Advanced Thermal Hydrogen Compression

presented to the

US DOE Hydrogen and Fuel Cells Program

2003 Annual Merit Review

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by

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Relevance / Objective

Project Objective: Develop an advanced thermal 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 for market penetration.

Relevance to National Technical Targets:

H_2 Cost: Reduce compression energy costs by an order of magnitude to meet the H_2 cost goals of:

Long Term: $1.50/gallon of gasoline equivalent (2010)

Near Term: $3.00/gallon of gasoline equivalent (2004)

Energy Density: Demonstrate pressures of 5,000 and 10,000 psi to support high pressure tank development.

H_2 Purity: Increase H_2 quality to protect both fuel cell catalyst and advanced hydrogen storage materials. (≤10 ppm CO)

Complex/Carbon: Knowledge of impurity-effects on compressor hydrides will establish a baseline for understanding impurity impact on advanced storage materials (alanates & carbon nanomaterials).

Approach

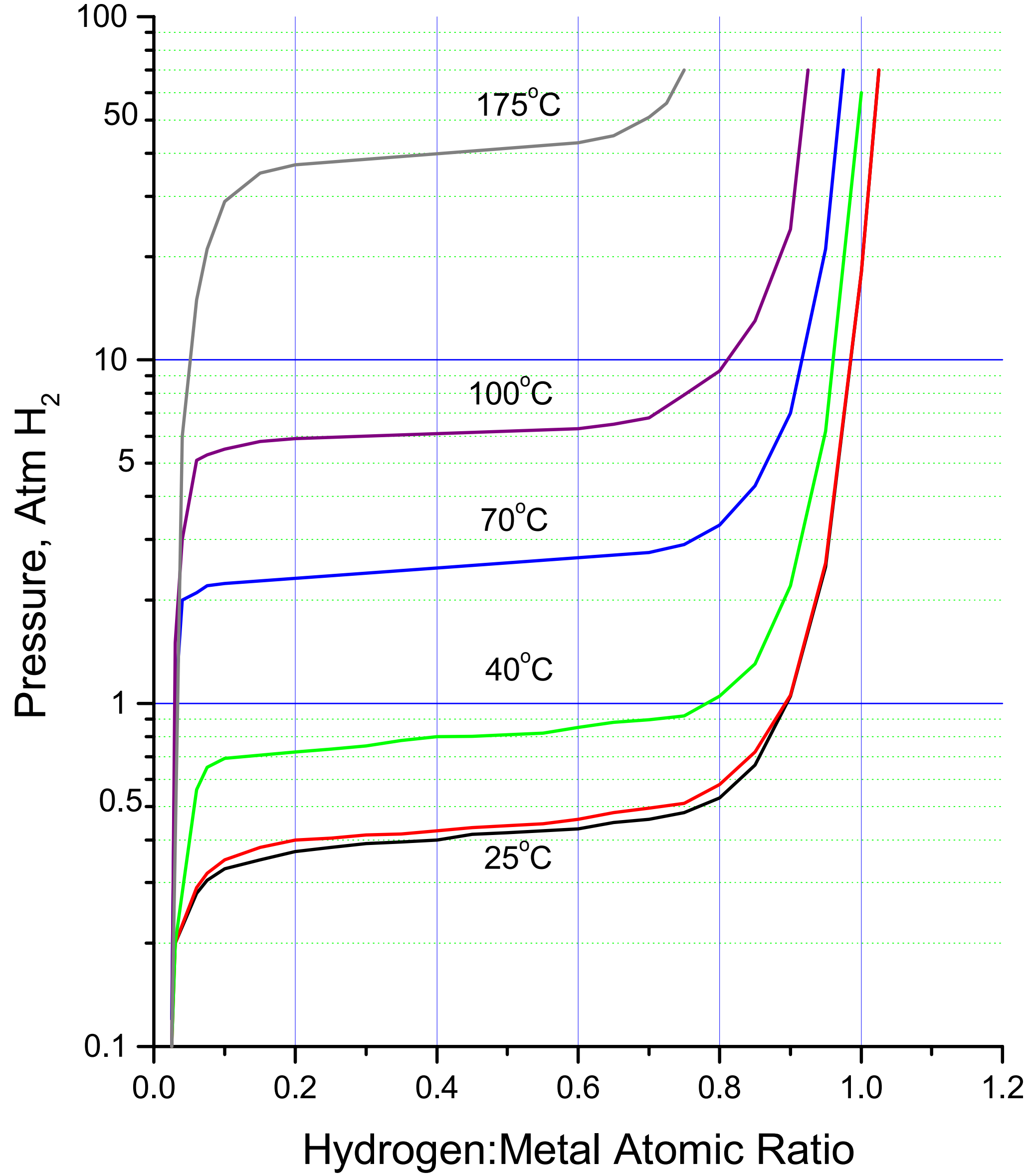
Thermal Compression with Metal Hydride Alloys

A modest increase in temperature results in a large increase in pressure.

Compression energy can be provided by hot water, rather than electrical power.

