PEM Electrolysis R&D Webinar

May 23, 2011

Presented by Dr. Katherine Ayers

Outline

- Key Messages About Electrolysis
- Company Intro and Market Discussion
  - Electrolysis Technology Comparison
- Infrastructure Challenges and Solutions
  - System Approaches: Capacity and Delivery Pressure
  - Materials Advancements: Cost and Efficiency Improvements
- Summary and Future Vision

Key Takeaways for Today

- Hydrogen markets exist today that can leverage advancements in on-site generation technologies
- PEM electrolysis already highly cost competitive in these markets
- PEM technology meets alkaline output capacities and has performance advantages for many applications
- Multiple fueling stations utilizing hydrogen from electrolysis: can help bridge the infrastructure gap
- Clear pathways exist for considerable cost reductions and efficiency improvements despite the maturity of the technology

Proton Energy Systems/Proton OnSite

- Manufacturer of onsite gas generation products
- Core competencies in Proton Exchange Membrane (PEM) technology
- Founded in 1996 – changed name from Proton Energy Systems in April 2011.
- ISO 9001:2008 registered
- Product development, manufacturing & testing
- Turnkey product installation
- World-wide sales and service
- Over 1,600 systems operating in 62 different countries.

Headquarters in Wallingford, CT

ANAB ACCREDITED

Certified to ISO 9001:2008

TÜVRheinland® Precisely Right.

Cell Stacks

Complete Systems

Storage Solutions

RFC Integration

Markets and Products

Power Plants

Heat Treating

Semiconductors

Laboratories

Government

2000: S-Series 1-2 kg/day

2006: HPEM

2009: Outdoor HPEM

2011: C-Series, 65 kg/day

Steady History of Product Introduction

1999: GC 300-600 mL/min

2003: H-Series 4-12 kg/day

2006: StableFlow Hydrogen Control System

2010: Lab Line

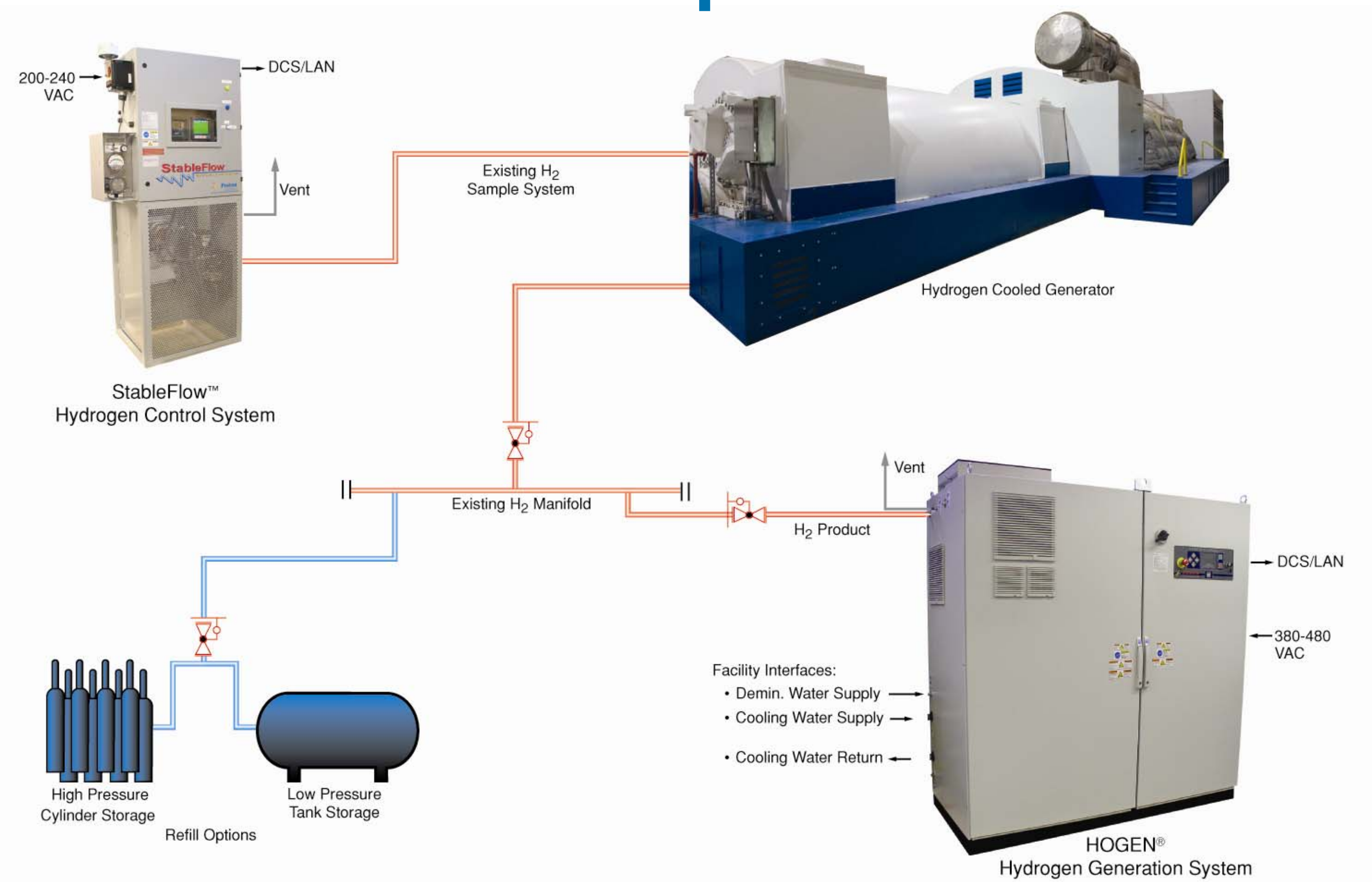
Industrial Hydrogen Markets

- Hydrogen is fastest growing industrial gas (7%/year)
- Major industrial gas consuming industries:
  - Power Plants/Electric Power Generator Cooling
    - Over 16,000 hydrogen-cooled generators world-wide
    - Addressable market estimated at over $2.0 billion
    - Improved plant efficiency and output/reduced greenhouse gas emissions
    - Payback typically less than one year
  - Semiconductor manufacturing
  - Flat panel computer and TV screens
  - Heat treating
  - Analytical chemistry (carrier gases for GC, etc.)

Proton ENERGY SYSTEMS

PROTON ON SITE

Typical Power Plant Implementation



Environmental Benefits: Pollution reduction

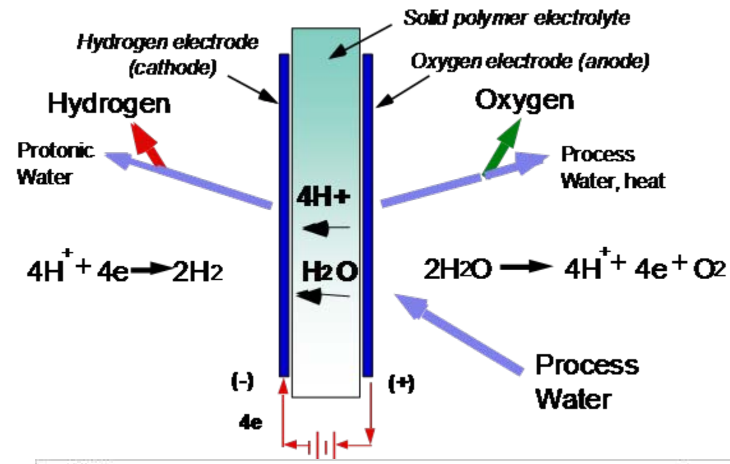
- 1 ton of CO_2 for every MW/hr improvement
- Based on improvement from 95% to 99% H_2 purity

