

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



**NREL**  
**Hydrogen Technologies  
and Systems Center**

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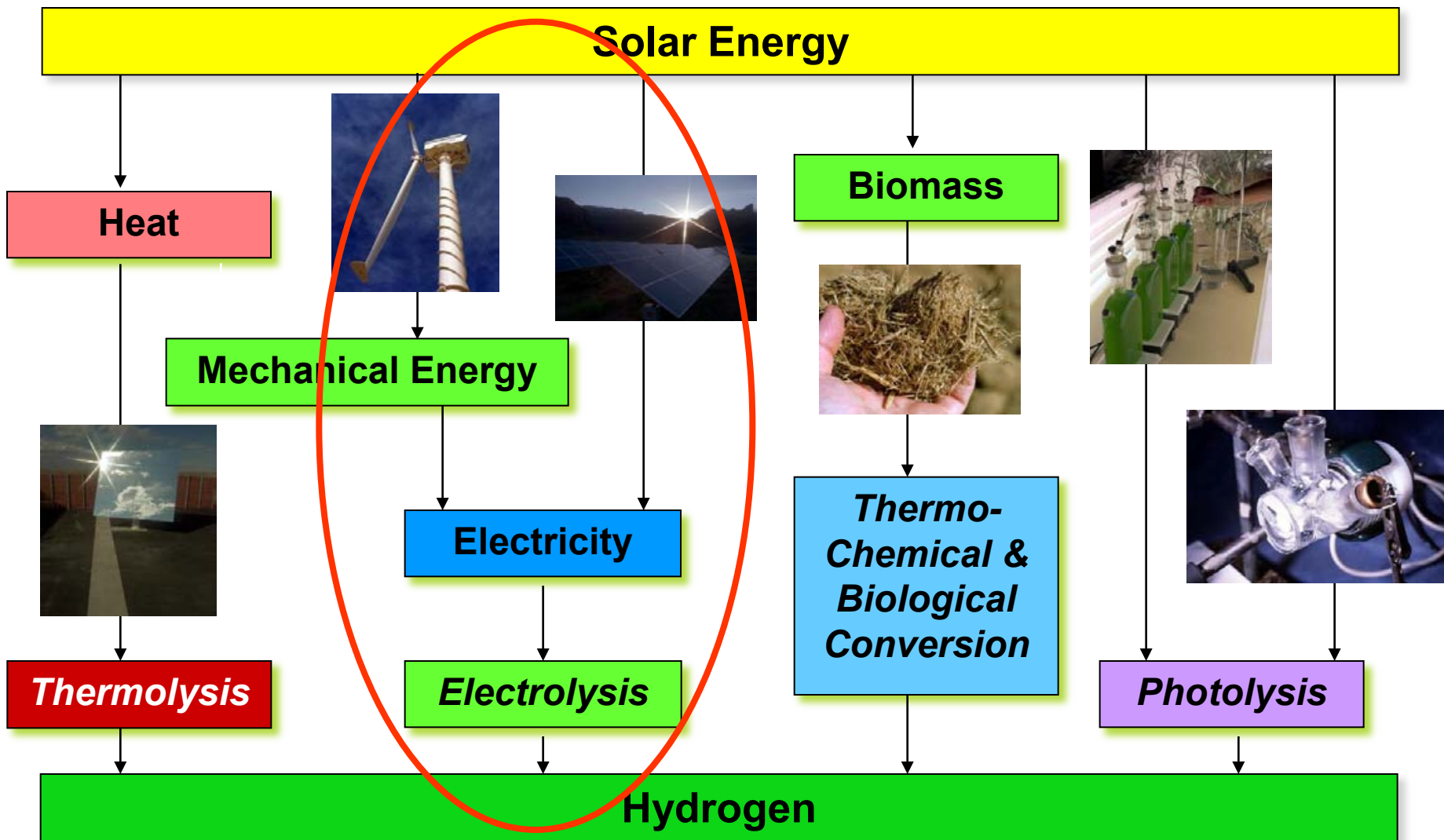
**NREL/PR-560-47432**

