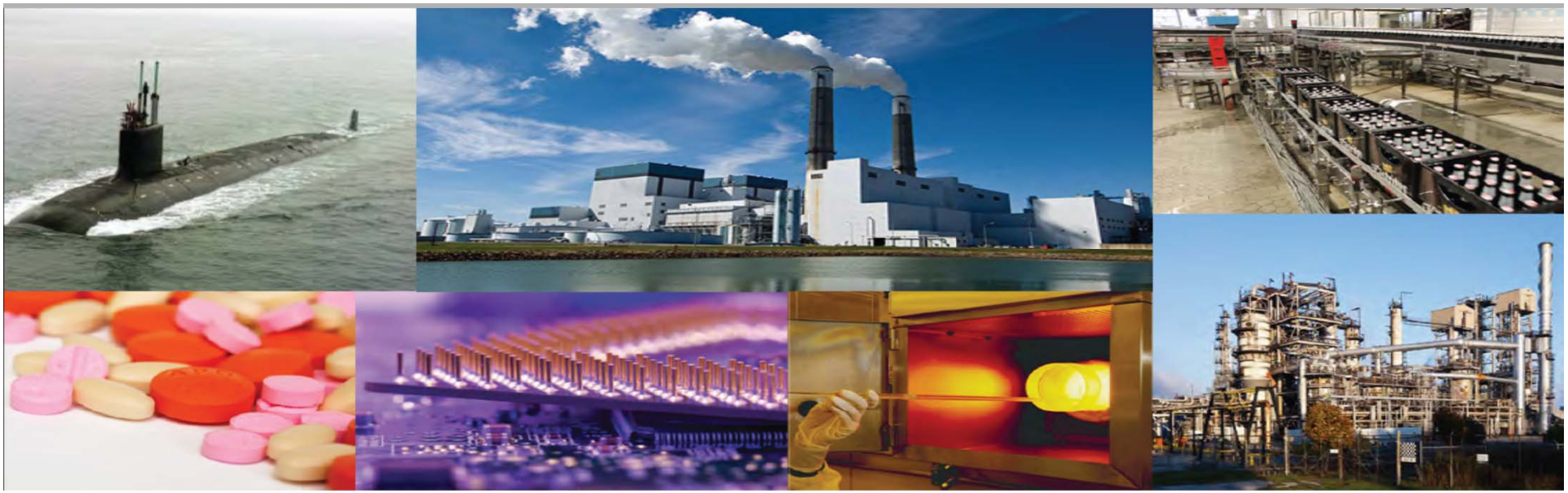
PROTON
THE LEADER IN ON SITE GAS GENERATION.



PEM Electrolyzer Reliability Based on 20 years of Product Experience in Commercial Markets

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

Everett Anderson
18 February 2016

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 2200 systems in more than 75 countries

Proton's World Headquarters in Wallingford, CT

Company Founding Premise - 1996

- Build a commercial business on existing industrial hydrogen markets.
  - Establish real commercial manufacturing
  - Hedge on timing of future energy markets
- Advance technology towards the “hydrogen economy” (which was only 5 years away).
- Capitalize on huge markets in transportation, energy storage and others to propel growth.

What Did We Learn

- The road to profitable, reliable products takes longer then you think.
- Having a quality system and a strong service organization are keys to success.
- Displacing existing technology is difficult.
  - Existing technologies do not stand still.
- It is too easy to learn to get comfortable losing money.
- You need to say NO to some opportunities.
- Defining your customer value proposition is essential.

Today…

- Focus is on commercial markets and profitability while still engaging in energy markets
  - Delicate balance
  - New energy applications present capital as well as operating cost challenges
- Demonstrated reliability of Proton's PEM-based hydrogen generators in industrial applications
  - Cell stack technology is the most reliable component in the system
- Necessary technology advances are the biggest risk to established durability and reliability
- Search for meaningful accelerated stress tests remains elusive
  - Still see potential value of AST's in reducing development risk

Proton Capabilities

PEM Cell Stacks

Complete Systems

Storage Solutions

- Complete product manufacturing & testing
- Containerization and hydrogen storage solutions
- Turnkey product installation
- World-wide sales and service

Power Plants

Heat Treating

Semiconductors

Laboratories

Government

Hydrogen Energy

- Emerging Markets
  - Gov't supported
  - Business cases still developing

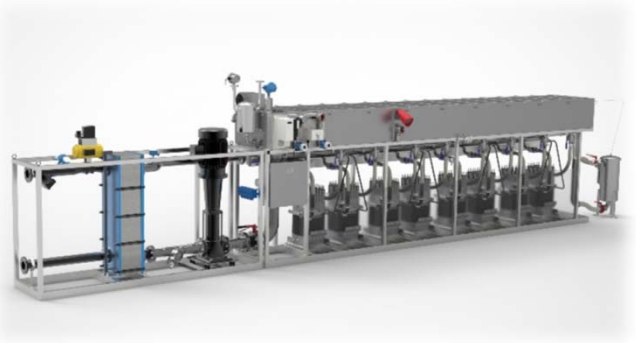
Hydrogen Fueling

Wind

Biogas Methanization

Solar

Wide Product Range to Meet Diverse Needs



G Series

200 - 600 cc/min

H Series

282 - 1'050L/h

2 - 6 Nm^3/h

M Series

10 - 30 Nm^3/h

50 to 400 Nm^3/h

S Series

C Series

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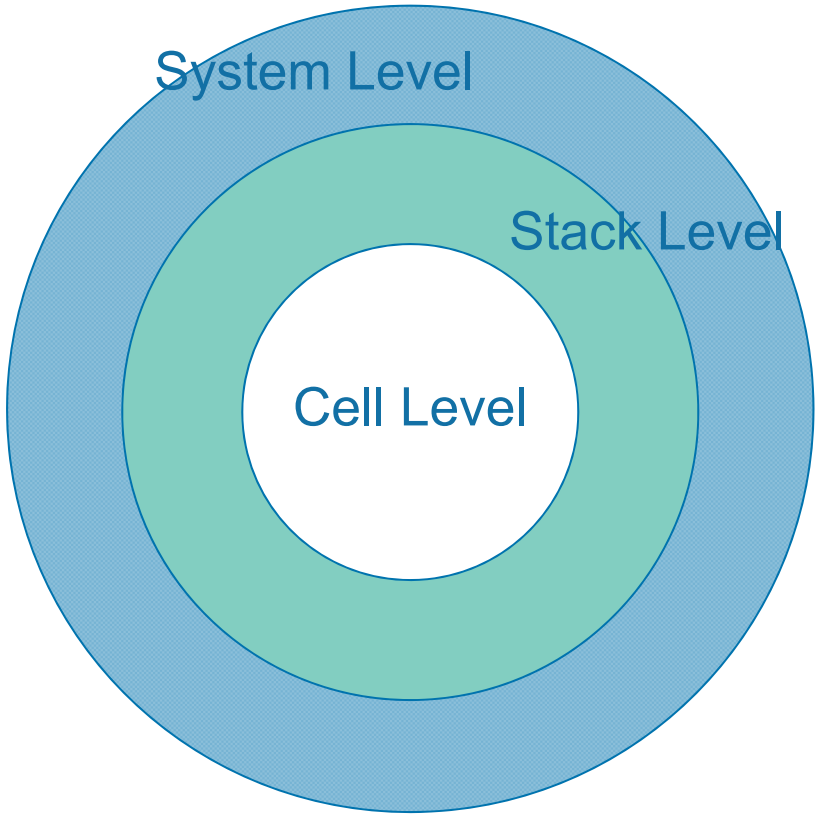
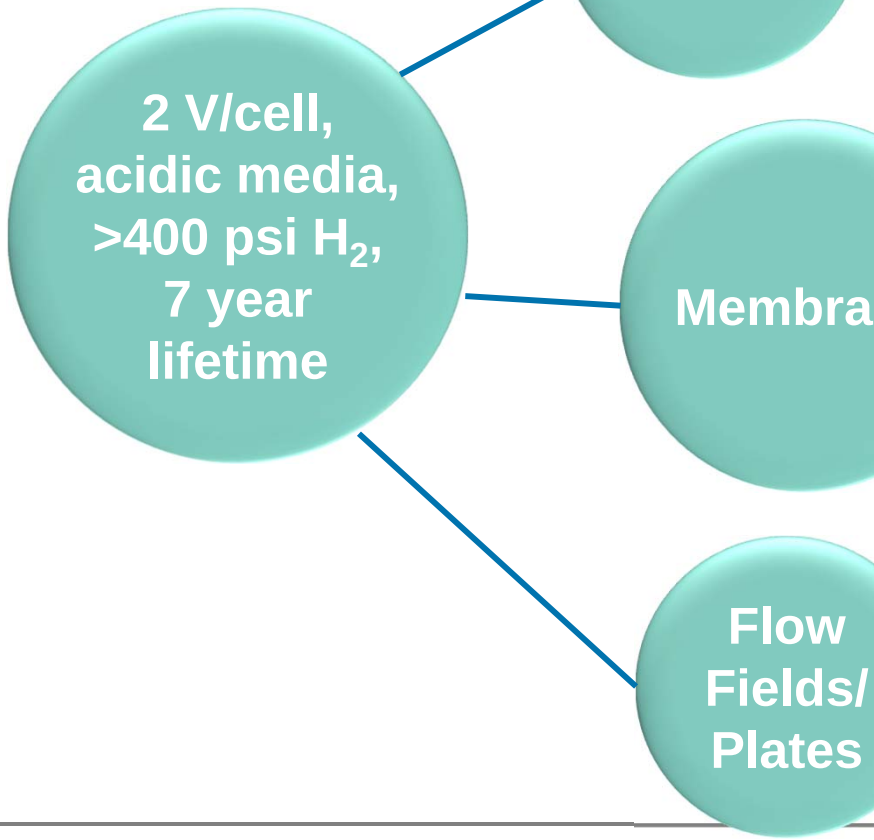
PEM Electrolysis Reliability