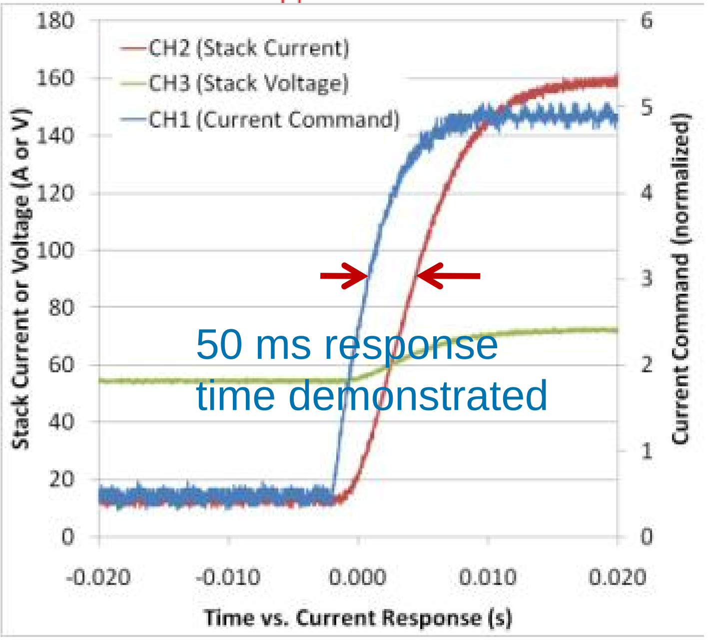
Demonstrated Benefits of Distributed Hydrogen Production

- Cost competitive vs. delivered solution
  - Delivered cost can exceed $15/kg for "remote" installations (>15 ft off major road)
- Removes price fluctuation based on fossil fuel costs
  - Natural gas is major delivered source, delivered by diesel truck
- Improves supply reliability
  - Removes delivery logistics, need for inventory tracking and ordering
  - Stack durability of over 50,000 hours demonstrated
- Improves safety due to automation and inventory reduction
  - Eliminates delivery and change outs of bottles or trucks
  - Reduces inventory by orders of magnitude vs. 12-pack or tube trailer

PEM vs. Alkaline Liquid Electrolysis

1. Membrane technology enables high differential pressure
   - Eliminates need for strict pressure controls and slow turndown
   - Enables rapid changes in current for renewable integration: fast response time to current signal
   - Enables low pressure oxygen for safety and lower cost
2. Non-corrosive electrolyte
3. Stack operates at 4-5X current density of alkaline systems
   - Counteracts higher cost materials





System Efficiency Comparison

- NREL-Xcel Energy Wind2Hydrogen Project

Proton Energy HOGEN 40RE (PEM)

Teledyne HM-100 (Alkaline)

- Actual Measured Efficiency[1]
  - PEM 57%
  - Alkaline 41%

} 39% Improvement

[1]K. Harrison, Hydrogen Works Conference, San Diego, CA, Feb 17-19, 2009

Hydrogen Infrastructure Challenges

- Ramp-up
  - Fuel production
  - Storage
  - Transportation
  - End-customer delivery
- Pace with parallel ramp-up of related vehicles
- Continuum of options
  - Large, centralized plants
  - Neighborhood / captive fueling stations
  - Home-based fueling

- Traditional Markets
  - Vehicle Fleets
  - Buses
- Alternative Markets
  - Materials Handling
  - Military / Aerospace
  - Bikes/Motorbikes
  - Marine

PEM Electrolysis Role in Hydrogen Fueling

- Traditional fueling station concept: grow capacity with number of vehicles
  - Over 20 demonstrations worldwide at up to 13 kg/day
  - Next generation product opens up next larger fueling opportunities (up to 65 kg/day)
  - Fully packaged solutions developed with Air Products and Linde
- Home fueling concept to bridge gap
  - Based on less production output but higher pressure
  - Developing neighborhood fueler at up to 2.2 kg/day
    - Full electrochemical compression to 5000 psi or mechanical compression to 10,000 psi
- Renewable-based hydrogen production viability for both

Proton System R&D Strategy: Leverage Commercial and Military Experience

Military Markets

- Submarine life support
- Unmanned vehicles
  - UAV
  - UUV
- Silent Camp
  - Back up power
- Military fueling needs
  - Fork lifts
  - Light duty vehicles

Commercial Markets

- Industrial
- Vehicle fueling
- Telecomm backup
- Renewable energy storage

Early Fueling Station Examples

Electrolysis System Development

Larger Capacity

13 kg/day

65 kg/day

Higher Pressure

200-435 psi

2400-2800 psi

Next Generation Fueling: 65 kg/day

- 5 times increase in hydrogen output at 1.5x foot print.
- Uses stack platform developed for Navy with Hamilton Sundstrand.
- Balance of plant funded by TARDEC, DOE, and internal funding
- Increased power supply and drying efficiency
- Now commercially available, first unit to AC Transit for bus fueling
- Also relevant for industrial applications

Proton Fueling Station

700 bar, 65 kg/day capacity

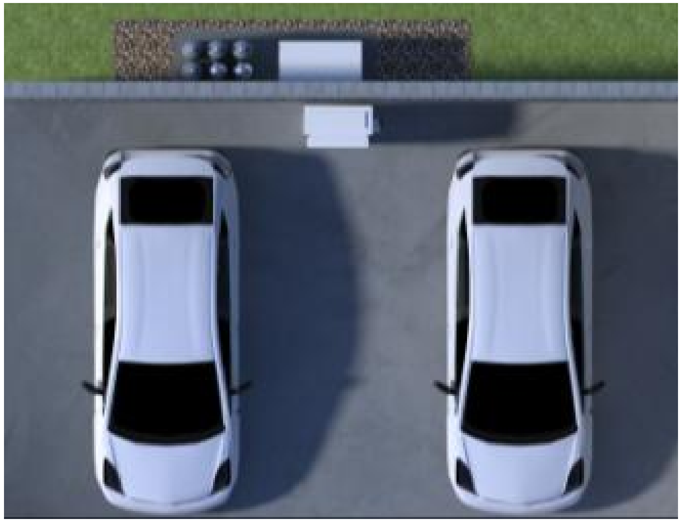
Greater than 10,000 miles / 300 H_2 fills to date

High Pressure: Neighborhood Fueling Prototype

- Electrochemical compression to 2400 psi, 2 kg/day
- 10,000 psi fueling capability
- Qualified for GM vehicle fueling

Conceptual Design: Neighborhood Fueler Gen 2

- Direct electrochemical compression and delivery at 5000 psi
- Currently performing on DOE Phase II SBIR to develop initial prototype

