Lifecycle Cost and GHG Implications of a Hydrogen Energy Storage Scenario

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# Energy Storage & Greenhouse Gases

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<tbody>
<tr>
<td>Additional energy from the windfarm can be captured for later use</td>
<td>Efficiency losses incurred by routing wind energy through the storage system reduce the greenhouse gas benefit of wind</td>
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A Realistic Case Study was used to Explore Cost and GHG Implications for a Hydrogen Energy Storage System

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

Outline
Study Framework
– Choose a specific realistic wind farm location
– Develop a “base case” without storage for comparison
– Develop storage scenarios
Preliminary Study Results
– Lifecycle cost analysis
– GHG emissions credit
Analysis of the base case provides LCOE and avoided emissions for comparison

Base Case (without storage)

- Curtailed electricity 17%
- Electricity to grid 83%
- 750 MW

Storage Constrained Case

- Curtailed electricity 2%
- Hydrogen Storage 400 MT
- Electricity to storage 16% of total wind farm output
- Electricity from storage 5% of total output
- 87% of total wind farm output
- 750 MW

Transmission Constrained Case

- Curtailed electricity 12%
- Hydrogen Storage 2,600 MT
- Electricity to storage 27% of total wind farm output
- Electricity from storage 7% of total output
- (storage + direct) 68% of total wind farm output
- 500 MW
Wind Farm Location

The NREL Western Wind Data Set was used to identify a realistic remote wind farm location.
The wind farm sits above a saline reservoir. Therefore, transport of the hydrogen to the storage site is assumed to be negligible.
Configure a Base Case Without Storage

**Shed electricity**

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**Base Case Configuration**

- 1,000 MW nameplate wind farm capacity (~50% capacity factor)
- Power from the wind farm is routed to the transmission line up to the maximum capacity of the line (MW)
- Power from the wind farm will be curtailed (shed) if it exceeds the maximum capacity of the transmission line
- Transmission line is 750 MW maximum capacity (~ 1.5x wind farm average output)

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The benefit of increasing the transmission line size decreases as the transmission line size approaches 100% of the nameplate capacity of the wind farm (1,000 MW).
Primary Study Assumptions

Major Assumptions

- Electrolyzer and PEM fuel cell performance and cost values derived from mid-cost case of lifecycle cost analysis
- Hydrogen storage in geologic storage
- The storage system is located at the wind farm & all electricity charged to the storage system is derived from the wind farm
- A dedicated transmission line carries electricity from the wind farm/storage system to the grid near demand centers.
- Power from the wind farm will be curtailed (shed) if:
  - It exceeds the maximum charging rate of the storage system + maximum capacity of the transmission line
  - The storage system is full
Preliminary Results for the Base Case

- **Shed electricity**

- **Curtailed electricity**
  - 17.3% of total wind farm output

- **Electricity to grid**
  - 82.7% of total wind farm output

- Nearly 20% of the wind farm output is lost even with a transmission line capacity of 1.5X average output.
Almost all of the wind output is captured

Configuration
- Hydrogen storage capacity is 400 MT hydrogen (~ 1 day)
- Transmission line is 750 MW maximum capacity (~ 1.5x wind farm average output)

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<th>Installed Cost ($/kW)</th>
<th>LHV Efficiency</th>
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<tr>
<td>Electrolyzer (200 MW)</td>
<td>$450</td>
<td>53</td>
</tr>
<tr>
<td>Fuel Cell (200 MW)</td>
<td>$800</td>
<td>53</td>
</tr>
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</table>

Curtailed electricity
- 2% of total wind farm output

Shed electricity

Hydrogen Storage

Electricity to storage
- 16% of total wind farm output

Electricity from storage
- 5% of total output

Electricity to grid (storage + direct)
- 87% of total wind farm output

Curtailed electricity
- 2% of total wind farm output

Installed Cost ($/kW) | LHV Efficiency
Electrolyzer (200 MW) | $450 | 53
Fuel Cell (200 MW)    | $800 | 53
Preliminary Results for the Transmission Constrained Case

Larger storage system does not fully compensate for smaller transmission line

- Hydrogen storage capacity is 2,600 MT hydrogen (~ 1 week)
- Transmission line is 500 MW maximum capacity (~ 1.0x wind farm average output)

Curtailed electricity
11.7% of total wind farm output

Electricity to grid (storage + direct)
68.2% of total wind farm output

Electricity to storage
27.5% of total wind farm output

Electricity from storage
7.4% of total output

Shed electricity
### Summary of Preliminary Results

Storage reduces the amount of electricity that must be curtailed and reduces the LCOE

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<th>Base Case</th>
<th>Storage Constrained</th>
<th>Transmission Constrained</th>
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<tr>
<td>(% of Total Wind Farm Output)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Electricity Direct from Wind Farm to Transmission Line</td>
<td>82.7</td>
<td>82.7</td>
<td>60.8</td>
</tr>
<tr>
<td>Electricity from Storage</td>
<td>N/A</td>
<td>4.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Electricity Shed</td>
<td>17.3</td>
<td>1.9</td>
<td>11.7</td>
</tr>
<tr>
<td>Net Electricity to Transmission Line</td>
<td>82.7</td>
<td>87.2</td>
<td>68.2</td>
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</table>

| (% of Total Transmission Line Capacity) |           |                     |                          |
| Transmission Line Utilization | 56.0      | 59.0                | 69.0                     |

| (LCOE ¢/kWh)                      |           |                     |                          |
| Without cost of carbon           | 13        | 10                  | 12                       |
| @ cost of carbon $50/MT CO2eq    | 9         | 6                   | 8                        |
| @ cost of carbon $100/MT CO2eq   | 5         | 2                   | 4                        |
Effect of a Cost of Carbon on the Competitiveness of Wind & Hydrogen Storage System

Credit for avoided emissions reduces LCOE for wind electricity below grid price

Cost comparison for Chicago Grid Electricity v Wind Electricity for Various Storage Configurations

Credit for avoided emissions reduces LCOE for wind electricity below grid price.
Proposed Future Work

• Develop a methodology for optimizing the size of the storage system components and transmission to minimize costs for an isolated wind farm or solar installation
• Perform an analysis for an isolated solar installation
• Compare greenhouse gas emissions/carbon tax implications for hydrogen storage and compressed air energy storage.
Thank You

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