Innovation for Our Energy Future

Renewable Electrolysis Integrated System Development and Testing

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This presentation does not contain any proprietary or confidential information.



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

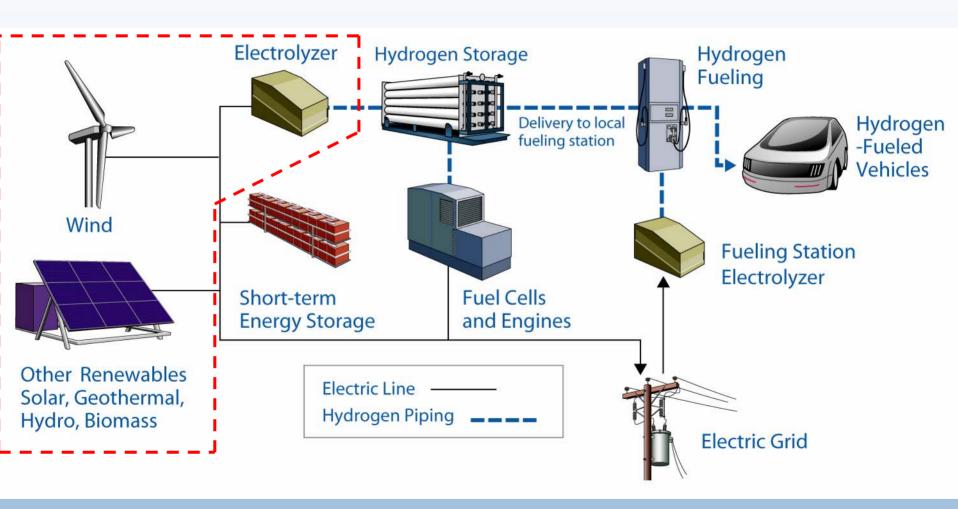
- By 2012, reduce the cost of distributed production of hydrogen from distributed electrolysis to \$3.70/gge of H2 (delivered) at the pump.
- By 2017, reduce the cost of distributed production of hydrogen from distributed electrolysis to <\$3.00/gge of H2 (delivered) at the pump.

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 BackgroundImportance 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

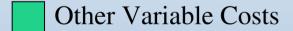
Characterization Testing and Protocol Development

Stack and system level analysis of performance



Electrolysis Analysis

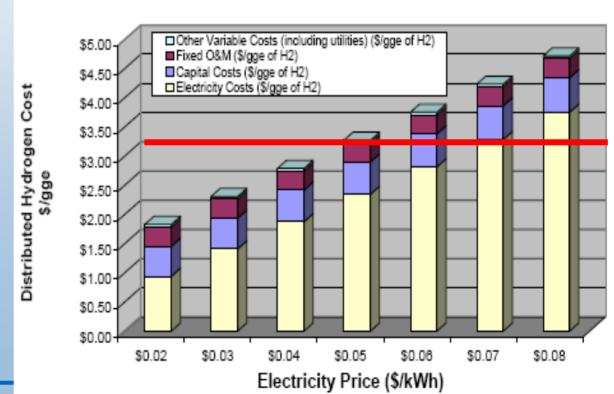
- Updated "Summary of Electrolytic Hydrogen Production" report.
- Current cost of hydrogen via electrolysis



