Renewable Electrolysis Integrated System Development and Testing

Project ID: PDP 4

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Overview

Timeline

Project Start Date: 9/2003

Project End Date: 9/2009

Budget

Total Project Funding:

FY06 - $625K DOE

- $1.3M Industry cost-share

FY07 - $1M DOE

FY08 - $1M DOE

- $500K DOE

Production Barriers

G. Cost

H. System efficiency

J. Renewable integration

Partners

- Xcel Energy
- Distributed Energy Systems
- Teledyne Energy Systems
- NASA, JPL
- Univ. of North Dakota/EERC
- Univ. of Minnesota
- DOE Wind/Hydro Program

Status & Technical 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 3.1.5. Technical Targets: Central Wind Electrolysis[a, b]				
Characteristics	Units	2006[c] Status	2012 Target	2017 Target
Hydrogen Cost (Plant Gate)	\$/gge H_2	5.90	3.10	<2.00
Electrolyzer Capital Cost[b, d]	\$/gge H_2 \$/kW	2.20 665	0.80 350	0.20 109
Electrolyzer Energy Efficiency[e]	% (LHV)	62	69	74

Research Barriers Addressed

Capital Costs: R&D is needed to lower capital while improving the efficiency and durability of the system.

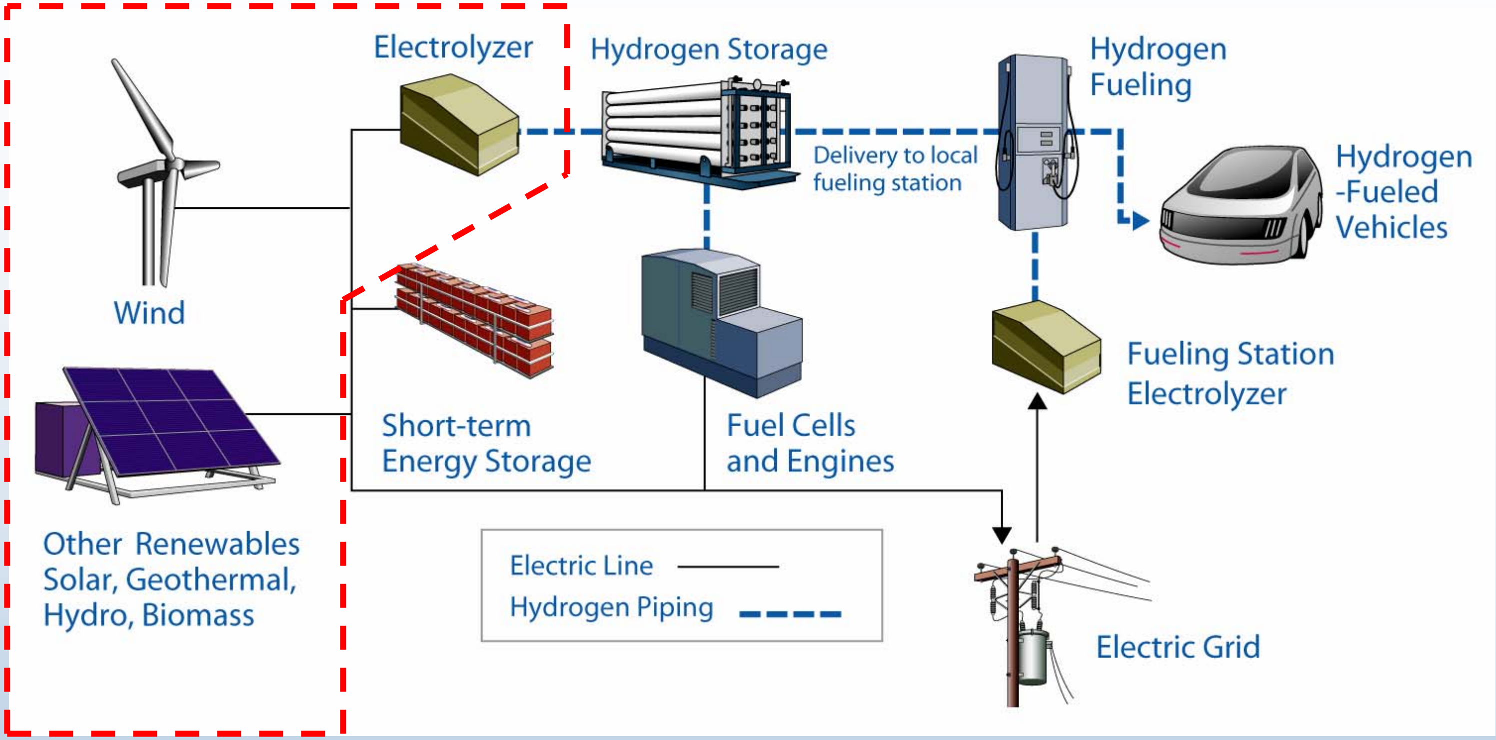
System Efficiency: Even slight increases in efficiency enable significant reductions in hydrogen cost. Efficiency gains can be realized using compression in the cell stack.

Renewable Electricity Generation Integration: More efficient integration with renewable electricity generation is needed to reduce costs and improve performance. Development of integrated renewable electrolysis systems is needed, including optimization of power conversion and other system components from renewable electricity to provide high-efficiency, low-cost integrated renewable hydrogen production.

