http://www.nrel.gov/hydrogen/pdfs/48360.pdf

Hydrogen for Energy Storage Analysis Overview

National Hydrogen Association Conference & Expo

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Hydrogen Energy Storage System Modeling

Objectives

Compare hydrogen and competing technologies for utility-scale energy storage systems.

Explore the cost and GHG emissions impacts of interaction of hydrogen storage and variable renewable resources

Outline

Study Framework

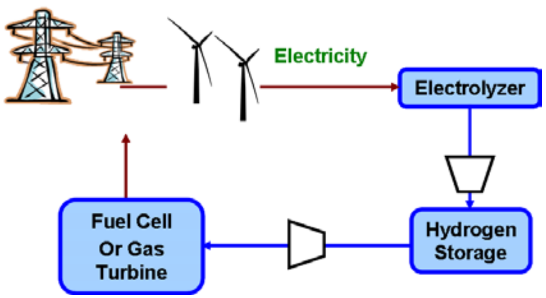
Preliminary Study Results

- Lifecycle cost analysis for hydrogen and competing technologies
- GHG emissions credit impact for a remote wind farm

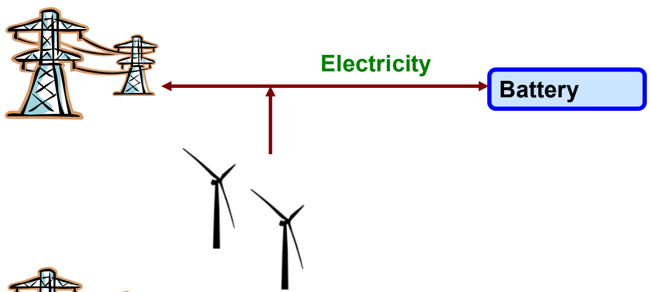
NREL Wind to Hydrogen Study Perspectives

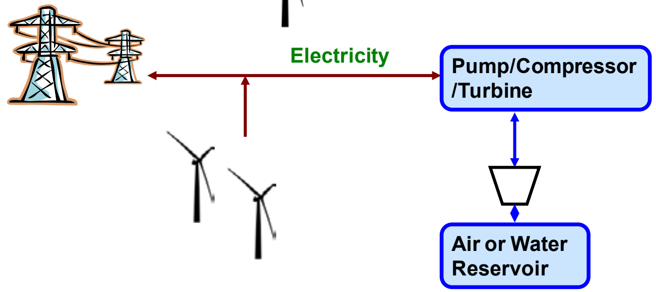
Scenarios for Hydrogen Energy Storage Analyses

Comparison of costs for hydrogen and competing technologies

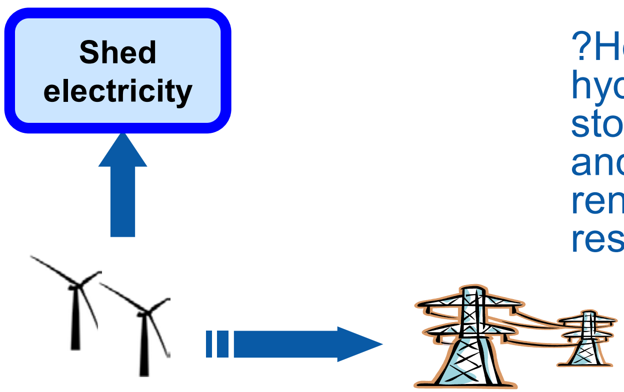


?Is hydrogen a potential solution for utility-scale energy storage

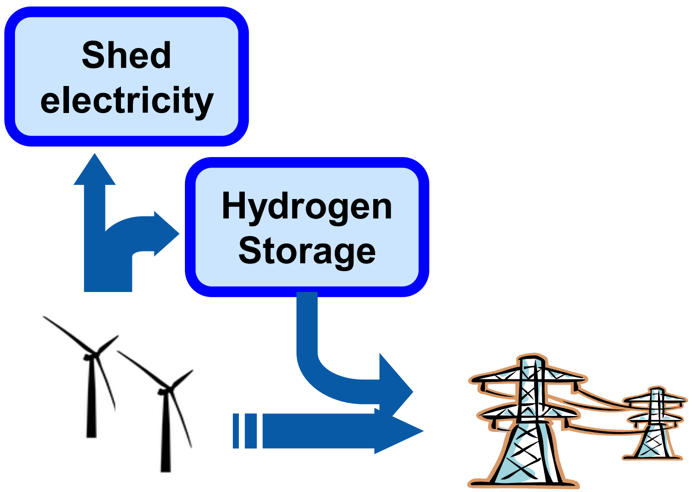




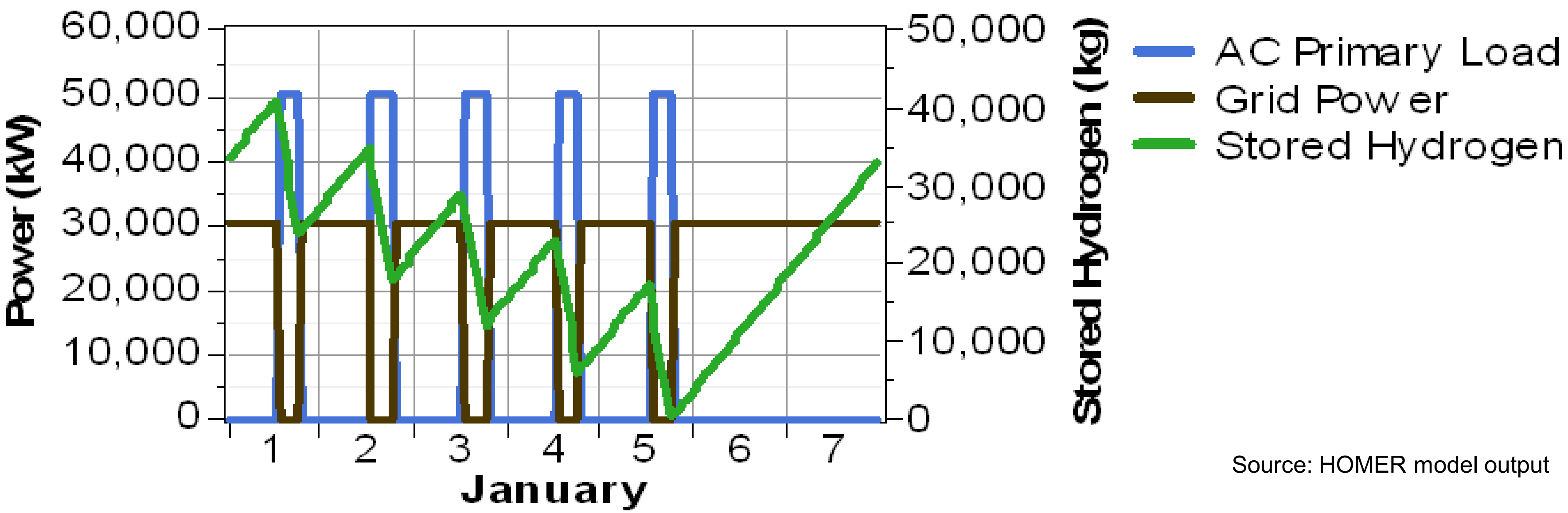
Study of hydrogen energy storage for a specific renewable resource



