



Development of a Natural Gas-to-Hydrogen Fueling System

DOE Hydrogen & Fuel Cell Merit Review

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May 2004

Cooperative Agreement DE-FC04-02AL67607

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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

Leverage
substantial CNG
experience base

Explore new
solutions and
companies



Project Plan Overview

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

Bold and underlined items are completed.

* These task and timing being reschedule due to technical and program funding issues.

- Phase I completed
- Fuel reforming task completed
- Fast-Fill characterization completed
- Phase II development in process with delays due to technical and budget factors

Plan & Approach at a Glance

Complete

> Task 1: Fuel Reforming

- Increase efficiency
- Improve turndown
- Controls

> Task 4: H2 Compressor

- Analytical design
- Tribology & materials
- Empirical testing
- Reformer/purifier interface

Complete

> Task 2: Fast-Fill Testing

- Build SOA Test Facility
- Refine CHARGE thermodynamic model
- Conduct testing

> Task 5: H2 Purification

- Adsorbent, membrane strategies
- Reformer/compressor interface

50% Complete

> Task 3: H2 Dispenser

- Validate filling algorithm
- Component availability & cost
- Metering and fill accuracy
- Code & safety issues

> Task 6: Design & Economics

- System design, model, and safety
- System controls
- Economic model

40% Complete

30% Complete

80% Complete

Safety Considerations

- > GTI has extensive H₂ 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

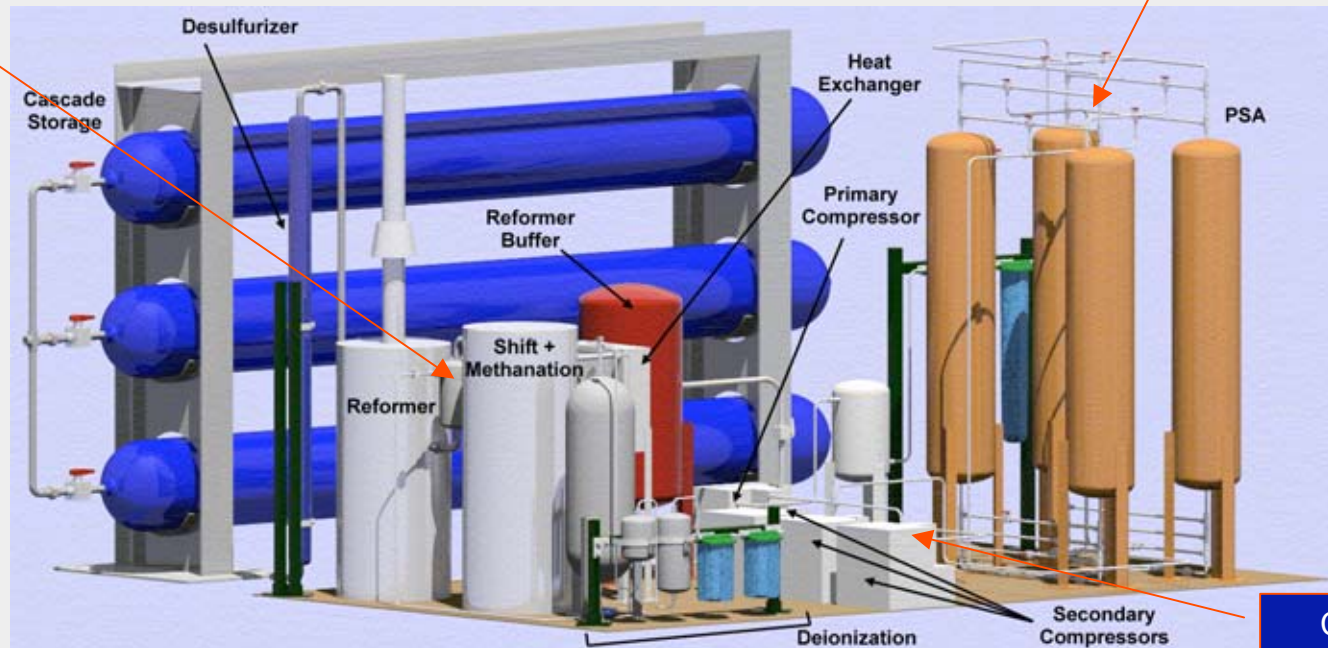
Accomplishments (cont.)