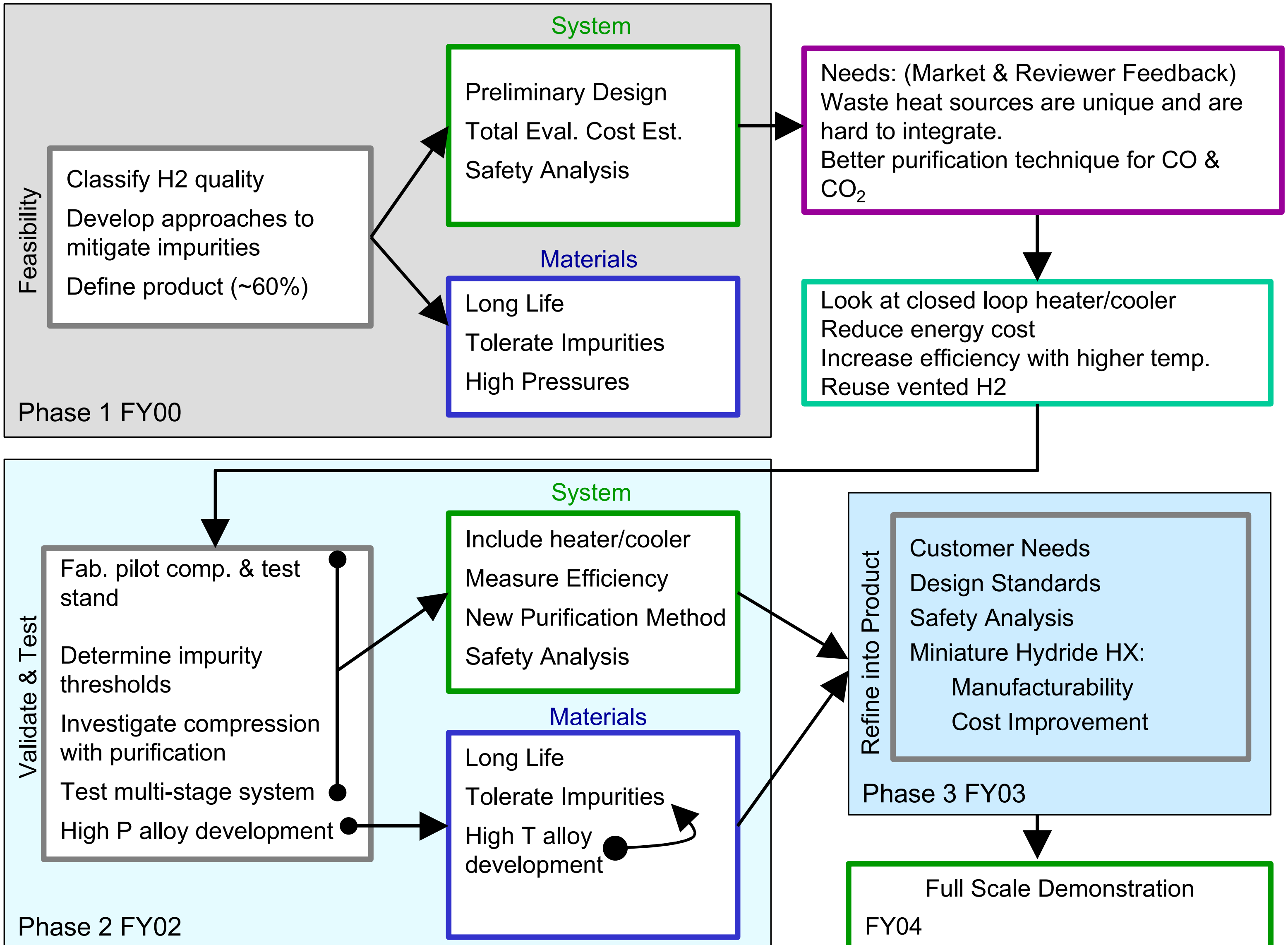
High compression ratios are achieved by staging alloys with increasing plateau pressures.

Hydride alloys and systems must tolerate impurities and elevated temperatures.



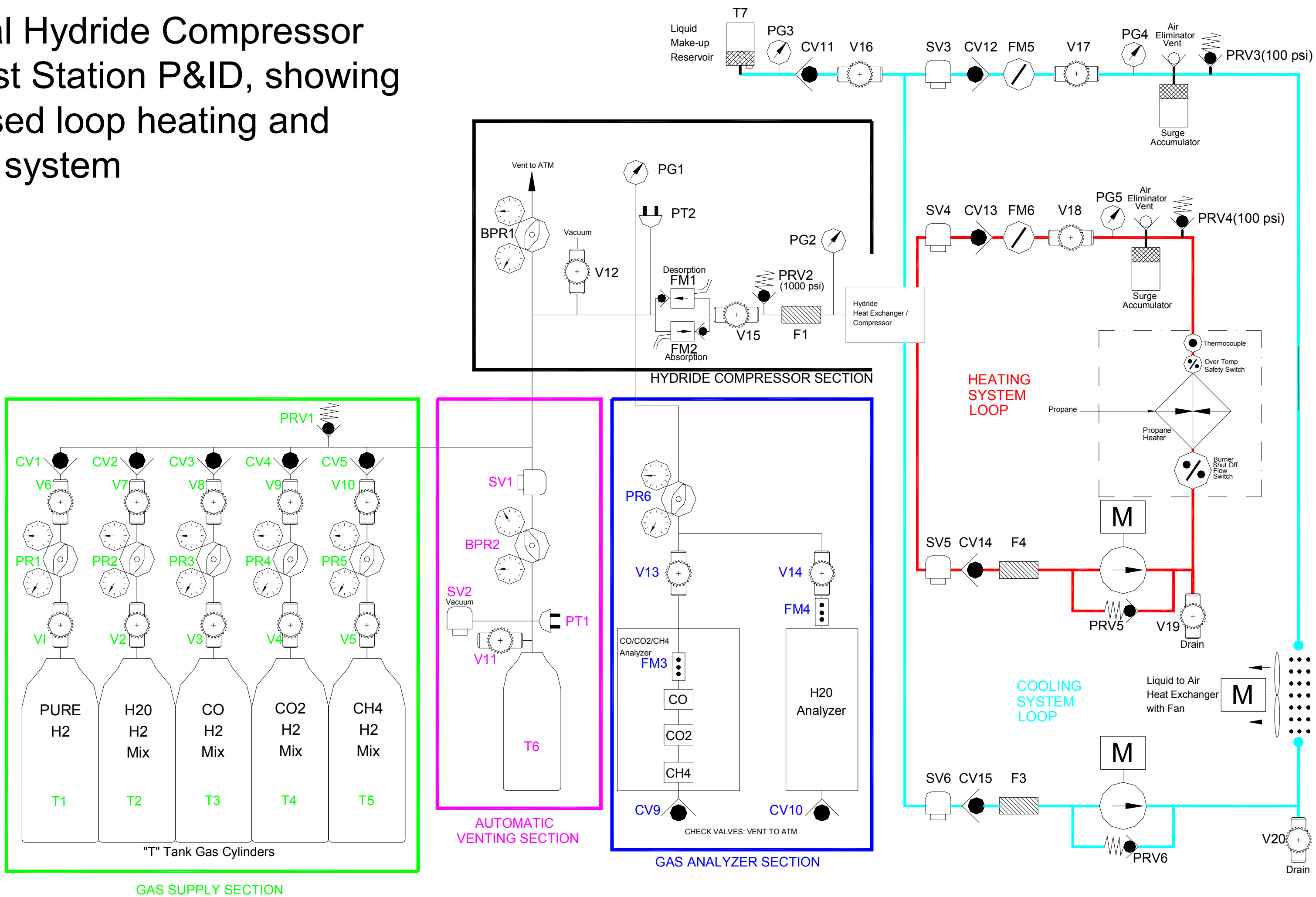
Project Title: Advanced Thermal Hydrogen Compression Contractor: Ergenics, Inc.

