NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

NREL Wind to Hydrogen Project: Renewable Hydrogen Production for Energy Storage & Transportation

NREL
Hydrogen Technologies and Systems Center

Todd Ramsden,
Kevin Harrison,
Darlene Steward

November 16, 2009

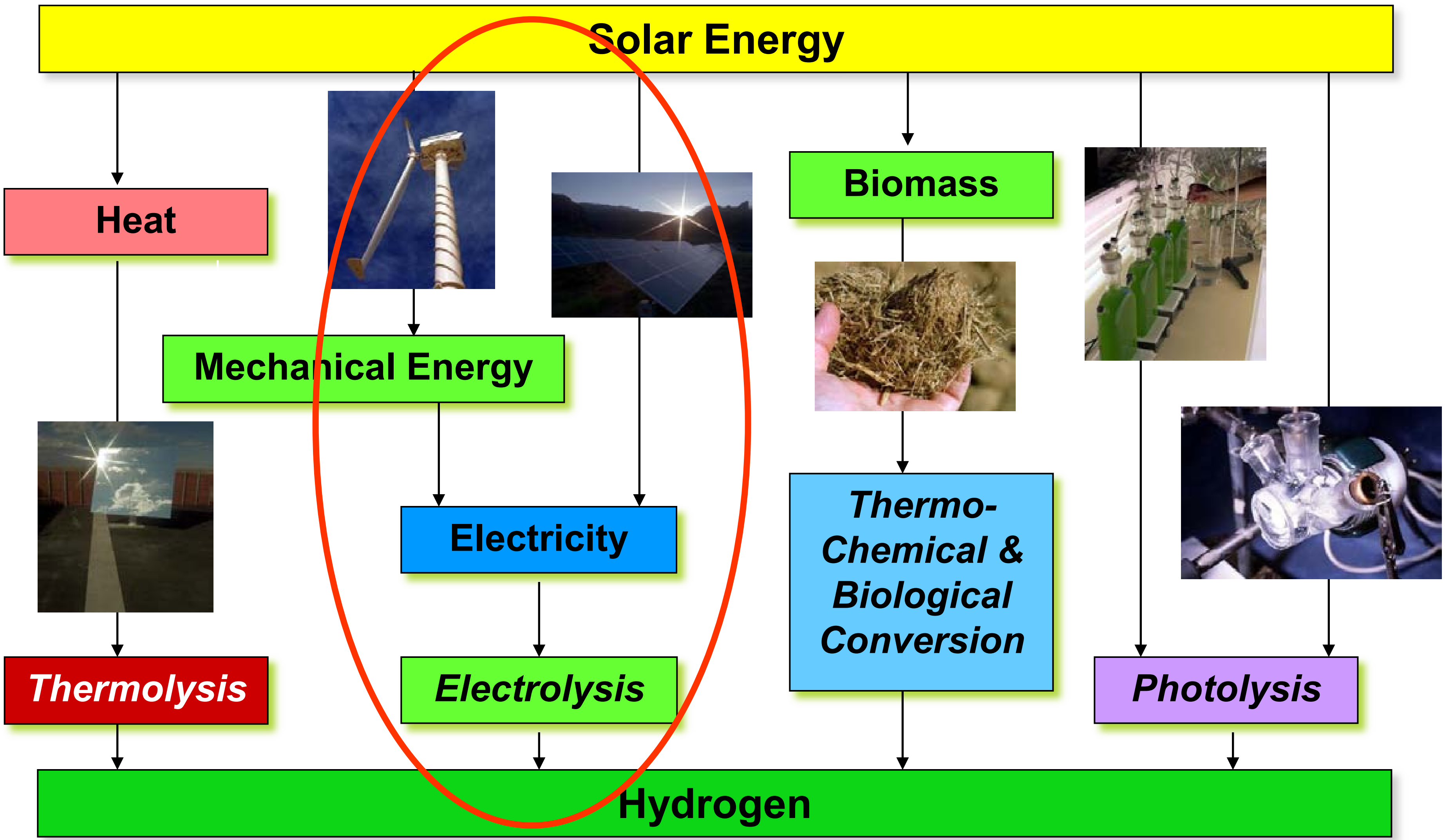
NREL/PR-560-47432

NREL Wind2H2 RD&D Project

- The National Renewable Energy Laboratory in partnership with Xcel Energy and DOE has designed, operates, and continues to perform testing on the wind-to-hydrogen (Wind2H2) project at the National Wind Technology Center in Boulder
- The Wind2H2 project integrates wind turbines, PV arrays and electrolyzers to produce from renewable energy