Status of Today's Commercial Electrolyzer Systems

- **Capital Cost** ($15,000/kW to $800/kW)
- **High Pressure Output** (200 – 2000 psig)
- **Energy Requirements**
  - 50-75% efficient today (HHV)
  - 1000 kg/day system requires 2.3 MW, not including compression
- **RE Integration**
  - One manufacturer with RE interface (2 power converters: AC/DC and DC/DC (Discontinued)
- **Water requirements**
  - Feedstock
    - 1 L/Nm^3 of Hydrogen standard (11 L/kg)
  - Cooling water required for most systems
- **Water purity requirements**
  - Resistivity of 1-5 MΩ-cm (PEM), 200 kΩ-cm (Alk)

Project Objectives



- Characterize electrolyzer performance with variable input power
- Design, build and test shared power electronics
- Identify opportunities for system cost reduction and optimization
- Test, evaluate and model the renewable electrolysis system

Technical Approach

Test, evaluate, model and optimize the renewable electrolysis system performance for both dedicated hydrogen production and electricity/hydrogen cogeneration

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

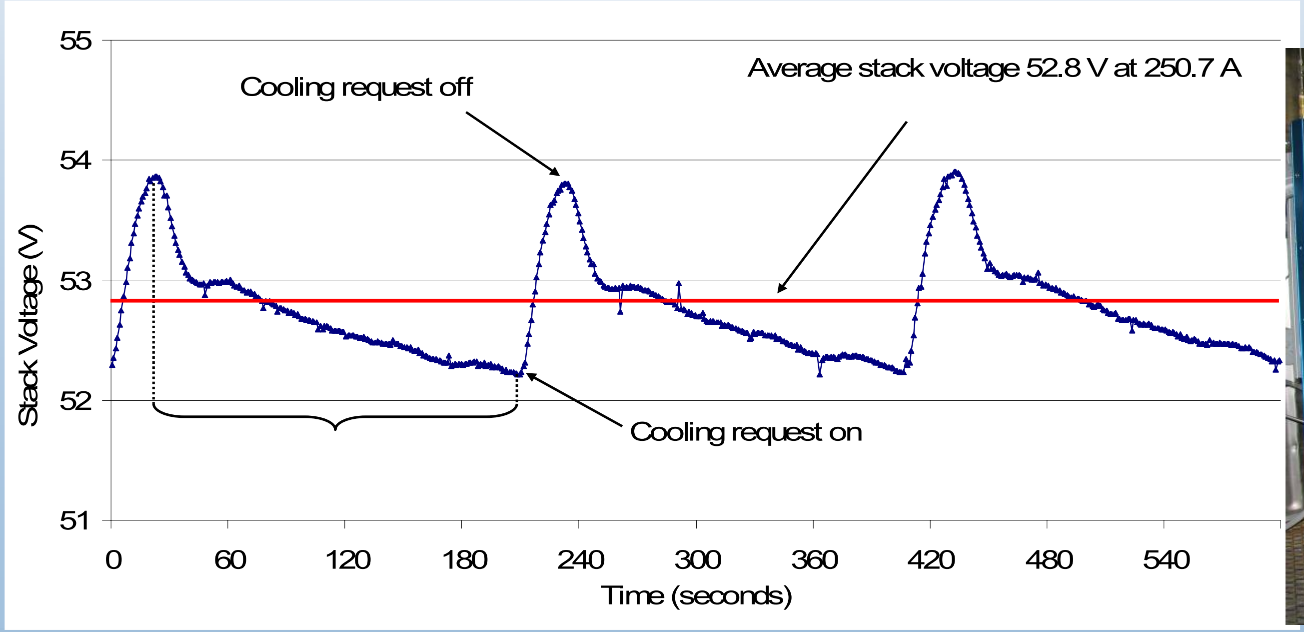
Equipment installation, performance characterization, and standard test procedure development

FY08 Technical Accomplishments

Characterization Testing and Protocol Development

System Efficiency: Department of Energy's Joule Milestone EE GG 1.1.01.1 which states, "Complete lab-scale electrolyzer, test to determine whether it achieves 64% energy efficiency and evaluate systems capability to meet $5.50/gge hydrogen cost target, untaxed at the station, and with large equipment production volumes [e.g., 500 units/year]."

Accomplishment: Provided testing required to meet DOE 2007 Joule Milestone, Giner Electrochemical Systems (EP-1), 1000 psig H_2, stack voltage efficiency 67% (HHV).

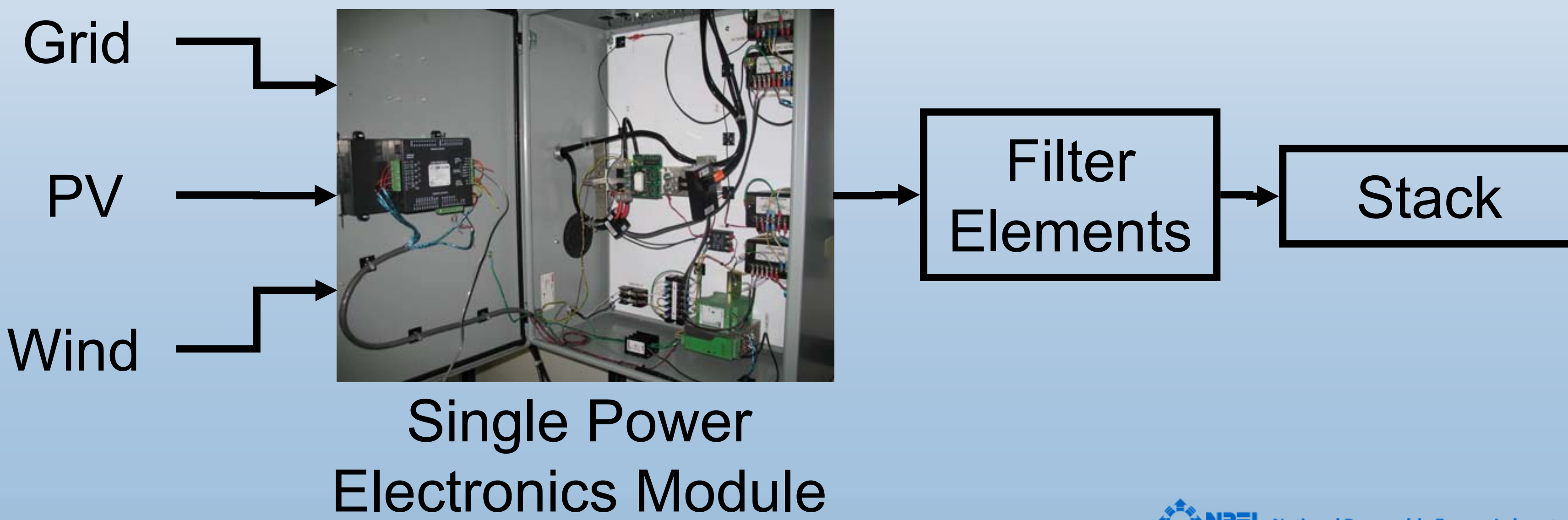


FY08 Technical Accomplishments

System Integration and Component Development

Capital Costs: Onboard power electronics (AC/DC) are relatively expensive accounting for 15 to 30% of the system cost. This problem is exacerbated when renewable power sources are used, adding a second onboard power electronics module.