- > 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

Evaluate more compact, simpler, lower cost PSA option

Testing new catalysts to boost output by 20% or more

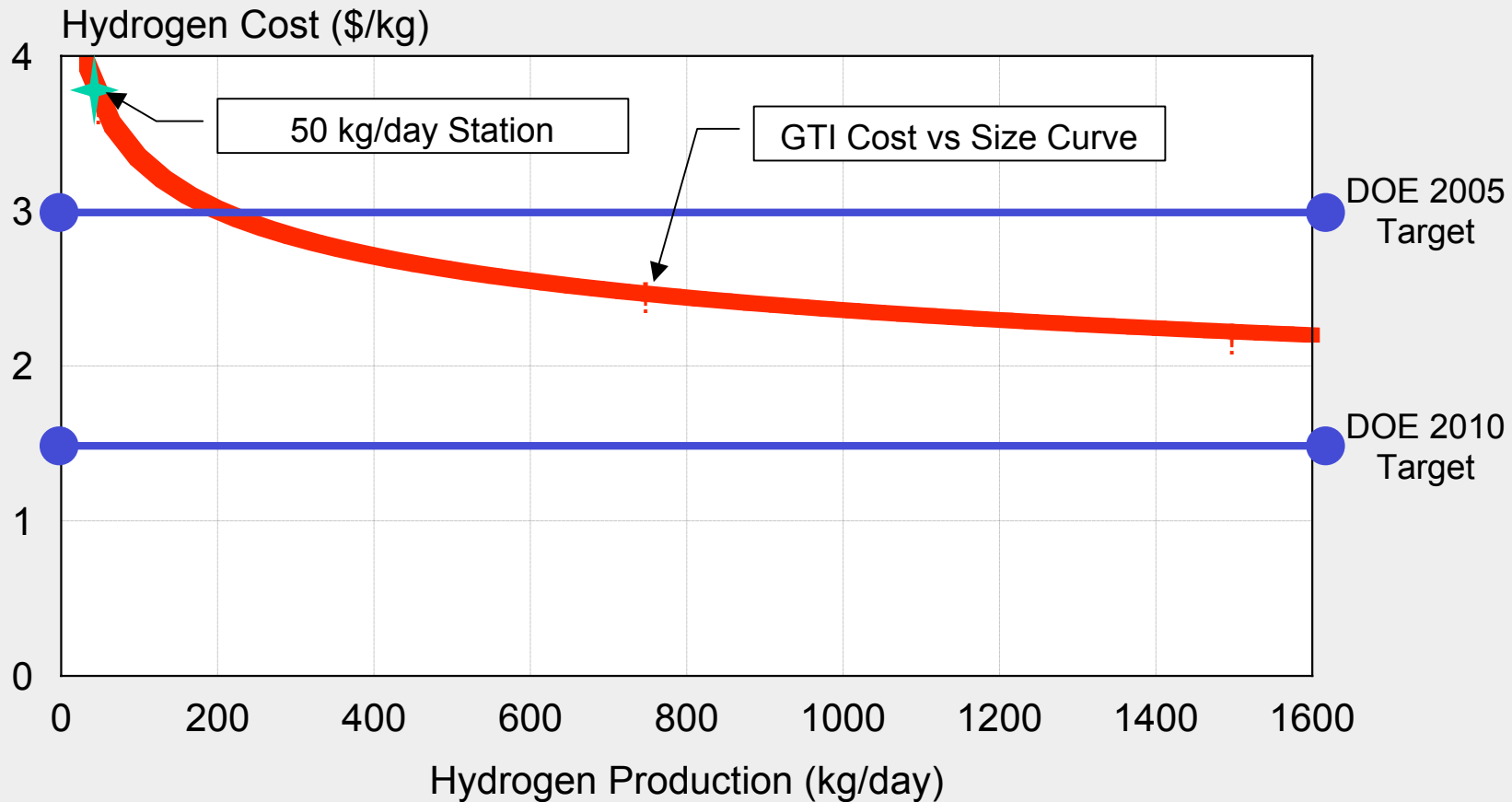


Further refinements underway to reduce size & cost

Consider options for gas compression

