Renewable Electrolysis Integrated System Development and Testing

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2007 DOE Hydrogen Program Annual Merit Review
May 15, 2007

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Project ID PD#8

Overview

Timeline

Project Start Date: 9/2003
Project End Date: Ongoing

Budget

Total Project Funding:
FY05 - **$400K**
FY06 - **$625K** DOE
- **$1.3M** Industry cost share

FY07 - **$1M** DOE

Production Barriers

- G. Cost
- H. System efficiency
- J. Renewable integration

Partners

- **Xcel Energy**
- **Distributed Energy Systems**
- **Teledyne Energy Systems**
- **Hydrogen Engine Center**
- **Univ. of North Dakota**
- **Univ. of Minnesota**
- **Basin Electric**
- **Ft. Collins Utilities**
- **DOE Wind/Hydro Program**

Project Objectives

This project examines the issues with using renewable energy to produce hydrogen by electrolyzing water.

- Characterize electrolyzer performance under variable input power conditions and develop standard testing procedure.
- Design, build and test shared power electronics packages and controllers to reduce cost and optimize system performance.
- Identify opportunities for system cost reduction through breakthroughs and incremental improvements in component integration focused on commercialization and manufacturability.
- Test, evaluate, model and optimize the renewable electrolysis system performance for both dedicated hydrogen production and electricity/hydrogen cogeneration.

Renewable Electrolysis

Verify DOE goals of:

Distributed electrolysis

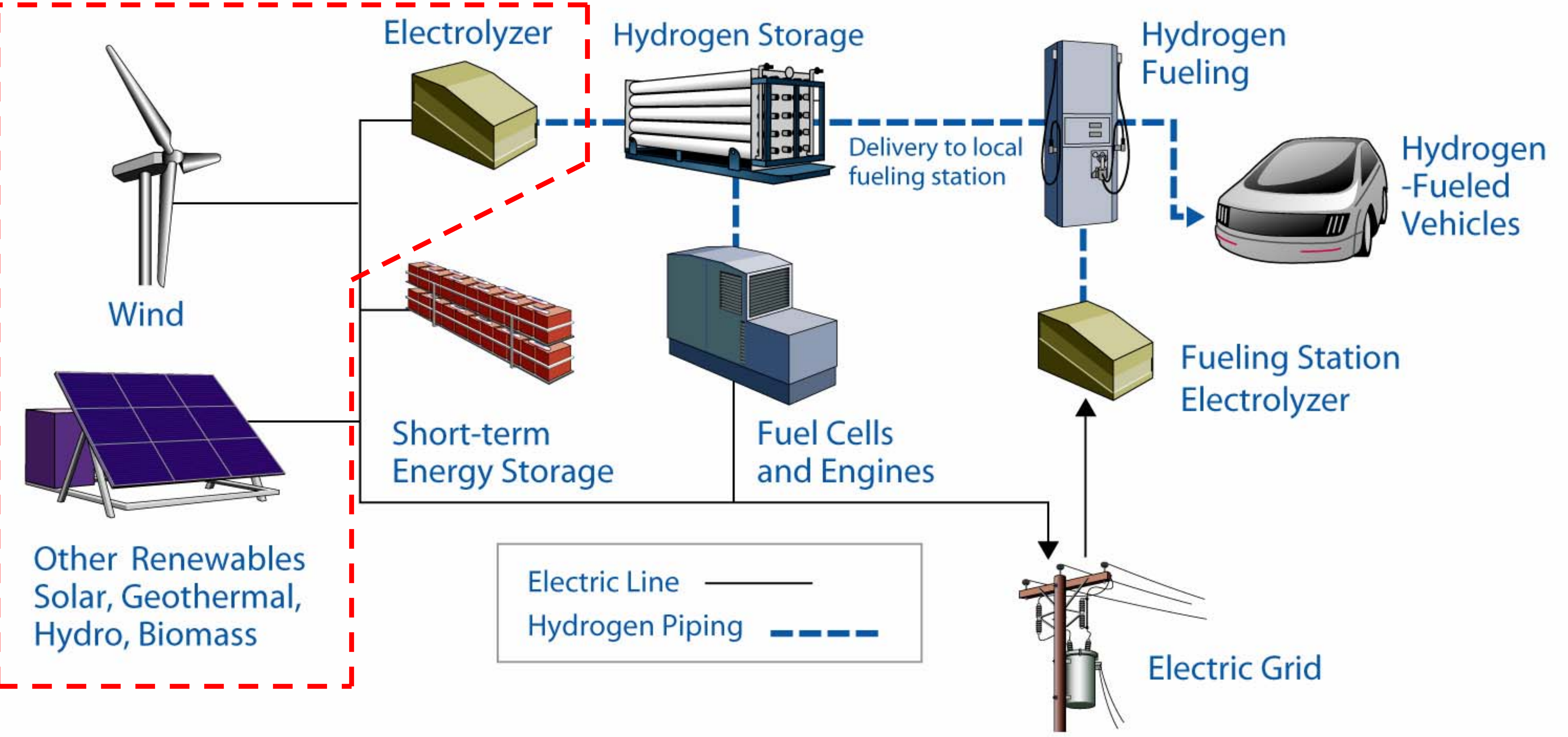
- By 2012, reduce the cost of distributed production of hydrogen from distributed electrolysis to $3.70/gge of H2 (delivered) at the pump.
- By 2017, reduce the cost of distributed production of hydrogen from distributed electrolysis to <$3.00/gge of H2 (delivered) at the pump.

Central Electrolysis

- By 2012, reduce the cost of central production of hydrogen from wind electrolysis to $3.10/gge of H2 at plant gate ($4.80/gge delivered),
- By 2017, reduce the cost of central production of hydrogen from wind electrolysis to <$2.00/gge of H2 at plant gate (<$3.00/gge delivered).

Project Background

Importance and Need – Project Focus



Project Tasks

Systems Engineering, Modeling, and Analysis

Develop concept platforms, develop and validate component and system models, system assessment, and optimization tools

System Integration and Component Development

Work with industry to develop new advanced hardware and control strategies to couple renewable and electrolyzer systems.

Characterization Testing and Protocol Development

Equipment installation, performance characterization, and standard test procedure development

Technical Accomplishments

Systems Engineering, Modeling, and Analysis

Summary report of electrolytic hydrogen production

Developed model and simulation of 10 kW WT and 6 kW PEM electrolyzer stack

System Integration and Component Development

Developed and tested second generation power electronics interface between 10 kW WT and electrolyzer

