Hydride Based Hydrogen Compression

presented to the

US DOE Hydrogen and Fuel Cells Program

2004 Annual Merit Review

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by

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This presentation does not contain any proprietary or confidential information.

Objectives

Project Objective: Develop hydride hydrogen compressor that operates in conjunction with advanced hydrogen production technologies and improves the efficiency and economics of the compression process. Thermal hydrogen compression must offer a sustainable competitive advantage over mechanical compression to meet the DOE goals and for market penetration.

2003 to 2004 Objectives:

Continue testing a single stage hydride thermal compressor that employs three purification technologies to determine threshold contamination levels for common impurities.

Investigate compressor capabilities to perform the dual function of compression with purification for impurities that adversely affect fuel cell operation (e.g. CO).

Develop miniature hydride heat exchanger manufacturing methods that will reduce cost to approach the 2010 cost targets.

Budget

	Total Project	Phase 1 FY2000	Phase 2 FY2002	Phase 3 FY2003
Total Cost	602,102	39,385	312,817	249,900
DOE Portion	423,967 (70.4%)	31,508	192,539	199,920
HERA Cost Share	178,135 (29.6%)	7,877	120,278	49,980

Technical Barriers and Targets

3.2.4.2 Barriers

B. High Costs of Hydrogen Compression. Hydrogen gas has a low volumetric energy density, especially at low pressures. Hydrogen compression is costly and energy intensive. Low-cost, efficient compression technologies are needed.

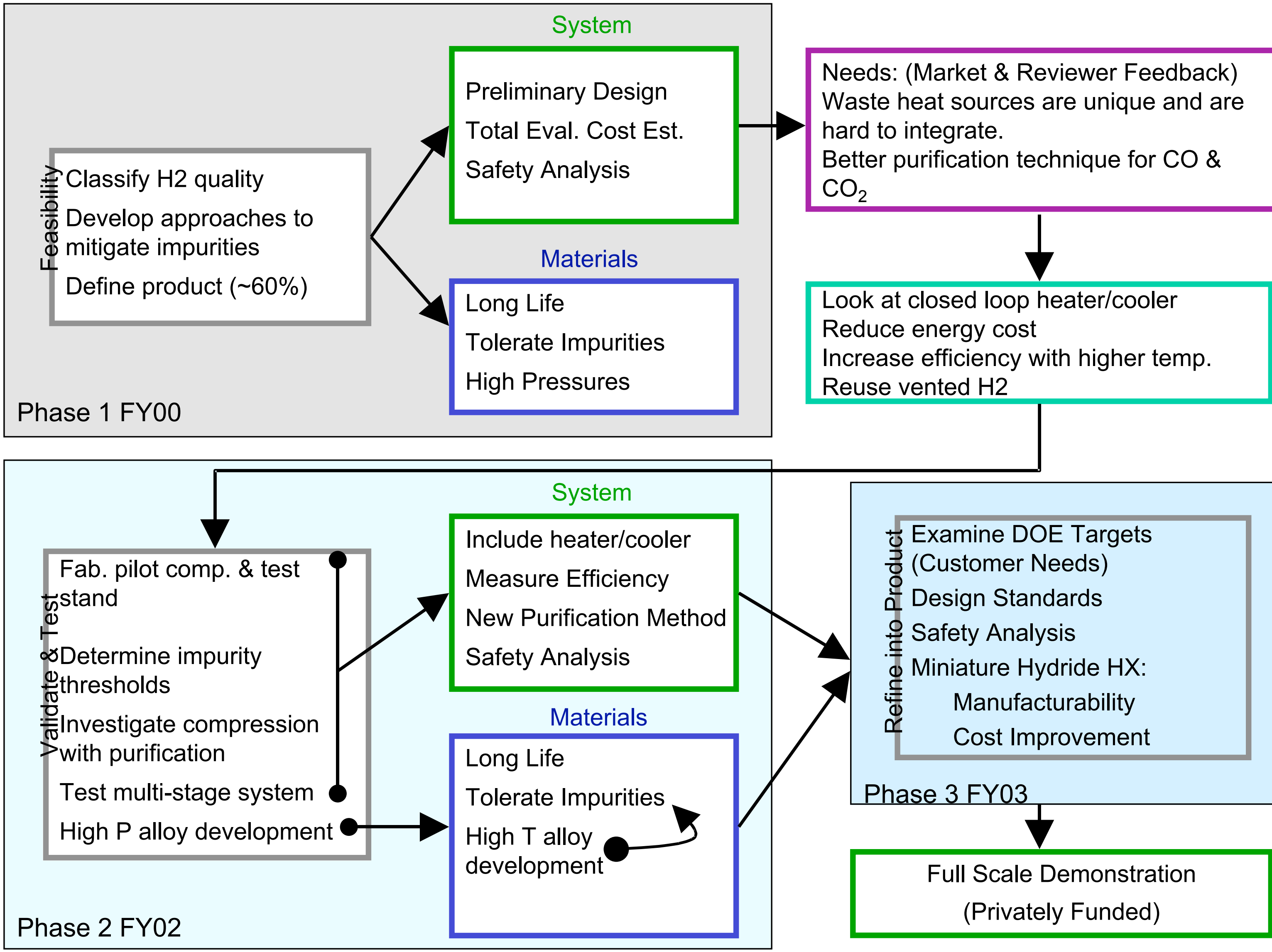
	Table 3.2.2 Hydrogen Delivery Targets				
	Delivery Method	**Target**	**2003 Status**	**2005 Target**	**2010 Target**
Primary	Gaseous Hydrogen Compression (3,000 psi)	Cost ($/kg H2) Energy Efficiency (% LHV)	$0.18 90%	$0.17 92%	$0.14 95%
	Table 3.1.2. Technical Targets: Distributed Production of Hydrogen from Natural Gas and Liquid Fuels				
Cross-cutting	Compression (3,600 / 5,000 psi)	Cost ($/kg H2)	0.34	0.29	0.24
		Primary Energy Efficiency (% LHV)	82%	85%	88%
	Table 3.1.8a. Technical Targets: Water Electrolysis				
	Compression (5,000 psi) 250 kg/day Refueling Station	Cost ($/kg H2)	0.47	0.32	0.16
		Energy Efficiency (% LHV)	90%	92%	95%
	Compression (5,000 psi) Small-Scale Refueling: 2 kg/day	Cost ($/kg H2)	0.34	0.21	0.09
		Energy Efficiency (% LHV)	83%	90%	93%

