R&D Focus Areas Based on 60,000 hr Life PEM Water Electrolysis Stack Experience

E. Anderson, K. Ayers, and C. Capuano

First International Workshop on Durability and Degradation Issues in PEM Electrolysis Cells and its Components

Freiburg, Germany

12 March 2013

Proton OnSite

Manufacturer of packaged products, systems

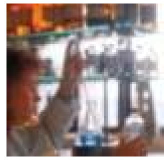
- *Proton Exchange Membrane (PEM) expertise*
- *H_2 generation by water electrolysis*
- *N_2 generation by membrane and CMS*
- *Founded in 1996*
- *100,000 ft^2 manufacturing/R&D facility*
- *ISO 9001:2008 registered*

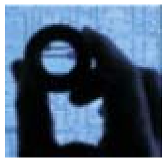
Over 2000 systems in more than 75 countries

Proton's World Headquarters in Wallingford, CT

Proton's Markets, Products & Capabilities

Power Plants





Heat Treating

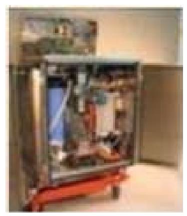
Semiconductors

Laboratories

Government

- Complete product development, manufacturing & testing
- Turnkey product installation
- World-wide sales and service
- Containerization and hydrogen storage solutions
- Integration of electrolysis into RFC systems

2000: S-Series 1-2 kg/day 13 bar



2006: HPEM 0.5 kg/day 138 bar

2009: Outdoor HPEM 2 kg/day 165 bar

2011: C-Series 65 kg/day, 30 bar

Steady History of Product Introduction

1999: GC 300-600 mL/min 13 bar

2003: H-Series 4-12 kg/day 30 bar

2006: StableFlow® Hydrogen Control System

2010: Lab Line

Over 10 MW Shipped – Future Growth from MW-Scale PEM Electrolysis

Today…

- Proton’s PEM-based hydrogen generators are demonstrating excellent reliability in industrial applications
- Cell stack technology is the most reliable component in the system
- New energy applications present capital as well as operating cost challenges
- Necessary technology advances are the biggest risk to established durability and reliability
- Meaningful accelerated stress tests could reduce that risk

Critical Needs for Energy Storage

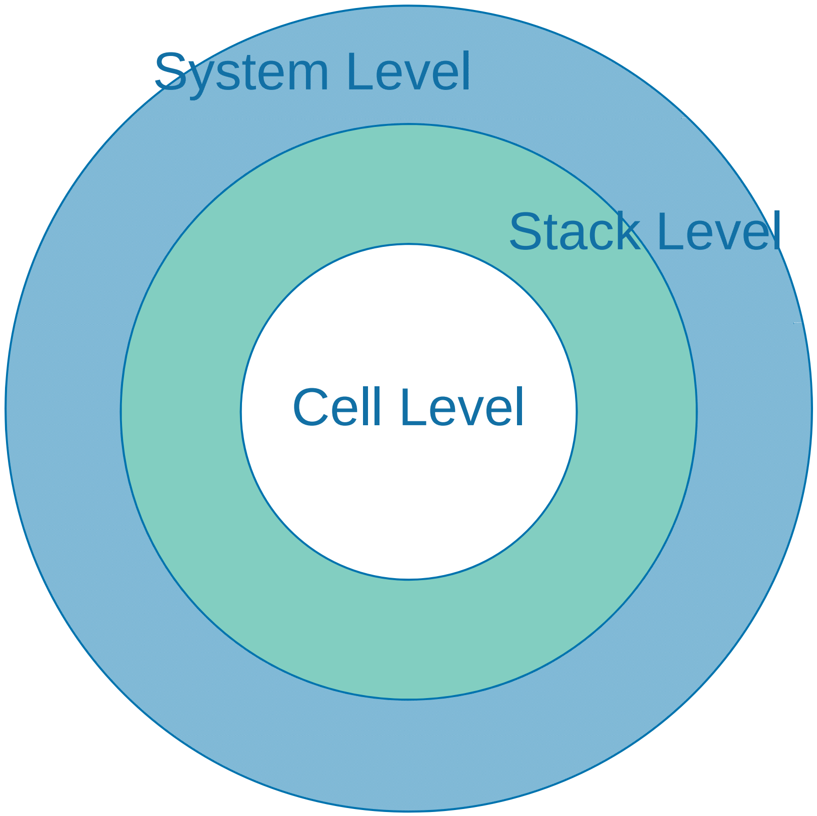
- Renewable energy is growing rapidly world-wide in both wind and solar
  - Inherent intermittency has more impact as RE becomes a larger portion of the grid capacity
  - Up to 20-40% of wind energy can be stranded without storage
- Need generation technologies for storing excess renewable capacity & balancing loads on the grid
- Energy storage can also provide a linkage between utilities & transportation

H_2 Energy Product Attributes

- Reliability – Cannot afford down-time or high replacement costs
- Cost – Price targets for energy market apps more difficult (Capex vs. Opex)
- Load-following – Need to handle fast response of varying renewable power
- Operating Range – Need to handle wide variability of available renewable power (i.e. 100% turndown)
- Efficiency – Cost of electricity impact (Opex)
- Scale – MW-class electrolysis required

