Overview

Timeline
• Project start date: May 2010
• Project end date: Nov 2011
• Percent complete: 70%

Budget
• Total project funding
  – DOE share: $85K
  – Contractor share: $0
• Funding received in FY10: $85K
• Funding for FY11: $ TBD

Barriers
• Non-technical barriers to commercializing hydrogen and fuel cells *(per Pete Devlin March 9, 2011)*

Partners
• Lead: Longitude 122 West
• Collaborator: Sandia National Laboratories

Accelerate the commercialization and deployment of fuel cells
Relevance - Objectives

• Address the market for large-scale storage of hydrogen & hydrogen technologies
• Enable greater penetration of clean renewable energy production
• Accelerate the commercialization and deployment of fuel cells

Facilitate the adoption of fuel cells across government and industry.
## Approach - Activities / Milestones

<table>
<thead>
<tr>
<th>Activity</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update utility energy storage model to include purchase of curtailed wind energy</td>
<td>Complete</td>
</tr>
<tr>
<td>Update costs for fuel cell &amp; hydrogen systems and other storage technologies and compare</td>
<td>Complete</td>
</tr>
<tr>
<td>Perform sensitivity analyses</td>
<td>Complete</td>
</tr>
<tr>
<td>Establish utility / renewables business case</td>
<td>Complete</td>
</tr>
<tr>
<td>Make benefit / cost estimates and draft business model</td>
<td>In progress</td>
</tr>
</tbody>
</table>

---

**Figure:**
- Electrical Grid
- Fuel Cell
- Electrolyzer
- Power Conversion
- Hydrogen
- Tank or underground

**Step-wise approach to set up business model**
# Approach - Lifecycle cost analysis

- **Capital cost**
  - Electrolyzer
  - Storage
  - Fuel cells
- **Annualized life-cycle cost**
  - Capital
  - O&M
  - Replacements
  - Electricity
- **Present value cost**
  - 20 year life
  - Duty cycle
  - 7 days/wk

## Efficiency and Cost Targets

<table>
<thead>
<tr>
<th>System</th>
<th>Current efficiency</th>
<th>Target efficiency</th>
<th>Mid-range cost</th>
<th>Target cost</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyzer</td>
<td>73%</td>
<td>75%</td>
<td>340 $/kW</td>
<td>125 $/kW</td>
<td>NREL, DOE2010</td>
</tr>
<tr>
<td>Gas storage</td>
<td>NA</td>
<td>NA</td>
<td>15 $/kWh</td>
<td>9 $/kWh</td>
<td>MYPP-Delivery</td>
</tr>
<tr>
<td>Underground storage</td>
<td>NA</td>
<td>NA</td>
<td>0.3 $/kWh</td>
<td>0.3 $/kWh</td>
<td>H2A, Lord</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>55%</td>
<td>58%</td>
<td>700 $/kW</td>
<td>434 $/kW</td>
<td>NREL</td>
</tr>
</tbody>
</table>

Analysis builds on extensive expertise in energy storage and hydrogen. Analysis consistent with DOE MYPP and other lab studies.
Technical Accomplishments (1)

Update cost model for utility energy storage

Model addresses storage system size and hours of operation
Technical Accomplishments (2)

Update technology costs and compare

Alternative energy storage technologies compared

Annual cost of Bulk energy storage systems charged off-peak
20-yr systems operating 365 days/yr

- Lead-acid battery (advanced)
- CAES
- Hydrogen fuel cell - target
- Na/S battery
- Flow battery
- Pumped Hydro
- Hydrogen fuel cell - current

122 West
Technical Accomplishments (3)

Establish business case based on curtailed wind

Avoiding Curtailed Wind is a Viable Business Case
Technical Accomplishments (4)

Perform sensitivity analysis

Results are sensitive to operational & economic assumptions
Technical Accomplishments (5)
Perform sensitivity analysis for business case

Present value of 20 yr costs for 6-hr hydrogen storage system with wind

Hydrogen storage results are sensitive to current and target costs and applications
Technical Accomplishments (6)
Benefit / cost analysis on $/kW basis*

