Proton ENERGY SYSTEMS | The Leader in On-site Hydrogen Generation

Transformative Renewable Energy Storage Devices Based on Neutral Water Input

Energy Storage Systems Update

ARPA-E GRIDS Kick-Off

4 November 2010

Team

- Proton Energy Systems
  - Dr. Kathy Ayers, PI
  - Luke Dalton, System Lead
  - Chris Capuano, Stack Lead
  - Project Lead; Electrolysis Stack and System; Fuel Cell System
- Penn State University
  - Prof. Mike Hickner
  - Prof. Chao-Yang Wang
  - Electrolysis and Fuel Cell Membrane Material; Fuel Cell Stack

Proton Energy Systems

- Manufacturer of Proton Exchange Membrane (PEM) hydrogen generation products using electrolysis
- Founded in 1996
- Headquarters in Wallingford, Connecticut.
- ISO 9001:2008 registered
- Over 1,200 systems operating in 60 different countries

ANAB ACCREDITED

Certified to ISO 9001:2008

TÜV Rheinland

Precisely Right.

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Proton Capabilities and Applications


PEM Cell Stacks


Complete Systems


Storage Solutions

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


Power Plants


Heat Treating


Semiconductors


Laboratories


Government

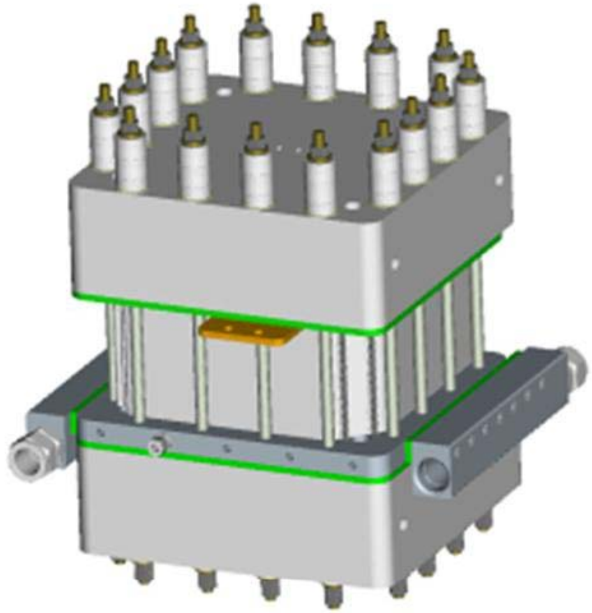
Proton ENERGY SYSTEMS

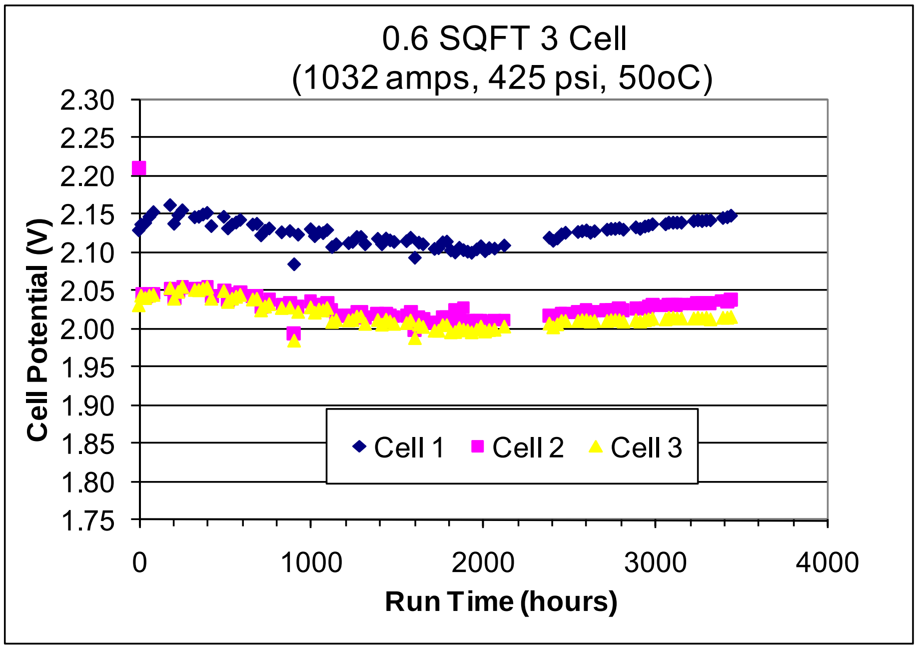
HOGEN® C Series

- Maximum Capacity: 30 $Nm^3/h\ H_2$ (65 kg/day) (~200 kW input)
- Commercial availability: Q1 2011
- 5X hydrogen output with **only 1.5X the foot print**