Approach



Approach

Thermal Hydride Compressor and Test Station P&ID, showing the closed loop heating and cooling system



Piping & Instrumentation Diagram

THIS DOCUMENT AND ITS CONTENTS:

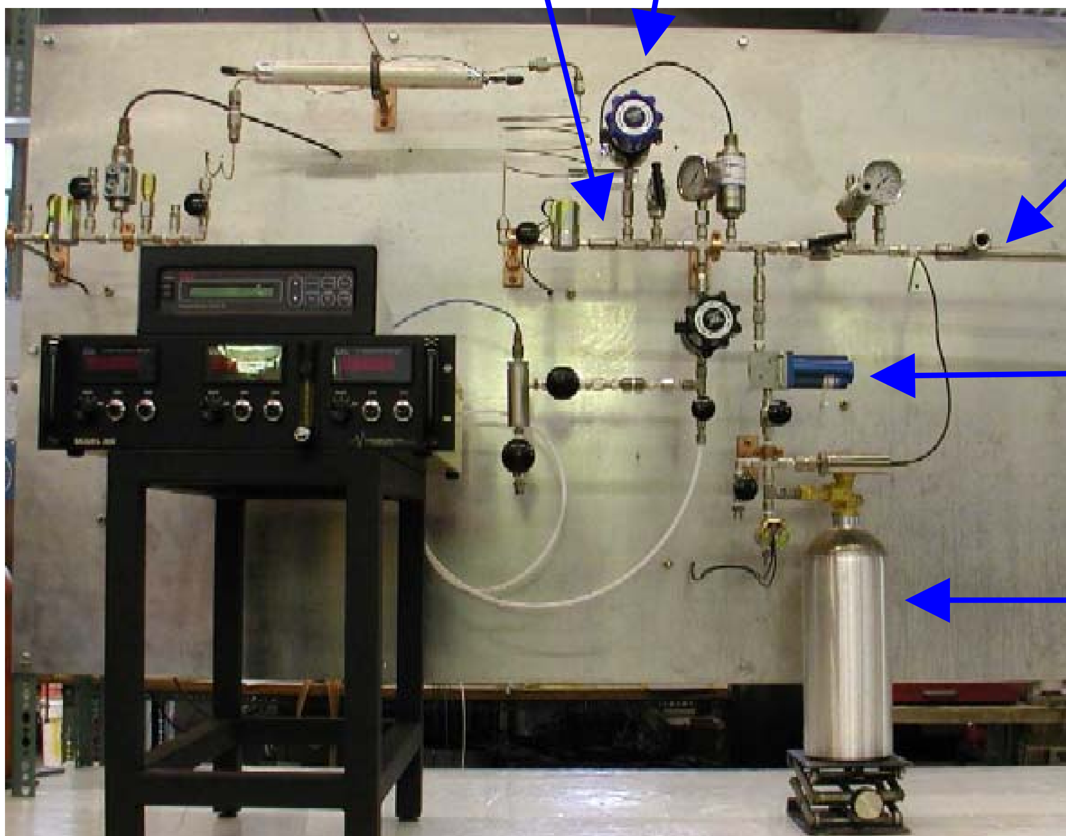
Approach

The compressor bed is a miniature hydride shell and tube heat exchanger measuring 0.75 inches in diameter by 60 inches long (19 mm D x 1524 mm L).

Hydride alloy is contained within four 0.125 inch diameter (3.2 mm) Inconnel tubes that are welded to a stainless steel tube sheet on one end and closed on the other end.

The tube “bundle” slides into the stainless steel shell, which is welded to the back side of the tube sheet. Heating/cooling fluid enters the shell via the perpendicular nozzle. The hydrogen manifold contains a filter disc to prevent alloy migration.

Approach



Hydride Compressor Test Stand

Project Title: Advanced Thermal Hydrogen Compression

Contractor: Ergenics, Inc.

