Proton ENERGY SYSTEMS | A Distributed Energy Systems Company

DOE Hydrogen Program

Hydrogen Generation from Electrolysis: 100 kgH_2/day Trade Study

Stephen Porter

Proton Energy Systems

June 10, 2008

Project ID
PD11

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Overview

Timeline

- Current Phase May 2007
- Project End April 2008
- 100% Complete

Budget

- Total project funding $2.2M
  - 50% Cost Share
- $760K DOE Funding for FY07

Barriers

- G. Capital Cost
- H. System Efficiency
- J. Renewable Electricity Generation Integration

Objectives

- Establish Pathway To Larger PEM Systems
  - 100 kgH_2/day With Growth To 500 kgH_2/day
- Optimize For Capital Cost And Energy Efficiency
  - Emphasis On Cell Stack And Power Supply
- Refine Focus Areas For Future Research
  - Which May Yield The Best Cost Reductions?

Milestones

- Submitted Final Report, April 2008
- Project Complete

Approach

- Optimize Functional Architecture, 100 kgH_2/day
  - Perform Design Trade Studies
  - Modeling And Analysis using H2A
  - Perform Subsystem Testing As Appropriate For Data
- Conceptual Design / Physical Architecture
  - Preliminary Sizing Of Components
  - Top Level Drawings
  - Perform Hazard Analysis
  - Obtain Relevant Budgetary Quotations

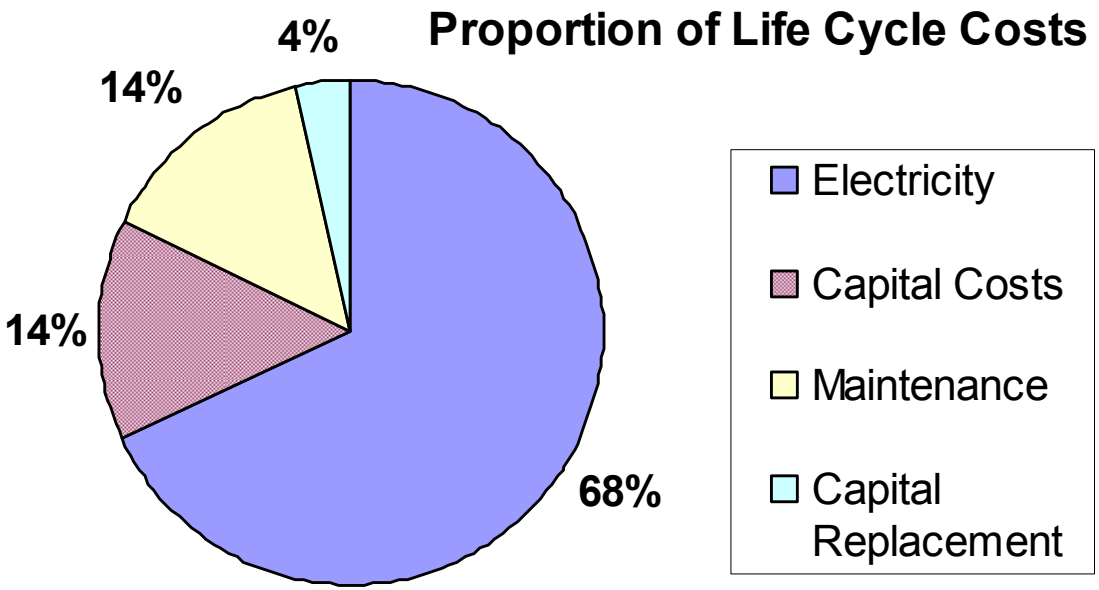
Results – DOE Targets

- Significant Gains Achievable At 100 kgH_2/day
- Addresses Near Term Market Requirements

Characteristics	Units	100 kg/day H2A Est. (2011)	DOE 1500 kg/day Target (2012)
Hydrogen Cost	($/kg)	5.21	3.70
Electrolyzer Capital Cost	($/kg) ($/kW)	1.74 1676	0.70 400
Electrolyzer Energy Efficiency	% (LHV)	58	69