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



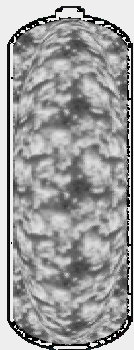
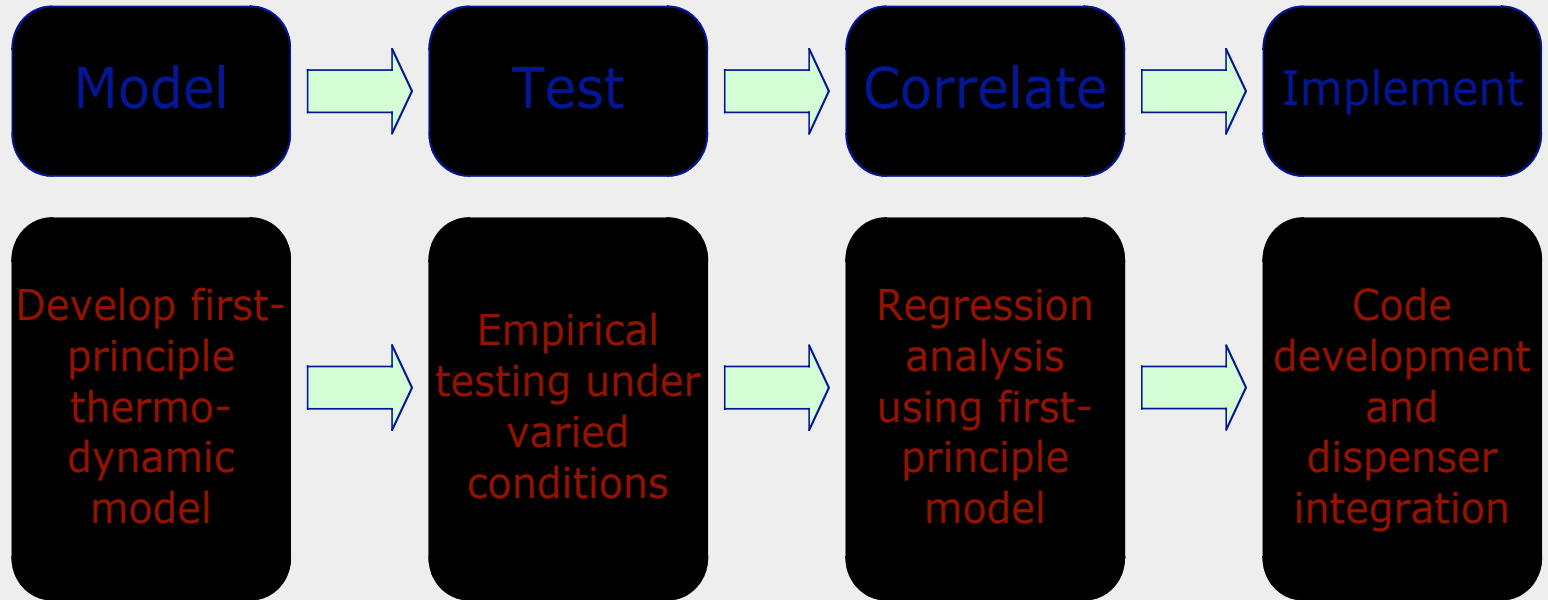
50-80 kg/day
H₂ Generator



H₂ Generator
Controls

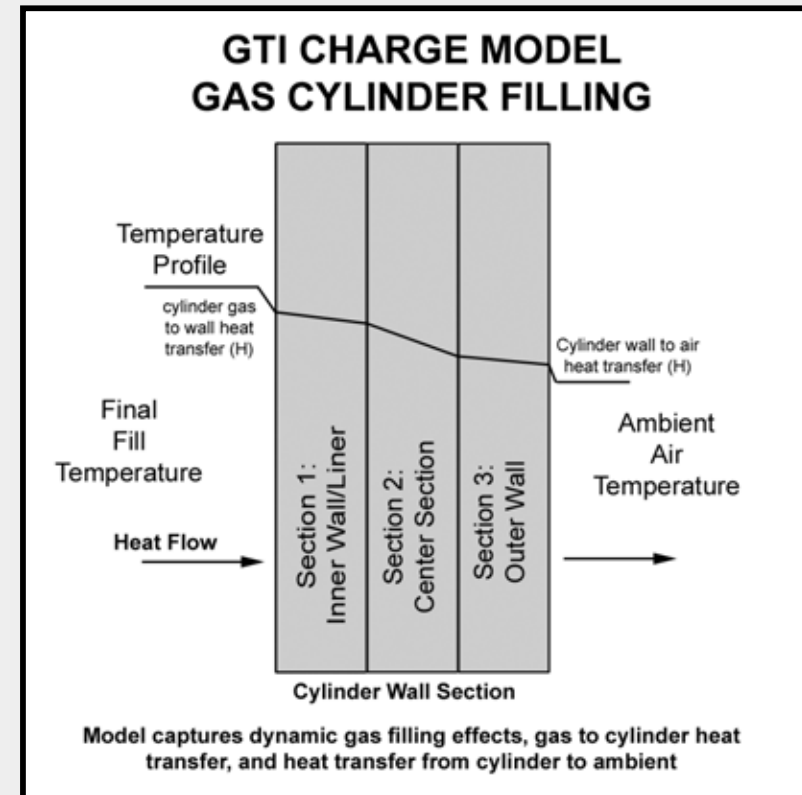
Complete
50 kg/day
fuel
processor
developed
Equipment
rated to
comply with
fire safety
codes