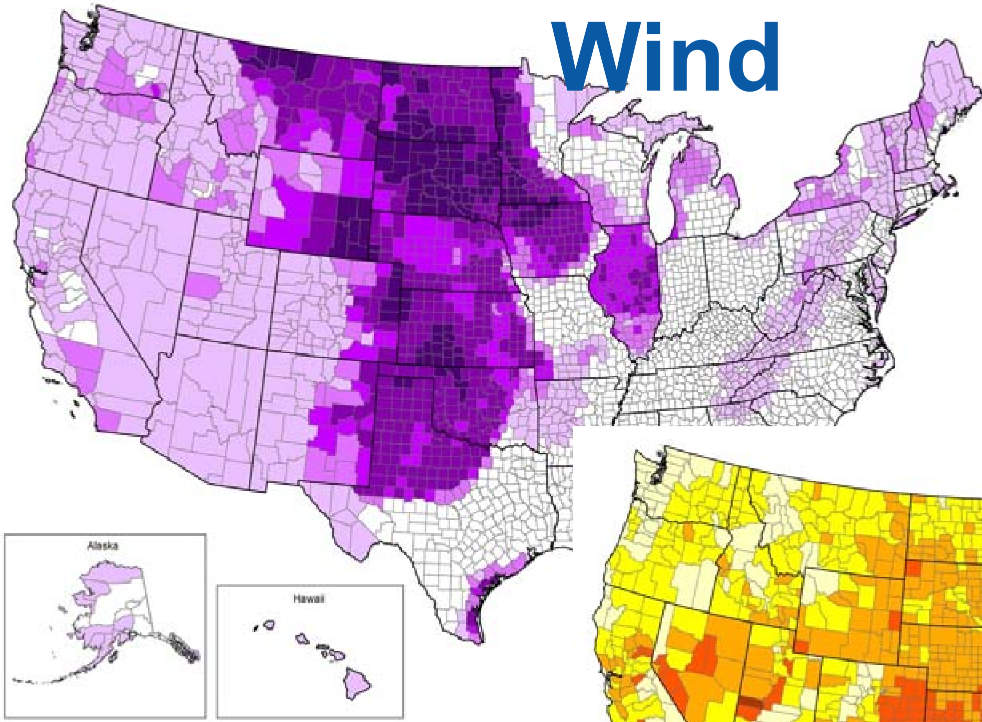



Sustainable Paths to Hydrogen

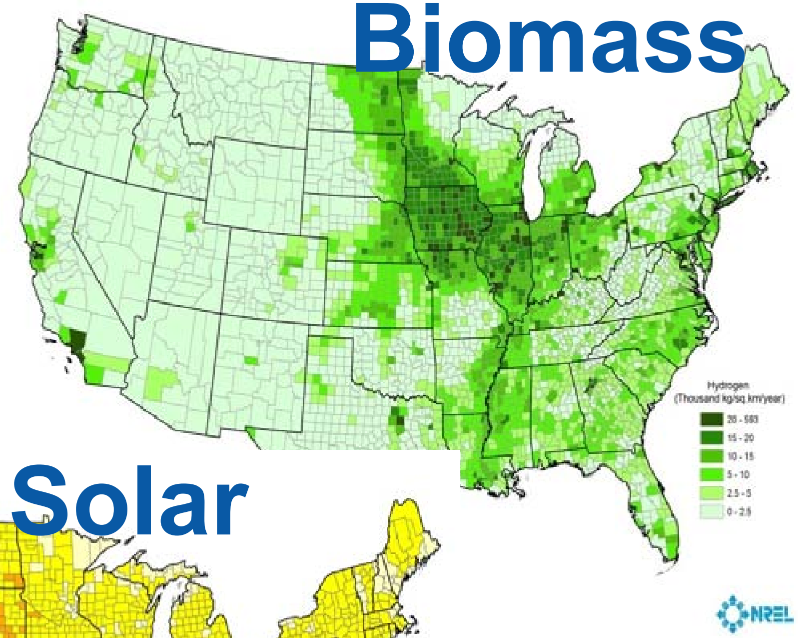


Hydrogen Potential from Sustainable Resources

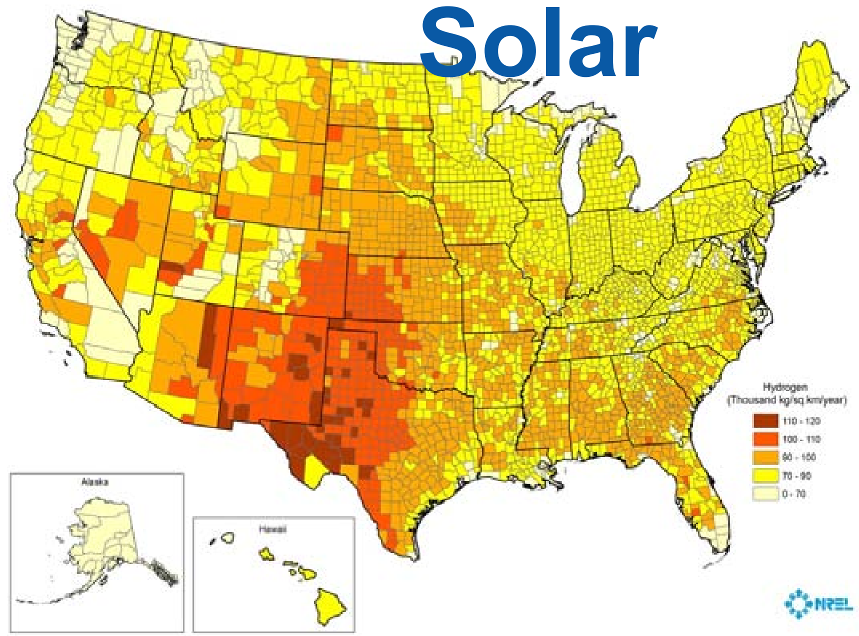
Wind



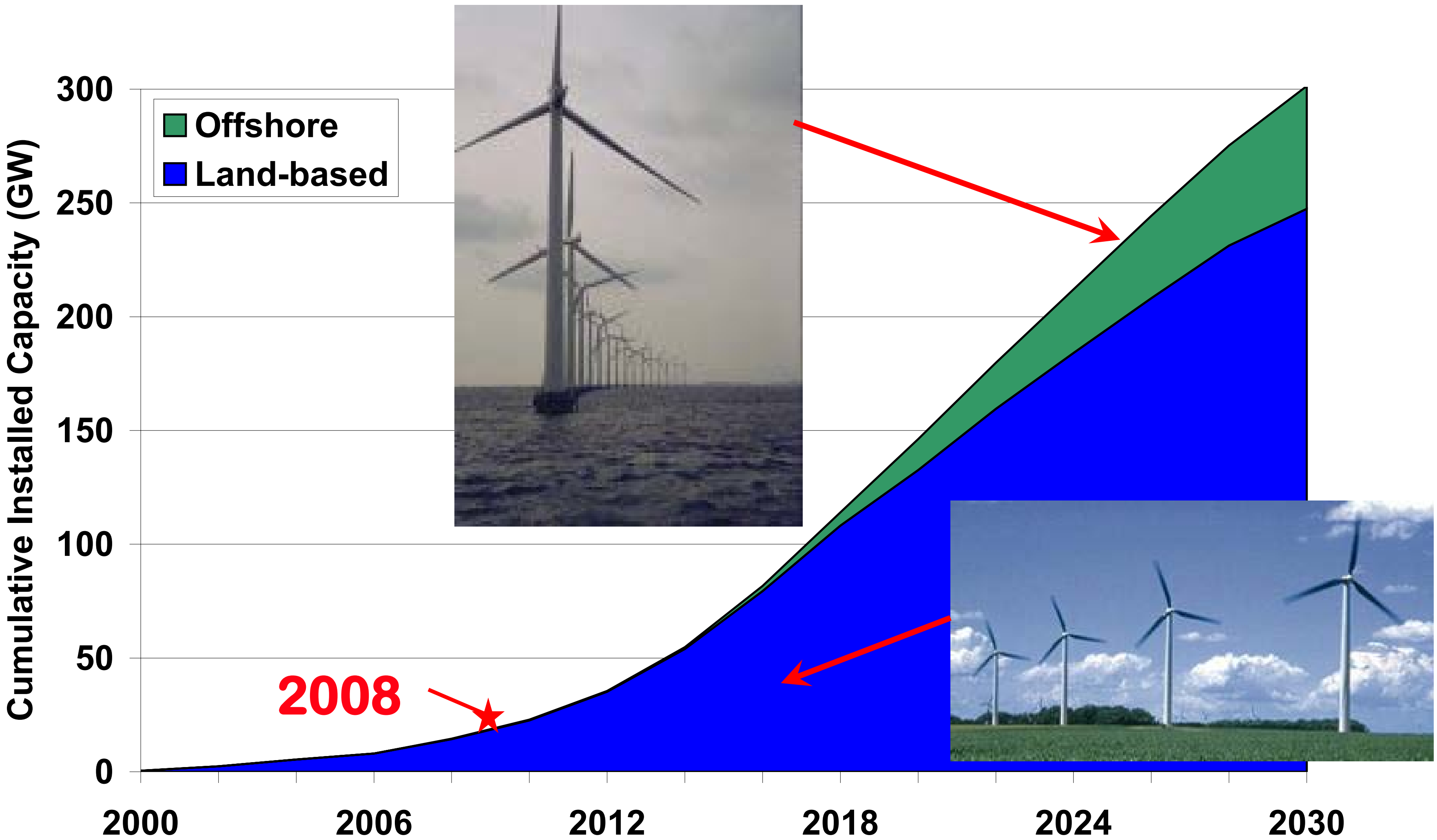
Biomass



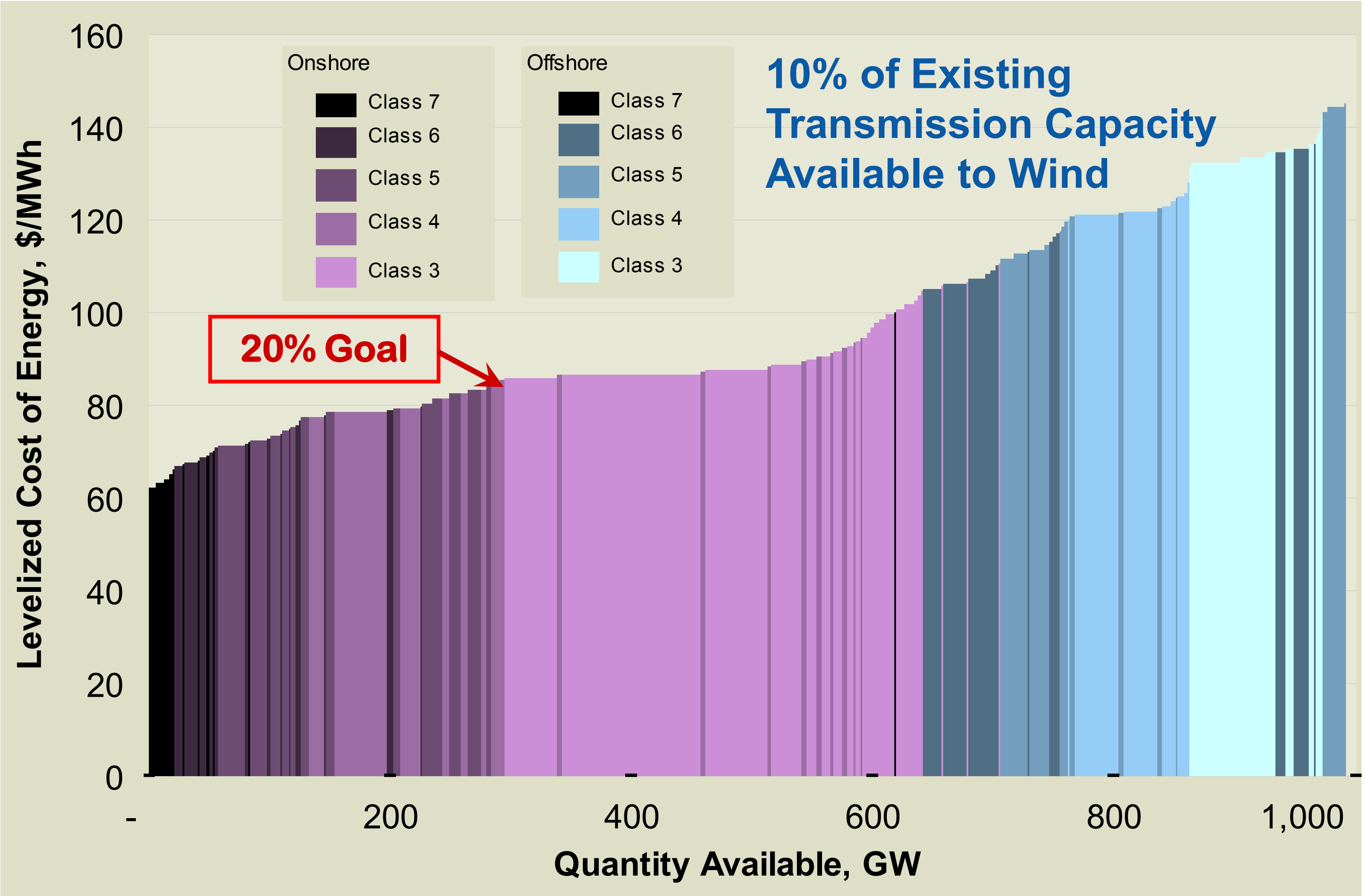
Solar



20% Wind Energy by 2030 Scenario



How Much Wind is Available in the U.S.?

