HYDROGEN ENERGY SYSTEMS

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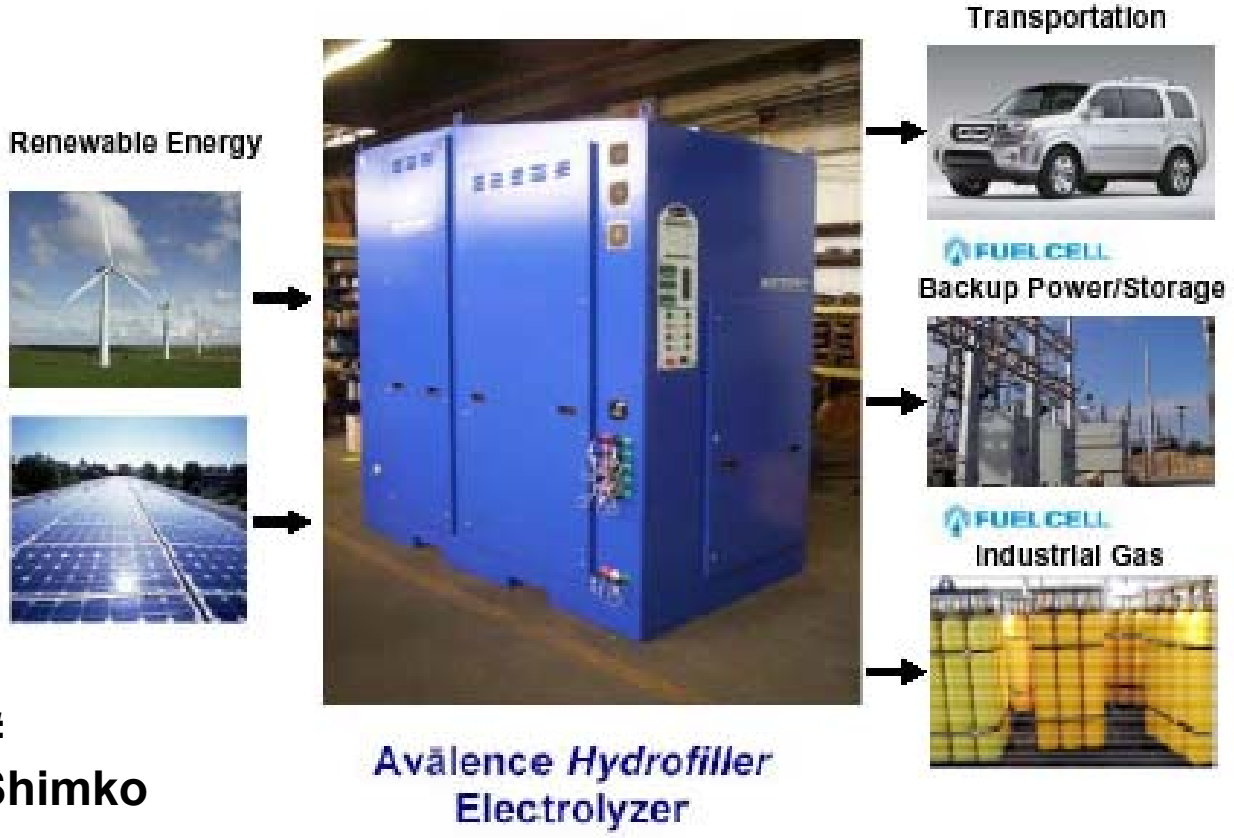
High-Capacity, High Pressure Electrolysis System with Renewable Power Sources



Project #
PD_20_Shimko

Martin Shimko, Avalence LLC, DOE Merit Review, May 19, 2009

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ELECTROLYZER DEVELOPMENT PROGRAM

Timeline

Start Date: May 2008
End Date: Sept 2011
Percent Complete: 15%

Barriers Addressed

Capital Cost
System Efficiency
Renewable Power Integration

Budget

Project Funds: $2.41M
DOE: $1.93M
Contractor: $0.48M

FY 08 Funds: $650K Allocated
FY 09 Funds: $230K Allocated

Partners

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

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ELECTROLYZER DEVELOPMENT 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

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ELECTROLYZER DEVELOPMENT PROGRAM

Project Technical Objectives
Determine a Manifolding and Sealing Arrangement for Nested Cell that Satisfies Need for H_2 and O_2 Gas Separation, Electrical Connection to Electrodes, and Electrolyte Replenishment
Determine Containment Penetration Size and Design that is Compatible with Composite Wrapped Vessel Constraints, Cell Electrode Current Transfer and Flow Requirements For Gas Off-Take and Electrolyte Replenishment
Design a Functional Shape of Outer Metal Jacket For Dual Purpose: 1) Outer Electrode's Inner Surface 2) Vessel Liner that is the Foundation for Composite Wrap
Demonstrate the Performance of the High Output Cell Core so that Accurate Projections of Energy Use can Be Integrated into the Cost Model
Demonstrate the Ability to Implement a Composite Fiber Outer Wrap Over the High Output Cell Core
Produce a Pilot Plant Design For Use as a Basis for a Sound Economic Analysis of Plant Fabrication and Operating Cost
Demonstrate the Operation and Efficiency of the Pilot Plant 1) Laboratory Testing at Avālence 2) Field Testing at NREL
Have a Site Ready to Accept the Completed Plant for Commercial Operation 1) 100 kW of Renewable Power in Place 2) Sale or Use of the Plant Products Defined