Accomplishment: Combining functionality and reducing or eliminating redundant components (i.e., switches, controllers and filter elements such as inductors/capacitors) decreases costs.

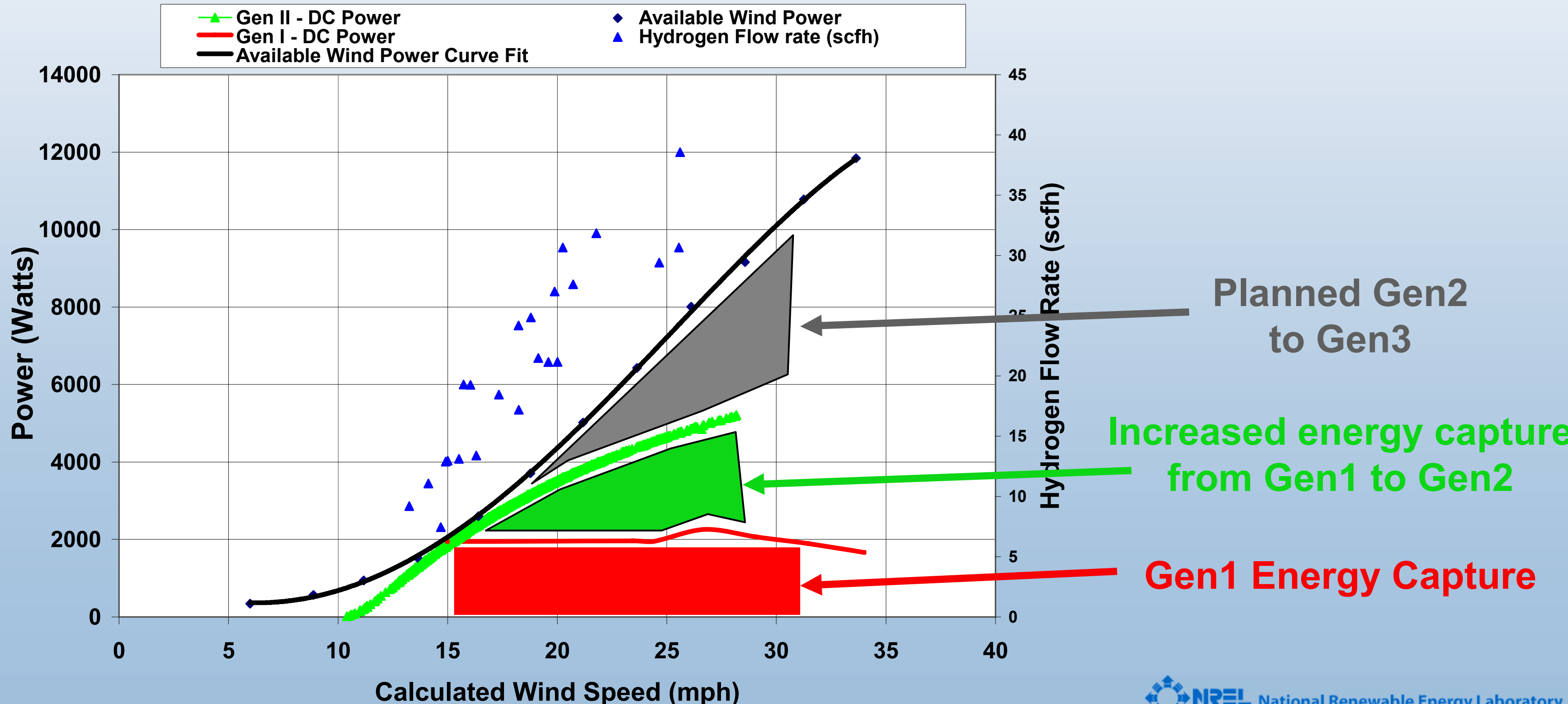


FY08 Gen2 PE Test Results

System Integration and Component Development

Renewable Electricity Generation Integration: Improving the energy capture from renewable energy sources through controlling renewable source, direct-coupling to stack and unique algorithms.

Accomplishment: Second generation power electronics improved energy capture while directly coupled to electrolyzer stack.

