/2002	2/2003	
Dispenser	8/2002	2/2004	7/2004
Compressor	8/2002	2/2004	2/2005
Purification	8/2002	2/2004	2/2005
Design/ Economics	8/2002	2/2004	2/2005

- Phase I completed and report submitted
- Fast-Fill characterization completed and reported
- Phase II development in process

Program on schedule

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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

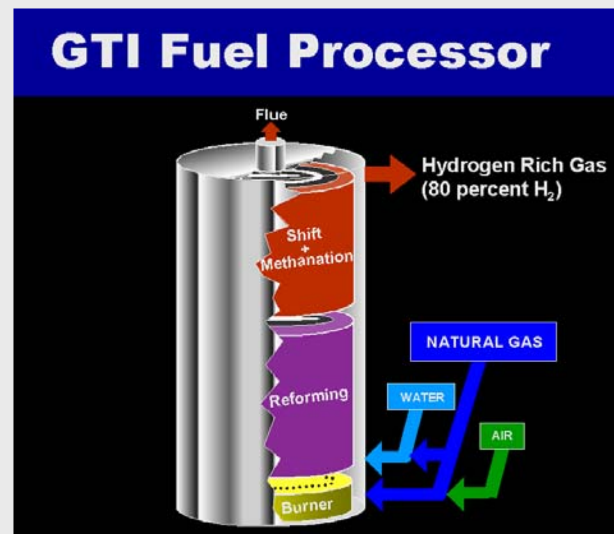
System Inputs & Outputs

Inputs:
- Natural Gas
- Water
- Electricity

<u>H2 Fuel Station</u>
Reformers
Purifiers
Compressors
Storage
Dispensers

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

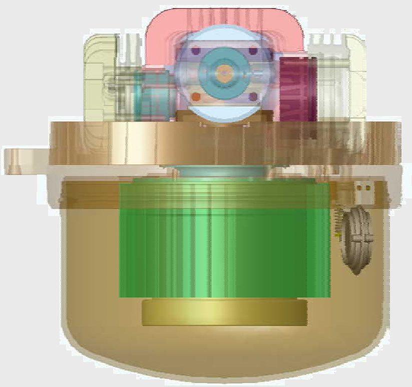
Outputs:
- Water Losses
- Energy Losses
- CO2 Effluent
- Trace Gas Effluent



Steam Methane Reformer/Fuel Processor

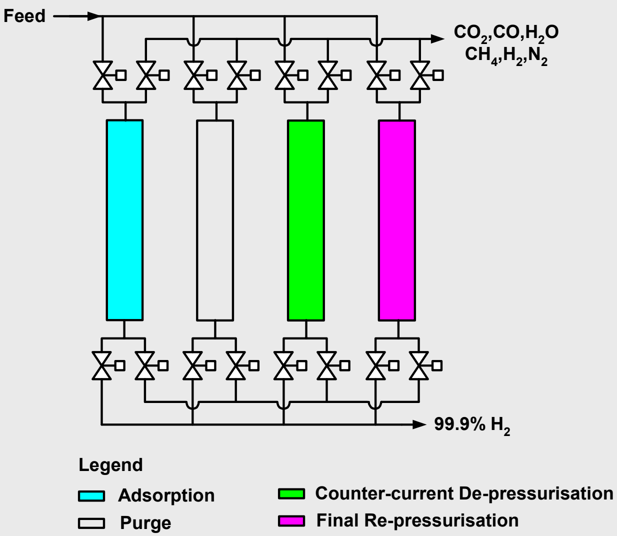
$$CH_4 + 2\,H_20 \leftarrow \rightarrow 4H_2 + CO_2$$

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

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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