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ELECTROLYZER DEVELOPMENT PROGRAM SCHEDULE

First Year – Tasks 1, 2, 3

Stretched to 24 Months Based on Anticipated Funding Availability

Remaining Tasks 4 – 8

18 Month Schedule Dependant on Funding Availability

PROJECT TIME LINE				Calendar Year Quarter										
	Q2 08	Q3 08	Q4 08	Q1 09	Q2 09	Q3 09	Q4 09	Q1 10	Q2 10	Q3 10	Q4 10	Q1 11	Q2 11	Q3 11
Preliminary Design	■	■	■	■										
Preliminary Nested Cell Demonstration (1,000 psi)					■	■								
Wrapped Cell Demonstration (2,500 psi)							■	■						
Go/No Go Decision Gate								Δ						
Final Cell Design									■					
Pilot Plant Design (40 kg/day)										■				
Pilot Plant Fabrication											■	■		
Pilot Plant Laboratory Testing													■	
Pilot Plant Testing at NREL														■

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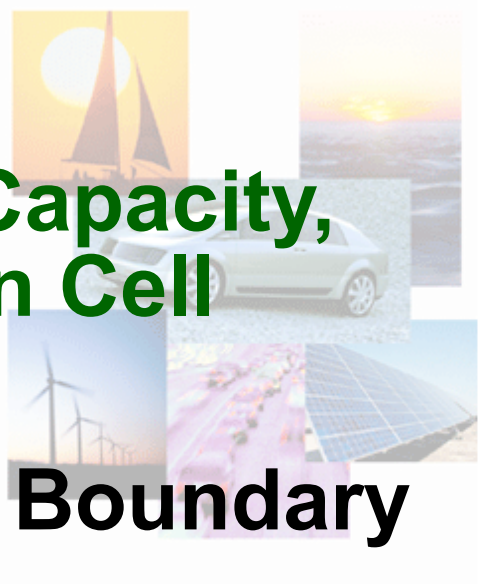
ELECTROLYZER DEVELOPMENT PROJECT MILESTONES

Original Project Milestones	
Milestone Description	**Revised Original Proposed Completed End of**
Preliminary Test Cell Fabricated	Month 15
Preliminary Test Cell Testing Complete (1000 psi)	Month 17
Cell Internal Design Frozen	Month 18
Carbon Wrapped Cell Delivered	Month 19
Single Cell Testing Complete (2,500 psi)	Month 22
Efficiency, Manufacturability, and Economics Updated	Month 22
Go/No Go Review (Technology and Economics)	**Month 22**
Pilot Plant Design Complete	Month 26
Pilot Plant Fabrication Complete	Month 32
Pilot Plant Shakedown Testing Complete	Month 34
Pilot Plant Performance Testing Complete	Month 37
NREL Performance Testing Complete	Month 40

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



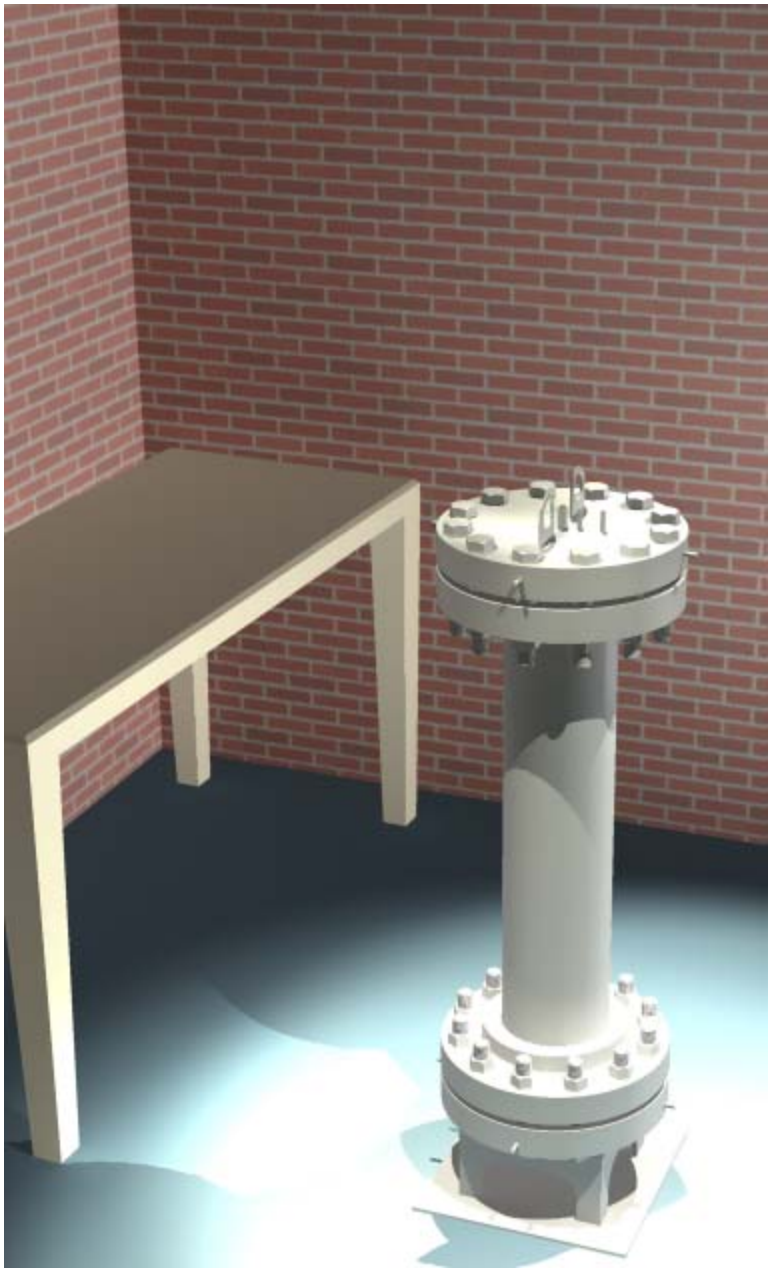
- Maintain Cylindrical Pressure Boundary Configuration
- Increase the Diameter By Using a Composite Outer Wrap
- Place Multiple Electrode and Membrane Pairings Inside a Single Cell Body
- Electrodes Act as Two Sided Unipolar Electrodes

