Overview

Timeline
- Project Start: Jan 2003
- Project End: Dec 2007
- Percent Complete: 100%

Budget
- Total Project Budget: $2.27M
  - DOE Share: $1.122M
  - Cost Share: $1.147M
- FY07 Funding
  - DOE: $110K
  - Cost Share: $103K
- FY08 Funding: $0

Barriers
Hydrogen Generation by Water Electrolysis
- G. Capital Cost
- H. System Efficiency

Targets

<table>
<thead>
<tr>
<th>DOE TARGETS: Distributed Water Electrolysis</th>
<th>GES STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Cost ($/gge)</td>
<td>4.75</td>
</tr>
<tr>
<td>Electrolyzer Cap. Cost ($/gge)</td>
<td>2.47</td>
</tr>
<tr>
<td>Electrolyzer Cap. Cost ($/kW)</td>
<td>600</td>
</tr>
<tr>
<td>Electrolyzer Cell Efficiency</td>
<td>68</td>
</tr>
</tbody>
</table>

Partners
- General Motors
- Center for Technology Commercialization-Public Outreach and Education
Project Objectives

**Overall Project**

- Develop and demonstrate a low-cost, moderate-pressure PEM water electrolyzer system
  - Reduce stack capital costs to meet DOE targets
  - Increase electrolyzer stack efficiency
  - Demonstrate 1200 psig electrolyzer system

**Past Year**

- Field test electrolyzer system at NREL
Advantages of GES PEM Electrolyzer

- PEM electrolyzers have higher stack efficiency than alkaline systems.
- Operation at higher current density partially offsets higher cost/area of PEM electrolyzer.
- With advanced membrane demonstrated 1.70V at 1750 mA/cm² Stack efficiency = 74% based on LHV).

<table>
<thead>
<tr>
<th>Performance</th>
<th>Stack Electric cost ($/gge @ 3.9¢/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES PEM</td>
<td>1.70V @ 1750 mA/cm²</td>
</tr>
<tr>
<td>Alkaline</td>
<td>Typically &gt;1.85V at 300-400 mA/cm²</td>
</tr>
</tbody>
</table>

- Electricity is the key cost component in electrolyzer systems.
- GES PEM differential pressure technology produces H₂ at moderate to high pressure with O₂ production at atmospheric pressure
  - Eliminates handling of high-pressure O₂, reducing system cost & complexity, and improving safety
- Cost is benefited by advances in PEM fuel cell technology
**Milestones FY2007**

**Jan 07**  
Complete fabrication of low-cost stack components

**May 07**  
Assemble & test modified stack with decreased parts-count per cell

**July 07**  
Incorporated low cost stack in modified system

**Sep 07 – Apr 08**  
Field testing at NREL

40 to 16 parts/cell  
>2500 to <1000$/kW
Approach

- Develop lower-cost materials and fabrication methods for cell components
  - Replace high-cost metal components with other materials
  - Develop fabrication methods suitable for large-scale fabrication
  - Reduce parts count/cell

- Increase operating current density to reduce cell active area (reduce stack cost) while retaining high efficiency
  - Evaluate trade-off of efficiency vs. capital cost
  - Develop high-efficiency membrane
  - Reduced catalyst loadings

- System innovations to replace high-cost, high maintenance components

- Emphasize safety in design and operation
Anode/Cathode Side Membrane Support Structure

- Prior ASMSS design consisted of 9 metal parts, which are individually cut, plated, welded, cut again and assembled; CSMSS, similar in design, incorporated expensive valve metals.