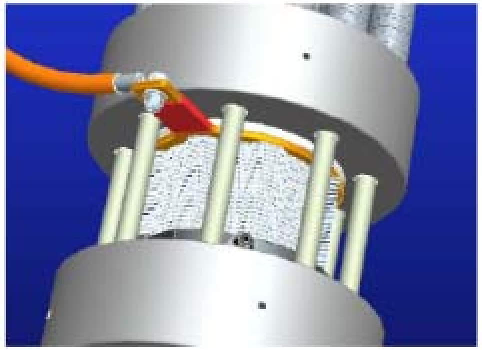


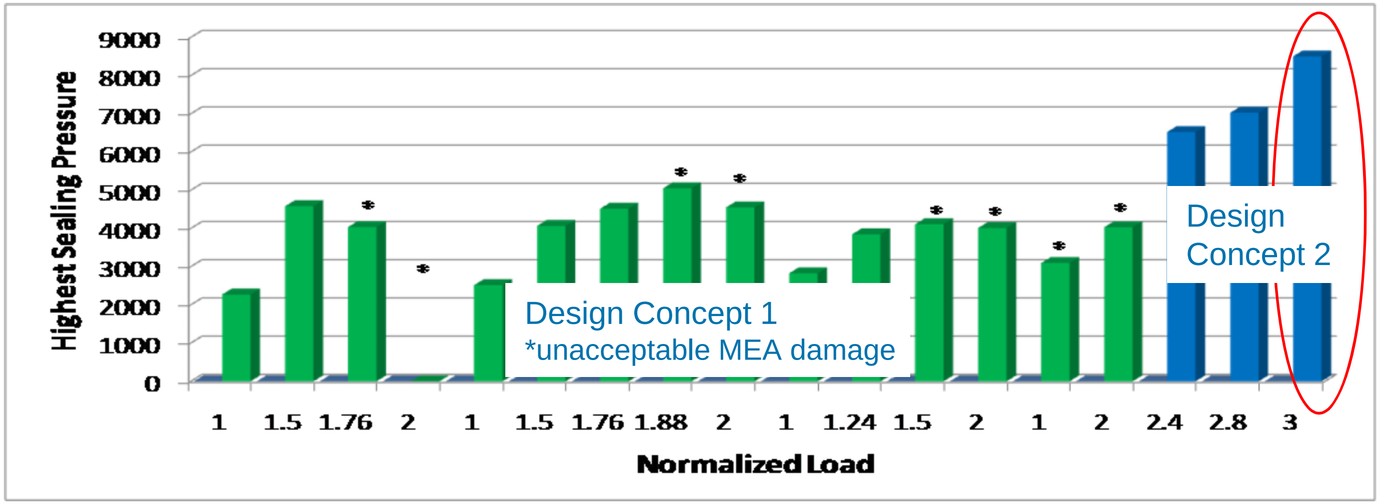
Proton ENERGY SYSTEMS

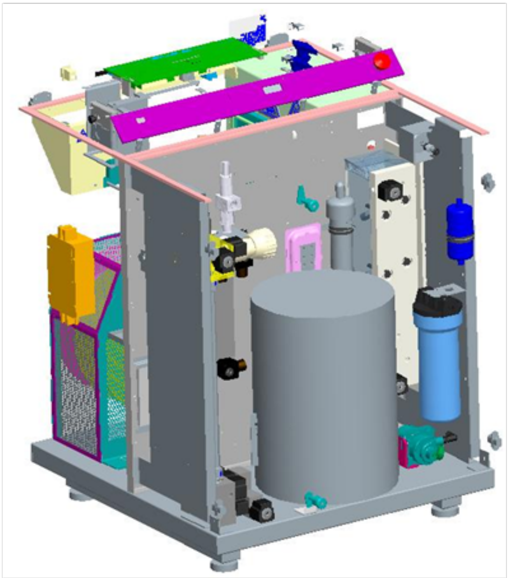
PROTON ON SITE

5000 psi System Development Progress

- Seal design verified at higher temperatures
- System concept and prototype design completed, hazard analysis completed
- Concept design of cell and stack components completed, prototypes on order

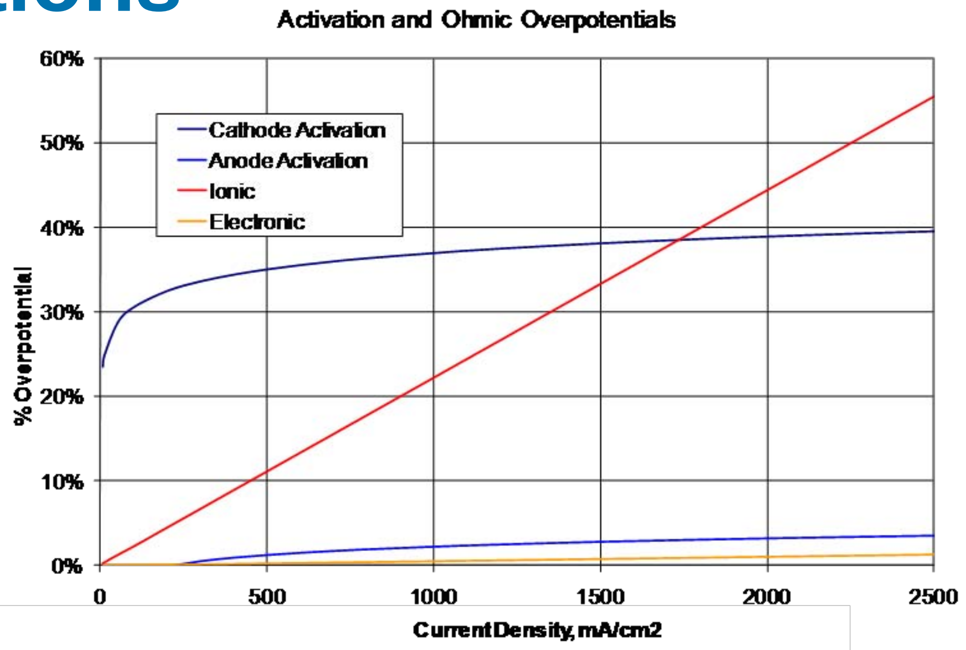


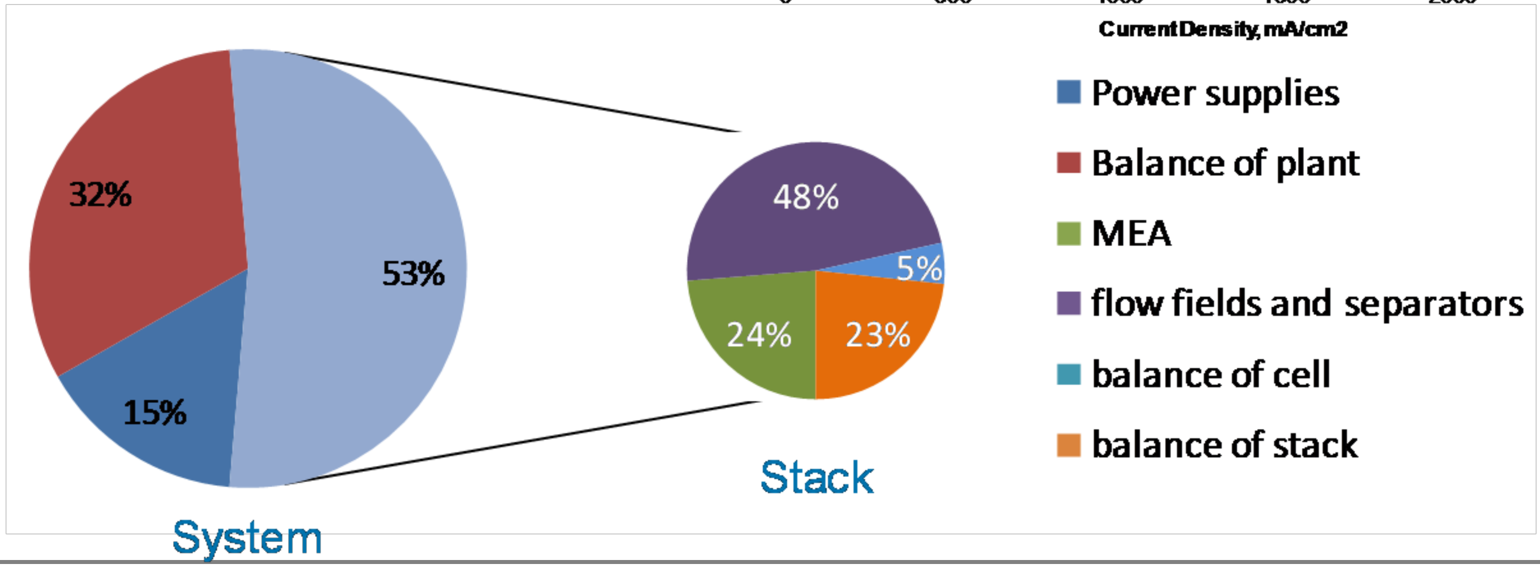




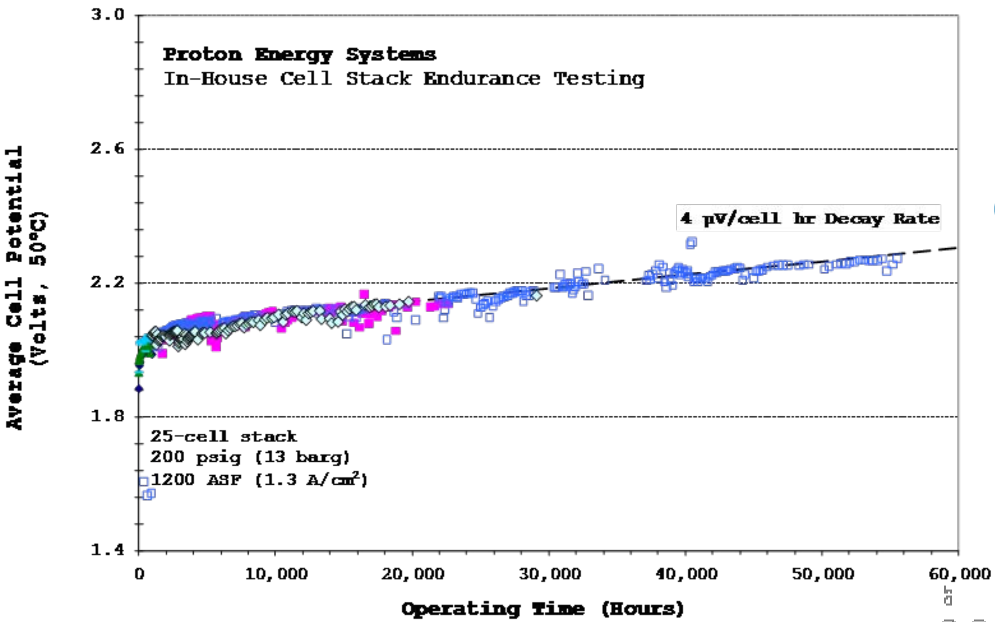
Current Stack Limitations

- Efficiency driven by:
  - Membrane resistance
  - Oxygen overpotential
- Cost driven by:
  - Membrane electrode assembly
  - Flow fields/separators



