Hydrogen energy storage and grid integration activities at NREL

Josh Eichman, PhD

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Next Generation Energy Storage
San Francisco, California
Outline

• NREL’s mission
• Hydrogen Infrastructure Testing and Research Facility (HITRF)
• Flexibility of hydrogen devices
• Opportunity and value of hydrogen grid integration
  o Wholesale markets
  o Retail utility rates
Scope of NREL’s Mission

### Energy Efficiency
- Residential Buildings
- Commercial Buildings
- Personal and Commercial Vehicles

### Renewable Energy
- Solar
- Wind and Water
- Biomass
- Hydrogen
- Geothermal

### Systems Integration
- Grid Infrastructure
- Distributed Energy Interconnection
- Battery and Thermal Storage
- Transportation

### Partners
- Private Industry
- Federal Agencies
- State/Local Govt.
- International
NREL Campus

Energy Systems Integration Facility (ESIF)

Dennis Schroeder, NREL 38015
Hydrogen Station at NREL’s ESIF Facility

Hydrogen Infrastructure Testing and Research Facility (HITRF)

**Specifications**
- Hydrogen production via on site water electrolysis
- Hydrogen purity testing performed every 6 months (meets SAE limits 3/1/15)
- SAE J2601 T40 rated dispensing
- 700 bar communication filling
- 350 non-communication filling
- WEH nozzle part #: TK17 & TK16
- Cascade filling system
  - 30kg storage capacity at 860bar (12,500 psi)
  - 80kg storage capacity at 400bar (6,000 psi)
- 20kg storage capacity at 200 bar (3,000 psi)
- Data collection and real-time component feedback
- Low ohm cement pad surrounded by blacktop driveway

**Safety**
- Emergency-stop located at the dispenser
- UV/IR detector monitoring fueling area
- Dispenser automatic shutoff when filling complete

Hydrogen Storage Configurations

**Electric Grid**

- **Grid Services**
  - **Water**
    - Electrolyzer
    - Fuel Cell or Combustion
    - Power-to-power
  - **Hydrogen Storage**
  - **Steam Methane Reformer**
    - Pipeline Injection
    - Power-to-gas
  - **Water**
  - **Fuel Cell Vehicles**
    - Power-to-hydrogen
    - Power-to-heat
  - **Chemical and Industrial Processes**

**Natural Gas Grid**

- **Direct injection or methanation**

Source: (from top left by row), Warren Gretz, NREL 10926; Matt Stiveson, NREL 12508; Keith Wipke, NREL 17319; Dennis Schroeder, NREL 22794; NextEnergy Center, NREL 16129; Warren Gretz, NREL 09830; David Parsons, NREL 05050; and Bruce Green, NREL 09408
Electrolyzer Validation Results

• Grid Service Requirements

Electrolyzers can respond fast enough and for sufficient duration to participate in electricity markets

Source: Kirby, B.J. 2006. Demand Response for Power Systems Reliability: FAQ. ORNL
Business case opportunities

• Wholesale markets
  o Energy
  o Flexibility (e.g., ramping)
  o Ancillary Services (e.g., regulation up and down, spinning reserve, non-spinning reserve)

• Retail utility rates
  o California near-term business case evaluation
  o With or without additional revenue from wholesale markets
Wholesale market value (energy and ancillary services)

Selling hydrogen increases competitiveness
Providing ancillary services > Energy only > Baseload
Electrolyzer providing demand response is promising

Blue bars represent a range of potential prices at which hydrogen can be sold ($3-10/kg)
Assumed value of grid services and hydrogen, less feedstock costs received by FC, EY or SMR

<table>
<thead>
<tr>
<th>Name</th>
<th>Technology</th>
</tr>
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<tbody>
<tr>
<td>HYPS</td>
<td>Pumped Hydro</td>
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<tr>
<td>Batt</td>
<td>Battery</td>
</tr>
<tr>
<td>FC</td>
<td>Fuel Cell</td>
</tr>
<tr>
<td>EY</td>
<td>Electrolyzer</td>
</tr>
<tr>
<td>SMR</td>
<td>Steam Methane Reformer</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>All Ancillary Services</td>
</tr>
<tr>
<td>Eonly</td>
<td>Energy Arbitrage only</td>
</tr>
<tr>
<td>Baseload</td>
<td>“Flat” operation</td>
</tr>
</tbody>
</table>

California near-term business case evaluation scenarios

1. Hydrogen for FCEVs, truck delivery
   – High FCEV market value and conventional delivery
   – Low demand for FCEVs

2. Hydrogen for FCEVs, pipeline delivery
   – High FCEV market value and potentially lower cost delivery.
   – Low demand for FCEVs

3. Hydrogen for refinery, pipeline delivery
   – Large demand for refineries and can take advantage of existing compression and pipeline equipment
   – Low LCFS credit

4. Hydrogen for HCEVs, inject into natural gas pipeline
   – Large demand in natural gas pipeline
   – Could adjust heating content of natural gas system
   – Low value for heating fuel and low LCFS value for HCEVs

Example cost/benefit figure

- Combines revenues and cost values

Total value represents the wholesale breakeven price of hydrogen. Does not include sale of hydrogen.