- 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,…)

Technology Challenges and Approaches



Likely limited to noble metals with PEM
- Improve manufacturing
- Improve OER activity
- Stable anode supports
- Nanoengineered structures

Creep-rupture and crossover
- Reinforced materials
- High T_g and alternate PFSAs
- Hydrocarbon membranes

H_2 embrittlement and O_2 oxidation
- Alternate coatings
- High yield manufacturing
- Part consolidation

Cell Stack / System Reliability Testing

- Reliability tracking through combination of in-house testing and field fleet information
- Expansive fleet of cell stack and system test beds
- Extensive in-house testing of design changes ahead of field introduction
- Hundreds of thousands of system/cell stack testing hours completed
- Tens of millions of cell-hours of data collected
- Multiple stacks with >60,000 hr. of demonstrated continuous operation

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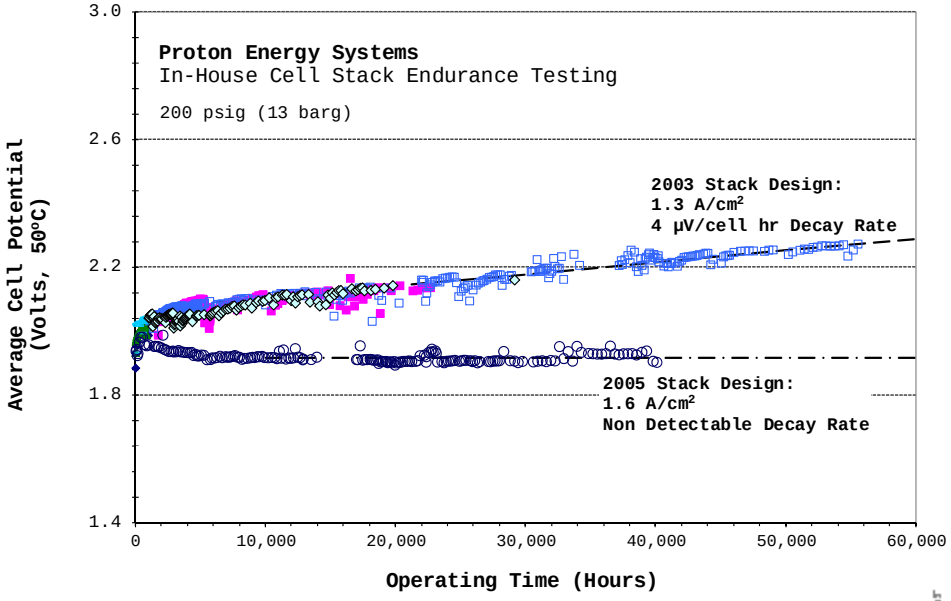
Established PEM Stack Durability