Project Design Challenges

- 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

Project Accomplishments To Date

- Identified and Tested Formable Sheet Membrane Material
- Successfully Demonstrated Membrane Tube Forming and Seam Joining
- Completed Design of Single Cell Test Article and Test Apparatus
- Completed Preliminary Design of Composite Wrap Cell
- Began Fabrication of Test Cell and Apparatus



Single Cell Rendering

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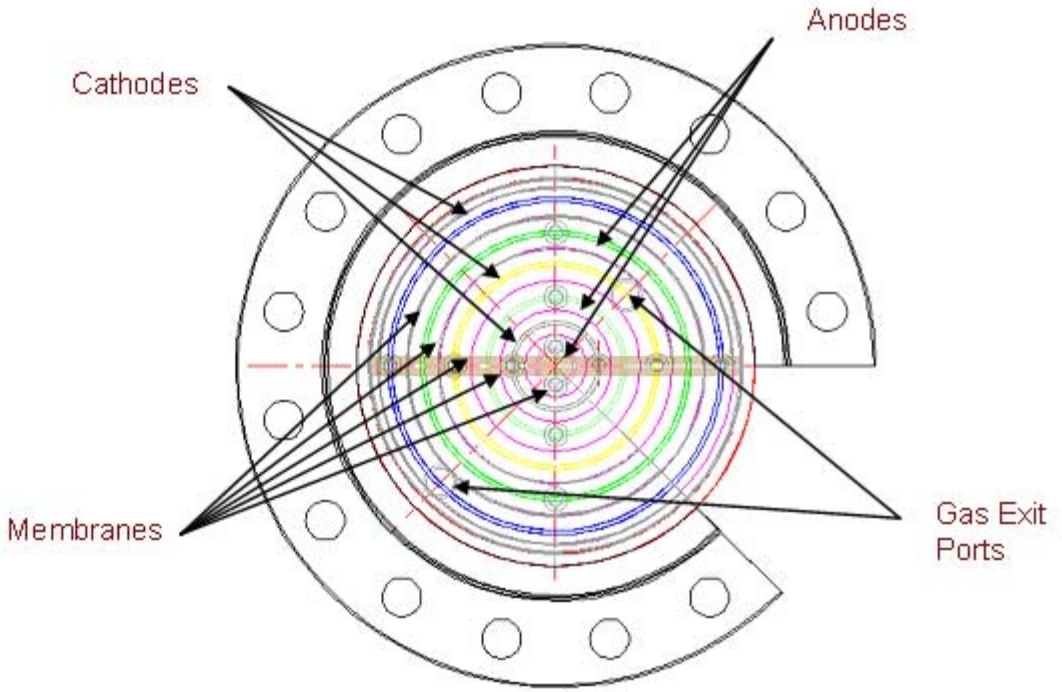
Initial 1000 psi Test Cell

- **Standard Flange and Steel Tube Containment**
- **"Same" Core Configuration as Composite Wrapped Cell**