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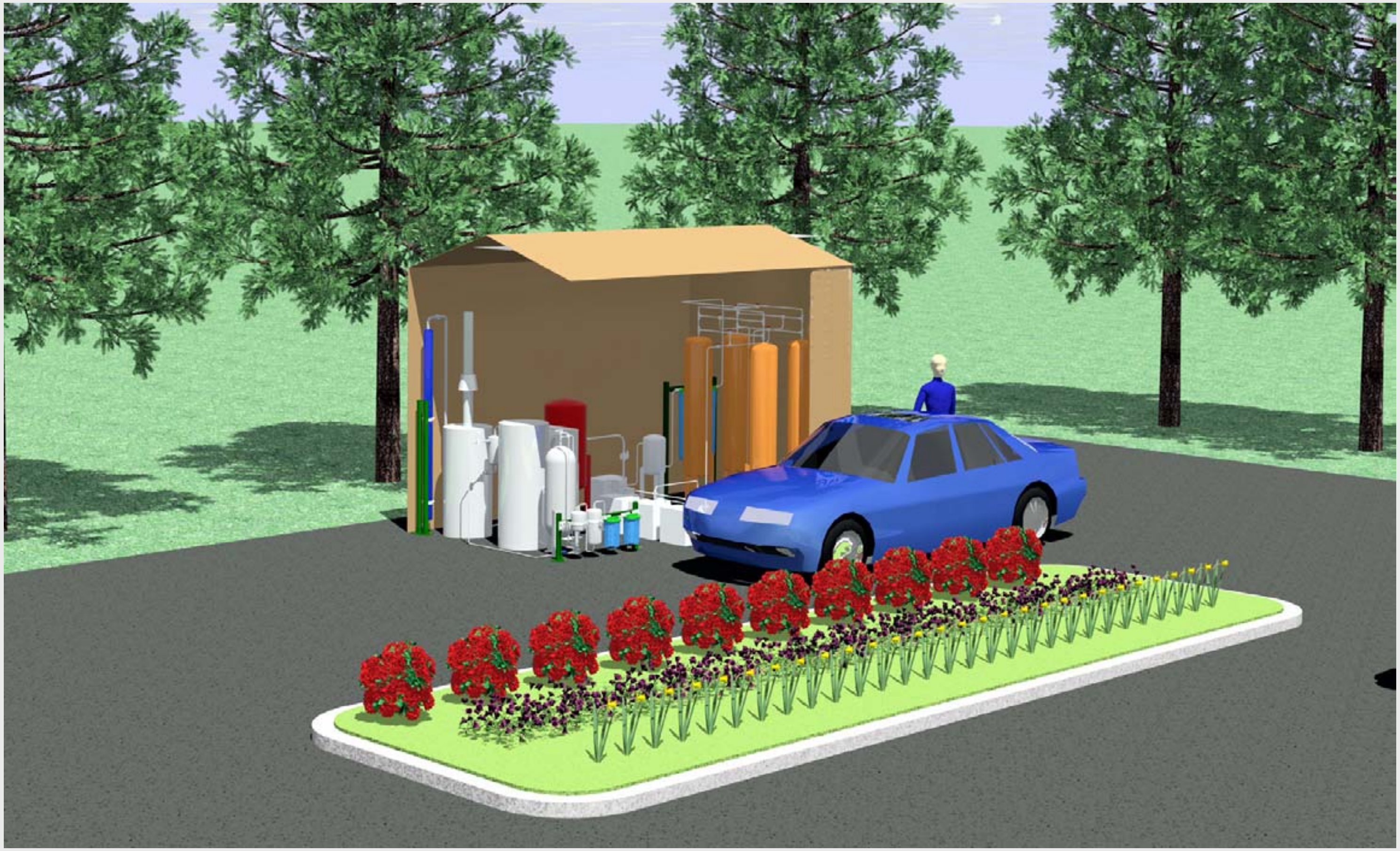