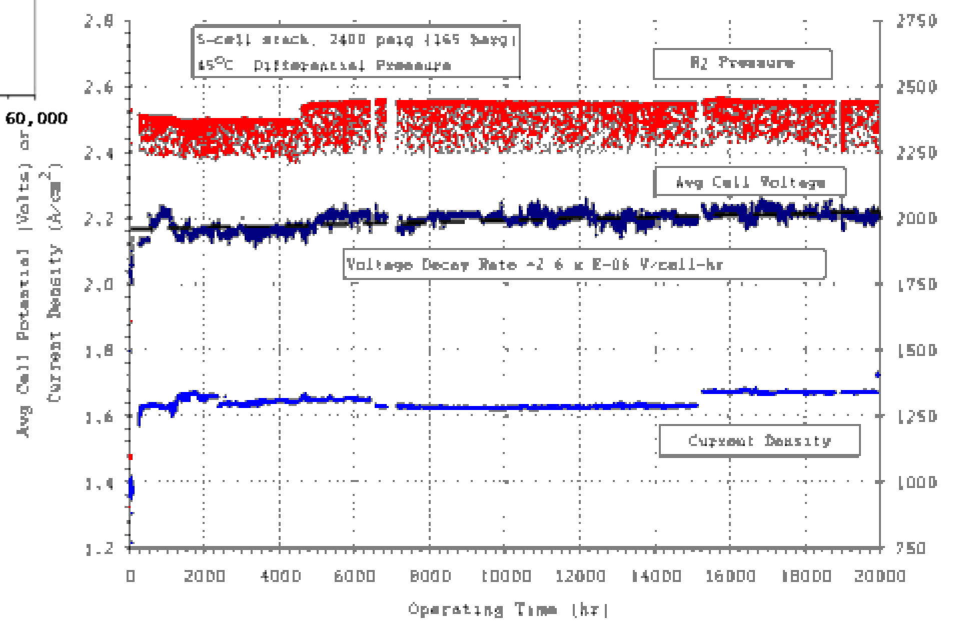


Established Stack Durability



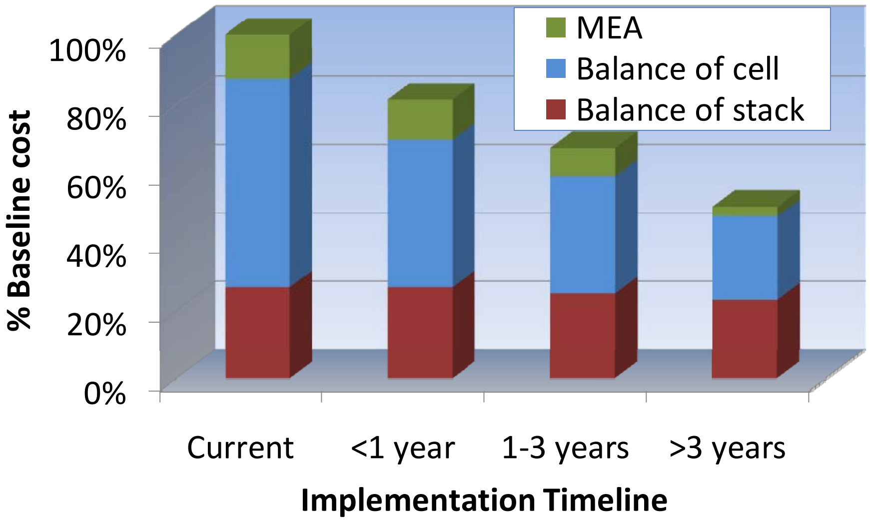
>60,000 hours of operation demonstrated in commercial stack

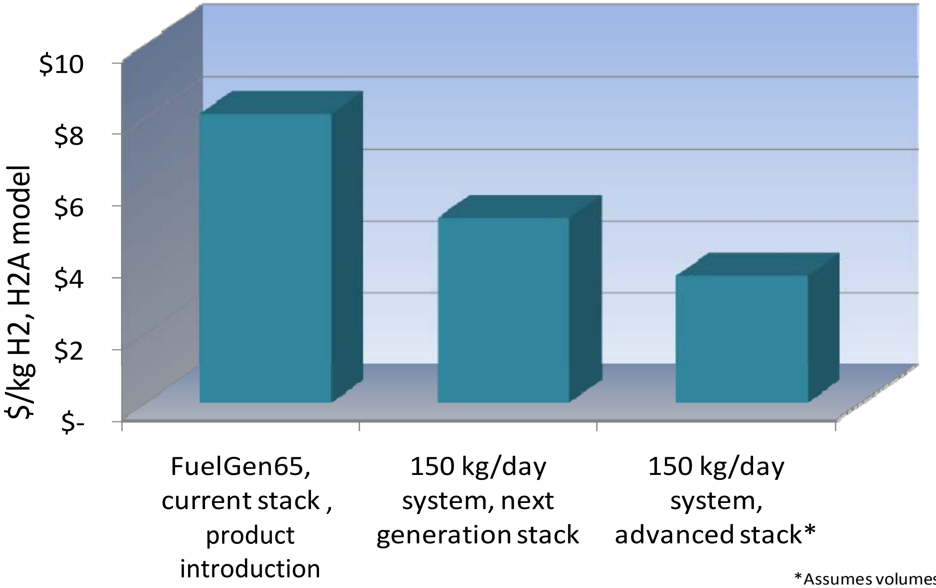
20,000 hours of operation demonstrated at 2400 psi



Technology Roadmaps

- Detailed product development pathways laid out internally
  - Balance of plant scale up
  - Cell stack cost and efficiency
  - Product improvements and introductions
- Balanced portfolio of near and long term implementation
- Executing on funded programs to address each area