# 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

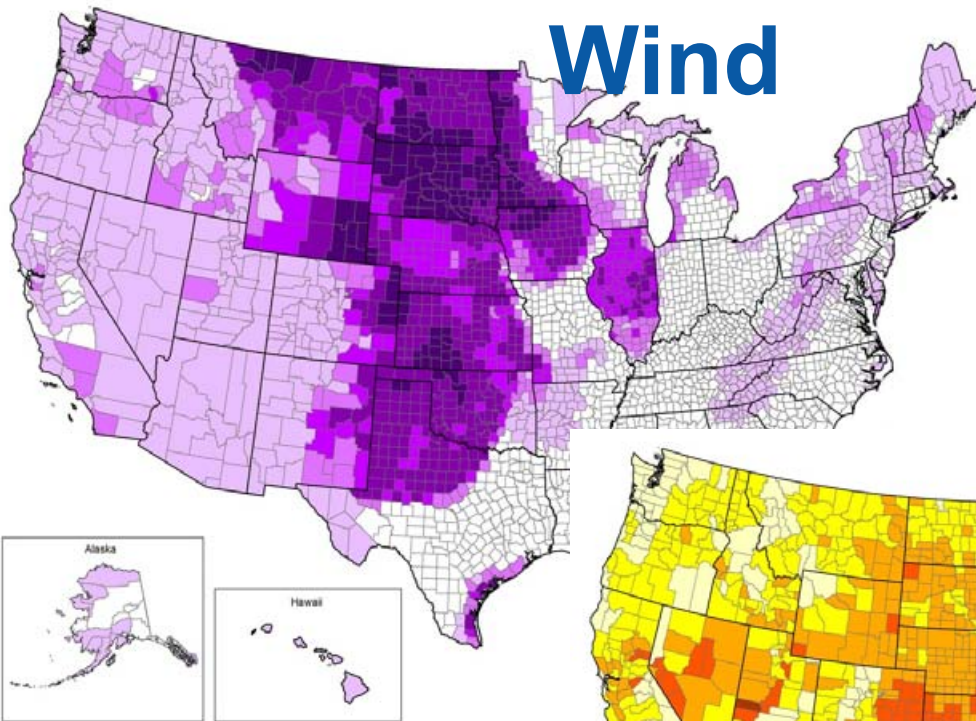


# Sustainable Paths to Hydrogen

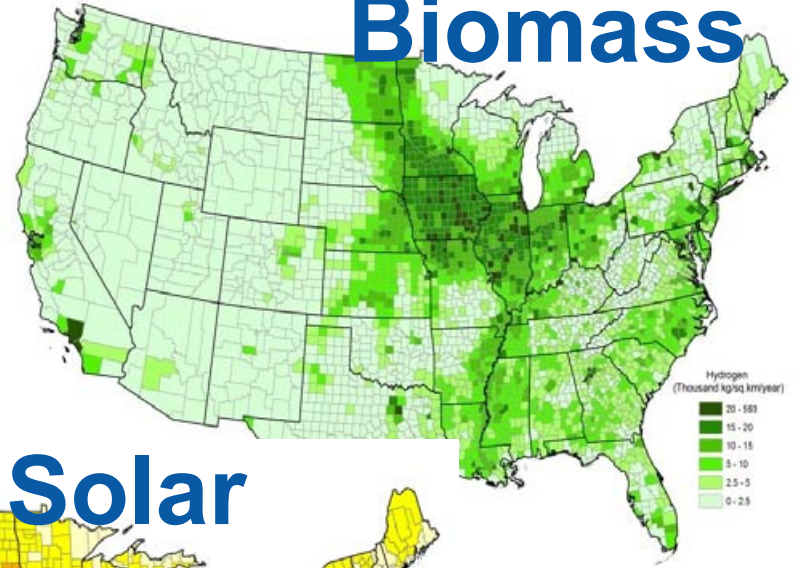


# Hydrogen Potential from Sustainable Resources

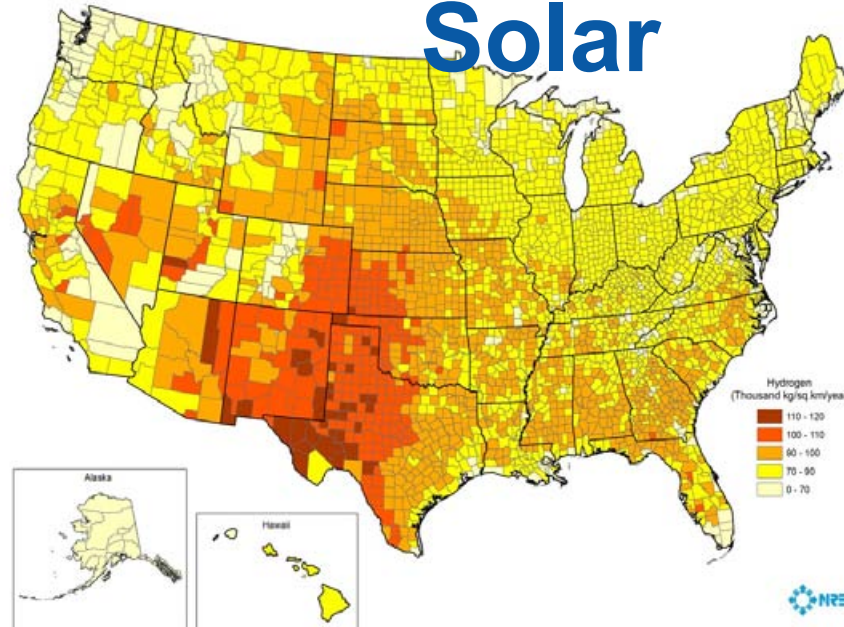
