Development of a Hydrogen Home Fueling System

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National Renewable Energy Laboratory, Golden, CO

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Project ID#: PD069
Overview

Timeline

• Project started: 07/20/2009
• Project ends: 04/19/2010
• Percent completed: 100%

Budget

• Total budget funding
  – DOE $100k
  – Contractor $0
• Funding received in FY09
  – $84k
• Funding for FY10
  – $16k

Barriers

Hydrogen generation by water electrolysis
• G – Capital cost
• H – System efficiency

Fuel Cell
• A – Durability
• C – Performance

Partners

• Materials and Systems Research Inc. – advanced H₂ production technology and system development (G. Tao)
• National Renewable Energy Laboratory – techno-economic analysis (M. Penev)
## Objective/Relevance

| Overall Objective | • To investigate the development of a hydrogen home fueling system that tri-generates hydrogen, power, and heat directly using distributed natural gas |

![Concept for Hydrogen Home Fueling Station](Image)
**Approach**

**H₂ Home Fueling System Development**

A. Fueling system requirement identification
B. H₂ home fueling system design
C. Stack stability evaluation

**Techno-economic Evaluation**

A. H2A analysis implementation
B. Technology development plan construction

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NREL, MSRI

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Materials and Systems Research, Inc.
## Milestones

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Progress Notes</th>
<th>Comments</th>
<th>% Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$ home fueling system design goal</td>
<td>Achieved the design goal of system efficiency $&gt; 55%$ for an optimum system configuration</td>
<td>System performance analyses were carried out with the ASPEN model for a H$_2$ home fueling system with different conceptual configurations.</td>
<td>100%</td>
</tr>
<tr>
<td>H2A model implementation</td>
<td>Implemented the H2A model with MSRI’s unique H$_2$ production technology</td>
<td>H$_2$ home fueling system would be treated as one type of home appliances. Government incentive is extremely important in the early stage of market penetration. Costs of stacks and BOP components should be reduced.</td>
<td>100%</td>
</tr>
<tr>
<td>Degradation rate less than 5%/1000 hrs</td>
<td>Demonstrated a degradation rate $&lt; 3%/1000$ hrs over a 500 hrs test</td>
<td>Built short stacks and tested them in hybrid mode fueled with line natural gas. 500 hrs long-term test was performed in the electrolyzer mode.</td>
<td>100%</td>
</tr>
</tbody>
</table>
H₂ Production via Electrolysis Technologies

Conventional electrolysis technologies: KOH & PEM (low temperature), SOEC (high temperature)

Input: H₂O, and electricity ($$$)
Output: H₂ and O₂ (by-product)

2H₂O → 2H₂ + O₂

SOEC mode
Cost of Hydrogen*

Fuel-assisted Electrolyzer for H₂ Production

A Solid Oxide Fuel-Assisted Electrolysis Cell (SOFEC) directly applies the energy of a chemical fuel to replace the external electrical energy required to produce hydrogen from water/steam; thus decreasing the costs of energy relative to a traditional electrolysis process.

CH₄-assisted SOFEC Reaction:

\[
\begin{align*}
4H_2O_{(ca)} + 8e^- &\rightarrow 4H_2_{(ca)} + 4O^{2-} \\
CH_4_{(an)} + 4O^{2-} &\rightarrow CO_2_{(an)} + 2H_2O_{(an)} + 8e^- \\
CH_4_{(an)} + 2H_2O_{(ca)} &\rightarrow CO_2_{(an)} + 4H_2_{(ca)}
\end{align*}
\]

Electrochemical Process

- at cathode
- Electrolyte
- at anode
- Overall

Pure H₂ formed. No need for H₂ separation membranes and have lower electricity requirement.
H₂ Production Using SOFEC-SOFC Hybrid Technology

5-cell (3SOFEC-2SOFC) Hybrid Stack
800°C, CH₄/air/steam, varying Uᵣ, fixed Uₐir/Uₙsteam @ 40%/60%

- Stack: 40/40/60
- 2-SOFC: 40/40/60
- 3-SOFEC: 40/40/60
- Stack: 50/40/60
- 2-SOFC: 50/40/60
- 3-SOFEC: 50/40/60
- Stack: 60/40/60
- 2-SOFC: 60/40/60
- 3-SOFEC: 60/40/60

Stack current, A
Voltage, V

2-SOFC voltage
3-SOFEC voltage
Hybrid stack voltage
Continuous H₂ Production Assisted with NG Fuel