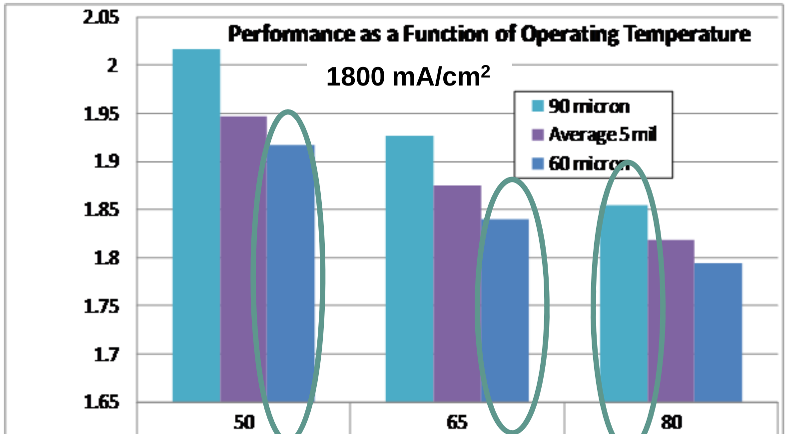




*Assumes volumes of 500 units/year

Membrane Resistance Reduction

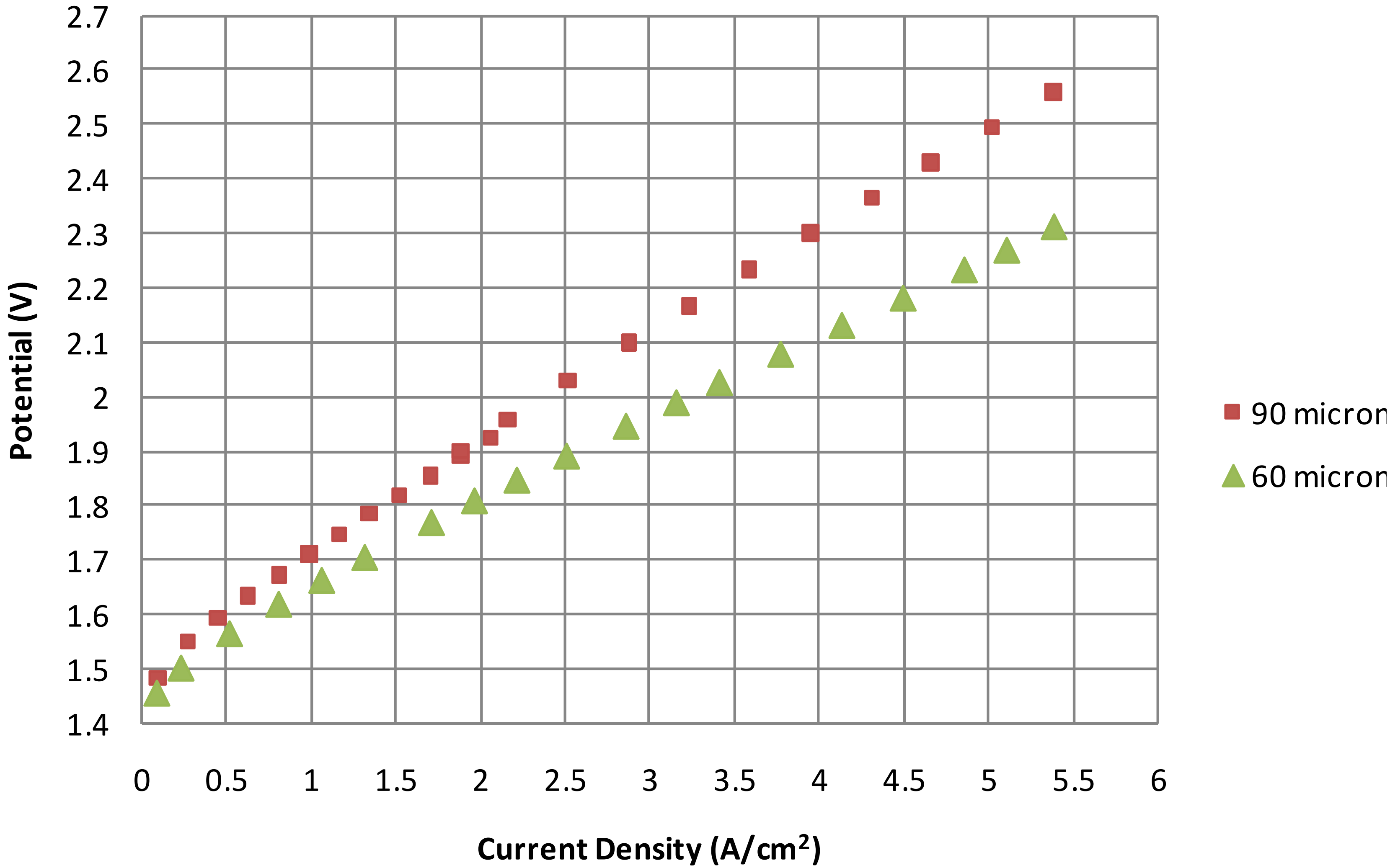
- Standard materials, 25% reduced thickness
  – Internally funded, **implemented 2010**
- Reinforced membranes, 60% reduced thickness
  – Internal and ONR funding
  – **Leverages W.L. Gore technology**
  – 1000 hours demonstrated, passed 300 cycle accelerated stress test (5-mil fails test)
  – Efficiency > 5-mil Nafion



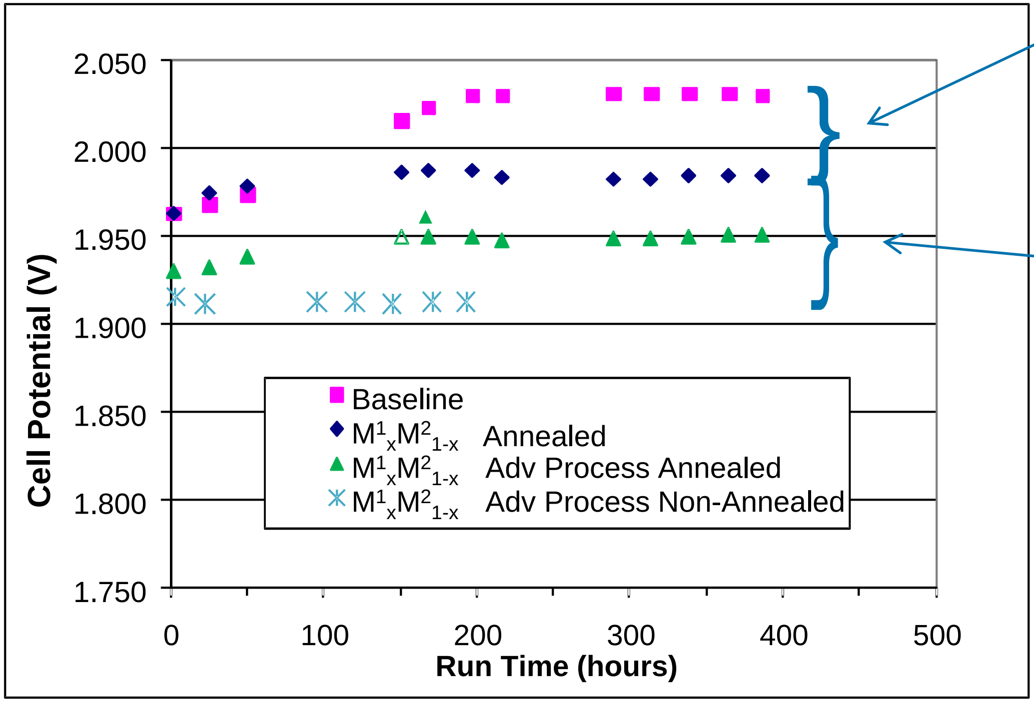
	50	65	80
90 micron	2.017	1.927	1.855
Average 5 mil	1.947	1.875	1.818
60 micron	1.917	1.840	1.794

- New chemistries (hydrocarbon), 80% reduced thickness
  – NSF funded project, Phase I/II STTR
  – Reduced H_2 crossover, improved voltage at higher temp