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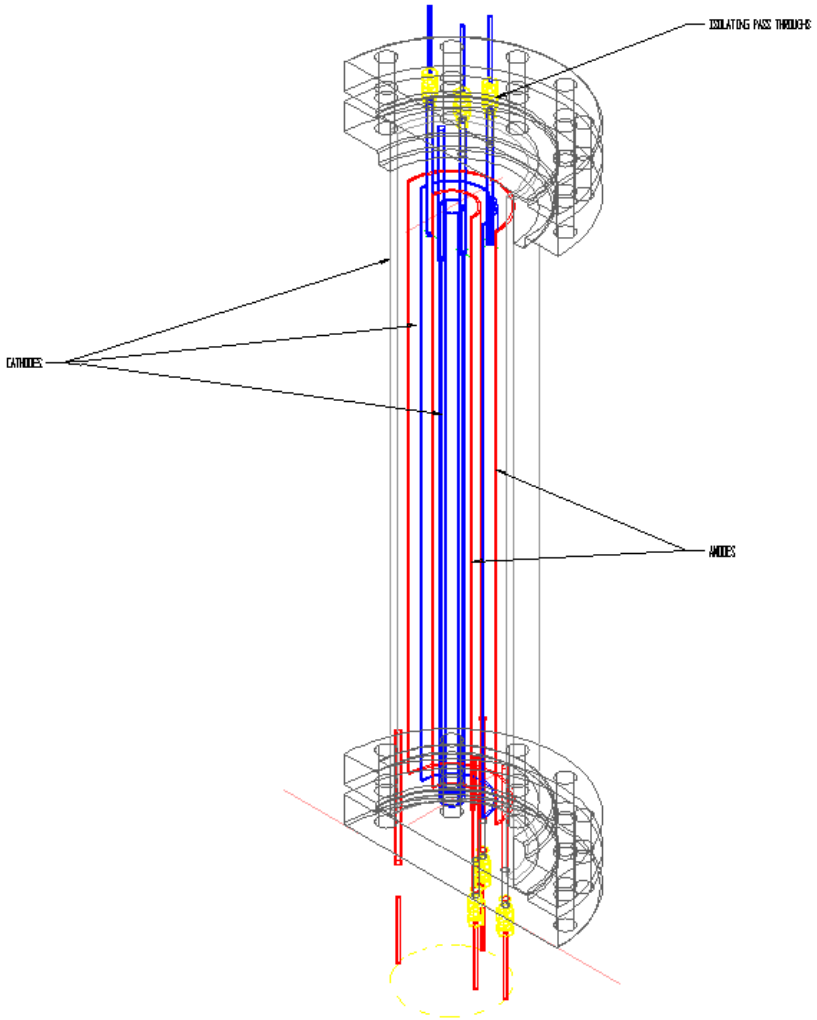
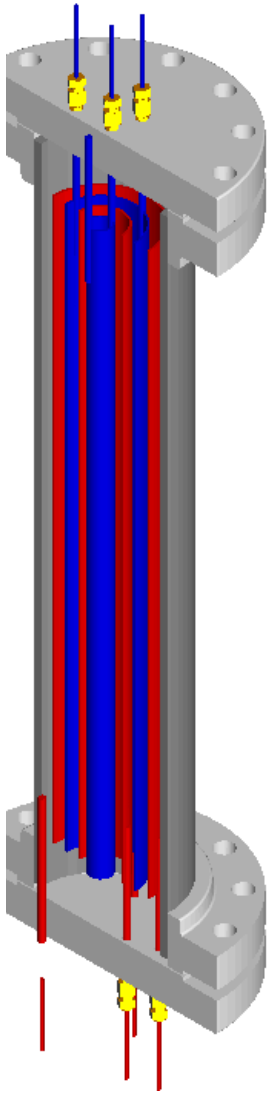
Initial 1000 psi Test Cell





Also Possible Composite Wrapped Configuration

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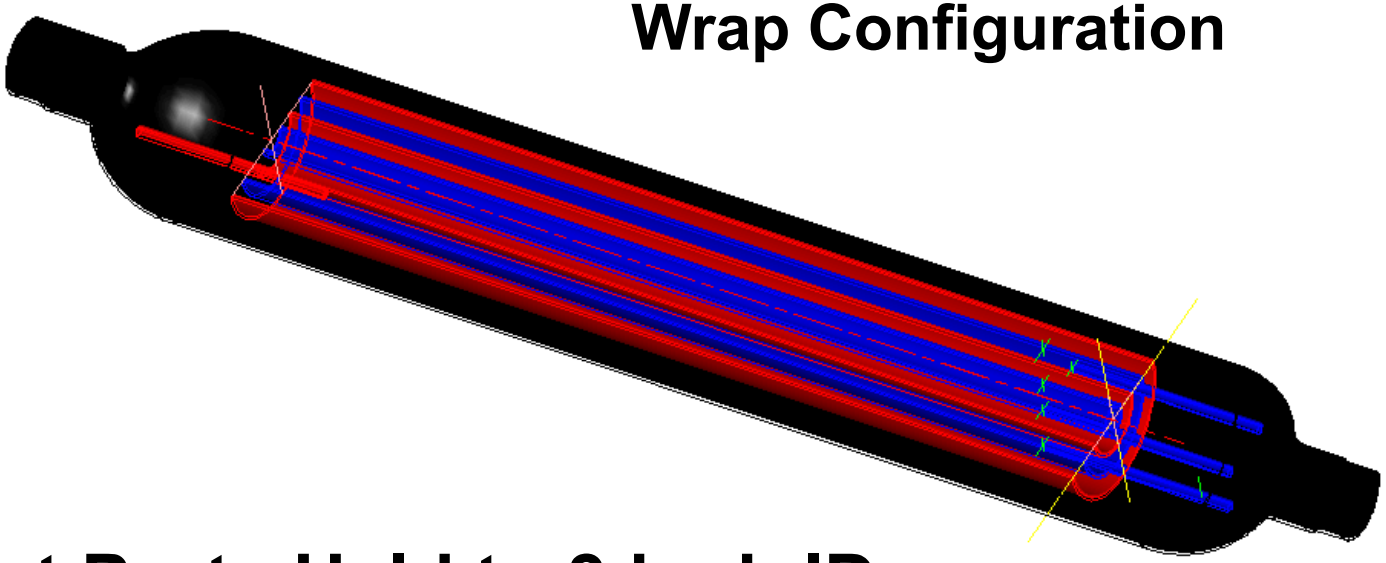
Composite Wrapped Cell