DOE cost estimates and targets for compression vary widely by application.

More importantly, Energy Efficiency DOES NOT INCLUDE electrical energy efficiency of ONLY 35%.

Project Title: **Hydride Based Hydrogen Compression** Contractor: **HERA USA Inc.**

Approach



Project Safety

The hydride compressor system was subjected to a hazard and operability analysis in conjunction with a major industrial gas company.

HERA USA employs an HSE program governing all activities within the facility. The safety officer reviews all systems before hydrogen is introduced. Employees undergo annual training and any incidents are formally reported, assessed and communicated to all employees via established procedures.

The facility and HSE program have been audited by a third party safety consultant.

Safety-related incidents have not occurred within this project.

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Project Timeline

Feasibility	Quantified H_2 quality anticipated from advanced and renewable production techniques. Preliminary design and Safety Analysis	9-1-99 to 8-31-00
Validate and Test	Determine hydride alloys' resistance to disproportionation. Validate compressor operation at >5,000 psi. Determine hydride alloys' tolerance to impurities while cycling. Test effectiveness of three purification techniques: • passive purification for H_2O & O_2 • elevated temperature desorption for CO & CO_2	9-1-00 to 6-30-03
Refine Product Design	• inert gas venting for N_2 & CH_4 **Determine if compression with purification is a viable alternative for improving fuel cell performance.** Reduce capital cost via miniature hydride heat exchangers and rapid cycling.	7-1-03 to 6-30-04

Status: Completed **In Progress**

Accomplishments / Progress - Reduce Capital Cost (1of 2)

Developed inexpensive method to double heat transfer surface area, increasing kinetics to reduce heat exchanger size and cost.

Steel is wound and soldered onto the hydride tube to form a fin.

Twelve combinations of fin size and spacing were evaluated.

Single-tube ring manifolds were constructed and tested for heat transfer kinetics.

Bare tube control

Finned tube test sample

Accomplishments / Progress - Reduce Capital Cost (2 of 2)

Developed inexpensive method to simultaneously bond multiple tube joints that can be leak tested before final assembly of hydride heat exchangers.

Full scale ring manifolds were constructed of finned tubes to develop cost effective, modular manufacturing methods.

Results: The finned tube ring manifold substantially reduces compression cost per kg of hydrogen produced in a refueling station-sized compressor. Currently estimated at \$0.45 to \$0.48/kg in quantities of 100 using bare, straight tube, welded heat exchangers, we estimate hydride compressors using finned tube ring manifolds should be able to approach the 3x cost reduction required to meet the 2010 targets (\$0.14 to \$0.16/kg, 3,000 to 6,000 psi).

