HYDROGEN ENERGY SYSTEMS
AVALENCE™ LLC

High-Capacity, High Pressure Electrolysis System with Renewable Power Sources

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DOE Merit Review, June 10, 2010

Project # PD029

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ELECTROLYZER DEVELOPMENT PROGRAM

Timeline

Start Date: May 2008
End Date: Sept 2011
Percent Complete: 30%

Barriers Addressed

Capital Cost
System Efficiency
Renewable Power Integration

Budget

Project Funds: $2.41M
DOE: $1.93M
Contractor: $0.48M
FY 08 Funds: $393K Spent
FY 09 Funds: $487K Spent
FY 10 Funds: $300K Allocated
(Pending Go/No Go Gate)
$0K Spent

Partners

Avalence: *Lead*
HyperComp: *Composite Wrapping*
Hydrogen Energy Center: *Installation Funding*
MaineOxy: *Revenue Operation*

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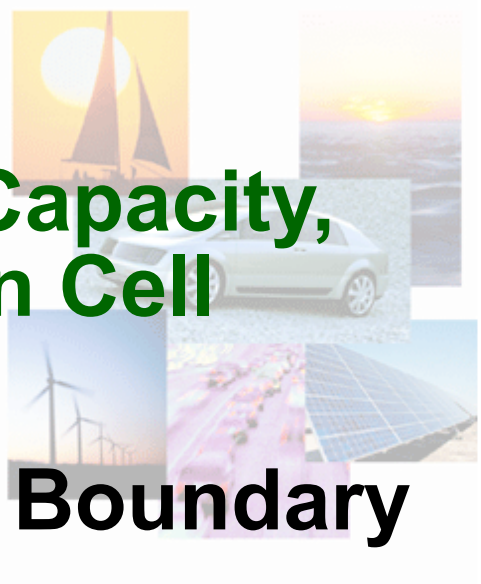
ELECTROLYZER DEVELOPMENT ORIGINAL PROJECT GOALS

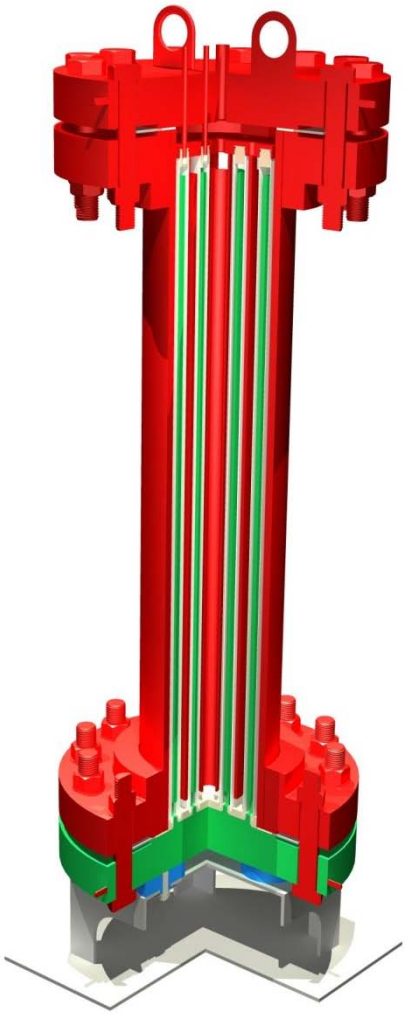
- **Achieving at Least a 15 X Increase in the Gas Production Rate of a Single High Pressure Production Cell**
- **Demonstrate the High Pressure Cell Composite Wrap Which Enables Significant Weight Reduction**
- ***Build and Test a 1/10th Scale Pilot Plant***
- **Perform Economic Assessment for Full Scale Plant (300 kg/day, 750 kW) That Meets DOE 2017 Cost Target of $3.00/gge**

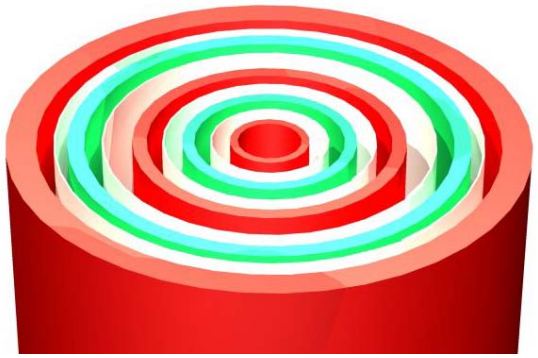
Design Approach For High-Capacity, High-Pressure Production Cell



