HYDROGEN ENERGY SYSTEMS AVALENCE LLC

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

Project # PDP06

Martin Shimko, Avalence LLC, DOE Merit Review, June 11 2008

ELECTROLYZER DEVELOPMENT PROGRAM

Timeline

Start Date: May 2008
End Date: Nov 2010
Percent Complete: 2%

Barriers Addressed

Capital Cost
System Efficiency
Renewable Power Integration

Budget

Project Funding: $2.41M
DOE:$1.93M
Contractor: $0.48M
FY 07 Funding: $0
FY 08 Funding: $650K

Partners

Avalence: *Lead*
HyperComp: *Composite Wrapping*
MIT: *Fluid Flow Design*
Hydrogen Energy Center: *Installation Funding*
MaineOxy: *Revenue Operation*

ELECTROLYZER DEVELOPMENT PROGRAM

US DOE R&D Grant - Research and Development for Hydrogen Production and Delivery Technology

Program Topic - Hydrogen Production from Electrolysis

Funding - $2.4 M with 20% Cost Share
$930K Planned for FY 2008/2009

Schedule – 2 ½ (3) Years Starting May 2008

ELECTROLYZER DEVELOPMENT PROJECT PARTNERS

Avalence, Milford, CT

Design, Fabrication, and Testing

MIT, Cambridge, MA

Two Phase Fluid Design

HyperComp, Brigham City, UT

Cell Carbon Fiber Wrapping

Hydrogen Energy Center, Portland, ME

Siting and Installation Funding

MaineOxy, Auburn, ME

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**

ELECTROLYZER DEVELOPMENT PROJECT MILESTONES

Original Project Milestones	
Milestone Description	**Original Proposed Completed End of**
Preliminary Test Cell Fabricated	Month 5
Preliminary Test Cell Testing Complete (1000 psi)	Month 7
Cell Internal Design Frozen	Month 8
Carbon Wrapped Cell Delivered	Month 9
Single Cell Testing Complete (6,500 psi)	Month 12
Efficiency, Manufacturability, and Economics Updated	Month 12
Go/No Go Review (Technology and Economics)	**Month 12**
Pilot Plant Design Complete	Month 16
Pilot Plant Fabrication Complete	Month 22
Pilot Plant Shakedown Testing Complete	Month 24
Pilot Plant Performance Testing Complete	Month 27
NREL Performance Testing Complete	Month 30

ELECTROLYZER DEVELOPMENT

DOE Barriers Addressed

- **Capital Cost –** Increasing the Production Capacity for a Single Module Will Take Advantage of Economies of Scale
- **System Efficiency –** Demonstrate that the Direct High Pressure Electrolysis Maintains the High System Efficiency Demonstrated in the Smaller Scale Systems
- **Renewable Power Integration –** The Pilot Plant System will Be Compatible with Wind Power Input (and PV inherently) for Performance Testing at NREL

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

<u>First Year – Tasks 1, 2, 3</u>
Stretched to 17 Months Based on Anticipated Funding Availability

<u>Remaining Tasks 4 – 8</u>
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	Q4 09
Preliminary Design	■	■										
Preliminary Nested Cell Demonstration (1,000 psi)			■	■								
Wrapped Cell Demonstration (6,500 psi)					■	■						
Go/No Go Decision Gate						**Δ**						
Final Cell Design							■					
Pilot Plant Design (30 kg/day)								■				
Pilot Plant Fabrication									■	■		
Pilot Plant Laboratory Testing											■	
Pilot Plant Testing at NREL												■

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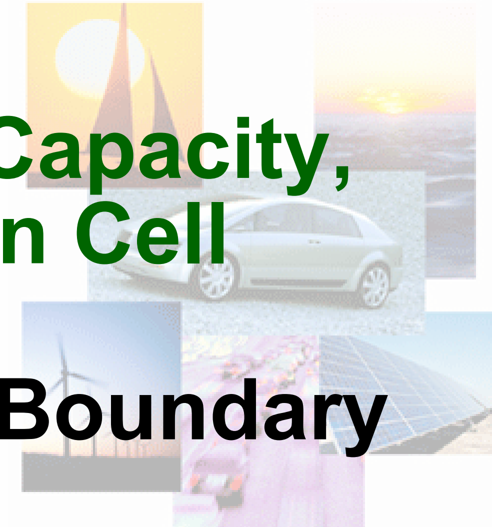