Another Possible Composite Wrap Configuration



- **Inlet Ports Held to 3 inch ID**
- **Top – 2 Gas Exit Ports, "Clamped" Cathode Connection**
- **Bottom – Anode Connection, Water Inlet**

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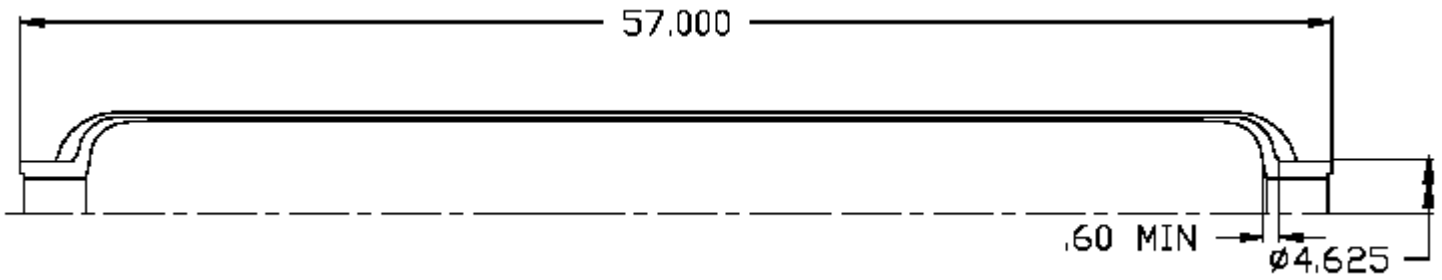
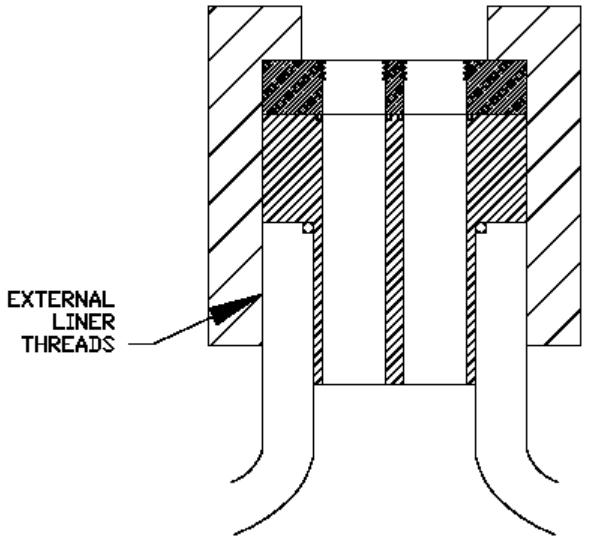
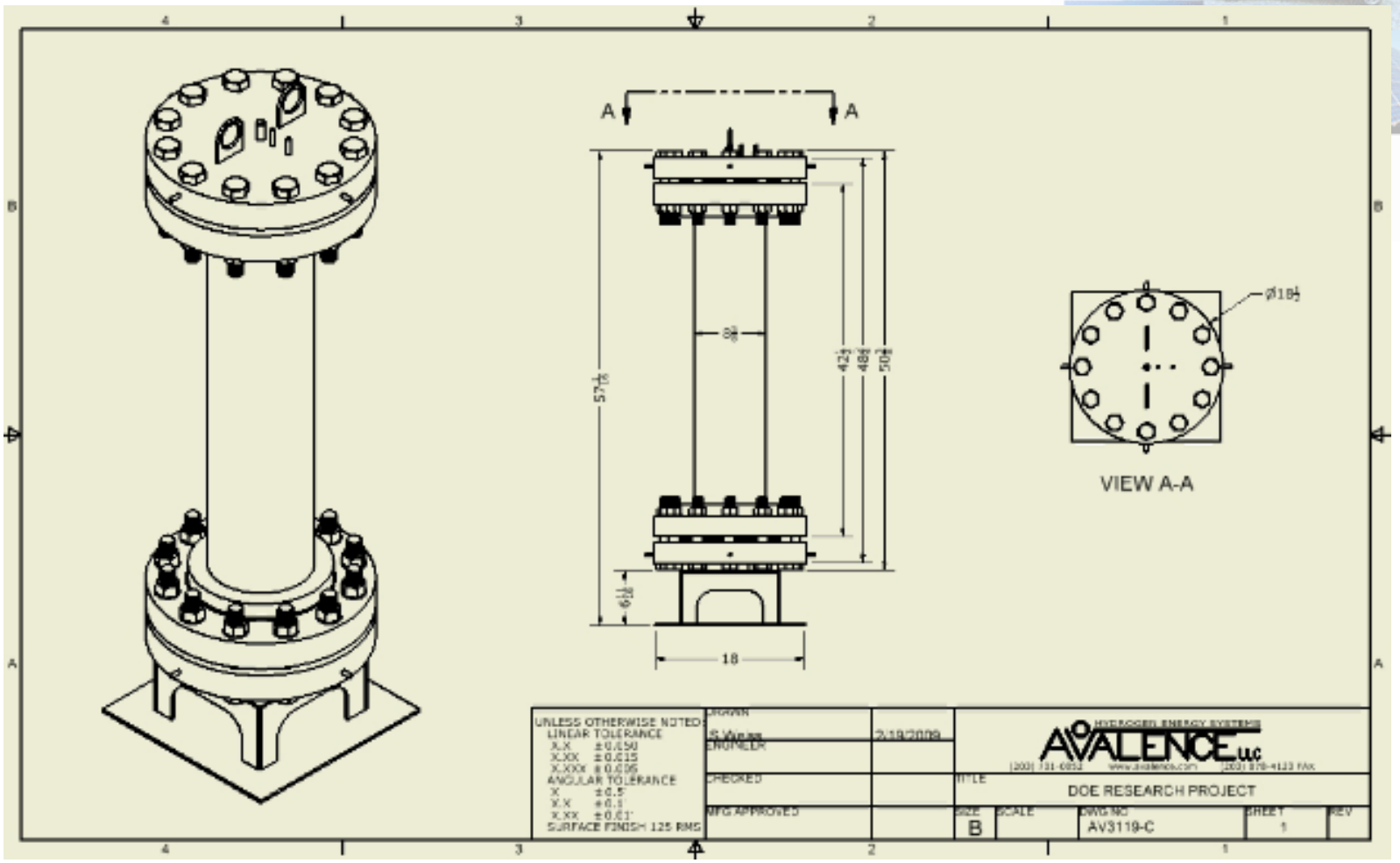
HEI Composite Shell Design