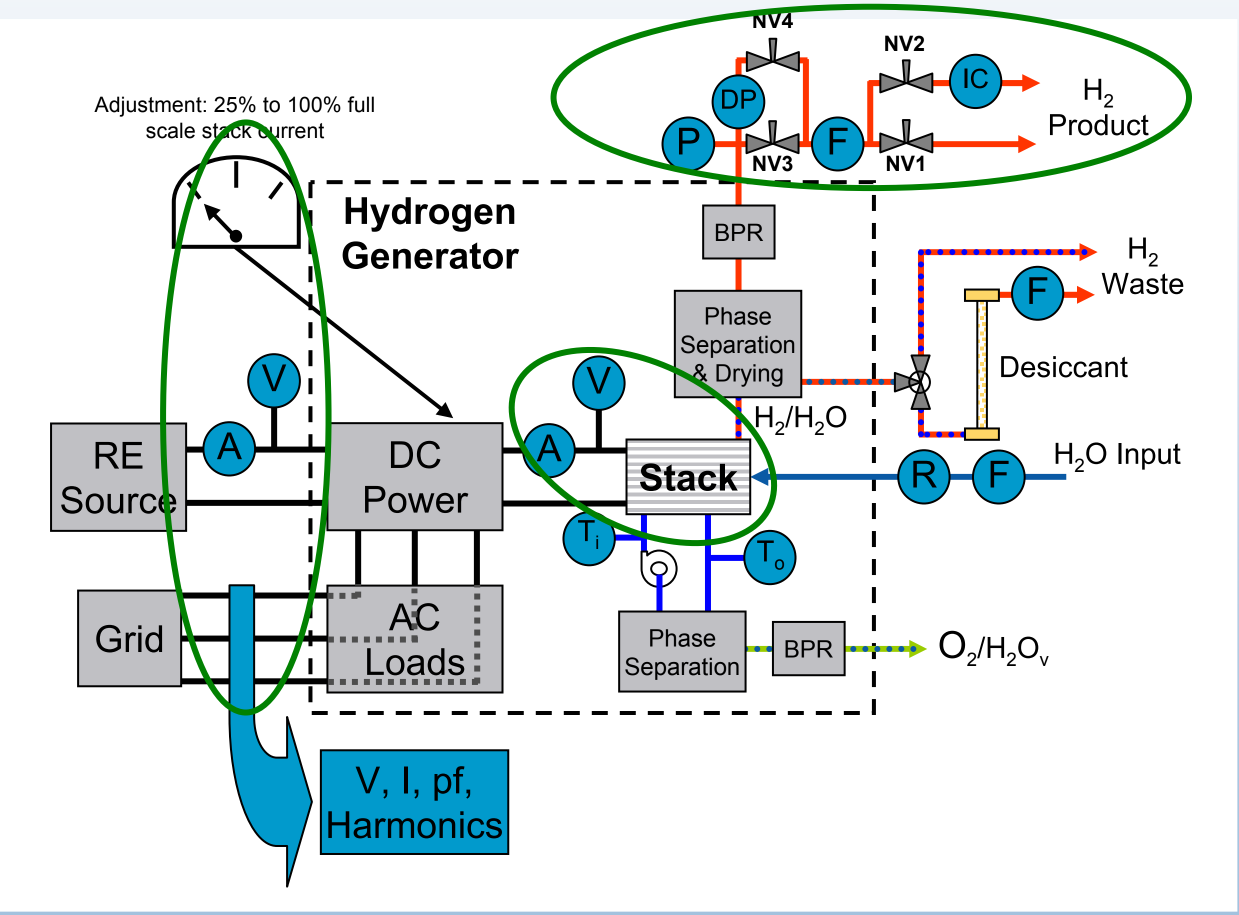


FY08 Technical Accomplishments

Characterization Testing and Protocol Development

Developed Standardized Test Protocol

- Intends to quantify performance under varying stack power
- Stack & System Efficiency
- Industry feedback through WEWG, HUG and IEA

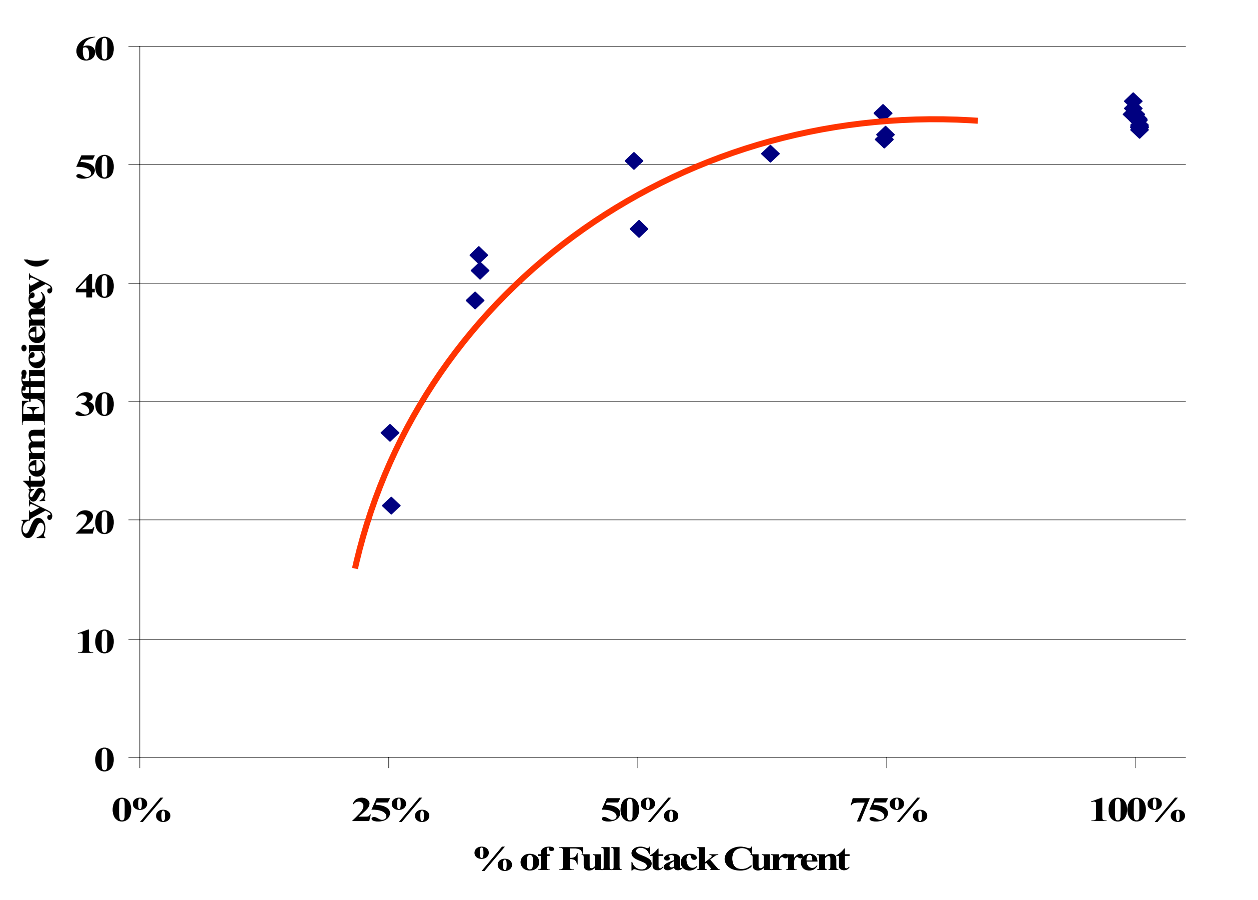


FY08 Technical Accomplishments

Characterization Testing and Protocol Development

Testing & analysis of system efficiency at various stack current levels

- Providing feedback to industry to improve integration of renewable energy sources



Electrolyzer Manufacturer Feedback

Systems Engineering, Modeling, and Analysis

NREL Electrolyzer Capital Cost Questionaire

This form is designed for use in an analysis of various electrolyzer systems available. It will be used as part of a renewable electrolysis systems integration project at NREL. Your response and participation is appreciated.