Next Steps in Scale Up

- 70 Nm^3/h
- 150 kg/day
- 400 kW input





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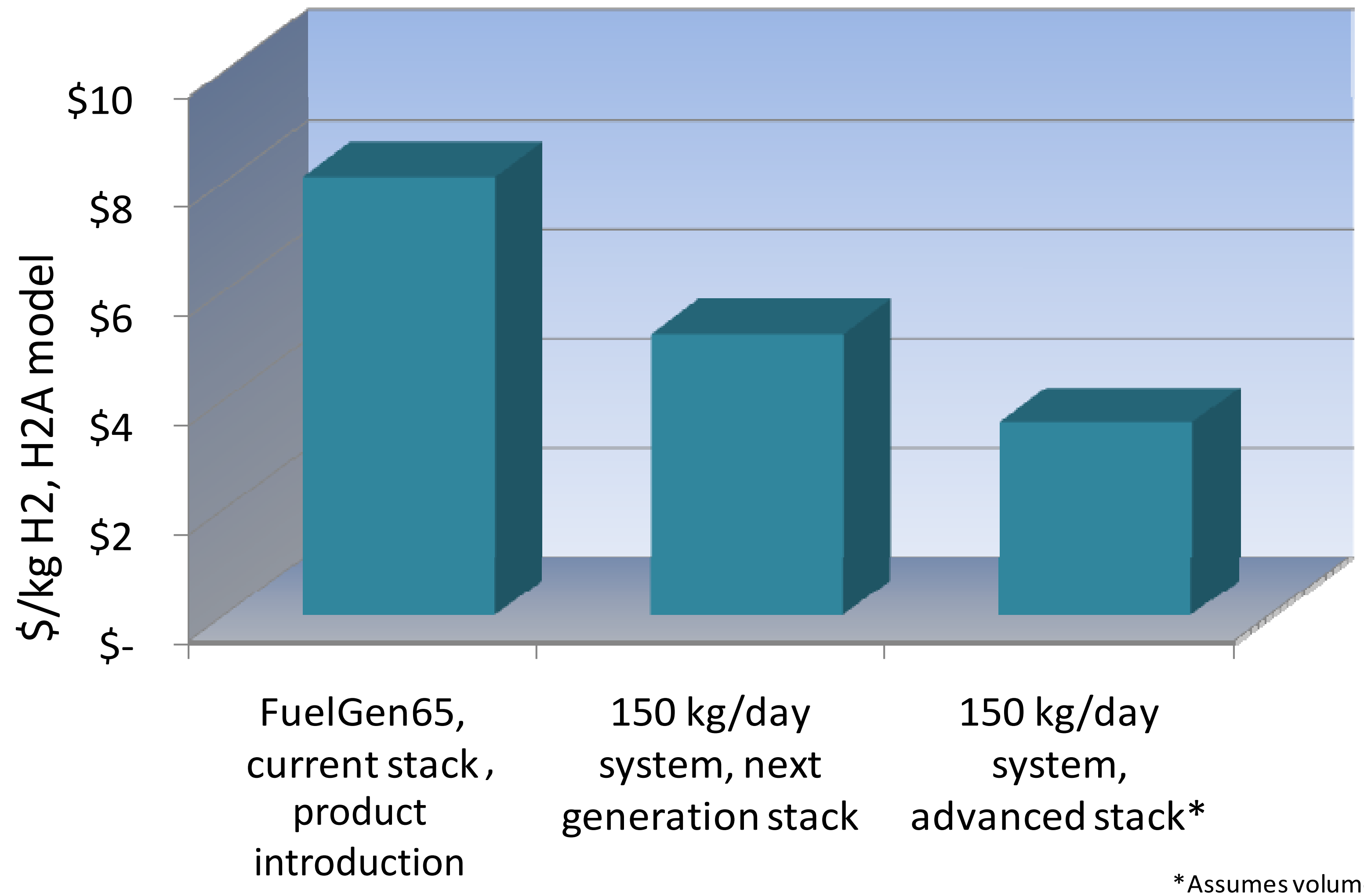
Hydrogen Cost Progression



*Assumes volumes of 500 units/year

Two Main Types of Low Temp Electrolysis

Alkaline Liquid Electrolyte

– Low bubble point requires balanced pressure
  – Controlled shutdown required
  – High pressure oxygen
– Corrosive solvent
– Complex balance of plant, high pressure lines
– Low current densities
+ Less expensive materials of construction

Proton Exchange Membrane (PEM)

+ Membrane enables differential pressure
  + Load following
  + Ambient pressure oxygen
+ Pure water
+ Simple balance of plant, plastic on O_2 fluids loop
+ High current densities
– High cost catalysts and flow fields

Alkaline membrane technology could provide best of both systems

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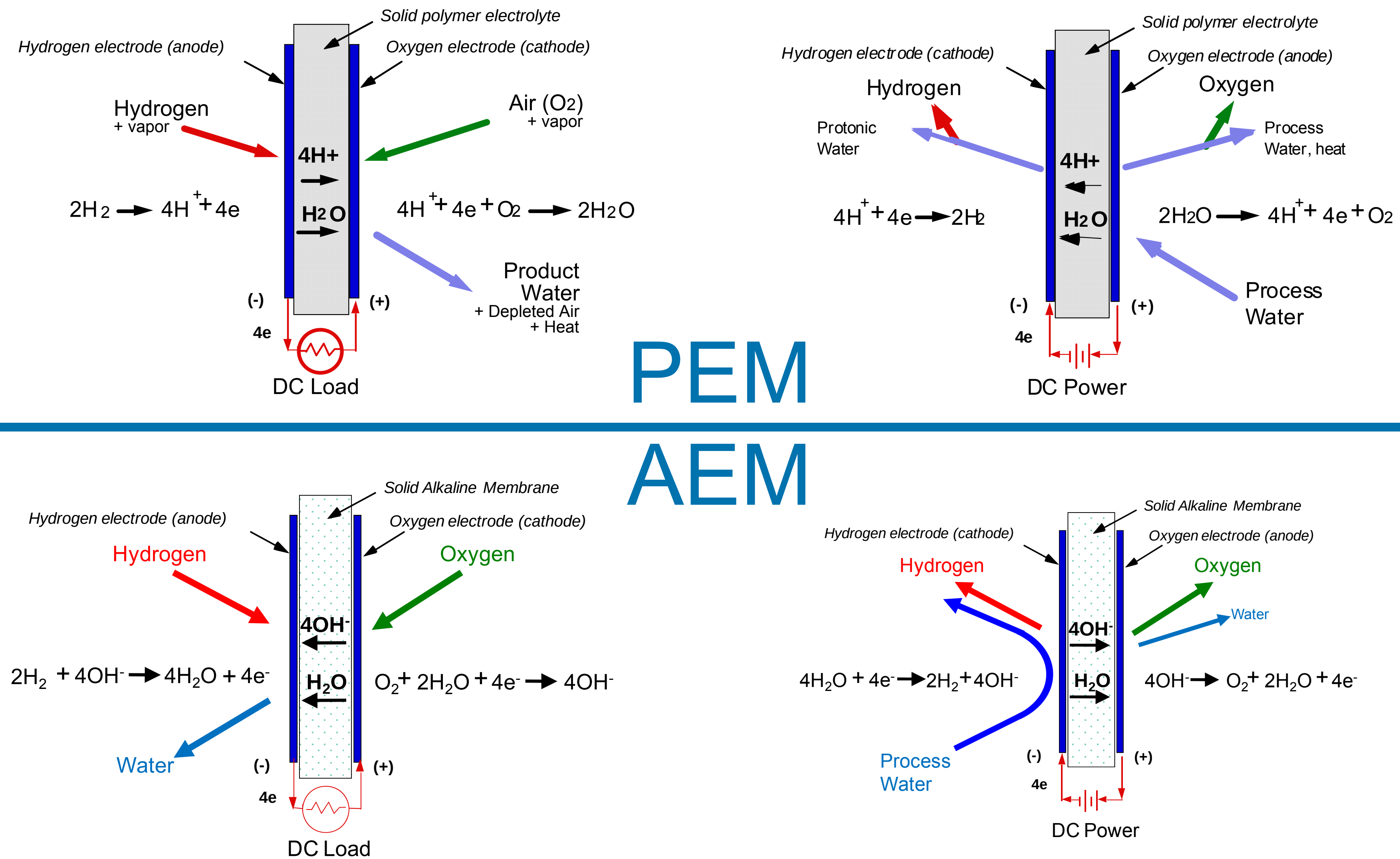
PEM / AEM Cell Comparison