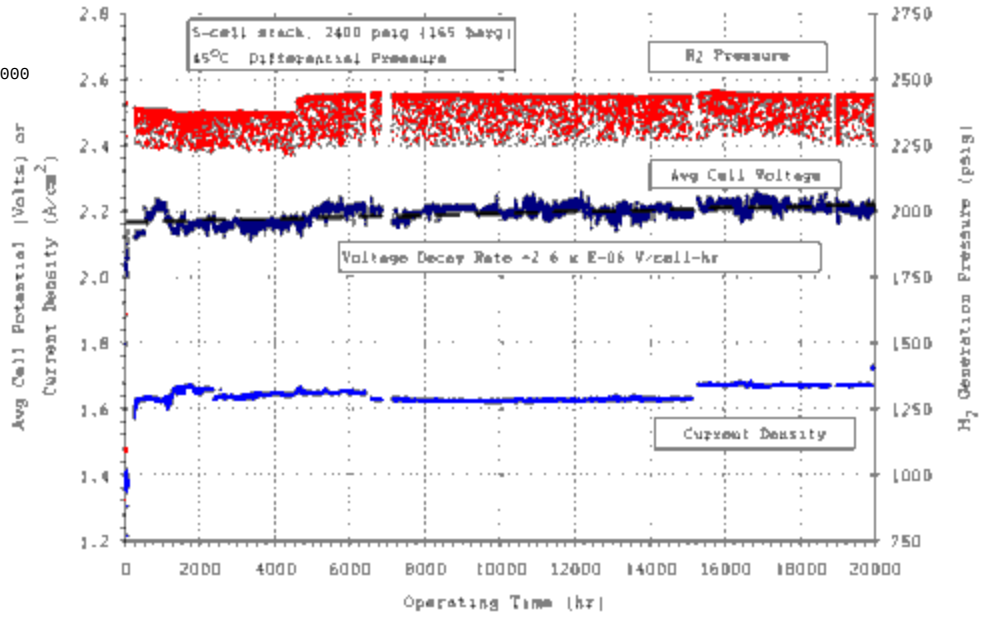


~60,000 hour life demonstrated in commercial stack designs

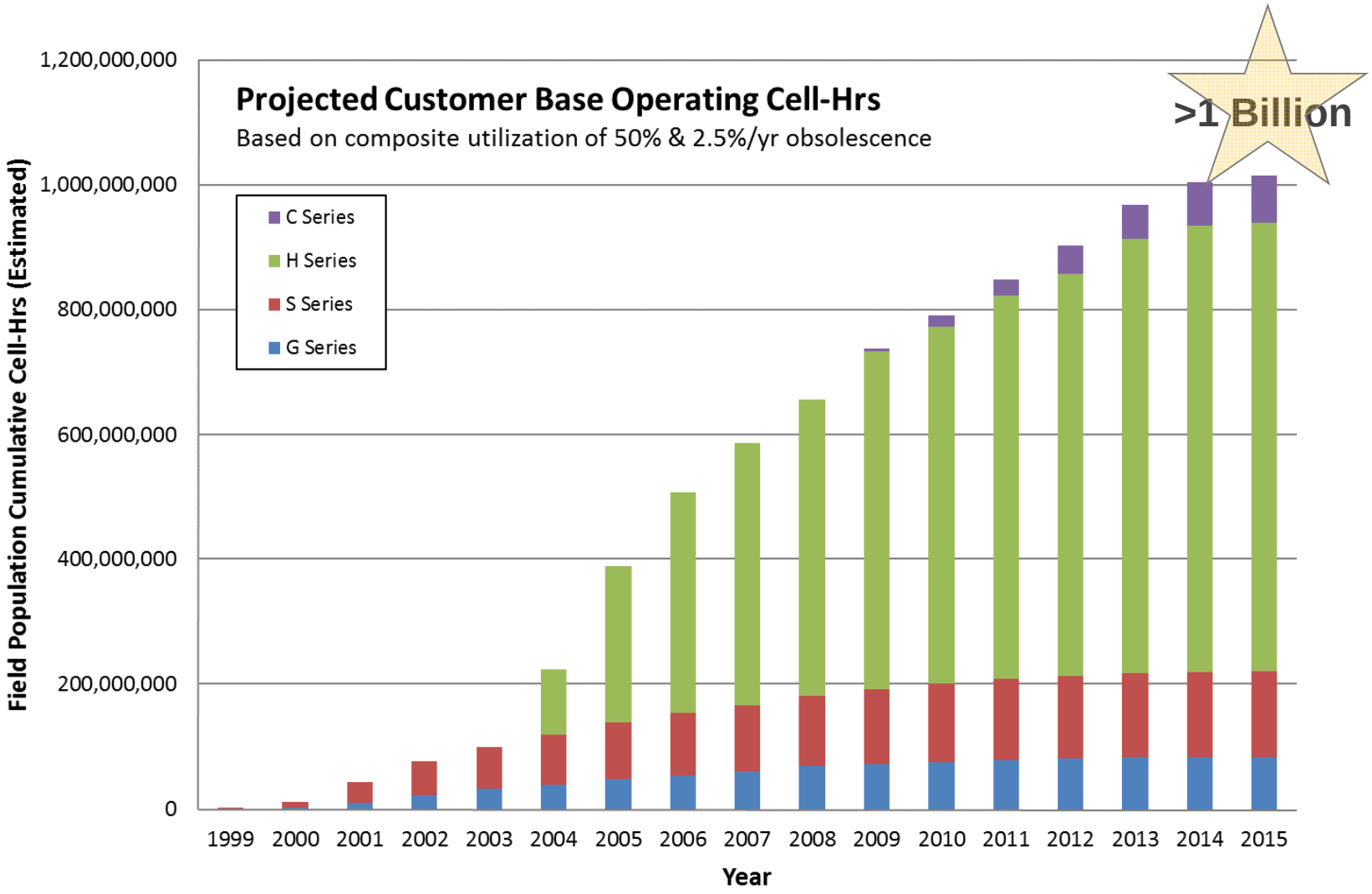
New designs have **no** detectable voltage decay

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

Strong lineage to low pressure design



Field Population Operating Cell-Hrs



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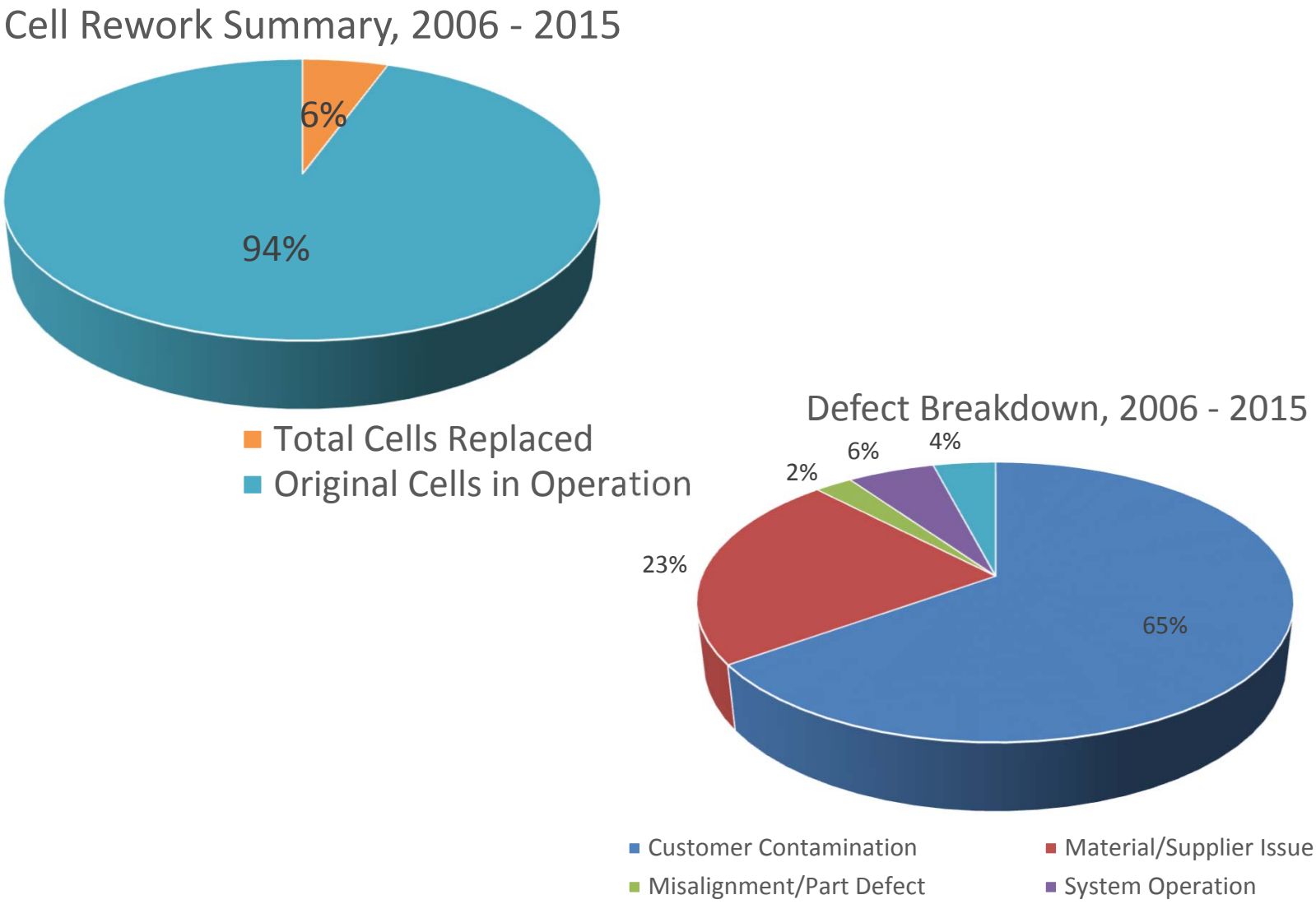
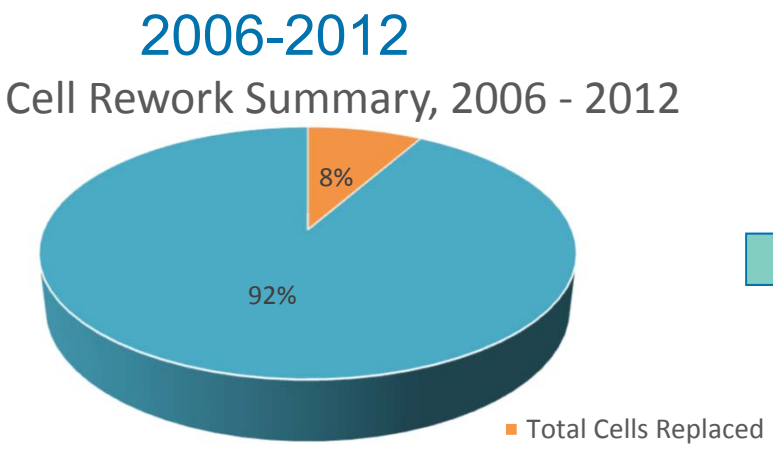
Cell Stack Reliability: 9 Years of Performance