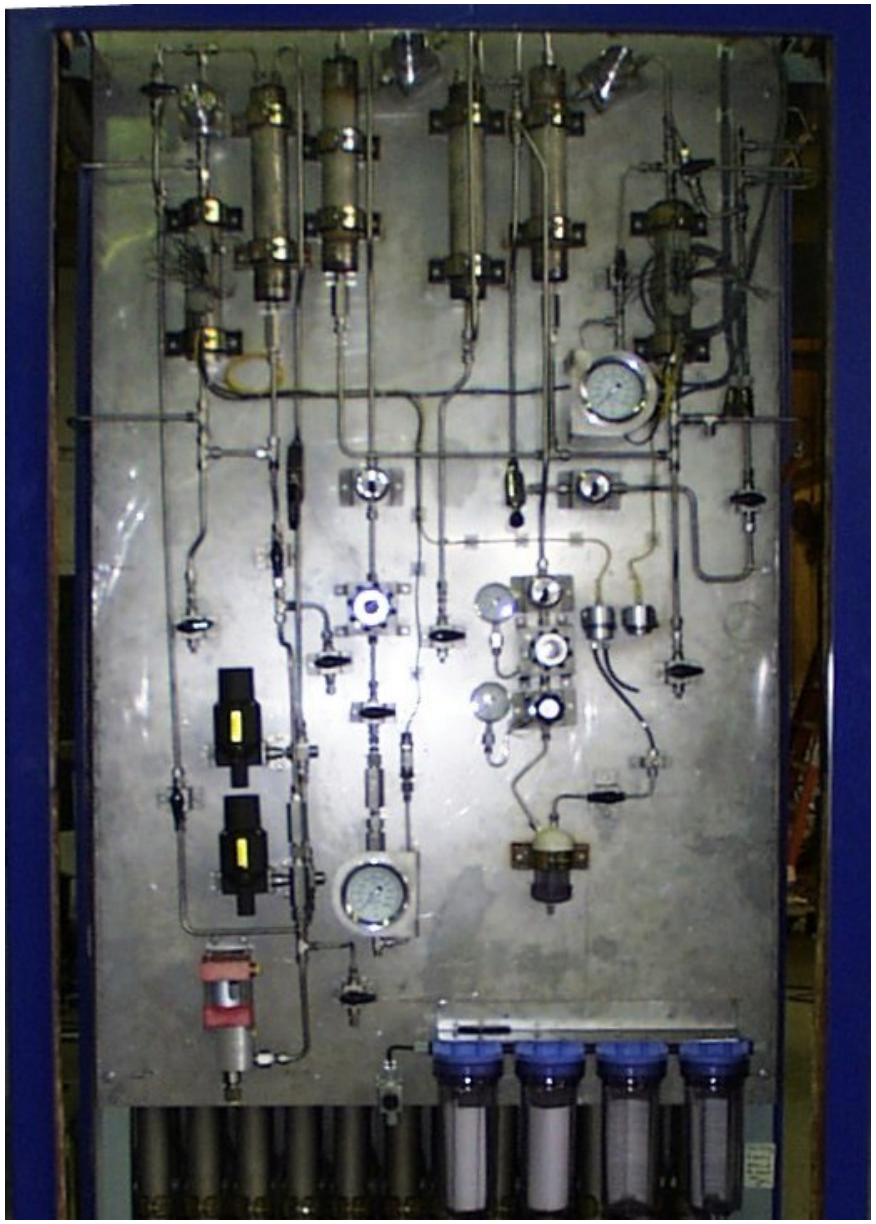


Need to settle on Design Pressure (2500 psi vs 6500 psi) before progressing further on the composite shell