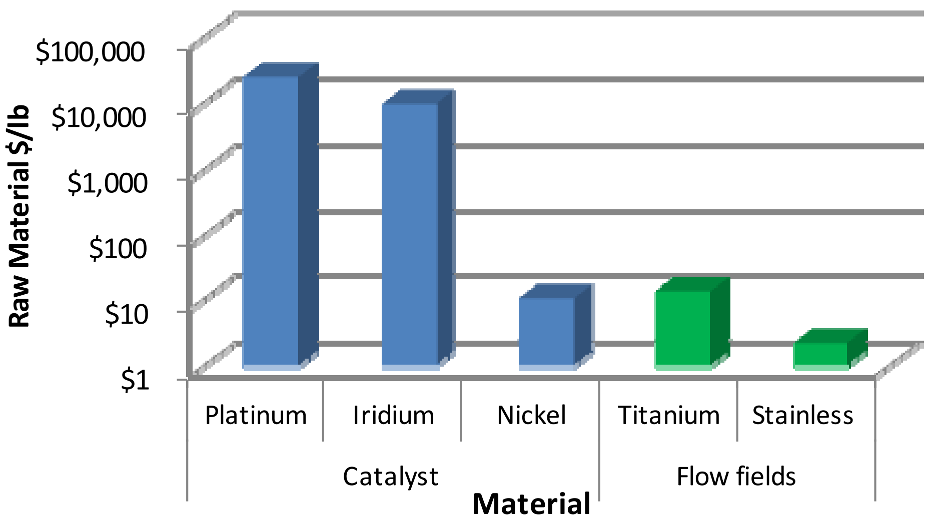


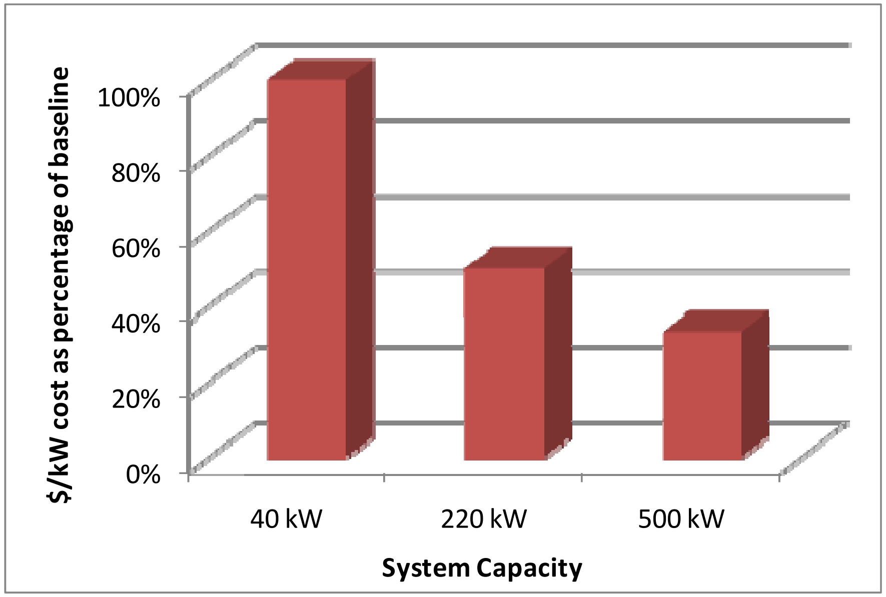
Rationale

- Alkaline advantage over PEM: lower cost materials of construction
- Disadvantages of alkaline liquid system:
  - Corrosive electrolyte
  - High pressure oxygen
  - Complex balance of plant
  - Lower purity hydrogen
  - Lower efficiency
- Alkaline membranes showing feasibility
  - Enables PEM advantages at low cost
  - Enables lower current density for high efficiency

Cost Justification

- 3-pronged approach





Labor minimization and high speed manufacturing at high production volume

Proposed Approach

- Design Trade Study
  - Select RFC configuration
- Membrane and Ionomer Development
  - Maximize durability and minimize ionic resistance and crossover
- Catalyst Development
  - Reduce activation overpotential
- MEA Fabrication
  - Optimize catalyst-membrane interaction
- Cell Stack Design
  - Leverage Proton experience and substitute materials
- System Design
  - Leverage Proton balance of plant designs
- Cost Analysis

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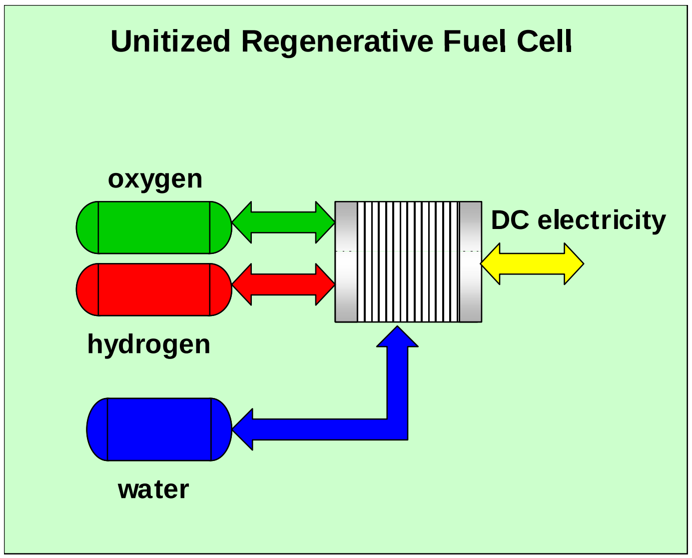
Trade Study: Configuration Options