Company Name	Proton Energy Systems
Contact E-mail	
Chemistry of units evaluated	PEM

If your company manufacturers more than one type of electrolyzer, i.e. PEM and alkaline, please fill out for each type separately.

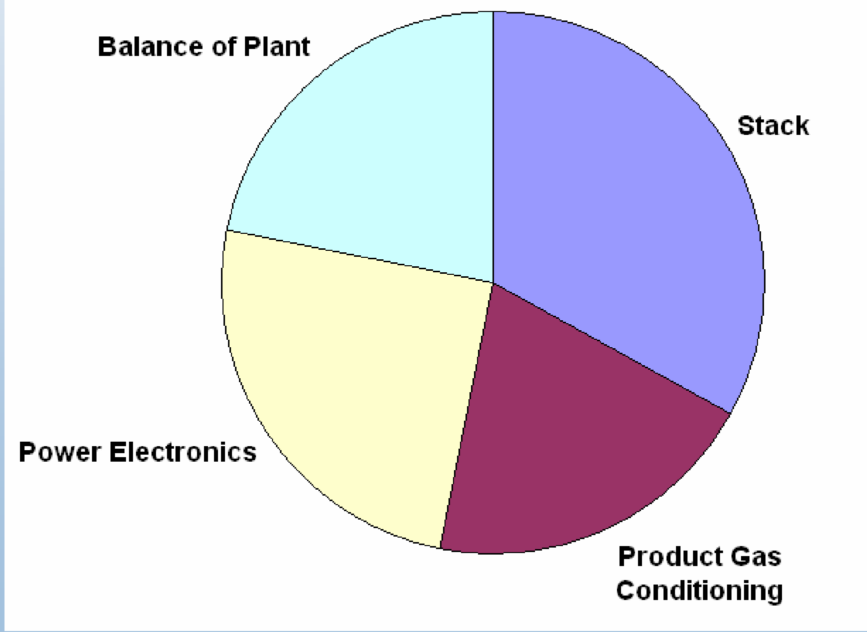
Instructions Part I: Please provide three models that represent your small, mid, and large ranges with the Flow Capacity H_2 delivered. Within the table, breakdown the cost as a percentage of the total unit cost. **Fill in the white cells.**

Part 1	Component Cost Breakdown							
	Model (small)		Model (mid)		Model (large)		Model (EXAMPLE	
	HOGEN S 40		HOGEN H 6m		HOGEN HP 40		XL08 PEM Proto	
	H_2 Flow Capacit		H_2 Flow Capacit		H_2 Flow Capacit		H_2 Flow Capacity	
	1.050	Nm3/hr	6.000	Nm3/hr	1.060	Nm3/hr	0.045	kg/day
Electrolyzer Stack		%		%		%	35	%
Power Electronics		%		%		%	30	%
Gas Conditioning		%		%		%	5	%
Balance of Plant		%		%		%	30	%
Other (Specify)								
		%		%		%		%
		%		%		%		%
		%		%		%		%
		%		%		%		%
Total Cost %	0.0%		0.0%		0.0%		100.0%	

Instructions Part 2: Please provide additional specifications of units.
Notes can be provided in the space provided. Any product brochure with specifications can also be attached and are appreciated. **Fill in the white cells**.

Part II	Other Parameters							
	Model (small)		Model (mid)		Model (large)		Model	
	HOGEN S 40		HOGEN H 6m		HOGEN HP 40		XL08 PEM Proto	
	Quantity	Units	Quantity	Units	Quantity	Units	Quantity	Units
Inputs								
Water Purity	1	MΩ·cm	1	MΩ·cm	1	MΩ·cm	500	kΩ·cm
Outputs								
H_2 System Pressure							2000	psig
Hydrogen Purity	99.9995	%	99.9995	%	99.9950	%	99.9995	%

- Questions focused on Capital Costs (%) and RE integration.
- Small 'test' group in June and the rest in July



Companies Involved

June

IHT, (alk)

PES, (pem)

Giner, (pem)

Teledyne, (pem)

Hydrogenics, (bth)

Avalence, (alk)