Single Cell Engineering Drawing





Test Cell Valve Control Panel

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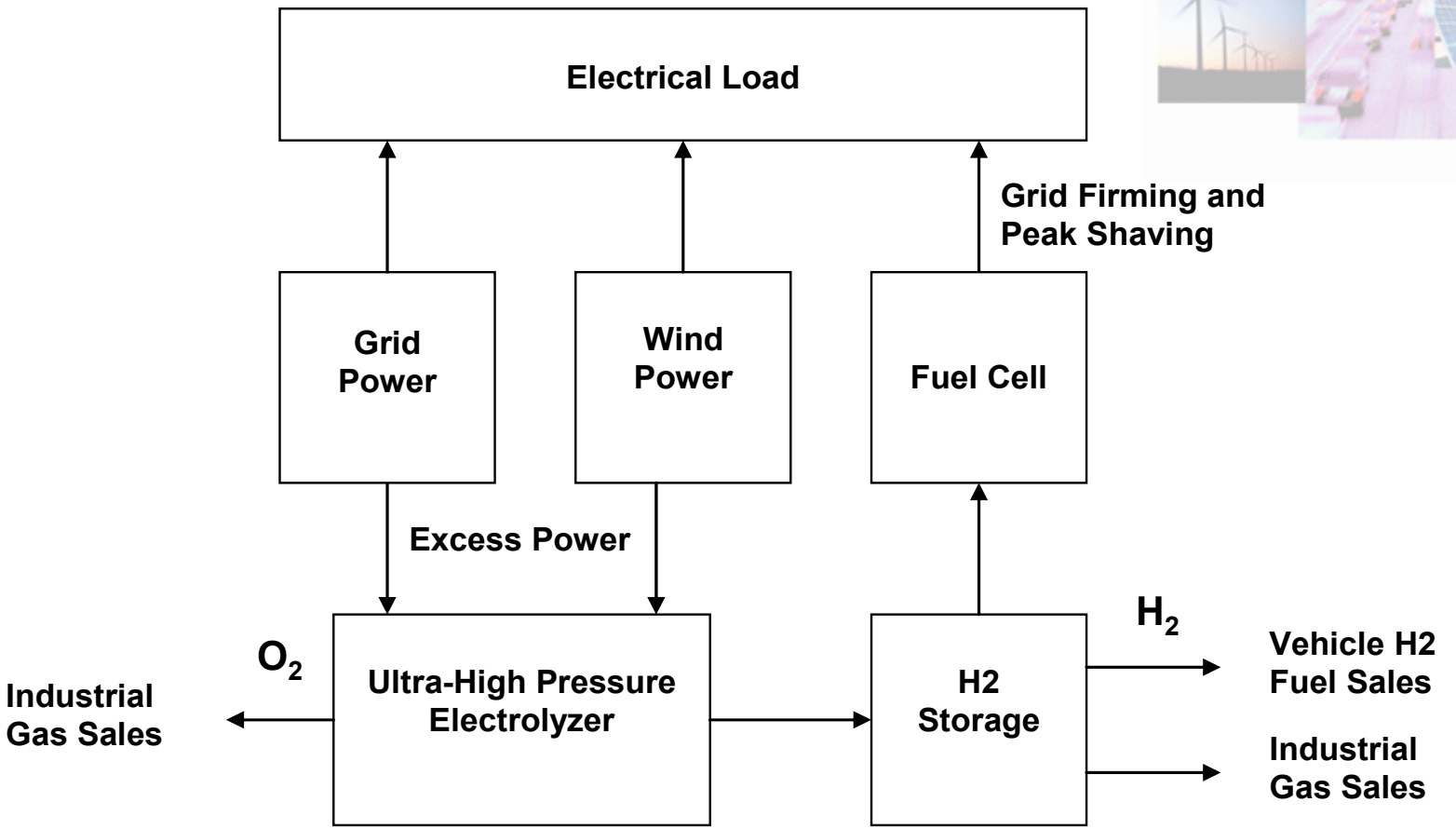
The Fully Integrated System Block Diagram