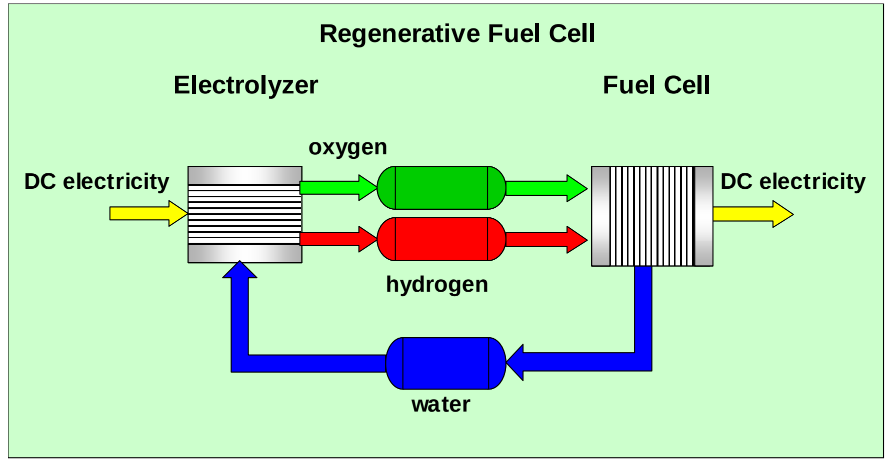
URFC – Unitized RFC

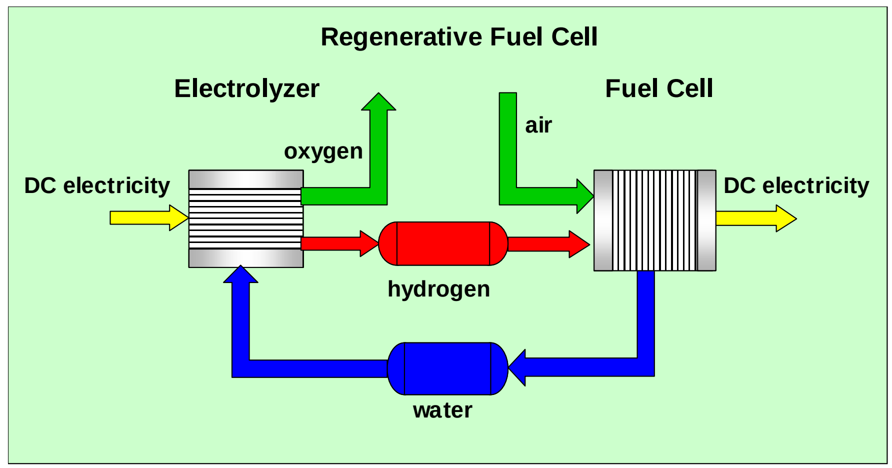
- A single cell stack that operates as both fuel cell and electrolyzer



DRFC – Discrete RFC

- Separate fuel cell and electrolyzer stacks





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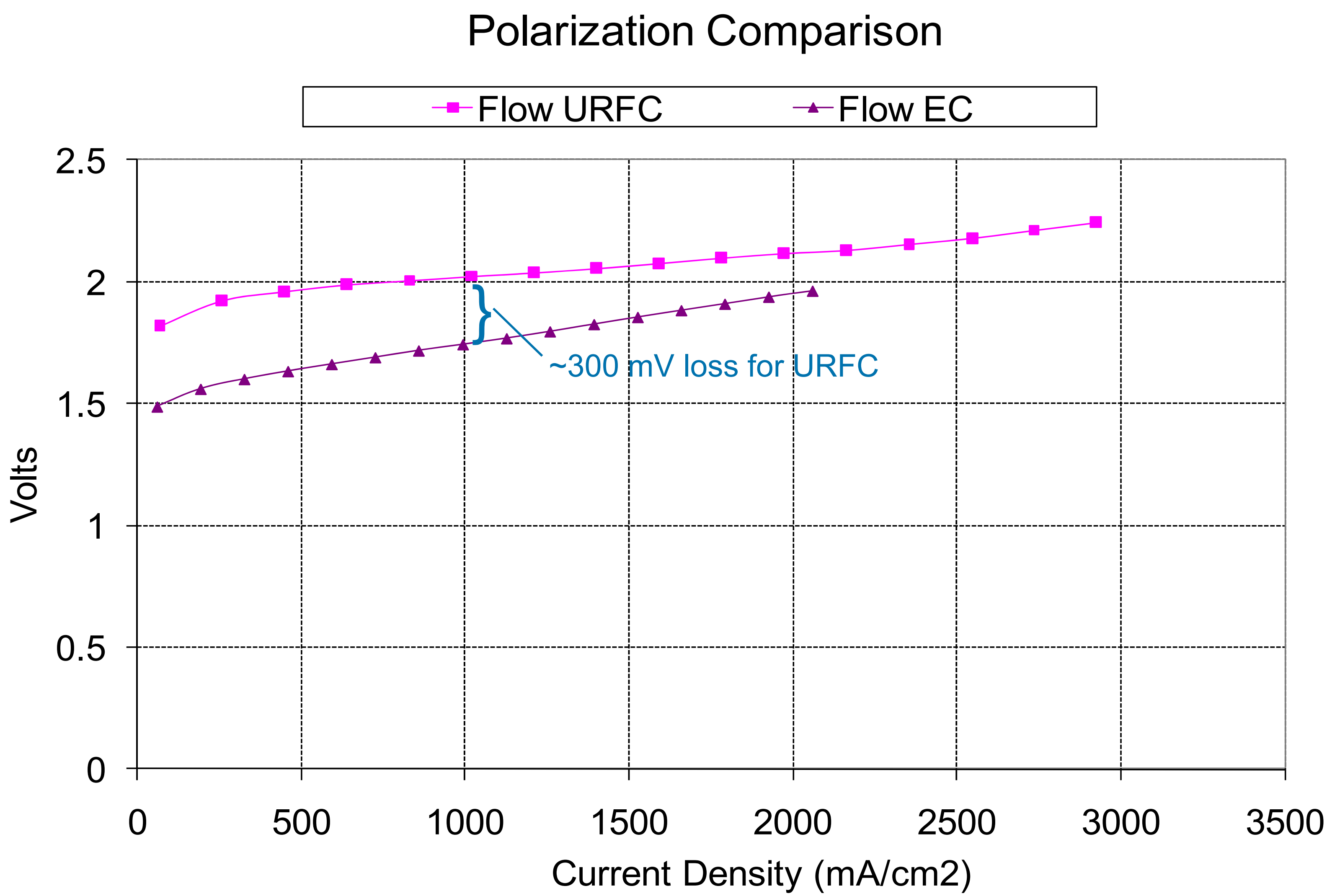
Trade Study – Electrolysis Example



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Trade Study: O_2 vs. air feed

- High pressure oxygen adds balance of plant complexity
- Requires special cleaning >150 psi
- O_2 feed requires drying of both gases

- Membrane is sensitive to CO_2
- Carbonate can replace OH- sites and reduce conductivity
- Removal of carbon from air reduces efficiency and increases cost

Need to look at trade of cost, efficiency, and simplicity in context of safety considerations