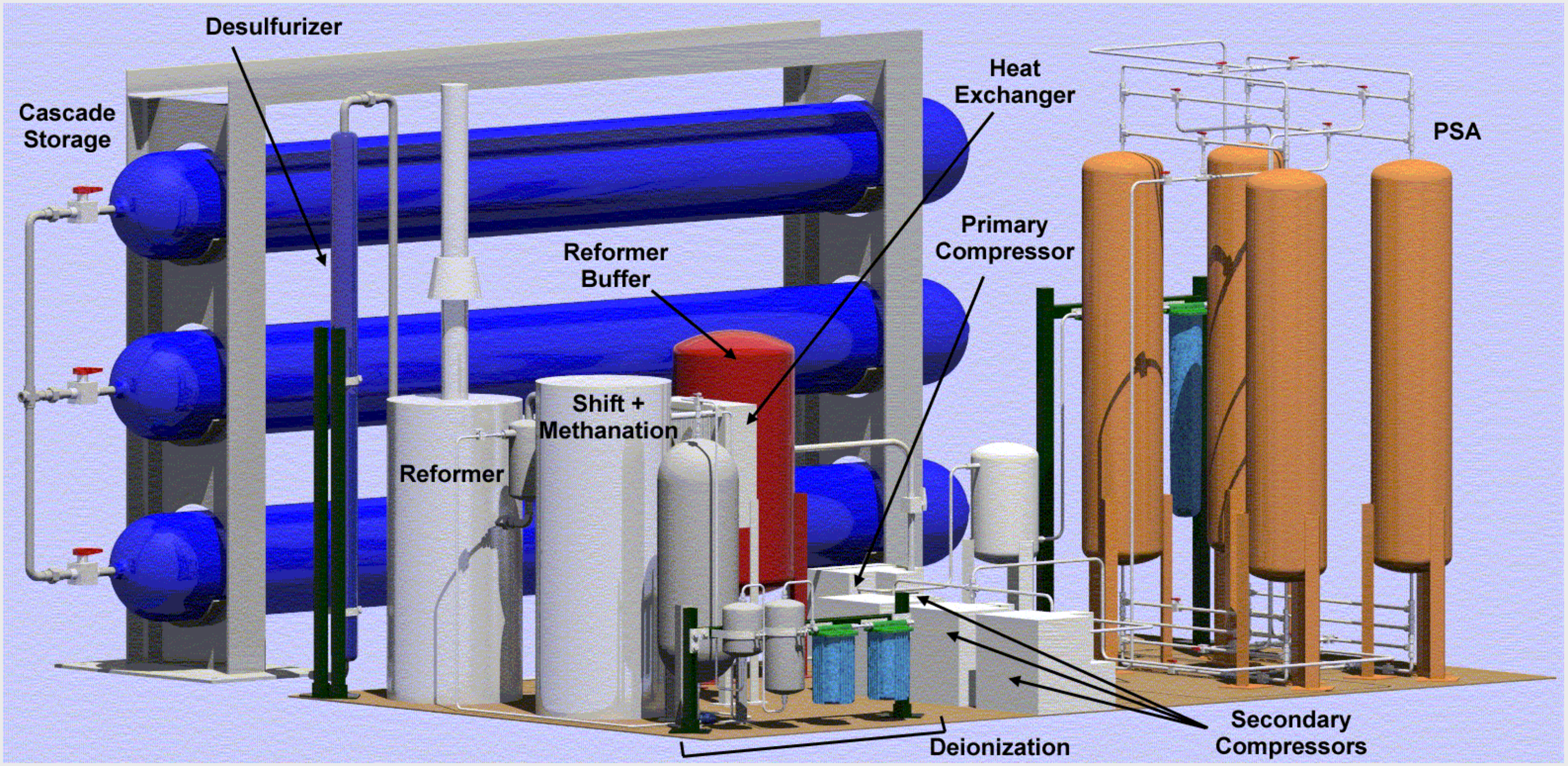
Natural Gas to Hydrogen Fueling System