High Current Performance, 80°C



O_2 Evolution Efficiency

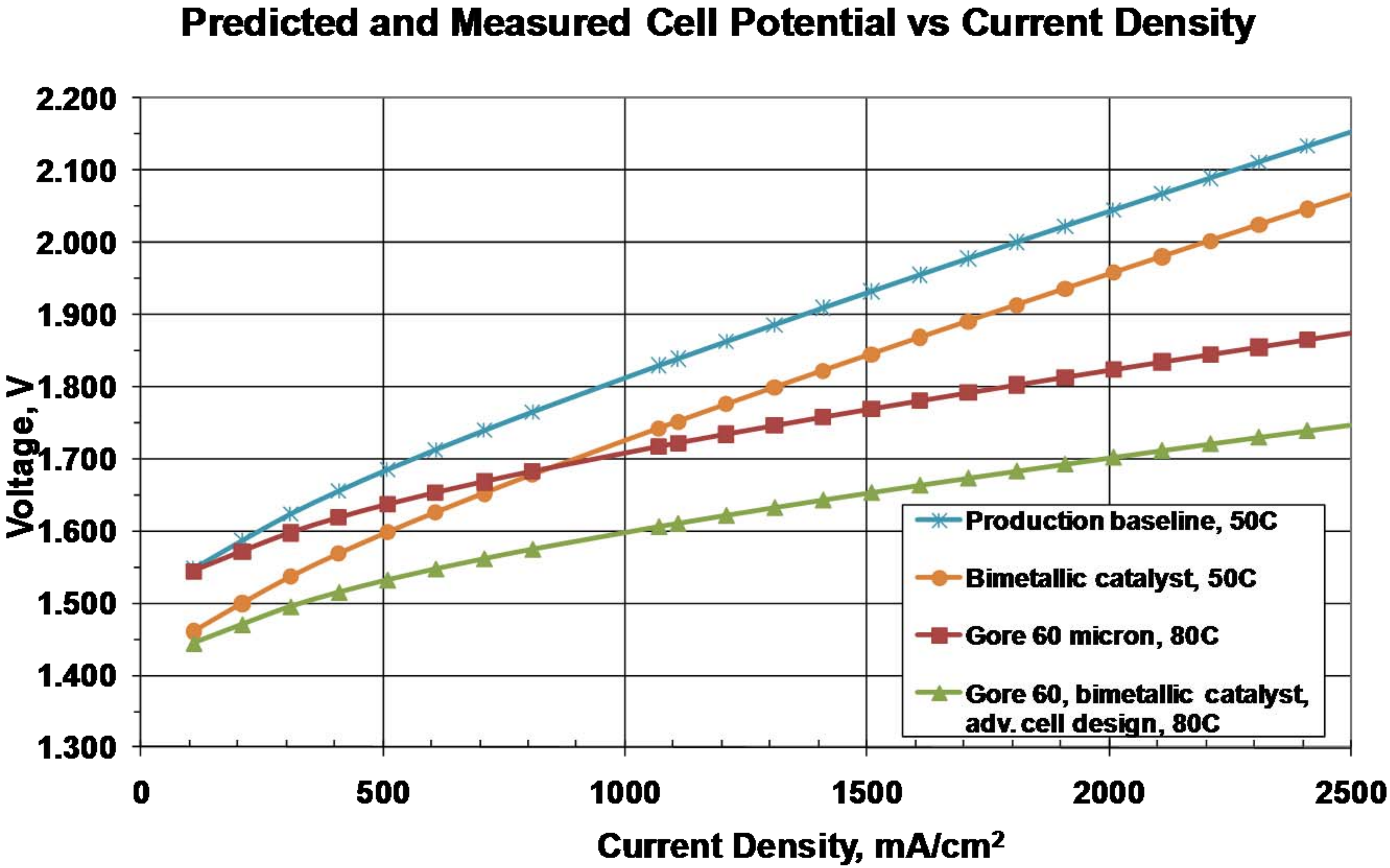


Bimetallic blends, 50 mV demonstrated efficiency gain

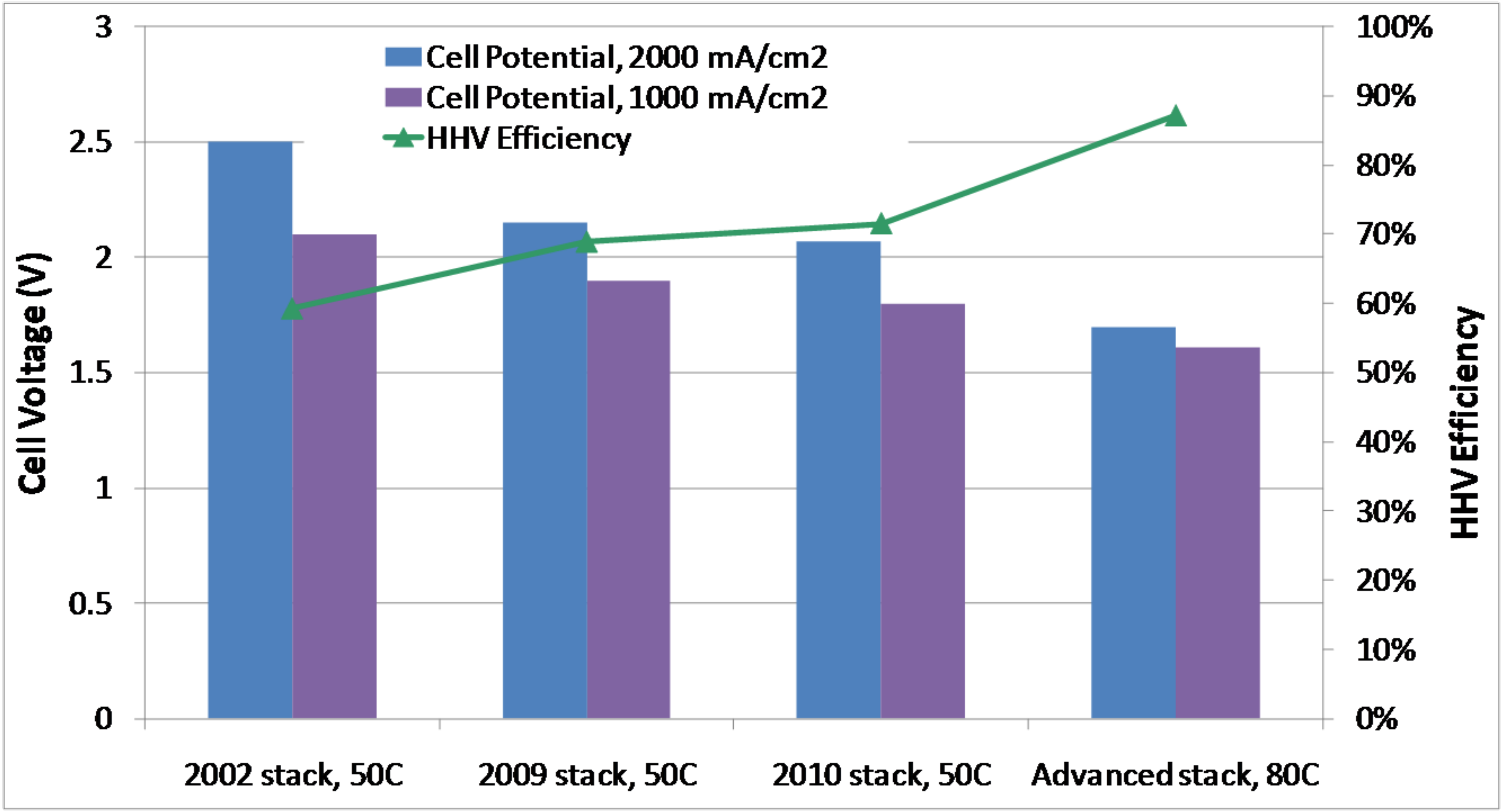
High surface area/utilization, 60 mV demonstrated gain

- Phase 1 SBIR results
- Pursuing funding for continued efficiency gains and catalyst loading reductions

Resulting Efficiency Improvements



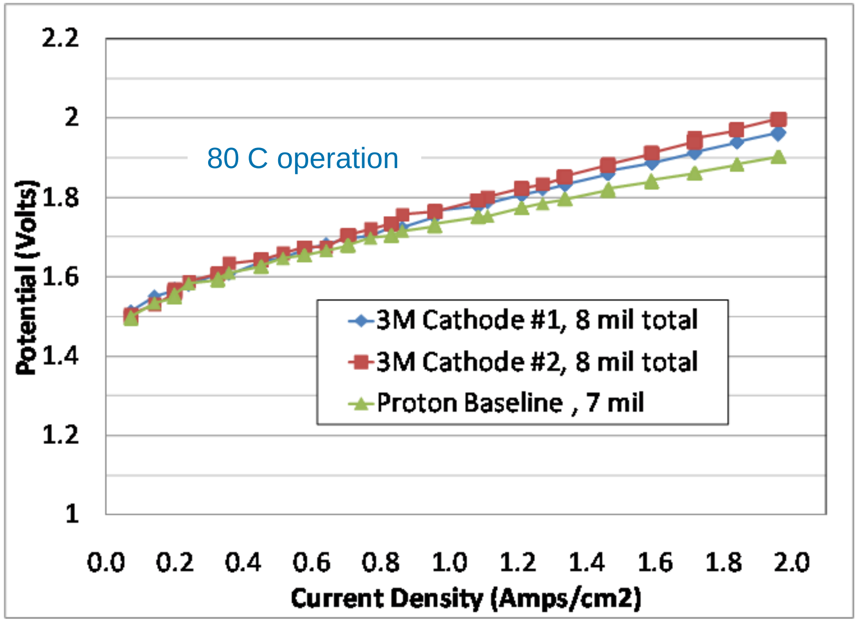
2002-2011 Progress



Improvements have enabled double the current density at the same cell voltage over 3 design generations

Noble metal reduction

- Optimize current production (25% reduction)
  – Internally funded, 25% reduction **implemented 2009**
- Next generation process (50% cumulative reduction)
  – Cathode: internally funded, 66% reduction **fully qualified for production 2009**
  – Anode: DOE funded, 55% loading reduction feasibility **demonstrated 2010**
- Alternate deposition techniques and engineered nanostructures (>90% cumulative reduction)
  – DOE + internal investment, 90% loading reduction **feasibility demonstrated 2010**
  – **Leverages 3M technology**
  – Separate test shows >1500 hours of continuous operation