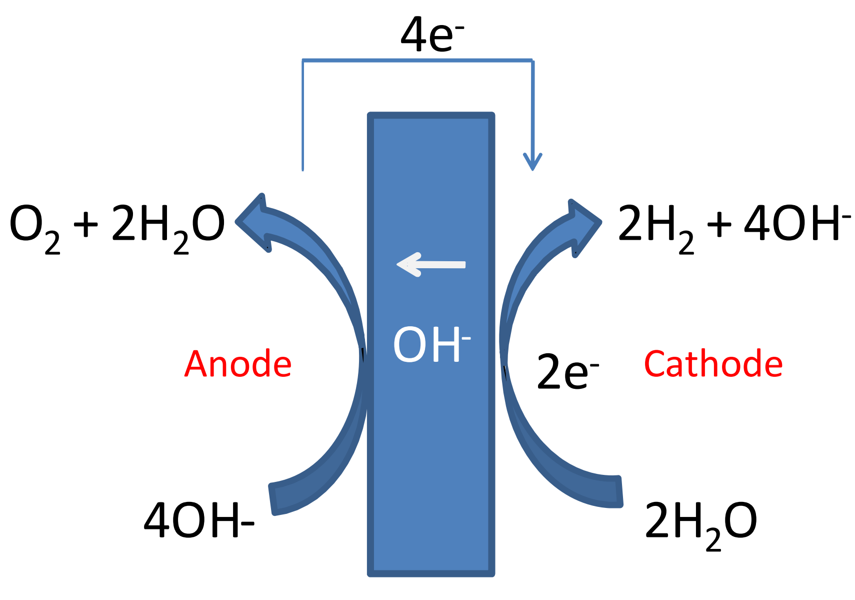
Trade Study: Anode vs. Cathode Feed

Alkaline electrolysis

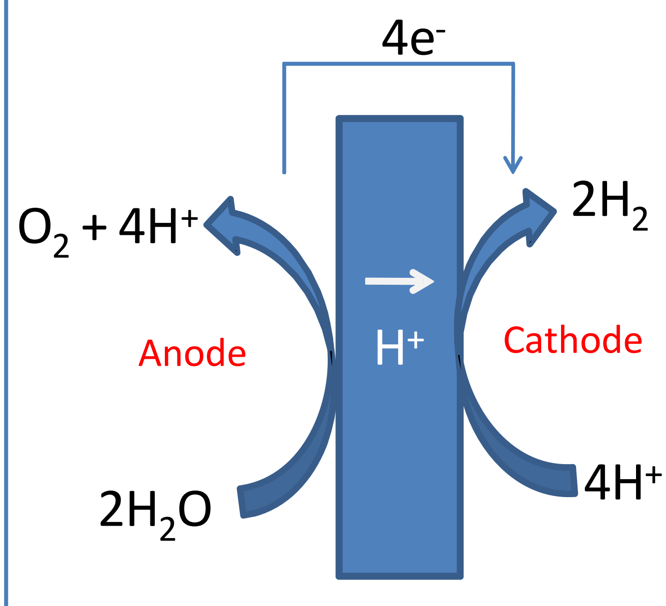
- Water consumed on hydrogen side of cell
- Hydrogen primary interest

PEM electrolysis

- Water consumed on oxygen side of cell
- Hydrogen is typically gas of interest, oxygen vented



Alkaline



Acid

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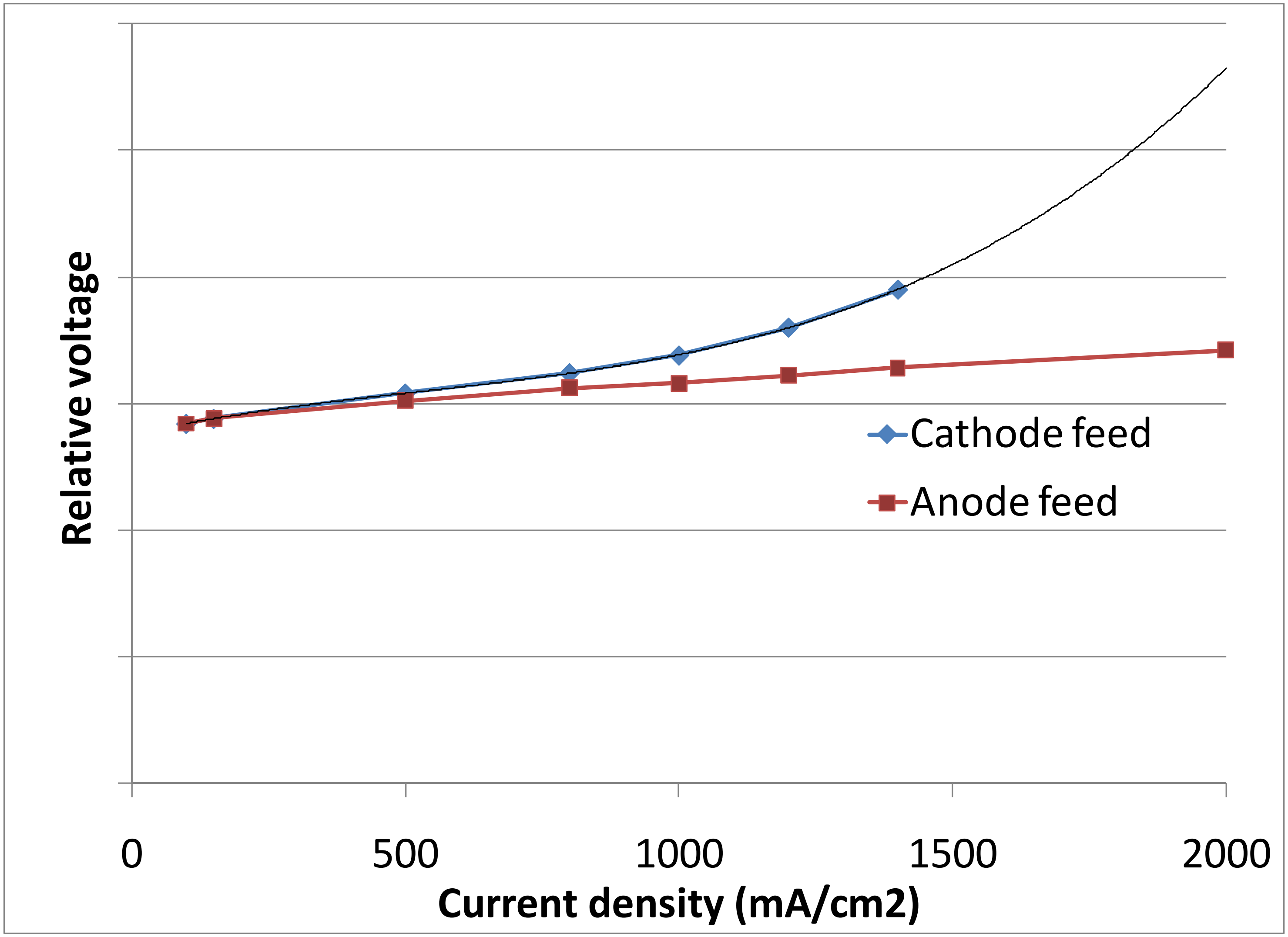
Trade Study: PEM Comparison