## Wind



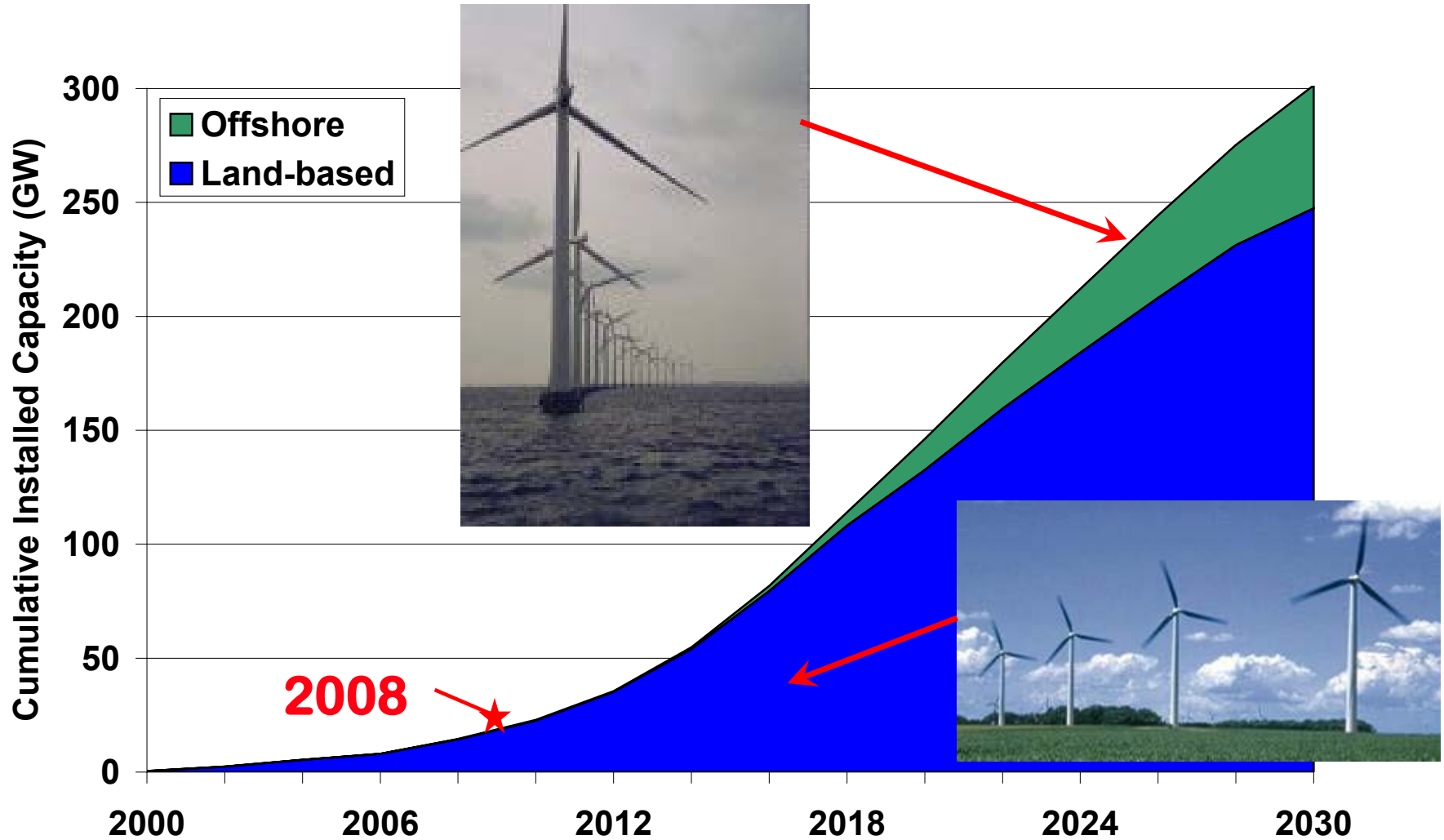
## Biomass



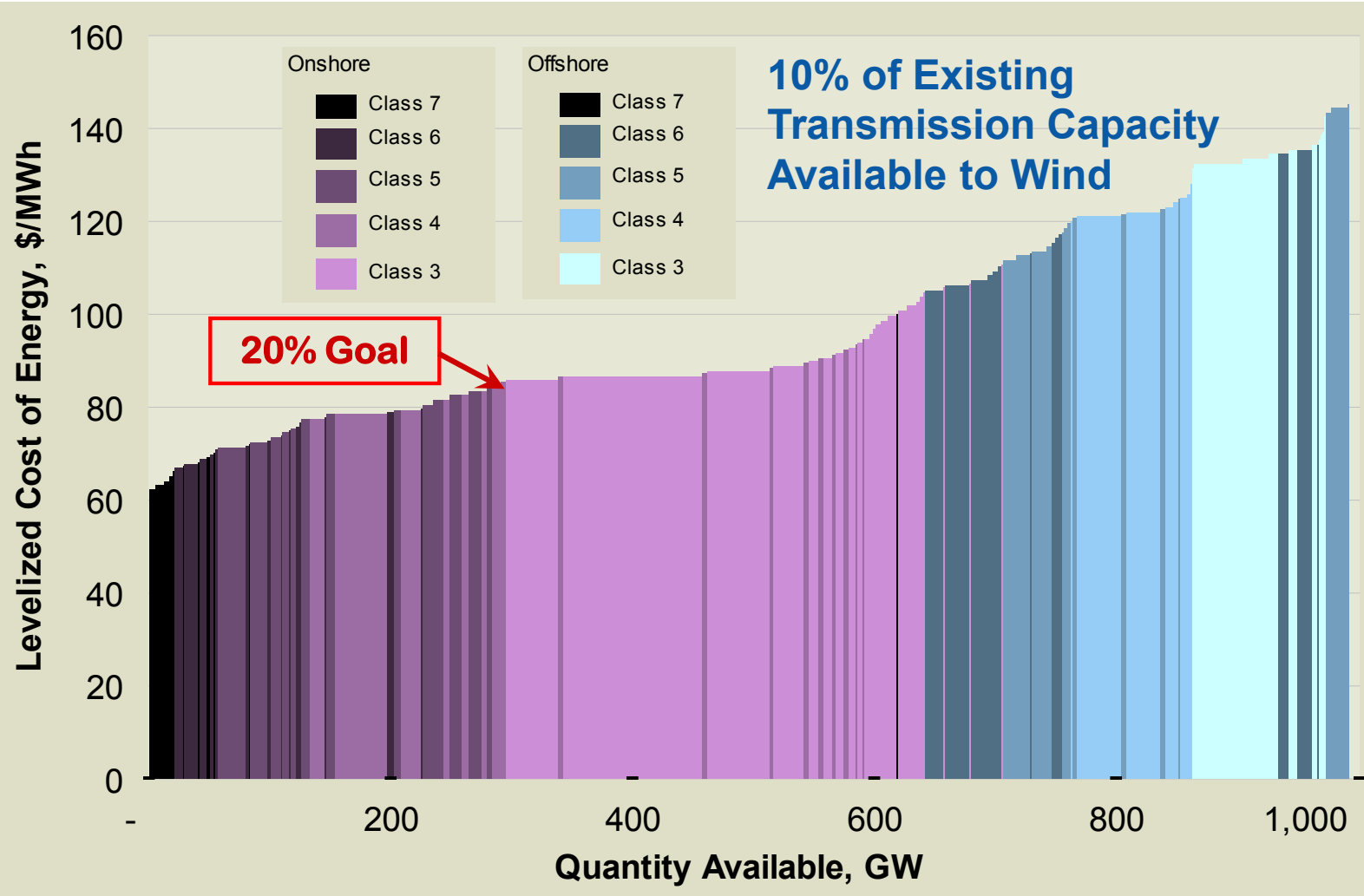
## Solar



# 20% Wind Energy by 2030 Scenario



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

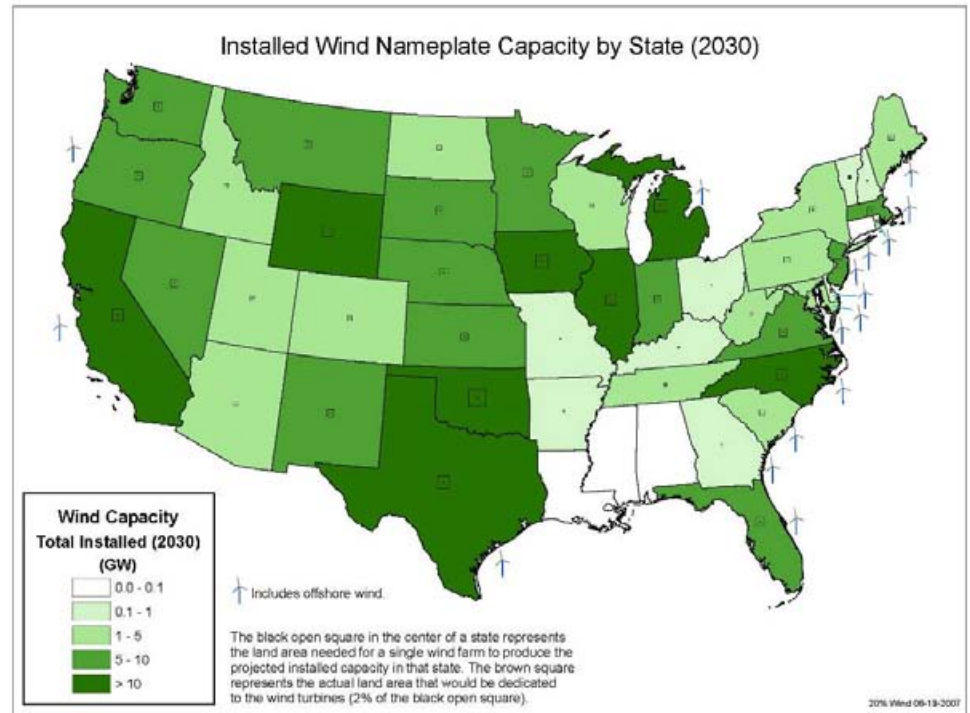
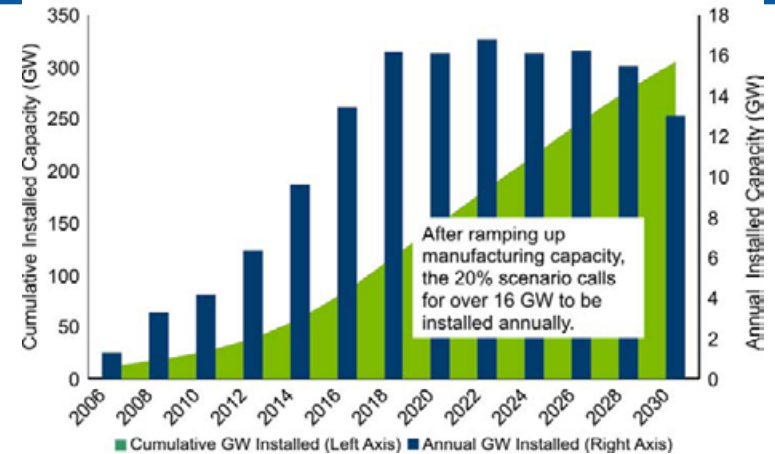