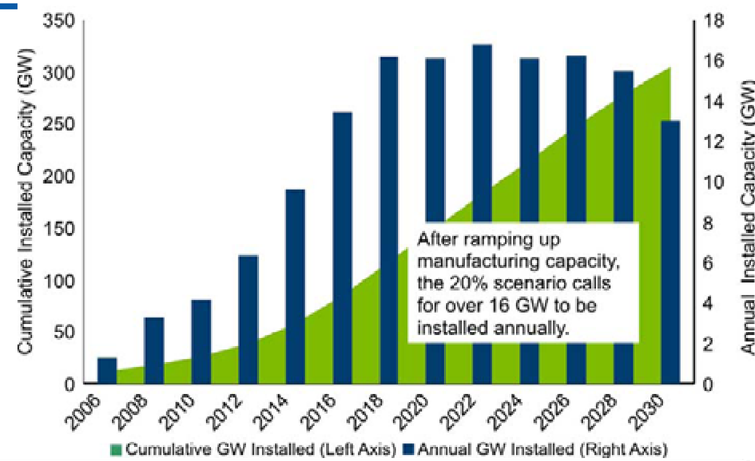


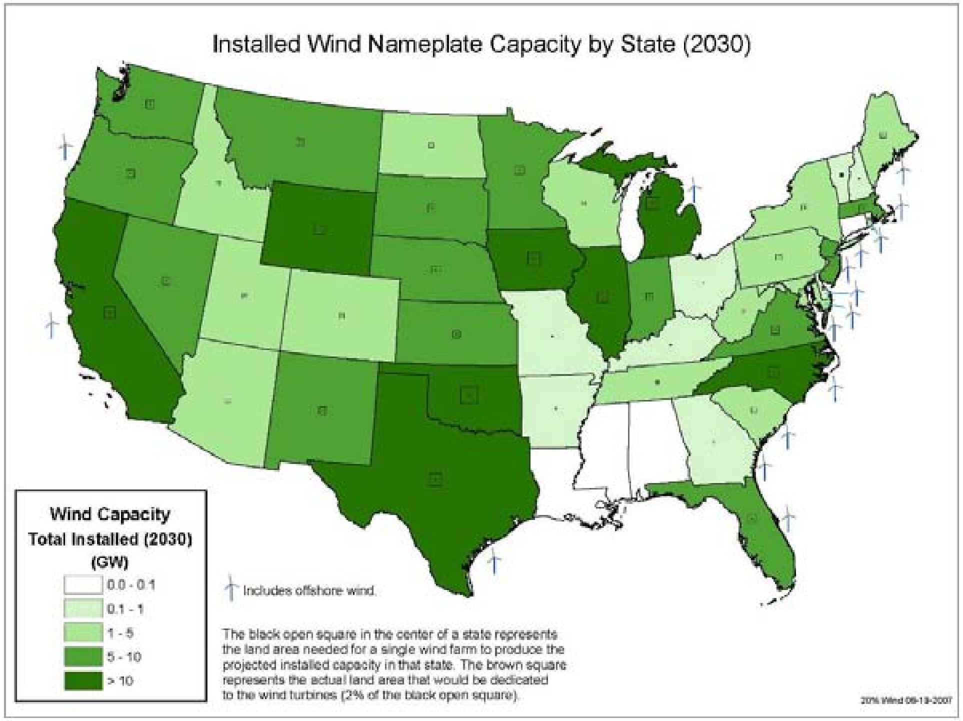
2010 Costs w/o PTC, $1,600/MW-mile, w/o Integration costs

Source: Black & Veatch/NREL

Technology Challenges to Meet 20% Goal

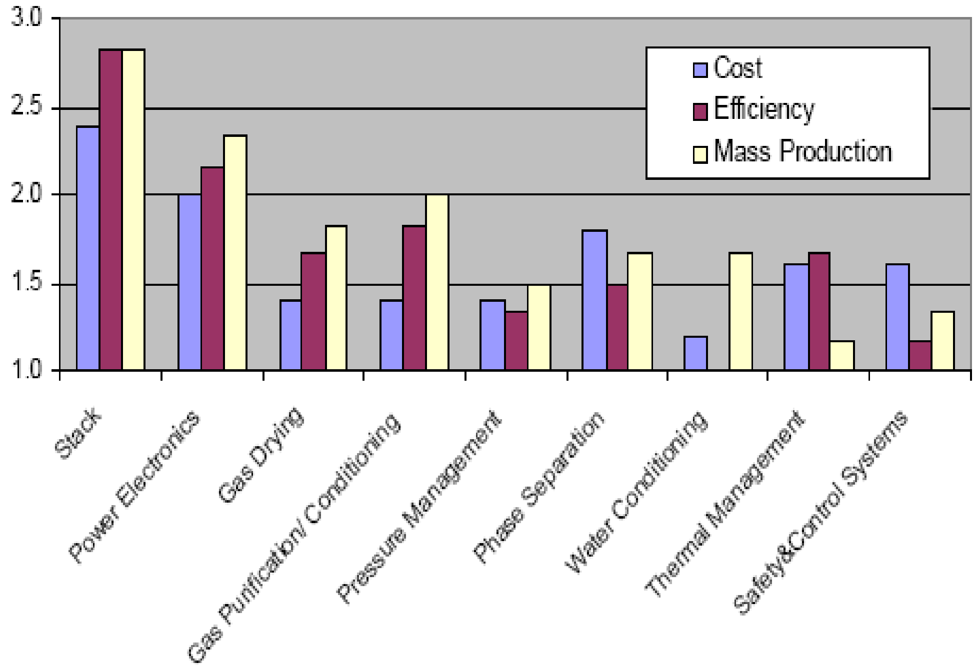
- Massive growth in installations
  - 8 GW installed in 2008
  - ~29 GW total as of 2009
  - Over 300GW by 2030
- Widely distributed across the nation
  - Many high wind sites
  - Substantial installation in moderate resource areas
  - Some offshore is needed
- Performance is critical
  - Capital cost
  - Capacity Factor
  - O&M
- Every 1 ¢/kWh of cost reduction saves the nation over $10 billion per year at 20% penetration





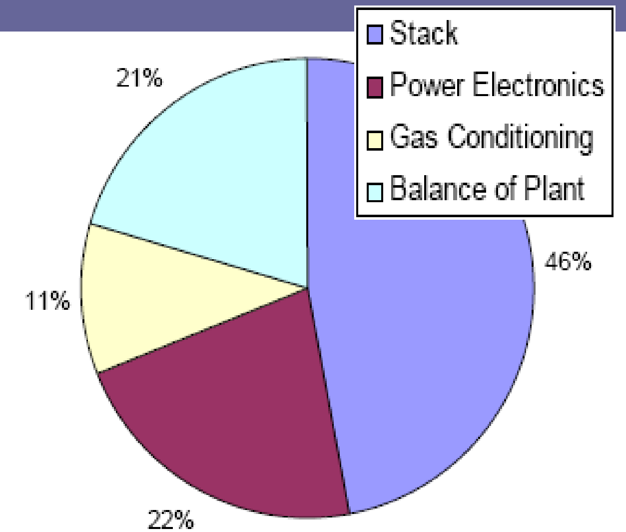
Wind2H2 Project – Overall Goal

- Provide RD&D to help DOE achieve it cost target for hydrogen production from wind-based water electrolysis of $4.80/gge by 2012 and to <$3.00/gge by 2017