Fixed O&M

Capital Costs

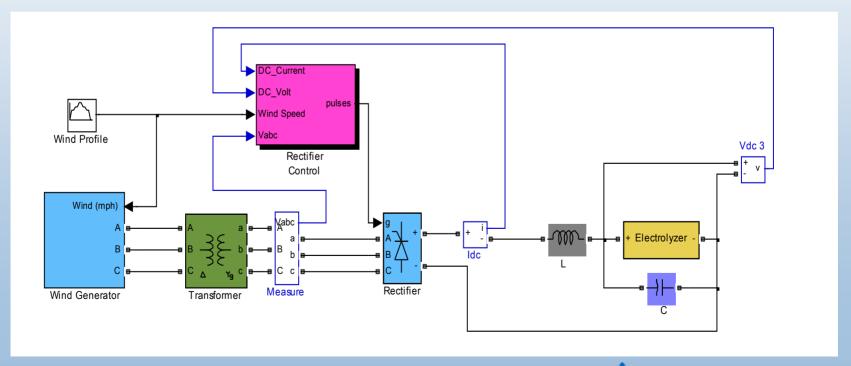
Electricity Costs



FY07 Technical Accomplishments

Systems Engineering, Modeling, and Analysis

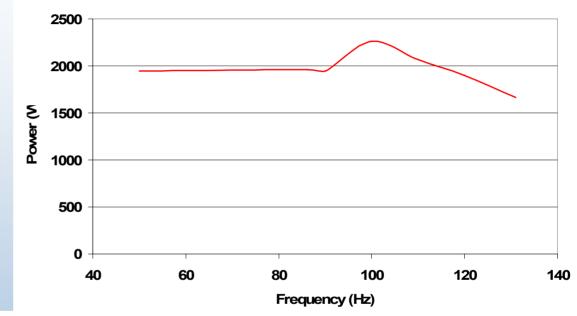
- Simulated wind turbine to stack system with Simulink
- Compared model and PE to explore gate-firing discrepancies and enhance control algorithm.

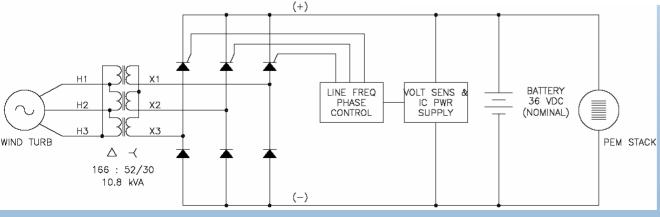


FY07 Gen1 PE Test Results

System Integration and Component Development

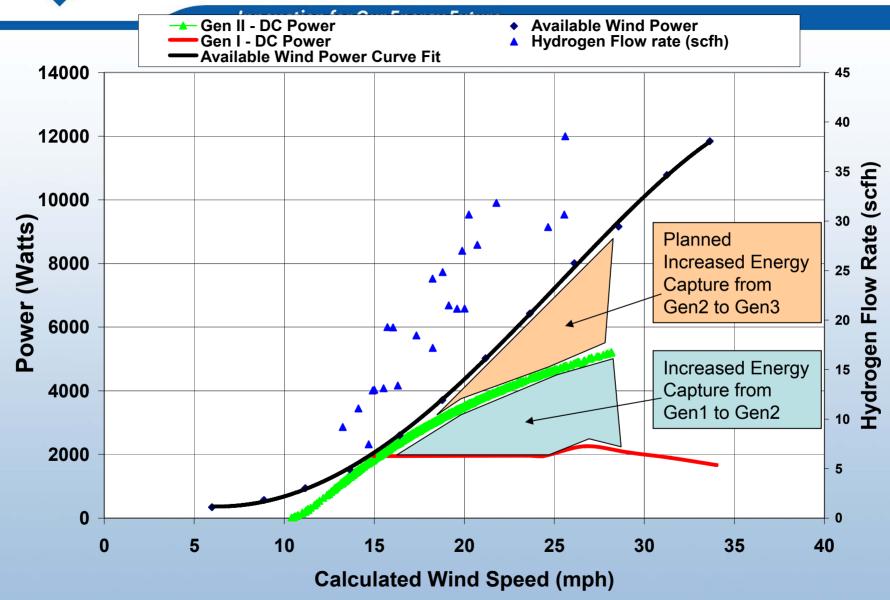
- Gen1 PE for 10kW WT
- Battery interaction at lower frequency and state-of-charge
- Big opportunity for optimization