2010 Costs w/o PTC, \$1,600/MW-mile, w/o Integration costs

Source: Black & Veatch/NREL

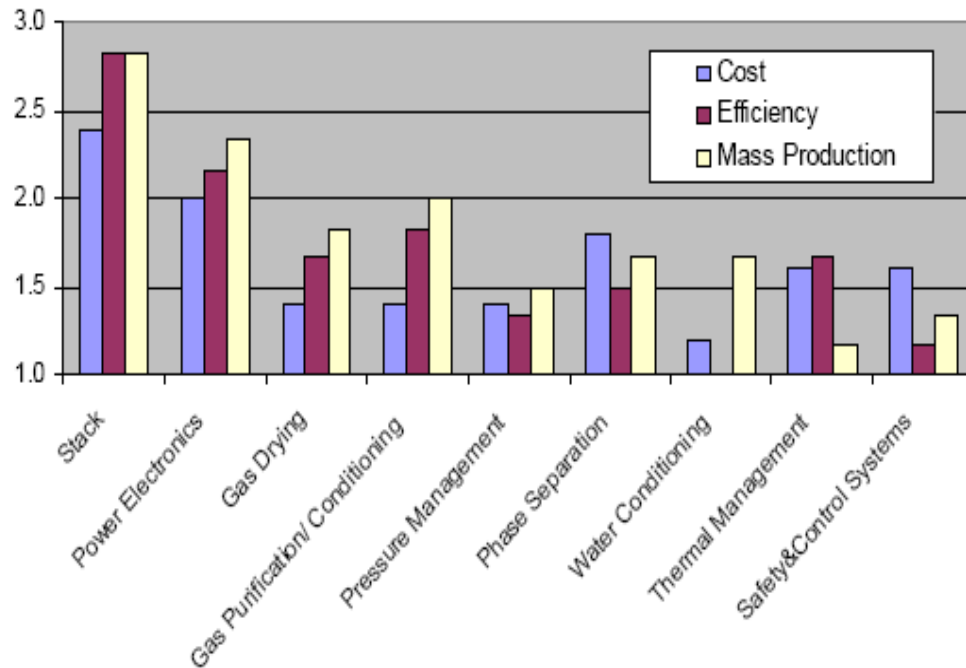
# Technology Challenges to Meet 20% Goal

- 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



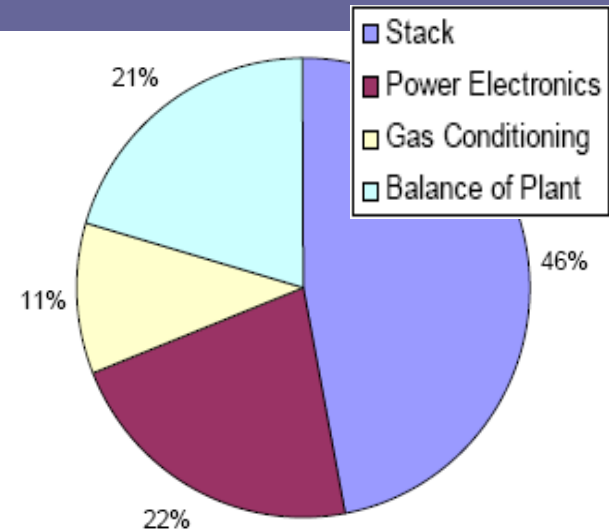
# Wind2H2 Project – Overall Goal

- Provide RD&D to help DOE achieve its 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