5-cell (3SOFEC-2SOFC) Hybrid Stack
800°C, line NG/air/steam with fixed \( U_f/U_{air}/U_{steam} @ 40%/40%/40\% \)

![Graph showing stack voltage, 2-SOFC voltage, 3-SOFC voltage, and hybrid stack current over time.]
Solid-Oxide Electrolyzer Stability Test (SOEC Mode)

5-cell Stack Long-term Test in SOEC Mode

- 800°C
- 70%H₂O bal. H₂
- Reversible SOFC/SOEC functional checks

- Stack current fixed @ 14.3A
- Stack voltage

H₂ production rate: 32.63 standard liters of H₂ per hour; or 64.56 grams per day
System Performance Analysis
### Cost of Hydrogen Analysis

- **System configuration-1: Current technologies**

<table>
<thead>
<tr>
<th>Specific Item Cost Calculation</th>
<th>Total Cost of Delivered Hydrogen</th>
<th>$10.61</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost Component</strong></td>
<td><strong>Hydrogen Production Cost</strong></td>
<td><strong>$6.14</strong></td>
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<tr>
<td></td>
<td><strong>Contribution ($/kg)</strong></td>
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<tr>
<td>Capital Costs</td>
<td></td>
<td></td>
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<tr>
<td>Decommissioning Costs</td>
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<td></td>
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<tr>
<td>Fixed O&amp;M</td>
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<tr>
<td>Feedstock Costs</td>
<td></td>
<td></td>
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<tr>
<td>Other Raw Material Costs</td>
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</tr>
<tr>
<td>Byproduct Credits</td>
<td></td>
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</tr>
<tr>
<td>Other Variable Costs (including utilities)</td>
<td>$0.51</td>
<td>4.8%</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$10.61</strong></td>
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</tbody>
</table>

- **System configuration-2: Improved technologies**

<table>
<thead>
<tr>
<th>Specific Item Cost Calculation</th>
<th>Total Cost of Delivered Hydrogen</th>
<th>$7.15</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost Component</strong></td>
<td><strong>Hydrogen Production Cost</strong></td>
<td><strong>$2.84</strong></td>
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<tr>
<td></td>
<td><strong>Contribution ($/kg)</strong></td>
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<tr>
<td>Capital Costs</td>
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<td></td>
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<tr>
<td>Decommissioning Costs</td>
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<td>Fixed O&amp;M</td>
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<tr>
<td>Other Raw Material Costs</td>
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<tr>
<td>Byproduct Credits</td>
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<tr>
<td>Other Variable Costs (including utilities)</td>
<td>$0.86</td>
<td>12.0%</td>
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<tr>
<td><strong>Total</strong></td>
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<td><strong>$7.15</strong></td>
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Collaboration

Partner:

• National Renewable Energy Laboratory
  – Performed a techno-economic analysis using the H2A model and ASPEN to provide an evaluation of a hydrogen home fueling system built upon the SOFEC-SOFC hybrid technology.
Future Work (FY 10 & beyond)

FY 10 & beyond

• Build and evaluation of a prototypal system at a smaller scale
  ➢ Evaluate the SOFEC-SOFC technology for tri-generation
  ➢ Investigate long-term degradation issues
  ➢ Procure and evaluate key BOP components
  ➢ Proof-of-concept demonstration
  ➢ Identify key factors for cost reduction
  ➢ Develop commercialization roadmap
# Project Summary

<table>
<thead>
<tr>
<th>Relevance:</th>
<th>Developing a hydrogen home fueling system for the tri-generation of hydrogen, power, and heat using distributed natural gas can reduce costs and the need for electrical input.</th>
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<tbody>
<tr>
<td>Approach:</td>
<td>Perform system analyses of a hydrogen home fueling system equipped with advanced SOFEC-SOFC technology, followed by an experimental evaluation of the technology on short hybrid stacks.</td>
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<tr>
<td>Project Accomplishments and Progresses:</td>
<td>Design specifications for a hydrogen home fueling system were defined, followed by a detailed system process design and system performance analysis. Process economics and merits of adopting the tri-generation technologies were analyzed. Short stacks were built and evaluated with different fuels to provide design parameters for system optimization.</td>
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<tr>
<td>Proposed future research:</td>
<td>A prototypal system at a smaller scale would be constructed and evaluated for proof-of-concept demonstration.</td>
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