Large Scale FuelGen® Hydrogen Fueling Systems for Material Handling and Other Applications

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Presentation Outline

- Introduction
- Infrastructure Challenges
- Larger Scale PEM Electrolysis
- Product Development
- Future Work

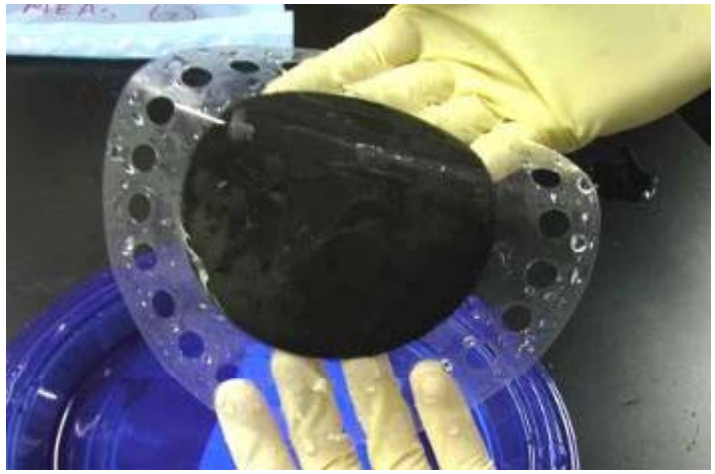
Proton Energy Systems

- World leader in PEM electrolysis
- Founded in 1996
- Located in Wallingford, Connecticut
- ISO 9001:2008 registered
- Over 1,200 systems operating in 56 different countries
- Current Employees - 75

Proton Capabilities

- Electrolysis System & Cell Stack Development
- Product Manufacturing & Testing
- World-Wide Sales & Service
- Integration of Electrolyzers into RFC systems

Proton Exchange Membrane (PEM) Core Technology



ISO 9001

Registered Facility

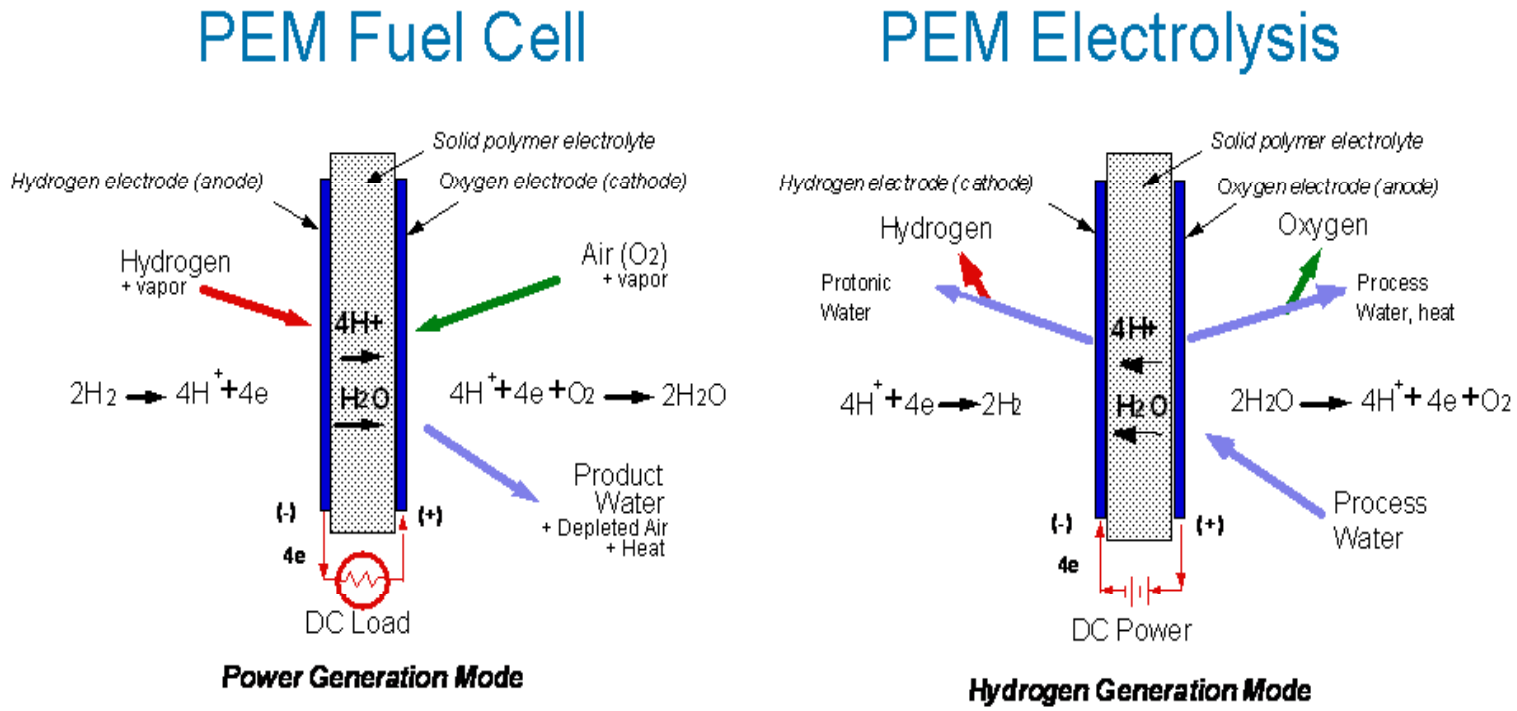
TUV Rheinland of North America, Inc.

CELL STACK MANUFACTURING

SYSTEMS MANUFACTURING

CELL STACK R&D

PEM Electrolysis



- Liquid water in contact with membrane
- Still have to consider 2-phase flow optimization in flow fields
- High (~2V) potential material compatibility
- High pressure differential (200 to >2400 psi) and high sealing loads
- Longer lifetime expectations (≥ 50,000 hours)