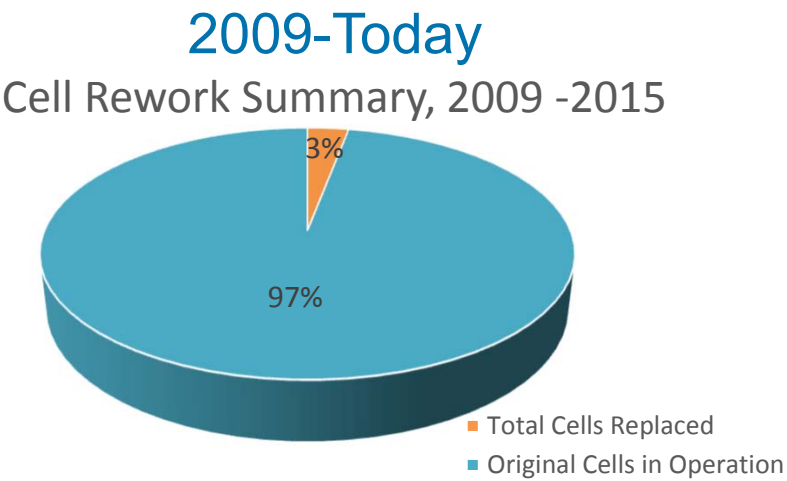


Cell Stack Reliability: Continuous Improvement

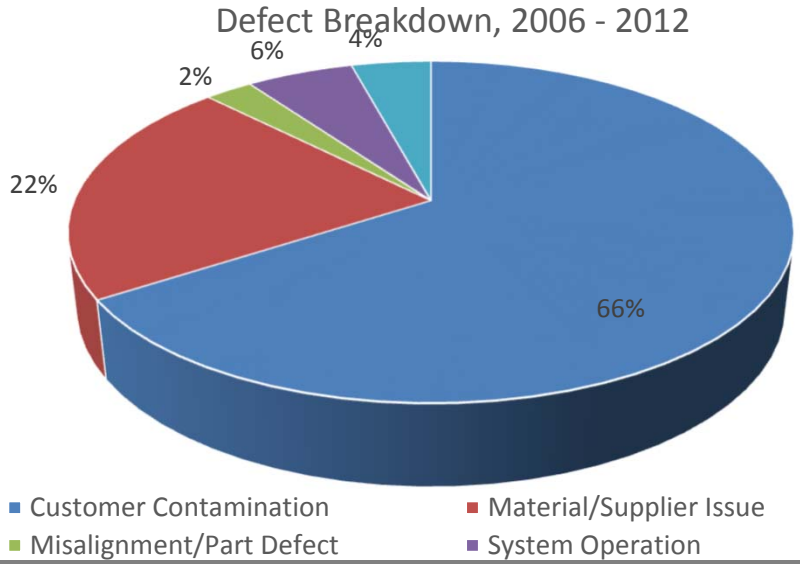
2006-2012



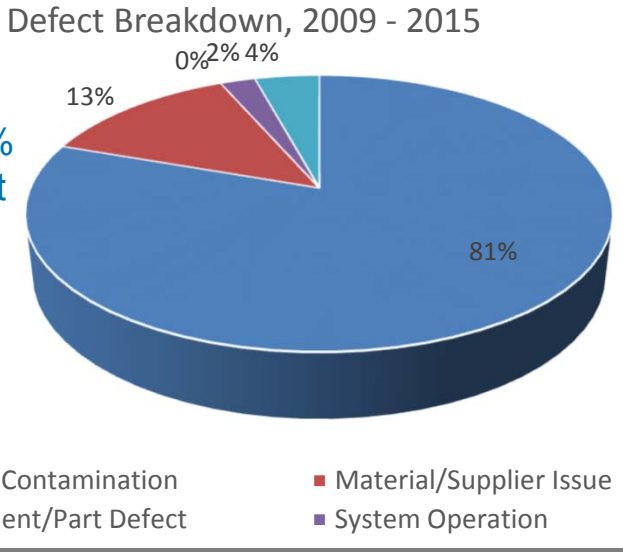
2009-Today



Rolling 6 year average shows high reliability continues to increase

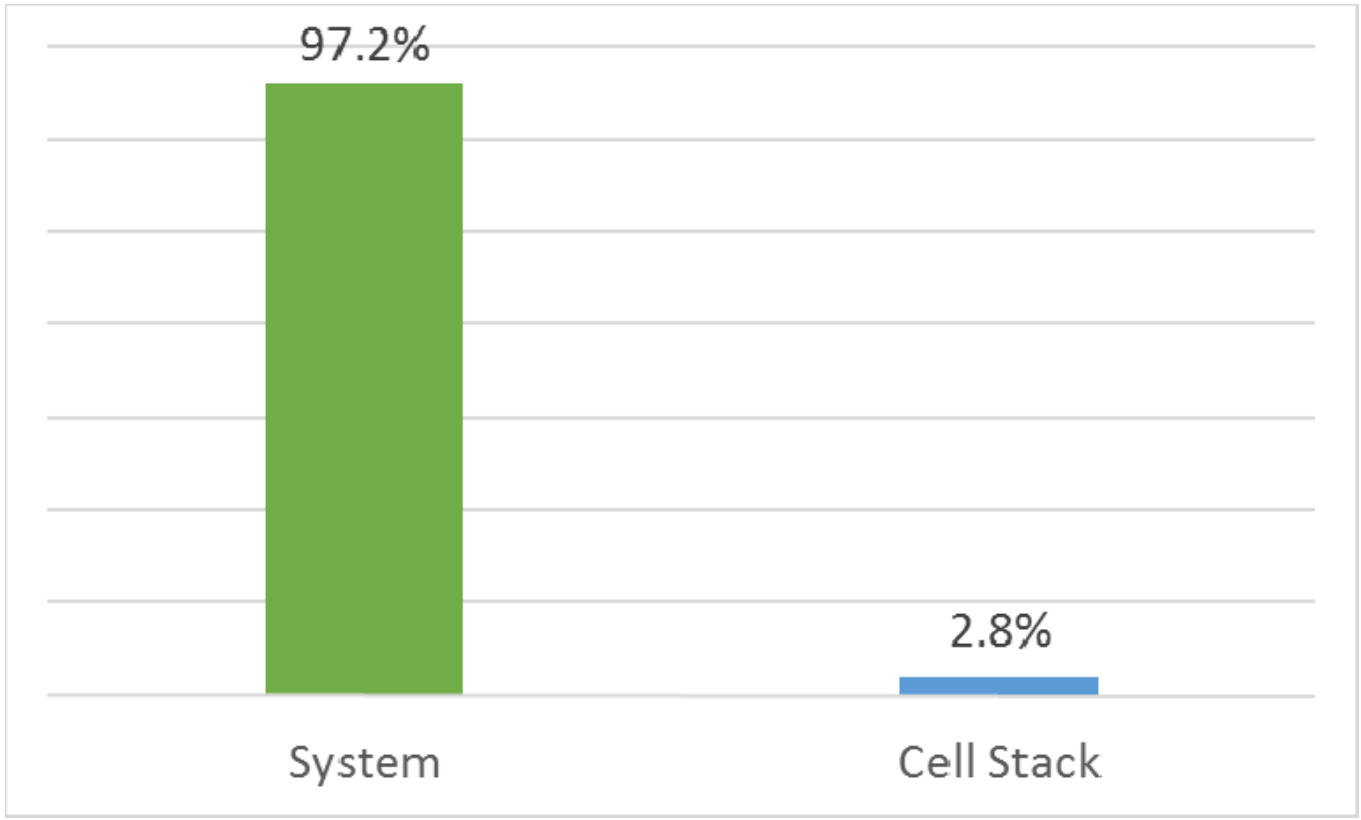


2nd pie chart represents <50% cell count vs. 1st

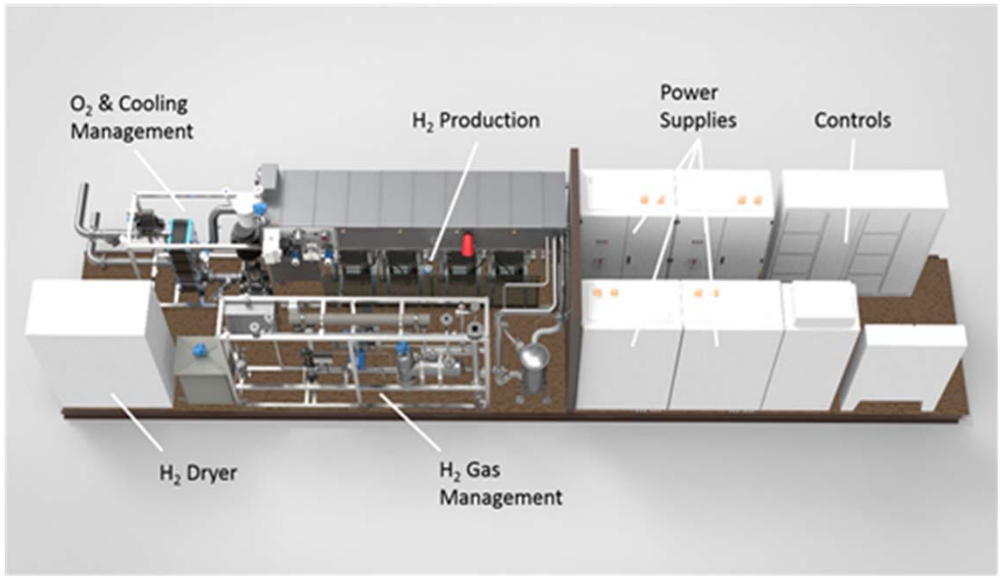