- Maintain Cylindrical Pressure Boundary Configuration
- Increase the Diameter By Using a Composite Outer Wrap
- Place Multiple Electrode and Membrane Pairings Inside a Single Cell Body
- Electrodes Act as Two Sided Unipolar Electrodes

Nested Cell Design with Composite Overwrap (Overwrap not Shown)





- Nested arrangement, electrically in parallel
- Green anode (oxygen production)
- Red cathode (hydrogen production)

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Project Challenges

Design and Fabrication

- Large Diameter Membrane Formation
- Membrane to Manifold Sealing
- Fluid and Power Penetrations
- Composite Wrapping “Heavy” Cylinder
- Process Control of a Multiple, High-Capacity Cell Array

Performance Demonstration

- Long-Term Operation at 6500 psi (O2 Side Purity)
- Low/No Leakage Electrical Isolation Hoses at 6500 psi

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DEVELOPMENT PROGRAM MILESTONES

Project Milestones	
Description	**Status**
Determine a Manifolding and Sealing Arrangement for Nested Cell 1) H_2 and O_2 Gas Separation 2) Electrical Connection to Electrodes 3) Electrolyte Replenishment	Complete
Determine Containment Penetration Size and Design 1) Compatible with Composite Wrapped Vessel Constraints, 2) Support Cell Electrode Current Magnitudes (>1000 amp) 3) H_2 and O_2 Gas Off-Take 4) Electrolyte Replenishment	Complete
Design a Functional Shape of Outer Metal Jacket For Dual Purpose: ➢ Outer Electrode's Inner Surface ➢ Vessel Liner that is the Foundation for Composite Wrap	Complete
Demonstrate the Performance of the Nested Cell Core so that Accurate Projections of Energy Use can Be Integrated into the Cost Model	In Process
Demonstrate the Ability to Implement a Composite Fiber Outer Wrap Over the Nested Cell Core	Not Yet Started
Produce a Pilot Plant Design For Use as a Basis for a Sound Economic Analysis of Plant Fabrication and Operating Cost	Not Yet Started
Demonstrate the Operation and Efficiency of the Pilot Plant ➢ Laboratory Testing at Avālence ➢ Field Testing at NREL	Not Yet Started
Have a Site Ready to Accept the Completed Plant for Commercial Operation ➢ 100 kW of Renewable Power in Place ➢ Sale or Use of the Plant Products Defined	Not Yet Started

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Significant Project Accomplishments

1) Identified and Tested Formable Sheet Membrane Material
2) Successfully Demonstrated Membrane Tube Forming and Seam Joining
3) Identified Vendor and Ordered 6500 psi Capable Electrical Isolation Hoses
4) Completed Design of Single Cell Test Article and Test Apparatus
5) Demonstrated 6500 psi Production on Small Capacity Cells