Hydrogen Products

Commercial Products

HOGEN™ Hydrogen Generators

GC

S-Series

H-Series

Hydrogen Control Systems

StableFlow™

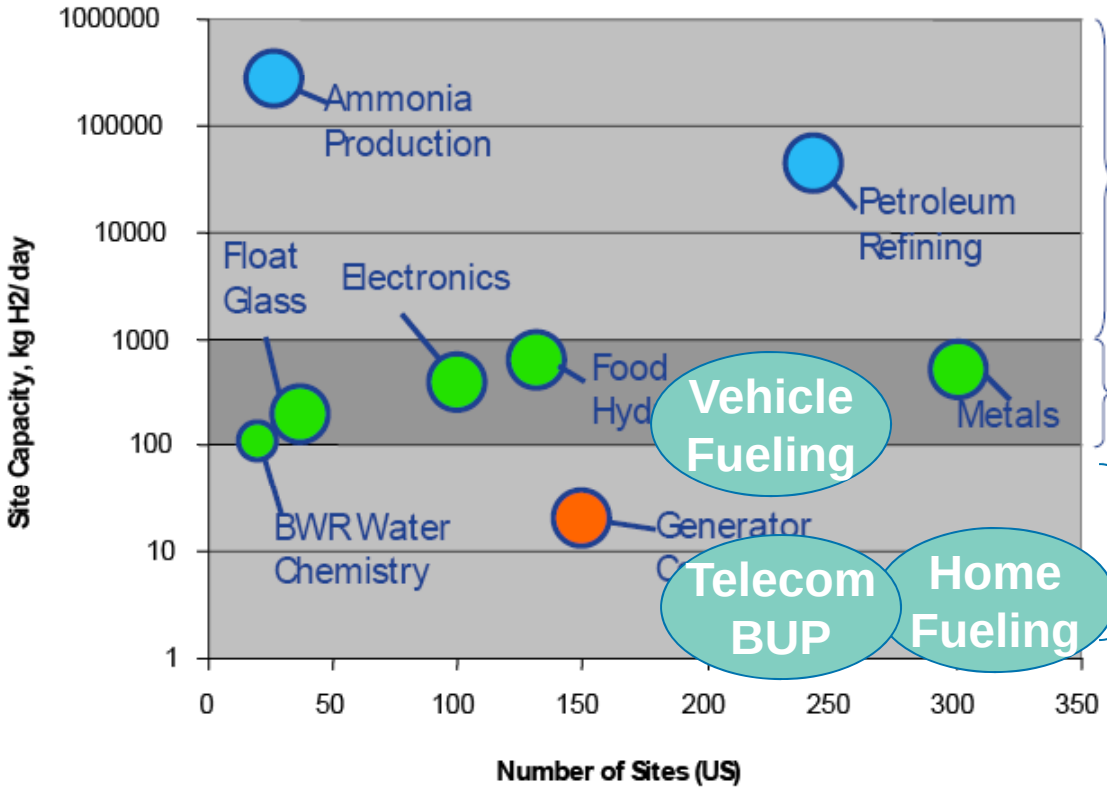
Future Products

Fueling

Backup Power

Renewable Energy Storage

Today's Hydrogen Economy



Large scale operations: 90% of consumption

Mid-scale Industrial

Proton Current/Near Term Markets

Source: GE, 2008

Proton ENERGY SYSTEMS

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

Fueling Markets

- Vehicle Fleets
- Buses

Traditional

- Materials Handling
- Military / Aerospace
- Bikes/Motorbikes
- Marine

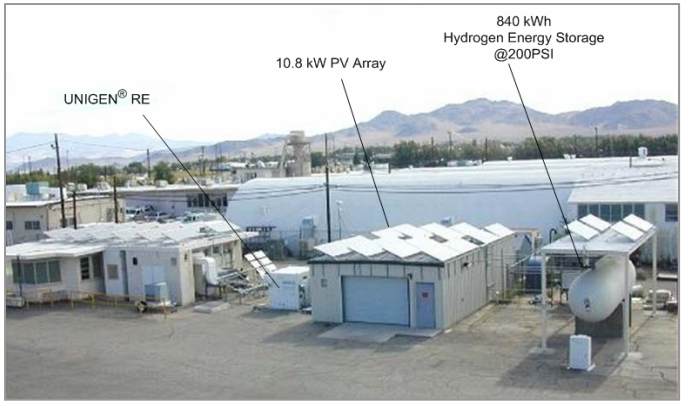
Alternative

Proton's Fueling Experience

Installations Completed

Installations Planned

Renewables to Hydrogen



Proton's Fueling Developments

- Near term 13 kg/day demonstrations
- *Traditional fueling station concept based on larger hydrogen production*
- Home fueling concept based on lower hydrogen production at higher pressure
- Renewable-based options for both
- Focus areas:
  - *Larger generation output*
  - Higher pressure capability (small-scale)

FuelGen®

HOGEN® HP

Product Development Phases

- Phase 1 - Trade Study and Conceptual Design
  - Optimize System Architecture For Cost
- Phase 2 - Prototype Subsystem Development
  - Cell Stack And Power Supply Development
- Phase 3 - Pre-Production Design / Verification

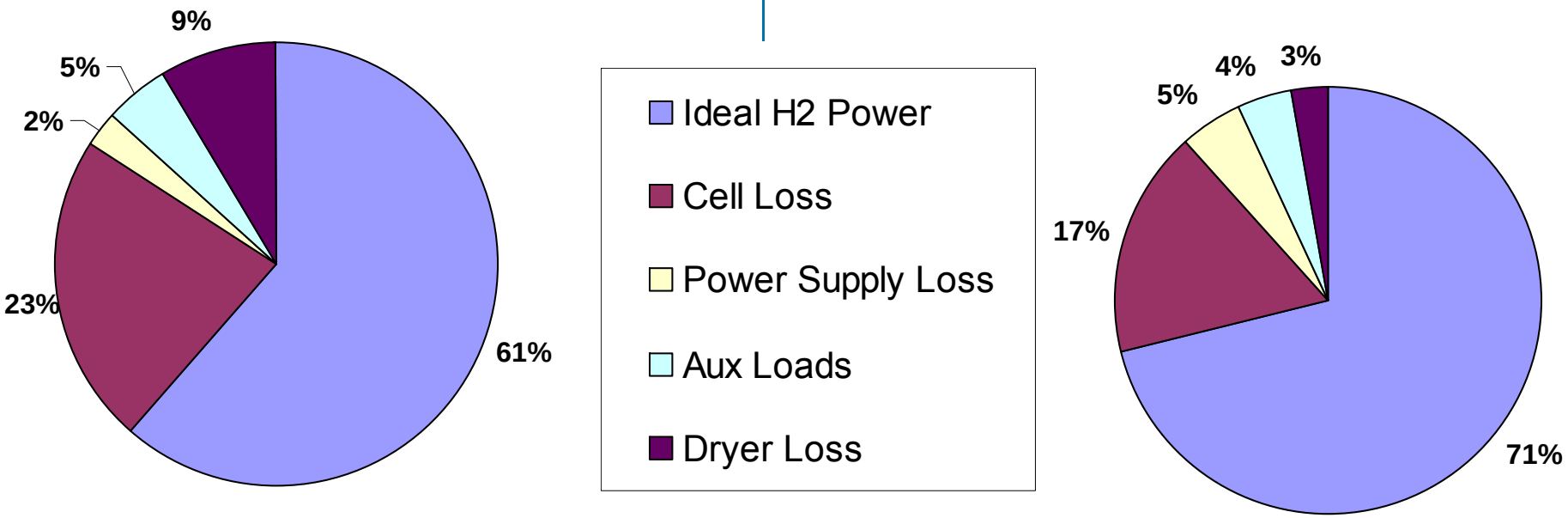
Trade Study Results - Efficiency

Present

- Operating assumptions: 1.9 A/cm^2, 50°C, 15 bar
- System assumptions: H-series, 12 kg/day