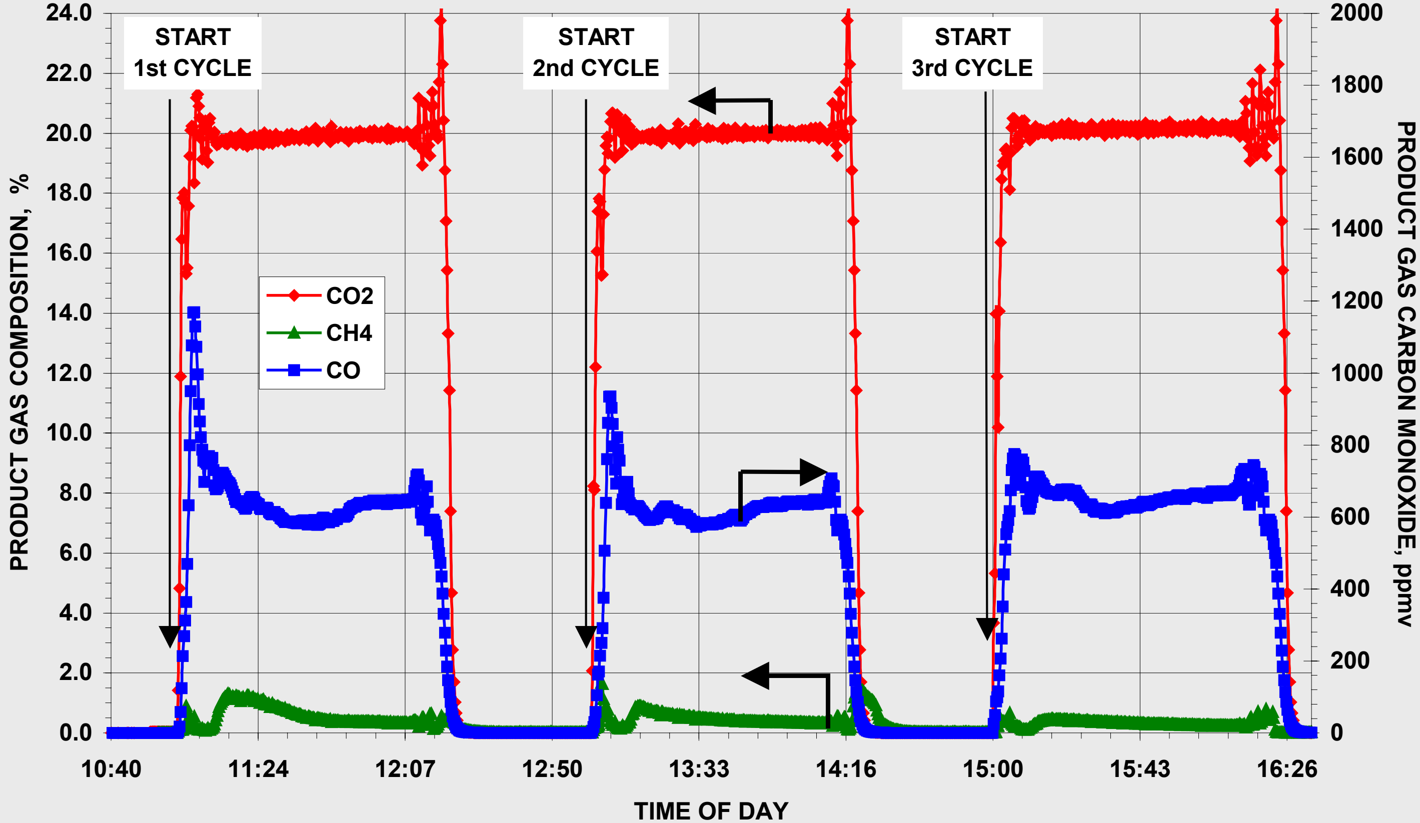


Preliminary Natural Gas to H2 Fueling Station Design



Further refinements underway to reduce size & cost

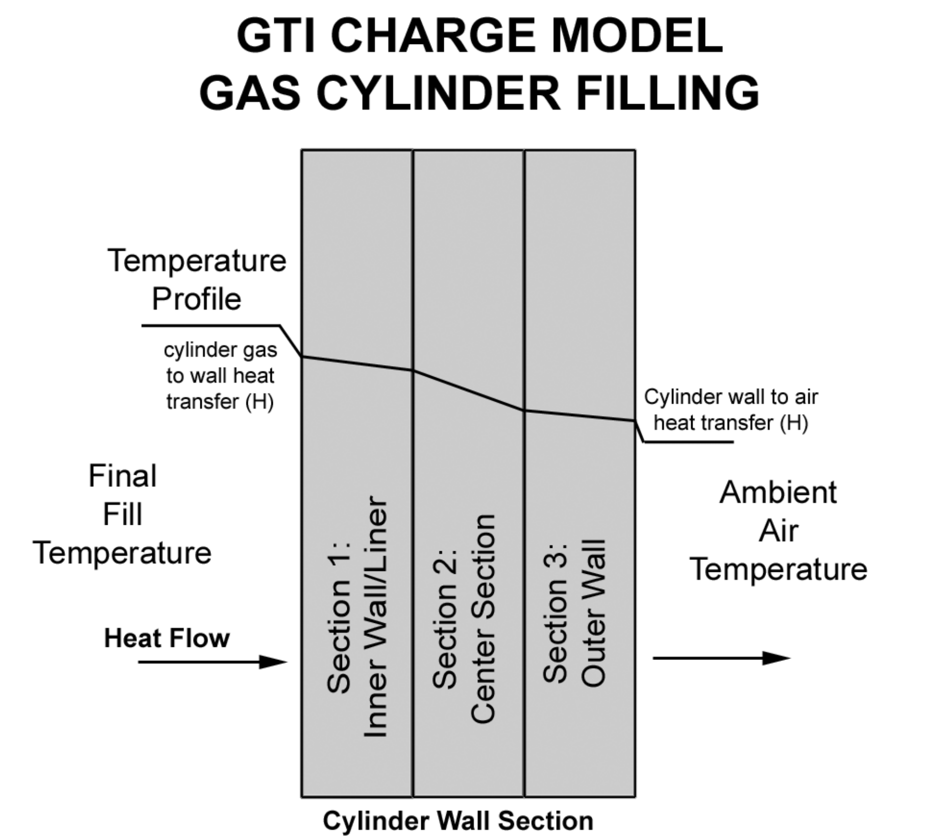