?How would using hydrogen for storage impact cost and emissions for renewable resources



Energy Storage Scenario for Comparison Study



Source: HOMER model output

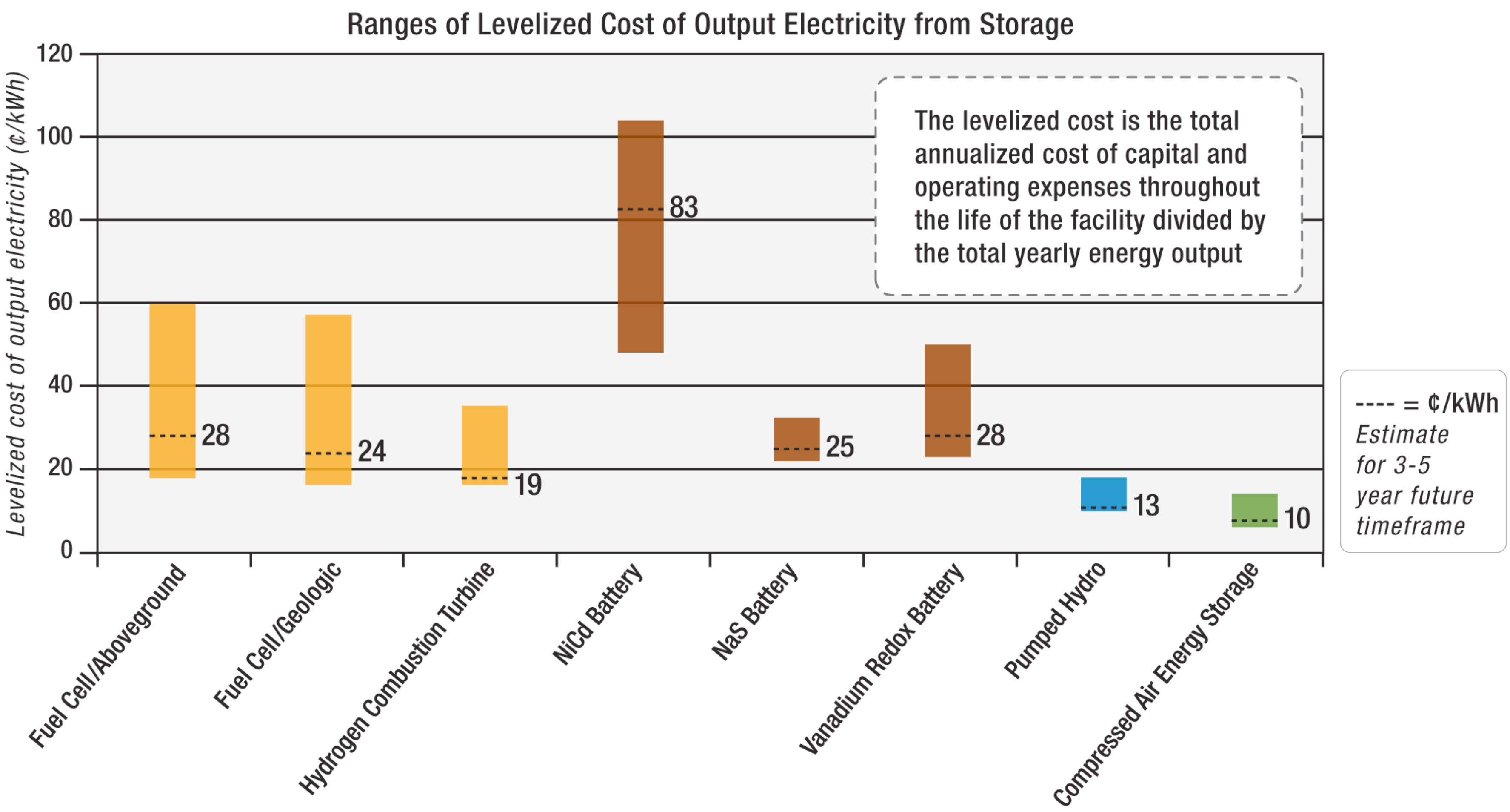
Nominal storage volume is 300 MWh (50 MW, 6 hours)