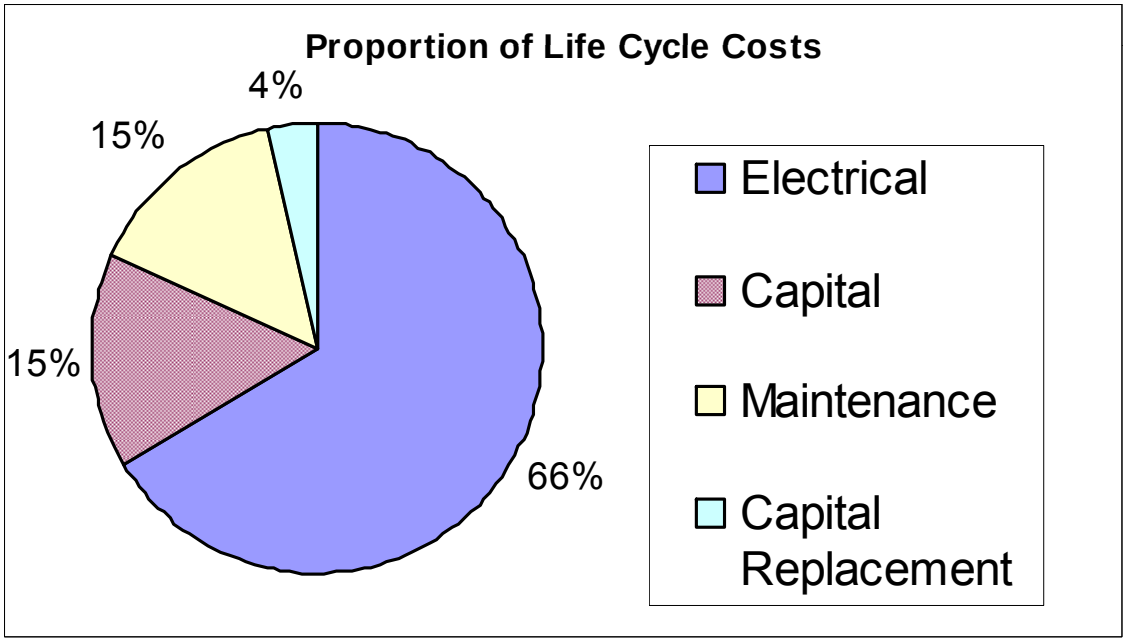
2012 projection

- Operating assumptions: 1.65 A/cm^2, 80°C, 30 bar
- System assumptions: Next generation cell stack, 95% efficient power supply, 3% dryer losses



Trade Study Results – Life Cycle Cost

- Electricity Use Dominates Cost
  - Electrical Efficiency Can Drive Cost Reduction
- Capital And Maintenance 1/3 Life Cycle Cost



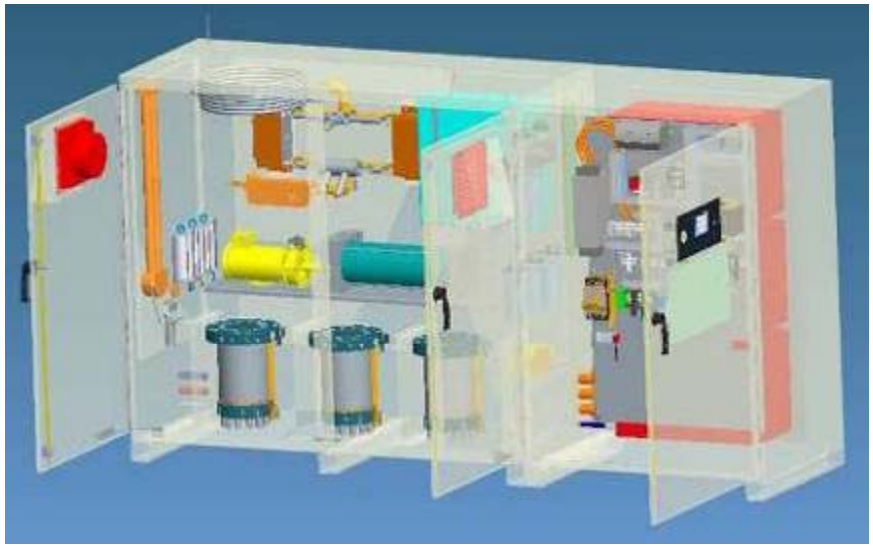
100 kgH_2/day
100 units/year
$0.05 kWh
20 year life
Purchase and Operational Costs Only

Larger Output Product Overview

- Same architecture as H-Series:
  - Modular
  - Configurable
  - Redundancy (High availability)
- Competitive with existing alkaline product offerings
- Emphasis on high reliability, low cost, small footprint
- Higher efficiency
- Low noise
- Load-following and tank-topping operating modes
- Outdoor option for moderate climates
- ISO container option for harsh climates
- Design to latest standards – ISO 22734-1 electrolyzer standard

HOGEN® C-Series 30m (FuelGen® 65)

- Generation Capacity: Up to 1140 SCFH H_2 / 30 Nm^3/hr / 65 kg/day
- Development cycle: 12 months to working prototype (11/09)
- Commercial availability: Q3 2010
- 5 times the hydrogen output of the H-Series, **only 1.5X the foot print**
- Larger cell stack based on previous development for Navy life-support
  - Designed & qualified for 800 psi (55 bar) generation

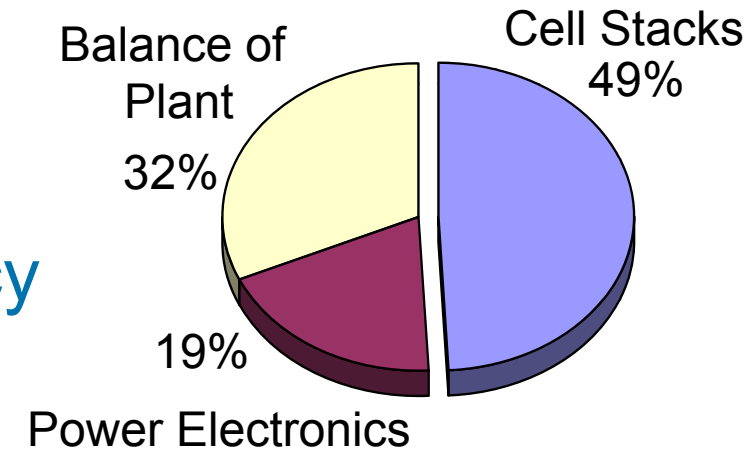


How Much Is 65 kg of Hydrogen?