Characterization Testing and Protocol Development

Stack and system level analysis of performance

Electrolysis Analysis

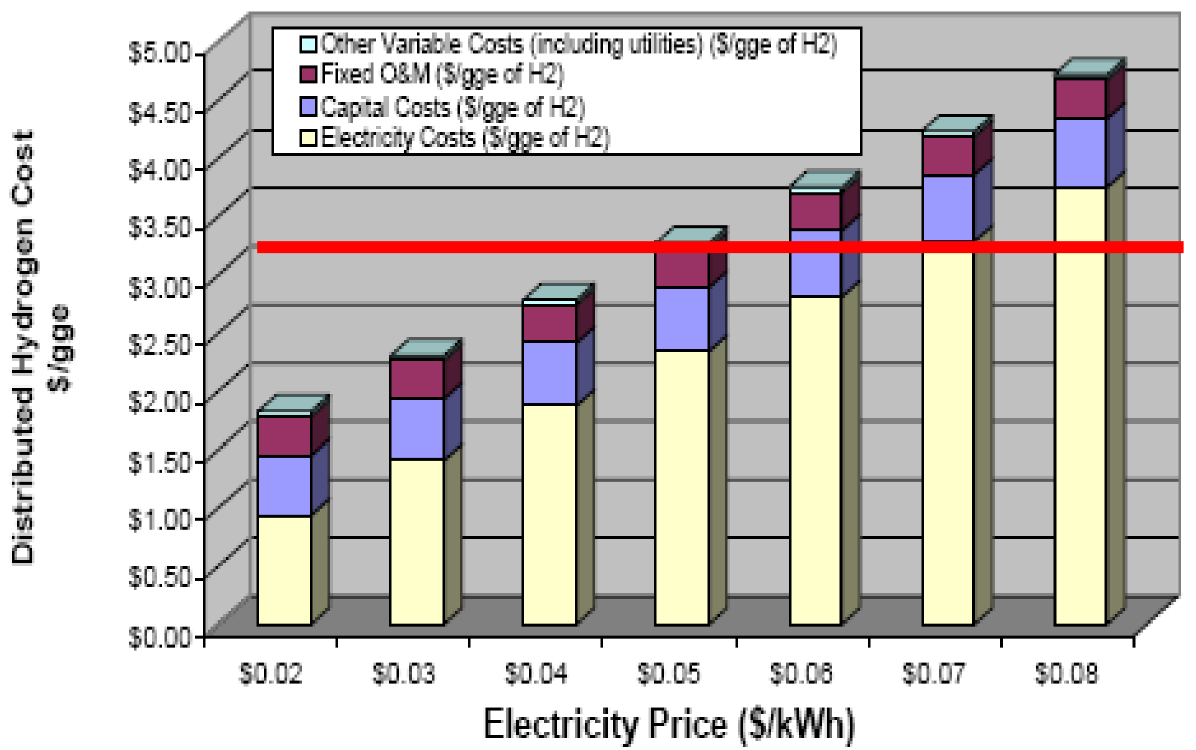
- Updated **"Summary of Electrolytic Hydrogen Production"** report.
- Current cost of hydrogen via electrolysis

Other Variable Costs

Fixed O&M

Capital Costs

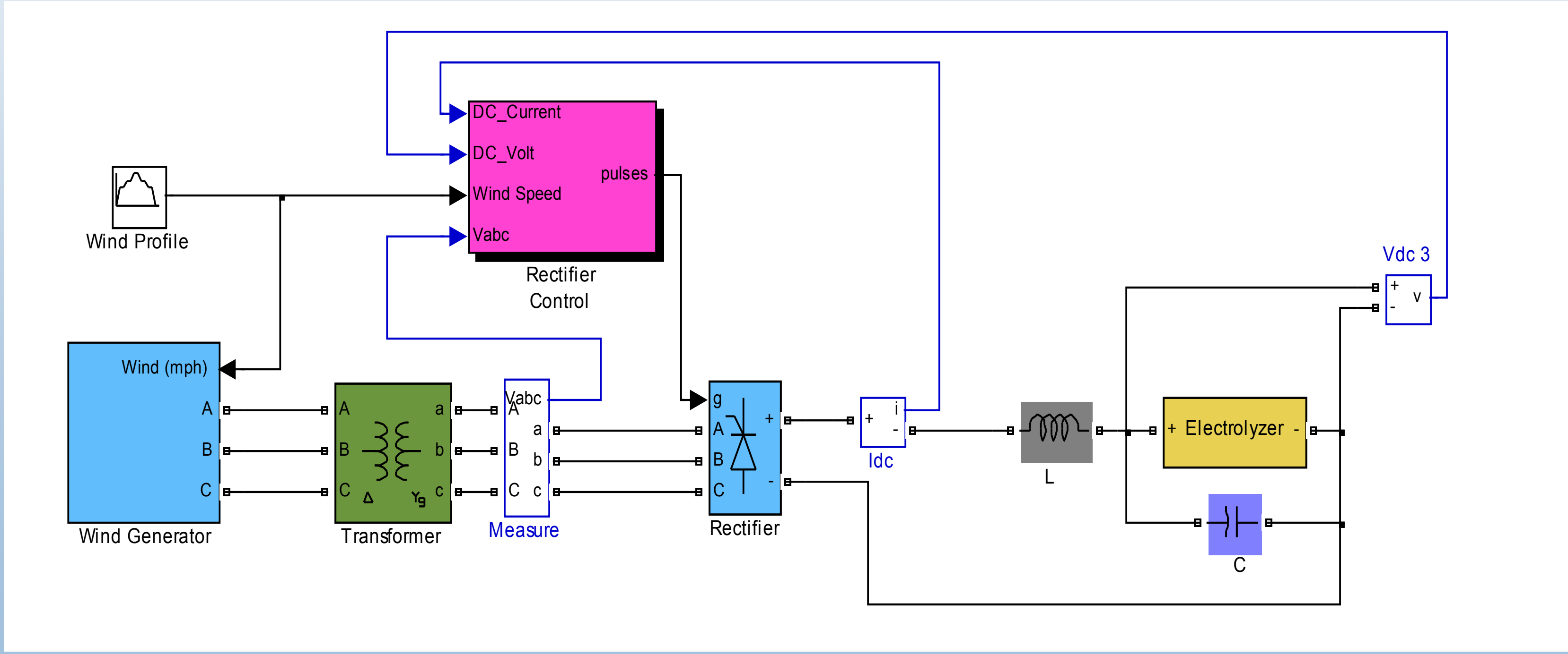
Electricity Costs



FY07 Technical Accomplishments

Systems Engineering, Modeling, and Analysis

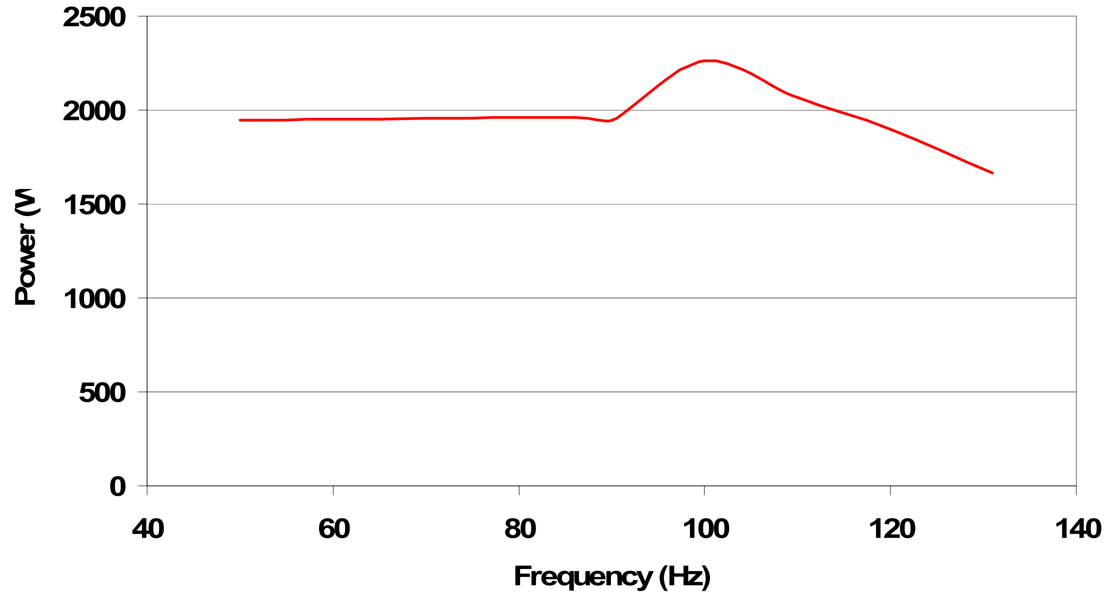
- Simulated wind turbine to stack system with Simulink
- Compared model and PE to explore gate-firing discrepancies and enhance control algorithm.