- 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

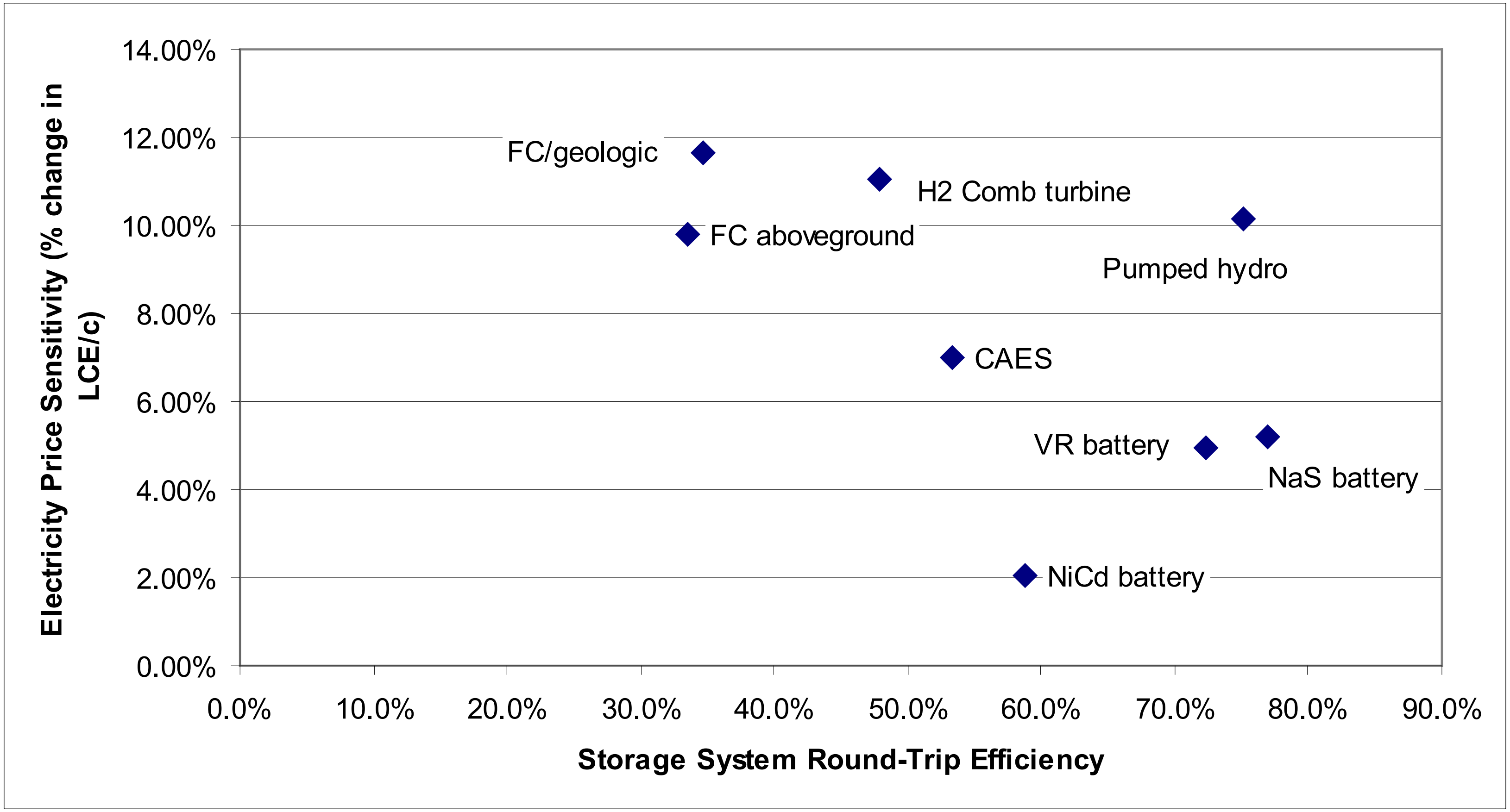
- Assumed steady and unlimited supply during off-peak hours (18 hours on weekdays and 24 hours on weekends)
- Assumed fixed purchase price of off-peak/renewable electricity

Levelized Cost of Hydrogen and Competing Technologies



Hydrogen is competitive with batteries and could be competitive with CAES and pumped hydro in locations that are not favorable for these technologies.

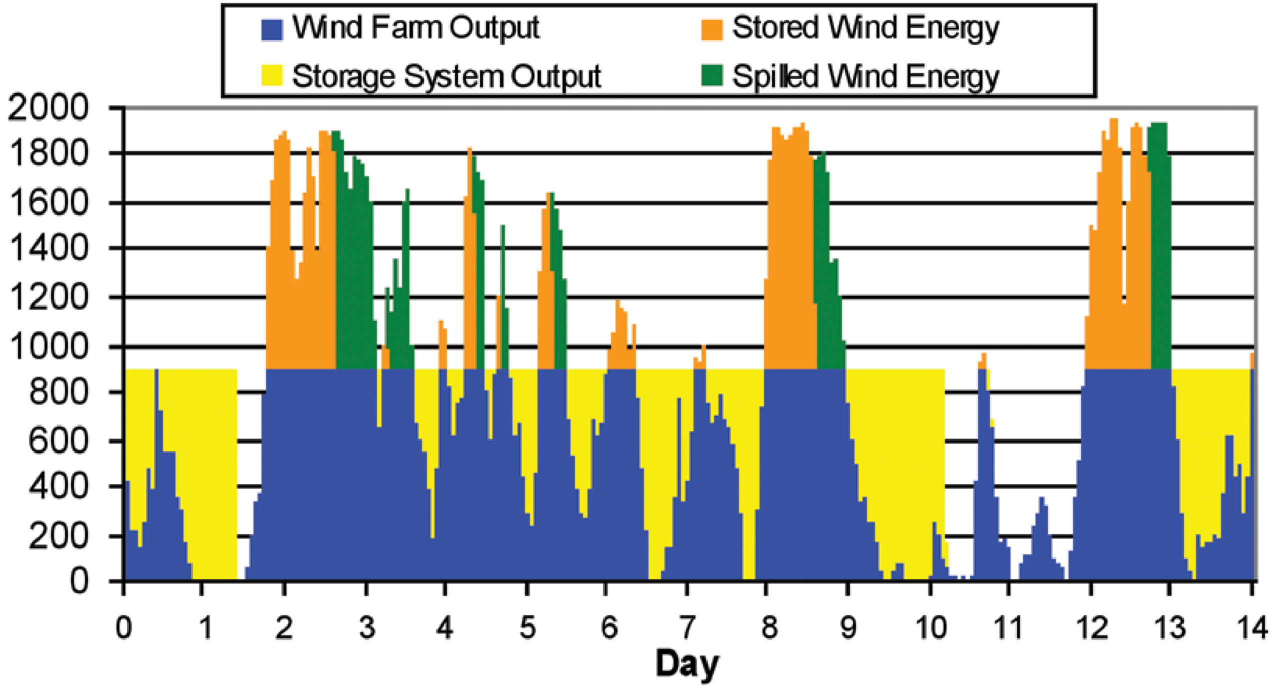
Round-Trip Efficiency and Electricity Price Sensitivity