- Enough to Fuel
  - 2 Fuel Cell Mass Transit Buses
  - 5 ICE Pickups
  - 13 Fuel Cell Cars
  - 35 Class III Fork Trucks

C-series Development Focus

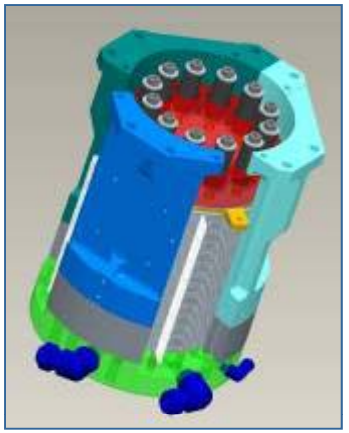
- Three main development areas
  - Cell stack
  - Hydrogen/oxygen gas management system
  - Power conversion efficiency



Cost Breakdown of H-series

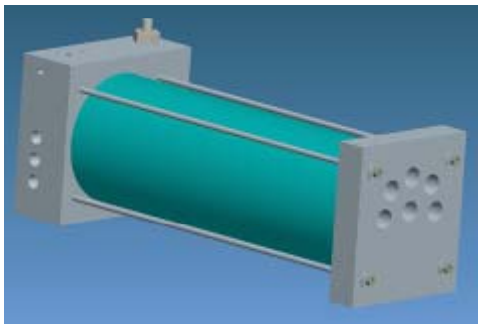
Electrolysis Cell Stack Development

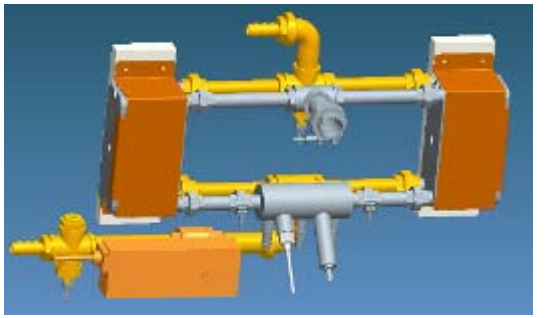
- Product design based on larger cell stack
- Previously developed for Hamilton Sundstrand for submarine life support
  - Stack development started in early 2007
  - Completed in late 2008
  - Fully qualified
    (Mil-spec shock and vibration)
- Stack design validation testing to date:
  - >48,000 stack-hours
  - >570,000 cell-hours
  - >6,400 operating hours on full-scale 65-cell stack
- Current development work to reduce cost through de-rating of stack to 435 psi (30 bar)

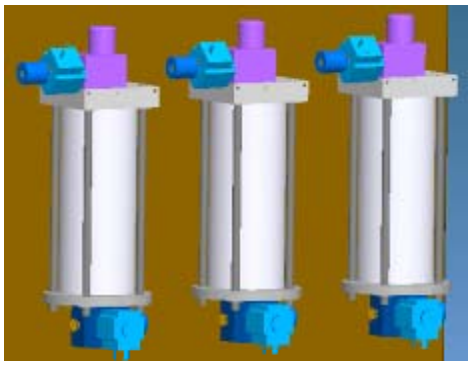


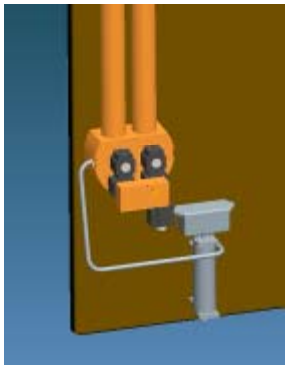
Gas Management System

- Pressurized water-oxygen system
- Capture and vent O_2 at up to 20 psi (1.5 bar)
- Improved hydrogen drying scheme
  - Reduce dryer loss to 6%
  - High efficiency option will target 2% loss
- Utilize multiple phase separators from H-series



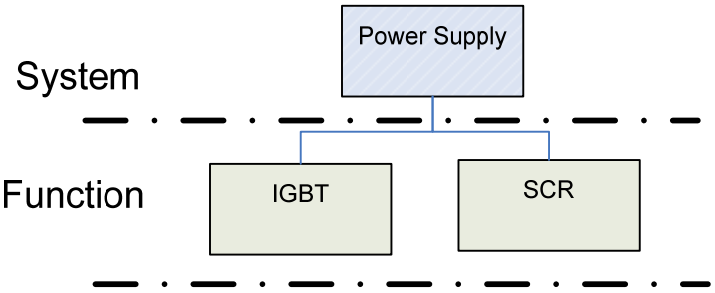


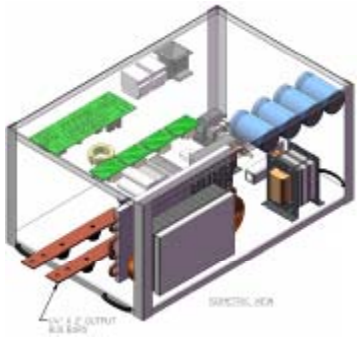




Power Conversion

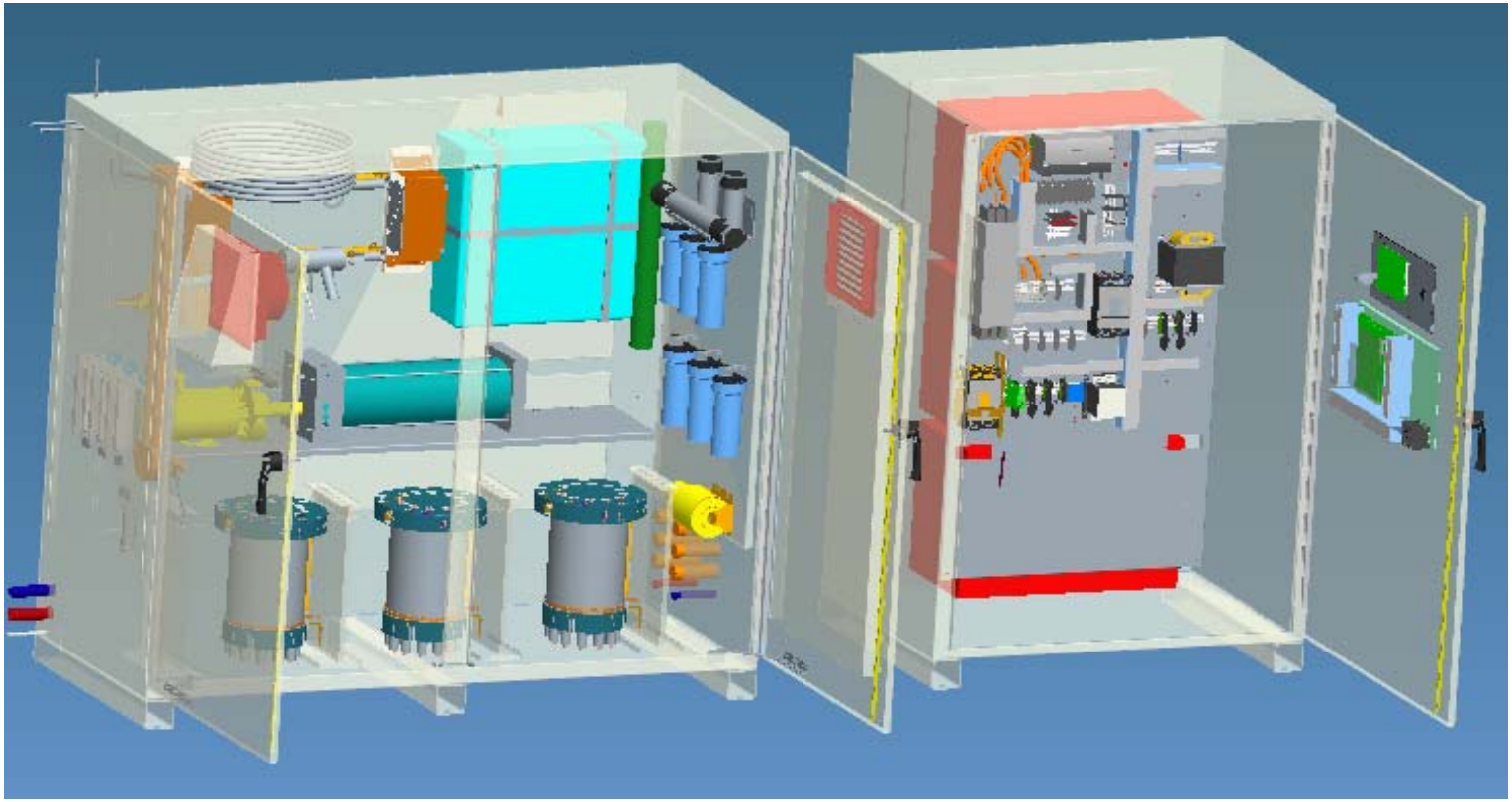
- Investigated multiple power supply pathways
- Trade off cost, efficiency, footprint
- Baseline IGBT-based design
- Demonstrated conversion efficiency of up to 95%
- Lowest volume & weight