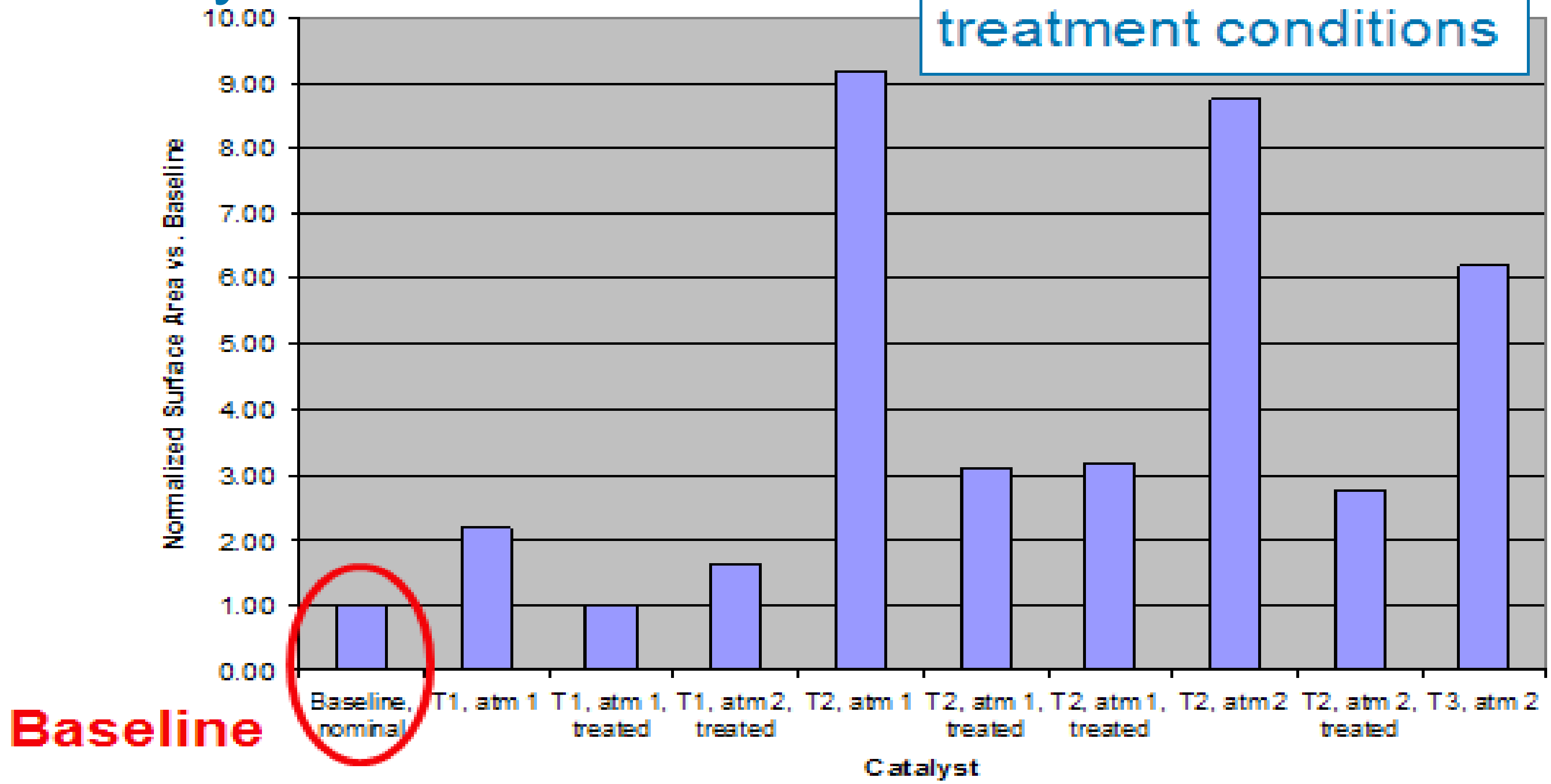
Membrane and Ionomer Development

- Penn State-led effort to develop an anion exchange membrane (AEM) and ionomer binder
  – Reduced cost through use of commercially available monomers
  – “Tune” ion exchange capacity and cross-linking to balance conductivity and mechanical properties/gas cross-over.
- Proton to assist with characterization
  – Conduct diffusion and performance evaluation to provide feedback on how to iterate on configuration
  – Have Tokuyama membranes and ionomers to test as a baseline for AEMs.

Catalyst Development

- Apply processes from PEM experience to AEM catalyst

Surface area vs. synthesis and post treatment conditions



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MEA Fabrication

- Vary temperature and dwell time
  - Find combination most conducive to electrode attachment

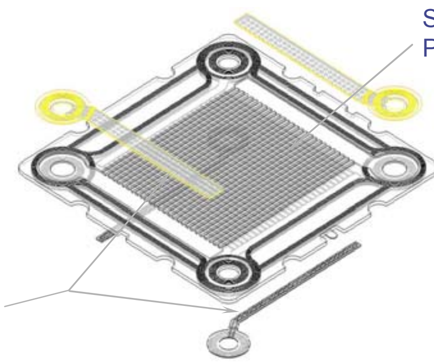
- Sub-scale membrane samples to be used for pressing half-MEAs
  - Two fabrication approaches to be considered

- Trials rated on uniformity, adhesion to membrane, and degree of flow for ink samples.
- Membrane assessed for mechanical degradation resulting from process

Electrolysis Stack Design

- Will incorporate outputs from the trade study to dictate configuration
  - *Bipolar plate design (high-efficiency, low-pressure)*
  - *Round design (lower-efficiency, high pressure)*
- Primary effort will be material substitution
  - *Alkaline allows replacement of titanium components with stainless steel.*