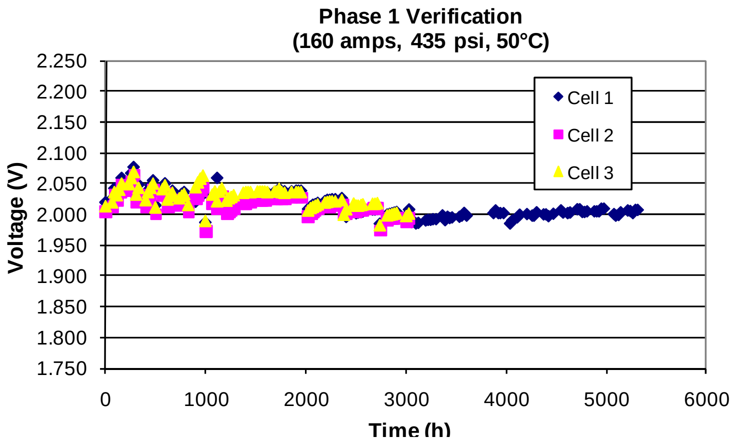


Flow Field Cost Reduction

~$1.5M DOE funding allocated to date

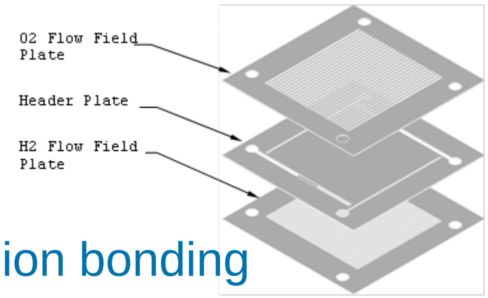
Traditional approaches, 25% savings

Implemented 2010



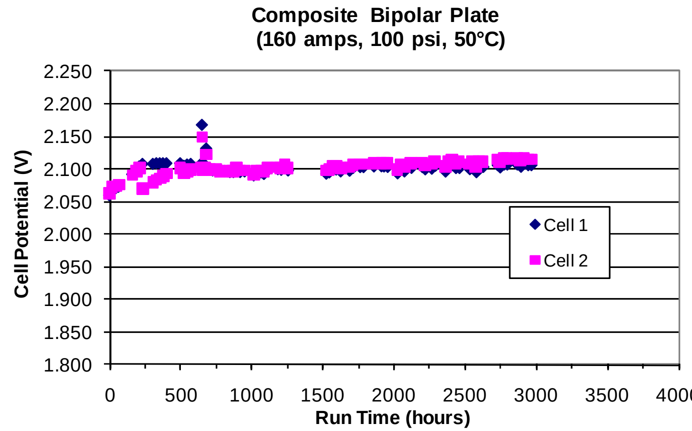
Unitized parts and low cost manufacturing method, 50% cumulative savings

Stamping



Diffusion bonding

Laminate designs, 70% cumulative savings (enabled by coating development)