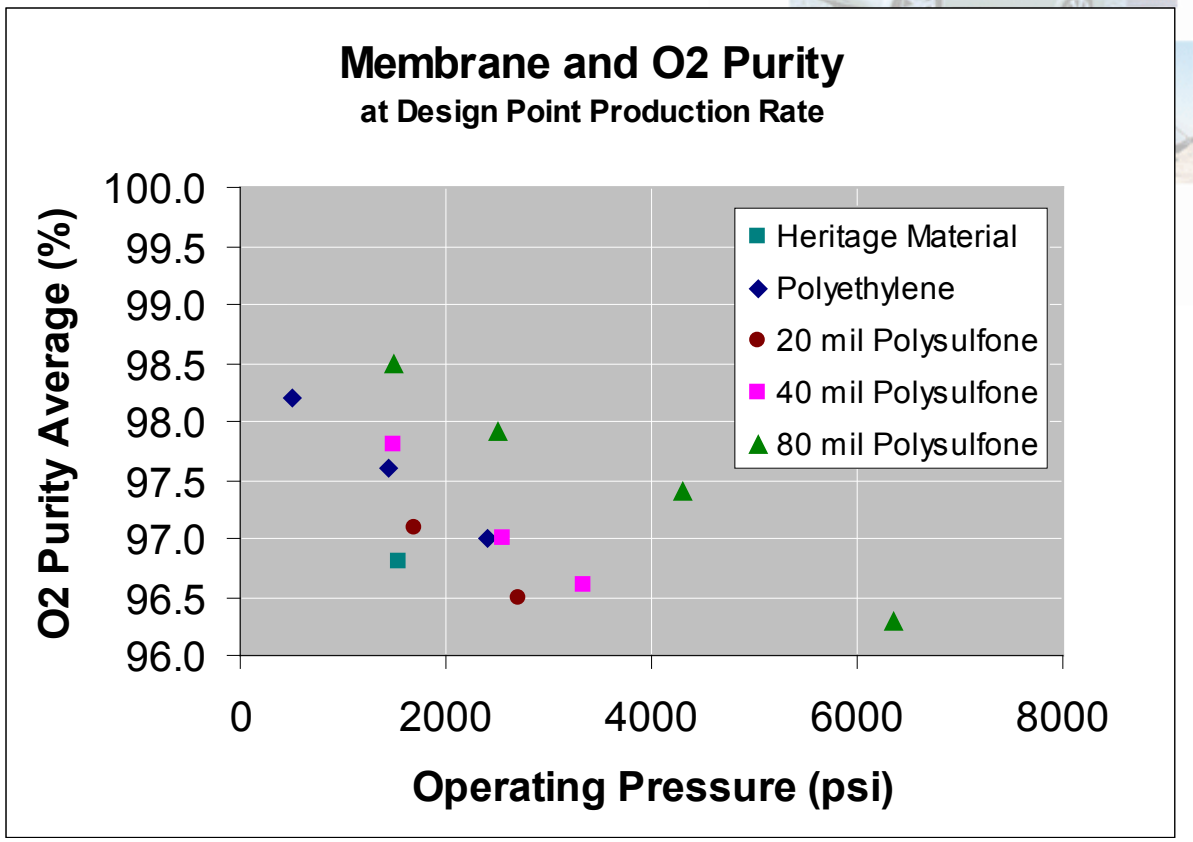
Demonstrated Membrane Sealing

- Poly-Sulfone Material Wrapped Around Perforated Tubular Form
- Proprietary Adhesive Used to Seal Overlapped Edges
- Vacuum Used to Maintain Membrane Shape During Curing

Formed and “Glued” Tubular Membrane

Demonstrated 6500 psi Operation

- 2 inch Diameter Cells Used for Testing
- Multiple Membrane Materials Tested
- 80 mil Thick PolySulfone Membrane Performed "OK"
- Electrolyte Requires Weekly "Decompression" to Maintain Purity



Increasing Polysulfone Thickness Decreased Efficiency	80 mil	67 kWh/kg
	40 mil	62 kWh/kg