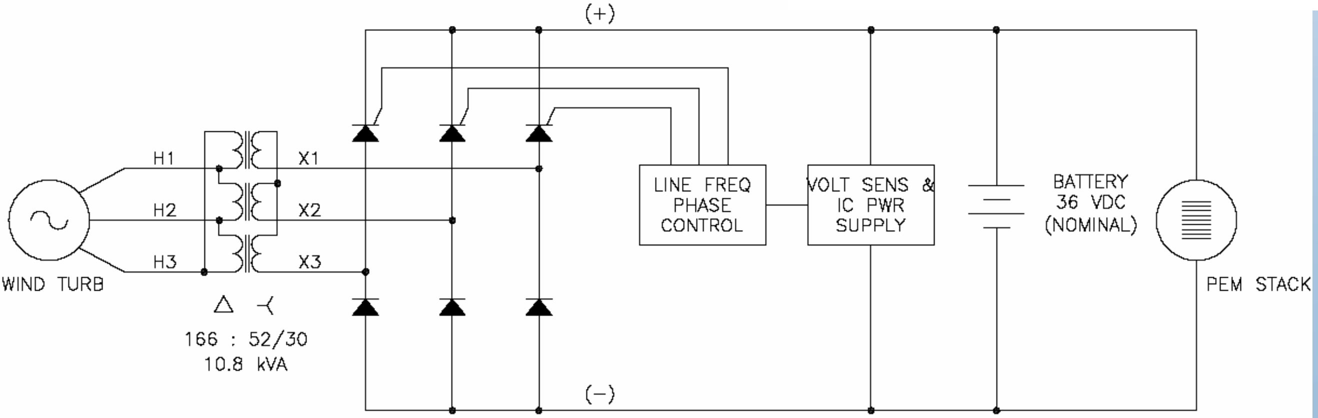


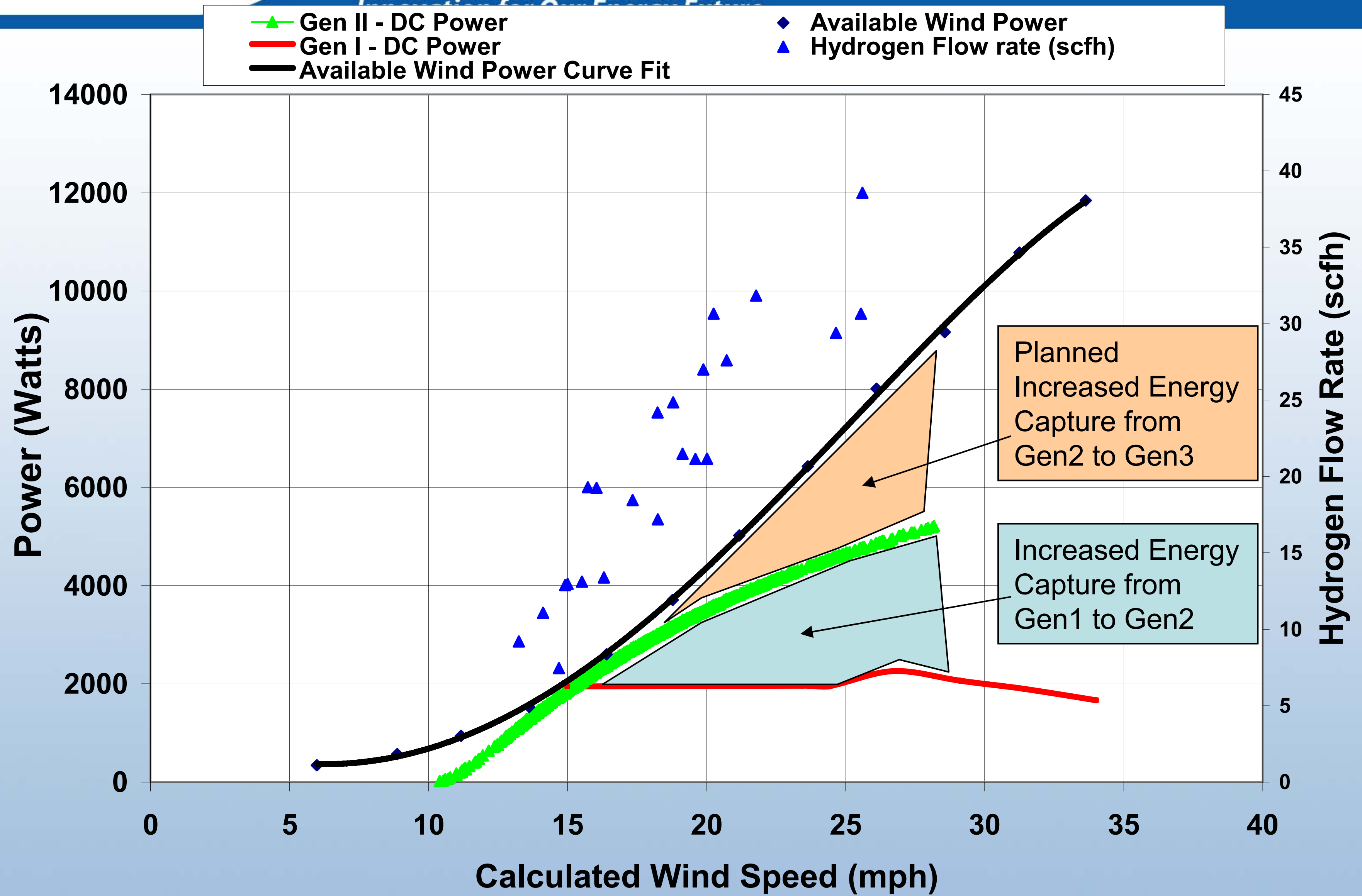
FY07 Gen1 PE Test Results

System Integration and Component Development

- Gen1 PE for 10kW WT
- Battery interaction at lower frequency and state-of-charge
- Big opportunity for optimization