Fuel Processor Testing



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

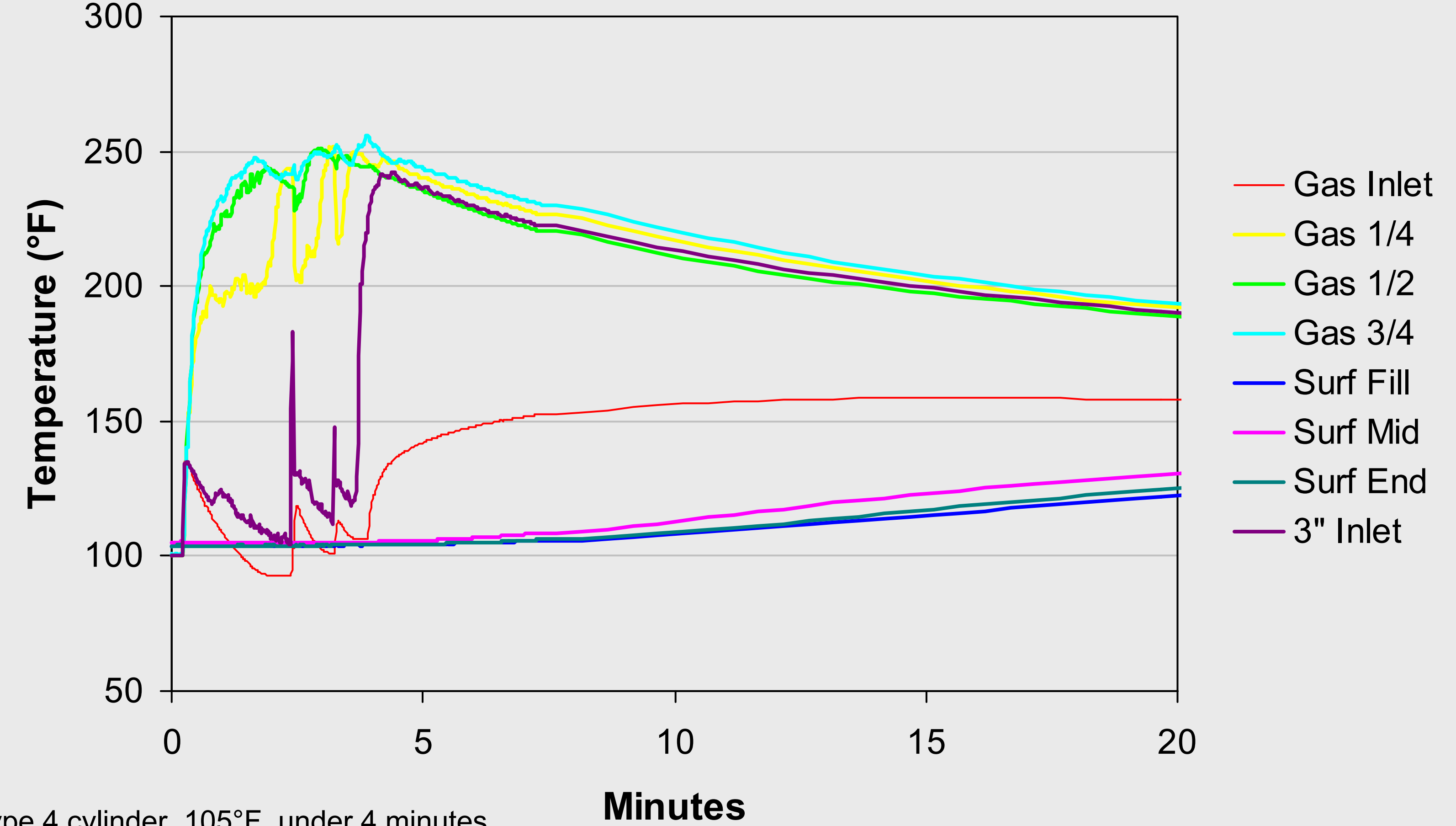
GTI High-Pressure Hydrogen Test Facility