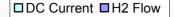


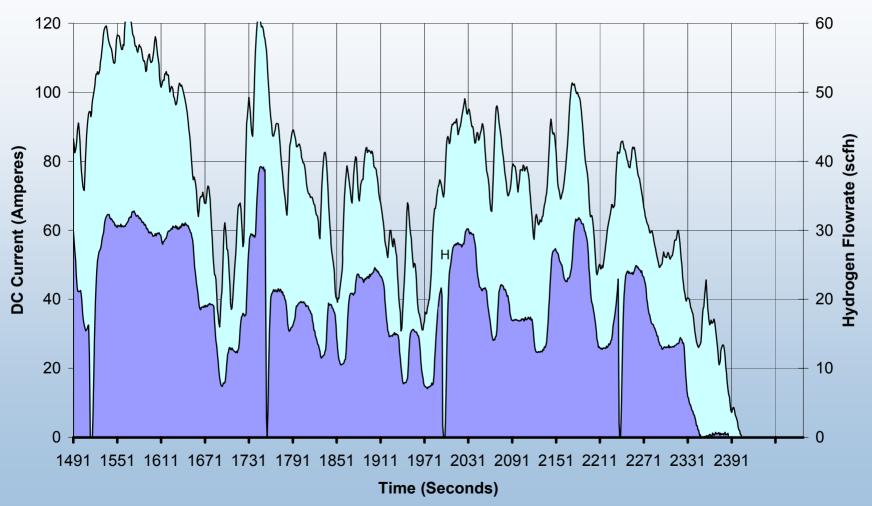
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FY07 Gen2 PE Interim Test Results

System Integration and Component Development





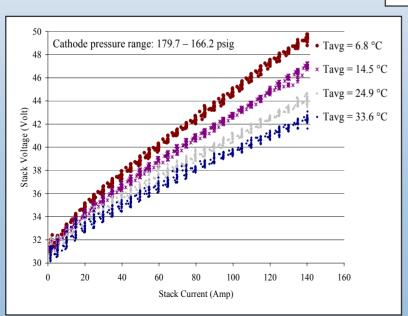
Hydrogen Production and Current as a function of Time

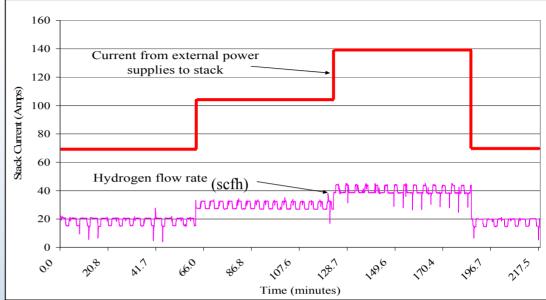
NREL National Renewable Energy Laboratory

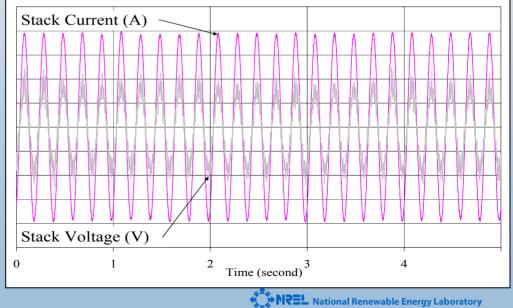
FY07 Technical Accomplishments

Characterization

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



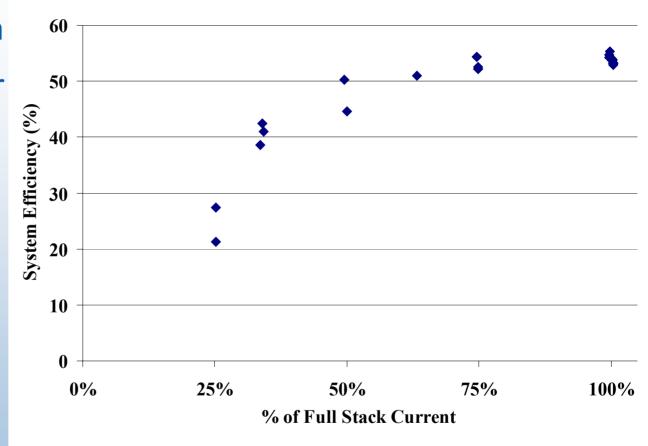




FY07 Technical Accomplishments

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.