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

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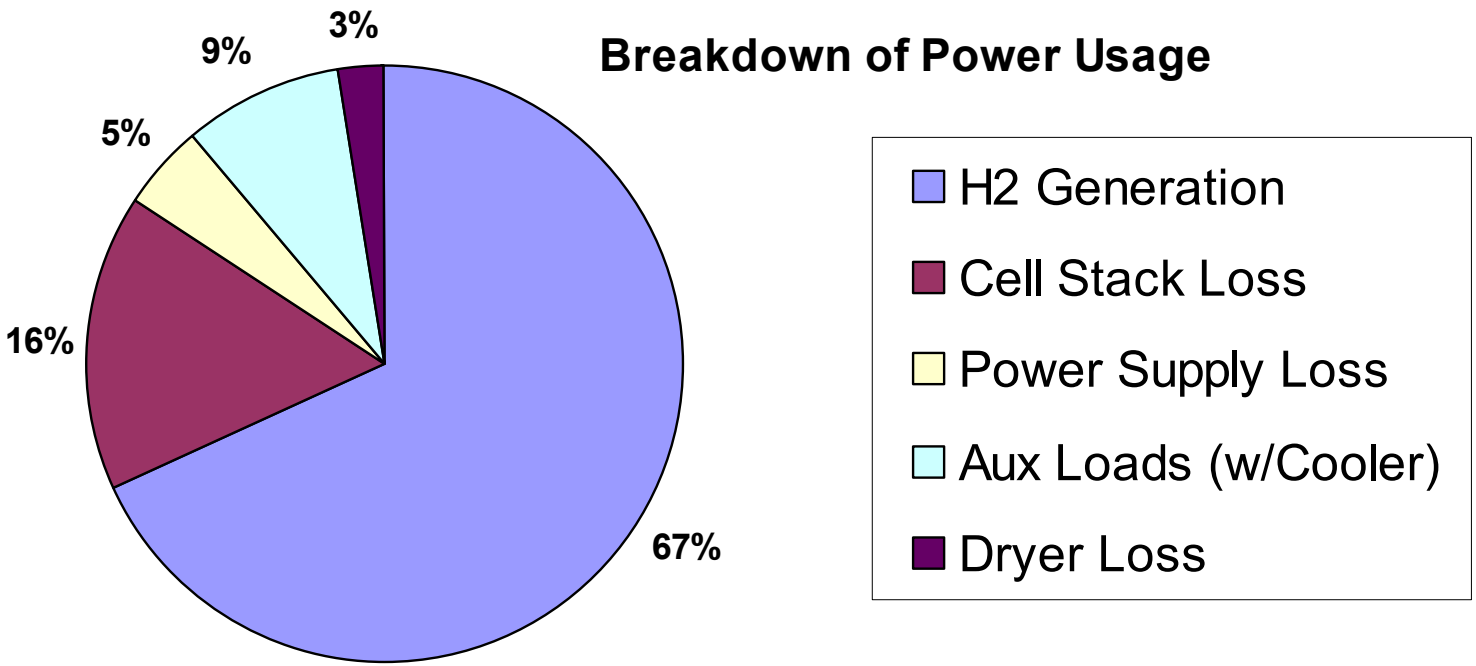
Results – Electrical Efficiency

- Cell Stack Losses About 20% Of Power Used
  - Direct Loss Plus Half of Aux Loads For Cooling