PROTON ON SITE

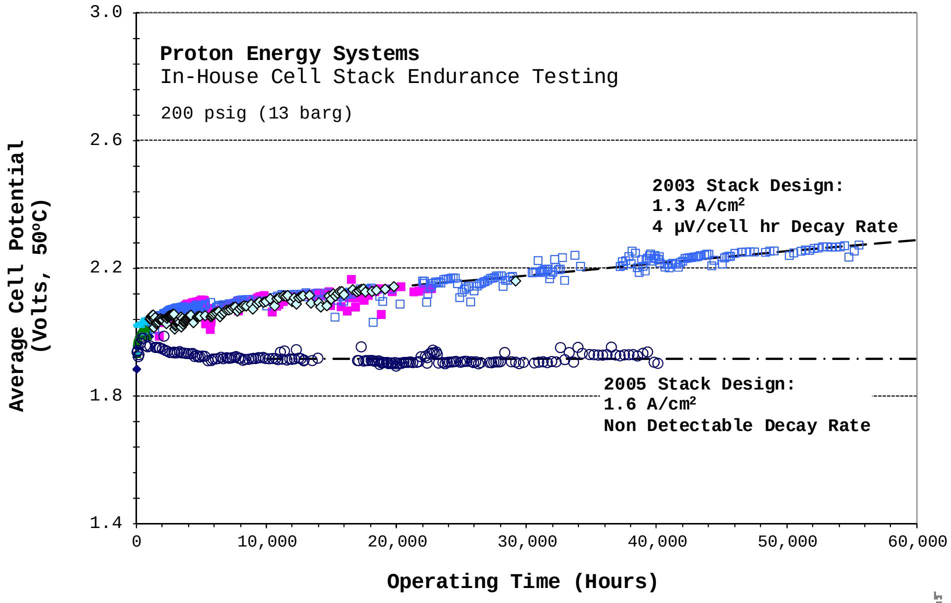
PEM Electrolysis Reliability



- Cell Examples:
  - Membrane chemical stability
  - Catalyst voltage decay
  - Material oxidation
  - H_2 embrittlement
  - Gas crossover
- Stack Examples:
  - Active area and seal area pressure
  - Flowfield component tolerances
  - Interface differential pressure
- System Examples:
  - Operating profile
  - Reactant purity
  - Power quality
  - Electromechanicals (sensors, pumps, valves,…)

PROTON ON SITE

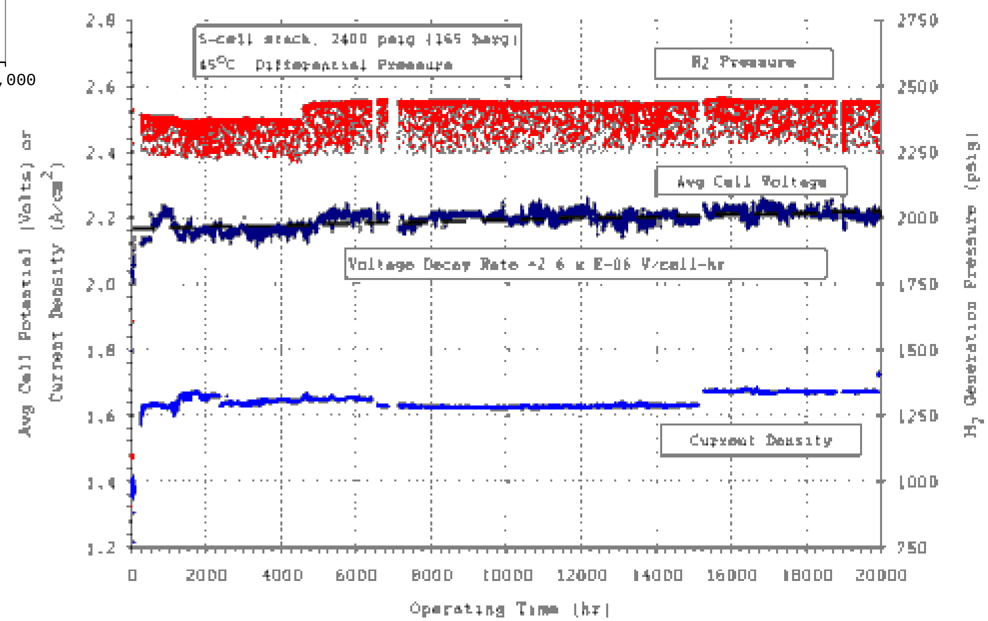
Established PEM Stack Durability



~60,000 hour life demonstrated in commercial stack designs

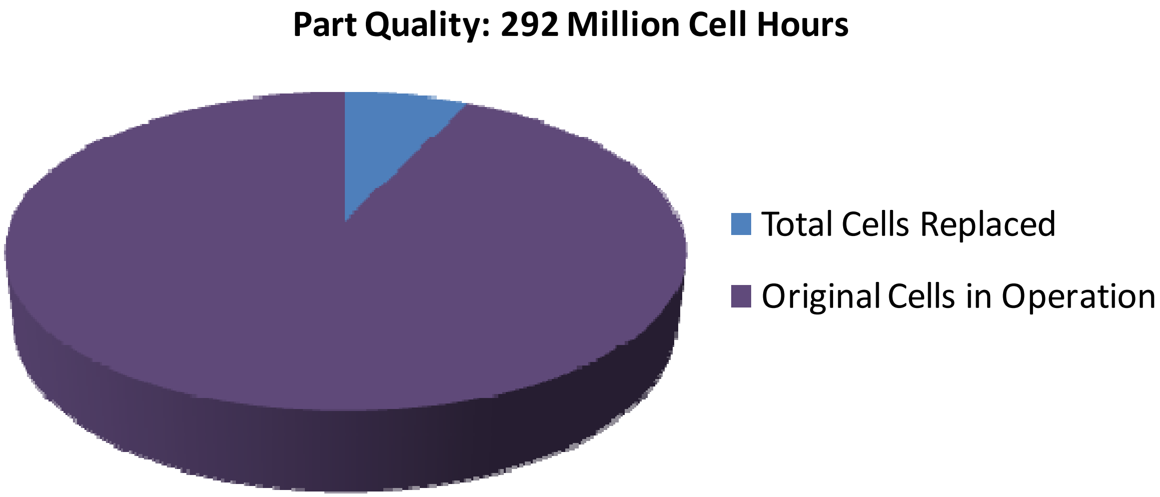
New designs have **no** detectable voltage decay