Project Timeline

Feasibility	**Quantified H_2 quality anticipated from advanced and renewable production techniques.** **Preliminary design and Safety Analysis**	FY2000
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, inert gas venting for N_2 & CH_4).**	FY2001 FY2002
Refine Product Design	**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.**	FY2003
Full Scale Demonstration	**To be proposed**	FY2004

Status: **Completed** **In Progress** **Future**

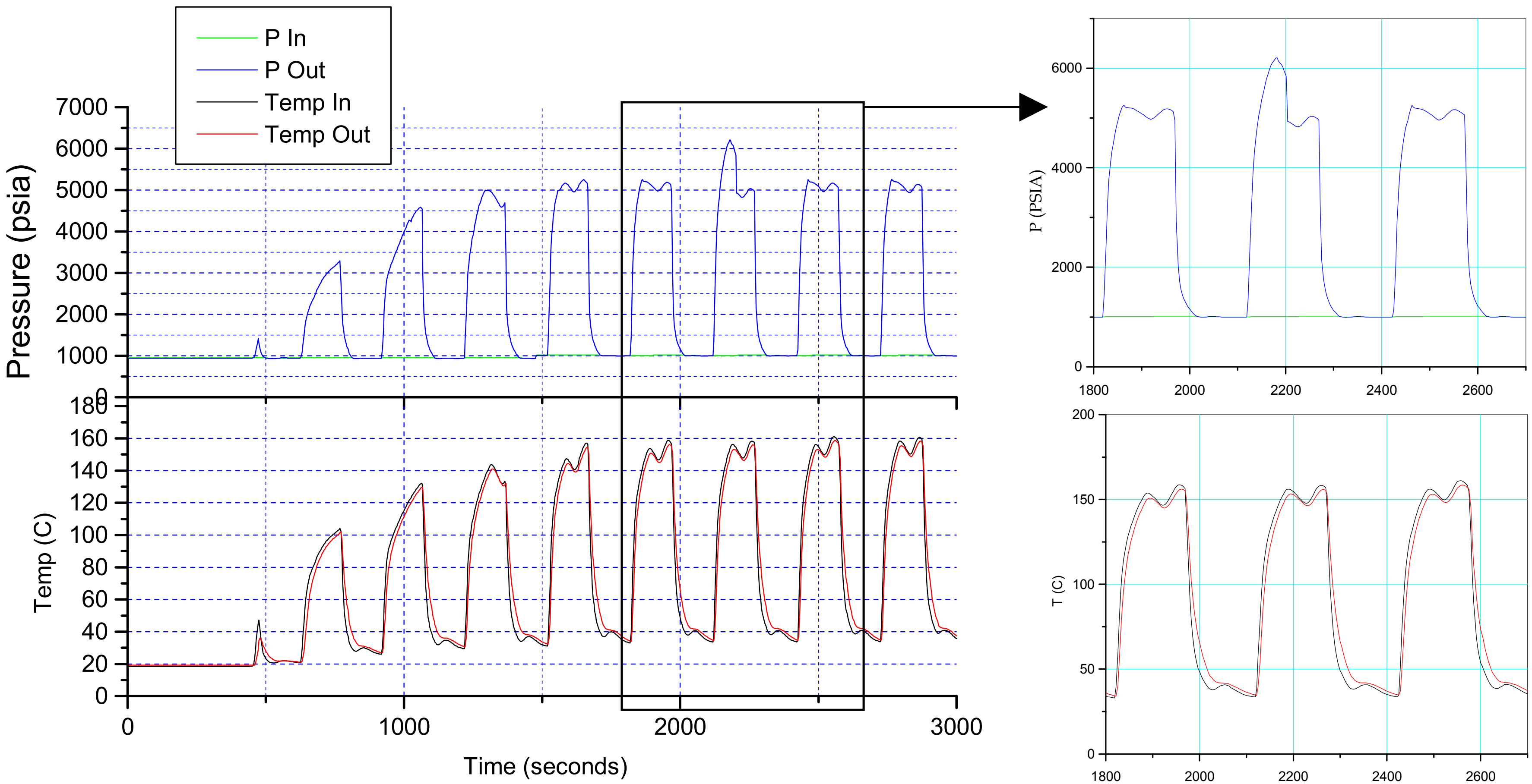
Accomplishments / Progress - H_2 Cost

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

H_2 Quantity	1 kg		1 kg	
Inlet Pressure	15 psia		15 psia	
Outlet Pressure	5,000 psia		10,000 psia	
Adiabatic Work	1,960 watt hours = 6,690 BTU		2,194 watt hours = 7,485 BTU	
Compressor Type	Mechanical	Hydride	Mechanical	Hydride
Efficiency	12%	15%	6%	10%
Fuel	Electricity at \$0.05 / kWh	Natural Gas at \$3 / MM BTU	Electricity at \$0.05 / kWh	Natural Gas at \$3 / MM BTU
Comp. Energy Cost / kg H_2	\$0.82	\$0.14	\$1.83	\$0.23
Energy Cost / H_2 Cost at \$3.00/gge (2004)*	27%	5%	NA	NA
Energy Cost / H_2 Cost at \$1.50/gge (2010)*	55%	9%	122%	15%

