Overview

Timeline
• Project start date: 7/15/10
• Project end date: 7/14/13
• Percent complete: 92%

Budget
• Total project funding
  – DOE share: $1993k
  – Contractor share: $629k
• Funding for FY13: $545k

Barriers
• Barriers addressed for gaseous hydrogen compression:
  – More reliable
  – Lower-cost
  – Higher efficiency

Partners
• Collaborations: Sustainable Innovations, LLC
• Project lead: FuelCell Energy
Impact of EHC:

• Increases reliability/availability over current mechanical compressors
• Ensures “no possibility of lubricant contamination” (No moving parts) → Fuel Cell Quality H₂
• Increases Compression Efficiency to 95% (DOE 2015 Target)
• Potentially reduces cost of H₂ delivery to <$1/gge (DOE Long Term Target)
Approach

- Use high-pressure electrolyzer experience for mechanically robust cell design
- Higher current density operation to minimize capital and operating costs
- Improved flow field design to increase H₂ recovery efficiency
- Simple system: Reduce capital cost by increasing cell size and reducing number of parts
## Approach

<table>
<thead>
<tr>
<th>ITEM</th>
<th>APPROACH</th>
</tr>
</thead>
</table>
| Increase Pressure, Life, Efficiency     | - Cell & Stack Design Enhancements  
- MEA Improvements  
- Multi-Stage Operation  
- Very High Single Stage Compression |
| Lower System Cost                       | - Cell & Stack Design Enhancements  
- Increase Current Density  
- Increased Durability/Life  
- Increase Single-Stage Pressure Capability  
- Design for Mfg & Assembly  
- Lower Labor Rates  
- Lower Cost Materials of Construction  
- Lower Part Count  
- Leverage Economies of Scale  
- Increase Cell Active Area |
Principle of Electrochemical Hydrogen Compressor

- Simple operating principle with no moving parts – **Solid State**!
- Use of hydrogen electrode for high compression efficiency
Compression Heat

Multistage Adiabatic Compression with Interstage Cooling

vs.

Isothermal Compression of EHC

Hydrogen does not significantly heat up during compression in EHC
EHC Pressure Capability

EHC Pressure Capability Progression

Improvements made:
- Seals with higher pressure capability
- Improved MEA support

Met DOE 2015 pressure target for forecourt compressors
Reduction in the Energy Consumption of EHC

**Program Progress**

- Lower cell resistance
- Lower applied voltage

**Improvements made:**

- Improved cell design for 3000 psi

**More effort needed for 6,000 - 12,000 psi range**
EHC Durability

Improvements made:
• Membrane with higher proton conductivity
• Matching electrodes
• Lower cell resistance

7,000 hr operation at elevated current density (750 mA/cm²)
Almost 10,000 hr operation at ≥ 95% hydrogen recovery
EHC Cost Reduction

EHC Hydrogen Flux Progression

Cell area 81 cm²; compression from <30 psig to ≥2,000 psig

Improvements made:
- Higher performance MEA
- Lower cell resistance at higher pressure
- Improved manufacturing tolerances
- Increased output
- Reduced part count

Ten-fold increase in current density
Reducing Cell Part Count
(Reduction in Parts per EHC Cell)

Advanced design has <50% part count of original design
Decrease in part count is opportunity for further cost reduction
Opportunities for Cost Reduction
(Stack Cost/H₂ Compression Capacity - $/kg-H₂/day)

Cost reduced by 50% in current program

Improvements planned:
- Higher current density operation
- Cell area scale-up
- Stack scale-up
- Reduction in # of cell parts
- Lower cost cell and stack materials
- Lower cost fabrication
## EHC Stack Development

<table>
<thead>
<tr>
<th></th>
<th>3-Cell Stack #1</th>
<th>3-Cell Stack #2</th>
<th>3-Cell Stack #3</th>
<th>5-Cell Stack</th>
<th>10-Cell Stack</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pressure, (psig)</strong></td>
<td>4,550</td>
<td>Up to 1,000</td>
<td>2-3,000</td>
<td>3,000</td>
<td>Up to 3,050</td>
</tr>
<tr>
<td><strong>Current Density, (mA/cm²)</strong></td>
<td>≤500</td>
<td>Up to 2,200</td>
<td>≤500</td>
<td>≤450</td>
<td>≤500</td>
</tr>
<tr>
<td><strong>Capacity, (lbs/day)</strong></td>
<td>0.2</td>
<td>Up to 0.8</td>
<td>0.2</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Operation, (hours)</strong></td>
<td>150</td>
<td>~100</td>
<td>&gt;2,000†</td>
<td>&gt;200*</td>
<td>~400</td>
</tr>
</tbody>
</table>