Cell Stack vs. System: 2009 to 2016

- Cumulative Customer Shipments - Warranty



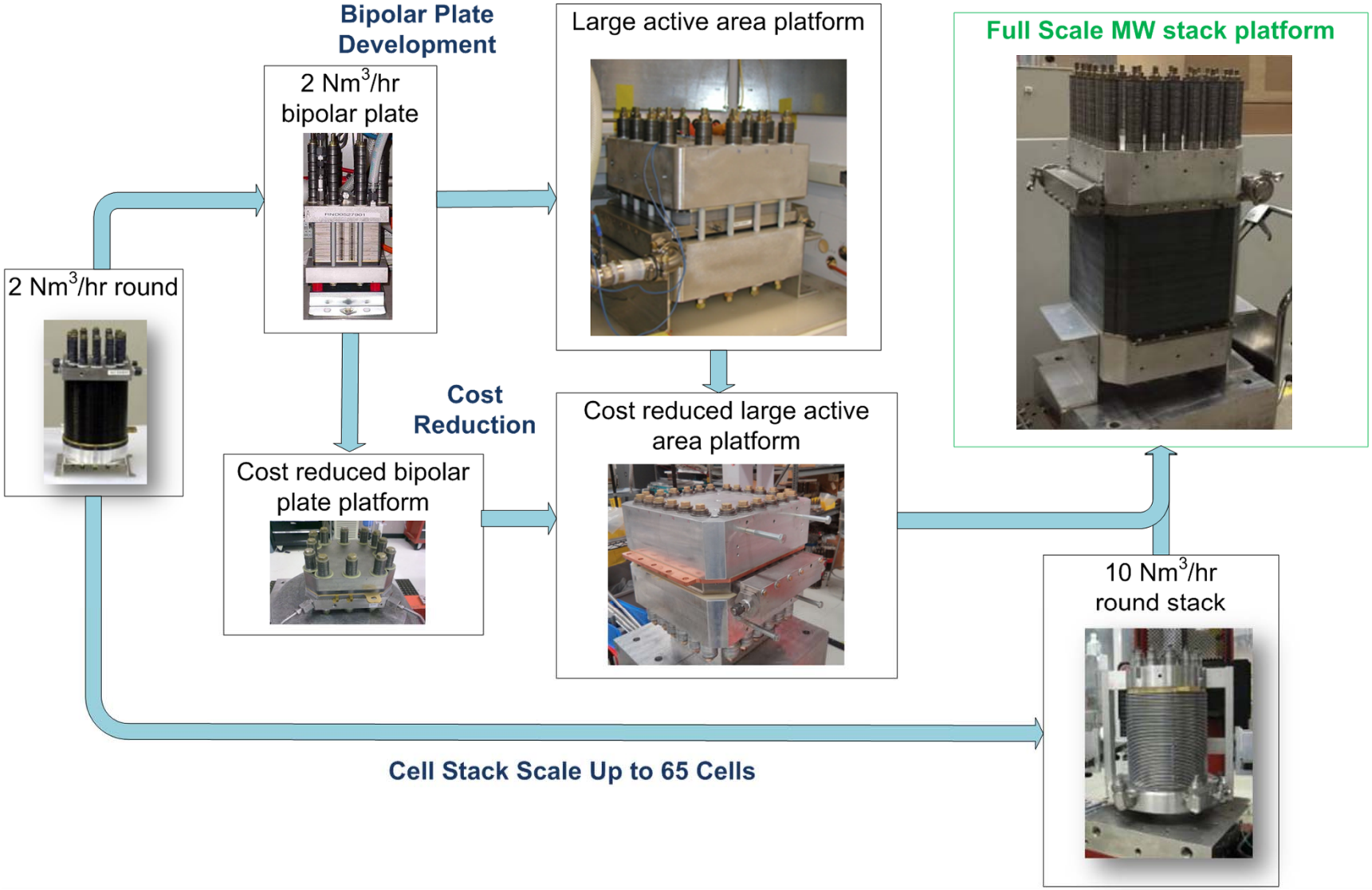
Proton OnSite M Series



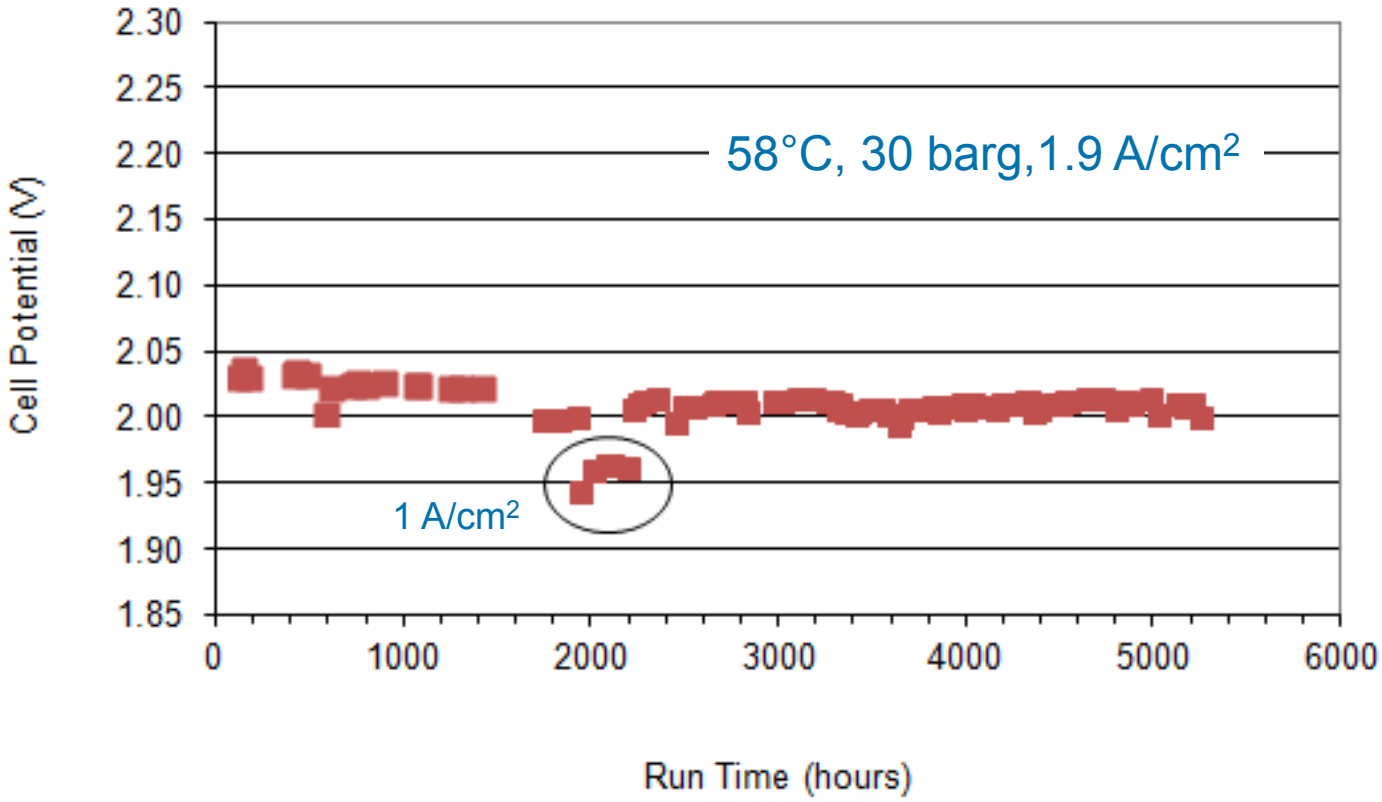
Standard Features

- Scalable – 1MW and 2MW building blocks
- Turn-key – all subsystems can be included
- Flexible – Containerized or custom structures
- Reliable –Proton's demonstrated PEM track record
- Safe – Proton PEM system architecture