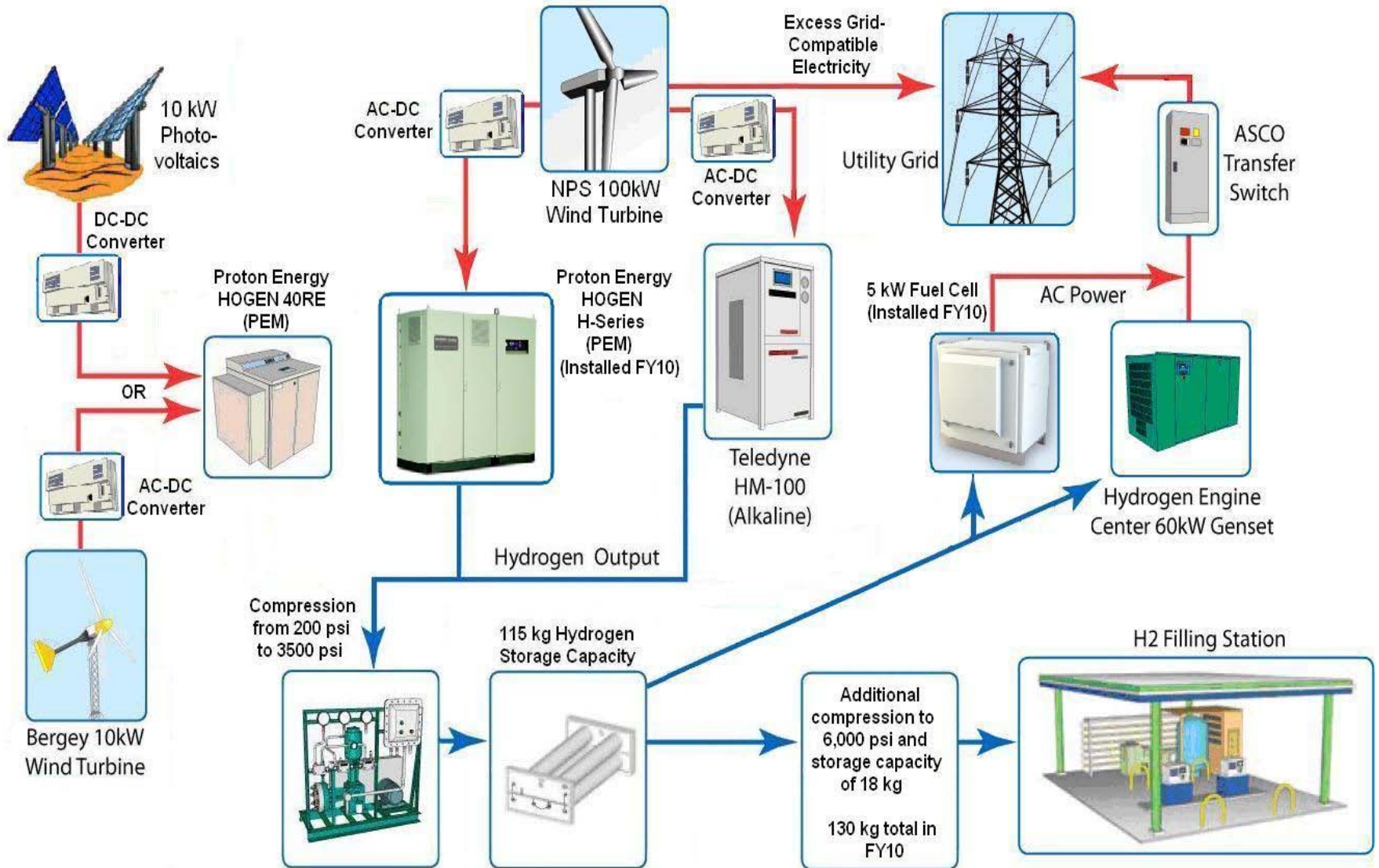


# Wind2H2 Project – Main Objectives

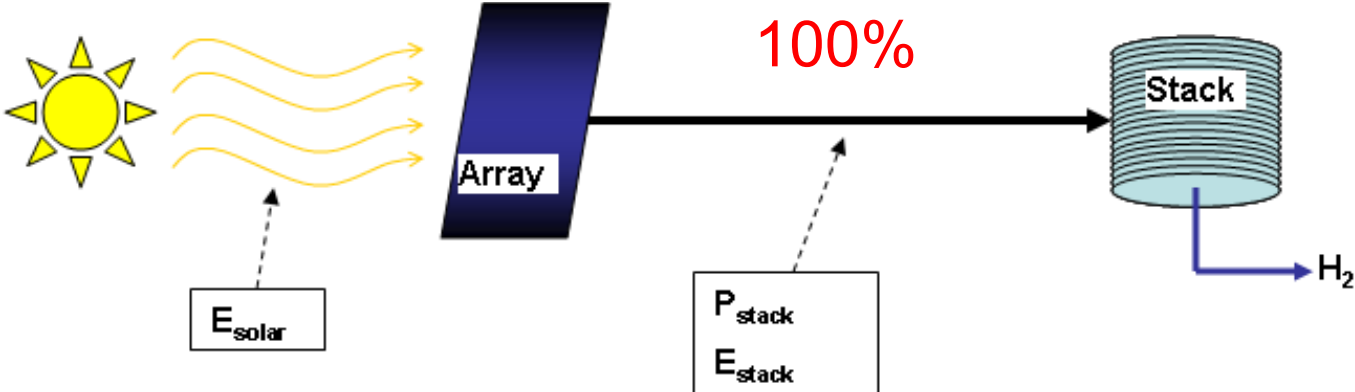
- Research the cost and capability of “time shifting” wind and PV energy through utility-scale hydrogen-based energy storage
- Research optimal wind/hydrogen through systems engineering
- Characterize and control wind turbine/PV and H<sub>2</sub>-producing stack
- Evaluate synergies from co-production of electricity and hydrogen
- Compare response and performance of alkaline and PEM electrolyzer technologies
- Realize efficiency gains through simplified and integrated power controllers
- Working towards ‘ideal’ wind to hydrogen
  - Simplifying PE, common controls, closely coupling wind input to stack, electricity regulation



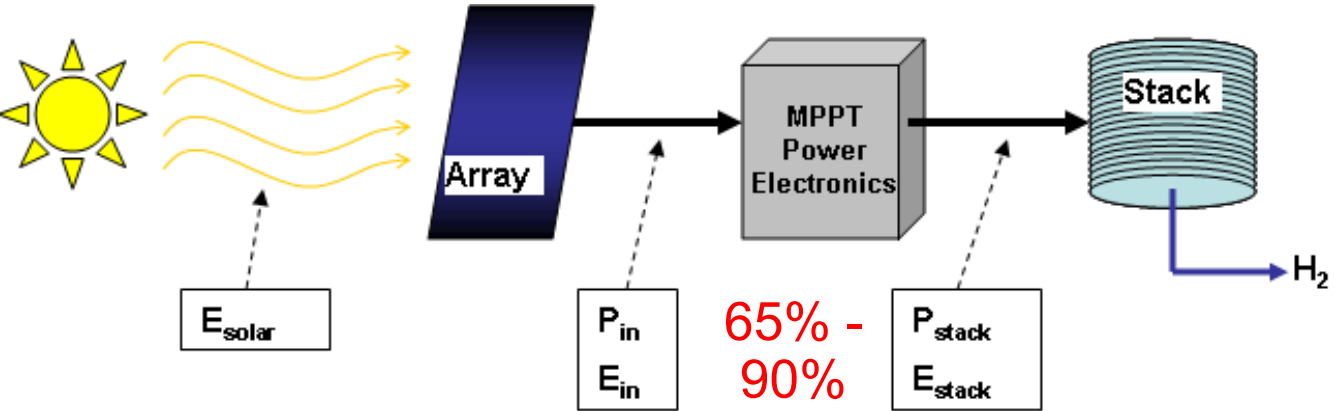
# Wind2H2 System Operating Modes



# PV Configuration Testing

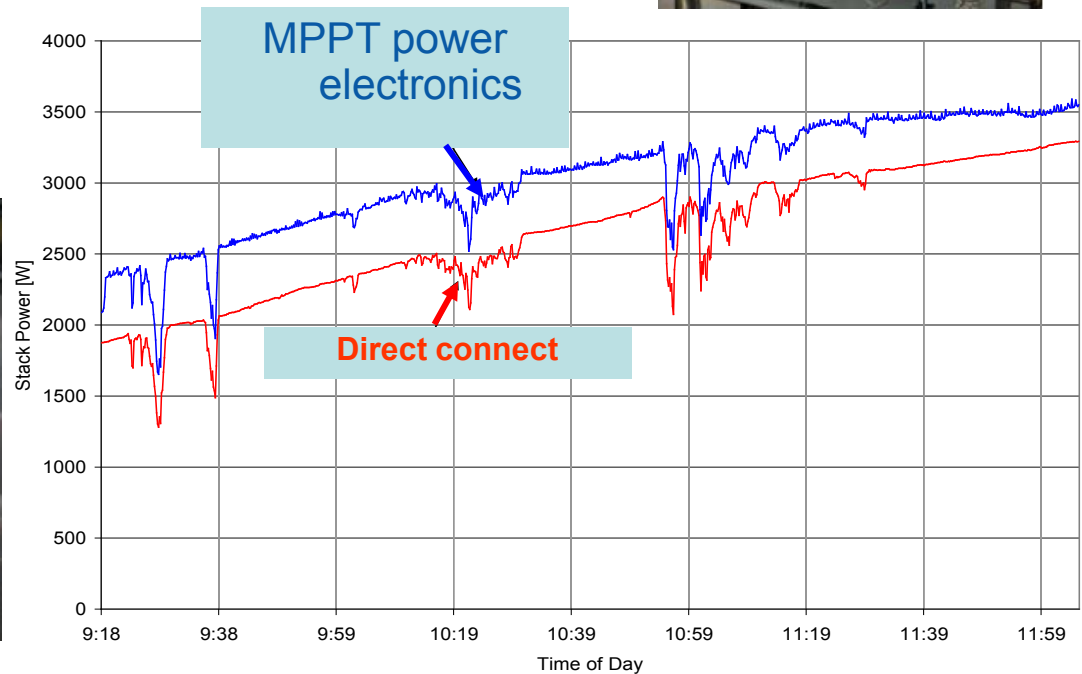


Direct connect versus various input voltages ( $E_{in}$ ) through power controller