Design Approach For High-Capacity, High-Pressure Production Cell

- 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

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

Pilot Plant Design

- **20 Cell Array**
- **6500 psi Capable**
- **At Least 30 kg/day Production**
- **Compatible With Variable Voltage Wind and Solar (PV) Power**
- **Capable of “Harvesting” Both H2 and O2**
- **Fully Automated Process Control**

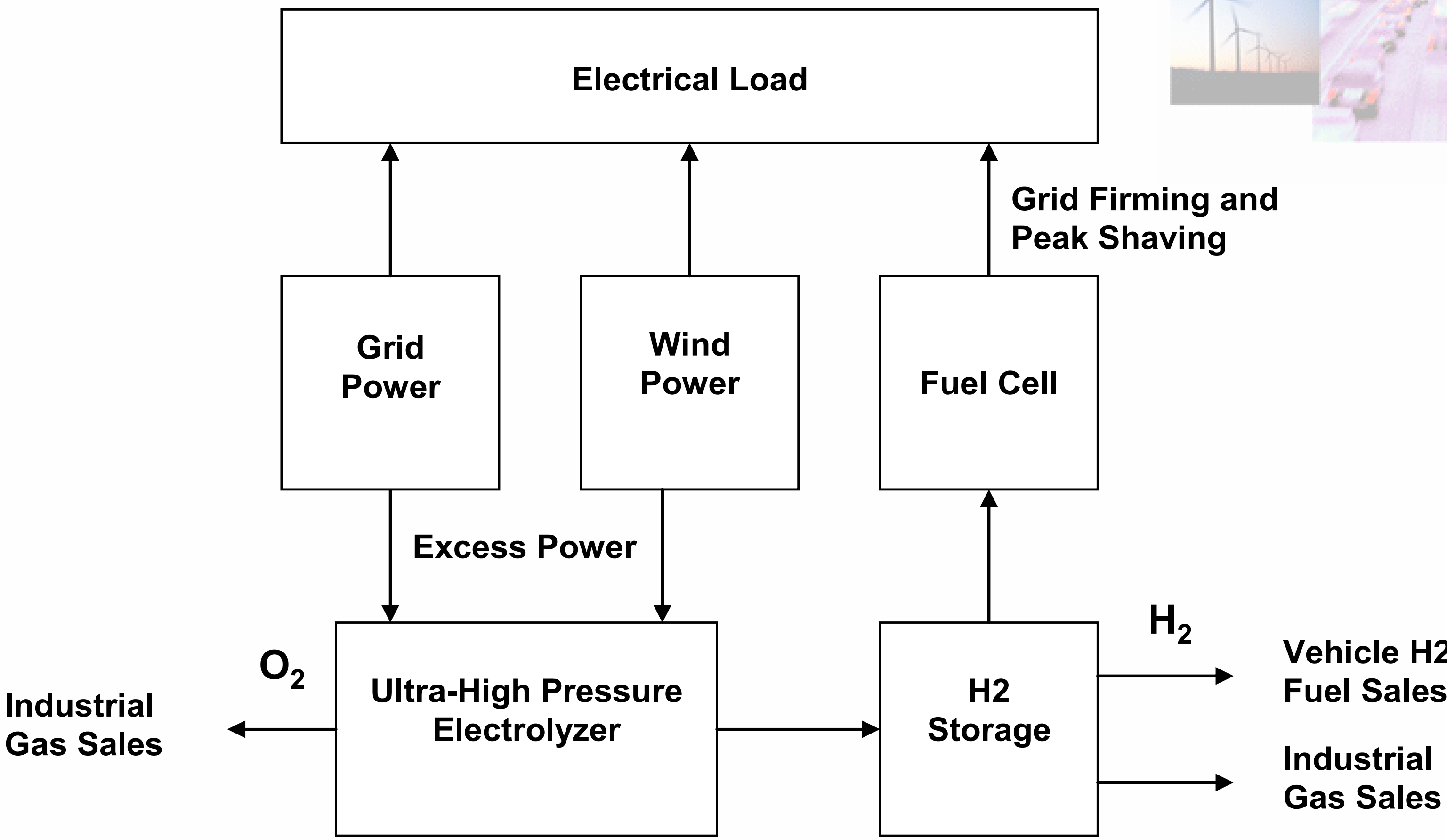
Energy Storage Utilizing Hydrogen

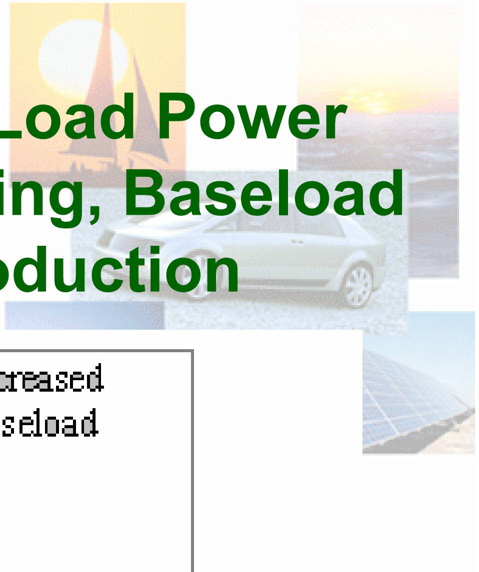
Unique Flexibility to Optimize System

- ❖ 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

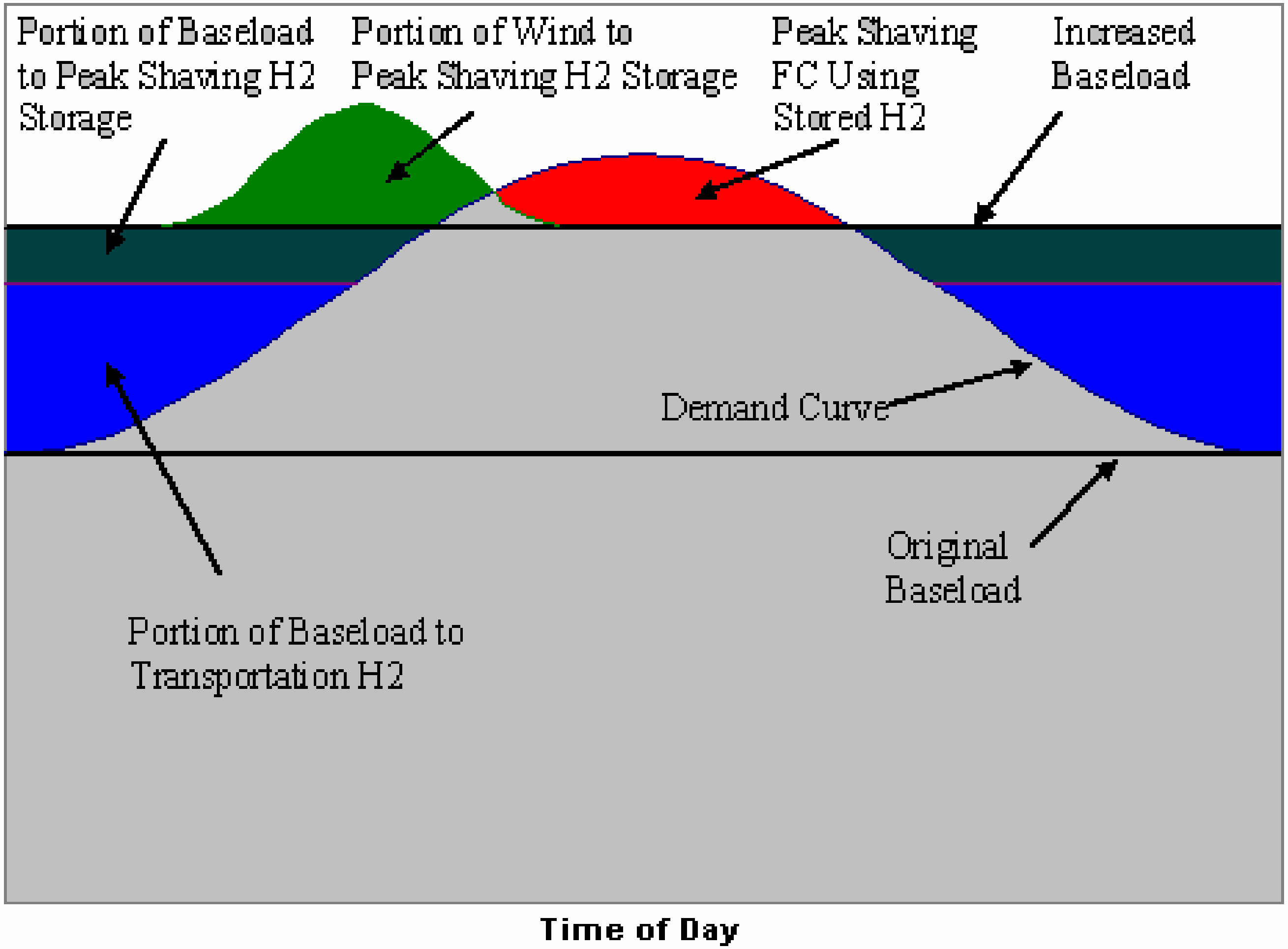
Maximize the Value of the Power Supplied