Challenges

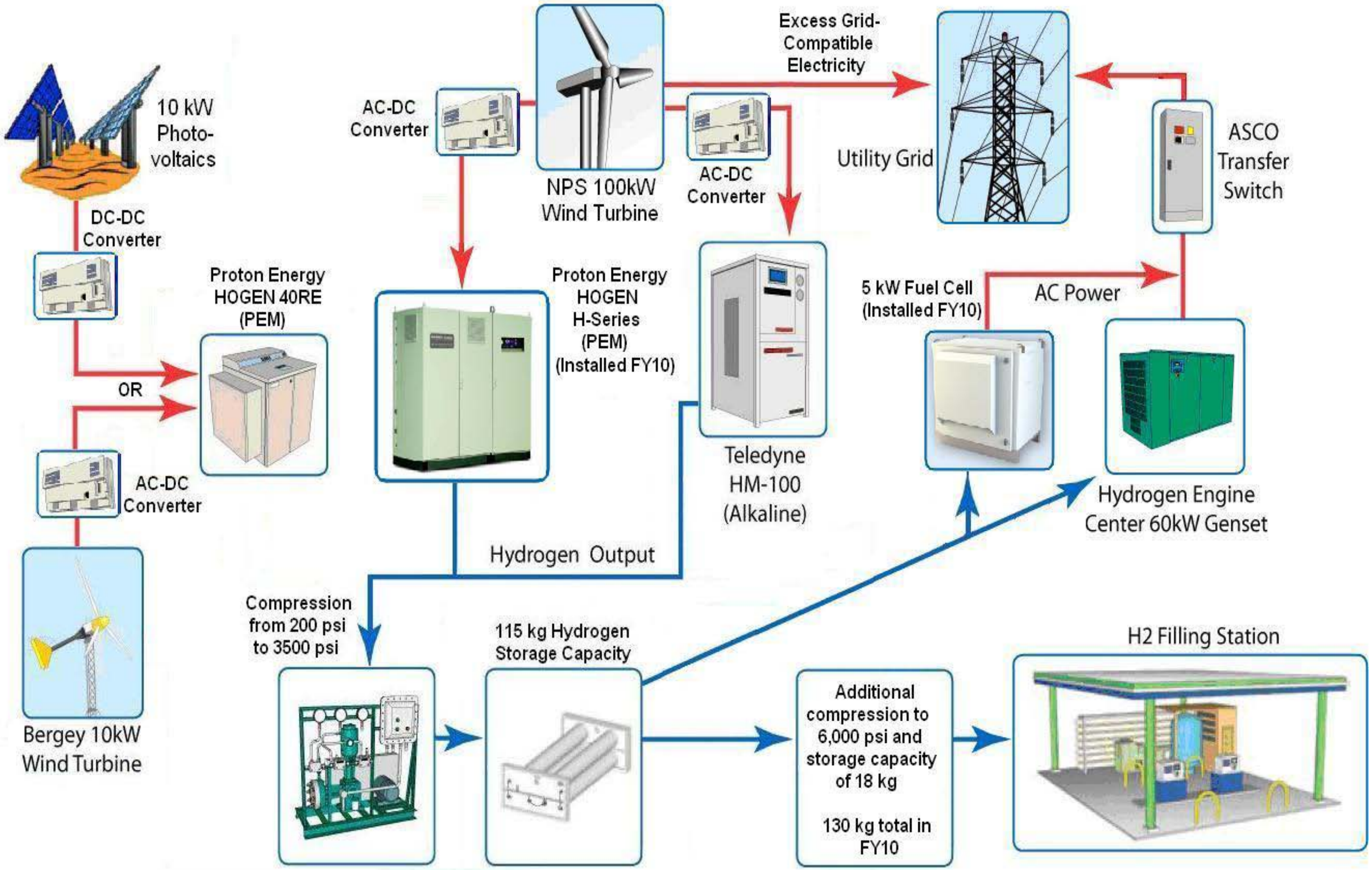
- *Reduce capital costs of electrolysis system through improved designs and lower cost materials*
- *Develop low-cost hydrogen production from electrolysis through integration with renewable electricity sources*
- *Develop strategies for low cost hydrogen production from electrolysis through utility coordination*



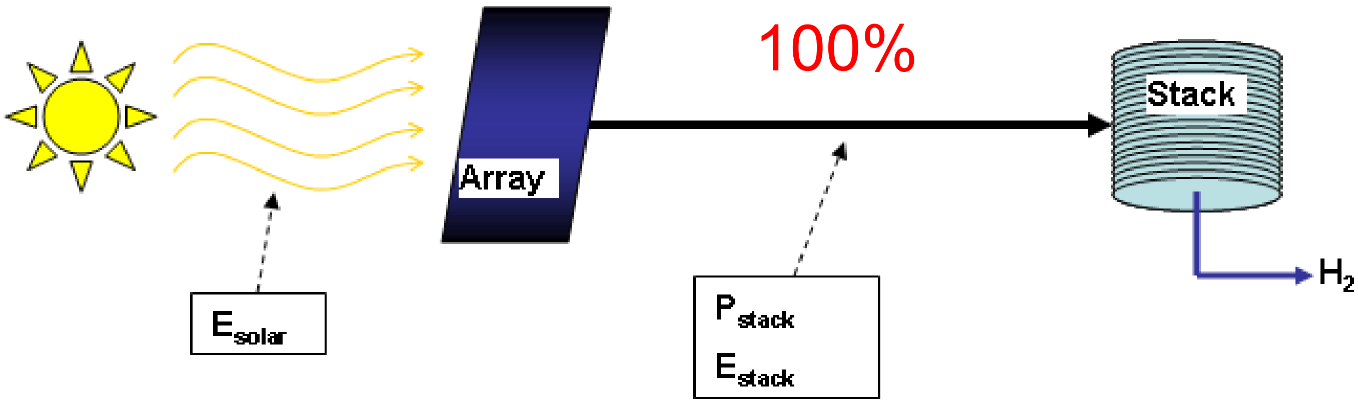
Wind2H2 Project – Main Objectives

- Research the cost and capability of "time shifting" wind and PV energy through utility-scale hydrogen-based energy storage
- Research optimal wind/hydrogen through systems engineering
- Characterize and control wind turbine/PV and H2-producing stack
- Evaluate synergies from co-production of electricity and hydrogen
- Compare response and performance of alkaline and PEM electrolyzer technologies
- Realize efficiency gains though simplified and integrated power controllers
- Working towards 'ideal' wind to hydrogen
  - Simplifying PE, common controls, closely coupling wind input to stack, electricity regulation