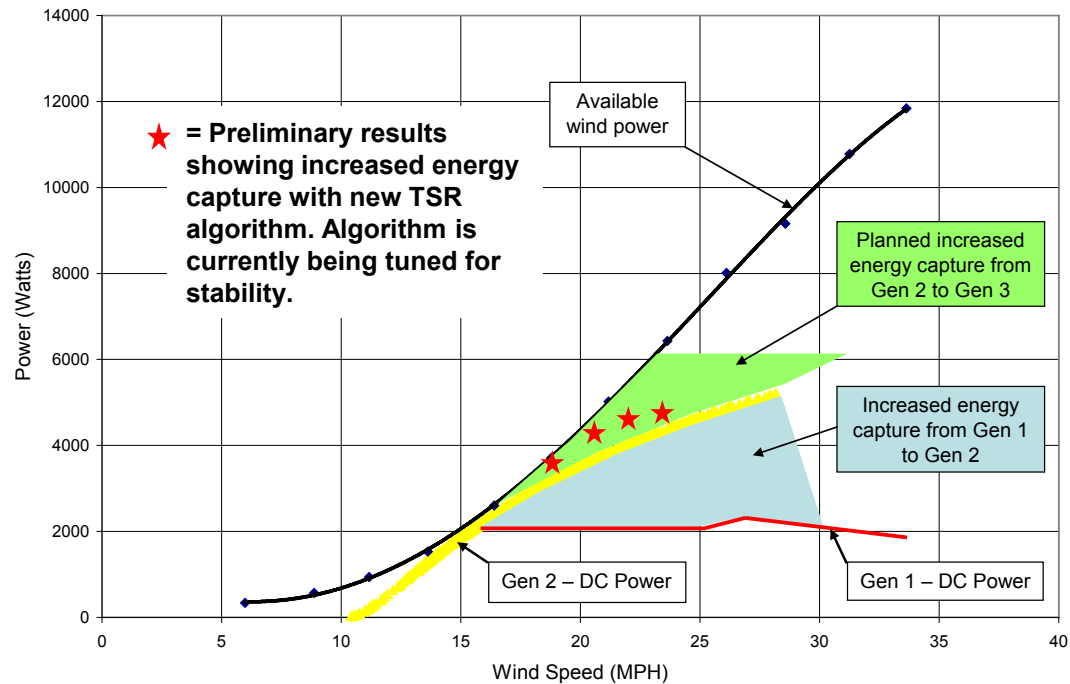
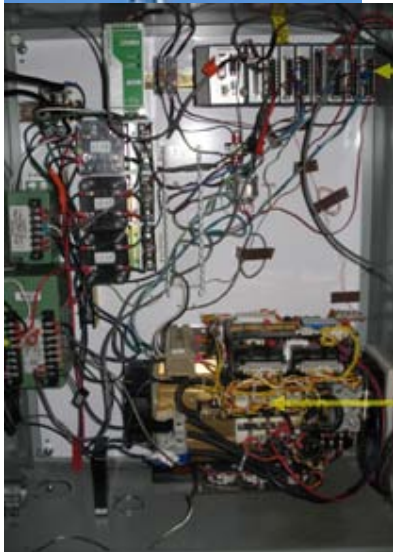
# PV Powered Electrolysis

- 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



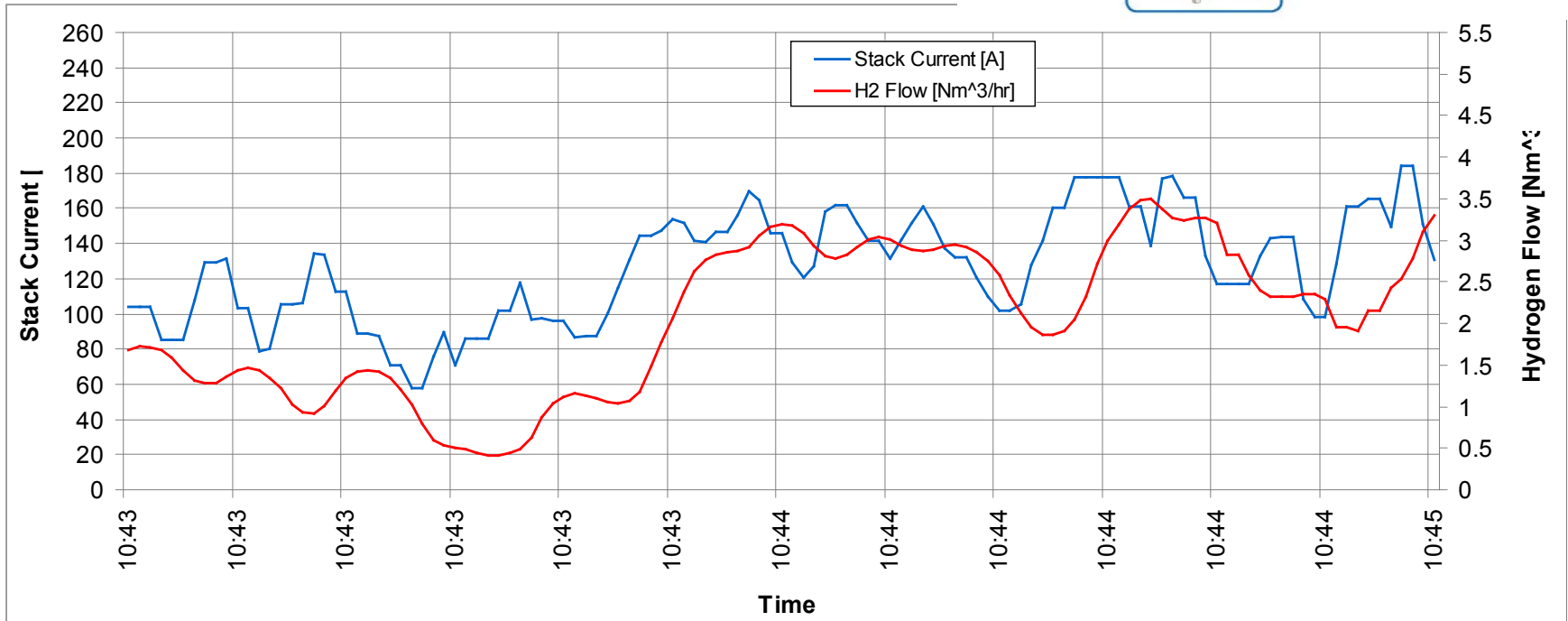
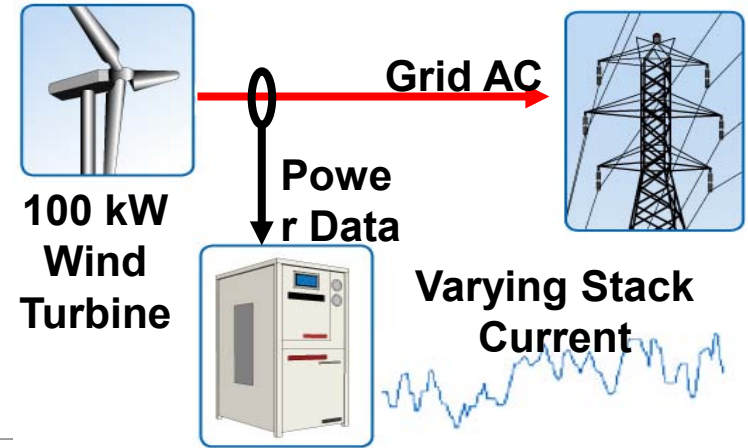
# 10kW Wind Turbine Powered Electrolysis

- 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
<u>Stack Efficiency</u>				
Low Current	80% (5A)	95% (5A)	78% (30A)	92% (30A)
Rated Current	63% (135A)	75% (135A)	59% (220A)	70% (220A)
<u>System Efficiency</u>				
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
<u>1.5 MW Wind Turbine</u>		
Rotor	\$248,000	\$248,000
Drive Train	\$1,280,000	\$1,180,000
<i>including power electronics</i>	\$100,000	\$0
Control System	\$10,000	\$10,000
Tower	<del>\$184,000</del>	\$184,000
Balance of Station	\$262,000	\$262,000
<u>2.33 MW Electrolyzer</u>		
<i>including power electronics</i>	\$220,000	\$0
<u>New Power Electronics Interface</u>	\$0	\$70,000
<b>Resulting Hydrogen Cost (\$/kg)</b>	<b>\$6.25</b>	<b>\$5.83</b>