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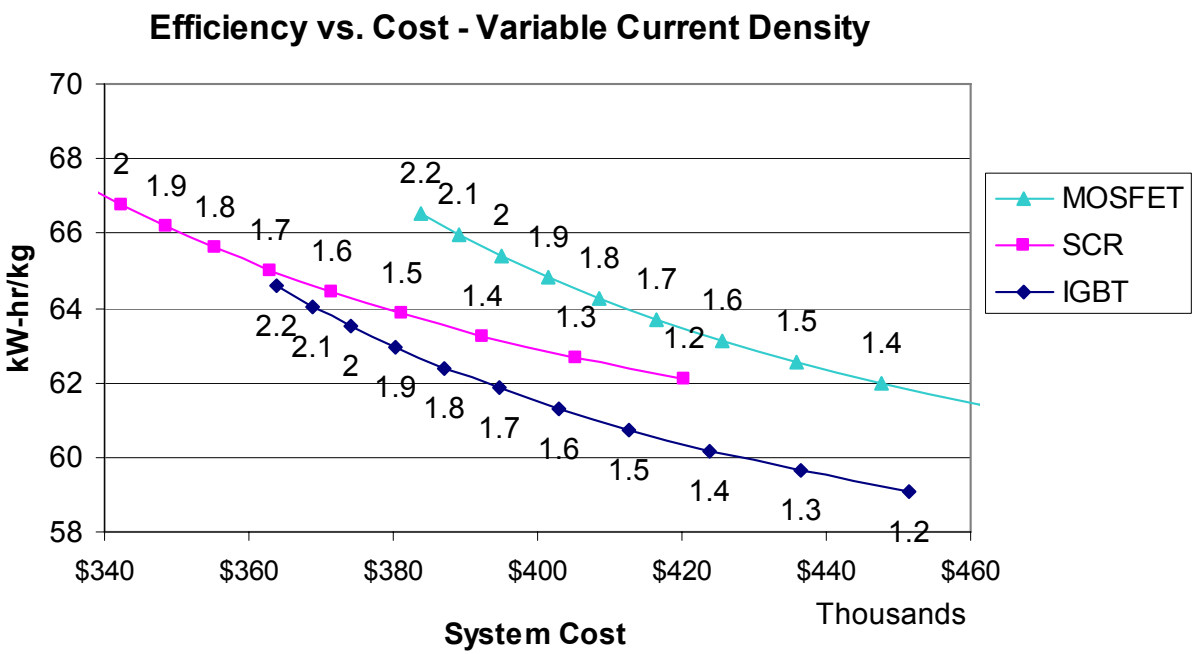
Results – Key Design Trade Study

- Power Supply And Cell Stack Interaction
  - Power Supply
    - High Voltage / Low Current Best For Efficiency
  - Cell Stack
    - Large Active Area / Least # Of Cells For Cost
  - Solution
    - One Power Supply Driving Multiple Cell Stacks In Series Enables A Cost Effective Middle Ground

Results – Power Supply Trade Study

- IGBT Technology Power Supply Best Solution
  - System Cost and Net Efficiency Combination
  - Integration With Renewable Power Sources (AC/DC)



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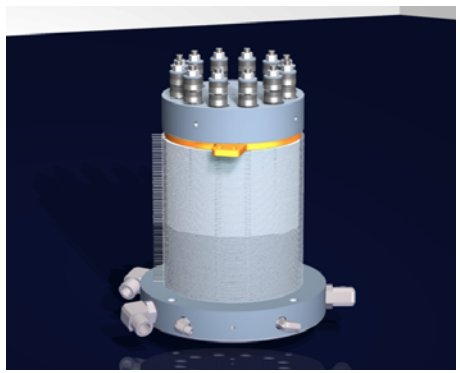
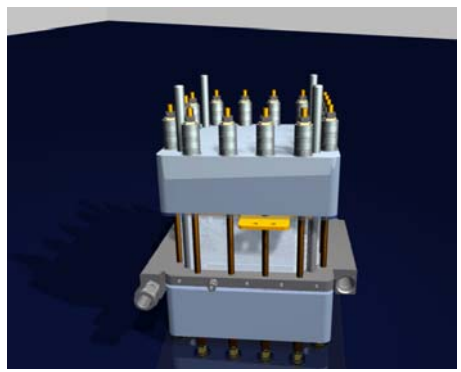
Results – Cell Stack Trade Study

- Current Production
  - Higher Labor Content
  - Marginal Efficiency
  - Lower Material Cost
- Bi-Polar Plate
  - Fewer Parts
  - Higher Efficiency Design
  - Higher Material Cost

Additional Development Required For Final Selection



210 cm^2 active area,
25 kg H_2/day cell stack



550 cm^2 active area,
34 kg H_2/day cell stack

Results – Hydrogen Drying Trade Study

- Production PSA Dryer Uses 10% Of The Product Hydrogen To Regenerate
- Increasing System Pressure To 30 barg Cuts Loss To 5%
- Cooling The Product Gas Prior To Dryer Reduces Loss Conservatively To 2-3%
- Larger Output System Enables Cost Effective Solution Not Possible At Current Size

Results – Separator Subsystem Testing

- Visualization of Higher Flows For Trade Study
- Hydrogen Separator
  - Indicates Feasibility Of Small Simple Separator
- Oxygen Separator
  - Large Simple Separator Is Unlikely
  - Multiple Separators May Be Required