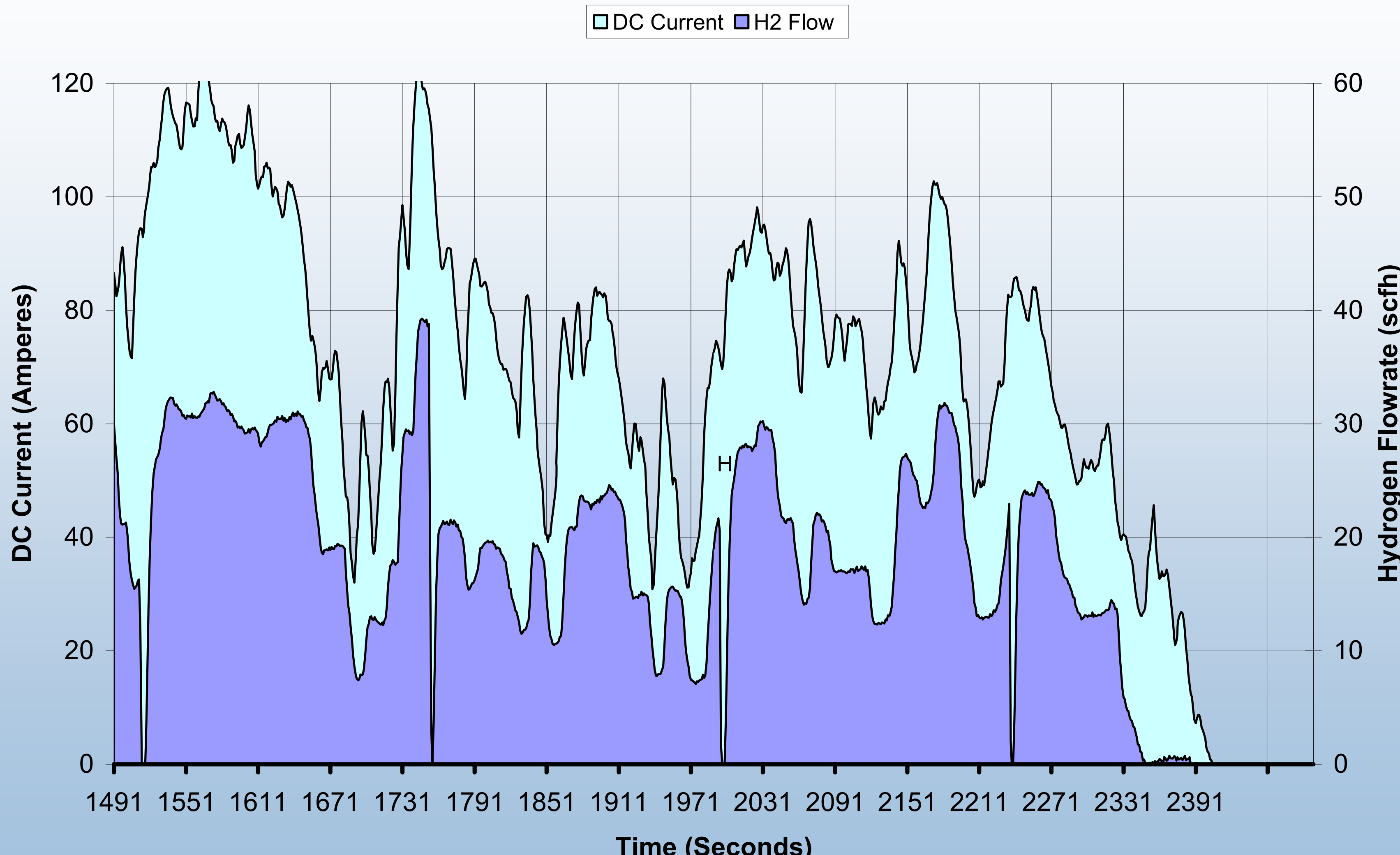





Gen II - DC Power
Gen I - DC Power
Available Wind Power Curve Fit
Available Wind Power
Hydrogen Flow rate (scfh)
Power (Watts)
0
2000
4000
6000
8000
10000
12000
14000
Hydrogen Flow Rate (scfh)
0
5
10
15
20
25
30
35
40
45
Calculated Wind Speed (mph)
0
5
10
15
20
25
30
35
40
Planned Increased Energy Capture from Gen2 to Gen3
Increased Energy Capture from Gen1 to Gen2

FY07 Gen2 PE Interim Test Results

System Integration and Component Development

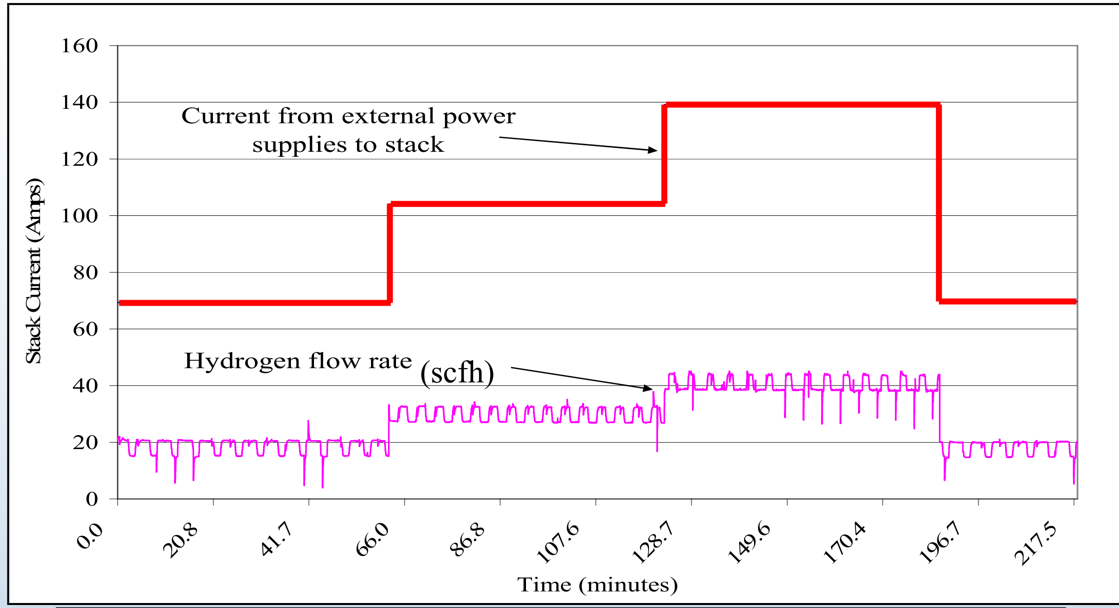


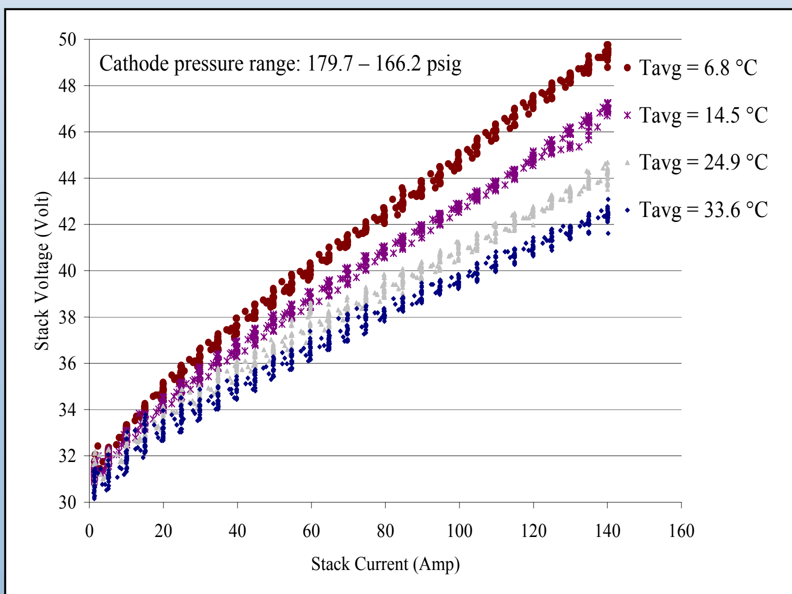
Hydrogen Production and Current as a function of Time

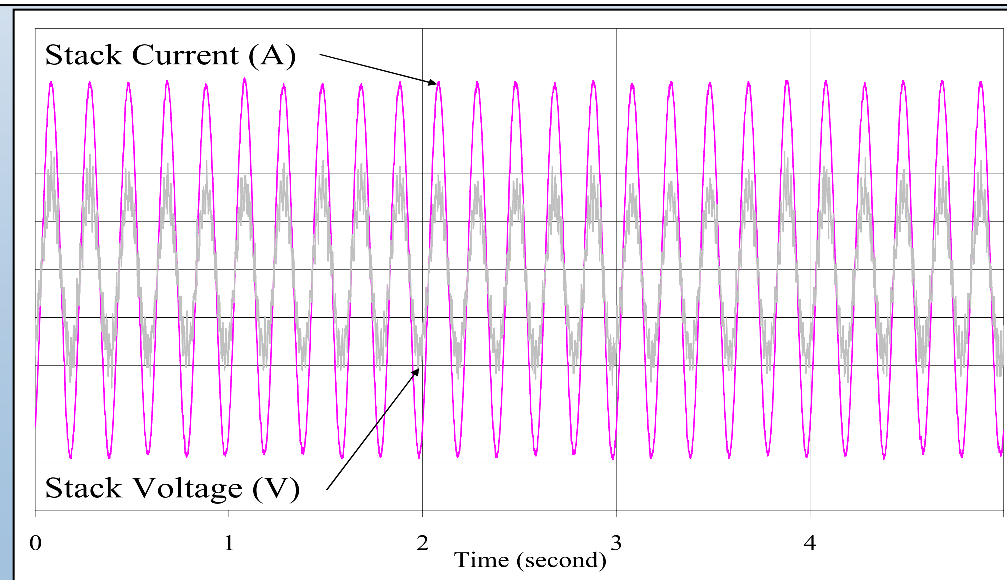
FY07 Technical Accomplishments

Characterization

- Stack level perspective
- Current control
- Step and frequency response
- Polarization curves f(T)