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

Accomplishments / Progress - Energy Density

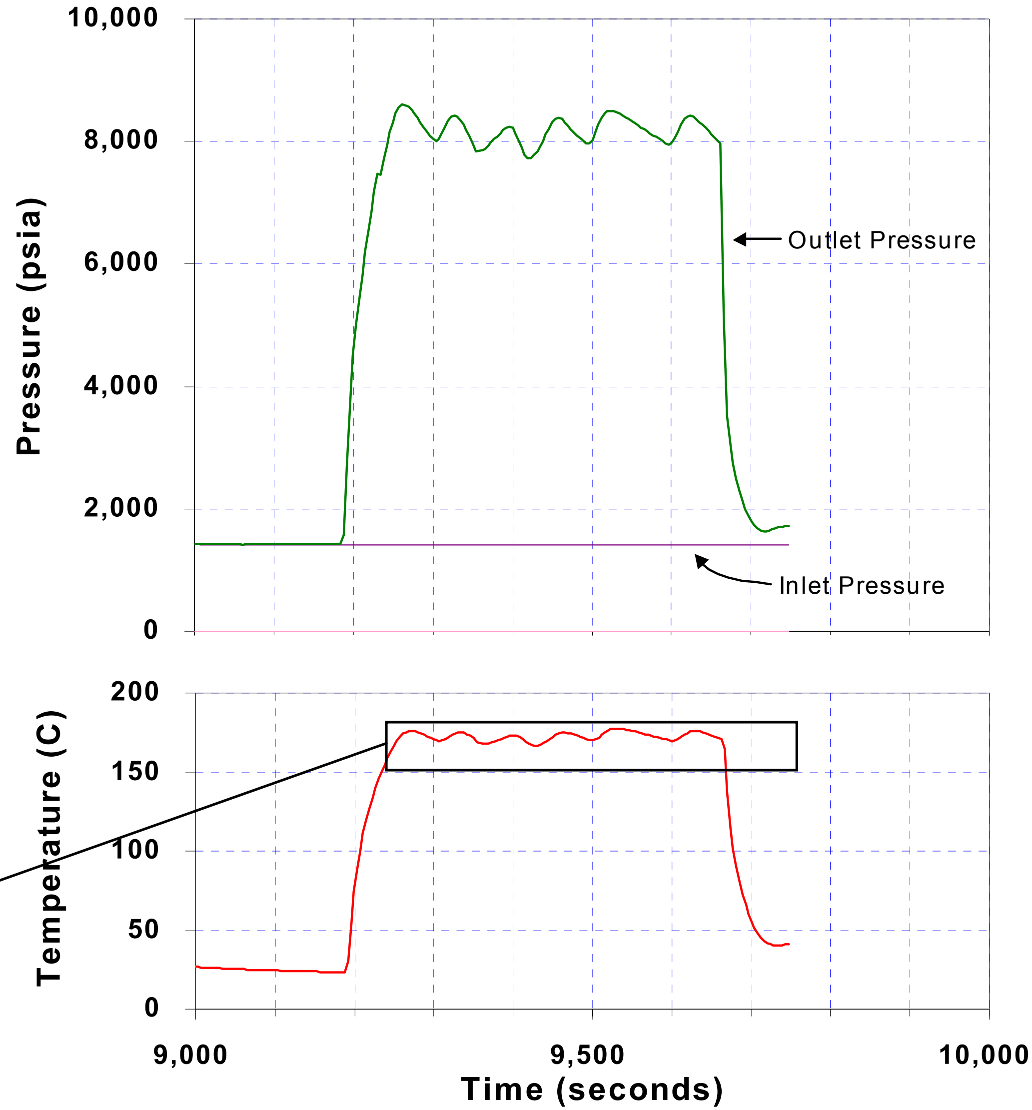


Compressed hydrogen is vented via a back-pressure regulator. The regulator was set at 5,000 psi (34 MPa) for most cycles, but was briefly increased to 6,000 psi (41 MPa) for the cycle that starts at Time = 2,000 seconds. The compressor is capable of operation to 10,000 psi (69 MPa).

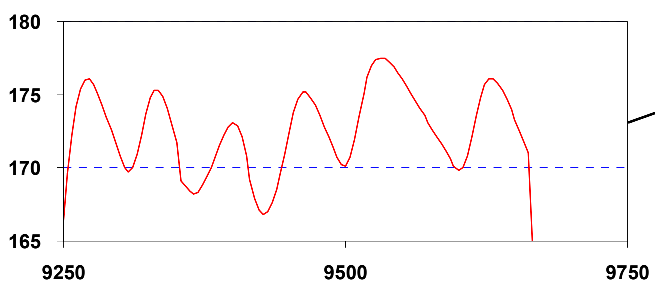
Accomplishments / Progress - Energy Density