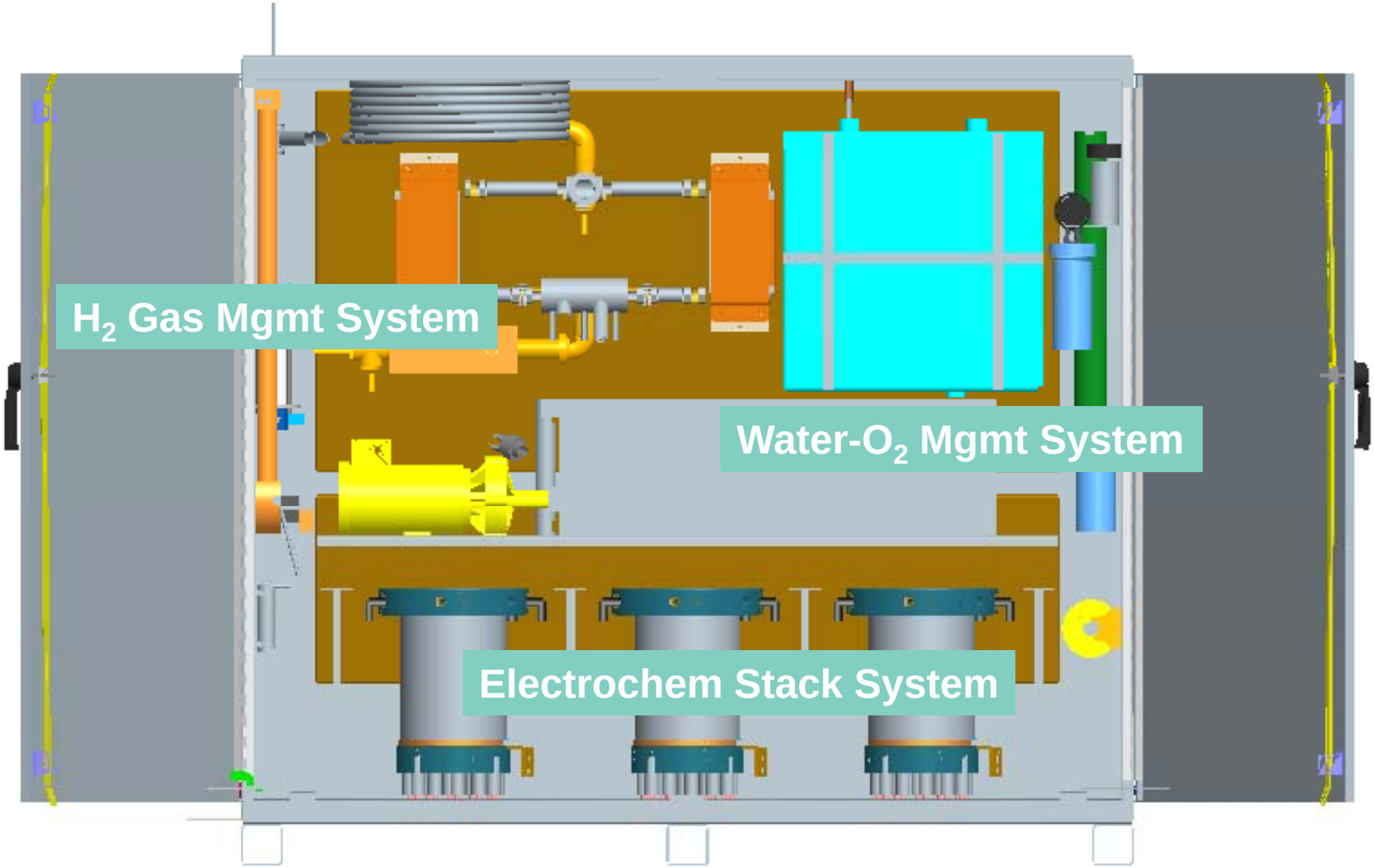


C-Series System Layout

- Separate Fluids and Electrical Cabinets

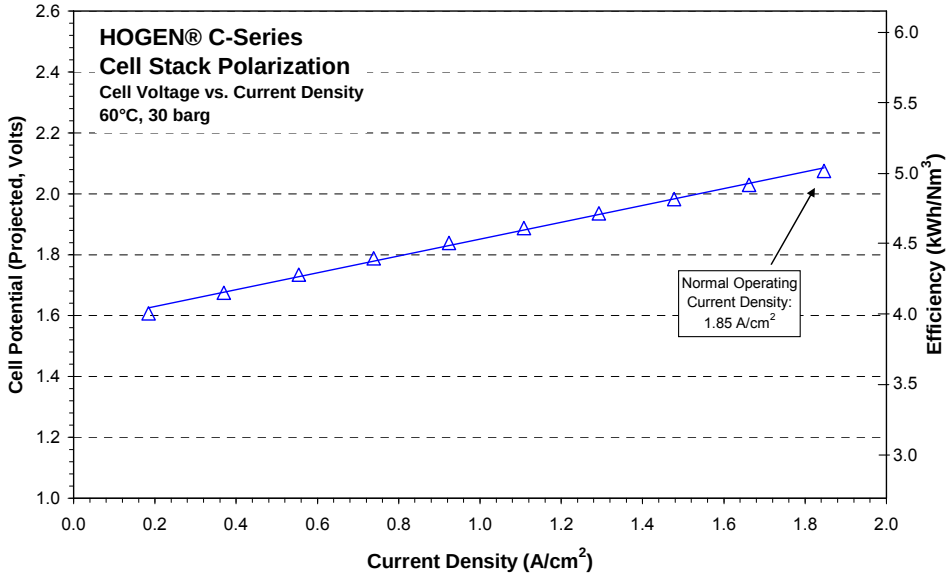


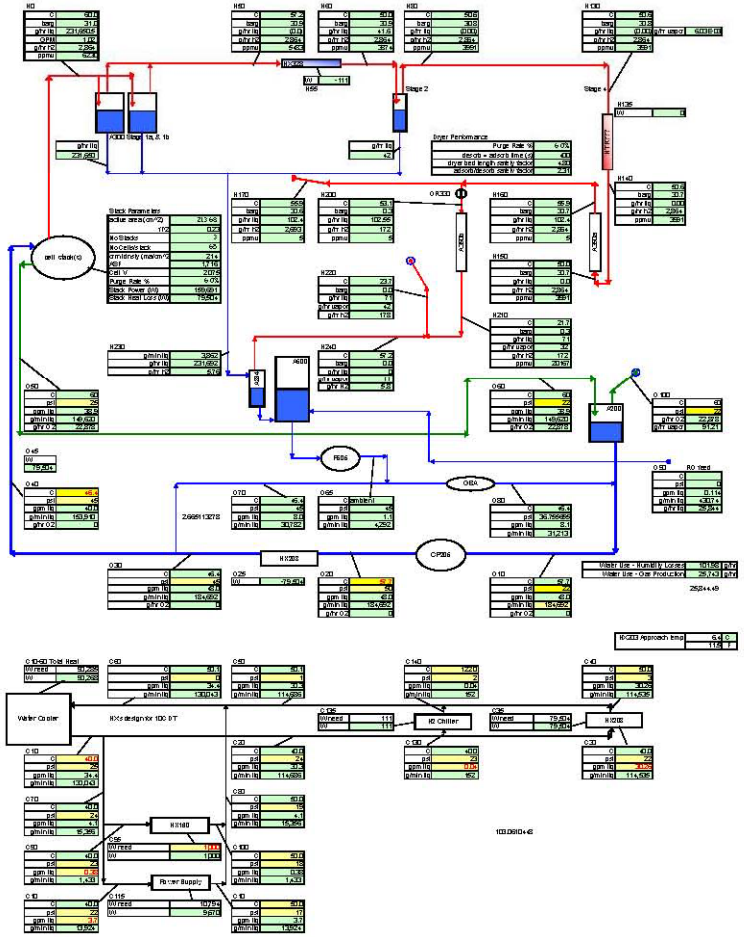