Round architecture



Bipolar plate design

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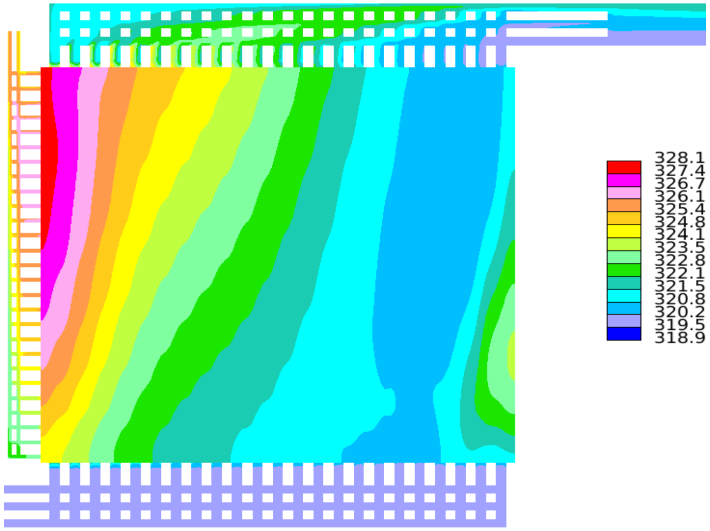
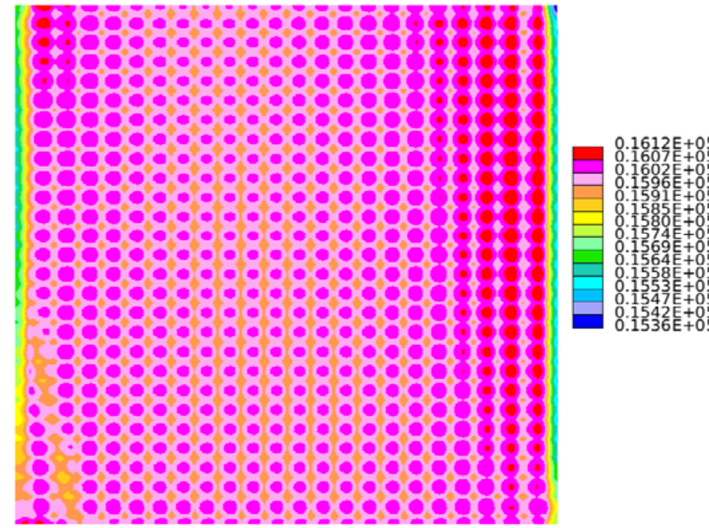
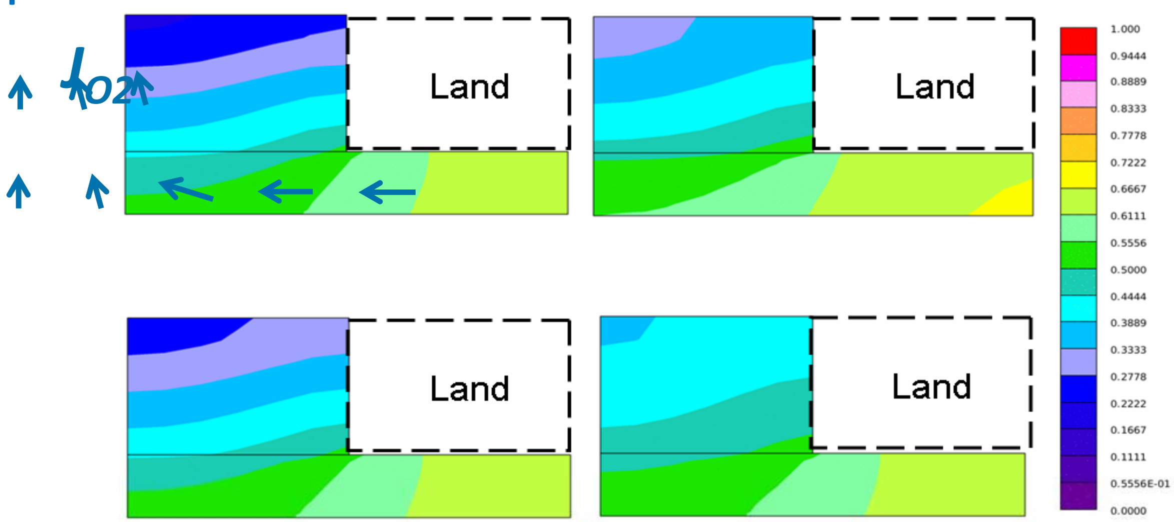
Electrolysis Cell Modeling



temperature distribution



current density distribution



oxygen transport

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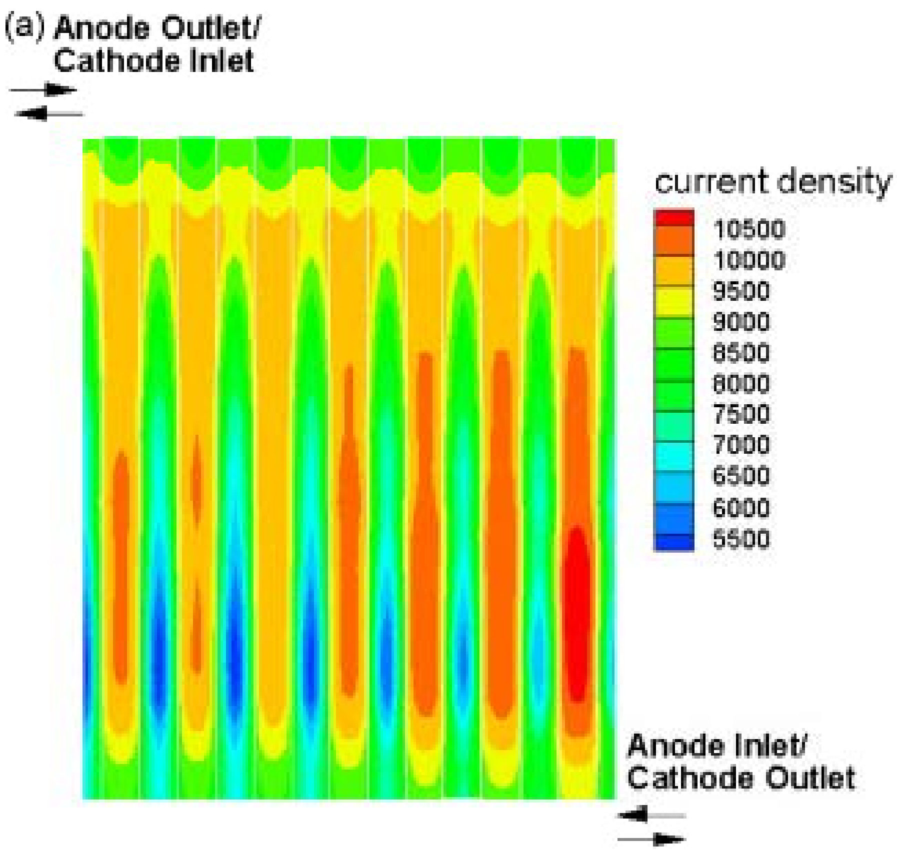
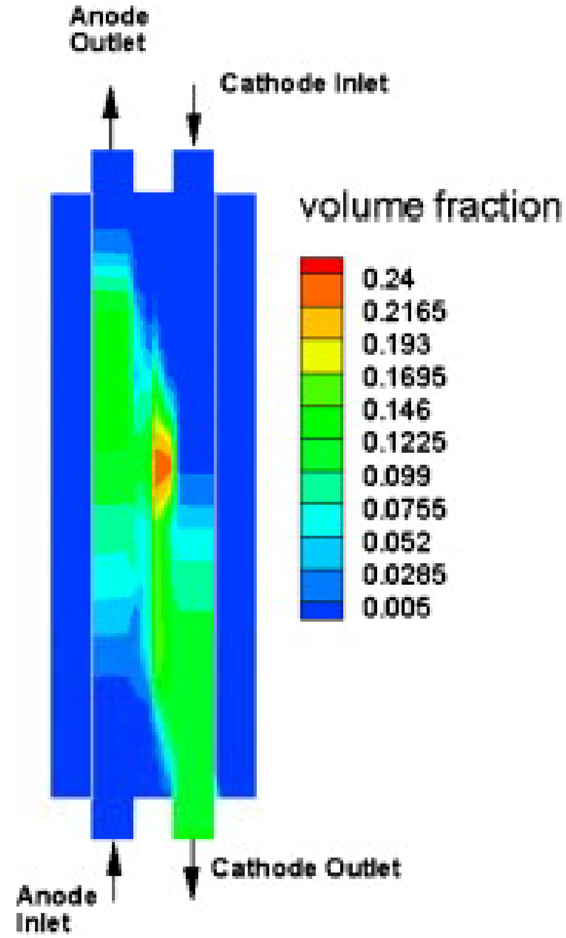
Fuel Cell Modeling