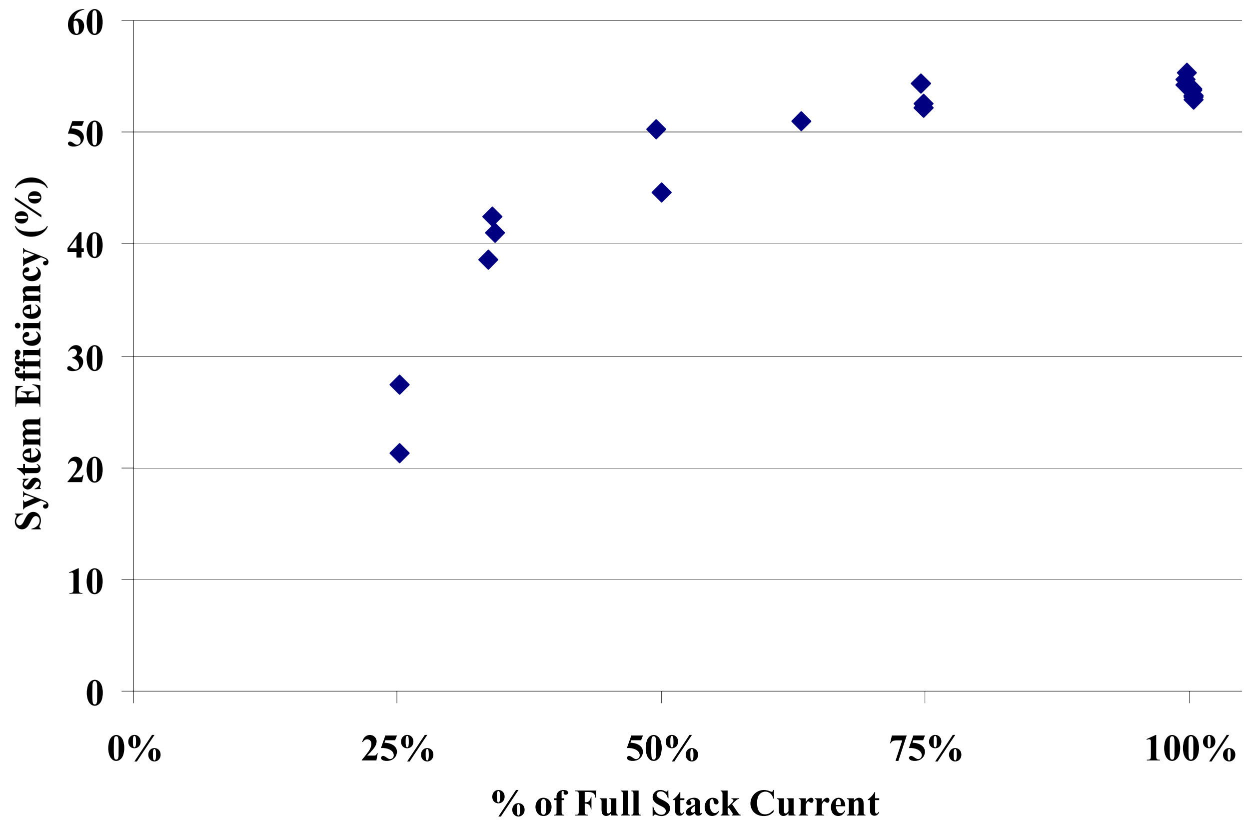




FY07 Technical Accomplishments

Characterization

- Single electrolyzer system-level perspective
- Efficiency suffers at low current
- Working with industry to improve opportunity for RE electrolysis



Xcel-NREL Wind2H2 Collaboration

Benefits of the Collaboration:

- Examine benefit to utility by shifting wind production in time
- Research optimal wind/hydrogen through systems engineering
- Characterize and control wind turbine and H2-producing stack
- Evaluate synergies from co-production of electricity and hydrogen
- Compare alkaline and PEM electrolyzer technologies
- Realize efficiency gains though a unique integrated PE

Xcel-NREL Wind2H2 Collaboration

Component Integration

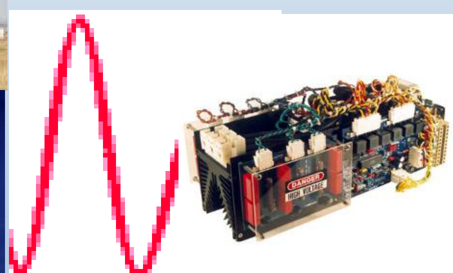
- Electrolyzers of both PEM and alkaline technologies.

- Ability to accommodate the varying energy input from wind and PV

Xcel-NREL Wind2H2 Collaboration

Direct Coupling

- Variable speed wind turbines directly-coupled to the hydrogen-producing stacks of commercially available electrolyzers.