System Layout – Fluids Bay



System Modeling

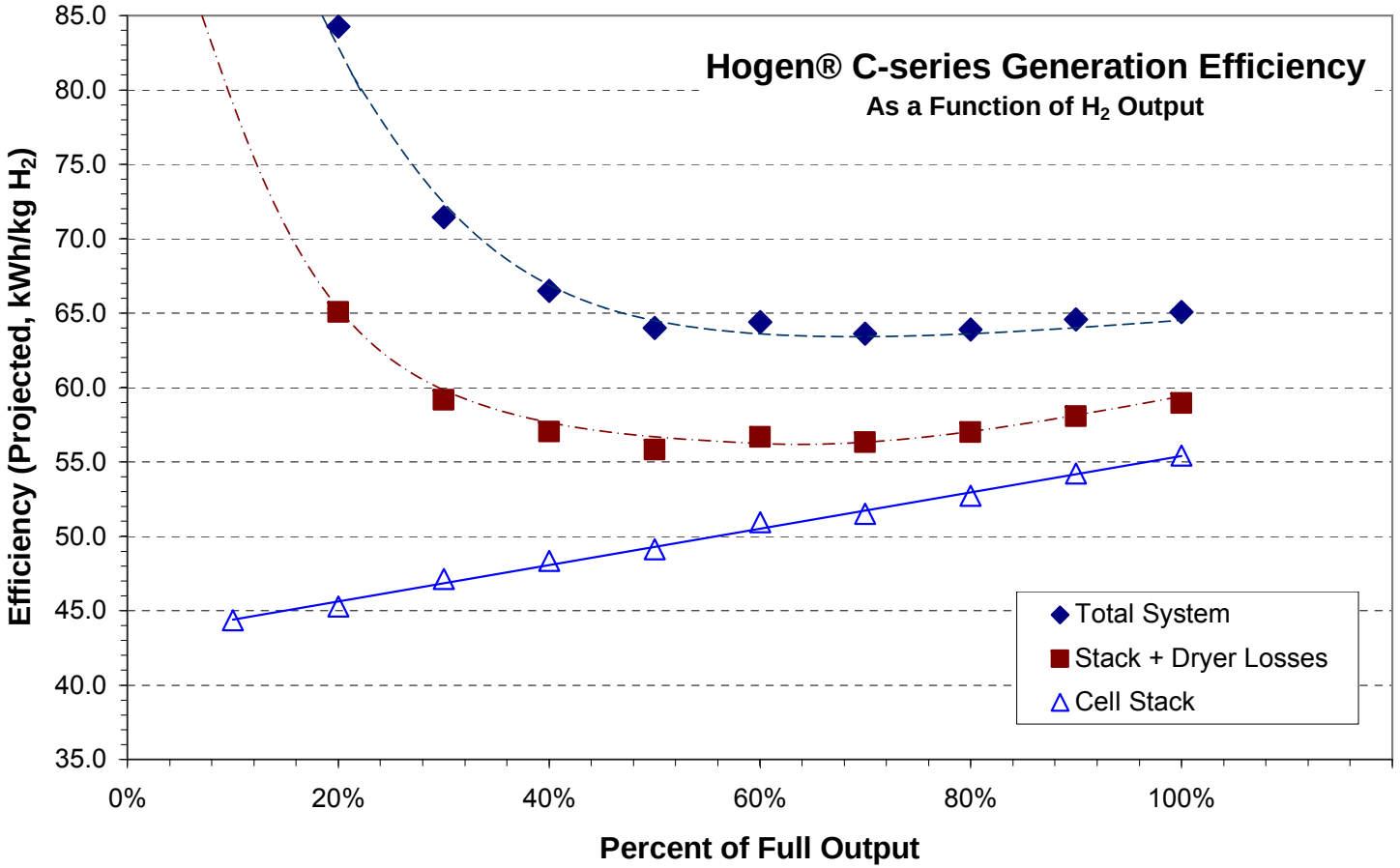
- Extensive spreadsheet model
- Parameter inputs based on experimentation