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 Ability to accommodate the varying energy input from wind and PV

Xcel-NREL Wind2H2 Collaboration

Direct Coupling

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



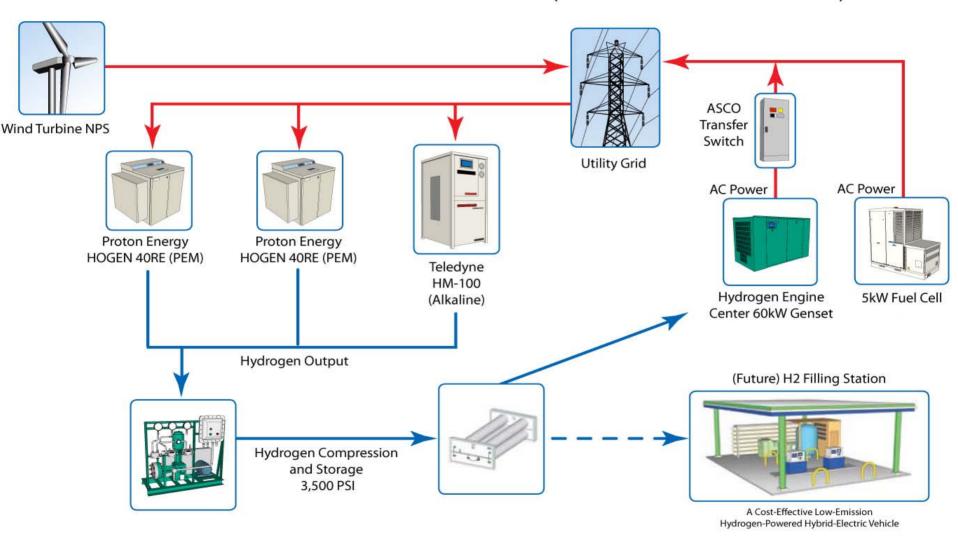


DC varying with wind speed



FY07 Testing

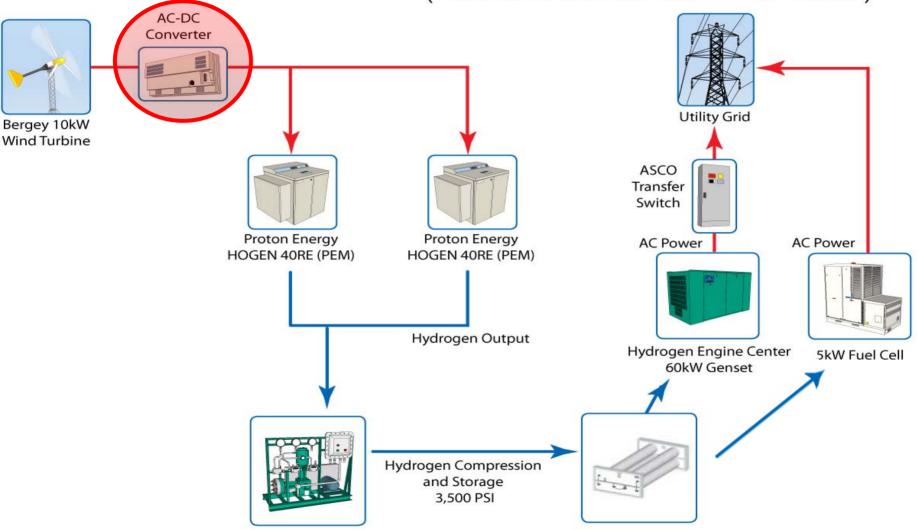
Wind2H2 Testing Configuration I (AC Grid Connected Baseline)