Results – Power Supply Testing

- SCR DC Motor Drive
  - Rated 98% Efficiency
  - Highest Efficiency Supply Studied
  - Current Pulse Output
- Sub-Scale Test
  - 12 kgH_2/day Unit
  - Cell Stacks In Series
- Insight Gained
  - Required 6% Additional Energy per kg H_2 vs. Baseline
  - Lowest Net System Efficiency Of Study

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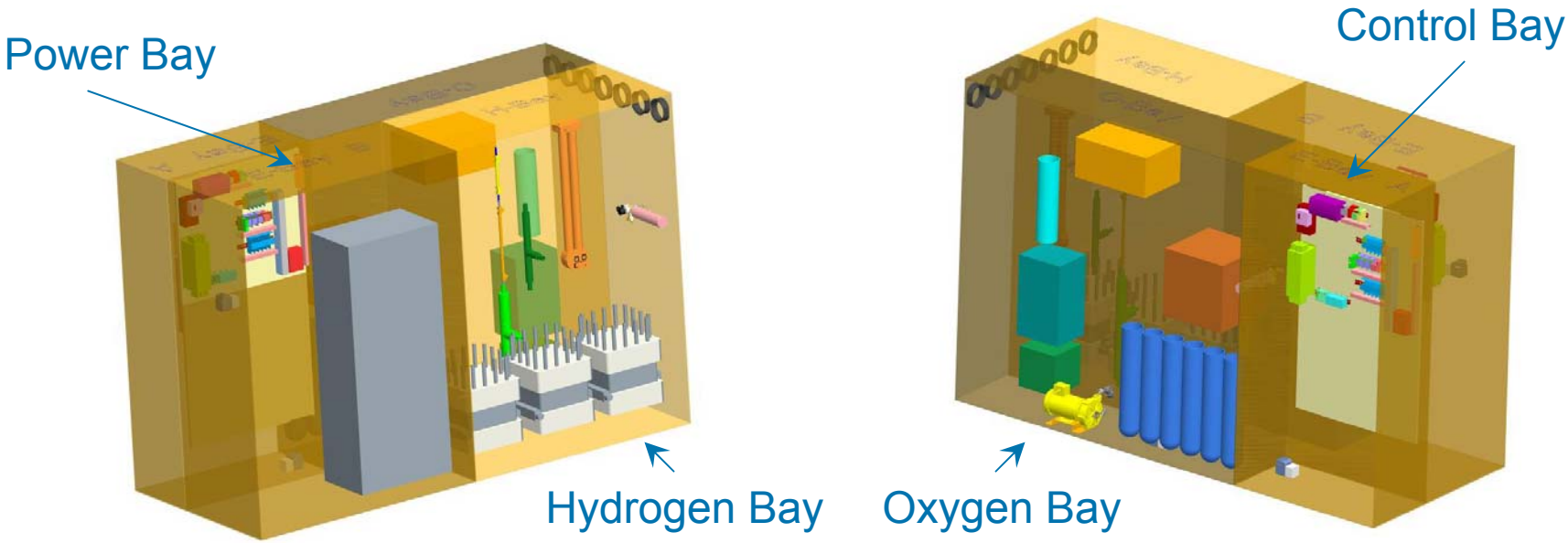
Results – Conceptual Design

- Eight Times Generation Capacity With Only Three Times Increase In Size (12’x5’x6’)
- Compartmentalized For Hazard Mitigation



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Proposed Future Work

- Program Complete
- Focus Areas Identified For Future Work
  - Bi-Polar Plate Cell Stack Development
    - Scale Up In Active Area, 6 x Present Design
    - Greatest Potential For Increased System Efficiency
  - Full Scale Balance Of Plant Development
    - Separation And Drying For High Efficiency And Low Cost

Summary

- **Relevance:** Establish Robust Estimates For Medium Scale Electrolysis Cost And Performance vs. DOE Targets
- **Approach:** Perform Trade Studies And Conceptual Design Of 100 kgH_2/day Electrolyzer
- **Results:** Significant Gains Against DOE Targets Achievable At 100 kgH_2/day Size
- **Future Work:** Program Complete