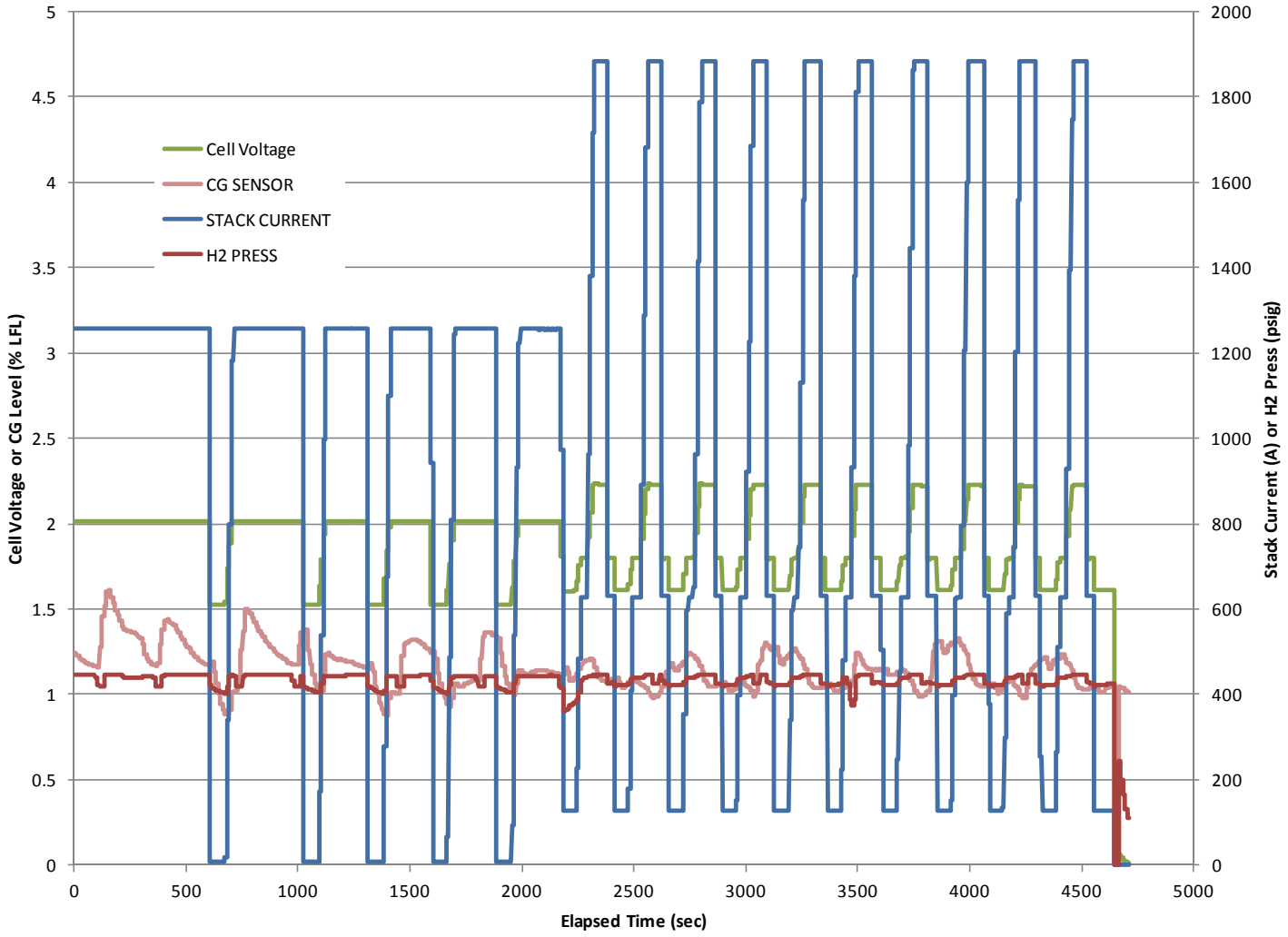
Stack Roadmap to MW Scale



Durability Testing – 3-Cell Verification



Electrolysis Stack Load Cycle Testing



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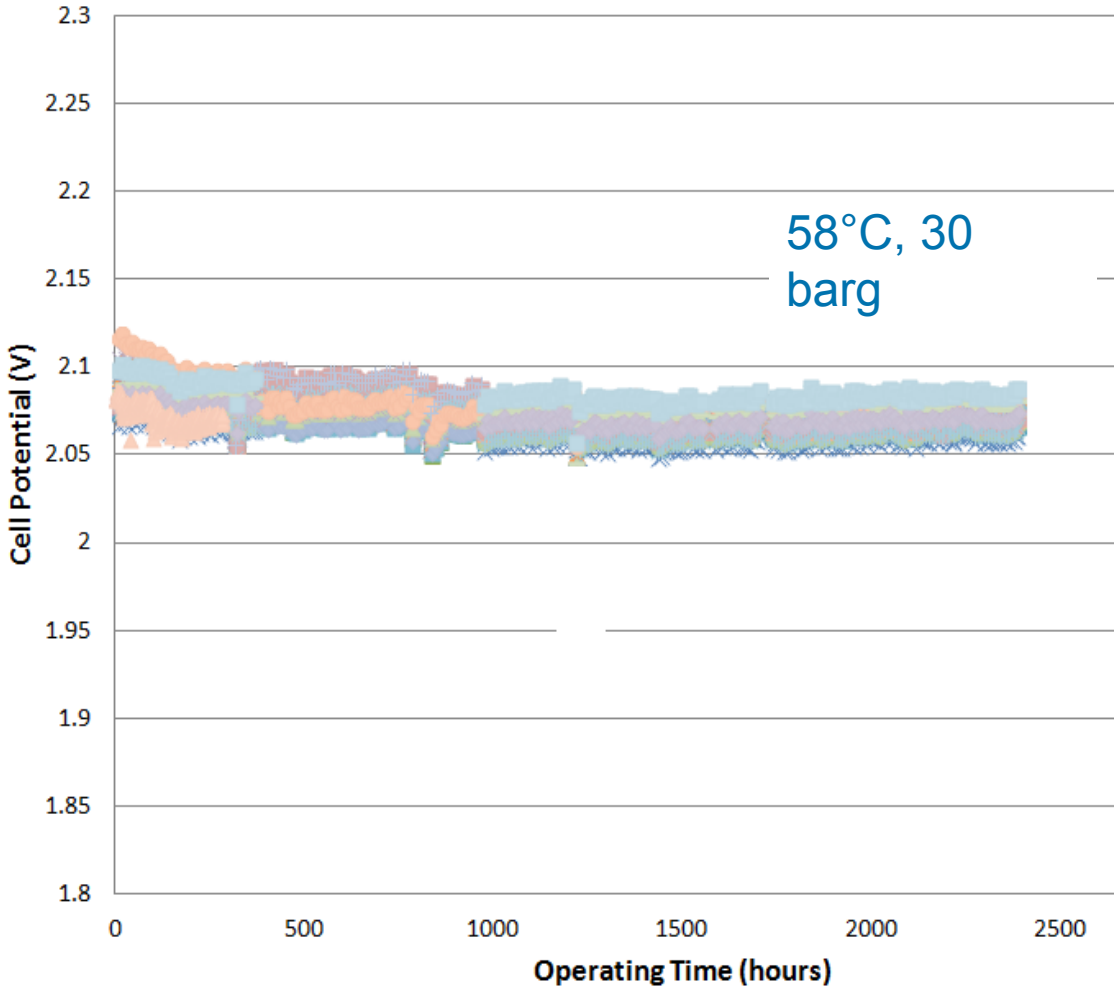
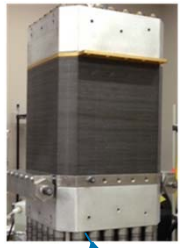
Durability Testing – 165 kW (65 cells)