>20,000 hour life demonstrated at 165 bar in high pressure stack design

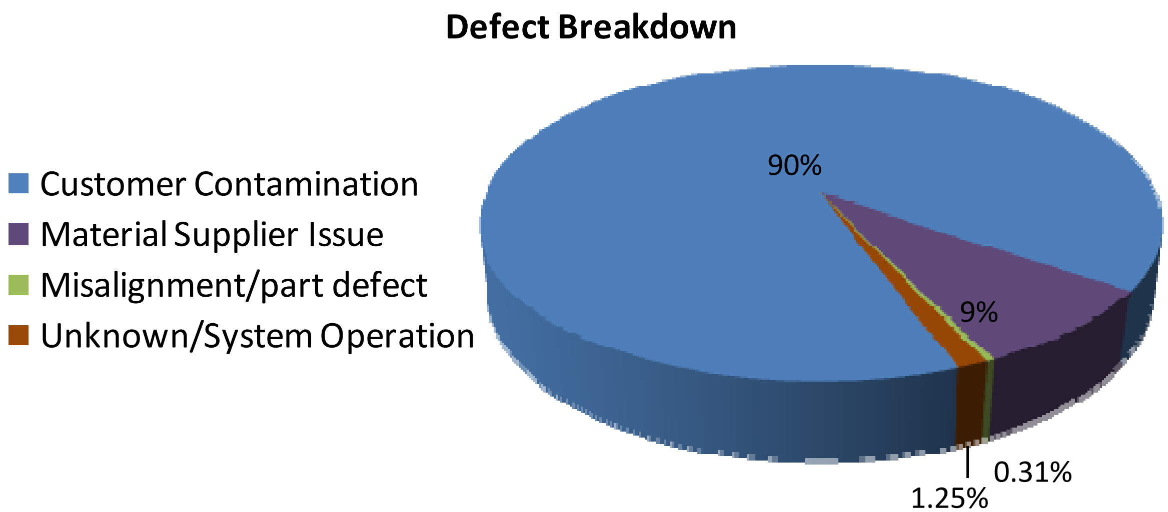


Strong lineage to low pressure design

Cell Stack Reliability – Over the past 6 yrs…



Hundreds of millions of cell-hours of field experience
>> 99% reliability

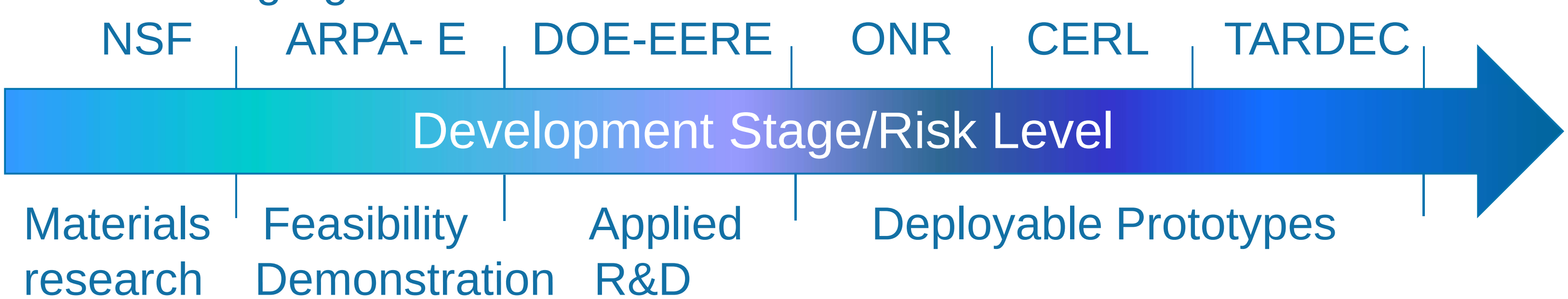


Corrective actions in place to address top 2 failure modes

Technology Roadmap Development

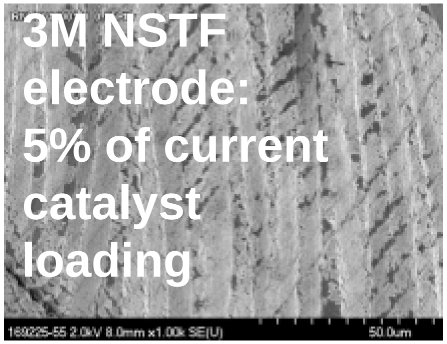
- Clearly defined pathways enable directed research
  - Product, cell stack, and balance-of-plant
- Balance portfolio with near and long term R&D
- Leverage 3rd party funding to subsidize internal R&D
  - Utilize military and aerospace as early adopters
  - Develop key partnerships to broaden skill base
- Feed into commercial markets as proven

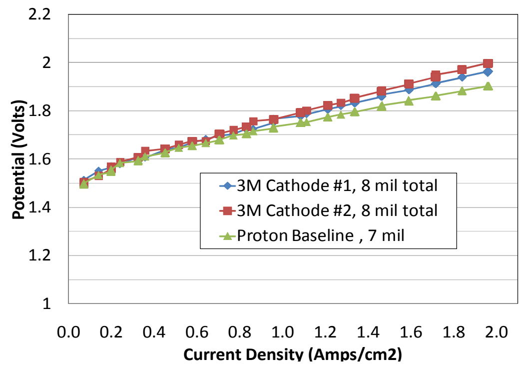
U.S. Funding Agencies:

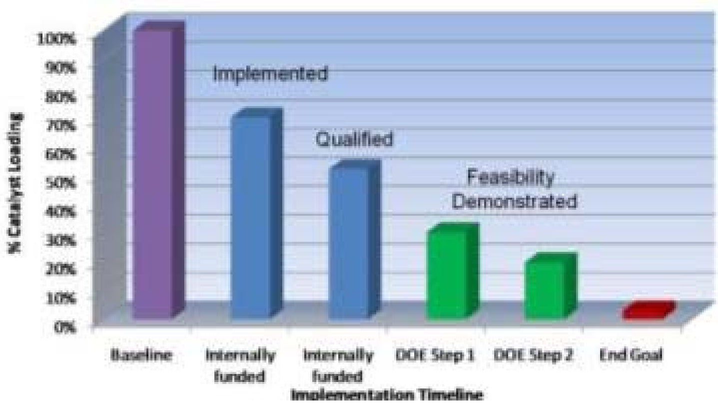


Cost Reduction Initiatives

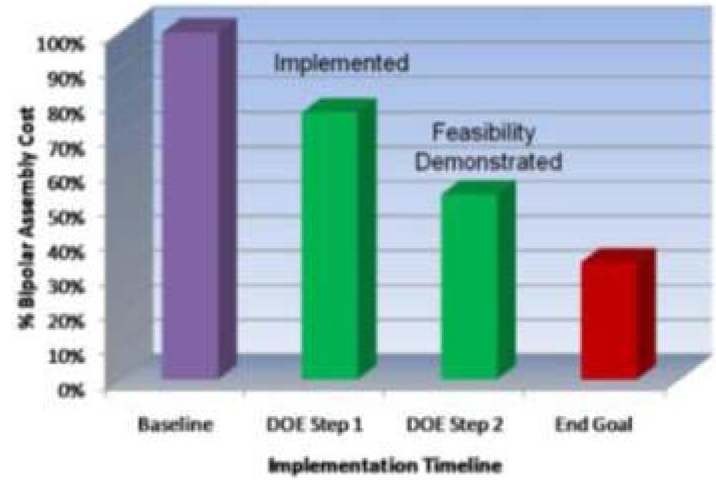
Noble Metal Reduction



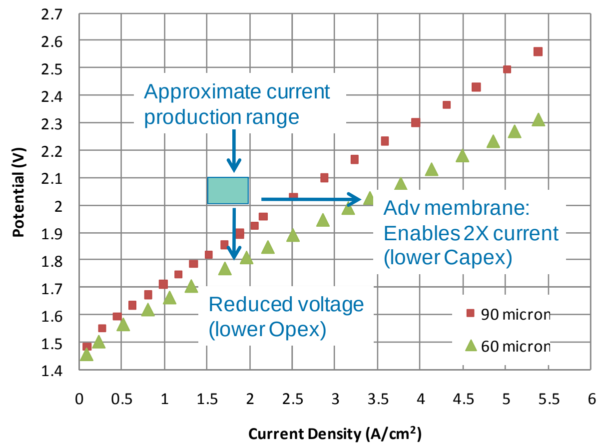




Flow Field Cost



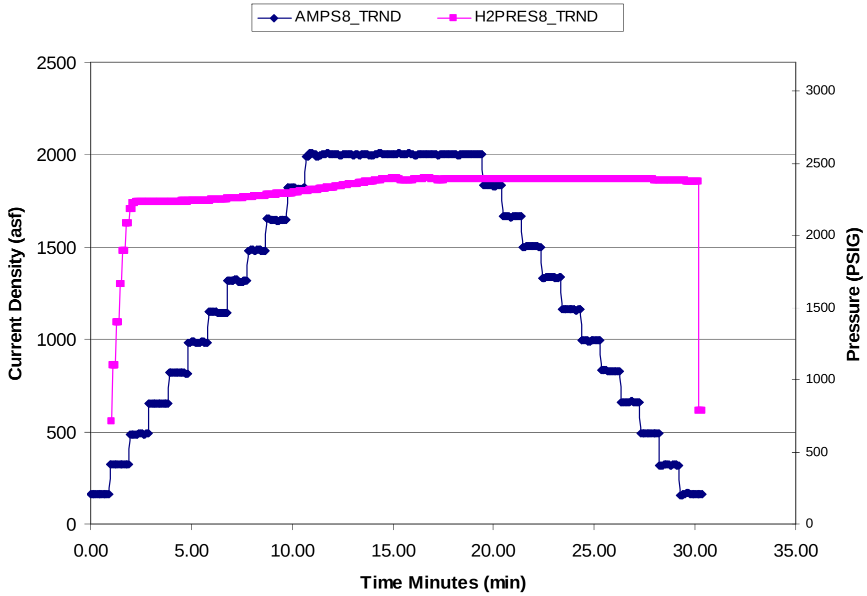
New design with ~50% less metal



Lower Cost Membranes

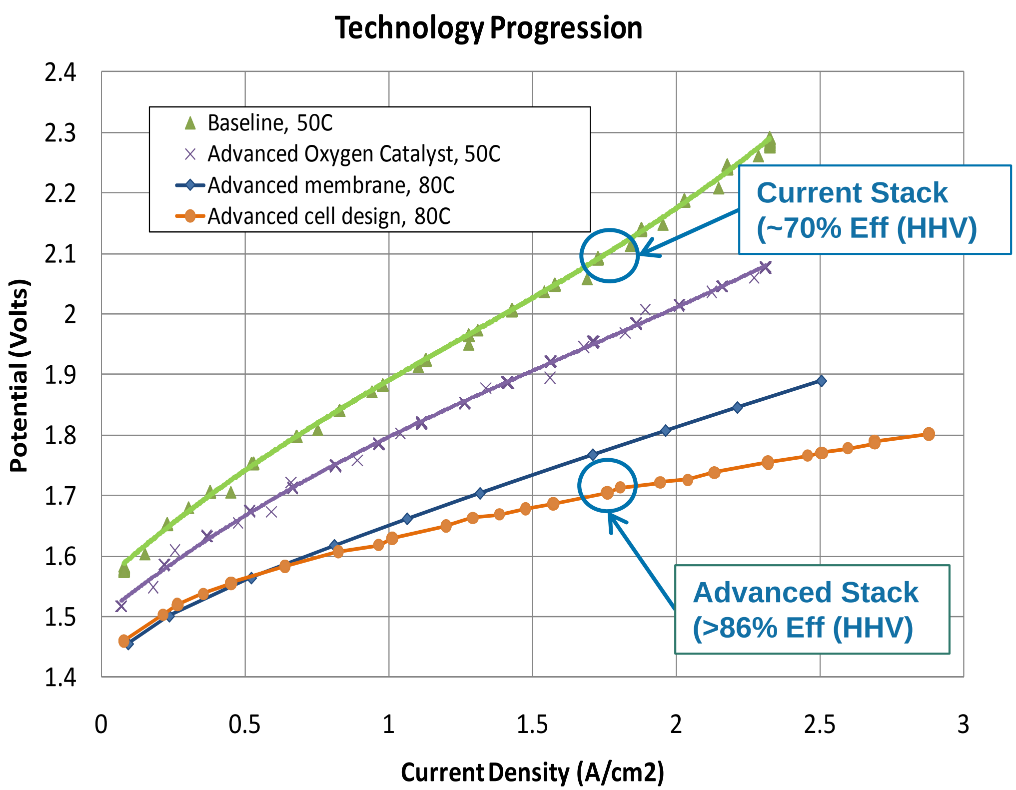
Electrolysis Membranes

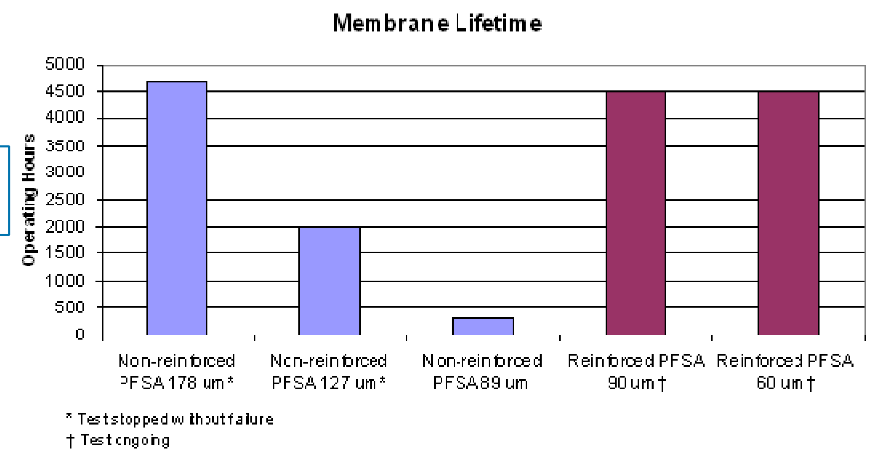
- Typically 170-250 microns thick versus 25-50 microns for fuel cells