- 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<sub>2</sub> 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

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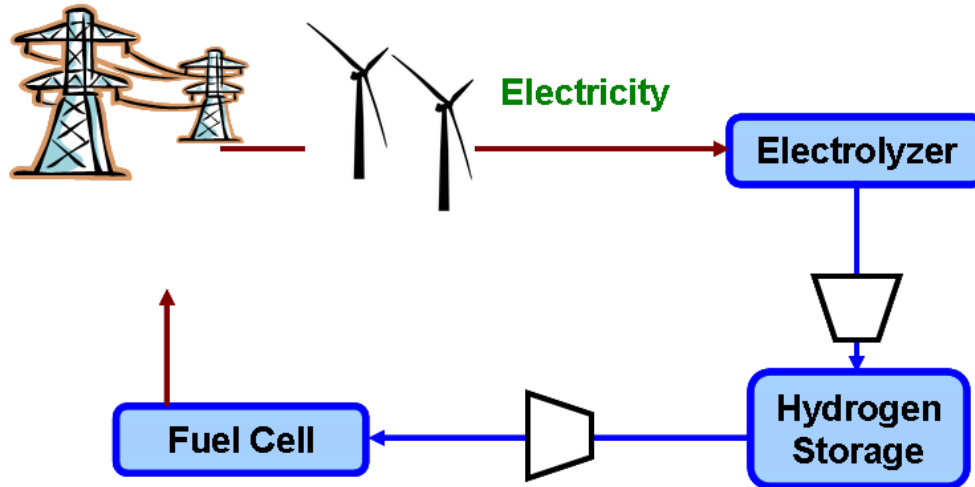
## Project Objective:

- 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

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## 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