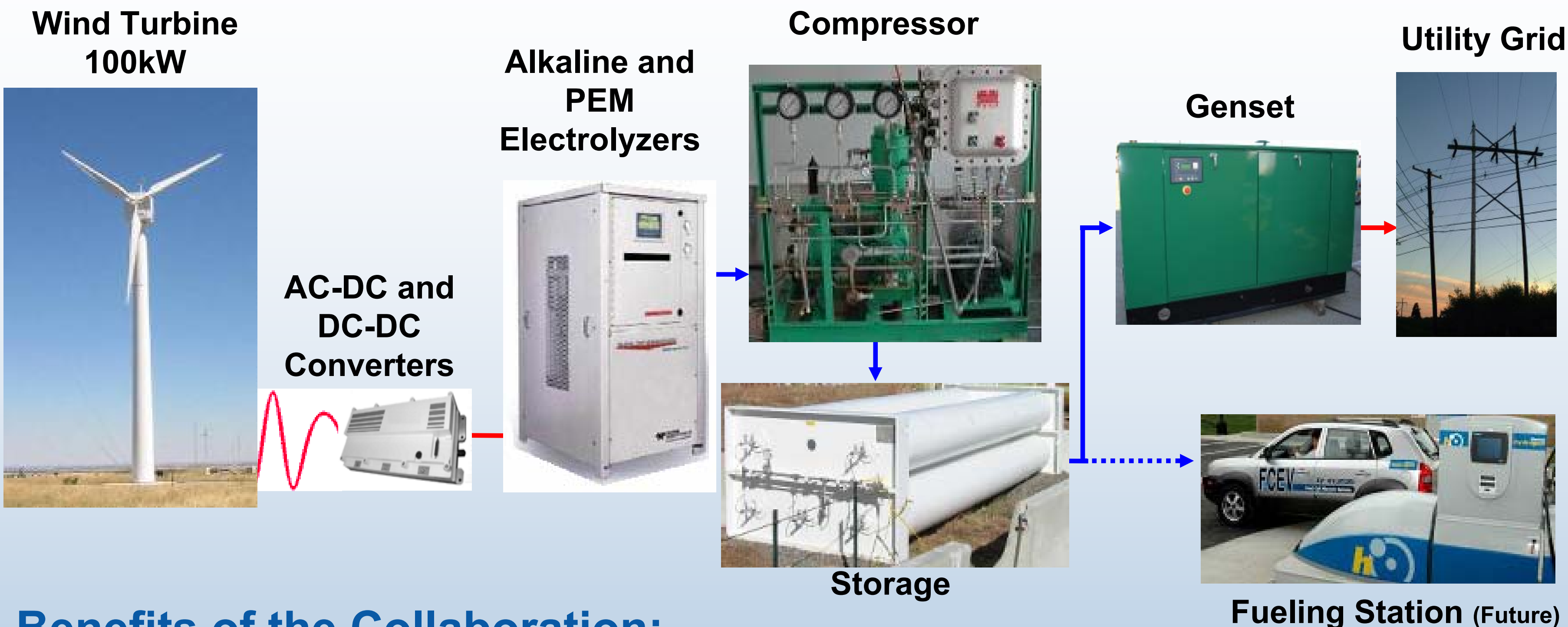
GE, (alk)

Previous work has surveyed only a few companies

July

Electric Hydrogen (Eh!)
Hamilton Sundstrand
Norsk Hydro (Statoil)
ITM
AccaGen
Shinko Pantec
Mitsubishi
ELT Elektrolyse Technik
H2-Interpower
Hydrogen Solar
Lynntech
Infinity Fuel
Treadwell
Siam Water Flame
Linde
Peak Scientific
Schmidlin-DBS
PIEL (ILT Tech.)
Gesellschaft für Hochleistungsele
Kline

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

Wind2H2 Primary Deliverables

System-wide efficiency of devices (Electrolyzers, Compression, Storage and H2-fueled ICE genset)

Comparing the following:

- PV to grid
- Wind Turbine to grid
- Grid to electrolyzer stack
- Wind/PV to electrolyzer stack
- Show the wind/solar resource correlation
- PEM/alkaline electrolyzer efficiency
- Compressor efficiency
- H_2-fueled genset efficiency
- Running the electrolyzer's in parallel (sequencing) the stacks to optimize overall system efficiency.

Xcel-NREL Wind2H2 Collaboration

Component Integration

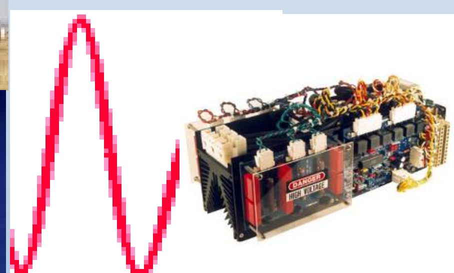
Comparing electrolyzers of both PEM and alkaline technologies

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.