The addition of on-site renewables reduces all energy cost components and is even valuable without the LCFS.

Scenario 1 and 2 are the most compelling because of the LCFS for FCEVs.

Pipeline delivery is cheaper but can vary significantly based on location compared to truck delivery.

Summary (Scenario 1, FCEV w/ truck delivery)

Locational value analysis

- Currently, energy market value comes from reducing demand during price spikes
- Areas with high average energy prices are good candidates to capitalize on price spikes

<table>
<thead>
<tr>
<th>Utility</th>
<th>Utility Rates</th>
<th>Ancillary Service Value</th>
<th>Average Energy Price</th>
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</thead>
<tbody>
<tr>
<td>SCE</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>PG&amp;E</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>SDGE</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Summary

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Backup
• Goal: Enable higher penetrations of solar power generation using the natural gas pipeline system for energy storage
Hydrogen Station at NREL’s ESIF Facility

High Pressure – 30kg
Medium Pressure – 80kg
Low Pressure – 20kg

700 bar communication filling
350 non-communication filling
INTEGRATE – Integrated Network Testbed for Energy Grid Research and Technology Experimentation

**Objective:** Demonstrate value of integrated approach to evaluating EE, RE & DER

- Completed the design, installation and commissioning of a 250 kW stack test bed
  - AC/DC power supplies are capable of 500 kW
- **Successful data exchange from INL to NREL**
  - Bi-directional communication between ESIF RTDS and INL RTDS (12/2014)
  - Bi-directional communication between ESIF RTDS and NWTC CGI RTDS allowing real-time exchange of data (2/2015)
- **Have performed testing with electrolyzer manufacturers**
  - Performed FAT of three 150 kW PEM stacks, which were then shipped to customers in Europe
  - Working with Giner to prepare for testing of 1/3 MW and then 1MW stacks requiring nearly 4000A DC.
- **Currently operating 250kW stack from Proton Onsite**
Electrolyzer Flexibility Validation

- Validation explored several parameters
  - Startup and Shutdown
  - Minimum Turndown
  - Response Time
  - Ramp Rate
  - Frequency Response

<table>
<thead>
<tr>
<th></th>
<th>PEM</th>
<th>Alkaline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Proton OnSite</td>
<td>Teledyne Technologies</td>
</tr>
<tr>
<td><strong>Electrical Power</strong></td>
<td>40kW (480VAC)</td>
<td>40kW (480VAC)</td>
</tr>
<tr>
<td><strong>Rated Current</strong></td>
<td>155A per stack</td>
<td>220A 75 cell stack</td>
</tr>
<tr>
<td><strong>Stack Count</strong></td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td><strong>Hydrogen Production</strong></td>
<td>13 kg/day</td>
<td>13 kg/day</td>
</tr>
<tr>
<td><strong>System Efficiency at</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rated Current</strong></td>
<td>75.6 (kWh/kg)</td>
<td>95.7 (kWh/kg)</td>
</tr>
</tbody>
</table>

Electrolyzer Response Time

- Power set-point was changed (PEM unit shown below)
  - Ramp Up: 25%, 50%, and 75% → 100%
  - Ramp Down: 100% → 75%, 50% and 25%

Electrolyzers can rapidly change their load point in response to grid needs

- Trigger at 0.02 seconds
- 5000 samples every second
- Response (±1% max current)
Electrolyzer Frequency Regulation Validation

- Validated frequency response using a microgrid
  Source: Harrison K., Mann M., Terlip D., and Peters M., NREL/FS-5600-54658

- Validated electrolyzer stack response to regulation signal
  Source: Peters, M., NREL 2014

Electrolyzers can respond to regulation signals and accelerate frequency recovery
Considerations for future impacts

**Impact on Electrolysis**
- Financing Interest Rate (5%, 7% (default))
- Renewable Fuel Standard (D5 Hydrogen RIN)
- Electrolyzer cost reduction ($1,460/kW, $3,308/kW (default))
- LCFS credit value ($200, $125 (default))

**Impact on SMR**
- Financing Interest Rate (5%, 7% (default))
- SMR cost reduction (25%) ($1,204/kg/day, $1,604/kg/day (default))
- Natural gas price increase (2x retail)

Production and Delivery costs ($/kg)