Advanced Thermal Hydrogen Compression
presented to the
US DOE Hydrogen and Fuel Cells Program
2003 Annual Merit Review
May 20, 2003
by
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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:

H₂ Cost: Reduce compression energy costs by an order of magnitude to meet the H₂ 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.

H₂ Purity: Increase H₂ 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).
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.
Approach

Project Title: Advanced Thermal Hydrogen Compression

Contractor: Ergenics, Inc.

Materials
- Long Life
- Tolerate Impurities
- High Pressures

Needs: (Market & Reviewer Feedback)
- Waste heat sources are unique and are hard to integrate.
- Better purification technique for CO & CO₂
- Look at closed loop heater/cooler
- Reduce energy cost
- Increase efficiency with higher temp.
- Reuse vented H₂

System
- Preliminary Design
- Total Eval. Cost Est.
- Safety Analysis

Materials
- Long Life
- Tolerate Impurities
- High T alloy development

Classify H₂ quality
Develop approaches to mitigate impurities
Define product (~60%)

Fab. pilot comp. & test stand
Determine impurity thresholds
Investigate compression with purification
Test multi-stage system
High P alloy development

Customer Needs
Design Standards
Safety Analysis
Miniature Hydride HX:
Manufacturability
Cost Improvement

Phase 1 FY00

Phase 2 FY02

Phase 3 FY03

Full Scale Demonstration FY04
Approach

Thermal Hydride Compressor and Test Station P&ID, showing the closed loop heating and cooling system
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.
Project Title: Advanced Thermal Hydrogen Compression

Approach

Hydride Compressor Test Stand

- H2 Inlet
- Gas Analyzers
- Check Valve
- H2 Outlet
- Compressor
- Inert Gas Vent Valve
- Vent Collection Tank
### Project Timeline

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<tbody>
<tr>
<td>Feasibility</td>
<td>定量 H₂ 质量从先进和可再生生产技术中预期。</td>
<td>初步设计和安全分析</td>
<td>确定合金的抵抗过量反应性。</td>
<td>验证压缩机操作在 &gt;5,000 psi。</td>
<td>确定合金在循环中的抗杂质性。</td>
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<tr>
<td>Validate and Test</td>
<td></td>
<td></td>
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<td></td>
<td>Test effectiveness of three purification techniques (passive purification for H₂O &amp; O₂, elevated temperature desorption for CO &amp; CO₂, inert gas venting for N₂ &amp; CH₄).</td>
</tr>
<tr>
<td>Refine Product Design</td>
<td></td>
<td></td>
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<td>Determine if compression with purification is a viable alternative for improving fuel cell performance.</td>
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<td>Full Scale Demonstration</td>
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<td>Reduce capital cost via miniature hydride heat exchangers and rapid cycling.</td>
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**Status:**
- Completed
- In Progress
- Future
Hydride Compression’s Low Energy Cost Will Substantially Reduce the Cost of Hydrogen

<table>
<thead>
<tr>
<th></th>
<th>H₂ Quantity</th>
<th>Inlet Pressure</th>
<th>Outlet Pressure</th>
<th>Adiabatic Work</th>
<th>Compressor Type</th>
<th>Efficiency</th>
<th>Fuel</th>
<th>Comp. Energy Cost / kg H₂</th>
<th>Energy Cost / H₂ Cost at $3.00/gge (2004)*</th>
<th>Energy Cost / H₂ Cost at $1.50/gge (2010)*</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1 kg</td>
<td>15 psia</td>
<td>5,000 psia</td>
<td>1,960 watt hours = 6,690 BTU</td>
<td>Mechanical</td>
<td>12%</td>
<td>Electricity at $0.05 / kWh</td>
<td>$0.82</td>
<td>27%</td>
<td>55%</td>
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<tr>
<td></td>
<td>1 kg</td>
<td>15 psia</td>
<td>10,000 psia</td>
<td>2,194 watt hours = 7,485 BTU</td>
<td>Hydride</td>
<td>15%</td>
<td>Natural Gas at $3 / MM BTU</td>
<td>$0.14</td>
<td>5%</td>
<td>9%</td>
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<td></td>
<td></td>
<td>Mechanical</td>
<td>6%</td>
<td>Electricity at $0.05 / kWh</td>
<td>$1.83</td>
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<td>122%</td>
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<td></td>
<td></td>
<td>Hydride</td>
<td>10%</td>
<td>Natural Gas at $3 / MM BTU</td>
<td>$0.23</td>
<td>NA</td>
<td>15%</td>
</tr>
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</table>

* FY 2004 Congressional Budget Request
  gge = gallon of gasoline equivalent, which is ~ 1 kg H₂
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).

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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.
When CO is added to feed H₂, alloy capacity-per-cycle gradually declines.

A recently developed, proprietary CO conversion feature maintains alloy capacity.
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
Outlet Hydrogen Composition w/o CO Conversion Feature
With 300 ppm inlet CO, CO outlet concentrations approach 250 ppm
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.

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.