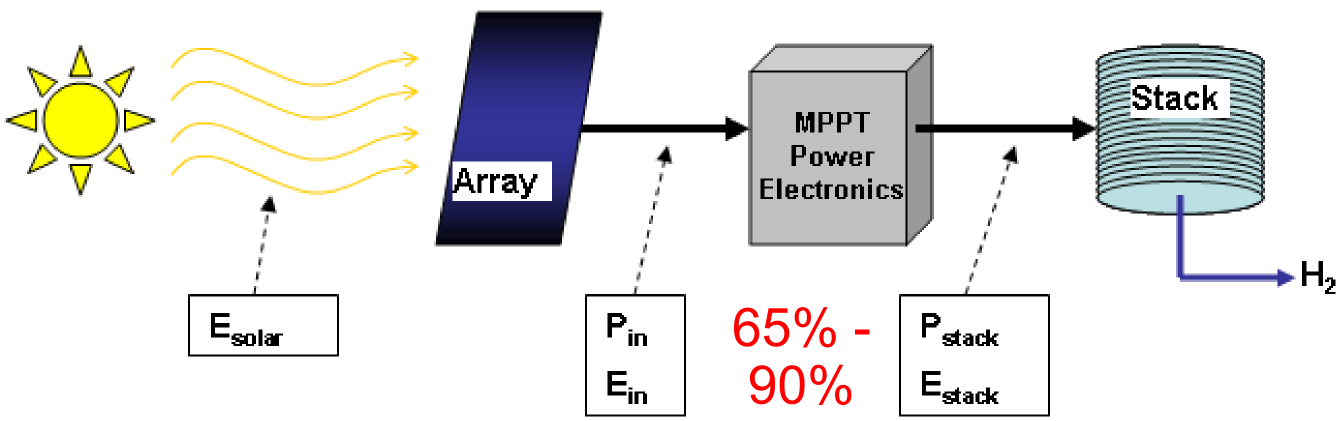
Wind2H2 System Operating Modes



PV Configuration Testing

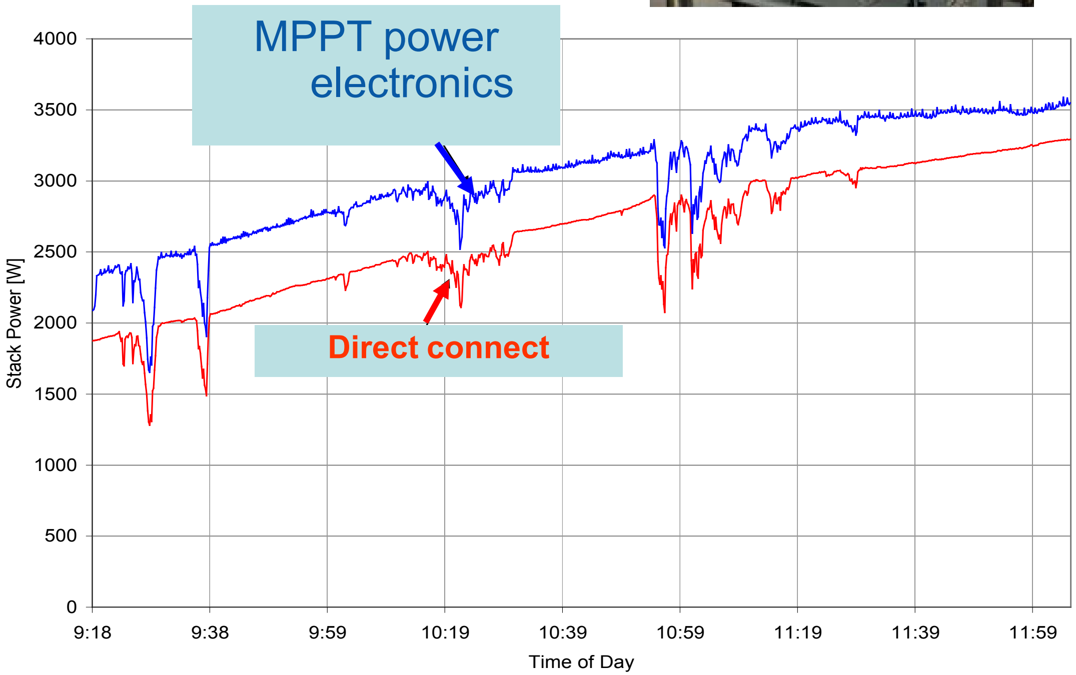


Direct connect versus various input voltages (E_{in}) through power controller



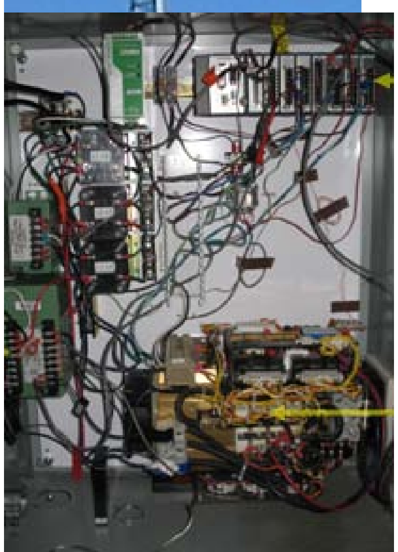
PV Powered Electrolysis

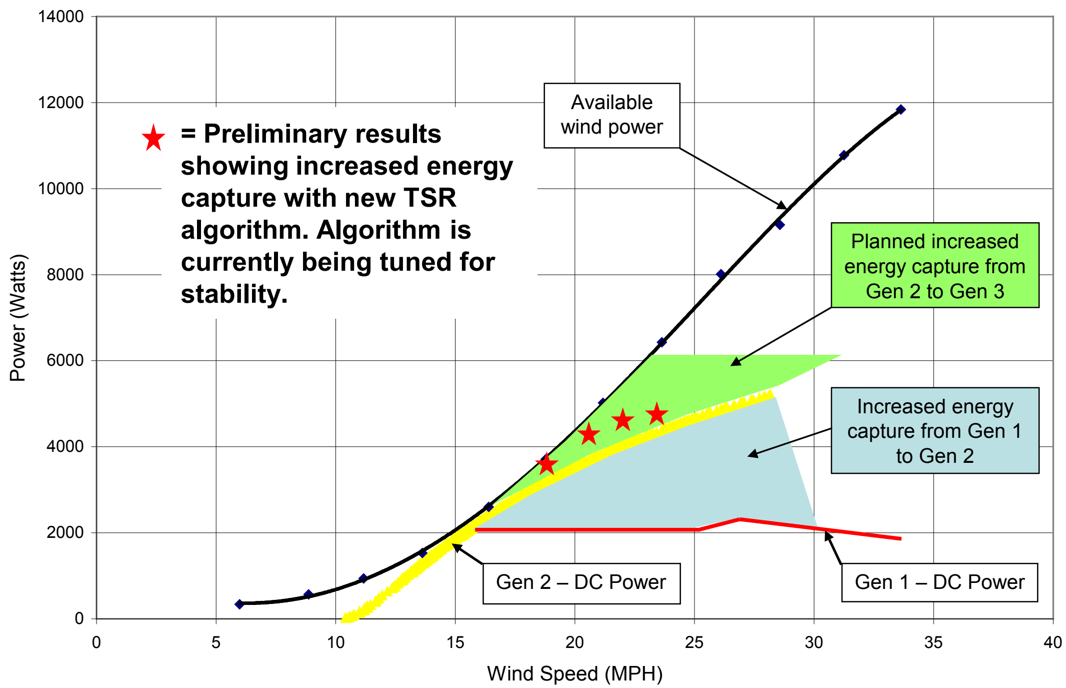
- Onboard power electronics account for 15 to 30% of the overall electrolyzer system cost
- Minimize redundant components
- Test data illustrates improvement in energy capture to stack when using MPPT power electronics
- Testing showed a 10% – 20% increase in energy capture



10kW Wind Turbine Powered Electrolysis

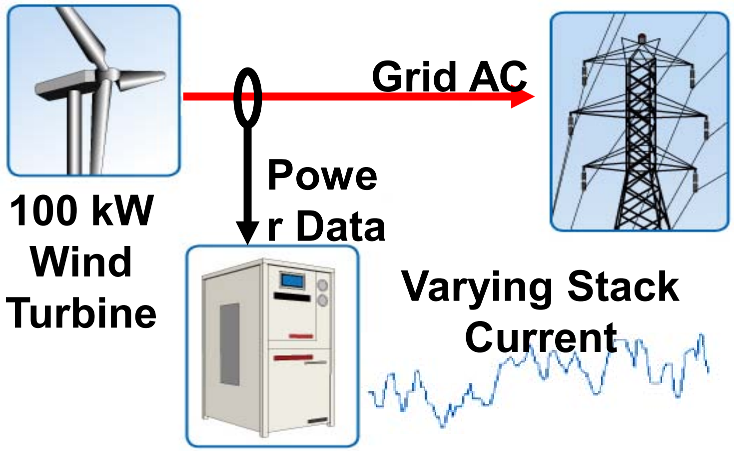
- Initial tests with third generation power electronics, wind speed measurement and control algorithm indicate further improved energy capture of wind electricity into hydrogen production