High Outlet Pressure

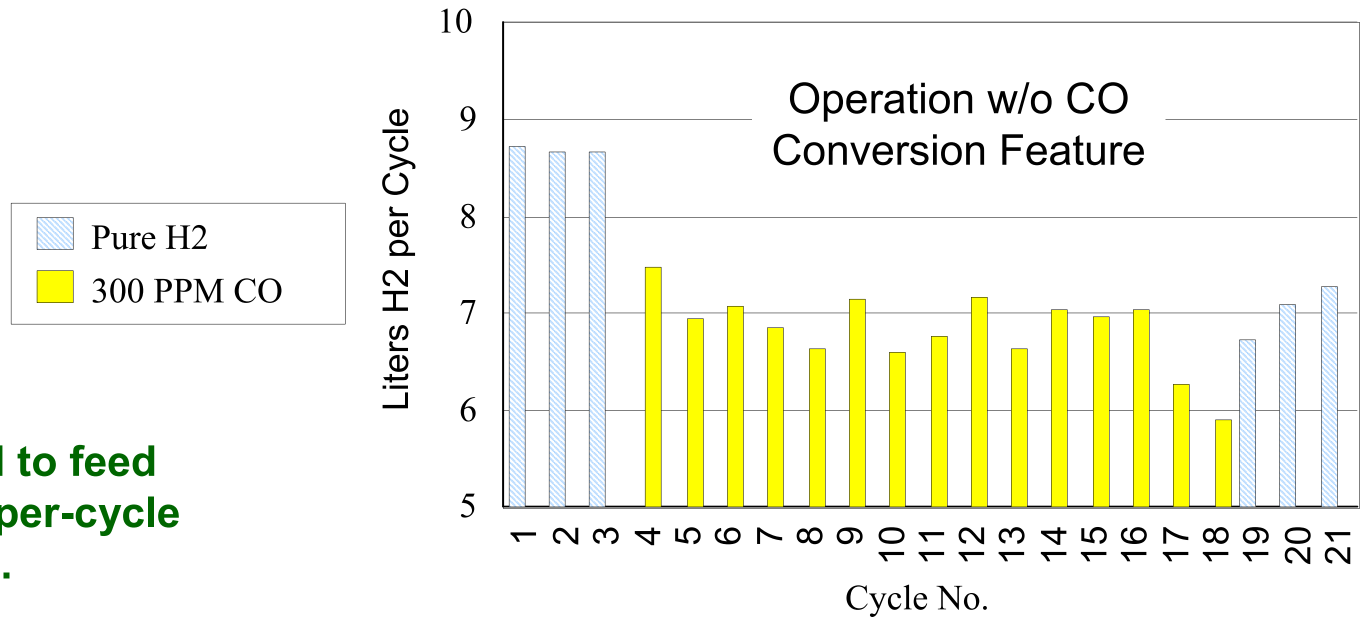
- Single Stage
- Inlet P = 1,200 psia
- Outlet P = >8,000 psia
- 10,000 psia will be achieved with elevated temperature



Pressure responds to fluctuation in water temperature as the heater cycles on and off

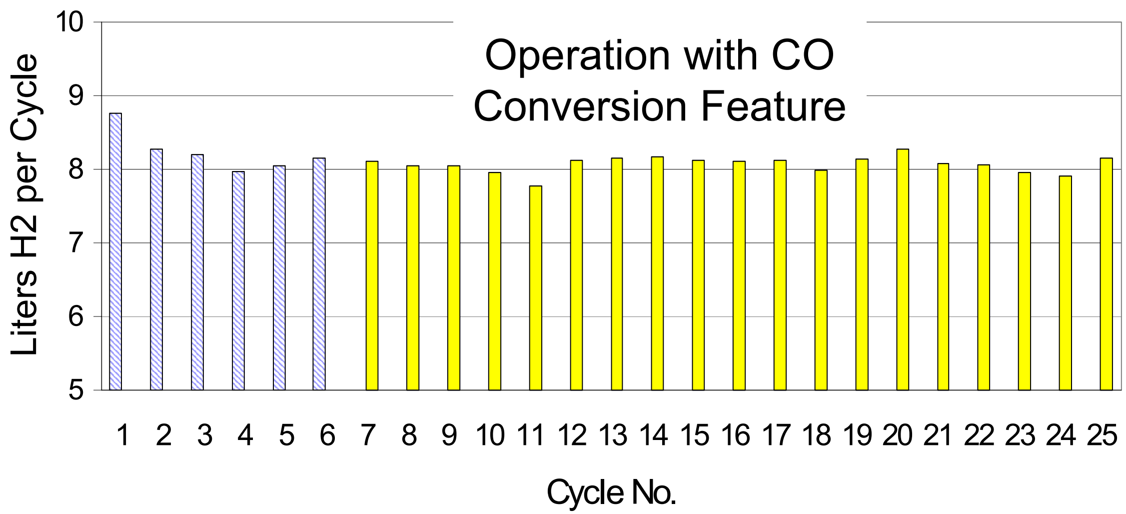


Accomplishments / Progress - H_2 Purity - Tolerating Impurities (1 of 2)



When CO is added to feed H_2, alloy capacity-per-cycle gradually declines.

A recently developed, proprietary CO conversion feature maintains alloy capacity.