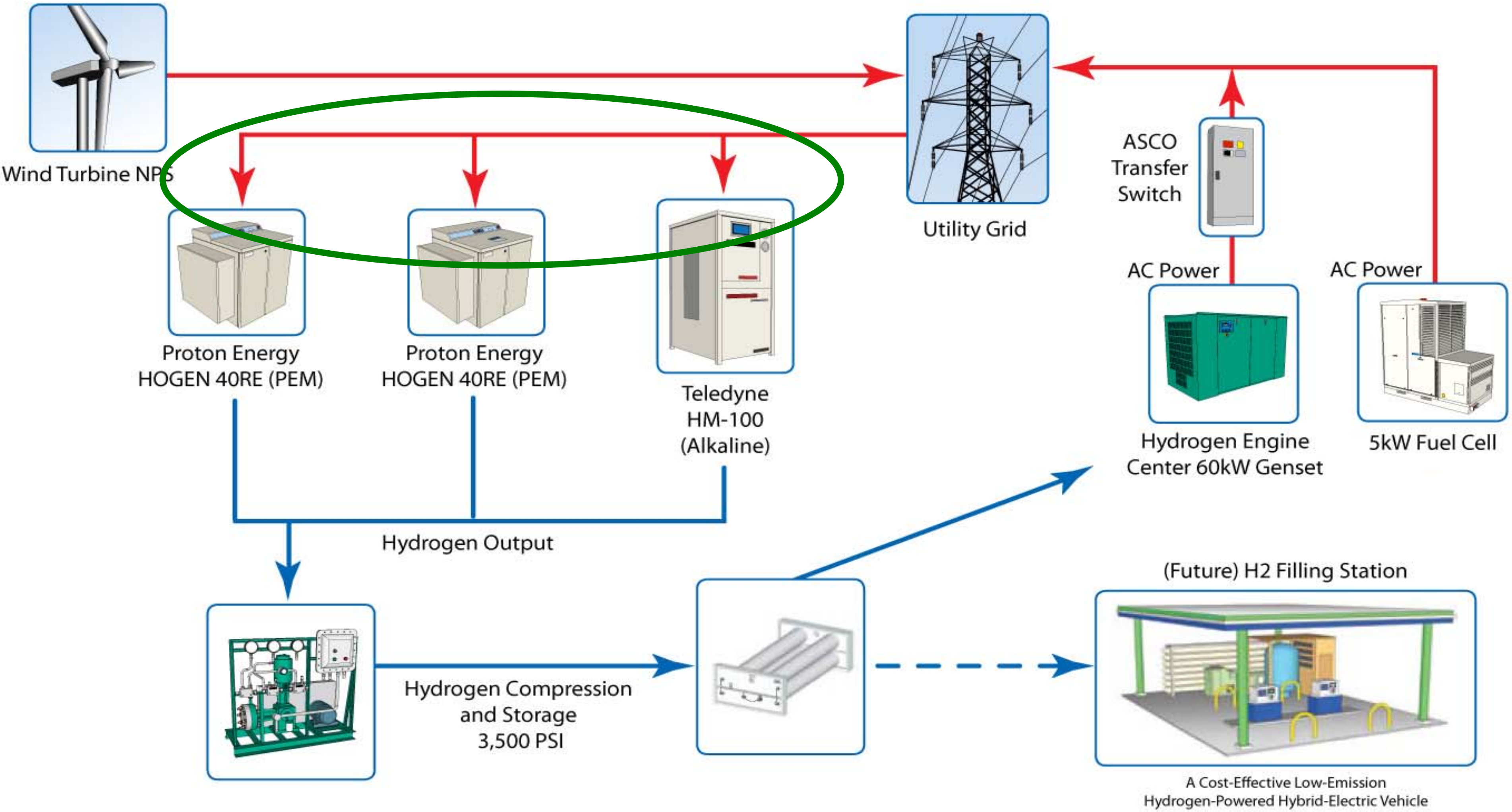
DC varying with wind speed

PEM Cell Stack

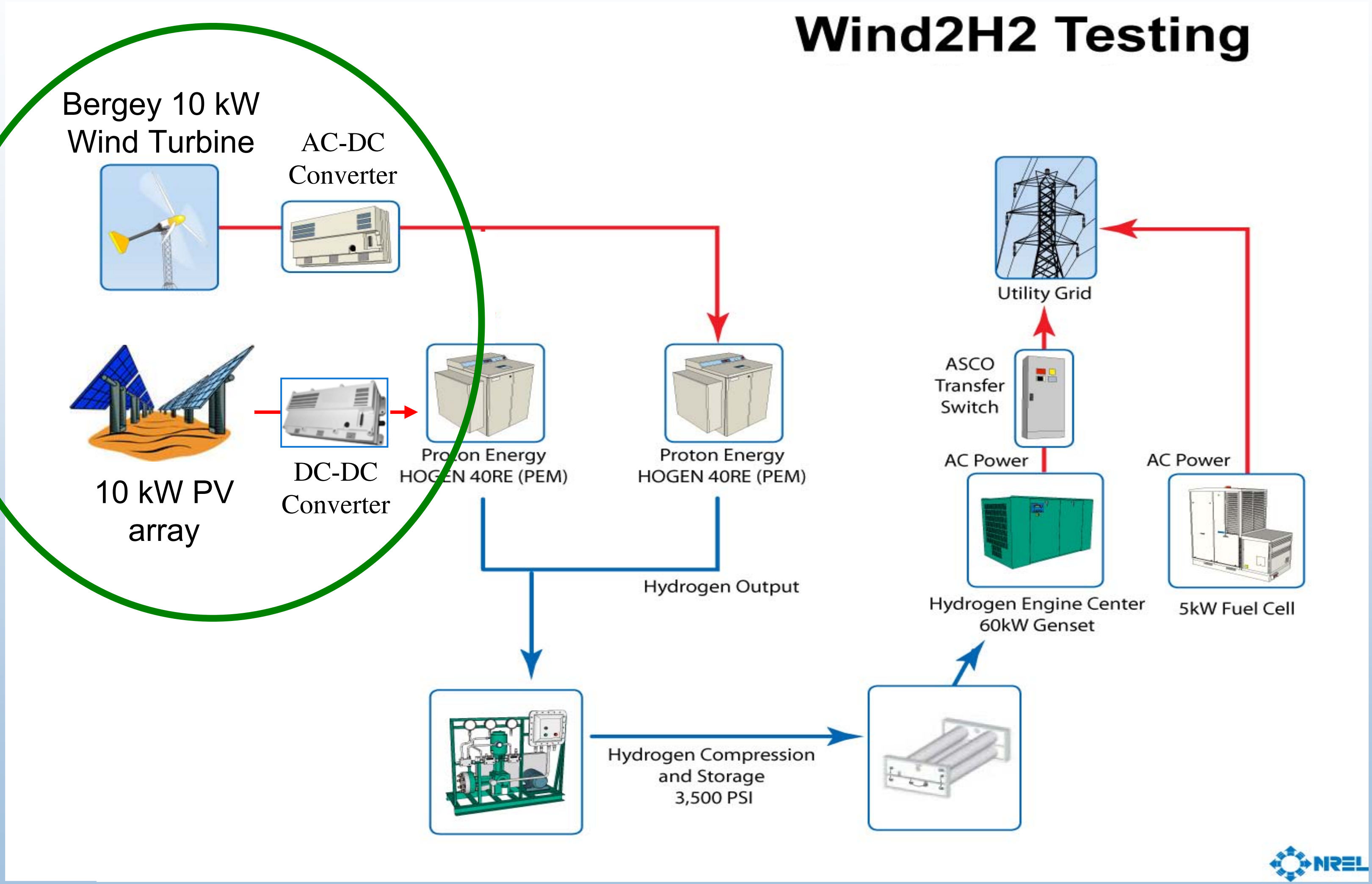
Grid Connected

Baseline Testing

Wind2H2 Testing Configuration I

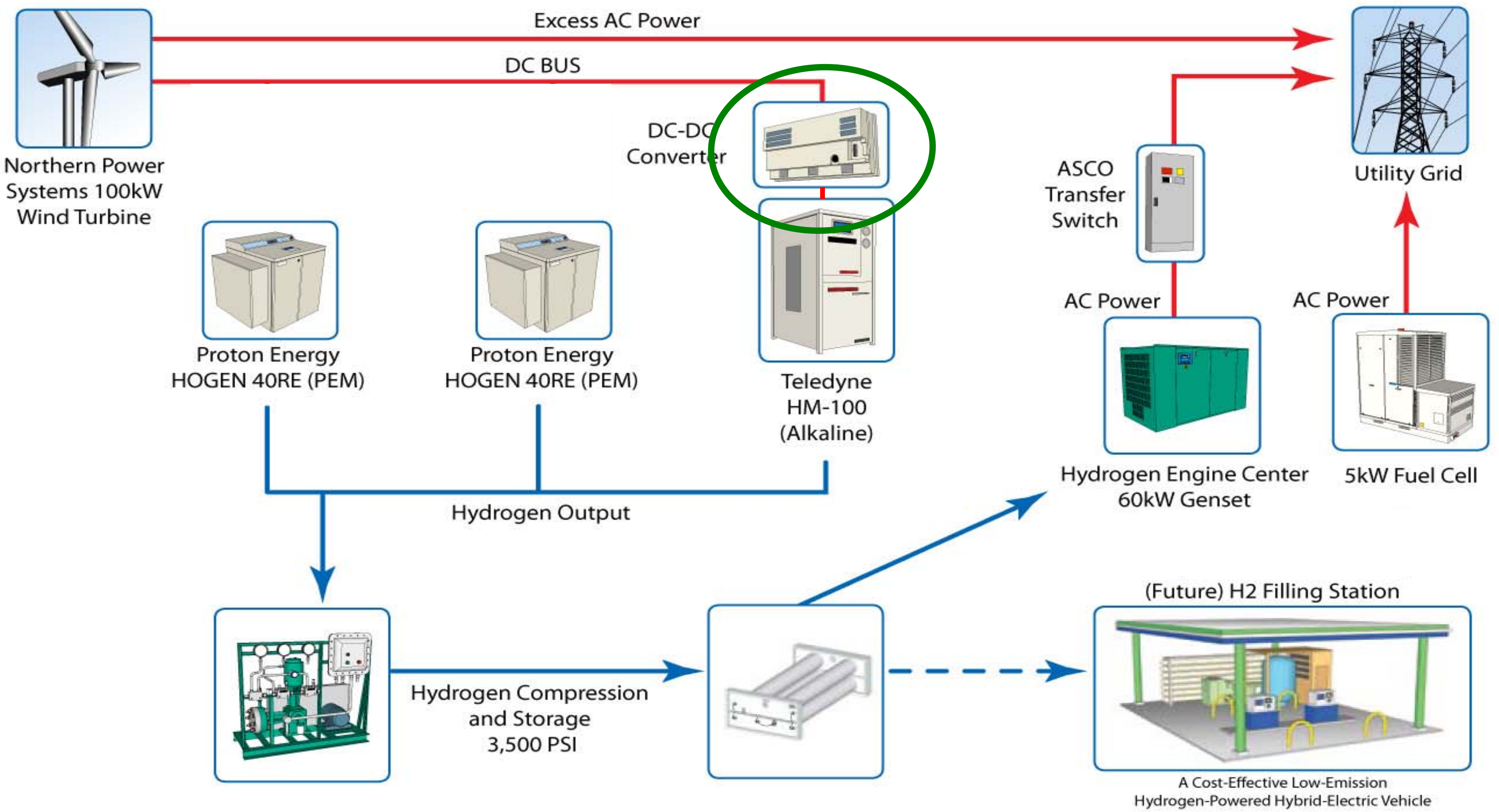


Power Converter Integration



Isolated DC/DC Design & Testing

Wind2H2 Testing Configuration II



NREL

Wind to Hydrogen Demonstration Project Accomplishments

- Obtained approval for daily operation:
  - Improved safety systems
  - Removed non-compliant devices
  - Instrumented equipment
  - Performed device warranty and maintenance
- Operating system in grid-connected mode
- Hydrogen production from wind and PV
  - New controllers design, built and tested

NREL Path Forward FY 2008

June – July 2008

- Complete Giner retrofit, testing and final report
- Complete design of hydrogen refueling station
- Wind 3rd generation power electronics startup & testing
- Component-level modeling (Manufacturer Feedback)
- Instrument and test hydrogen-fueled genset
- NW100 power converter build

August – September 2008

- Installation of hydrogen refueling station
- Test NW100 power converter
- Complete baseline Wind2H2 testing, analysis & report
- Complete small wind, PV and Grid integrated power electronics build and programming

NREL Path Forward FY 2009

- Complete small wind, PV and Grid integrated power electronics testing and analysis
- Renewable electrolysis test protocol update
- Verify automated operation of wind to hydrogen project
- Complete wind to hydrogen testing and analysis
- Ion chromatography of hydrogen product testing and analysis
- Model/simulation of renewable-electrolyzer performance
- Test and validation support for DOE electrolysis-based hydrogen production awarded projects
- Shutdown and relocate facilities

Project Collaboration