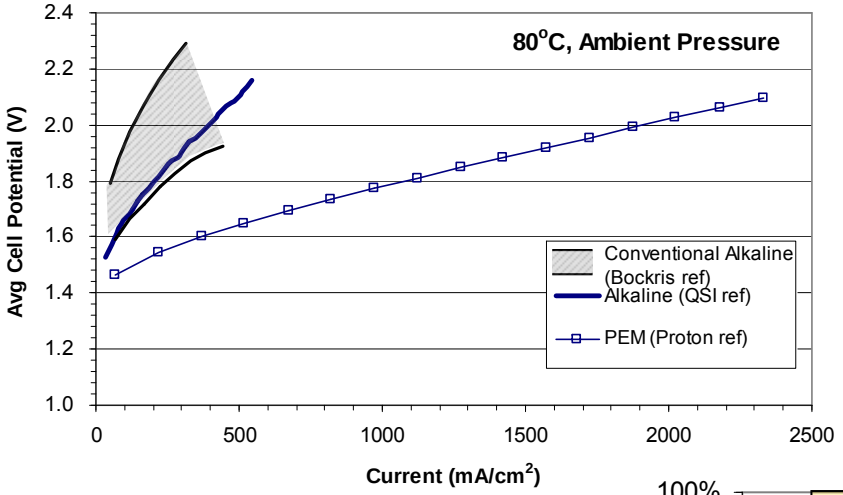


Proton ENERGY SYSTEMS

System Efficiency Modeling

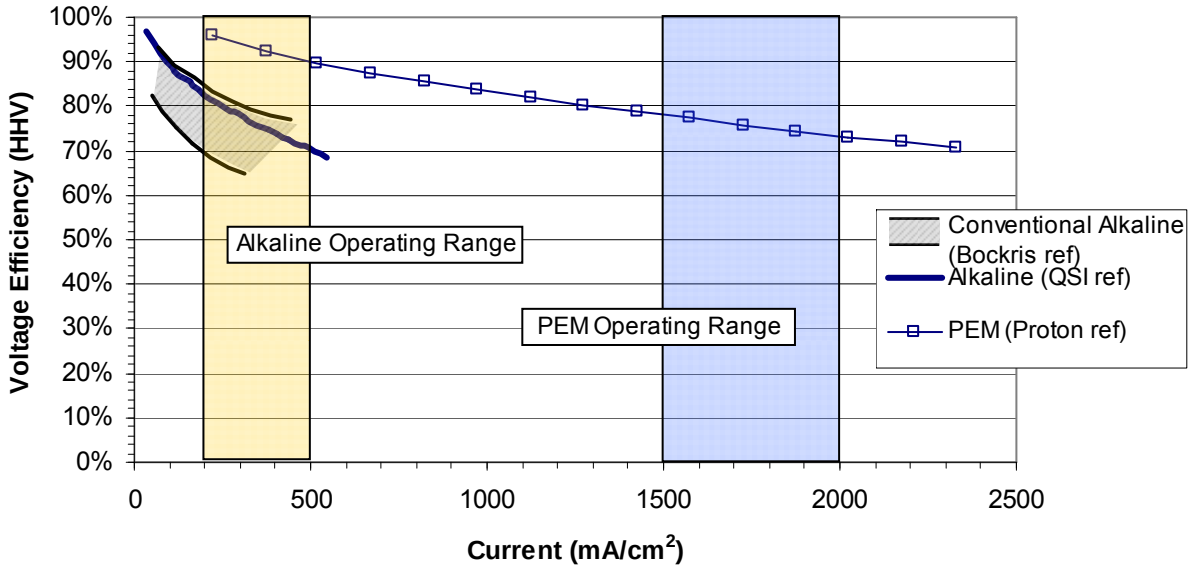


Cell Stack Efficiency Comparison



- Cell performance of PEM vs. alkaline

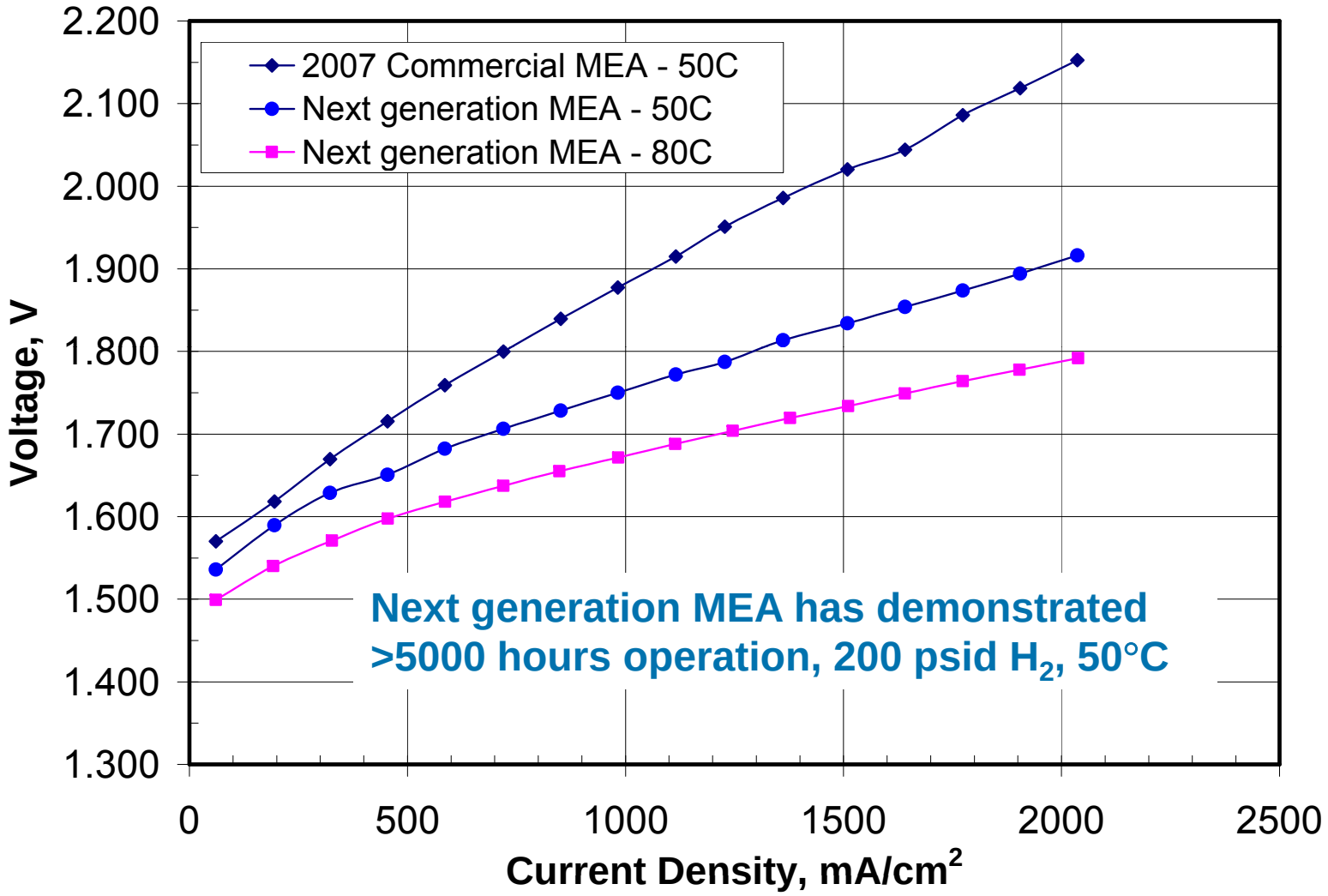
- Efficiency dependent on current density