2010 Project Focus

Meet Remaining Go/No Go Objective

- Demonstrate Large Diameter Cell Operation at 1000 psi

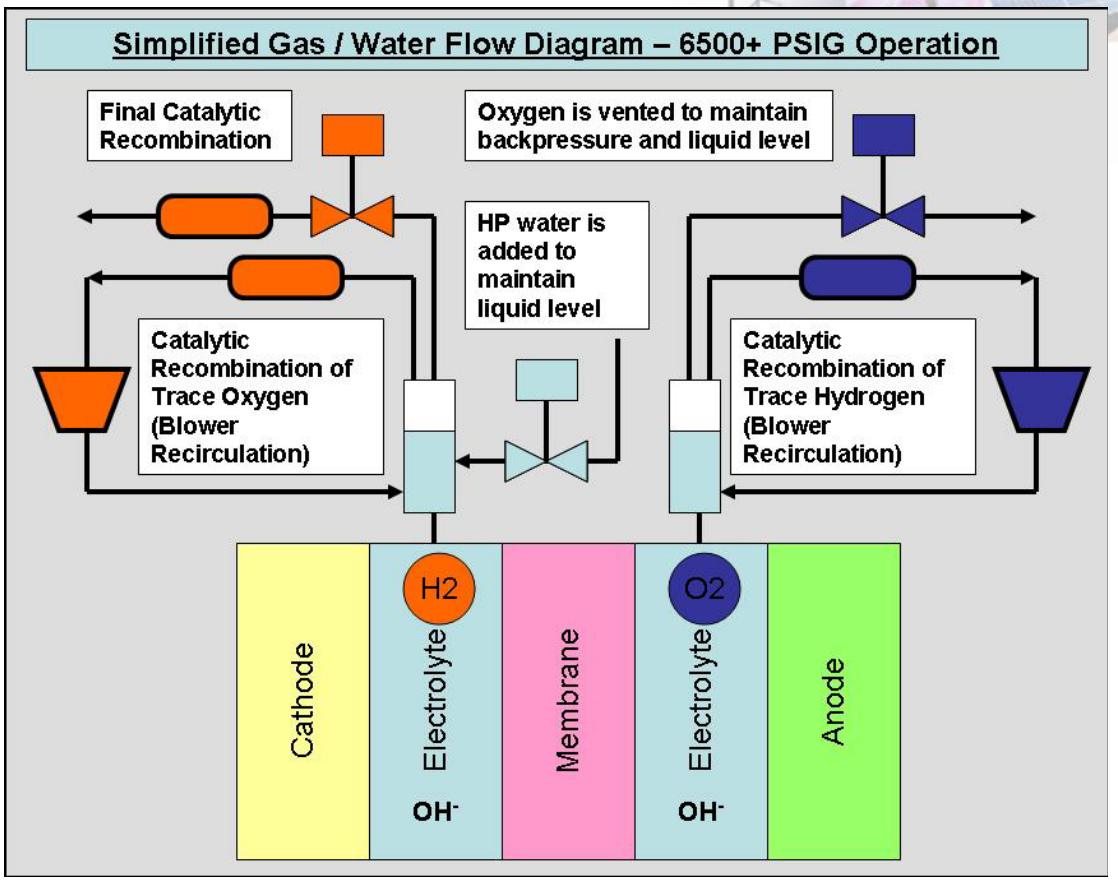
Test Long-Term 6500 psi Operation Approaches

- Use Existing Small Cell Apparatus
- Purified Gas “Recirculation/Dilution” Approach
- Neutral Electrolyte Chamber Approach

Long –Term 6500 psi Operating Approach I

- Recirculate Post-Catalyst Gas into Gas/Liquid Separator Vessels
- Recirculation Rate Will Set Dilution Rate and Therefore "Raw" Gas Purity
- Perform Initial Tests on Existing "Small-Scale" Cells