Accomplishments / Progress - Reduce Operating Cost

Hydride Compression's Low Energy Cost Will Substantially Reduce the Cost of Hydrogen

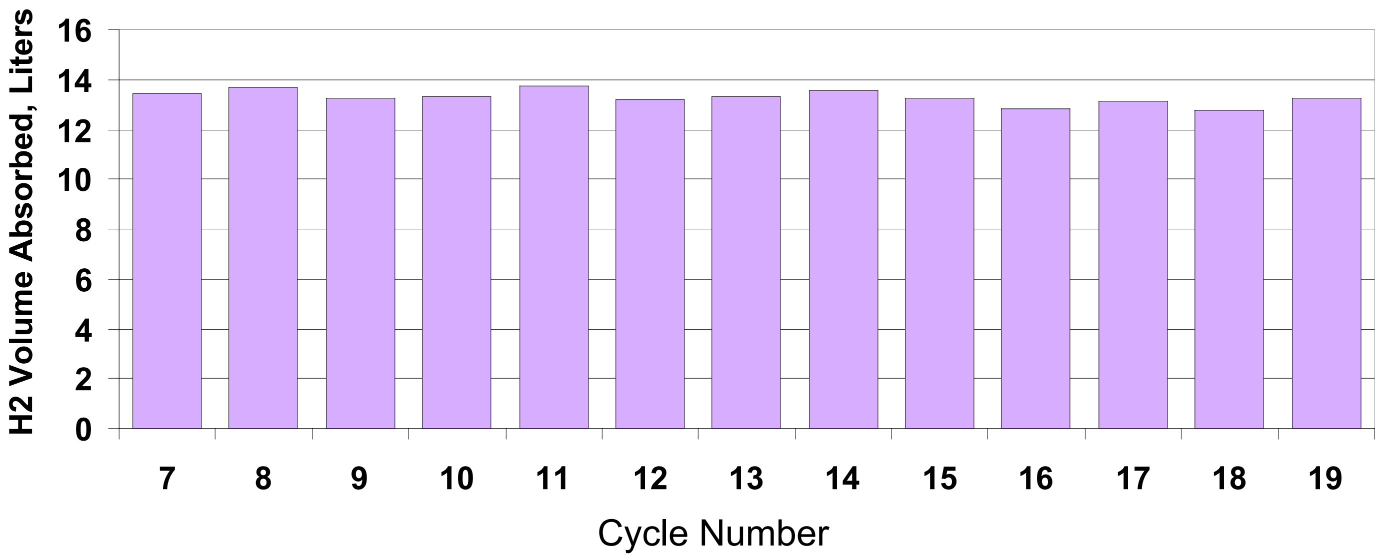
H_2 Quantity	1 kg	
Inlet Pressure	15 psia	
Outlet Pressure	5,000 psia	
Isothermal Work	1,960 watt hours = 6,690 BTU	
Compressor Type	Mechanical	Hydride
Efficiency	29%	15%
Fuel	Electricity at $0.07 / kWh	Natural Gas at $4 / MM BTU
Comp. Energy Cost / kg H_2	$0.47	$0.18
Energy Cost / H_2 Cost at $3.00/gge (2004)*	16%	6%
Energy Cost / H_2 Cost at $1.50/gge (2010)*	31%	12%

* FY 2004 Congressional Budget Request
gge = gallon of gasoline equivalent, which is ~ 1 kg H_2

Target cost of compression sources do not appear to include energy costs. Hydride compressor energy cost is 3x lower than mechanical, but may be equivalent to electrochemical compression, anticipated to be integrated into electrolysis by 2010.

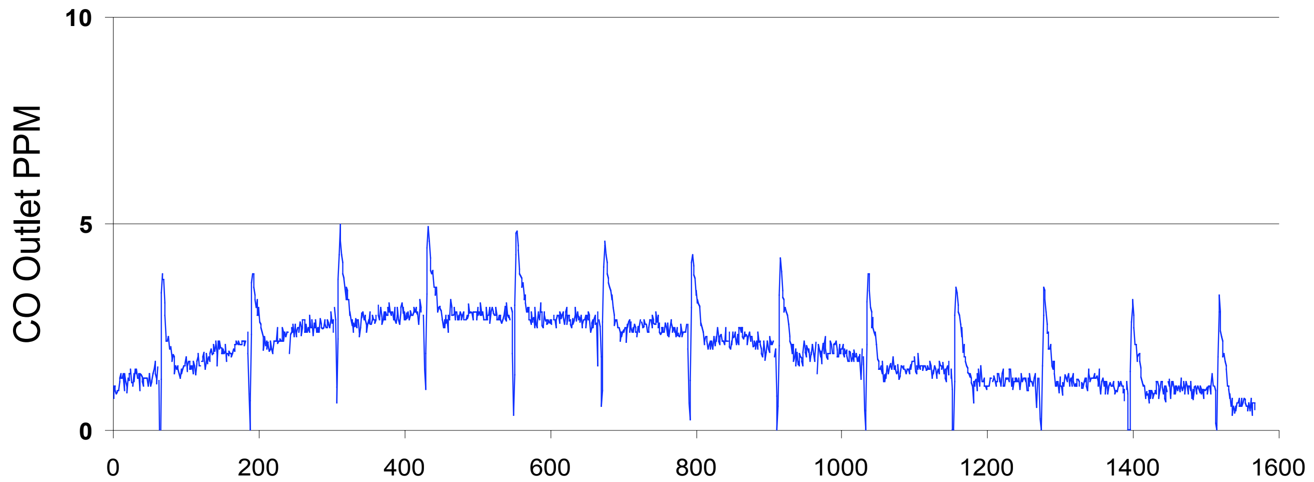
Accomplishments / Progress - H_2 Purity - Tolerating Impurities