- Need reinforcement to withstand high pressures
- Durability requirements make qualification challenging
- Accelerated testing: combination of pressure, voltage, and temperature cycling



Efficiency Needs and Progress: Membrane

- Reduce Membrane Thickness
- Increase Operating Temperature





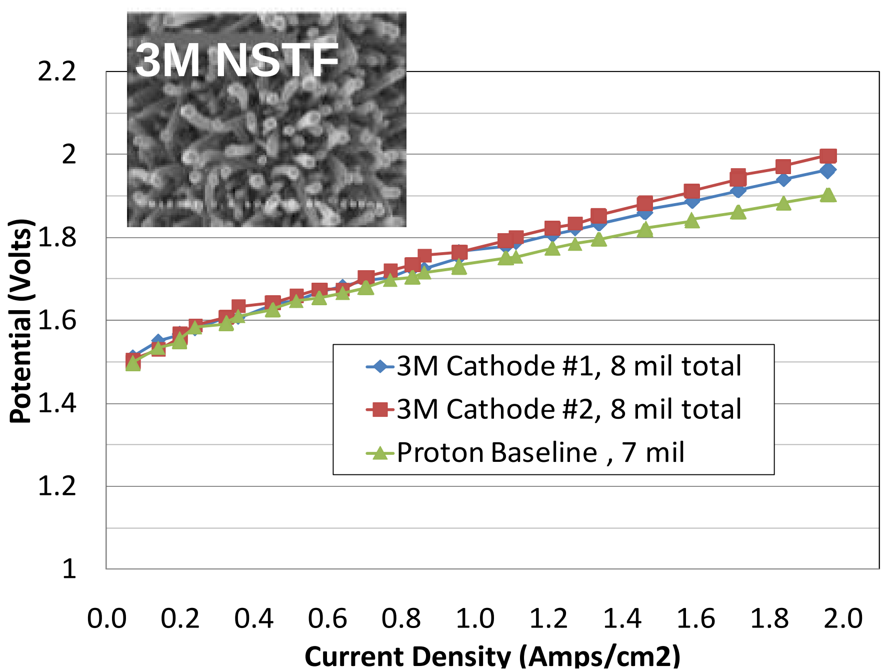
Advanced membranes show pathway to high efficiency

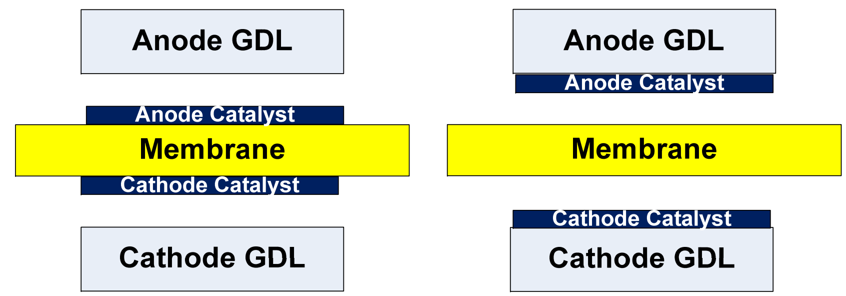
Durability promising but needs to be proven at 80C

