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Company Overview:

- World leader in PEM water electrolysis
- 2,600 Systems delivered in 75 countries for:
  - Industrial applications
  - Laboratory markets
  - Military customers
  - Fueling and energy storage
- ISO 9001:2008 certified
- ~ 100 employees
Where our electrolyzers are used:

- **Power Plants**
  - Cooling electric generators

- **Laboratories**
  - Carrier gas for analytical instrumentation

- **Other Industrial**
  - Process gas for semiconductors, heat treatment, and meteorology

- **Transportation**
  - Fueling fuel-cell vehicles

- **Grid Energy Storage**
  - Storing stranded excess renewable energy

- **Biogas**
  - Turning waste CO₂ into methane

- **Military**
  - Oxygen production and specialty vehicle fueling
PEM versus AEM Electrolysis:

Proton’s Core Technology

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\begin{align*}
O_2 + 4H^+ & \rightarrow 2H_2 \\
2H_2O & \rightarrow 4H^+
\end{align*}
\]

Anion Exchange Membrane (AEM) Technology

\[
\begin{align*}
O_2 + 2H_2O & \rightarrow 2H_2 + 4OH^- \\
2H_2O & \rightarrow 4OH^-
\end{align*}
\]

• R&D on AEM materials initiated in 2010 (ARPA-E GRIDS)
  • Forward looking pathway to cost reduction
  • Non-precious metals, cheaper cell components
PEM Electrolysis Status: What AEM has to compete with

- 60,000 hour lifetimes
- Scaled to 700 cm$^2$ active area and larger
- MW scale capacity
- Manufacturing processes and supply chain very well established
- Still room for commercial cost and efficiency improvements
Motivation for AEM Research:
Enabling cost effective hydrogen energy storage
“Power-to-Gas” (P2G) use cases:

1. **Conversion & Storage**
   - Methanation: $4H_2 + CO_2 \rightarrow CH_4 + H_2O$
   - Biomethane ($CH_4$)
   - Seasonal Storage
   - To Electricity Grid

2. **Leverage Natural Gas Network**
   - Natural Gas Grid
   - Pipeline ($CH_4$)
   - CNG Fueling
   - Dispachable with renewable gas

3. **Increase Renewables**
   - Load-Following
   - Surplus RE
   - No curtailment

4. **Using Hydrogen**
   - PEM Electrolyser
   - $H_2$ Fueling
   - Industrial
   - Fuel Cell / HICE
   - To Electricity Grid
P2G enables bulk-seasonal energy storage:

“P2G Hydrogen”: hydrogen is the end-use fuel

“P2G Methane”: hydrogen is converted to syngas

Fraunhofer ISE, 2015
P2G Costs versus Li-Ion:

**Case 1:** Dedicated fuel cell for converting stored energy back to electricity.

**Case 2:** Hydrogen is transported via CNG distribution system and used in existing generation asset.

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**CHBC White Paper, Power-to-Gas: The Case for Hydrogen**

**Key Takeaway:**
Even with a dedicated fuel cell for converting the stored energy back to electricity, P2G is cost effective at longer discharge times.
AEM Technology Pros and Cons:

Benefits

- Materials required for AEM platforms can significantly reduce manufacturing costs

Problems

- AEM membranes and ionomers not as conductive or stable as PEM
- Catalysts under alkaline conditions less stable and less active relative to PEM
- Water transport and management within the cell critical in AEMs
Cost reduction opportunity:

ARPA-E program analysis shows an 85% cell cost reduction opportunity relative to today’s PEM cost baseline.
Critical Issues For Development:

- New membrane chemistries still needed for operating stability
  - Will likely change process conditions and break in
- Processing and catalyst-ionomer interactions
- Poor thermal stability of AEMs requires alternate manufacturing methods
NYSERDA / NY-BEST Project:

- Cornell University leads AEM material and process development.
- Proton leads cell integration and characterization task.
- Leverages AEM RFC system hardware and research learnings from ARPA-E program.
- Primary focus has been on the electrolysis reaction, which is a harsher environment.
Technical Approach:

1. **Monomer A**
   Imparts Structural Integrity
   
   Cornell composite membranes to optimize properties

2. **Monomer B**
   Imparts Functionality and Ionic Conductivity

   - ROMP Polymerization
   - Catalyst

   **Chemically Inert and Mechanically Robust Hydrocarbon Backbone**

   - Novel Base-Stable Cation

   Porous transport layer optimization for water management (fluorine mapping shown)

   Proton test system for electrolysis and fuel cell performance evaluation
Results – Membrane Characterization:

Percent cation versus water uptake

Membrane optimization to control water swelling in cell

Ionomer testing showed higher efficiency after start up for some Cornell configurations
Results – Cell and System:

Velocity model and pressure models for modified flow fields show acceptable flow

Parts procured and stack assembled for fuel cell and electrolyzer cycle testing

System controls upgraded and errors and warnings verified for operation
Going Forward:

- Proton is polymer and catalyst agnostic; strength is in integration and manufacturing
  - Looking for the best materials for the application
  - Can provide perspective on what has and hasn’t worked
- Water management being addressed through flow field and GDL control
- Continuing programs with DOE and USDA
- Electrolysis is primary focus but also other conversion processes (ammonia synthesis, etc.)
  - AEM fuel cell technology benefits as well
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