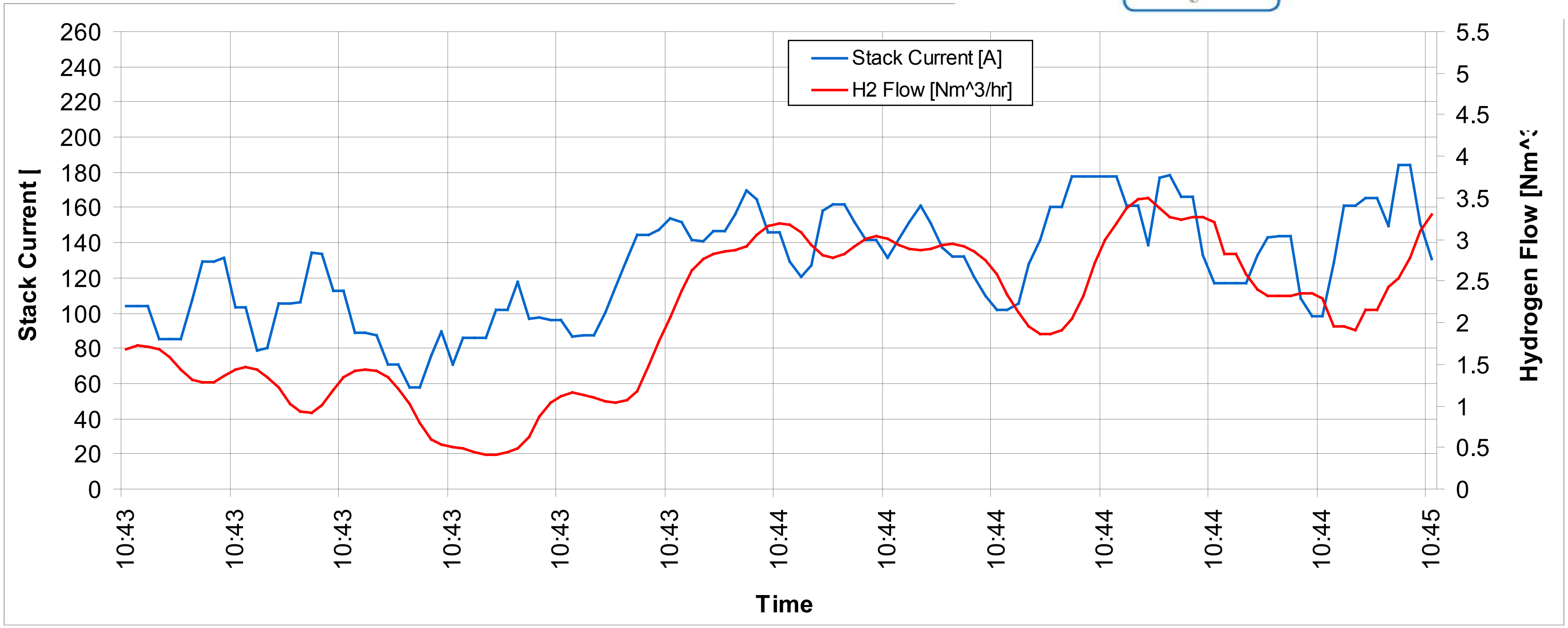




100kW Wind Turbine Powered Electrolysis

- Instrumented power signal from 100 kW wind turbine to drive 33 kW alkaline stack current to follow power available from turbine





Electrolyzer System Efficiency

- Wind2H2 system used to assess electrolyzer performance
- Stack and system efficiency of alkaline (33 kW stack, 40 kW system) and PEM-based (6 kW stack, 7 kW system) measured

Efficiency	PEM Electrolyzer		Alkaline Electrolyzer	
	LHV	HHV	LHV	HHV
Stack Efficiency				
Low Current	80% (5A)	95% (5A)	78% (30A)	92% (30A)
Rated Current	63% (135A)	75% (135A)	59% (220A)	70% (220A)
System Efficiency				
Low Current	0% (15A)	0% (15A)	0% (35A)	0% (35A)
Rated Current	49% (135A)	57% (135A)	35% (220A)	41% (220A)

Cost Analysis

Capital Component (uninstalled)	Baseline System	Optimized System
1.5 MW Wind Turbine		
Rotor	$248,000	$248,000
Drive Train	$1,280,000	$1,180,000
including power electronics	*$100,000*	*$0*
Control System	$10,000	$10,000
Tower	$184,000	$184,000
Balance of Station	$262,000	$262,000
2.33 MW Electrolyzer	$1,570,000	$1,350,000
including power electronics	*$220,000*	*$0*
New Power Electronics Interface	$0	$70,000
Resulting Hydrogen Cost ($/kg)	**$6.25**	**$5.83**

- Cost analysis performed based on NREL's power electronics optimization and testing and on our electrolyzer cost analysis study
- Large centralized system capable of 50,000 kg per day production
- Optimized power conversion system due to a closer coupling of the wind turbine to the electrolyzer stack can reduce the total cost of hydrogen by 7%.

350 bar Vehicle Fueling System

- Outdoor rated compressor
- 400 bar tank (18 kg)
- 350 bar non-communication fill dispenser
- 1.8 kg (110 mile range) Mercedes-Benz FC vehicle

Key Findings from Wind2H2 RD&D

System Efficiency (HHV): At rated stack current…

- The PEM electrolyzer system efficiency of 57%
- The alkaline system had a system efficiency of 41%
  - H_2 production about 20% lower than the manufacturer's rated flow rate
  - 50% system efficiency would be realized if rated flow were achieved

Cost Reductions from Power Electronics Optimization:

- Analysis showed a potential 7% reduction in cost per kg of hydrogen based on capital cost improvement
  - Projected cost of hydrogen falling to $5.83/kg from a baseline of $6.25/kg

Energy Transfer Improvements: PV configuration testing compared direct-connection to the electrolyzer stack with a connection through power electronics

- The MPPT power electronics system captured between 10% and 20% more energy than the direct-connect configuration

Hydrogen-Based Energy Storage Cost Analysis

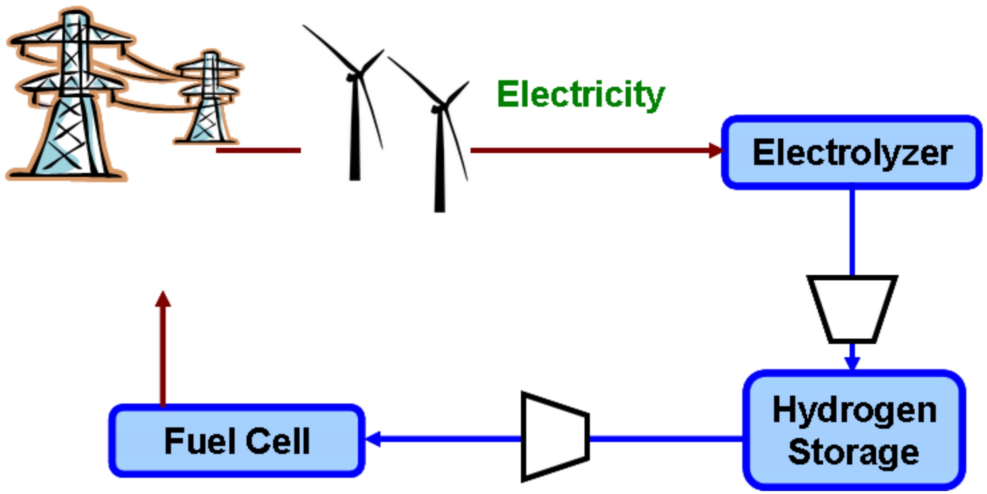
Project Objective:

- Evaluate the economic viability of the use of hydrogen for medium- to large-scale energy storage applications in comparison with other electricity storage technologies

Project Background:

- FY2009 study builds upon and expands on an initial scoping study of hydrogen-based energy storage conducted in FY2008
- Benchmarking against competing technologies (batteries, pumped hydro, CAES)
- Expanded analysis of PEM fuel cells and hydrogen combustion turbine
- Analysis of production of excess hydrogen for vehicles
- Preliminary analysis of environmental impacts

Energy Storage Scenario



- Nominal storage volume is 300 MWh (50 MW, 6 hours)
  - Electricity is produced from the storage system during 6 peak hours (1 to 7 pm) on weekdays
  - Electricity is purchased during off peak hours to charge the system
- Electricity source: excess wind / off peak grid electricity
  - Assumed steady and unlimited supply during off peak hours (18 hours on weekdays and 24 hours on weekends)
  - Assumed fixed purchase price of 3.8¢/kWh with sensitivities run at 2.5¢/kWh and 6¢/kWh

Analysis Framework

Major Assumptions

- No taxes or transmission charges are included in the analysis
- The supply of off peak and/or renewable electricity is unlimited
- Costs are presented in $2008