- Successfully incorporated single-piece CSMSS metal part
- A single-piece ASMSS part demonstrated acceptable pressure drop in a 160-cm$^2$ cell and demonstrated stable electrolyzer performance. Further development required for larger stacks.
Stack Cost Reduction Progress

- *Thermoplastic Cell Frame Enhancement*

  - Conducts fluids into/out of active area
  - Aids in pressure containment- highly stressed component
  - Presently these parts are molded and machined; machining accounts for 95% of part cost

  - GES developed molding process, low-cost fabrication method that eliminates machining.
  - Molding process reduces cell cost by 40%
Stack Cost Reduction Progress

- **Cell Separator**
  - Key component that must be compatible with high-pressure hydrogen on one side and oxygen at high potential on the other
  - Previous technology was a very expensive part consisting of two different valve metals
  - Evaluated several approaches for lower-cost part
    - Carbon coating on a titanium separator to reduce hydrogen embrittlement
      - Difficult to obtain an impervious, pinhole-free coating
    - Metal oxide coatings on titanium to reduce hydrogen-embrittlement
    - Short-term solution is a two-piece titanium separator
      - Projected to have lifetime of 5000 hours
      - Longer life separator needs to be developed
Progress in Part Count Reduction

2002

Present Goal (2006)

40 + Parts

16 Parts
Increasing Operating Current Density - Progress

- High-current-density operation reduces stack active area, and therefore stack cost
  - Thin membranes have low resistance, allowing efficient operation at high current densities. Thinner membranes operating at higher temperatures are required to achieve the DOE efficiency
  - Drawback is poor mechanical properties, limiting operation to moderate differential pressures

- GES has reduced the thickness of the Nafion membrane used from 10 mils to 7 mils, and has demonstrated performance and short-term life of a 5 mil Nafion membrane in a short stack at 400 psid

- GES is developing an advanced supported membrane structure
  - Excellent mechanical properties- suitable for high differential pressure
  - High proton conductivity- equivalent to 2 mil Nafion membrane
  - Hydrogen and oxygen permeability equivalent to N112
**Supported Membrane**

- **Superior Mechanical Properties**
  - No x-y dimensional changes upon wet/dry or freeze-thaw cycling
  - Much Stronger Resistance to tear propagation
  - Superior to PTFE based supports
    - 10x stronger base properties

- **Ease of MEA/Stack configurations**
  - Direct catalyst inking onto membranes
  - Possible to bond support structures into bipolar frame to eliminate sealing issues

- **Customized MEAs**
  - Provide more support at edge regions and/or at ports

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Figure 1. Scanning Electron Microscope (SEM) micrograph of the polymer membrane support structure with definable straight hole pattern.

Figure 2. Dynamic Mechanical Analysis (DMA) shows the modulus of the novel supported membrane is ~10X higher than the N112 membrane.
Demonstration of Advanced Membrane in 160-cm² cell

- **Performance of the Advanced DSM is superior to that of Nafion 117**
  - DSM has demonstrated stable short-term operation
  - Membrane is expected to be highly durable; this needs to be verified
  - Further development required to decrease fabrication costs
Progress in Stack Cost Reduction

Stack Capital Cost ($/kW)

- Misc Non-Repeating Parts
- End Plates
- Misc Repeating Parts
- Compression
- Separator
- Frames
- Cathode MSS
- Anode MSS
- Catalyst
- Membrane
H2A Model Results

- Lowest cost H₂ at lowest pressure
- Higher pressure requires additional sealing components, smaller diameter
- Lower cost at 2000 - 3000 mA/cm² (tradeoff of efficiency vs. capital cost)
- Can achieve ~$3.00/kg at 3.5¢ electricity
Demonstrated System at NREL

- System Evaluation at NREL - Summer 07
- System produces 0.25 kg/hr at 1200 psig
- High-performance stack
  - 28 cells
  - 12.8 kW input power
  - Incorporates the low-cost components developed in this program

Operating Conditions
- Temperature: 124°F
- Pressure: 965 psig
- MEA size: 0.17 ft²

Voltage (V/Cell) vs. Current Density (mA/cm²)

EP-1 System Polarization Scan

NREL 1.89 V@1583 mA/cm²
Future Plans

- FY2008
  - NREL completing testing of system to verify hydrogen production rate

- Work is being continued under new project
  - Development of low cost, high efficiency membrane
  - Continued reduction of stack capital costs and stack scale-up to 290 cm² active area
Summary

- GES PEM Electrolyzer has potential to meet DOE cost and performance targets
- GES has made significant progress in stack cost reduction
- Further development of a high-strength, high efficiency membrane is recommended
  - Demonstrate reproducibility and durability
  - Decrease fabrication cost
- Development of a low-cost long-life separator is required