With 1,000 ppm CO in the inlet H2, alloy capacity does not degrade.

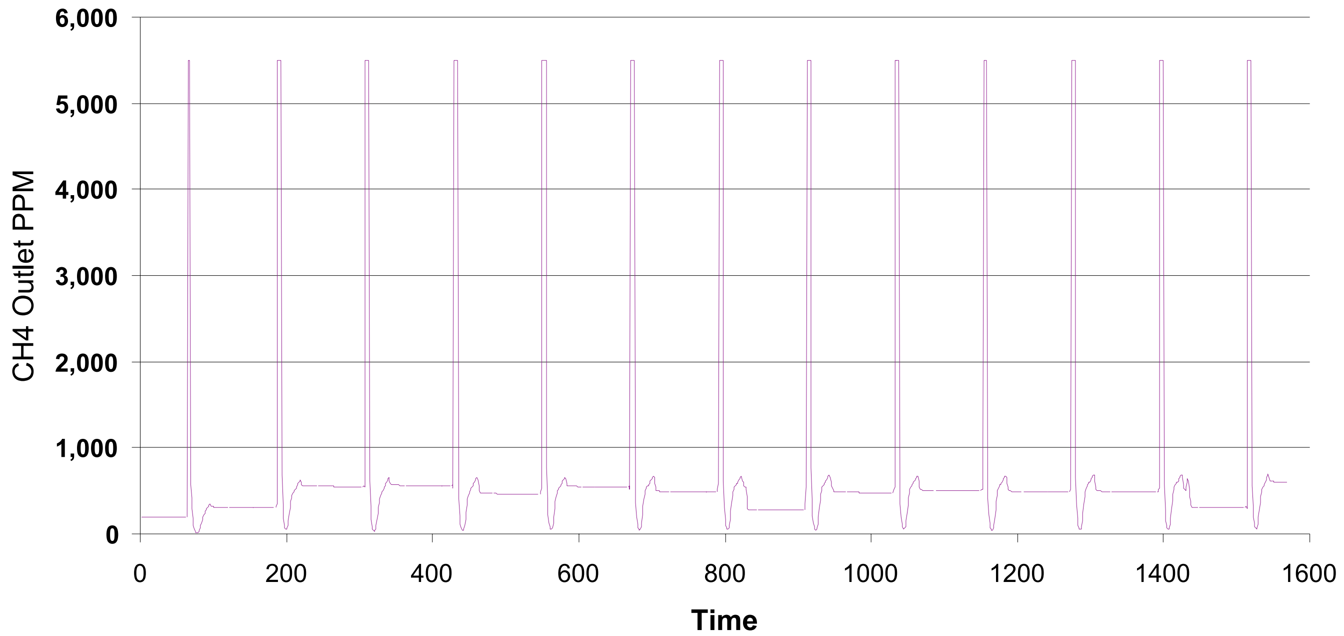


Accomplishments / Progress - H_2 Purity - Removing CO

1,000 ppm Inlet CO is reduced to <5 ppm to protect fuel cell electrode catalyst.



The large CH_4 spike at the beginning of each compression cycle was intended to be removed via inert gas venting, but positive results have not yet been achieved. Work is continuing.



Response to Reviewers Comments

This project is more relevant to infrastructure development than the hydrogen storage goals of the R&D plan.

- The project was moved into H2 Production and Delivery.
- HERA has evaluated the application of hydride compression for crosscutting applications, in addition to the original focus on a refueling station.

What is the overall balance between benefits and barriers?

- Extensive progress directed at meeting the 2010 cost targets for compression.
- Hydride compressor anticipated long term reliability advantage over mechanical compression has been predicted using MTBF analyses of active components, but, commercial demonstration is needed to provide proof.
- Consultant has been retained for mechanical compressor capital and installation cost analysis.

Need to work on minimizing HC bleed through.

- A series of tests are underway to shed light on cause of HC venting difficulty.

Future Work

This project is nearing completion, with the majority of the objectives met.

The next step will be a full scale demonstration (funding from private sources).