- **Electricity price sensitivity**
  - Low-capital-cost, high-efficiency pumped hydro system is sensitive to electricity price
  - High-capital-cost NiCd system is insensitive to electricity price
  - For other storage systems, sensitivity to electricity price is roughly inversely proportional to round-trip efficiency

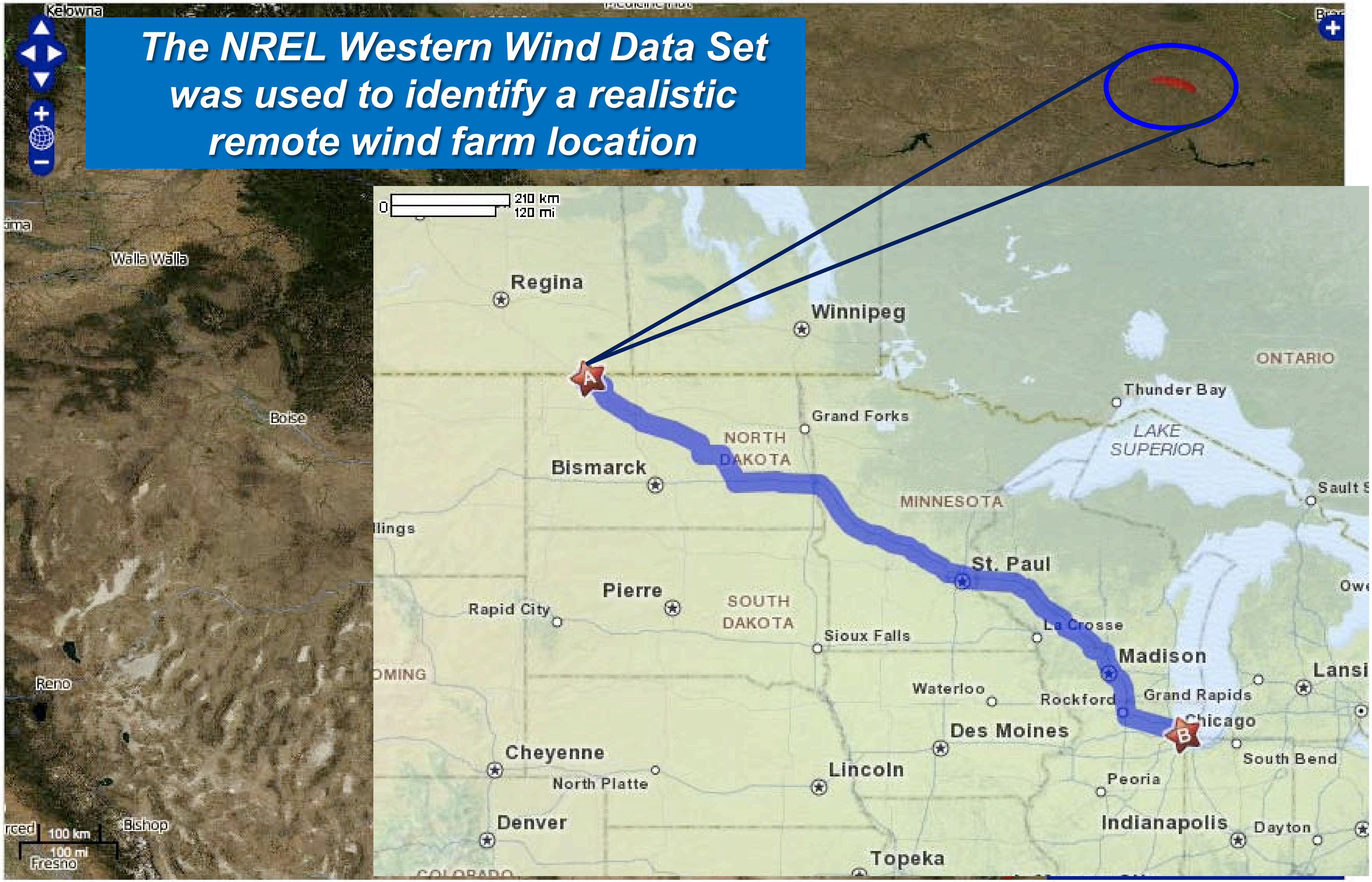
Energy Storage & Greenhouse Gases

+	-
Additional energy from the windfarm can be captured for later use	Efficiency losses incurred by routing wind energy through the storage system reduce the greenhouse gas benefit of wind



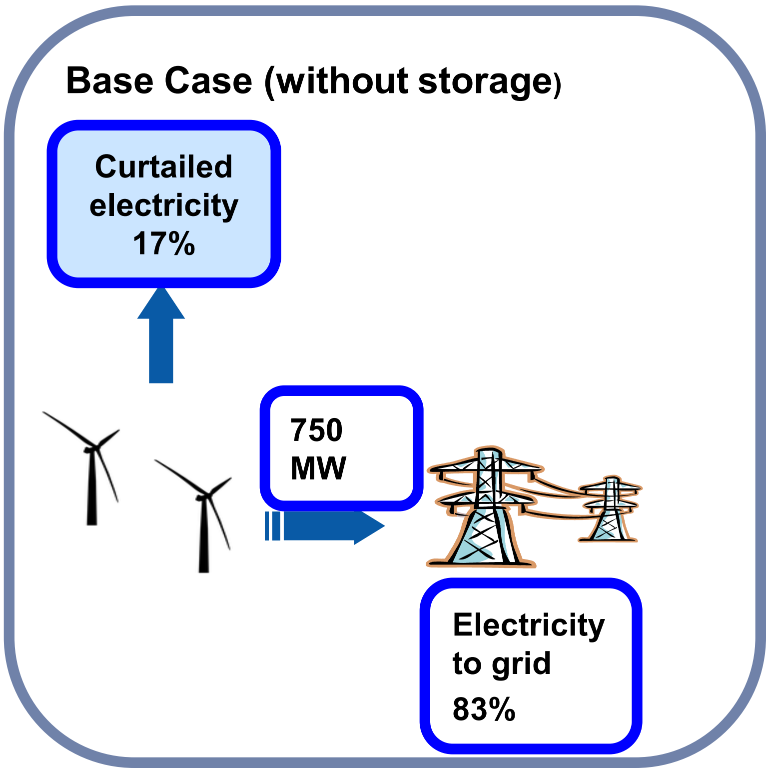
Source: Denholm, Paul. (October 2006). "Creating Baseload Wind Power Systems Using Advanced Compressed Air Energy Storage Concepts." Poster presented at the University of Colorado Energy Initiative/NREL Symposium. http://www.nrel.gov/docs/fy07osti/40674.pdf