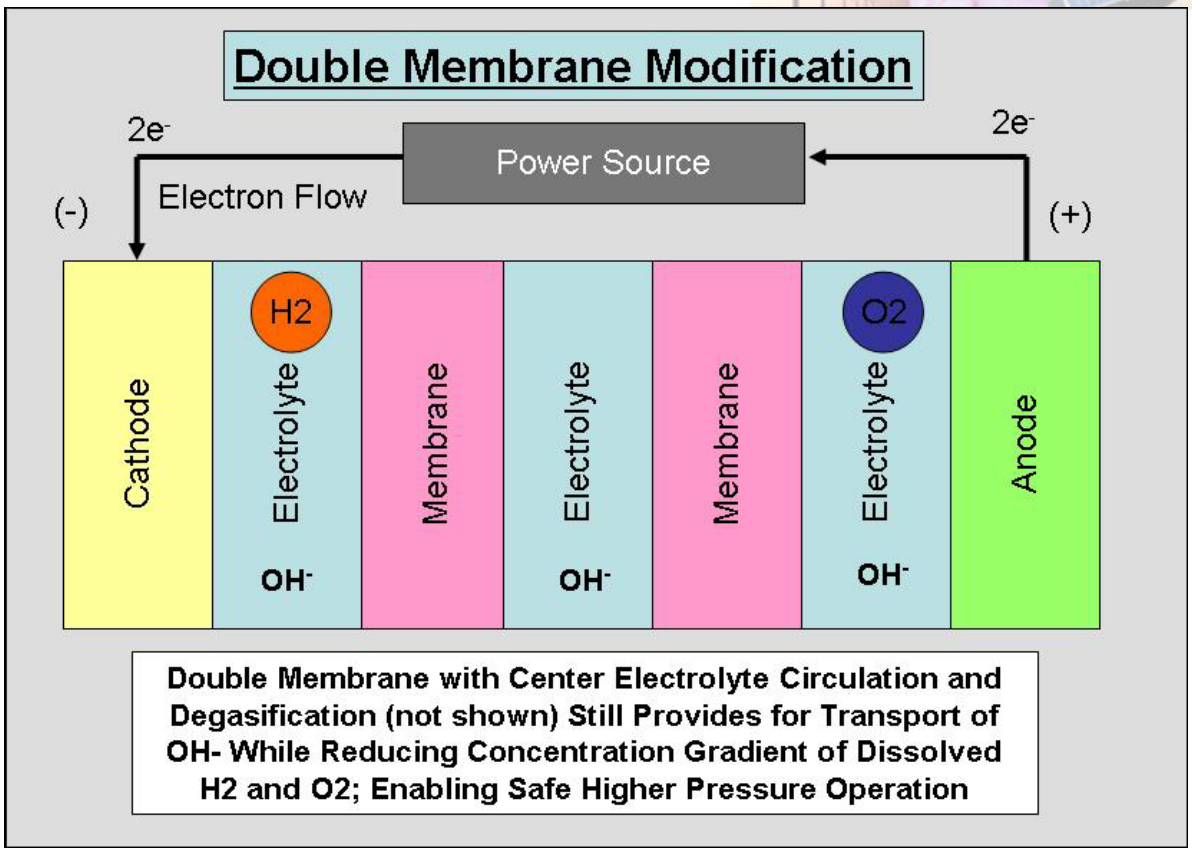
Recirculation/Dilution With Purified Gas



Long –Term 6500 psi Operating Approach II

- Neutral Electrolyte Region Gives "Long" Dissolved Gas Diffusion Length
- Use Thinner Membranes to Minimize Resistance to Ion Transport
- Perform Initial Tests on Existing "Small-Scale" Cells

Neutral Electrolyte Chamber



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Program Status/Future Plans

Original Effort (Key Technical Goals)

- Demonstrate 6500 psi Single Cell (Go/No Go)
- Build 6500 psi, 20 Cell Pilot Plant

Present Status

- Achieved 6500 psi Operation in Small Cells
  - Significant Program Effort
  - Improved O2 Side Purity Margin is Desirable for Long Term Operation
  - Resolved 6500 psi Electrical Isolation Hose Issue
- Large Cell Design ”Ready-to-Go”
  - Resolved Key Membrane Forming and Sealing Issues

Proposed Redefined Project Goals

- Demonstrate Large Diameter Cell Operation at 1000 psi (Go/No Go)
- Demonstrate Long-Term 6500 psi Operation
  - Test Recirculation and Neutral Buffer Approaches
- Build 6500 psi Pilot Plant
  - Reduce Number of Cells as Needed

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Why Bother?

One Example: Baseload Firming

1/3 of the Available Power Converted to H2
1 Full Day Fuel Cell Power Stored

100 MW Installed Wind, 33 MW Electrolyzer (50 Units), 22,500 kg Storage, 25 MW Fuel Cell	Without H2 System	With H2 System
Annual Electrolyzer, Storage, Fuel Cell System Cost (20 Year Amortization)	-	$1.3 MM
Annual Wind Turbine Installation Cost (20 Year Amortization)	$7.5 MM	$7.5 MM
Annual Operating, Maintenance, Refurbishment	$1.5 MM	$2.0 MM
Annual "Junk" Power Yield (35% Capacity Factor)	307 GWh	205 GWh
Annual On-Demand Power Yield (50% Efficiency)	-	51 GWh
Annual Value of "Junk" Power @ 3.5¢/kWh	$10.7 MM	$7.2 MM
Annual Value of "Peak" Power @ 15¢/kWh		$7.6 MM
Annual Profit	$1.7 MM	$4.0 MM

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