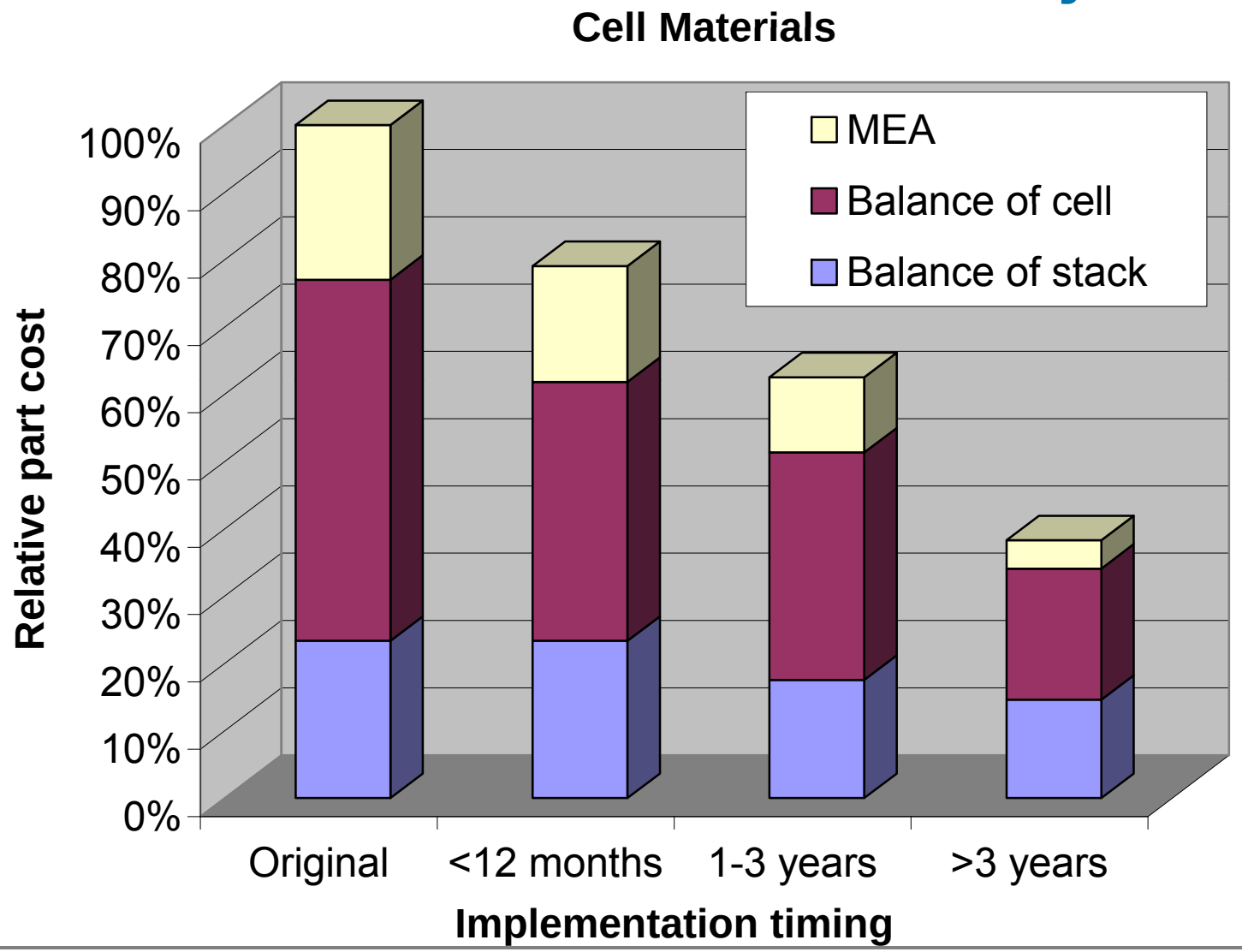
Future Work

- Complete product development cycle
  - Verification and validation
  - Product introduction
- Continue technology development
  - Higher operating efficiency
  - Additional cost reduction opportunities
  - Further scale up

MEA Efficiency Improvements

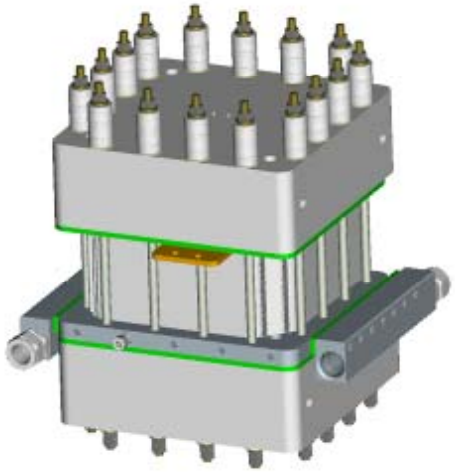


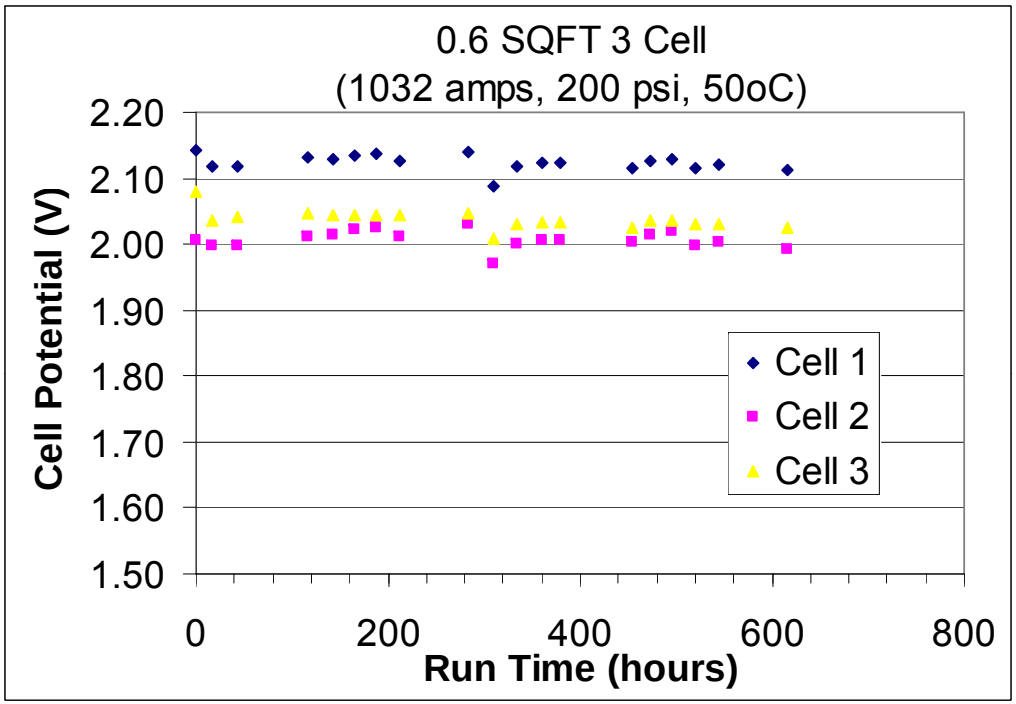
Cell Stack Cost Reduction Projections



550 cm² Stack Development

- Bipolar plate design
- Up to 55 kg/day stack
- 200 and 400 psi operation demonstrated
  - Single and multi cell stacks tested





Pathway Forward

- Grow commercial business to a level of sustained profitability.
- Continued development of larger systems and high pressure systems as market conditions dictate.
- Pursue third party funding to help fund development activities – Government and Industry.
- Broaden our product reach and acceptance more internationally.
- Be the continued world leader in electrolysis technology.

Acknowledgements

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