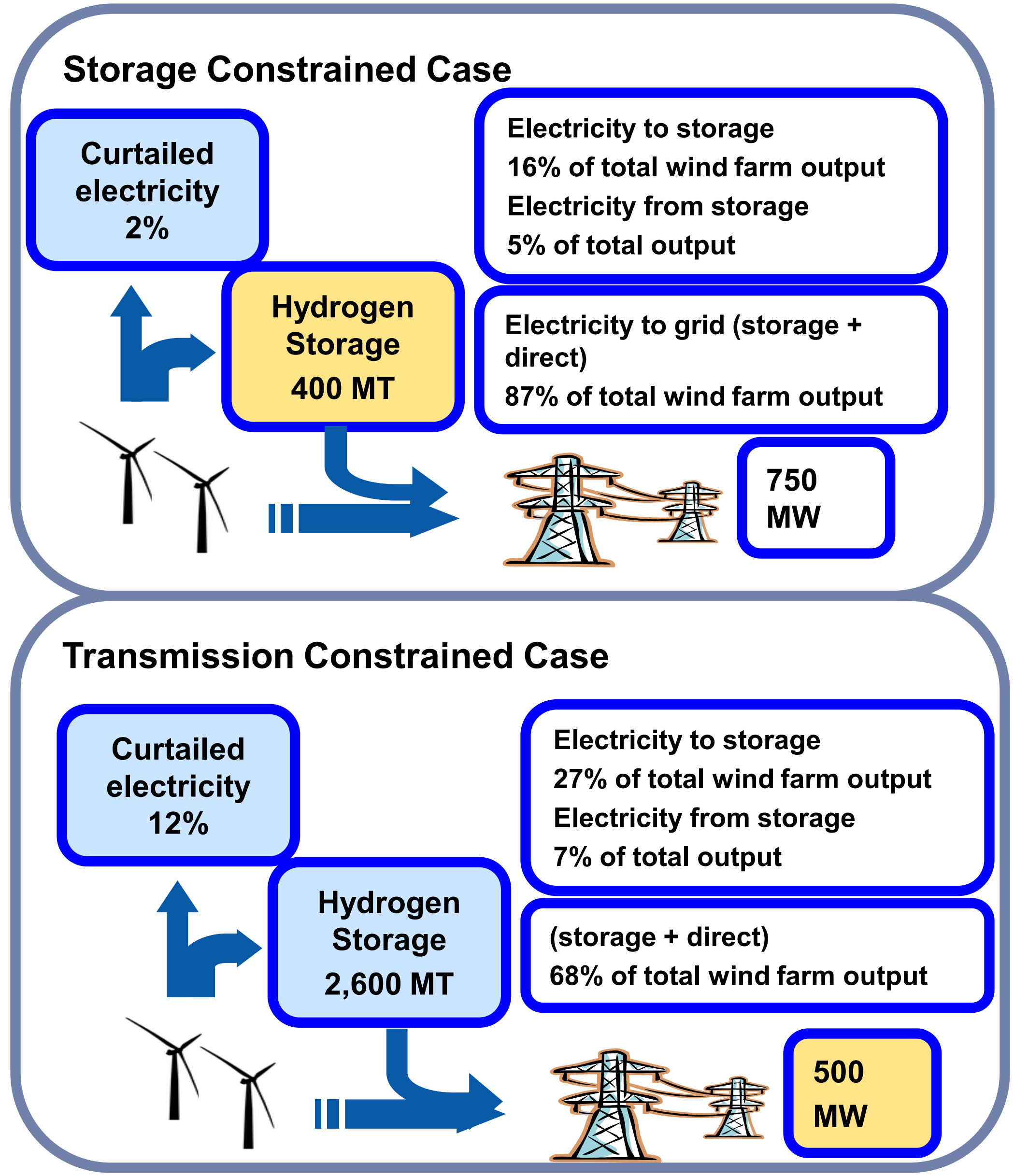
Wind Farm Location



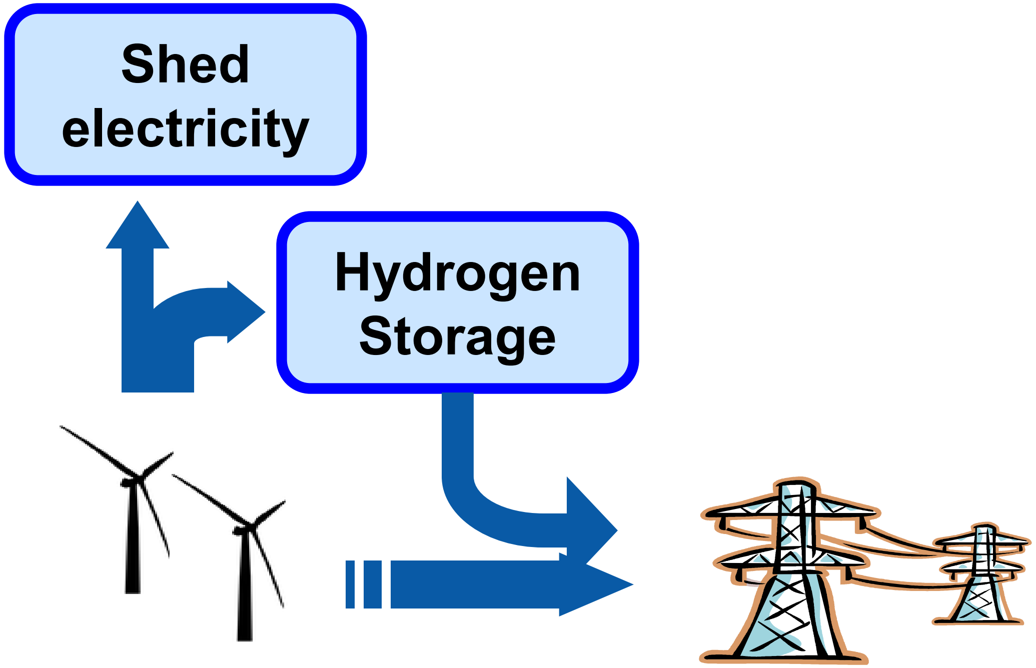
Study Framework - Add Hydrogen Storage to a Base Case Without Storage