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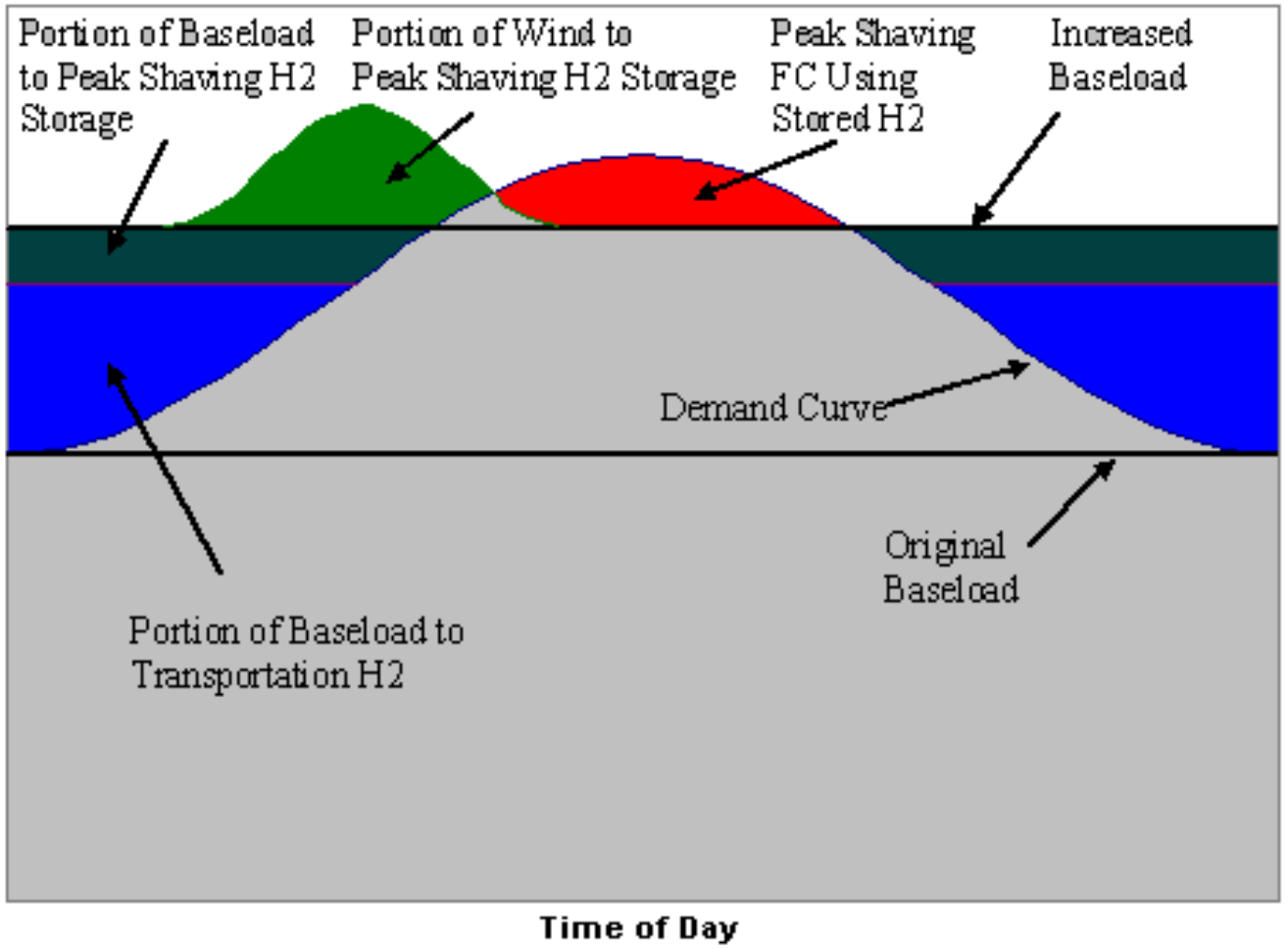
Energy Storage Utilizing Hydrogen

Unique Flexibility to Optimize System

- Allows Independent Sizing of Components to Optimize System Performance and Economics
  - Fuel Cell – Sets Power Output from Stored H2
  - Storage – Supply H2 for Required Period of Power
  - Electrolyzer – Fill H2 Storage in Required Period
    or
    Absorb Set Fraction of Available Power
- Both Peak Shaving and Off-Peak Utilization for Baseload Stabilization (Grid Firming)
- Allows H2 Production and Sale for Transportation Fuel

Maximize the Value of the Power Supplied

Example of Fully Integrated Wind, Base Load Power And Electrolyzer Hydrogen For Peak Shaving, Baseload Firming, And Transportation Fuel Production



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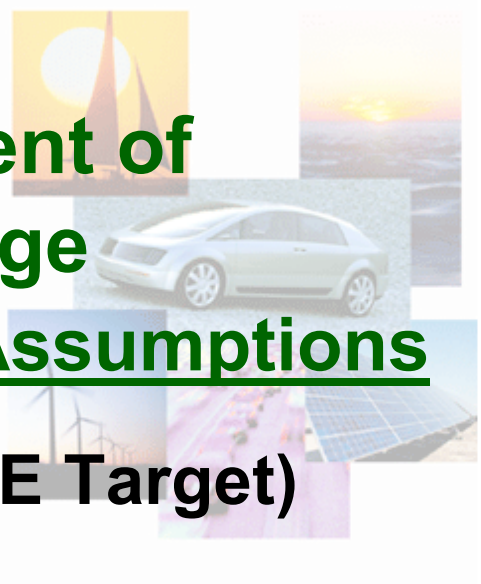
Simple Economic Assessment of Large Wind Energy Storage

Fully Commercial CapEx and Cost Assumptions



- Electrolyzer: $480/kW (Meeting DOE Target)
- Fuel Cell: $200/kW
- H2 Storage:$200/kg
- Annual O&M, Refurbishment Reserve:
  - 3% of System CapEx for H2 System
  - 1% of System CapEx for Wind System
- Wind Power Installed Cost: $1.50/W
- Average PPA for Raw Wind: 3.5¢/kWh
- Average Value of “Peak” Power is 15¢/kWh

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Detailed Economics: 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, 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

HYDROGEN ENERGY SYSTEMS
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