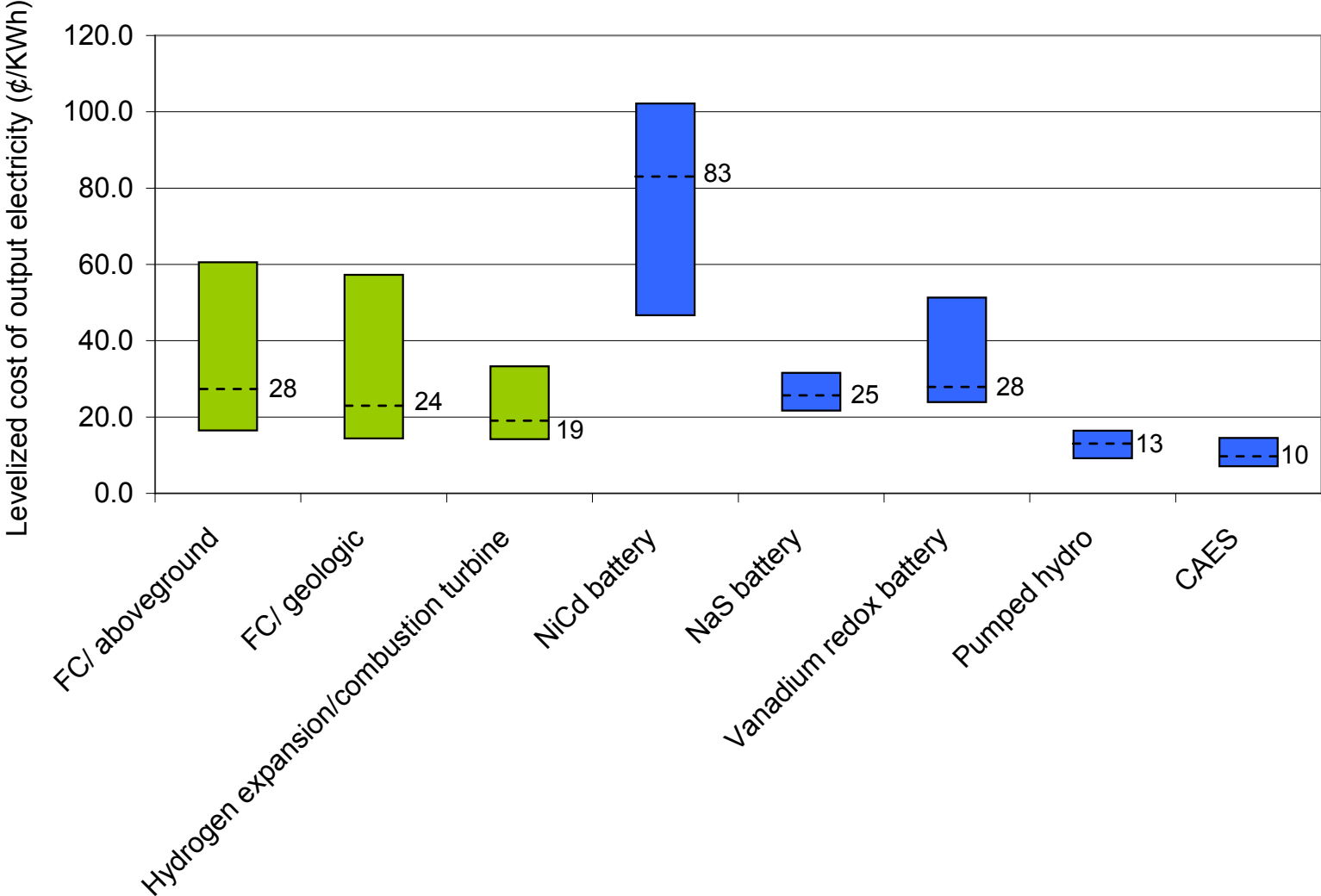
## Timeframes

- 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

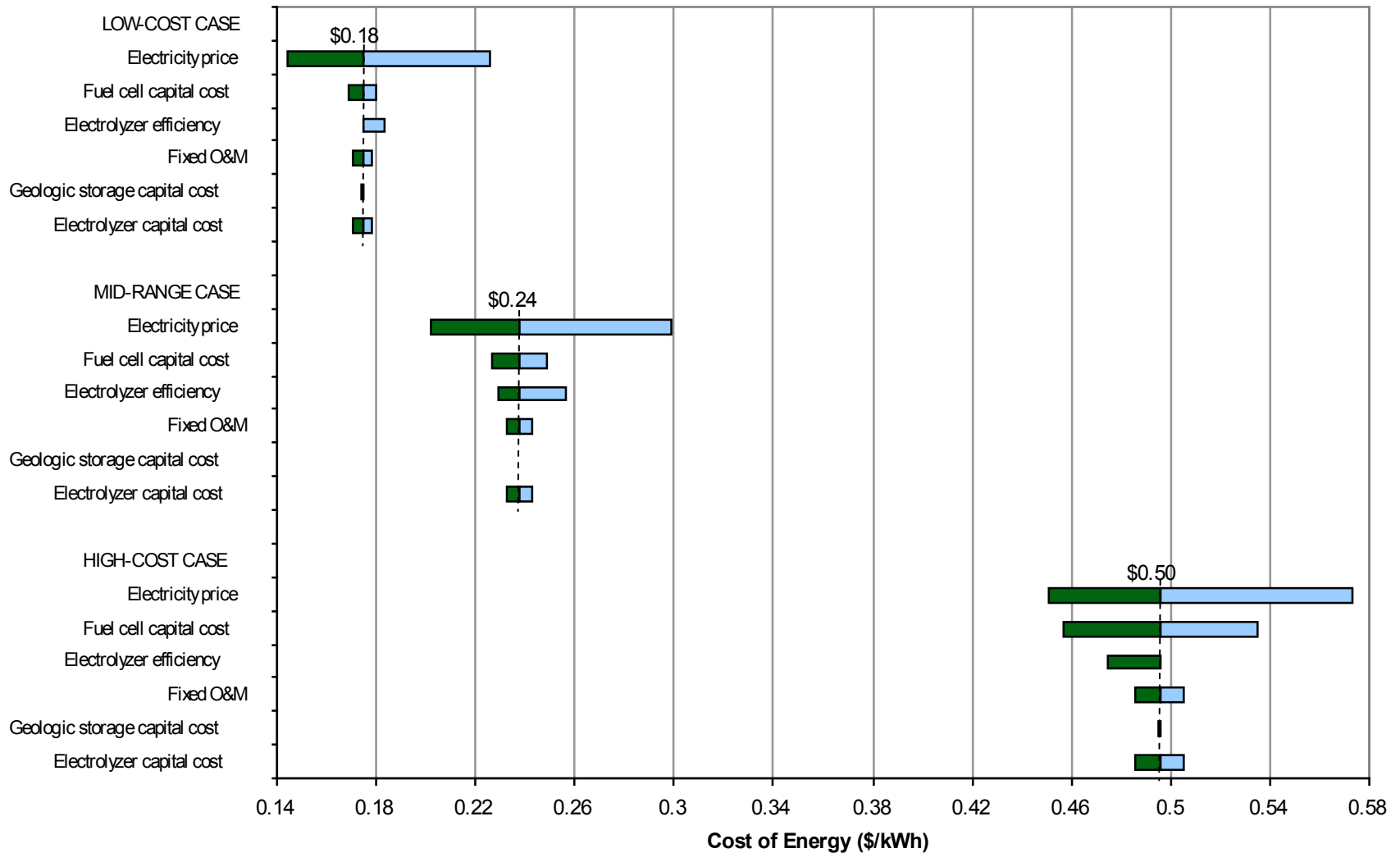
# Energy Storage Study Findings



## Comparison of hydrogen and competing technologies

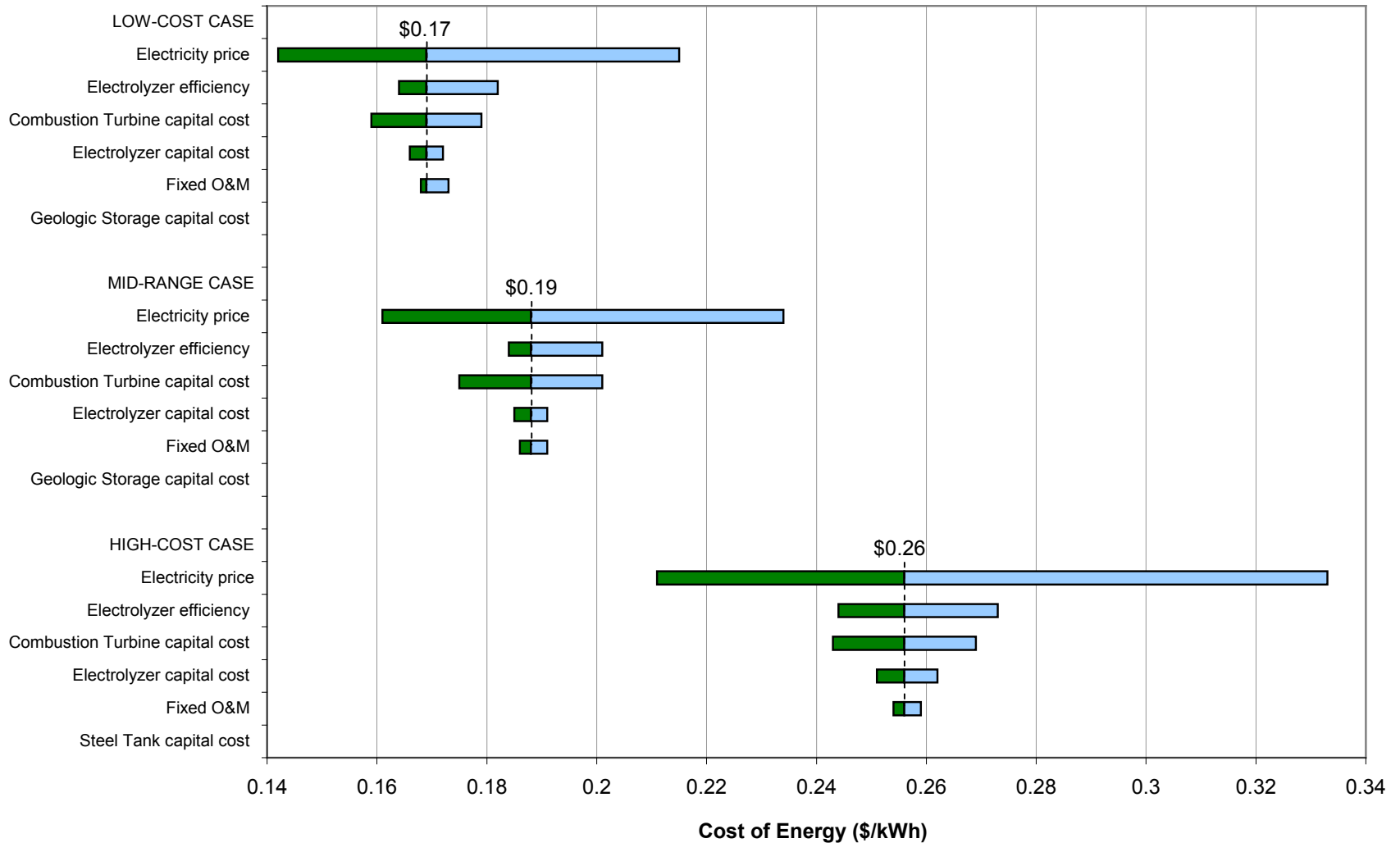
# Analysis Results - Hydrogen

## 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](http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html)

The cover features the NREL logo and the text 'National Renewable Energy Laboratory' and 'Innovation for Our Energy Future'. The title 'Wind-To-Hydrogen Project: Electrolyzer Capital Cost Study' is prominently displayed. Below the title, the author 'Genevieve Saur' is listed. The report number 'NREL/TP-550-44103' and the date 'December 2008' are also present. The background includes a stylized wind turbine and a grid pattern.

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

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The cover features the NREL logo and the text 'National Renewable Energy Laboratory' and 'Innovation for Our Energy Future'. The title 'The Wind-to-Hydrogen Project: Operational Experience, Performance Testing, and Systems Integration' is prominently displayed. Below the title, the authors 'K. Harrison, G. Martin, T. Ramsden, B. Kramer' and 'F. Novachek' are listed, along with their affiliations 'National Renewable Energy Laboratory' and 'Xcel Energy'. The report number 'NREL/TP-581-44082' and the date 'February 2009' are also present. The background includes a stylized wind turbine and a grid pattern.

**Technical Report**  
**NREL/TP-581-44082**  
**February 2009**

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