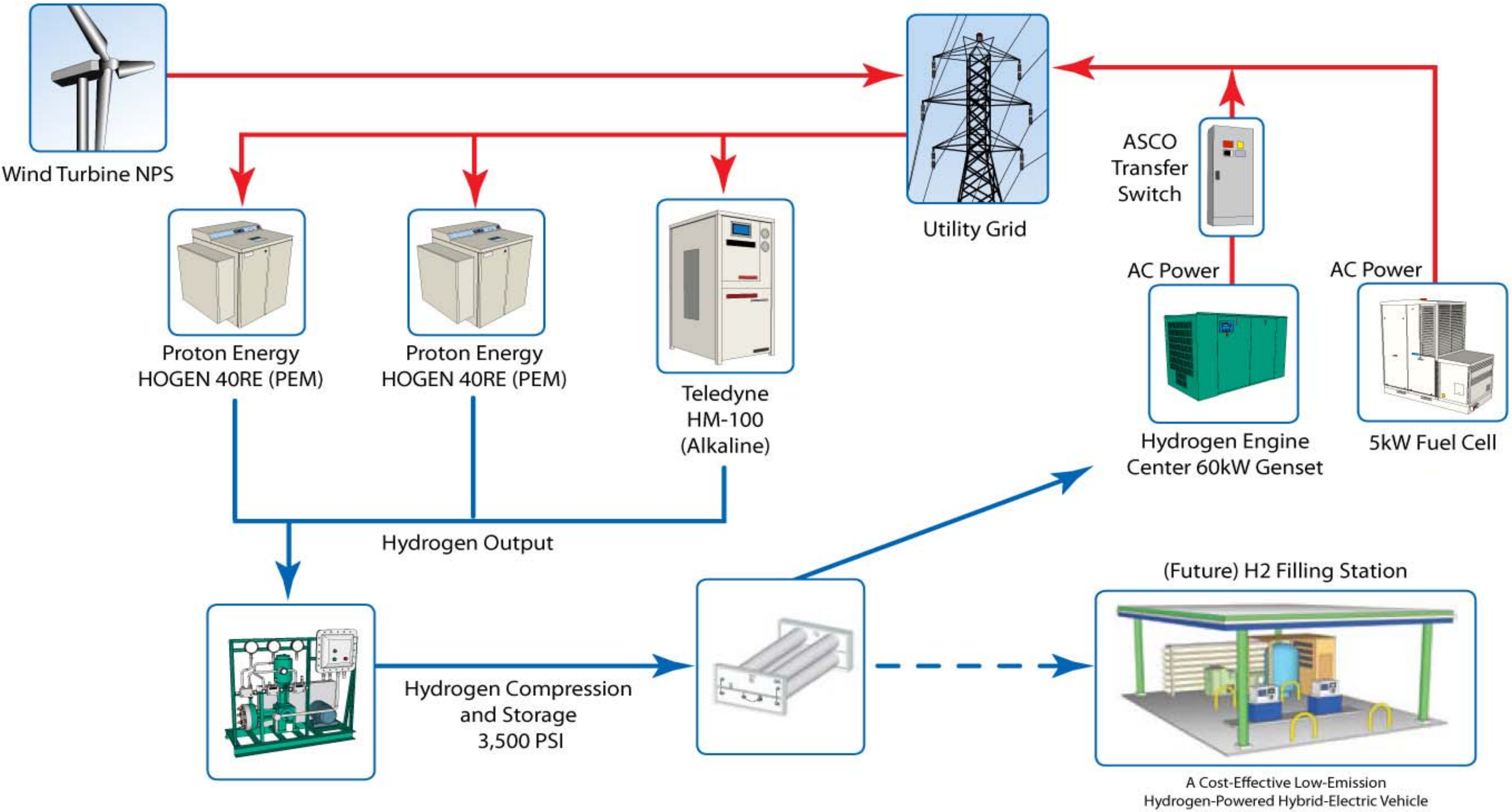
DC varying with wind speed

PEM Cell Stack

FY07 Testing

Wind2H2 Testing Configuration I

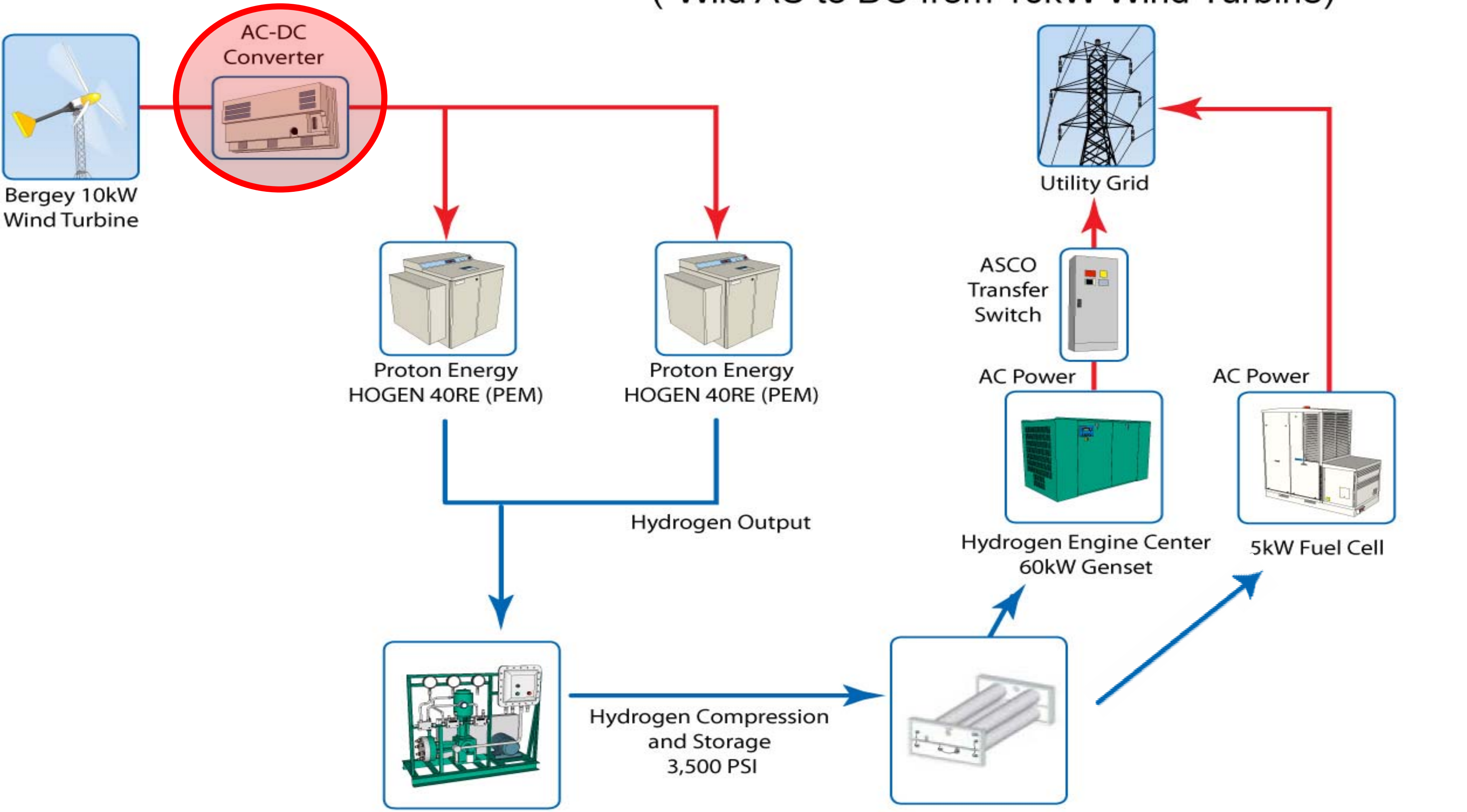
(AC Grid Connected Baseline)



FY07 Testing

Wind2H2 Testing Configuration III

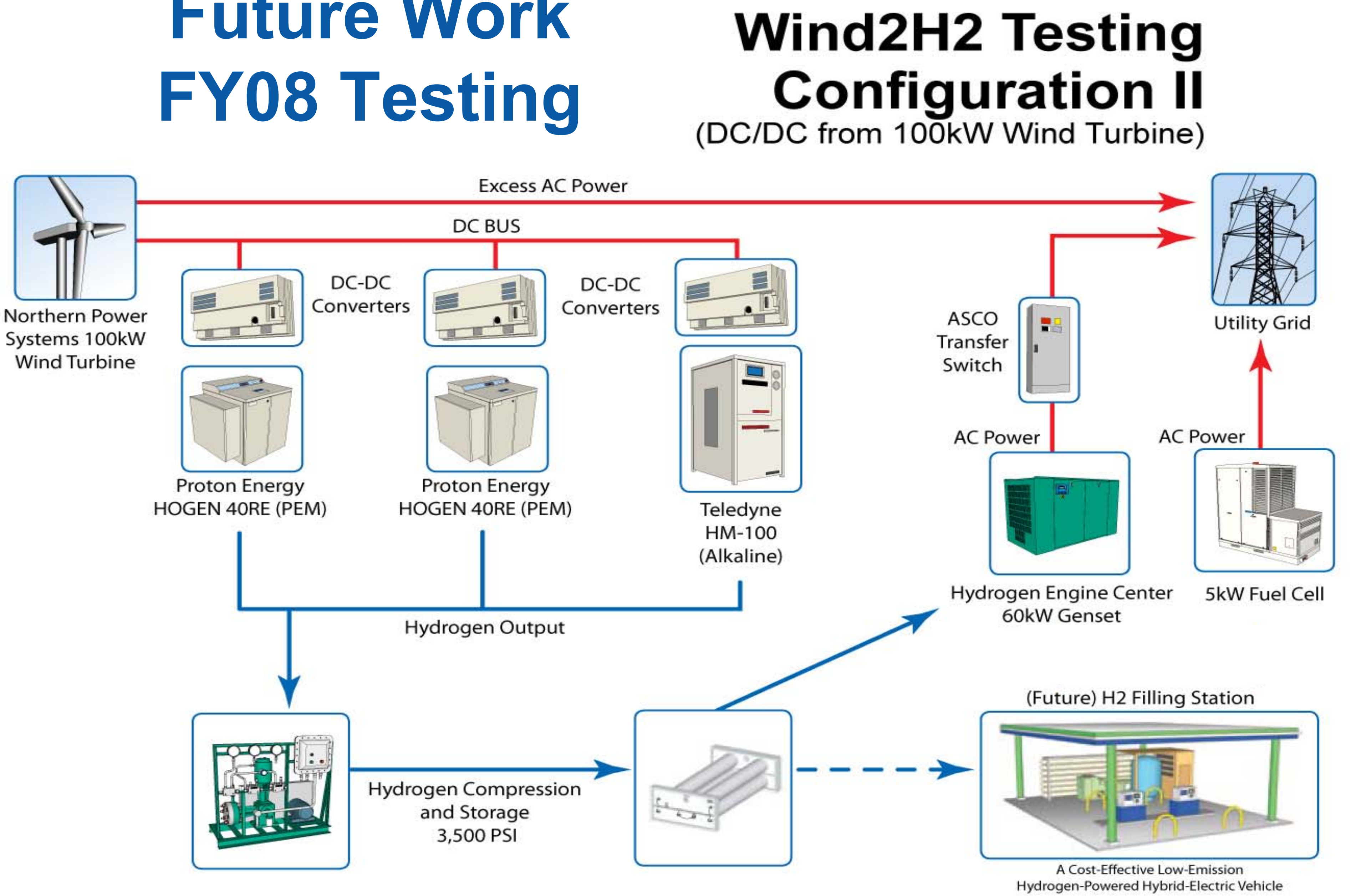
("Wild AC to DC from 10kW Wind Turbine)