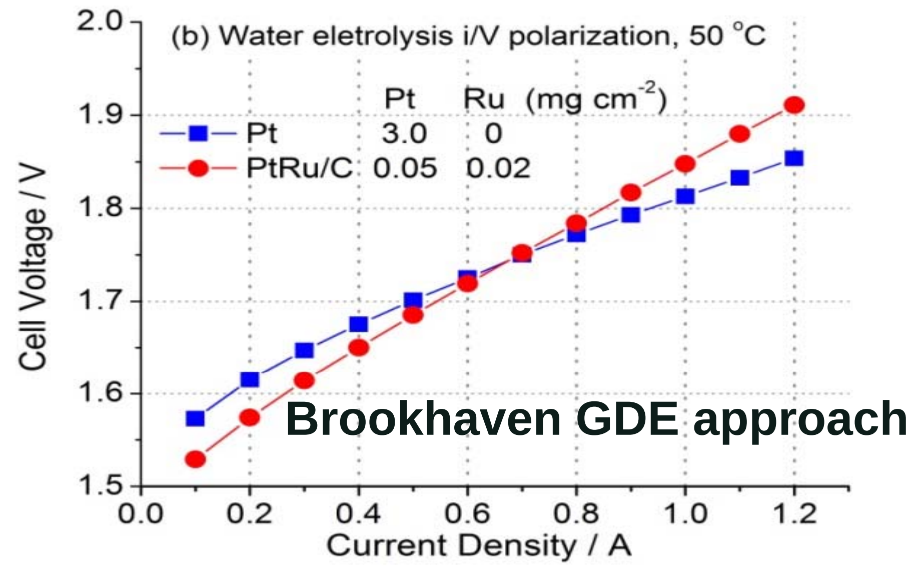
PROTON ON SITE

Cost Needs and Progress - Catalyst

- Engineered structures for ultra-low PGM loadings



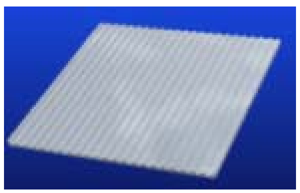


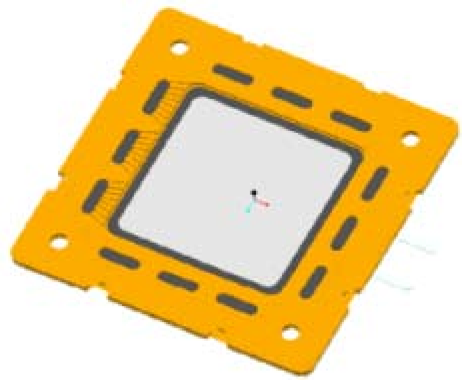


Polarization curves: 3M loading < 1/20th baseline, Brookhaven <1/30th loading

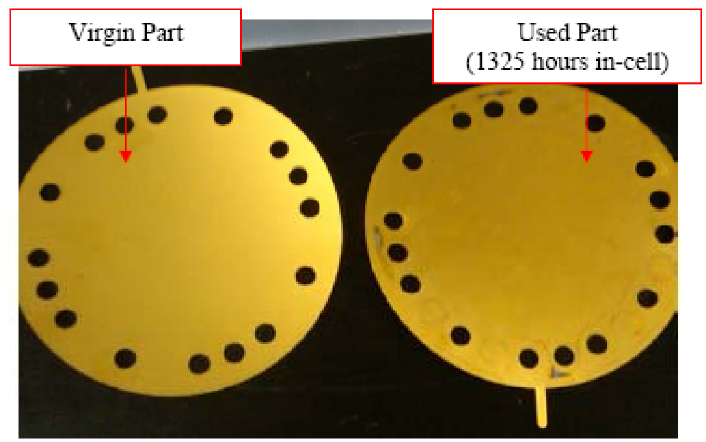
Cost Needs and Progress: Flow Fields

- New bipolar cell assembly design: 50% metal reduction



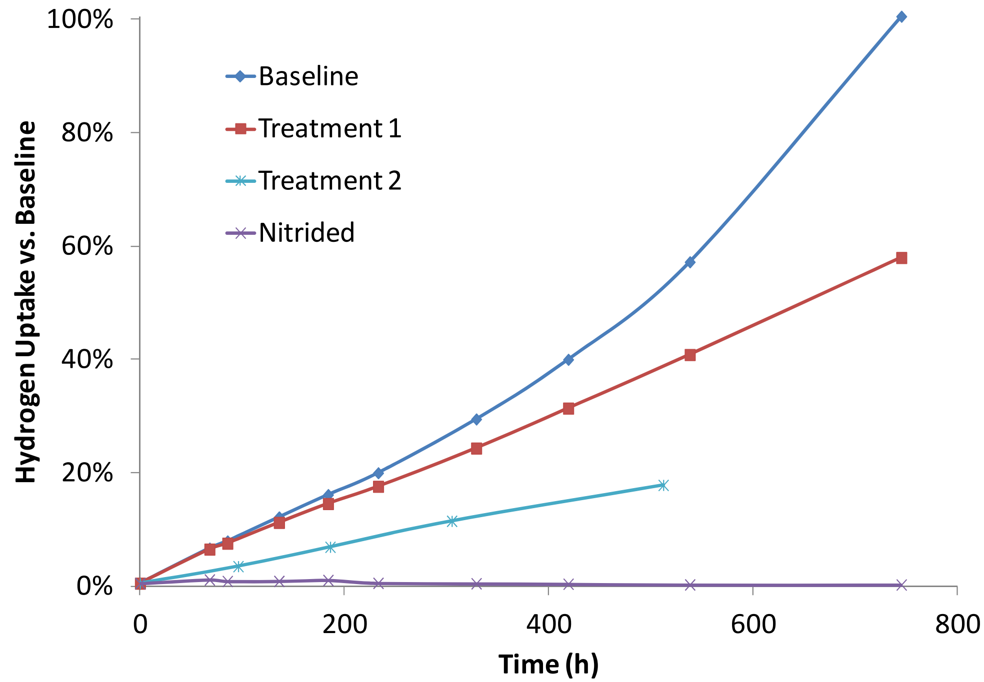


- Alternative coatings: Eliminates process steps and mitigates hydrogen embrittlement