Alternate coating strategies, 30% cumulative savings

Ti Ti-10Zr Ti-10V-5Zr

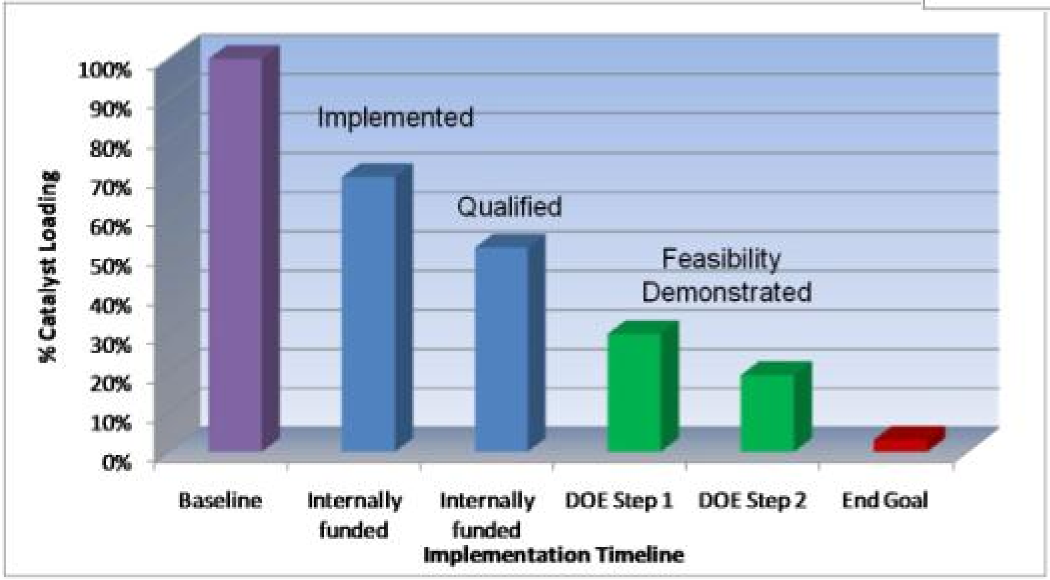
Proton ENERGY SYSTEMS

PROTON ON SITE

Cell Stack Cost Reductions

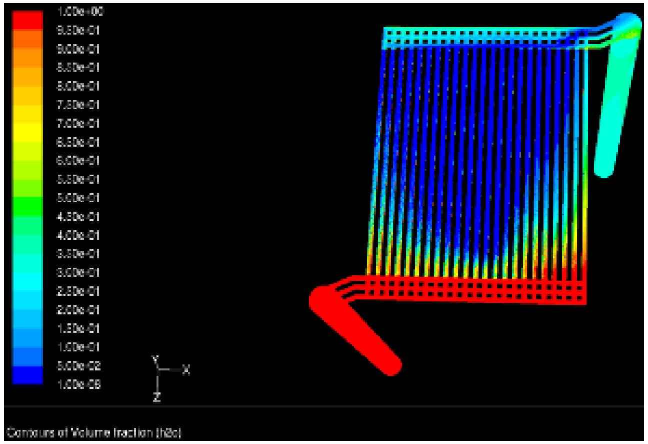
Flow Field Cost

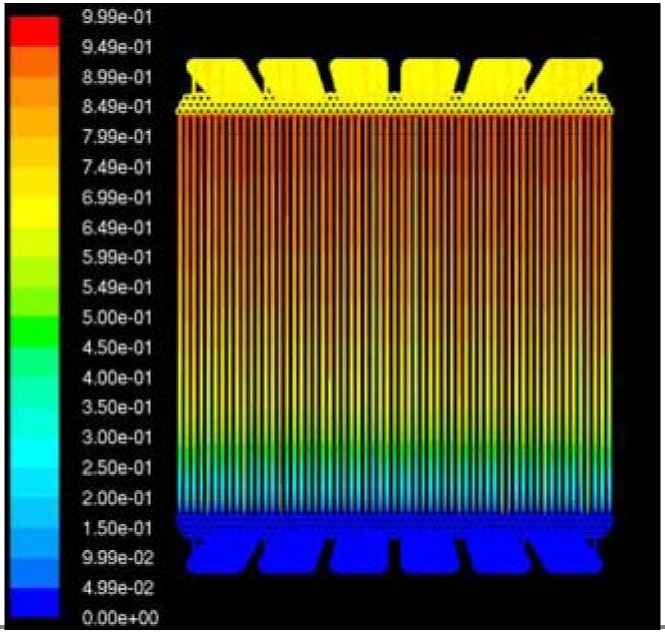
Noble Metal Reduction

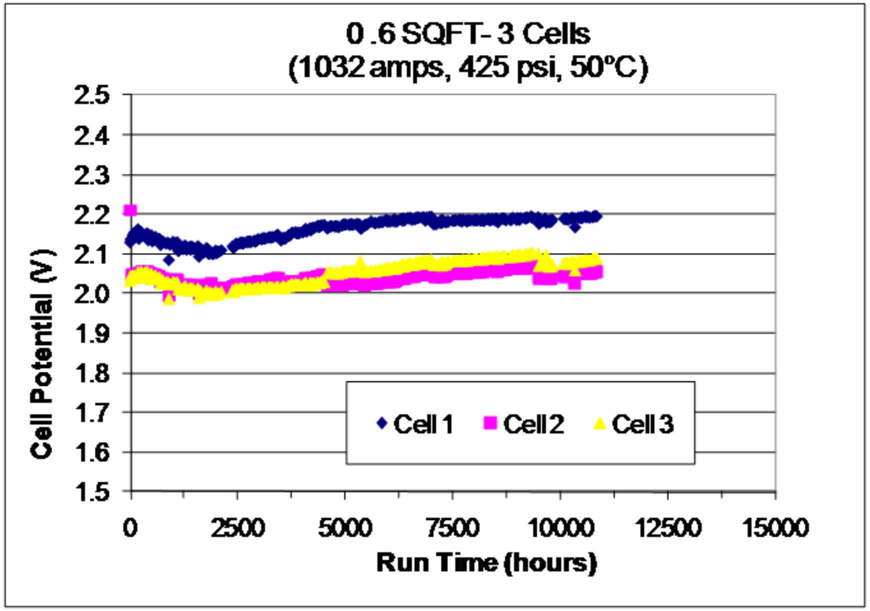


0.6 ft^2 Stack Development

- Improvement in bipolar plate design
  - Current 0.1 ft^2 design tested to over 1 million cell hours
  - CFD modeling shows more uniform flow
- Demonstrated operation up to 425 psi
  - >10,000 hours validated

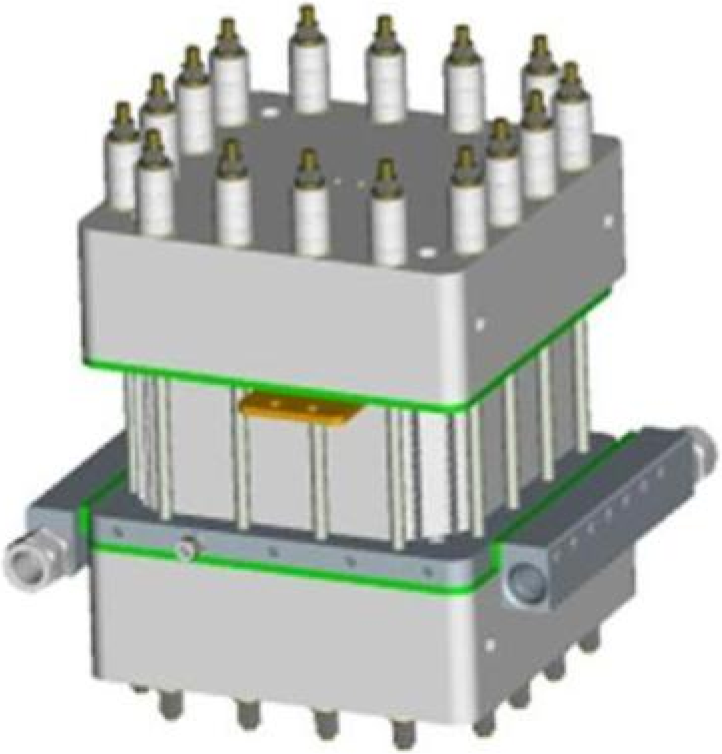




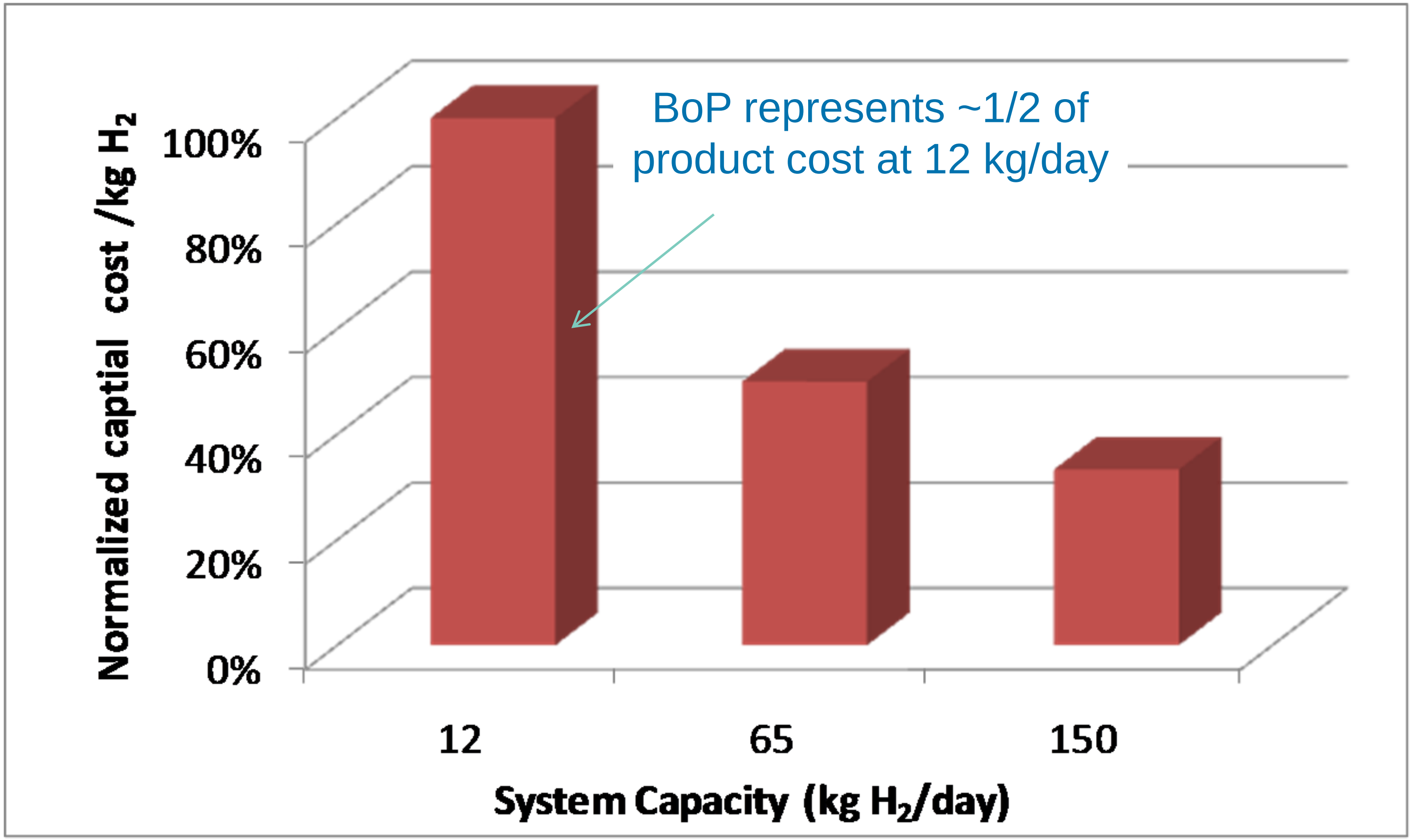


Next Steps: Scale Up

- Fully tested at 1-3 cell level
- TARDEC FY11 program: Scale up to 50 kg/day full size design point



Impact of Scale Up on Balance of Plant Cost



Summary and Future

- Commercial products leveraging PEM electrolysis are growing in capacity and advancing in cost and efficiency
- These products serve existing markets and can directly leverage investments in PEM fuel cell technology
- PEM electrolysis can help to bridge the infrastructure gap and has already been demonstrated at relevant scale
  - Additional advantages in potential for zero carbon footprint

- Cost/efficiency targets can be achieved through leveraging of existing science, without major new invention
- Investment in electrolysis is key to move demonstrated cost and efficiency improvements from the lab to production

Acknowledgments

Cell Stack

- Luke Dalton
- Everett Anderson
- Chris Capuano
- Andy Roemer
- Brett Tannone
- Mike Niedzwiecki
- Judith Manco
- Danna Begnoche

High Pressure System

- Bob Avery
- Steve Tommell

High Capacity System

- Steve Porter
- Ken Dreier
- Larry Moulthrop
- Mike Spaner
- Curt Ebner
- John Griffin
- Chau Chuong

Collaborators

- W.L. Gore
- 3M
- Penn State University
- Oak Ridge National Lab
- National Renewable Energy Lab

Funding

- Department of Energy EERE
- Army TARDEC
- Office of Naval Research
- National Science Foundation