Life-Time Prediction of PEM Water Electrolysis Stacks Coupled With RES

2nd International Workshop Durability and Degradation Issues in PEM Electrolysis Cells and its Components

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Outline

• Introduction
• Motivation
• Summary of Research 2006 - 2015
  – RES Integration
  – Electrolyzer response
  – Long-duration stack operation
• Path Forward
• Conclusion
NREL Fuel Cell & Hydrogen Technologies Program

- Hydrogen production and delivery
- Hydrogen storage
- Fuel cells
- Fuel cell manufacturing R&D
- Technology validation
- Market transformation
- Safety, codes and standards
- Systems analysis
Hydrogen Production and Delivery

- Photoelectrochemical (PEC) water splitting
- Photobiological water splitting
- Fermentation
- Conversion of biomass and wastes
- Solar thermochemical water splitting
- **Renewable electrolysis**
- Dispenser hose reliability testing
- Pathway analysis
ESIF - Hydrogen Systems R&D
H₂ Generation & Dispensing Capabilities

• **Onsite H₂ production – 50 kg/day**
  – 2016 - Double production capacity
  – Adding (2) 1000A power supplies

• **Compression & Storage**
  – Three levels 200, 400 and 875 bar
  – Uses – ESIF FC labs, testing and fueling
  – Additional compression and storage

• **Dispensing**
  – Typical FCEV refueling 3 – 4 kg
  – Fueling at 350 and 700 bar
  – Fork lifts, busses and light-duty
SoCal Gas/NREL Power-to-Gas

- ~ $1M CRADA
- Scale-up of benchtop
- Solar-powered electrolysis
- Synthetic natural gas production
- Systems integration & optimization
- Bioreactor & Filtration
  - Pipeline quality
  - High pressure operation
  - Push reaction limits
GW-Scale H₂ - Key Part of Solution

**Value Added Applications**
- Natural Gas Infrastructure
- Vehicle Fuel
- Synthetic Fuels
- Upgrading Oil / Biomass

**Electricity Grid**
- Solar
- Wind
- Nuclear
- Concentrated Solar Power

**Generator**
- Fuel Cell, Combustion

**Hydrogen**
- Storage/Distribution
- Hydrogen Generation

**Other End Use**

**Metals Refining**

**INDUSTRIAL**
Energy “Storage”

Hydrogen goes beyond electrons to electrons; value-added sink for electrons rather than a capacitor. Making fair comparisons is difficult, so many peripheral impacts.
Renewable Electrolysis – Systems Integration

**Primary Goals**

- RES Integration
- Electrolyzer Efficiency
- Power Conversion
- Grid Support
- Energy Storage

**Other R&D Areas**

- Compressors
- Infrastructure
- Mobility
PV to H₂ – Direct and Close Coupling

On average 10% improved energy capture of system capable of switching between direct coupling and power converter.

Direct Coupling

Close Coupling

Current (A)

Voltage (V)

PV Array IV

20-cell stack

30-cell stacks

PV array maximum power point

Power Electronics with MPPT

Irradiance [W/m²]

Stack Power / Irradiance

5 6 7 8 9 10 11 12

50 150 250 350 450 550 650 750 850 950 1050

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Electrolyzer System Response

- PEM & Alkaline electrolyzer systems
  - Startup and Shutdown
  - Minimum Turndown
  - Response Time
  - Ramp Rate
  - Frequency Response

Diesel Powered Microgrid

<table>
<thead>
<tr>
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<th>PEM</th>
<th>Alkaline</th>
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<tbody>
<tr>
<td>Manufacturer</td>
<td>Proton OnSite H-6M</td>
<td>Teledyne Energy HMXT-100</td>
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<tr>
<td>Electrical Power</td>
<td>40kW 480VAC, 3p</td>
<td>40kW 480VAC, 3p</td>
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<tr>
<td>Rated Current</td>
<td>155 A per stack 3 stacks, 43 cells</td>
<td>220 A 75-cell stack</td>
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<tr>
<td>Hydrogen Production</td>
<td>13 kg/day</td>
<td>12 kg/day</td>
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Electrolyzer Response

Microgrid – Freq. Response

• Sensed local frequency drop
  • 10 kW resistive load
• PEM and Alkaline tests ran separately
• Both responded quickly to mitigate disturbance once freq. ≤ 59.8 Hz

Supporting grid stability

• Typical utility profile to validate performance
• System response, not just stack
• 120 kW PEM stack operating on NREL’s electrolyzer stack test bed

Source: Harrison K., Mann M., Terlip D., and Peters M., NREL/FS-5600-54658
Stack Degradation Testing

Monitoring and Control

- Highly variable power
- Stack input and output temperature
- Stack voltage and current
- Individual control over each of 3 stacks
- Programmable wind/solar profiles

PEM Electrolyzer Stack Operation Profiles

Steady-State Stack Current Periods
Stack Degradation Testing

~2 Volt difference
8.3 μV/cell-hr at 40°C

7,100 hours into testing
Start of testing

Voltage (V)

80 90 100 110 120

Temperature (°F)

y = -0.1534x + 90.716
R² = 0.991

~2 Volt difference
8.3 μV/cell-hr at 40°C

y = -0.1673x + 90.152
R² = 0.9849

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<th>Stack-Test</th>
<th>Mode</th>
<th>Runtime [Hours]</th>
<th>Decay Rate [μV/cell-h]</th>
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Goal - Reduce cost of hydrogen

- Modular design
- Develop and demonstrate
  - Advanced power and control systems
  - Balance of plant optimizations coupled to RES
- Provide flexible validation platform
- Provide up to 4000 A, 250 V DC
- Cell-level voltage sensing
- 250 kW stack (2016)
Simulating Renewable & Regulation Profiles

Ability to program profiles into the stack test bed

- Examples of renewable and regulation profiles
- Profiles using 120 kW stack from Proton Onsite
Dynamic Modeling and Validation of Electrolyzers in Real Time Grid Simulation

Curve-fitting to determine electrochemical properties and time response
Path Forward – Stack Testing Variable Power

- **Solid State Design**
- **Cell level monitoring**
  - Isolated common mode
  - Multiple (< 5) Samples/sec
  - Up to 125 cells @ 2V/cell
- **16 bit A/D**
  - ~1mV resolution
- **μController-based data acquisition, communications and archiving alongside system data**
Summary

• One way to store a growing amount of renewable electricity for energy storage, chemical feedstock (e.g., CH$_4$, NH$_3$) and fuel for mobility
  o Zero-carbon fuels and chemicals

• Low temperature electrolyzers can provide sub-second electrical response to participate in grid ancillary services

• There doesn’t seem to be a significant difference between stacks operating with variable versus constant power

• Advanced power systems and BoP R&D will continue to improve efficiency

• Grid operational and power market rule changes will ease integration challenges for large-scale electrolyzer systems
  o Expanding markets for flexible electrical loads
References

20% Wind Energy by 2030

PV – Stack Coupling

PEM & Alkaline Electrolyzer Response Testing

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