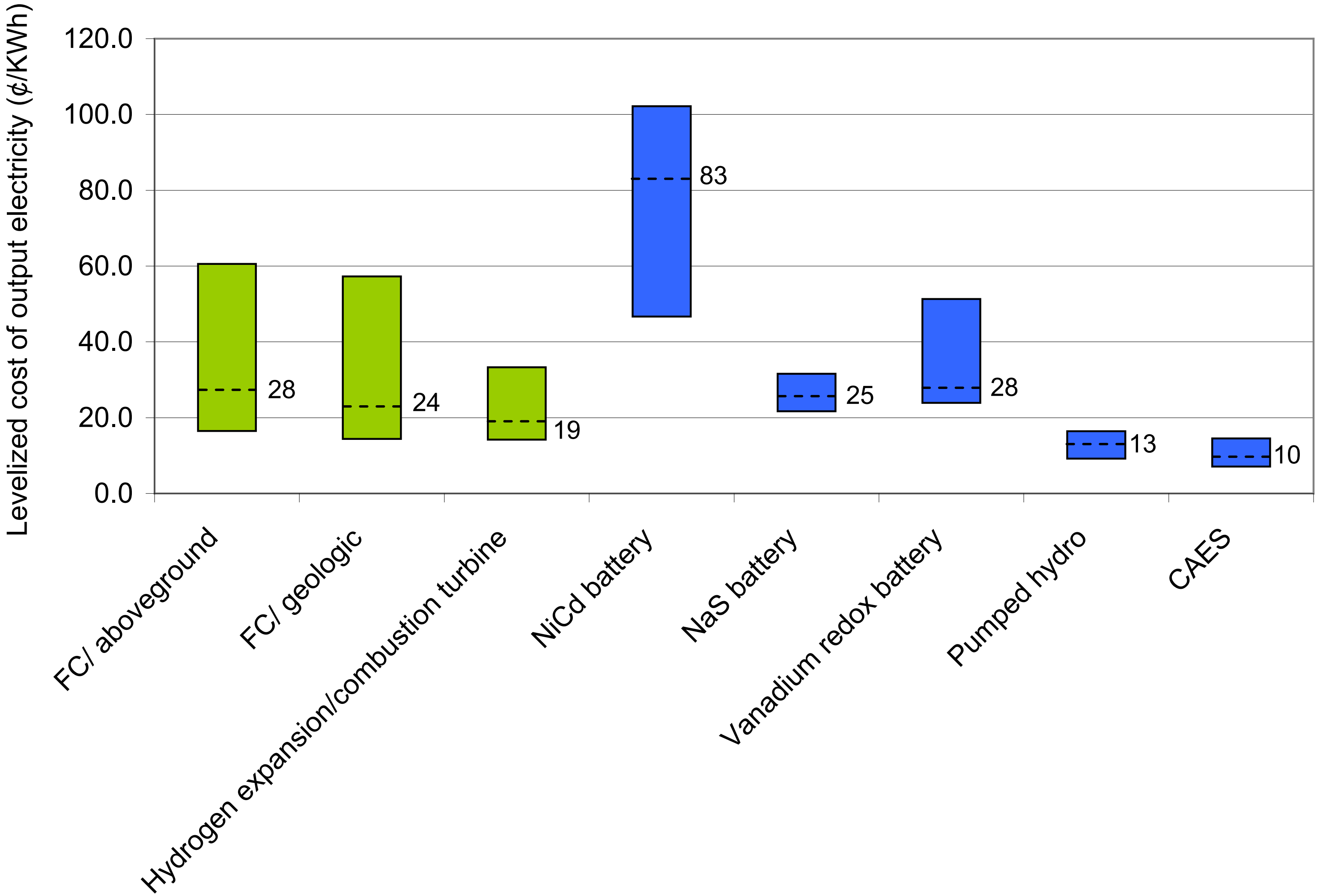
Timeframes

- High cost or “current” technology
- Mid range cost
  - Some installations exist
  - Some cost reductions for bulk manufacturing and system integration have been realized
  - Installations are assumed in the near future; 3 to 5 years.
- Low range cost
  - Estimates for fully mature technologies and facility experience