Analysis of the base case provides LCOE and avoided emissions for comparison





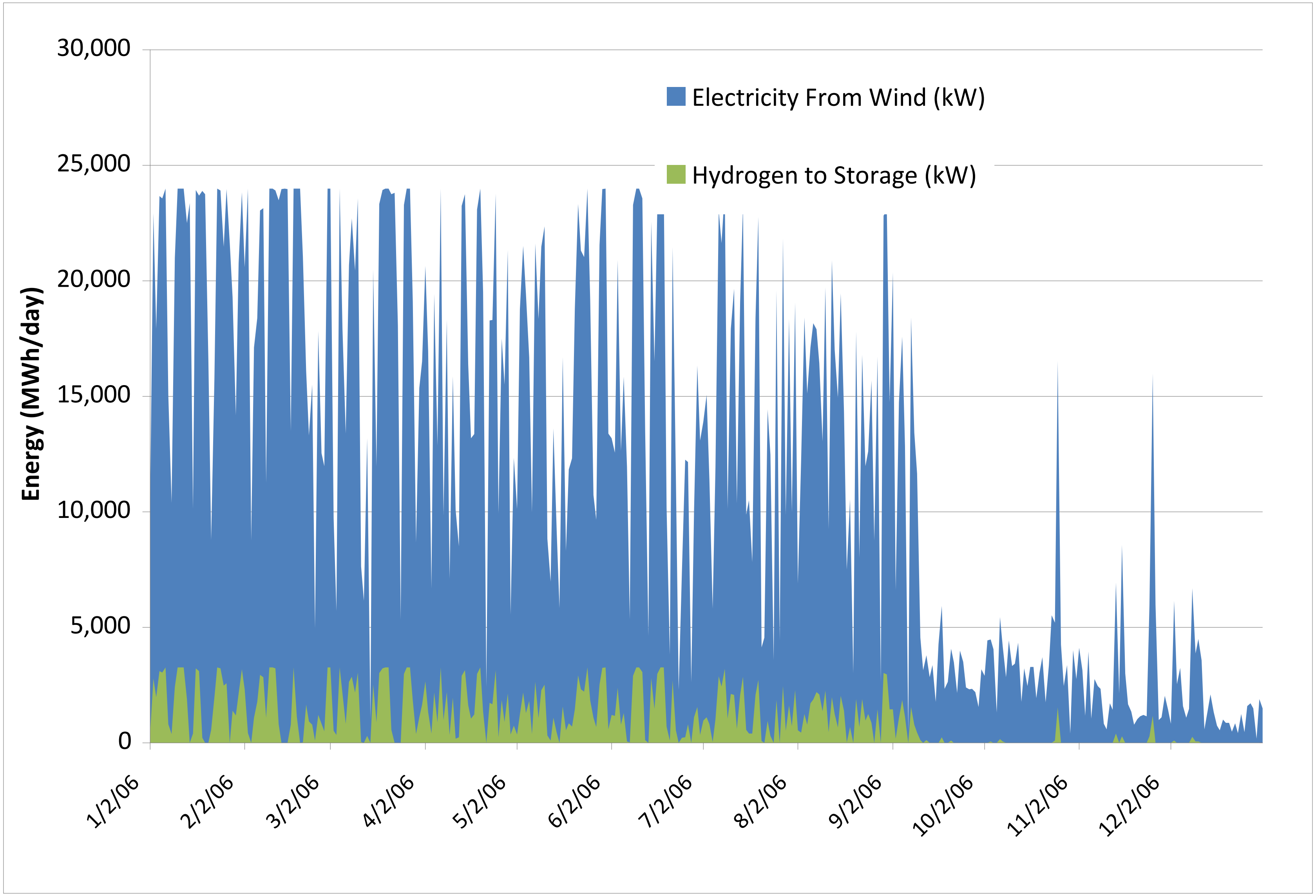
Primary Study Assumptions



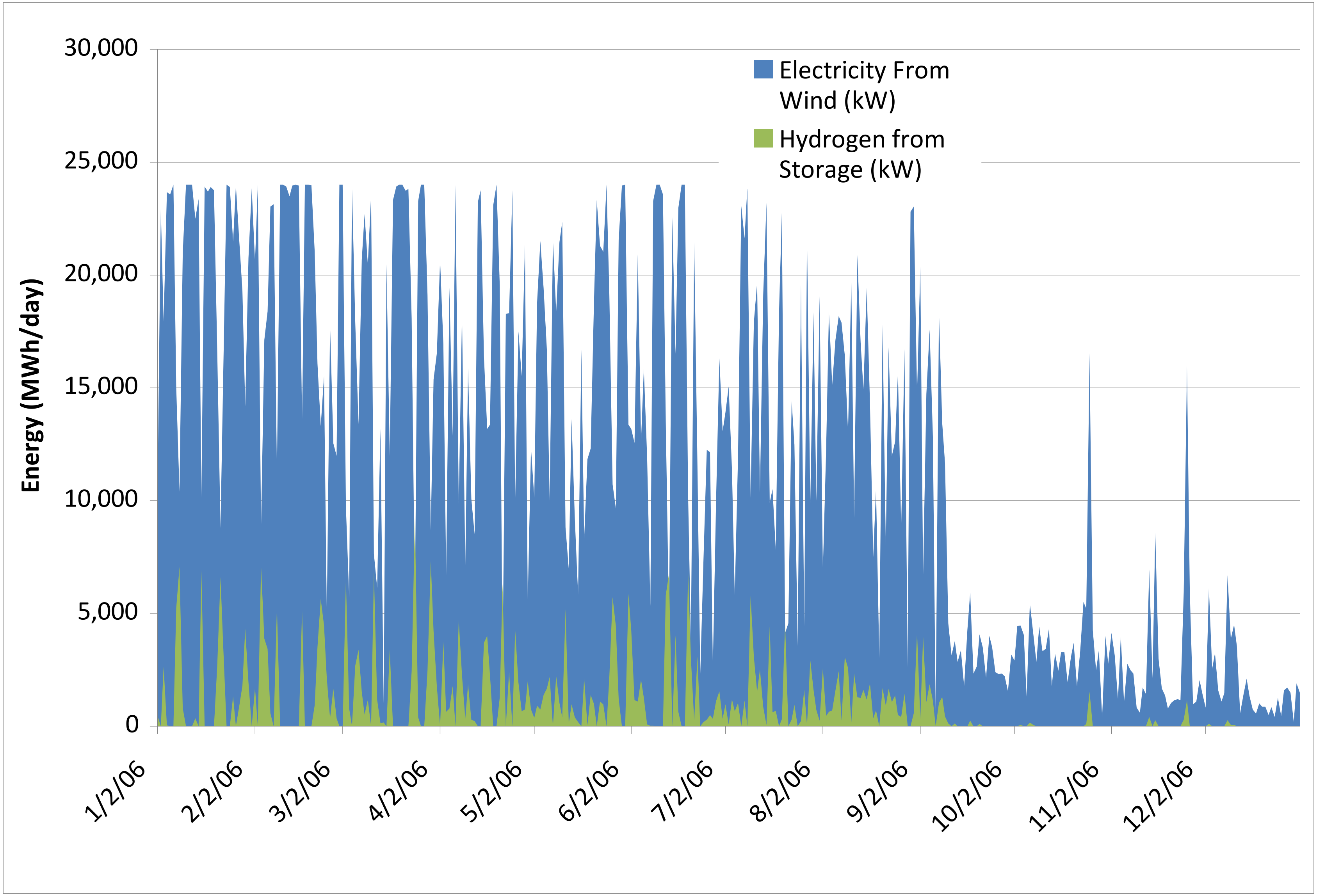
Major Assumptions

- Electrolyzer and PEM fuel cell performance and cost values derived from mid-cost case of lifecycle cost analysis
- Hydrogen storage in geologic storage
- The storage system is located at the wind farm & all electricity charged to the storage system is derived from the wind farm
- A dedicated transmission line carries electricity from the wind farm/storage system to the grid near demand centers.
- Power from the wind farm will be curtailed (shed) if:
  - It exceeds the maximum charging rate of the storage system + maximum capacity of the transmission line
  - The storage system is full

Wind Farm and Hydrogen Storage for Storage Constrained Case - Hydrogen to Storage



Wind Farm and Hydrogen Storage for Storage Constrained Case - Hydrogen from Storage