- 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

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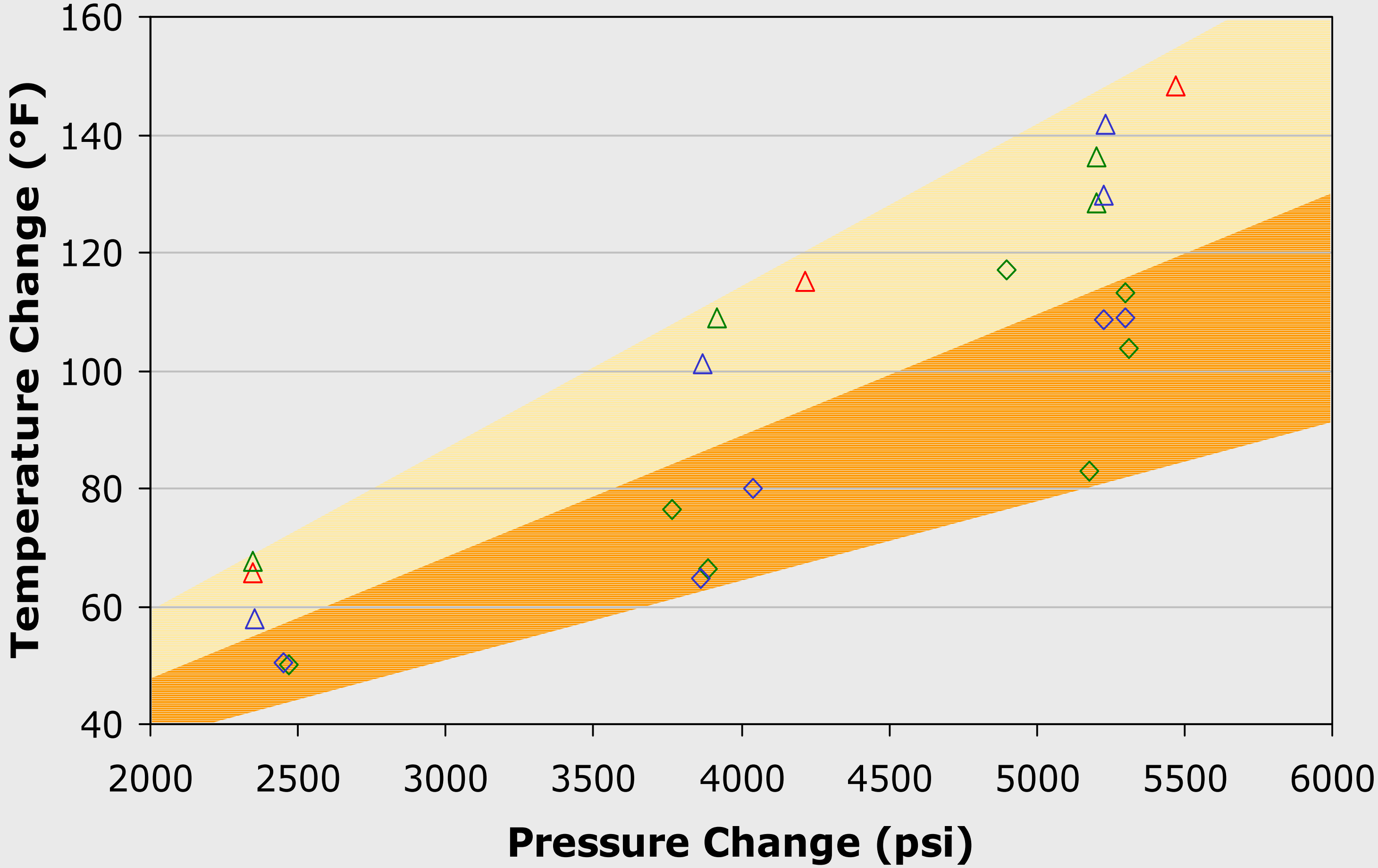
Hydrogen Cylinder Filling Test Summary



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

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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