* Currently In Operation at FCE
† At Sustainable Innovations

Cumulatively ~3,000 hr operating experience
EHC 5-Cell Stack

Up to 3,000 psi capability
Achieved stable operation
Collaborations

Prime

  - System development and application engineering
  - Membrane and electrode design and fabrication

Subcontractor

- Sustainable Innovations, LLC (Small Business):
  - Cell and stack design and fabrication
  - Scale-up design and fabrication
  - EHC stack cost reduction and estimates
Proposed Future Work

- Continue endurance test of 10,000 hr cell
- Continue testing of 5-cell 81 cm² stack
- Begin testing 185 cm² single cell to verify successful area scale-up
- Complete fabrication of 185 cm² 8-cell stack
- Prepare test facility for larger capacity EHC
- Demonstrate ≥ 2 lb/day H₂ capacity compressing to 3,000 psi
## Scale-Up Plan to Reach 8 lb/day

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Active Area (cm²)</th>
<th>Current Density (mA/cm²)</th>
<th>Maximum Weight Gain (lb/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single Cell</strong></td>
<td>185</td>
<td>500 – 1500</td>
<td>Up to 0.5</td>
</tr>
<tr>
<td><strong>5 - Cell</strong></td>
<td>81</td>
<td>500 - 1500</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>8 - Cell</strong></td>
<td>185</td>
<td>500 – 1000</td>
<td>2 - 3</td>
</tr>
<tr>
<td><strong>25 - Cell</strong></td>
<td>185</td>
<td>500 – 1000</td>
<td>Up to 8</td>
</tr>
</tbody>
</table>

**Activity Covered Under Current Funding**

- 8 - Cell 185 cm² Active Area
  - 500 – 1000 mA/cm²
  - Up to 2 - 3 lb/day

**Activity Not Covered Under Current Funding**

- 25 - Cell 185 cm² Active Area
  - 500 – 1000 mA/cm²
  - Up to 8 lb/day
# Achievements in EHC Technology Development

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Program Goals</th>
<th>Current Status</th>
<th>DOE Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Product Pressure</td>
<td>Up to 3,000 psi building block, 6-12 kpsi</td>
<td>12,800 psi single stage 6,000 psi 2-stage</td>
<td>12,500 psi</td>
</tr>
<tr>
<td>Hydrogen Inlet Press.</td>
<td>5 - 300 psi</td>
<td>0 – 2,000 psi</td>
<td>300 psi</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>Up to 300:1</td>
<td>300:1</td>
<td>43:1</td>
</tr>
<tr>
<td>Hydrogen Recovery Efficiency</td>
<td>90 - 95%</td>
<td>&gt;95%</td>
<td>99.5%</td>
</tr>
<tr>
<td>Hydrogen Flux</td>
<td>500 - 1,000 mA/cm²</td>
<td>750 mA/cm² for 7,000 hr</td>
<td>-</td>
</tr>
<tr>
<td>Hydrogen Capacity</td>
<td>2-4 lb/day at 3,000 psi</td>
<td>~0.6 lb/day</td>
<td>Up to 1000 kg/day</td>
</tr>
<tr>
<td>Endurance Capability</td>
<td>1,000 hrs at 3,000 psi</td>
<td>10,000 hrs at 3,000 psi</td>
<td>&gt;5 years</td>
</tr>
<tr>
<td>Compression Efficiency</td>
<td>&lt;10 kWh/kg at 3,000 psi</td>
<td>4-12 kWh/kg from &lt;30 to 3,000 psi</td>
<td>6.2 kWh/kg from 300 to 12,500 psi</td>
</tr>
</tbody>
</table>
Project Summary

Relevance: Provide highly efficient, reliable and cost-effective hydrogen compression (up to 6,000/12,000 psi)

Approach: Develop electrochemical compressor – solid state device

Technical Accomplishments:
- Reduced capital cost by > 50% by increasing current density from 400 to 750 mA/cm² and by design improvements (reduced cell part count)
- Operated almost 10,000 hrs at high H₂ recovery (≥ 95%)
- Demonstrated single stage pressure capability to >12,000 psi

Collaborations: Active partnership with industry (Sustainable Innovations) on materials, design and fabrication

Proposed Future Work: Scale-up 185 cm² cell design to short stack to increase throughput and lower the cost
Acknowledgement

- FCE: Pinakin Patel, Ray Kopp, Jonathan Malwitz, Paul Pinard
- Sustainable Innovations, LLC: Trent Molter and team
- DOE: Erika Sutherland, Dave Peterson, Sara Dillich, Scott Weil, Monterey Gardiner, Paul Bakke