Flowfield/Bipolar Plate Reliability

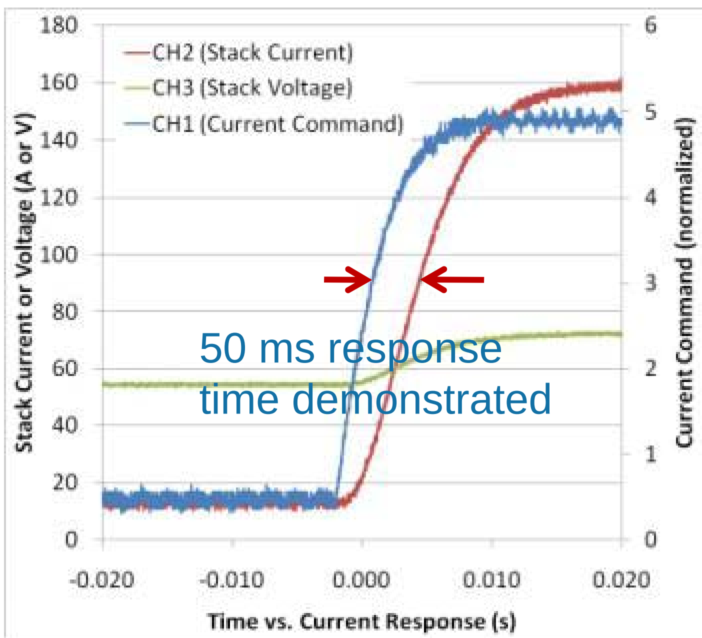
- Typical materials are semi-precious metals
  - Precious metal coatings added to reduce resistance
- Susceptible to oxidation (anode) or embrittlement (cathode) with prolonged operation
- Need lower cost alternatives
- Investigating impact of process methods & alternative non-precious metal coatings on durability



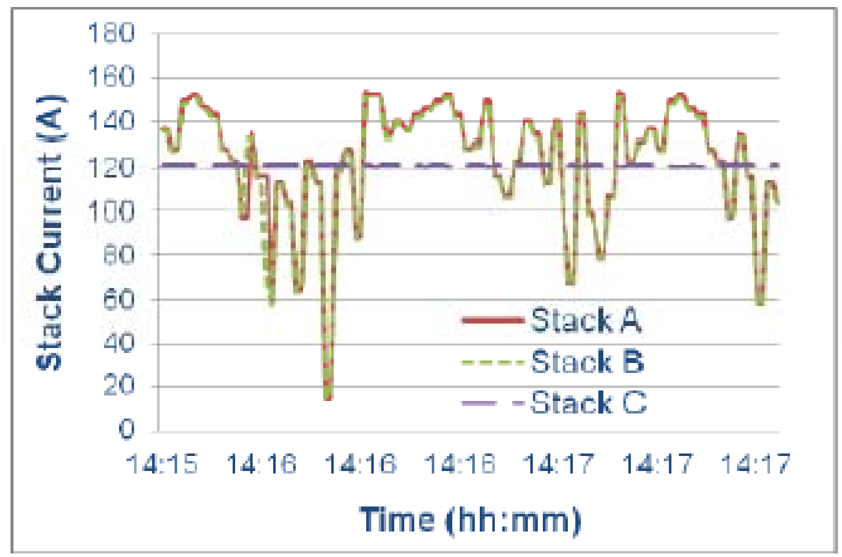
Accelerated H_2 Exposure Testing
(100 hrs → 10 yr operation)

Intermittency and Variable Load Input

- Electrolysis is well suited to load following
  - Stable performance
  - Rapid response time to current signal
  - Tolerance to variable power input