current density distribution



Liquid water distribution

Electrolysis and Fuel Cell Stack Test Plan

- Design phase and concept review
- Prototype flow field fabricated using production tooling and techniques
- Anode flow field verification
- Cathode flow field verification
- Short stack testing and operation for prototype review
- Deliverable stack assembly and operation

Cell Stack Operational Verification

- Multi-cell operational testing
- Allows for fine control over operating parameters
  - Temperature
  - Generation Pressure
  - Current Control
  - Water Flow Rates

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Energy Storage System Design

- PEM system should be largely transferrable to proposed AEM-based system
  - Common fluids of interest (H_2, H_2O, O_2)
- Trade study work will impact type of system
- Leverage prior experience in closed loop REFCs
- Output:
  - Design Intent Document
  - P&ID
  - Component selection (comprehensive BOM)
  - Haz-op and design review

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Alkaline REFC Approach

- Well-suited to load-following
- Easily scalable

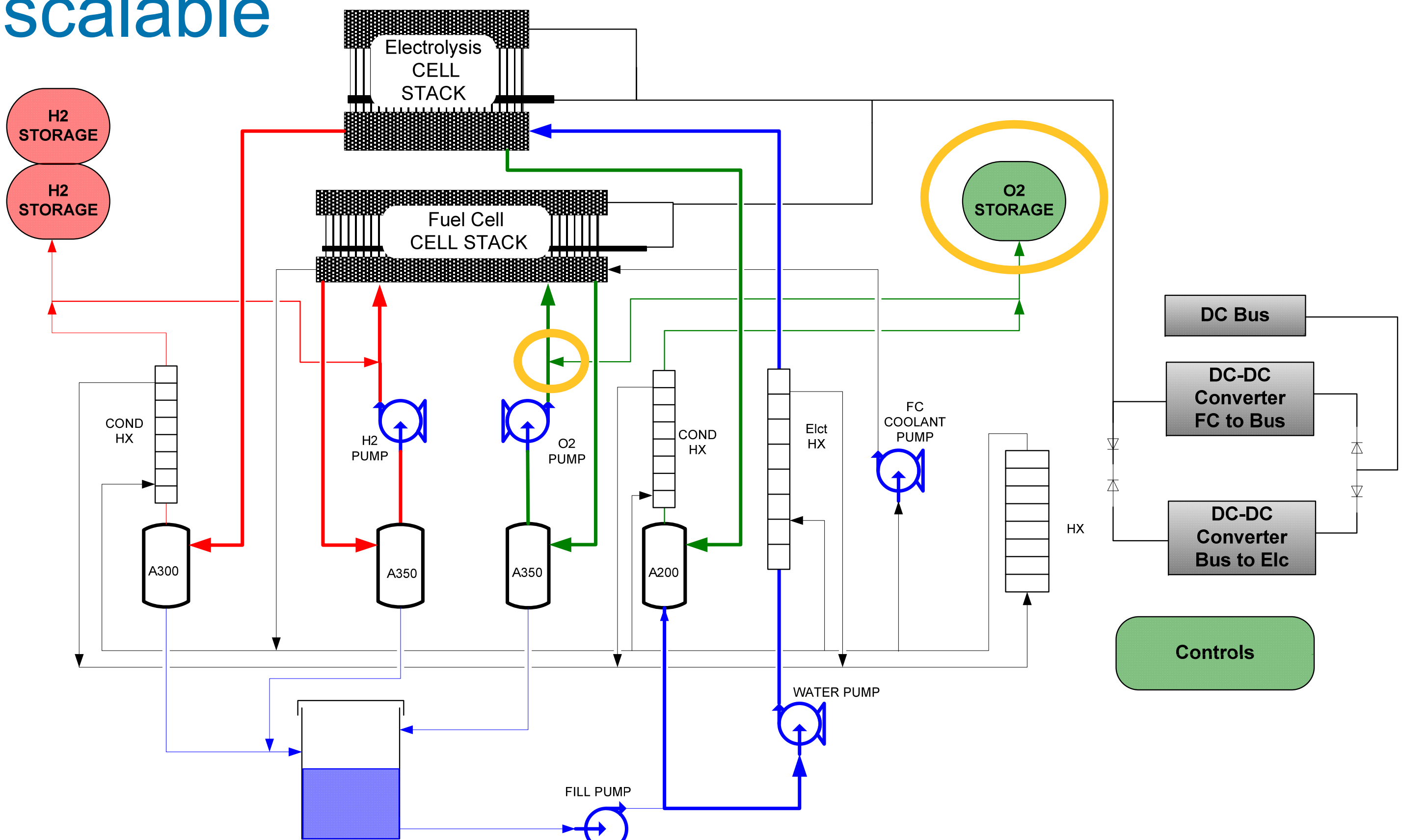

Figure 1. Closed-loop, pure oxygen, discrete regenerative fuel cell system P&ID.

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Examples of Demonstrated Energy Storage Systems

Missile Defense Agency:
Closed loop RFC

“Regenerative Fuel Cell” integrated into CERL’s Silent Camp system concept

Near-Term Milestones

- Kickoff meeting – October 6, 2010
- Trade study results on discrete vs. unitized stack
- Initial survey of commercial catalysts
- MEA formulation studies with baseline membrane and catalyst
- Survey of stack part availability in alternate materials

Major Project Milestones

- System Configuration Trade Study
- Electrolysis and Fuel Cell Membrane Material Improvements
- Electrolysis and Fuel Cell Membrane-Electrode-Assembly Fabrication Optimization
- Fuel Cell Stack Design and Test
- Electrolysis Stack Design and Test
- Integrated Energy Storage System Demonstration