M Series Platform Features

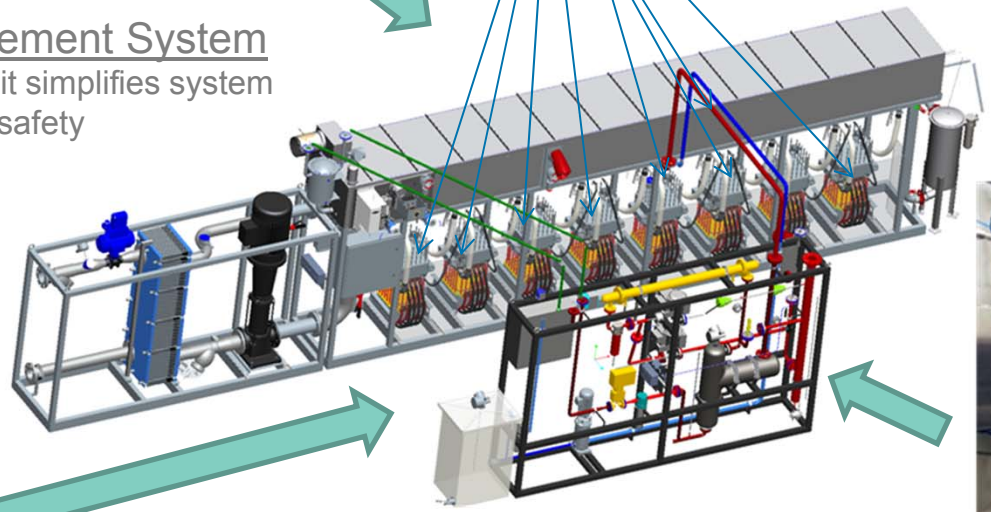


250 KW PEM Cell-Stack

- Redundant cell-stack modules with full differential pressure (30 bar) capability allows for ambient pressure O_2 architecture and provides “assured availability” of H_2 in event of a stack failure

Water Oxygen Management System

- Ambient pressure O_2 circuit simplifies system design (cost) & enhances safety



Skid Based Design

- Offers flexibility for process plant layout and / or containerized options

Hydrogen Gas Management System

- Simple design is scale-up of heritage system architecture

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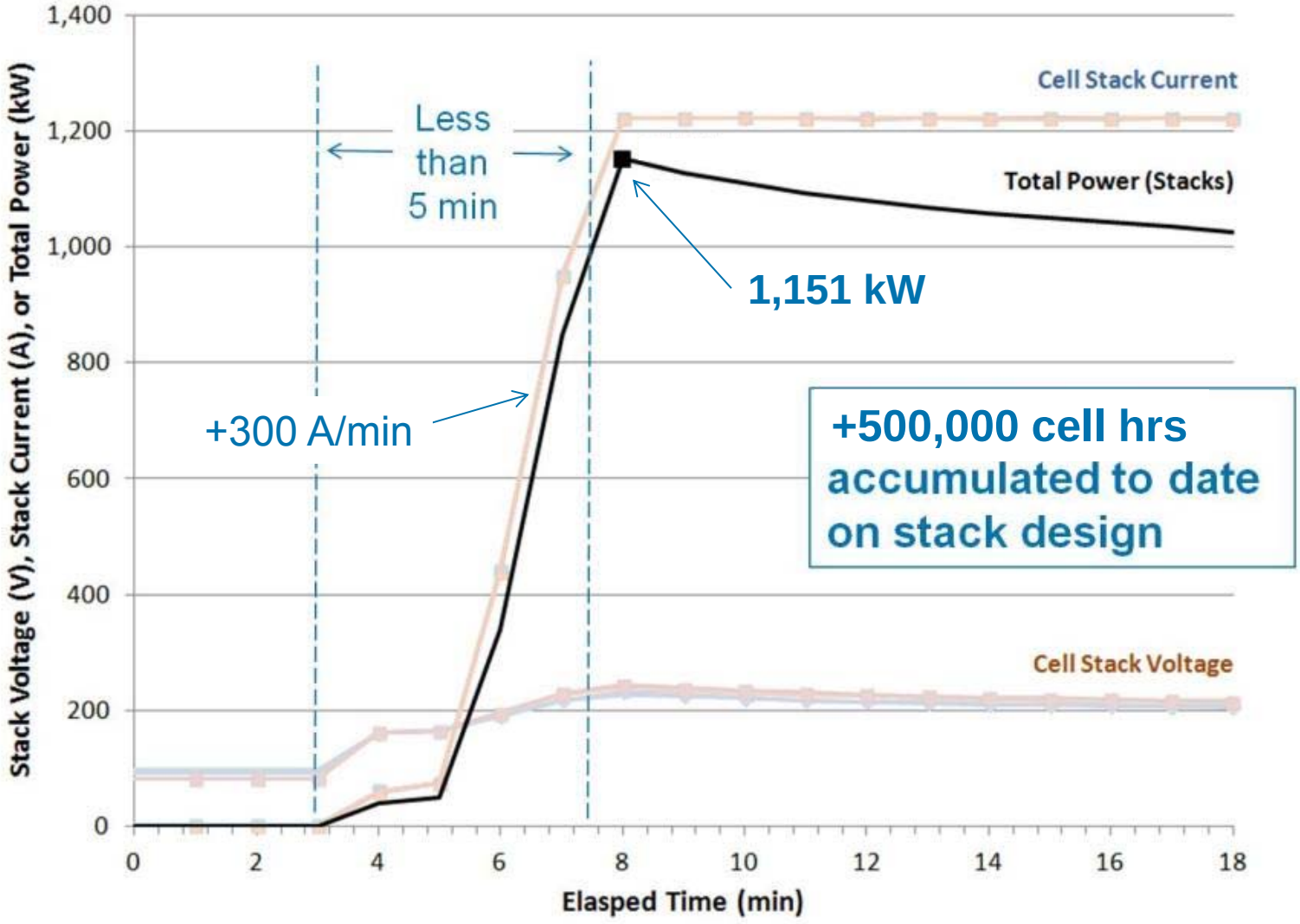
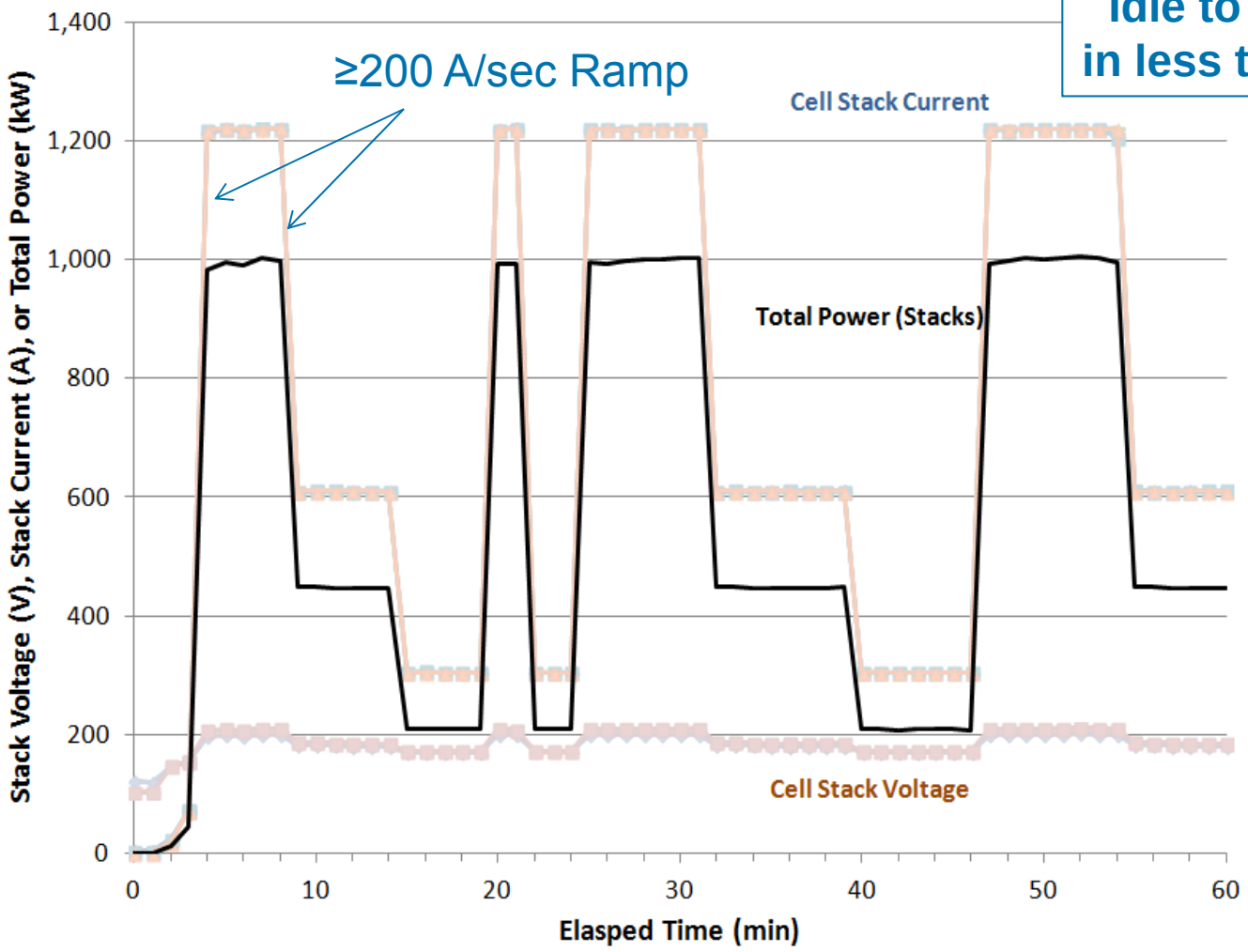
MW PEM Demonstrated