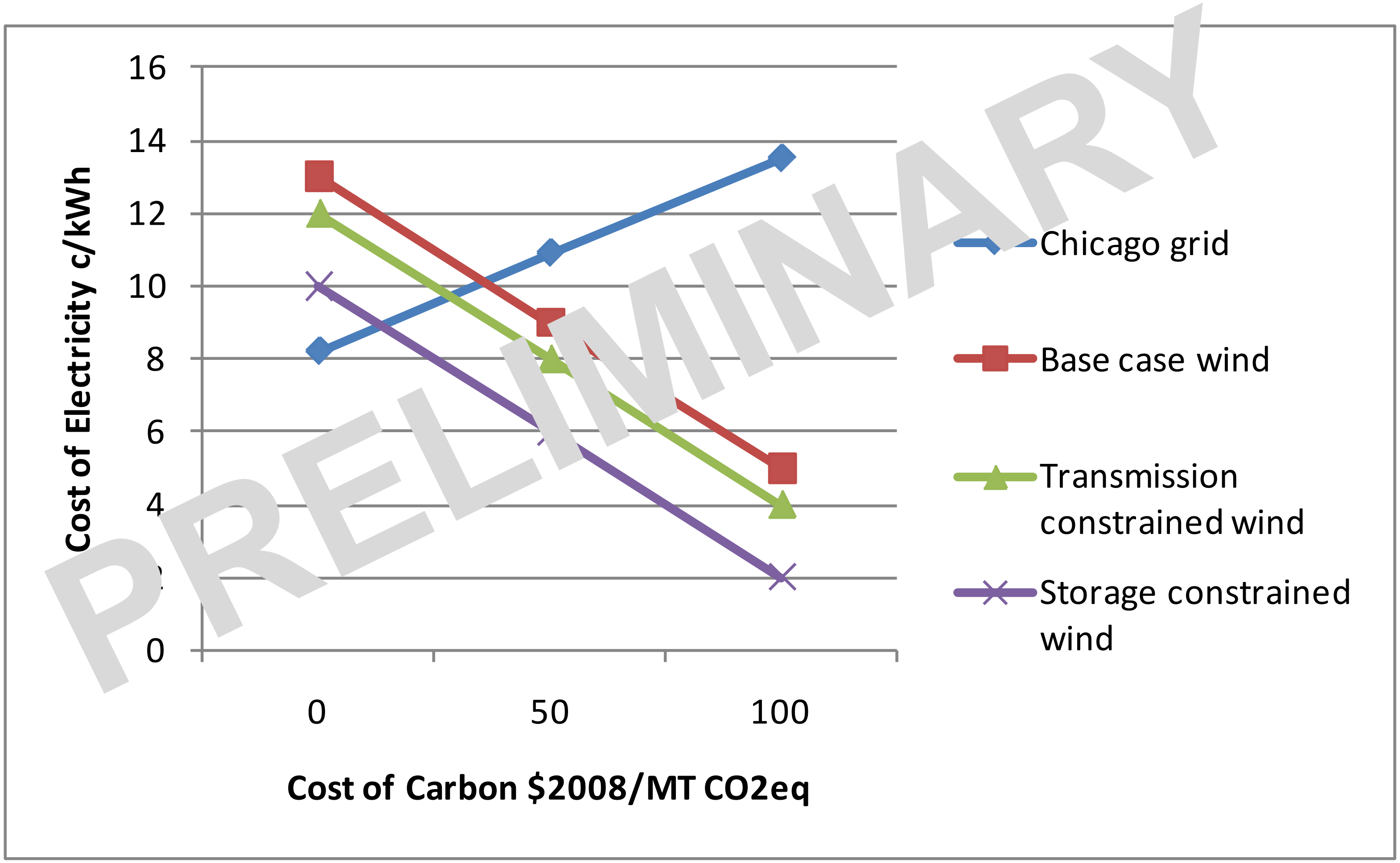
Summary of Preliminary Results

Storage reduces the amount of electricity that must be curtailed and reduces the LCOE

	Base Case	Storage Constrained	Transmission Constrained
	(% of Total Wind Farm Output)		
Electricity Direct from Wind Farm to Transmission Line	82.7	82.7	60.8
Electricity from Storage	N/A	4.5	7.4
Electricity Shed	17.3	1.9	11.7
Net Electricity to Transmission Line	82.7	87.2	68.2
	(% of Total Transmission Line Capacity)		
Transmission Line Utilization	56.0	59.0	69.0
	(LCOE ¢/kWh)		
Without cost of carbon	13	10	12
@ cost of carbon $50/MT CO2eq	9	6	8
@ cost of carbon $100/MT CO2eq	5	2	4