Present Value of Hydrogen System costs:
6-hr storage 20-year systems

The Benefit / Cost ratio is Attractive for Curtailed Wind

*SNL
Technical Accomplishments (7)

Benefit / cost analysis on $/kWh basis**

PV of hydrogen system costs:
6 hr systems, 20 year life, 10% interest

Base Case

Spilled wind

The Benefit / Cost ratio is even more Attractive on an energy basis

Value of renewables integration

** EPRI
Business model / market analysis (In Progress)

Business Approach for Renewable Power Generation Through Hydrogen Energy Storage
Maui-Based Wind-to-Hydrogen for Off-Grid End-Users
18 January 2011

Comments in Response to Request for Information DE-FOA-0000429

Fuel Cell Technologies Early Market Opportunities
Area of Interest 2: Turnkey Project Approaches for Hydrogen Energy Storage for Renewable Power Generation

Prepared for:
Department of Energy
Office of Energy Efficiency and Renewable Energy
Dr. Sunita Satyapal, Program Manager
Mr. Peter Devlin, Market Transformation Team Lead

Matching the business model and market potential
Collaborations

• Sandia National Laboratories
  – Collaborator on geologic cost estimates

• Austin Energy
  – Utility company with excess wind resources - informal advisor

• Schafer Corporation
  – Industry with industry clients needing innovative energy solutions - informal partner

• Hydrogen Utility Group (HUG)
  – Reports to HTAC - exchanging data on opportunities for grid storage, preparing hydrogen energy storage model

• Hydrogenics
  - Industrial provider of large-scale electrolyzers - interested party

Utilities and industry are interested in this opportunity
Proposed Future Work

FY11
• Complete benefit / cost analysis; market potential framework
• Finish report

FY12
• Add **scaling** considerations to utility business model, considering spectrum of value propositions
• Add **location** considerations to cost and benefit analysis
• Build **third-party** (non-utility) opportunities business model
• Continue discussions and deliberations with **commercial** interests, market potential

Detailed considerations and discussions are needed
Summary

• **Relevance:** Market growth for hydrogen technology
• **Approach:** Benefit / cost analysis for hydrogen to enable penetration of dispatchable renewables
• **Technical accomplishments**
  – Model and database updates for cost analysis
  – Comparisons with other large-scale energy storage
  – Sensitivity, focusing on DOE target costs
  – Benefit / cost analysis of viable business case
  – Fostering commercial conversations
• **Collaborations / contacts**
  – Within the DOE fuel cell program: SNL, Hydrogen Utility Group
  – External / commercial contacts: Austin Energy, Schafer Corp., Hydrogenics, Ballard, Next Hydrogen, Nebraska Public Power
• **Proposed future work:** Additional real-world considerations for market development

This work is on schedule and meeting objectives
Technical Back-Up Slides
Capital Cost

Capital Cost = \boxed{\text{Cost of Power equipment}} + \boxed{\text{Cost of storage}}

\[ \text{Cost}_{\text{total}}(\$) = \text{Cost}_{\text{pcs}}(\$) + [\text{Cost}_{\text{storage}}(\$) + \text{Cost}_{\text{Bop}}(\$)] \]

\[ E_{\text{storage}}(\text{kWh}) = \text{Power}(\text{kW}) \times \text{time (hr)} \]

\[ \text{Cost}_{\text{total}}(\$) = [P(\text{kW}) \times \text{Cost}_{\text{pcs}}(\$/\text{kW})] + [\text{Cost}_{\text{storage+BOP}}(\$/\text{kWh}) \times \text{time (hr)} \times \text{Power}(\text{kW})] \]

\[ \text{Cost}_{\text{total}}(\$/\text{kW}) = \text{Cost}_{\text{pcs}}(\$/\text{kW}) + \text{Cost}_{\text{storage+BOP}}(\$/\text{kWh}) \times \text{time (hr)} \]

\text{Total Cost} = \text{Cost of hydrogen tanks or reservoir} + \text{Cost of electrolyzer} + \text{cost of fuel cell} + \text{balance of plant}
Annual Life-cycle and Present Value Costs