Xcel-NREL Wind2H2 Collaboration

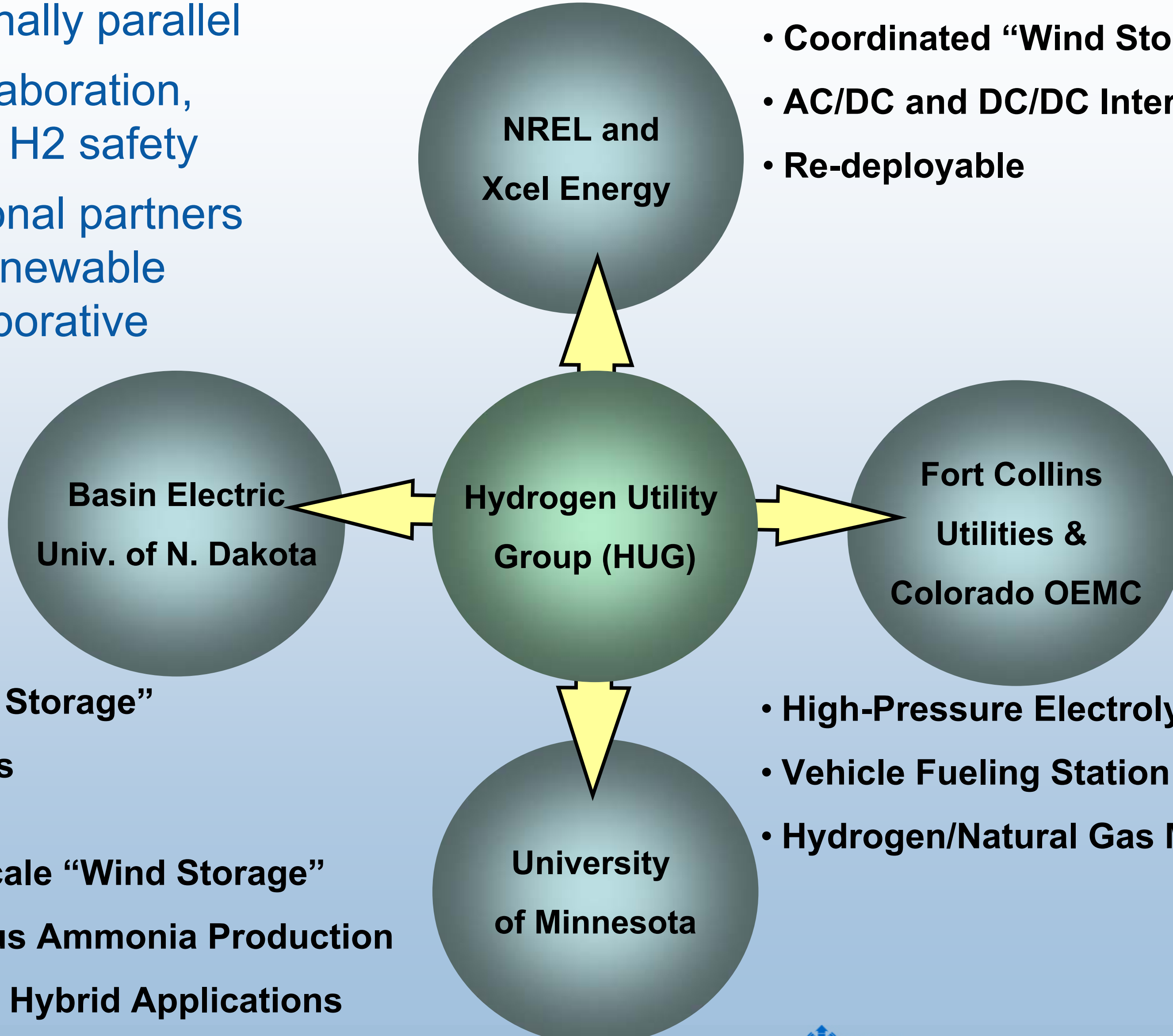
Dick Kelly (Xcel) and Dan Arvizu (NREL) shake hands after pushing button to light H2 sign and dedicate system in December 2006

Future Work FY08 Testing



Added Value from Collaboration

- Timetables originally parallel
- Inter-project collaboration, data sharing and H2 safety
- Welcome additional partners to the informal renewable electrolysis collaborative



- **Coordinated "Wind Storage"**
- **AC/DC and DC/DC Interface**
- **Re-deployable**

- **Larger Scale "Wind Storage"**
- **Vehicle Applications**

- **High-Pressure Electrolysis**
- **Vehicle Fueling Station & FC**
- **Hydrogen/Natural Gas Mixing**

- **Larger Scale "Wind Storage"**
- **Anhydrous Ammonia Production**
- **Vehicle & Hybrid Applications**

Path Forward

FY07
- Operation of Wind2H2 Project in Grid and small WT
- Test high-pressure PEM electrolyzer

FY08
- Design, built and test of PE for 100kW WT to stacks
- Complete standard test protocol development for renewable-electrolyzer performance and operation
- Model/simulation of renewable-electrolyzer performance

FY09 - FY10
- Test and validation support for DOE Electrolysis-based Hydrogen Production projects
- R&D MW-scale wind to electrolysis components and systems

Summary Slide

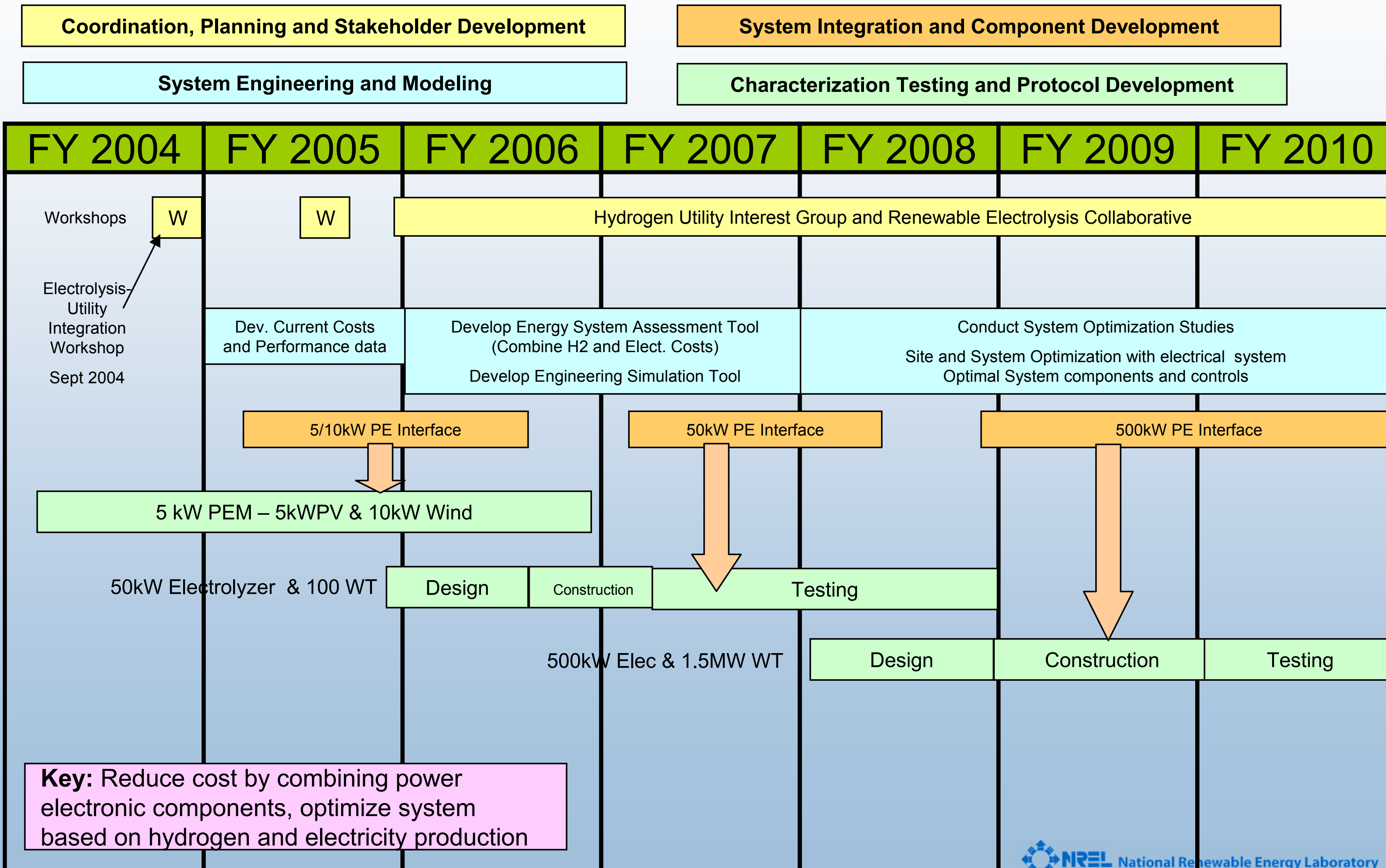
- Economic analysis shows that renewable electrolysis can meet DOE hydrogen cost targets
- Integrate components and engineer systems to increase efficiency and reduce cost of renewable electrolysis
- Multi-partner collaborative effort to evaluate renewable electrolysis and share safety and operational experience. (industry, universities, utilities, government)
- Work with HUG to examine how utilities can effectively produce and use hydrogen