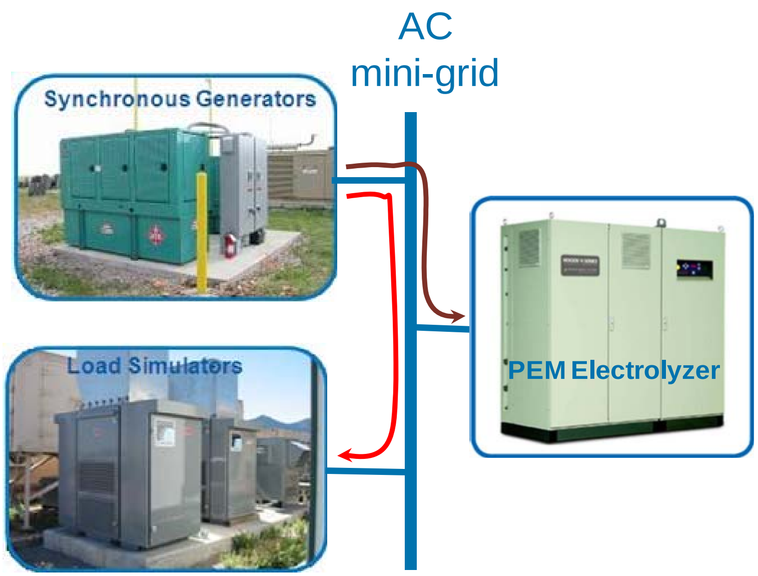


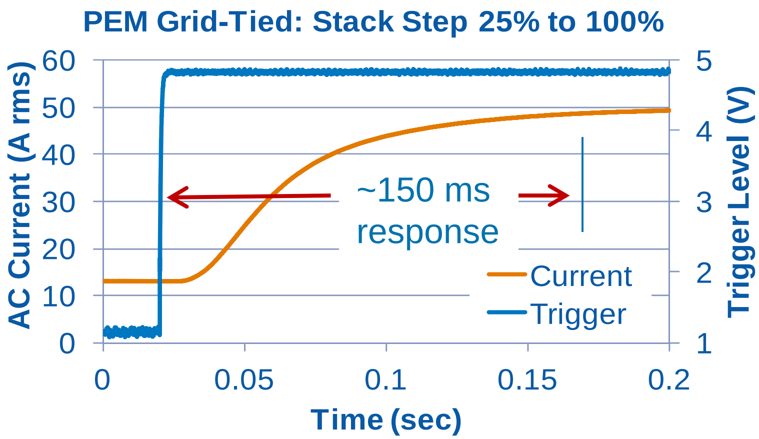
~2 minute snapshot of stack current



Courtesy of NREL

Grid Support Using PEM Electrolysis*





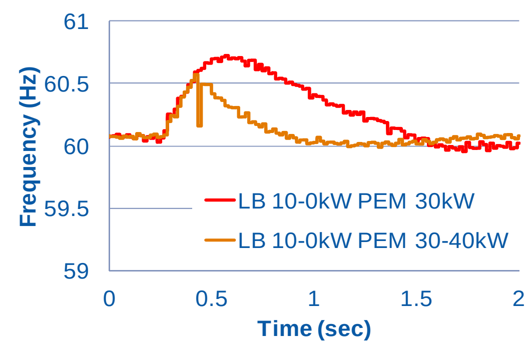
*Courtesy of K Harrison, NREL, 2011

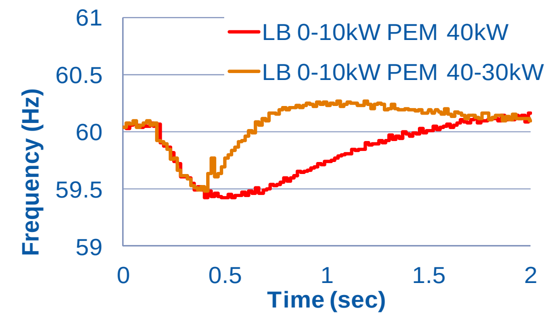
Approach

- Simulate deviation on diesel generator-based AC mini-grid
- Trigger electrolyzer at +/- 0.5 Hz from 60 Hz, add or shed load to stabilize AC grid by regulating frequency

Results

- Responded as needed
- Re-stabilization achieved in less than 1 sec
- Large loads & varied trigger points can be use to optimize response

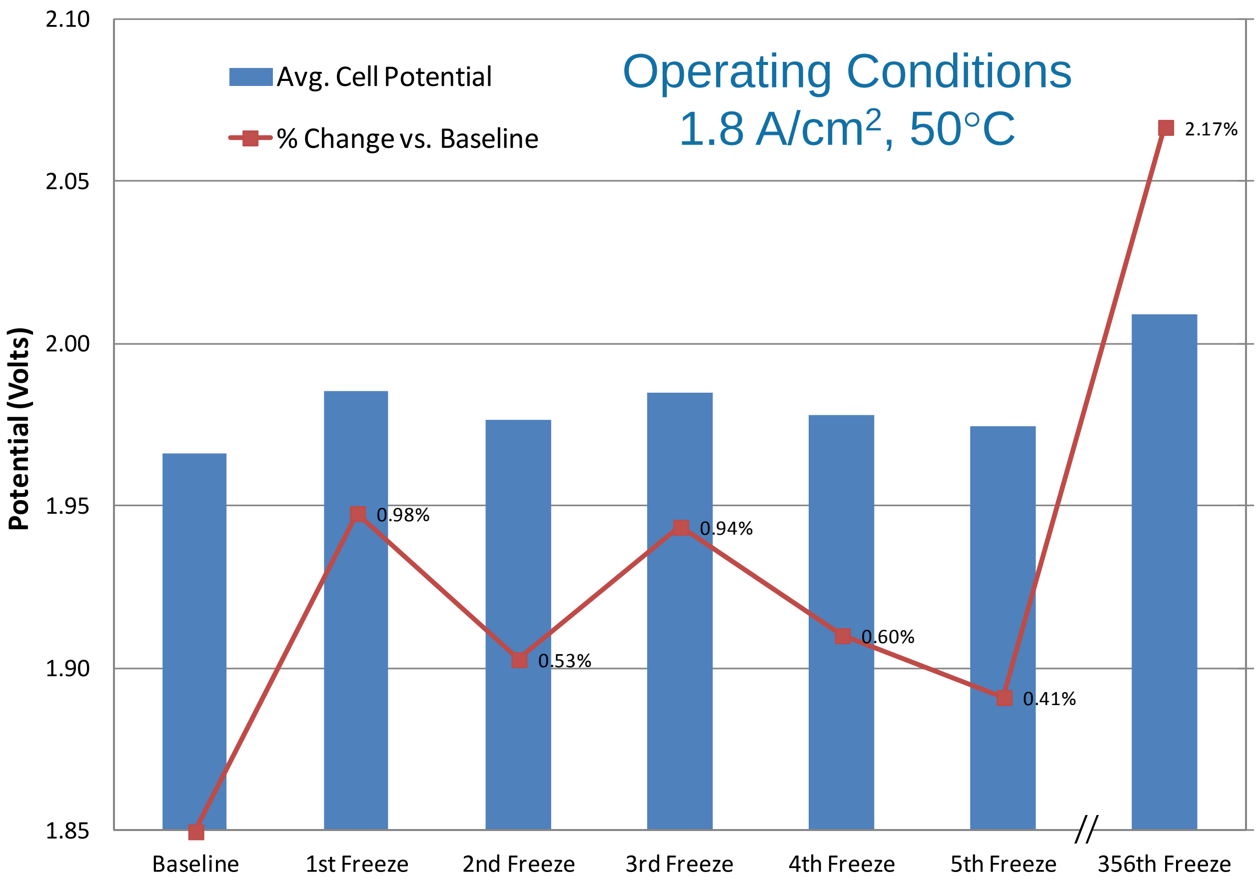




Red line – Without PEM Load
Gold line – With PEM load

Adverse Environmental Conditions

- Short stack freeze-thaw cycle testing



Other Reliability Concerns

- Transition to multi-stack systems
  - Increased system complexity
  - Stack-to-stack interactions
- Power conversion/power quality issues
- Sensing in unique environments

From Single to Multi-Stack Systems

Summary

- Industrial PEM electrolysis systems have excellent reliability track record
- New energy applications will challenge that reliability as technology advancements to drive cost and reliability are adopted
- Market needs for hydrogen energy storage are emerging rapidly
- Development of AST protocols could shorten development time while reducing risk in order to meet the growing market needs