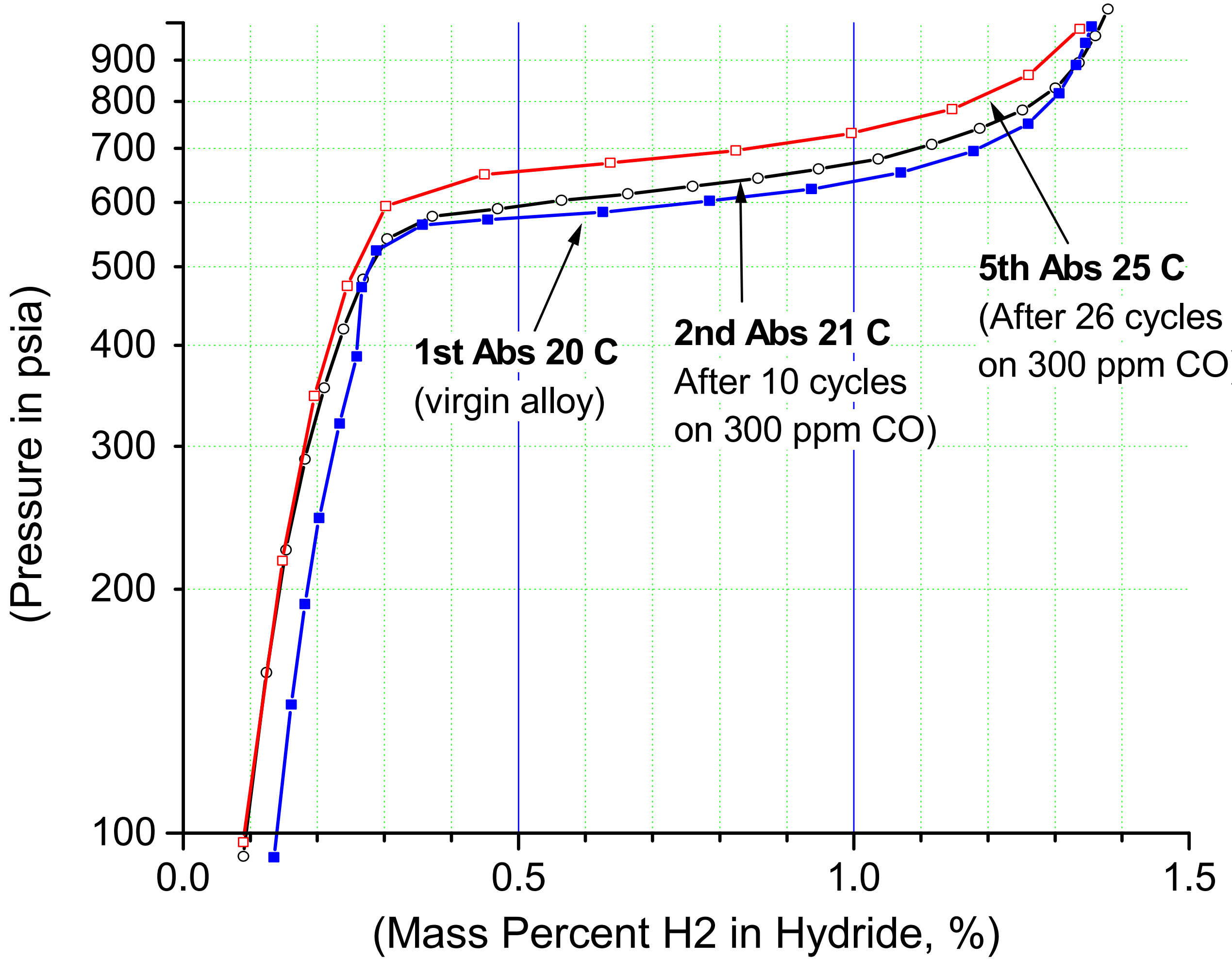


Accomplishments / Progress - H_2 Purity - Tolerating Impurities (2 of 2)

Compressor Alloy PCT Isotherms

PCT Isotherms* indicate the alloy was not damaged by CO. The differences in plateau pressures are a function of ambient temperature.

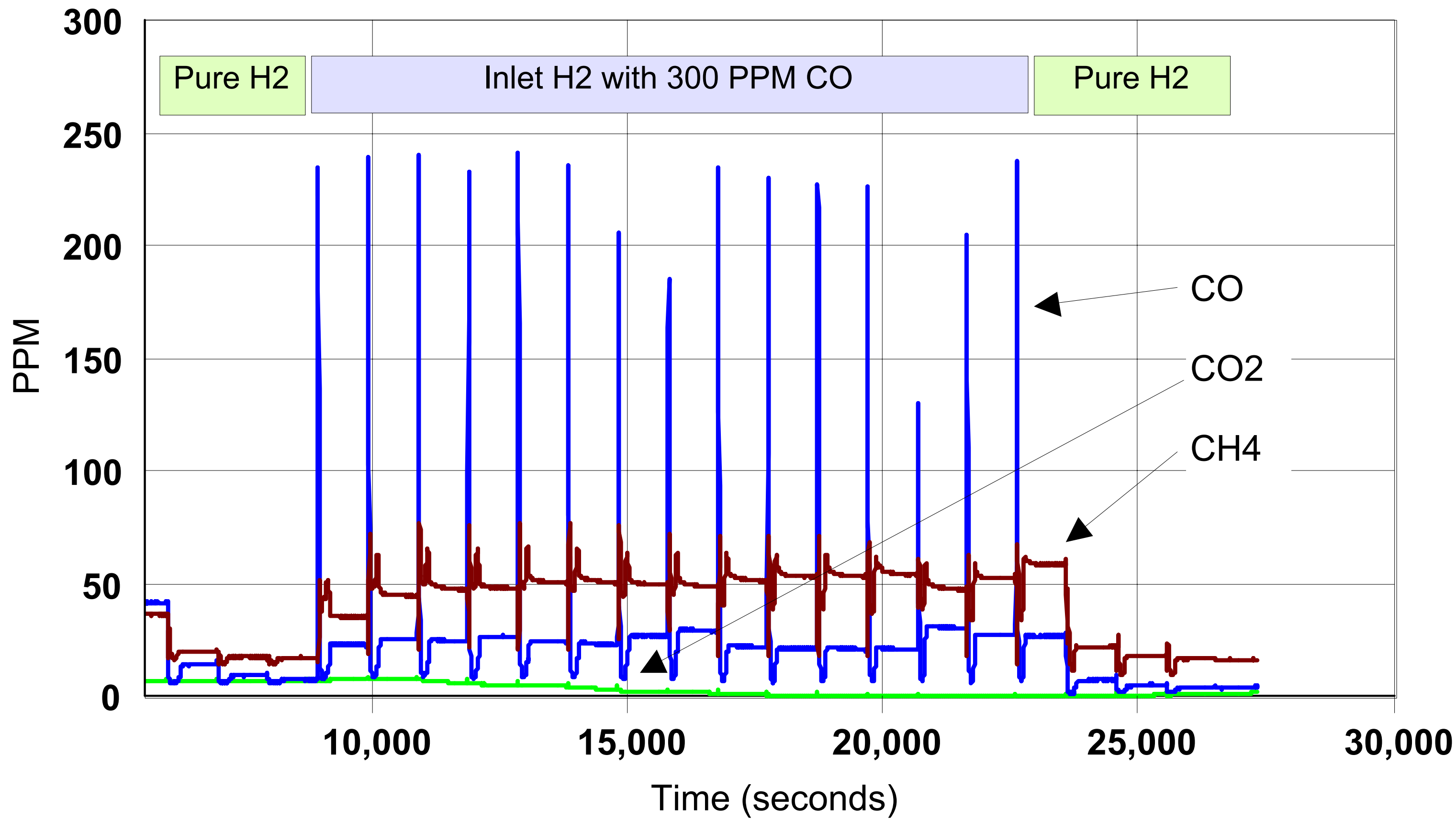
* PCT = pressure, composition, temperature