Additional Slides

- The following slides are included as supplemental information.

Project Timeline

Renewable Electrolysis - Integrated Systems Development and Testing



National Renewable Energy Laboratory

Distributed Electrolysis Targets

Table 3.1.4 Technical Targets: Distributed Electrolysis Hydrogen Production[a,b,c]					
Characteristics	Units	2003 Status	2006[c] Status	2012 Target	2017 Target
Hydrogen Cost	$/gge	5.15	4.80	3.70	<3.00
Electrolyzer Capital Cost[d]	$/gge $/kW	N/A N/A	1.20 665	0.70 400	0.30 125
Electrolyzer Energy Efficiency[f]	% (LHV)	N/A	62	69	74

Table 3.1.4A Distributed Electrolysis H2A Example Cost Contributions[a,b,c]					
Characteristics		Units	2006[c] Status	2012	2017
Electrolysis Unit	Cost Contribution[d]	$/gge H2	1.20	0.70	0.30
	Capacity Factor[e]	%	70	70	70
	Energy Efficiency[f]	% (LHV)	62	69	74
Compression, Storage, Safety and Dispensing [g,h,i,j,k]	Cost Contribution	$/gge H2	0.60	0.40	0.30
	Energy Efficiency	% (LHV)	93.8	93.7	95.0
O&M	Cost Contribution	$/gge H2	0.80	0.60	0.40
Electricity	Cost Contribution[l]	$/gge H2	2.20	2.00	1.80
Total[m]	Energy Efficiency	% (LHV)	60.0	66.2	71.0
	Cost	$/gge H2	4.80	3.70	<3.00

Central Wind Electrolysis Targets

Table 3.1.5 Technical Targets: Central Wind Electrolysis[a,b]				
Characteristics	Units	2006[c] Status	2012 Target	2017 Target
Hydrogen Cost (Plant Gate)	$/gge H2	5.90	3.10	<2.00
Electrolyzer Capital Cost[b,d]	$/gge H2 $/kW	2.20 665	0.80 350	0.20 109
Electrolyzer Energy Efficiency[e]	% (LHV)	62	69	74

Table 3.1.5A Central Wind Electrolysis H2A Example Cost Contributions[a,b]					
Characteristics		Units	2006[c] Status	2012	2017
Wind Farm[f]	Cost Contribution	$/gge H2	2.50	2.10	3.00
	Capacity Factor	%	41	50	54
Electrolysis Unit	Cost Contribution[d]	$/gge H2	2.20	0.80	0.20
	Capacity Factor	%	44	58	77
	Energy Efficiency[e]	% (LHV)	62	69	74
O&M	Cost Contribution	$/ggeH2	1.50	0.80	0.80
By-product Electricity	Cost Contribution[g]	$/gge H2	-0.30	-0.60	-2.00
	Percentage of electricity produced sold as by-product[h]	%	10	27	59
Total	Cost	$/gge H2	5.90	3.10	<2.00

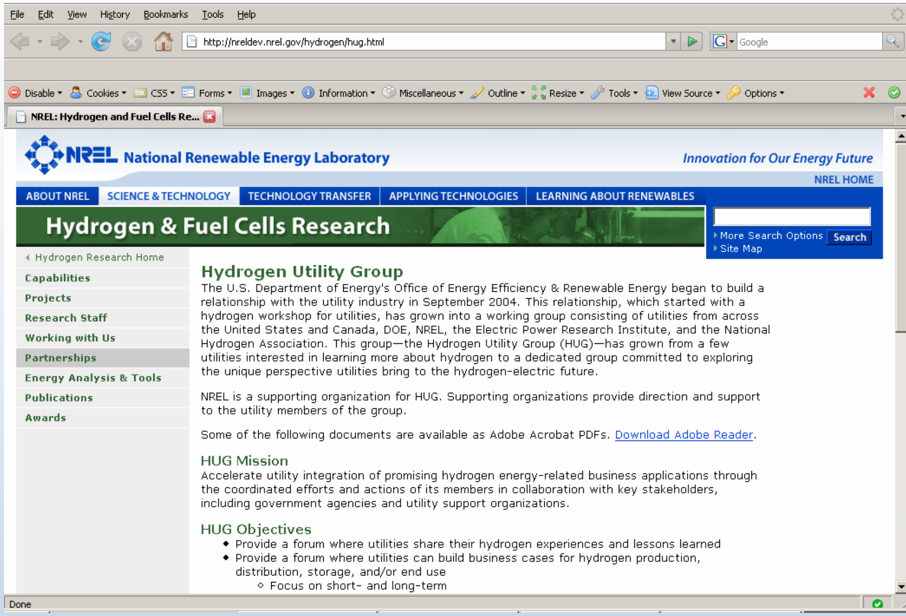
Technical Barriers

- **Electrolysis**: Capital cost reductions and efficiency improvements are required along with the design of utility-scale electrolyzers capable of grid integration and compatible with low-cost, near-zero emission electricity sources.

- Capital Cost. The capital costs of electrolysis systems are prohibitive to widespread adoption of electrolysis technology for hydrogen production. R&D is needed to develop lower cost materials with improved manufacturing capability to lower capital while improving the efficiency and durability of the system.
- System Efficiency. New membrane, electrode, and system designs are needed to improve system efficiency and durability. Development is needed for low-cost cell stack optimization addressing efficiency, compression, and durability.

Hydrogen Utility Group (HUG)

This Project has also worked with HUG



Dedicated group committed to exploring the unique perspective utilities bring to the hydrogen-electric future

Utilities: DTE Energy, Sacramento Municipal Utility District, Nebraska Public Power District, Connexus Energy, BC Hydro, KEPRI Nuclear Power Laboratory, Arizona Public Service Company, Entergy, Xcel Energy, Southern California Edison, Fort Collins Utilities, New York Power Authority, Southern Company, and Sempra Energy.

Supporting Organizations: DOE, NREL, EPRI, NHA