Levelized annual cost ($/kw-yr)

\[ \text{Levelized annual cost} = \text{Cost of capital} + \text{cost of fixed O&M} + \text{cost of variable O&M} + \text{annualized replacement costs} + \text{consumables (fuel and electricity)} \]

<table>
<thead>
<tr>
<th>Business case parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage charging</td>
<td>6 hrs</td>
</tr>
<tr>
<td>Storage discharging</td>
<td>Min 6 hrs</td>
</tr>
<tr>
<td>Cost of charging electricity</td>
<td>0.00 $ / kWh for 6 hrs</td>
</tr>
<tr>
<td>Cost of charging electricity</td>
<td>0.05 $ / kWh thereafter</td>
</tr>
<tr>
<td>Days of operation per year</td>
<td>365</td>
</tr>
<tr>
<td>Cost of natural gas (for CAES)</td>
<td>5 $/ BTU</td>
</tr>
</tbody>
</table>

Present Value Calculation:

\[ PV = \frac{F_0}{(1 + i)^0} + \frac{F_1}{(1 + i)^1} + \frac{F_2}{(1 + i)^2} + \ldots + \frac{F_n}{(1 + i)^n} \]

<table>
<thead>
<tr>
<th>Economic parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>System lifetime</td>
<td>20 years</td>
</tr>
<tr>
<td>Capital charge rate</td>
<td>15%</td>
</tr>
<tr>
<td>Discount rate</td>
<td>10%</td>
</tr>
<tr>
<td>Inflation rate</td>
<td>2%</td>
</tr>
</tbody>
</table>
# Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide

A Study for the DOE Energy Storage Systems Program

Jim Eyer
Garth Corey

<table>
<thead>
<tr>
<th>Benefit Type</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Electric Energy Time-shift</td>
<td>400</td>
<td>700</td>
</tr>
<tr>
<td>2 Electric Supply Capacity</td>
<td>359</td>
<td>710</td>
</tr>
<tr>
<td>3 Load Following</td>
<td>600</td>
<td>1,000</td>
</tr>
<tr>
<td>4 Area Regulation</td>
<td>785</td>
<td>2,010</td>
</tr>
<tr>
<td>5 Electric Supply Reserve Capacity</td>
<td>57</td>
<td>225</td>
</tr>
<tr>
<td>6 Voltage Support</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>7 Transmission Support</td>
<td>192</td>
<td></td>
</tr>
<tr>
<td>8 Transmission Congestion Relief</td>
<td>31</td>
<td>141</td>
</tr>
<tr>
<td>9.1 T&amp;D Upgrade Deferral 50th percentile</td>
<td>481</td>
<td>687</td>
</tr>
<tr>
<td>9.2 T&amp;D Upgrade Deferral 90th percentile</td>
<td>759</td>
<td>1,079</td>
</tr>
<tr>
<td>10 Substation On-site Power</td>
<td>800</td>
<td>3,000</td>
</tr>
<tr>
<td>11 Time-of-use Energy Cost Management</td>
<td>1,226</td>
<td></td>
</tr>
<tr>
<td>12 Demand Charge Management</td>
<td>582</td>
<td></td>
</tr>
<tr>
<td>13 Electric Service Reliability</td>
<td>359</td>
<td>978</td>
</tr>
<tr>
<td>14 Electric Service Power Quality</td>
<td>359</td>
<td>978</td>
</tr>
<tr>
<td>15 Renewables Energy Time-shift</td>
<td>233</td>
<td>389</td>
</tr>
<tr>
<td>16 Renewables Capacity Firming</td>
<td>709</td>
<td>915</td>
</tr>
<tr>
<td>17.1 Wind Generation Grid Integration, Short Duration</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>17.2 Wind Generation Grid Integration, Long Duration</td>
<td>100</td>
<td>782</td>
</tr>
</tbody>
</table>
Storage Benefits Analysis

Electricity Energy Storage Technology Options
A White Paper Primer on Applications, Costs and Benefits

December 2010
Publications and Presentations


• Schoenung, “Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications,” International Colloquium on Environmentally Preferred Advanced Generation, sponsored by the National Fuel Cell Research Center, 8-10 February, 2011, Costa Mesa, CA


• SNL (SAND) Report - in process

Presentations well received by industry, utility and academic communities