Bolded: Projects involved with informal wind to hydrogen data-sharing

National

- **NREL Test & Validation (Boulder, CO)**
- **Xcel-NREL Wind2H2 Project (Boulder, CO)**
- **Basin Electric (Minot, ND)**
- **Univ. of Minnesota (Morris, MN)**
- **Ft. Collins Utility (Ft. Collins, CO)**
- e-Vermont (Burlington, VT)

International

- **Center for Renewable Energy Sources (Greece)**
- International Energy Agency, Annex 24 "Wind Energy and Hydrogen Integration"
- Prince Edward Island (Canada)

Project Summary

Relevance: Addressing capital cost, efficiency and renewable energy source integration to reduce the cost per kg of H_2

Approach: Demonstrating advanced controls, system-level improvements and integration of renewable energy sources to electrolyzer stack

Technical Accomplishments:

- Increased energy capture of 2nd generation wind to stack power electronics. (Renewable Energy Integration)
- Verified stack voltage efficiency to help meet DOE Joule milestone. (System Efficiency)
- Integrating grid, wind and PV functionality into single power electronics module to reduce capital cost. (Capital Cost)

Technology Transfer & Collaborations: Gathering feedback from and transferring results to industry to enable improved renewable and electrolyzer integration and performance. Active and informal partnerships with industry, academia and domestic/international researchers.

Future Research: Complete high-pressure electrolyzer testing, continue baseline and renewable energy source testing for the wind to hydrogen demonstration project, accelerate cost and performance modeling/simulation of renewable electrolysis systems.

Additional information can be found at

http://www.nrel.gov/hydrogen/renew_electrolysis.html

Additional slides including publications and comments from 2007 AMR follow

Thank you!