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

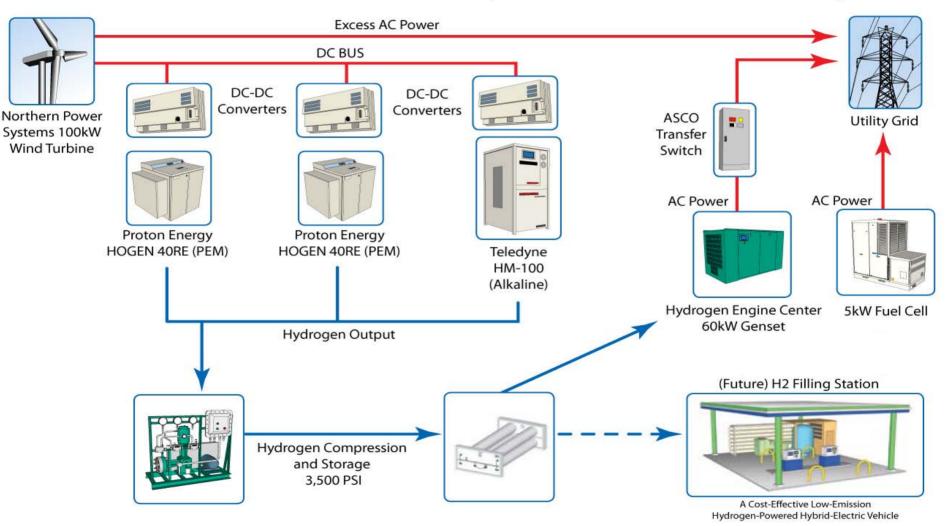






Future Work FY08 Testing

Wind2H2 Testing Configuration II (DC/DC from 100kW Wind Turbine)





Added Value from Collaboration

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

• AC/DC and DC/DC Interface

· Re-deployable

Coordinated "Wind Storage"

Basin Electric
Univ. of N. Dakota

Hydrogen Utility
Group (HUG)

University

of Minnesota

Xcel Energy

Fort Collins
Utilities &
Colorado OEMC

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

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

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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 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

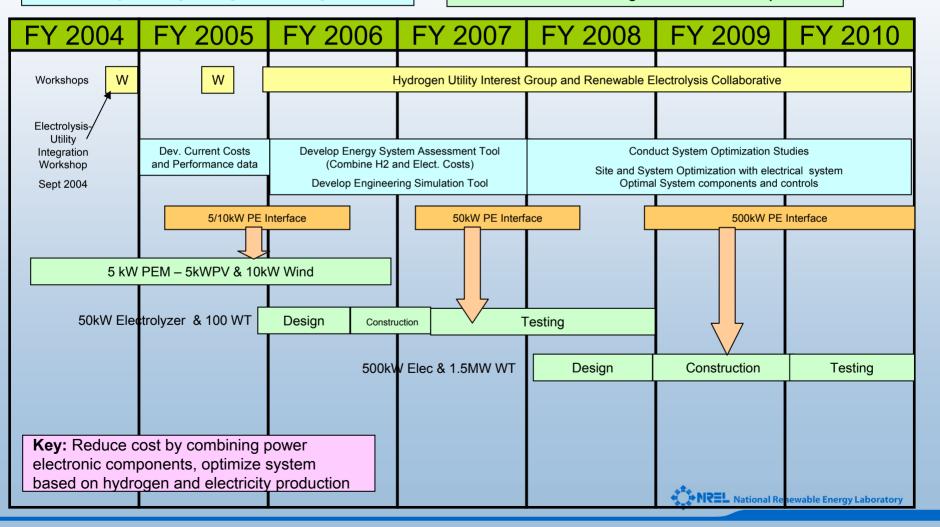
Renewable Electrolysis - Integrated Systems Development and Testing

Coordination, Planning and Stakeholder Development

System Engineering and Modeling

System Engineering and Modeling

Characterization Testing and Protocol Development



Distributed Electrolysis Targets

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

Table 3.1.4A Distributed Electrolysis H2A Example Cost Contributions ^{a,b,c}					
Characteristics		Units	2006° Status	2012	2017
Electrolysis Unit	Cost Contributiond	\$/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,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	\$/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° 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° 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 ⁹	\$/gge H2	-0.30	-0.60	-2.00
	Percentage of electricity produced sold as by-		40	0.7	50
	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 hydrogenelectric future

Utilities: DTE Energy, Sacramento Municipal Utility District, Nebraska Public Power District, Connexus

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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