Effect of a Cost of Carbon on the Competitiveness of Wind & Hydrogen Storage System

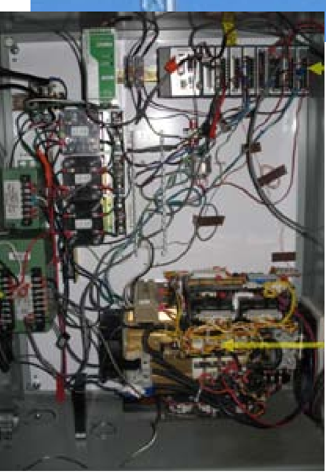
Credit for avoided emissions reduces LCOE for wind electricity below grid price

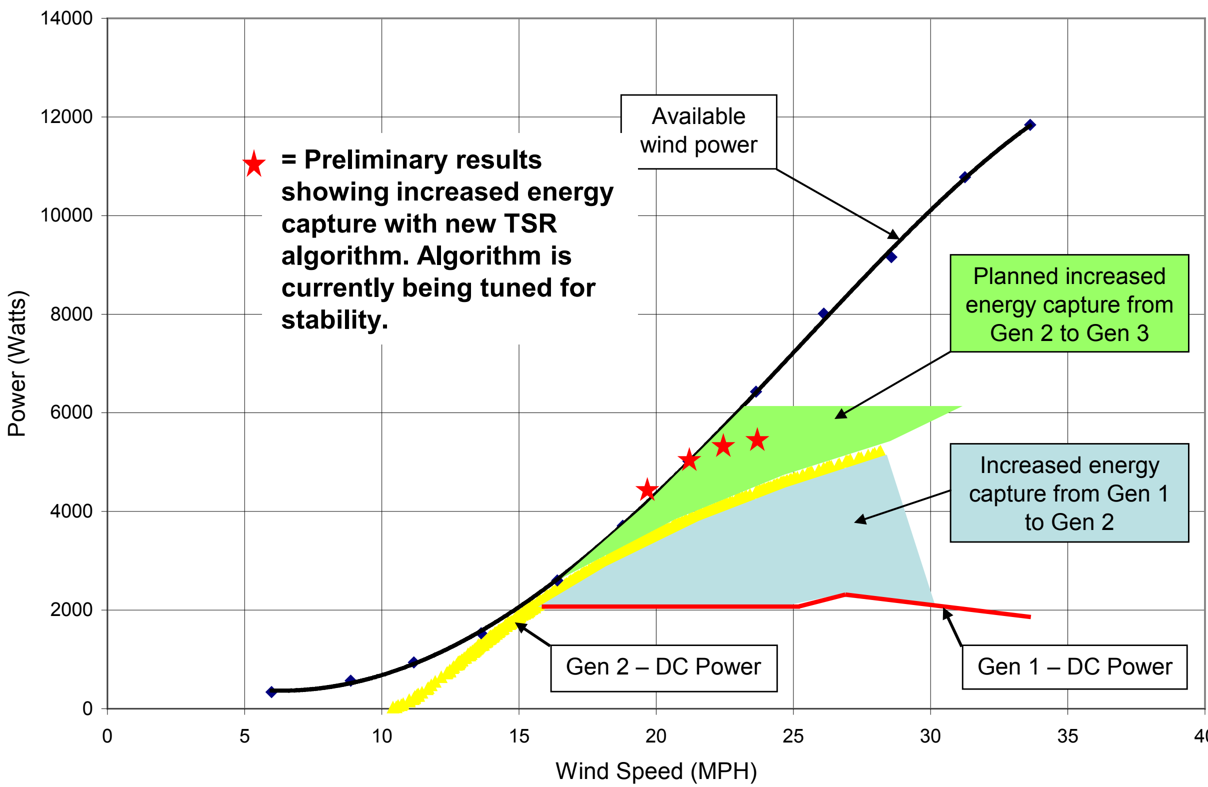


Cost comparison for Chicago Grid Electricity v Wind Electricity for Various Storage Configurations

NREL Wind to Hydrogen Project - 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





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%.

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%
  - H2 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

Thank You

Questions?

Thank You

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