Four-Step Hydrogen AccuFill Development Process



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

Simulated
hydrogen
dispenser



1

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



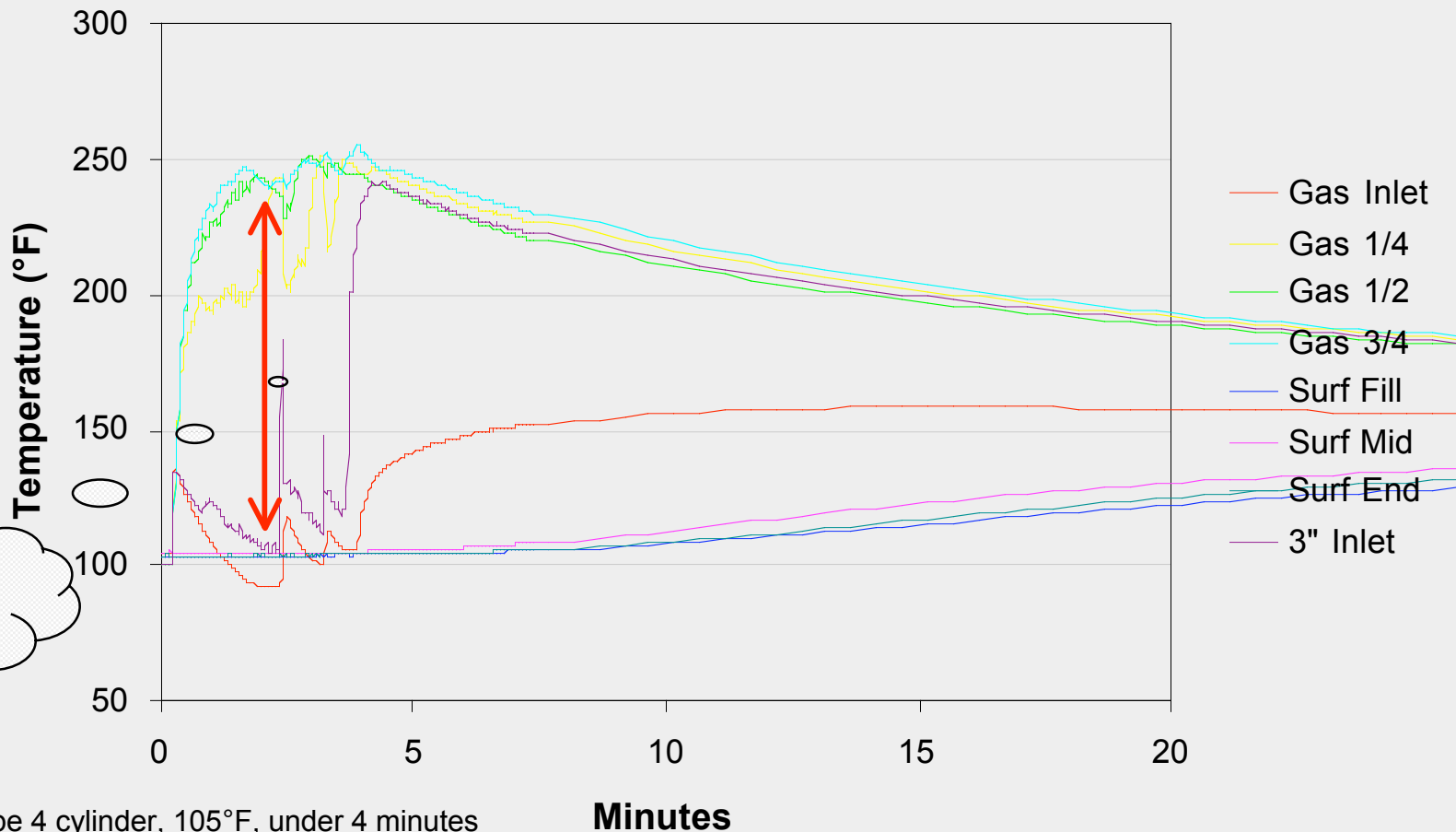
2



3

Hydrogen Cylinder Filling

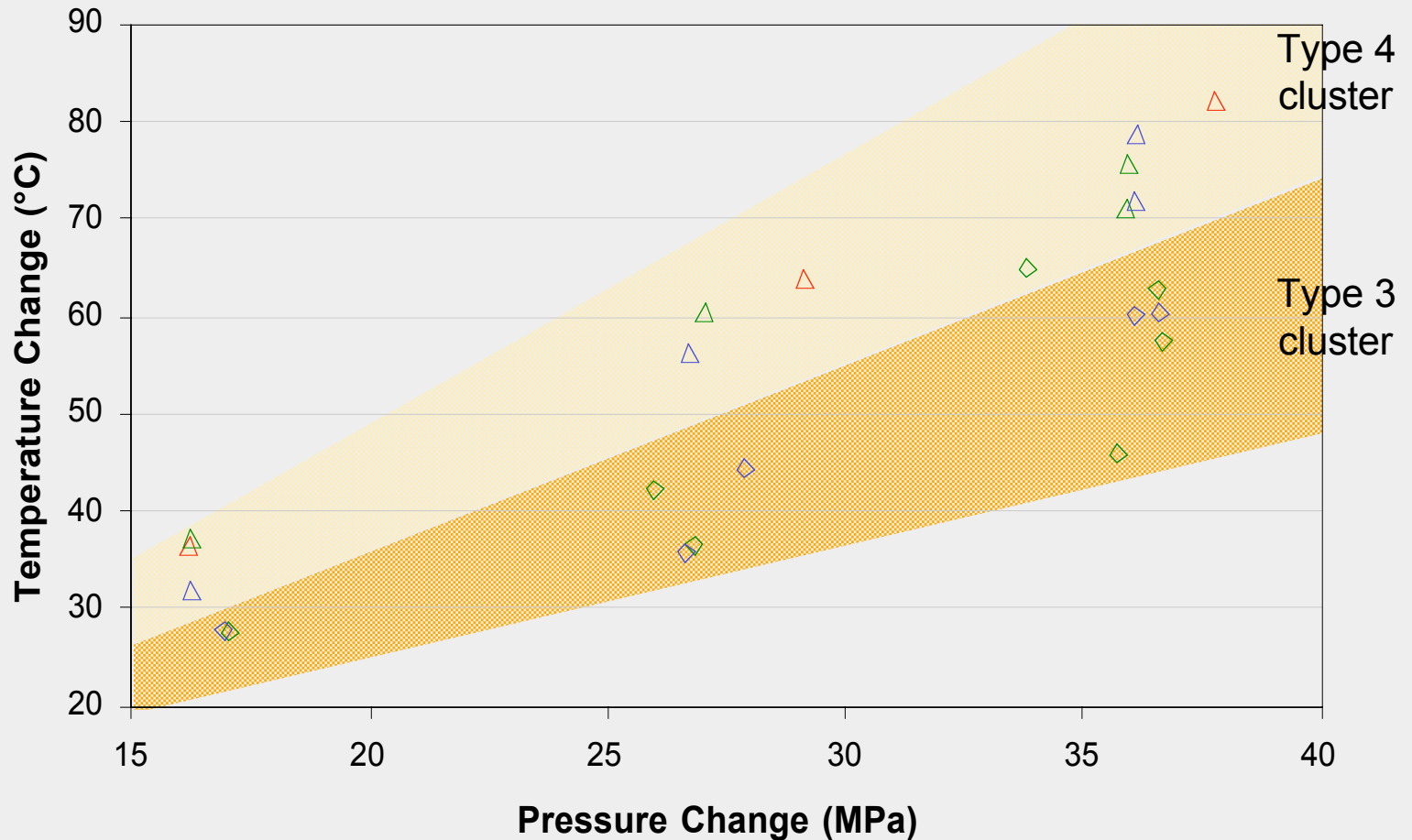
- > Highly dynamic process with temporal and spatial temperature dependencies



Type 4 cylinder, 105°F, under 4 minutes

Minutes

Hydrogen AccuFill Test Scatter plot



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

Group	Avg. Fill %	–	n
All	100.5	2.68	44
> -20°C	99.6	2.19	32
Type 3 > -20°C	100.8	1.38	20
Type 4 > -20°C	96.9	1.26	7

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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