Accomplishments / Progress - H2 Purity - Removing CO (1 of 2)

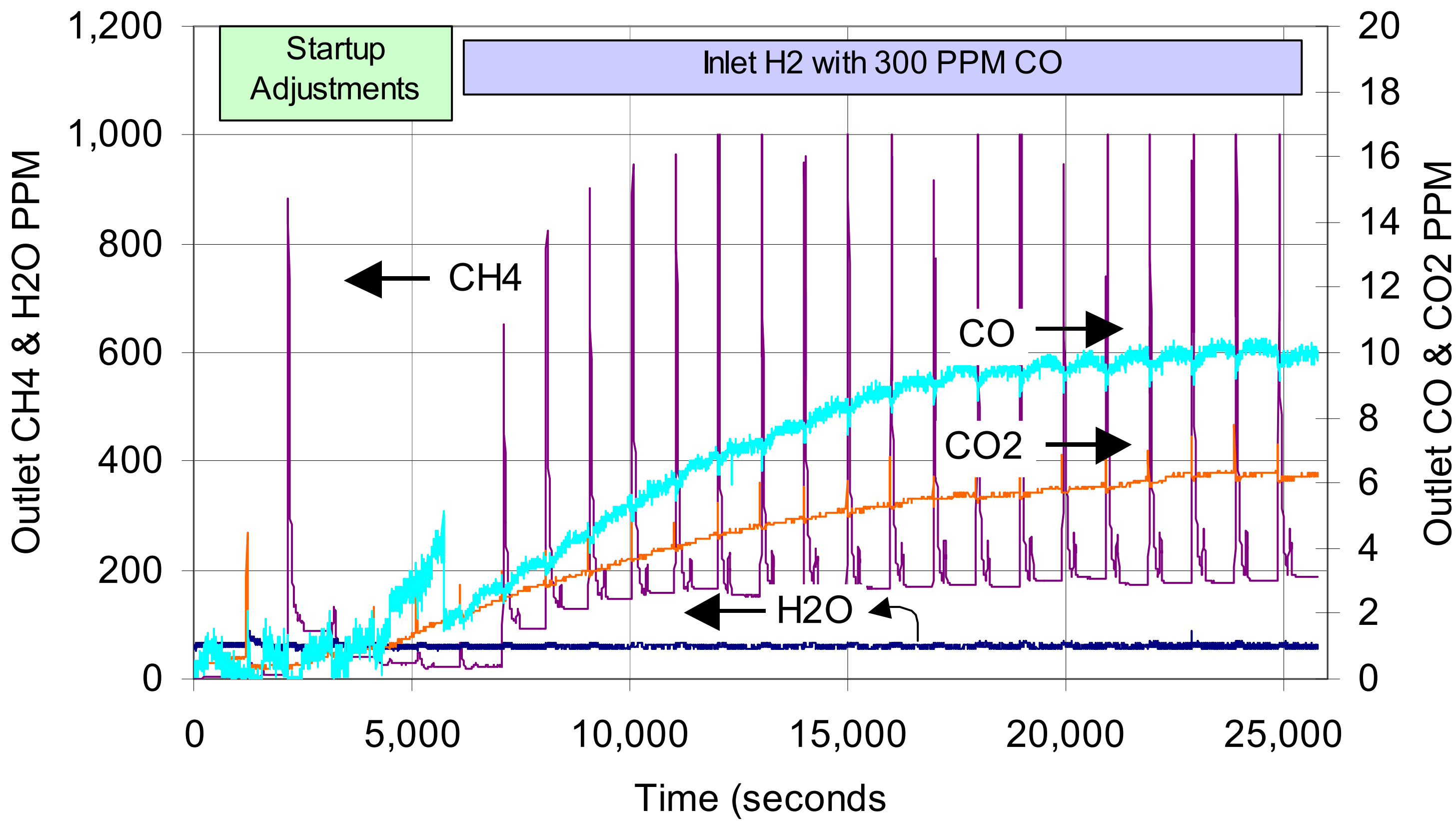
Outlet Hydrogen Composition w/o CO Conversion Feature

With 300 ppm inlet CO, CO outlet concentrations approach 250 ppm



Accomplishments / Progress H2 Purity - Removing CO (2 of 2)

Outlet Hydrogen Composition with CO Conversion Feature



300 ppm Inlet CO is reduced to 10 ppm to protect fuel cell electrode catalyst. CH4 will be removed via inert gas venting, made possible by the >1,000 ppm spike that is released at the very beginning of each desorption cycle.

Collaboration and Future Plans

Ergenics is contributing to the International Energy Agency Hydrogen Implementing Agreement for Solid and Liquid State Hydrogen Storage Materials.

Submitting patent application for CO conversion feature.

Seeking a H_2 refueling site and partners for a full scale thermal hydrogen compressor demonstration for FY2004. Are in discussions with three site operators, two hydrogen producers and a major oil company.