Cost analysis performed using the HOMER model

- Results are presented as levelized cost of energy; $/kWh or $/kg for hydrogen

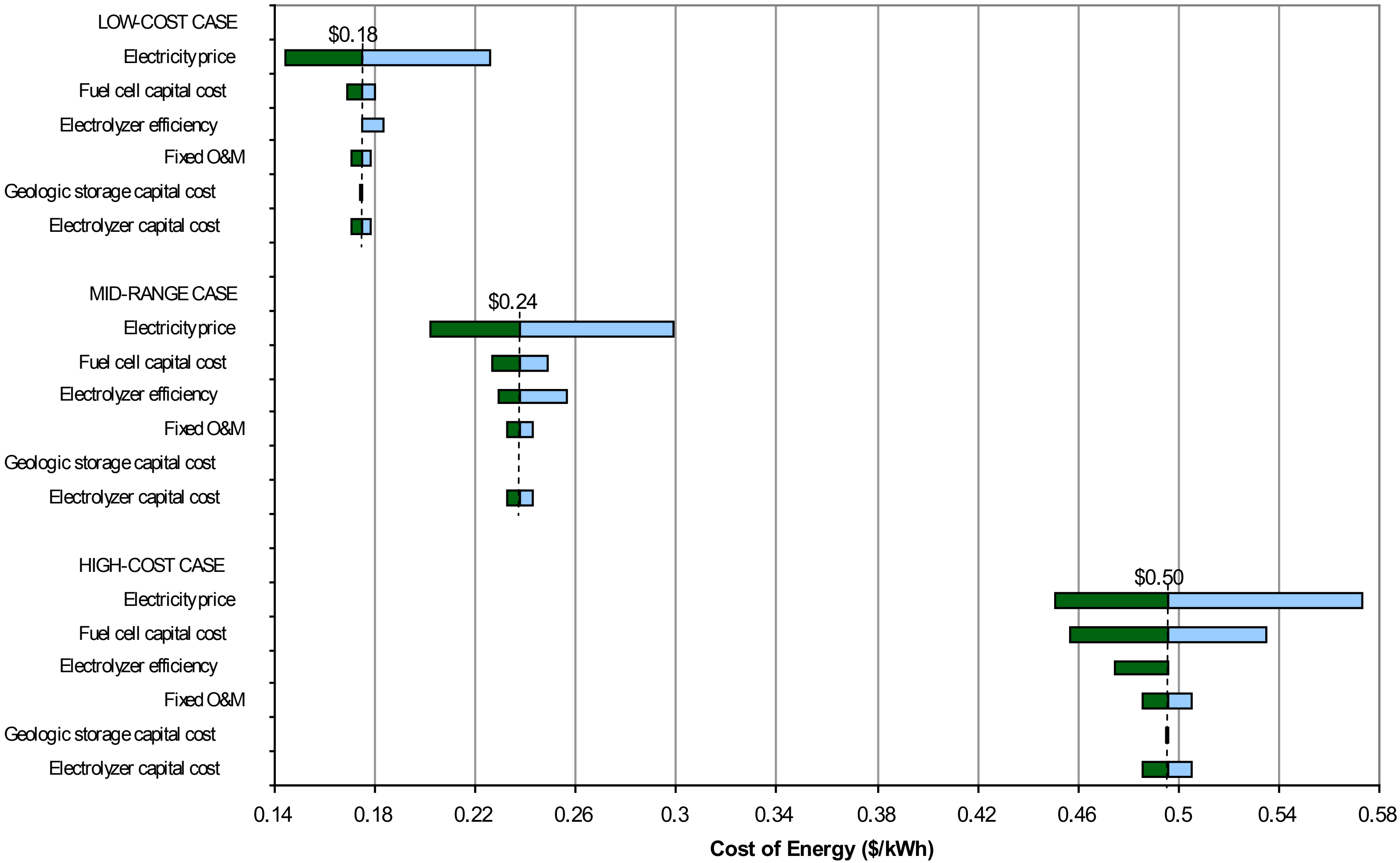
Energy Storage Study Findings



Comparison of hydrogen and competing technologies

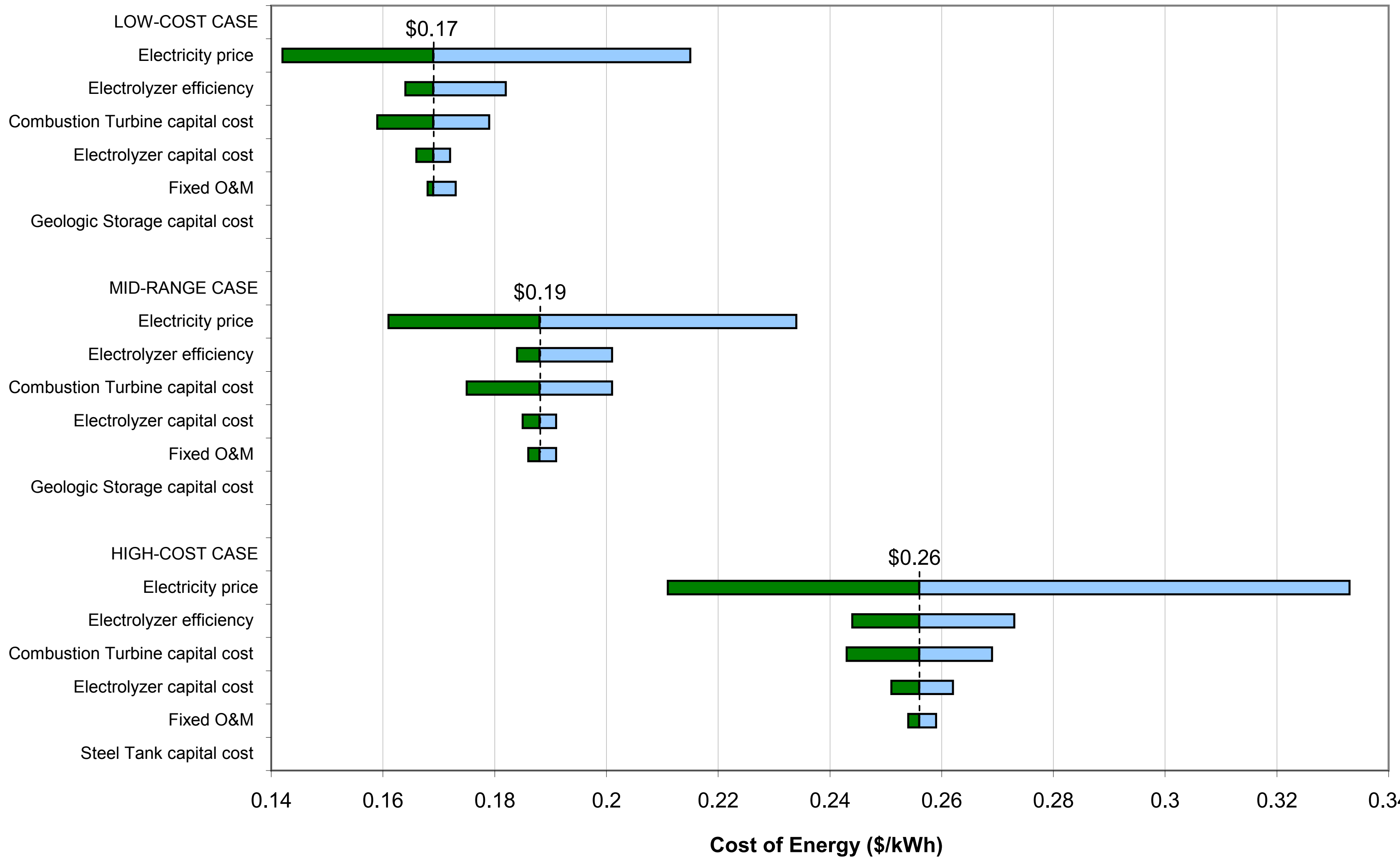
Analysis Results - Hydrogen

Hydrogen fuel cell with geologic storage



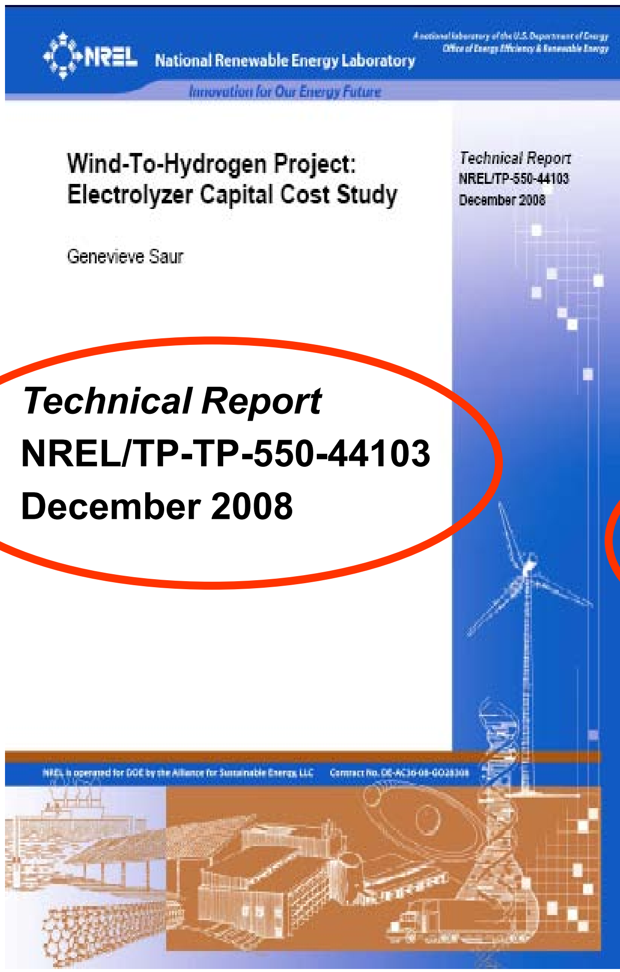
Analysis Results - Hydrogen

Hydrogen gas turbine with geologic storage

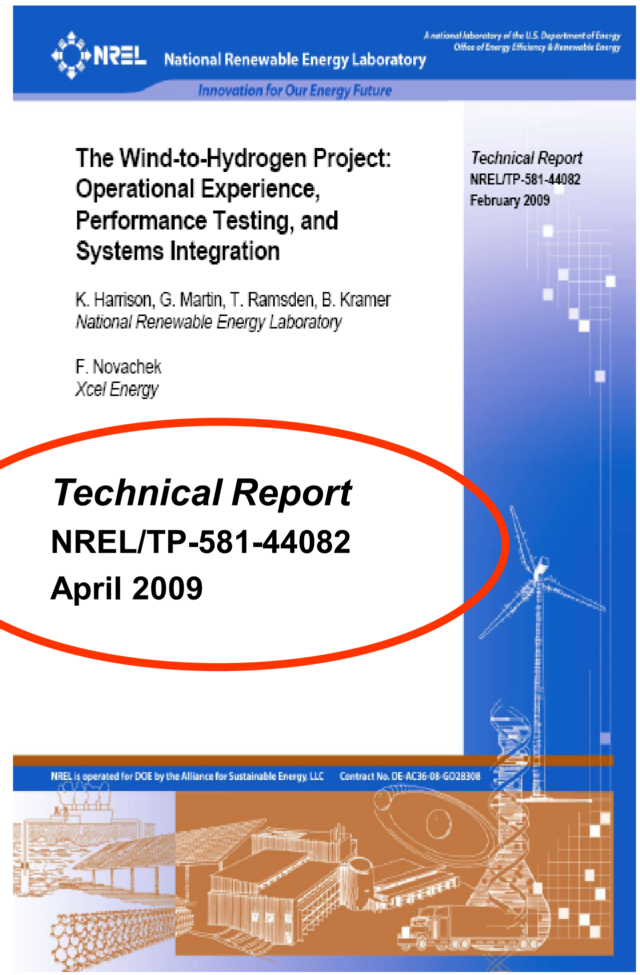


Recent Publications

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

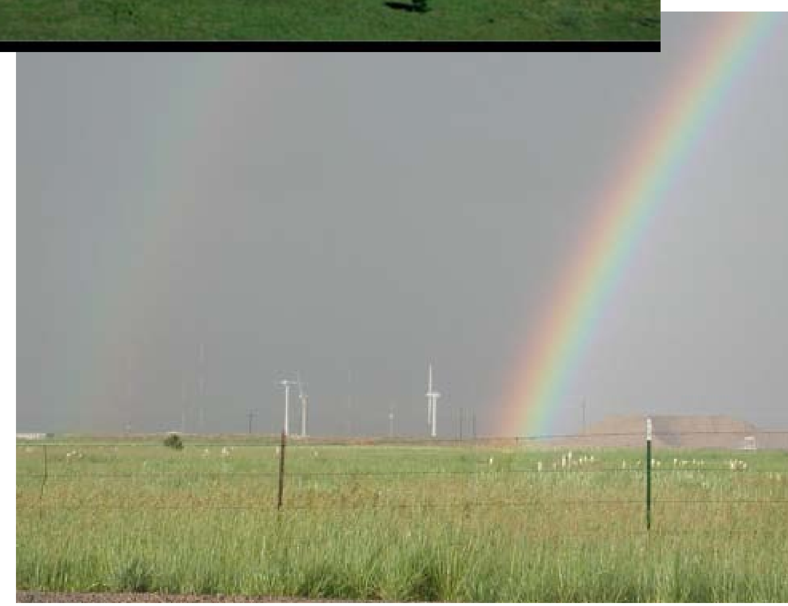


Technical Report
NREL/TP-TP-550-44103
December 2008



Technical Report
NREL/TP-581-44082
April 2009

Acknowledgments



Xcel Energy
- Frank Novachek
- Vicki McCarl
- Brad Hollenbaugh

DOE
- Roxanne Garland
- Richard Farmer
- Monterey Gardiner

Contractors
- John Cornish (EPC)
- Marc Mann (Spectrum)

NREL
- Kevin Harrison
- Greg Martin
- Keith Wipke
- George Sverdrup
- Robert Remick
- Genevieve Saur
- Bill Kramer
- Ben Kroposki
- Mike Stewart