Cost and GHG Implications of Hydrogen for Energy Storage

2011 Hydrogen Program Annual Merit Review and Peer Evaluation Meeting

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10 May 2011
Project ID # AN006

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Overview

Timeline

• Start: October 2008
• End: September 2011
  (expected to continue in FY12)
• Complete: 60% (FY2011 work)

Budget

• Total Project Funding: $340k
  – 100% DOE-funded
• FY2010: $40k
• FY2011: $150k

Barriers

• Stove-piped/Siloed Analytical Capability [4.5.B]
• Suite of Models and Tools [4.5.D]
• Unplanned Studies and Analysis [4.5.E]

Partners

• NREL Strategic Energy Analysis Center analysts
• Pacific Northwest Laboratory
• Xcel Energy (Utility)
Relevance: Increasing Renewable Electricity Production Provides an Opportunity for Hydrogen

Energy storage is needed to make variable renewable resources dispatchable.

A load is needed to “soak up” excess electricity generation.

Hydrogen could play dual role as a storage medium for electricity and as a fuel for vehicles.

Near-term hydrogen production from renewables could be made more economical if hydrogen provides other services.
Objective

Use analysis of scenarios for renewable electricity generation coupled with hydrogen systems to find opportunities for cost savings and other benefits of hydrogen energy storage and renewable hydrogen for vehicles.
# Relevance: Impact on Barriers

<table>
<thead>
<tr>
<th>Barrier</th>
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| Stove-piped/Siloed Analytical Capability [4.5.B]                       | • Competing hydrogen energy storage against other alternatives in a lifecycle cost analysis provides context for results  
• Analysis of production of excess hydrogen for vehicles integrates transportation and electricity sectors |
| Suite of Models and Tools [4.5.D]                                      | • Fuel Cell Power model modified to evaluate storage integrates hourly energy analysis capability with H2A economic analysis capabilities  
• Results from storage studies can be evaluated geographically in the SERA model |
| Unplanned Studies and Analysis [4.5.E]                                 | • Analysis integrating renewable resources (wind and solar) in specific locations with hydrogen storage |
## Approach: Milestones and Deliverables

<table>
<thead>
<tr>
<th>Milestone/Deliverable</th>
<th>Title</th>
<th>Date</th>
<th>Status</th>
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<tbody>
<tr>
<td>Milestone</td>
<td>Complete literature review for new storage systems and cost projections</td>
<td>April 2011</td>
<td>In Progress</td>
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<tr>
<td>Milestone</td>
<td>Provide update on preliminary results</td>
<td>June 2011</td>
<td>In Progress</td>
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<tr>
<td>Deliverable</td>
<td>Quarterly Reports</td>
<td>1/11, 4/11, 7/11, 10/11</td>
<td>In Progress</td>
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<tr>
<td>Deliverable</td>
<td>Internal draft for DOE review: technical report on hydrogen and competing storage technology case studies</td>
<td>July 2011</td>
<td>In Progress</td>
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Objective
Explore the cost and GHG emissions impacts of interaction of hydrogen storage and variable renewable resources
– Specific locations and wind profiles
– Hourly energy analysis to capture detail

The NREL Western Wind Data Set was used to identify realistic wind farm locations

- Calculate the levelized, profited cost of the delivered electricity from the wind farm/storage system
- Focus = load leveling and transmission line utilization

Base Case (without storage)

- Some electricity curtailed
- Transmission line size constrains energy flows
- Electricity to grid

Hydrogen for Energy Storage Case

- Curtailed electricity = 0%
- Hydrogen Storage
- Electricity to grid (storage + direct) – transmission line size constrains energy flows
- Transmission

*Do the advantages of dispatchability and lower transmission line costs outweigh the cost of the storage system?*
Calculate the levelized, profited cost of the delivered electricity from the wind farm; then add hydrogen production.

**Base Case (without hydrogen production)**
- Some electricity curtailed
- Transmission line size constrains energy flows
- Electricity to grid

**Hydrogen for Vehicles Case**
- No Curtailed electricity
- Hydrogen production
- Transmission line
- Delivery

Apportion costs between electricity and hydrogen:
- Only otherwise curtailed wind is “free” for hydrogen production
- Electrolysis is “paid for” by hydrogen revenue

**What is the lowest cost mix of electricity and hydrogen?**
Approach: The Fuel Cell Power Model was used for Hourly Energy Analysis.
Accomplishments: Hourly Model of Hydrogen for Energy Storage

Modified Fuel Cell Power Model was used to calculate the storage needed and optimal equipment sizes for each wind farm.

Hydrogen storage capacity needed varies seasonally and between wind farms.
Accomplishments: Storage System Output is the Economic Metric for Comparison to the Baseline

Storage of electricity reduces peaks and valleys in wind farm output, but losses reduce the benefit.
Accomplishments: Storage System Sensitivity to Electrolyzer Costs

Electrolyzer costs must decrease for hydrogen energy storage to be less expensive than curtailing excess wind.

Transmission Line Capacity as a Percentage of Windfarm Nameplate Capacity

- Electrolyzer [$825/kW]
- Electrolyzer [$400/kW]
- Electrolyzer [$250/kW]
- Base Case
What is the optimal balance between hydrogen and electricity?

Diverting more electricity to the electrolyzer increases the electrolyzer capacity factor but also increases the cost of the electricity.
Accomplishments: Hydrogen for Vehicles Sensitivity to Electrolyzer Cost

Hydrogen cost is more sensitive to electrolyzer cost at low utilization because electricity cost is a smaller percentage of overall cost at low utilization.
Proposed Future Work

- Perform an analysis for an isolated solar installation
- Compare greenhouse gas emissions/carbon tax implications for hydrogen storage and compressed air energy storage.
- Obtain better cost estimates for geologic storage
- Sensitivity analyses for fuel cell and electrolyzer efficiency
- Add delivery of hydrogen for vehicles
  - Look at rail and pipeline delivery of hydrogen
## Summary

### Relevance
- Hydrogen could bridge power and transportation sectors
- Hydrogen storage could provide an advantage for large scale isolated renewables
- Use of hydrogen for storage or dispatchable load could stimulate the market for lower cost electrolyzers

### Approach
- Analysis of hydrogen storage for realistic case studies for wind farms of various sizes, classes and proximity to demand centers.
- Hourly analysis of energy flows

### Accomplishments
- Hydrogen storage could reduce the amount of electricity that must be curtailed and reduce the LCOE for wind farms.
- Hydrogen can be produced from curtailed wind, but electrolyzer costs must come down for this option to be economical

### Collaborations and Reviewers
- Xcel Energy
- NREL Strategic Energy Analysis team

### Proposed Future Work
- More detailed analysis of geologic storage and above-ground storage options
- Analysis of solar installations
- Analysis of hydrogen delivery costs
- Analysis of GHG implications (see CAES supplementary slide)