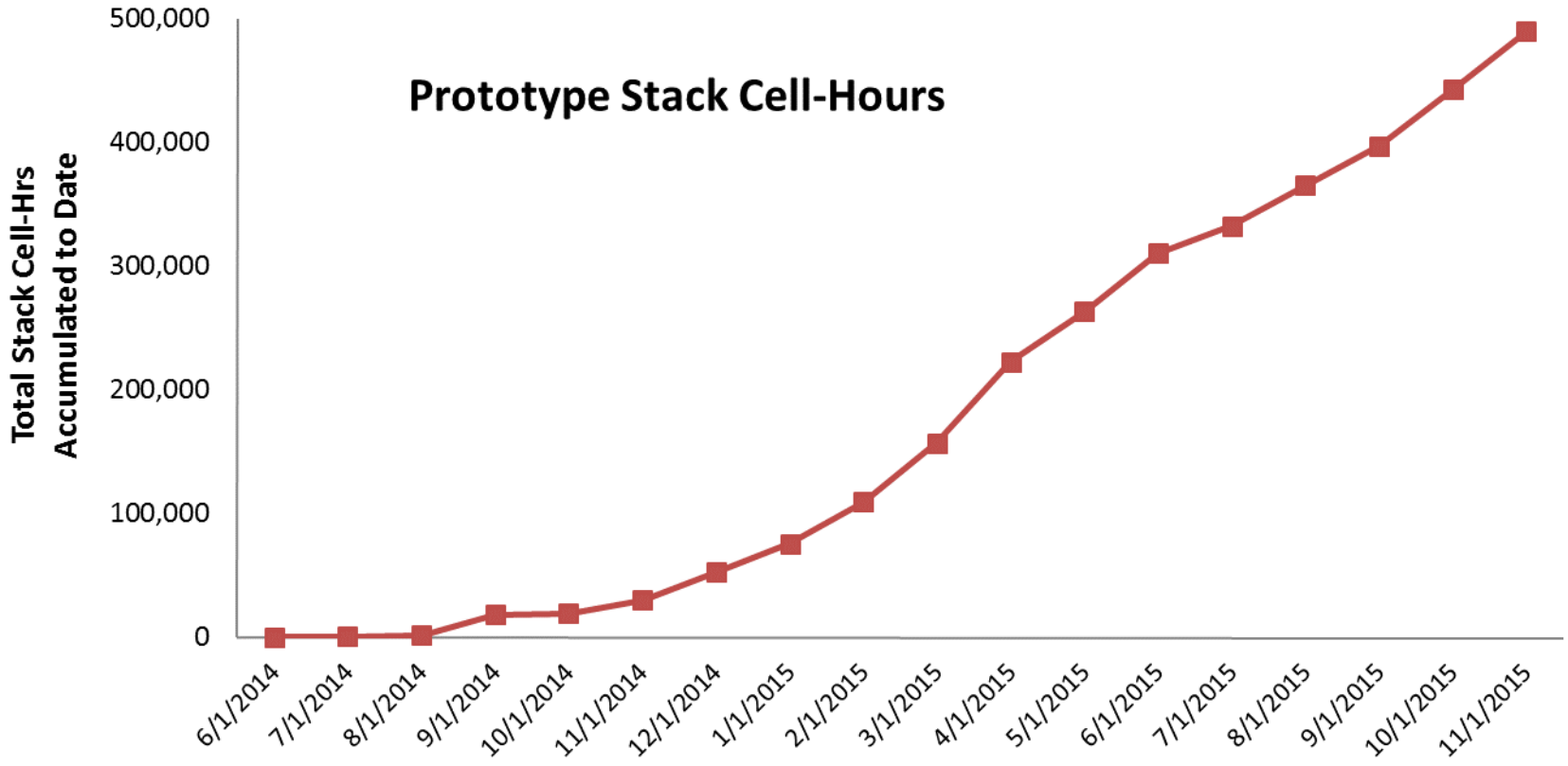


MW PEM Demonstrated

Idle to Full Load in less than 10 sec



MW Cell Stack Validation

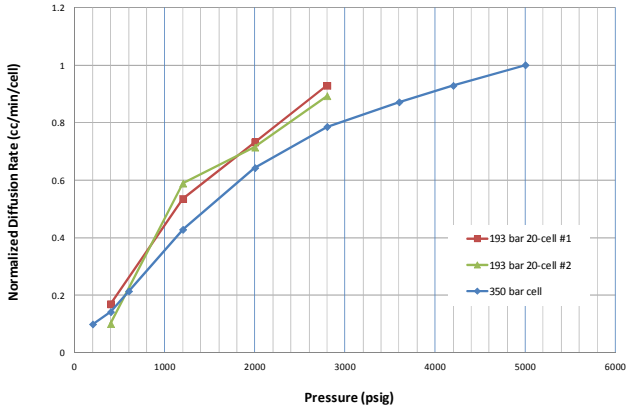


Cumulative cell-hours >500,000 to date (no failures)

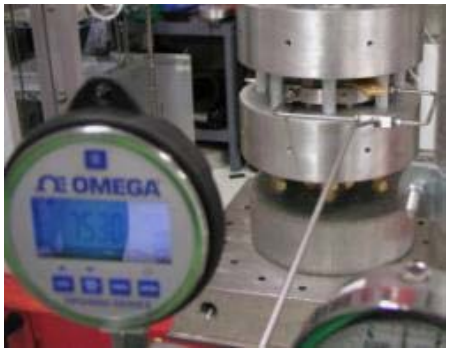
5,000 psig Stack Platform

- Developed and demonstrated through DOE support

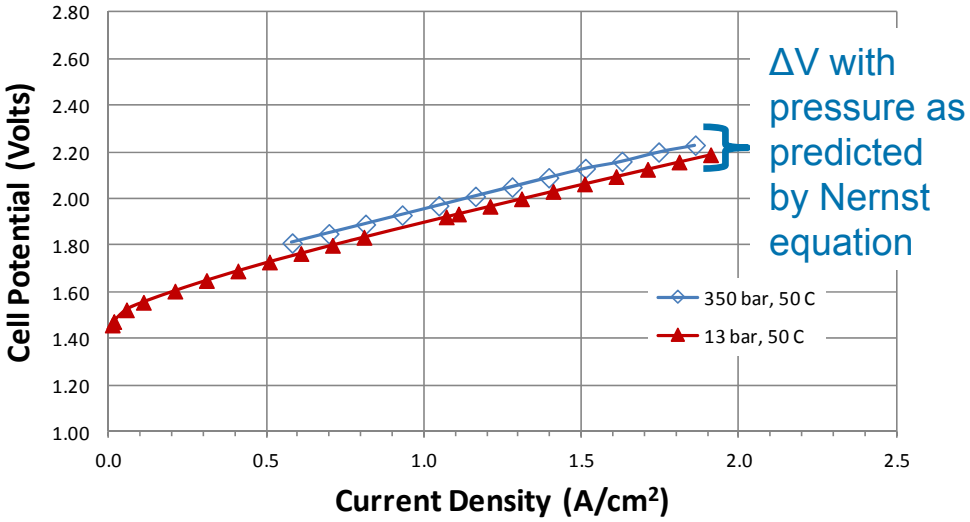
Cross-cell permeation measurements



Proof pressure testing >7,500 psig



Full system operation at 5,000 psig H_2



Summary

- PEM electrolysis is a mature technology serving many industrial applications
- 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
- Need understanding of likely failure mechanisms and corresponding AST's to shorten development time while reducing risk