The Fully Integrated System Block Diagram





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



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Hydrofiller 5000 to Produce Green Hydrogen *For* Transportation Fuel Sales

Hydrofiller 5000 Using Wind Power Is Superior To Retail Gasoline At $3/Gal

❖ *300 Kg/Day 750 kW Rating* ❖ *2012 Commercial Price Target: $650K*

❖ *Assume 35% Availability for Wind Power Yields 38,000 kg/yr*

"Green" Hydrogen Costs:

▪ 20 Yr. Depreciation	:$0.85/Kg
▪ 3%/Yr. O&M and Overhaul Average	: 0.51
▪ Wind Power Cost ($.035/kWh & 54 kWh/kg)	: 1.89
▪ Transport To User Site	: 0.50
▪ Markup	: 1.00
▪ Green H2 Retail Price	:$4.75/Kg

"Green" FC Vehicle @55 Mi/kg (@$4.75/kg) = 8¢/Mi

Polluting Gas Vehicle @30 Mi/Gal (@$3/Gal In US) = 10¢/Mi

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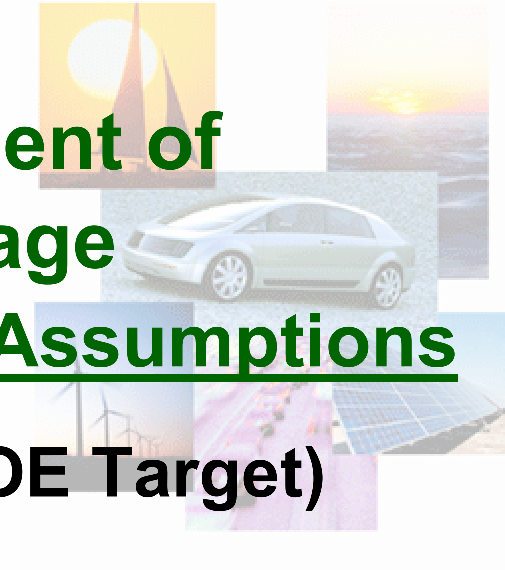

Simple Economic Assessment of Large Wind Energy Storage

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

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 AVALENCE™ LLC

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