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# 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

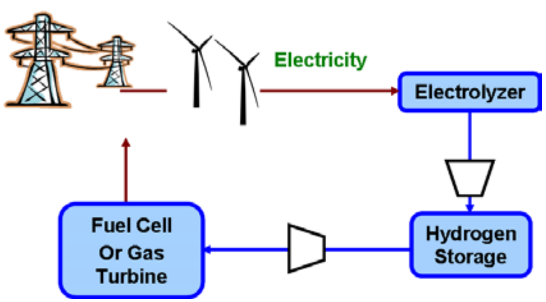
Preliminary Study Results

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

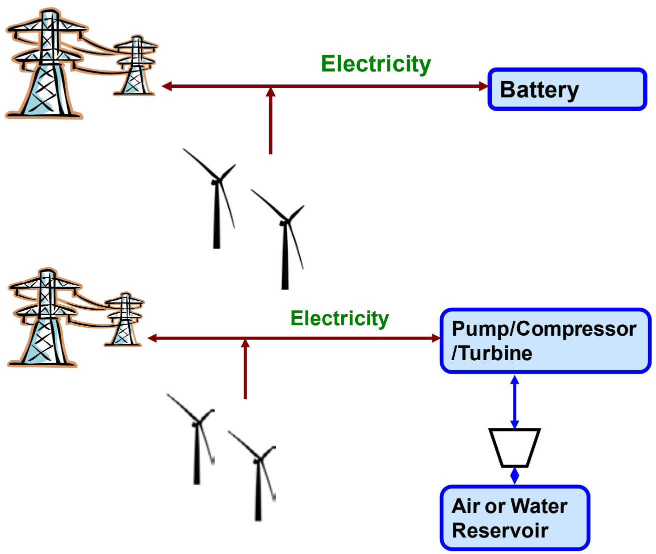
NREL Wind to Hydrogen Study Perspectives

# Scenarios for Hydrogen Energy Storage Analyses

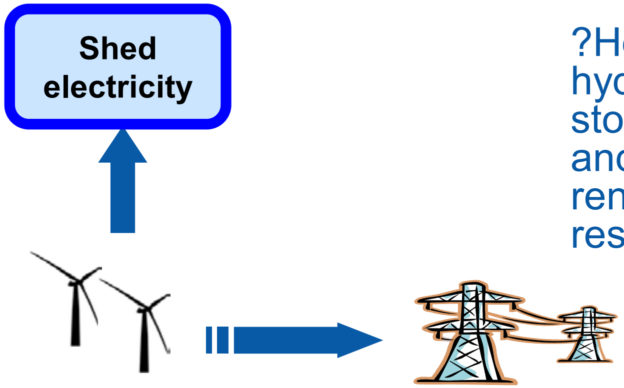
## Comparison of costs for hydrogen and competing technologies



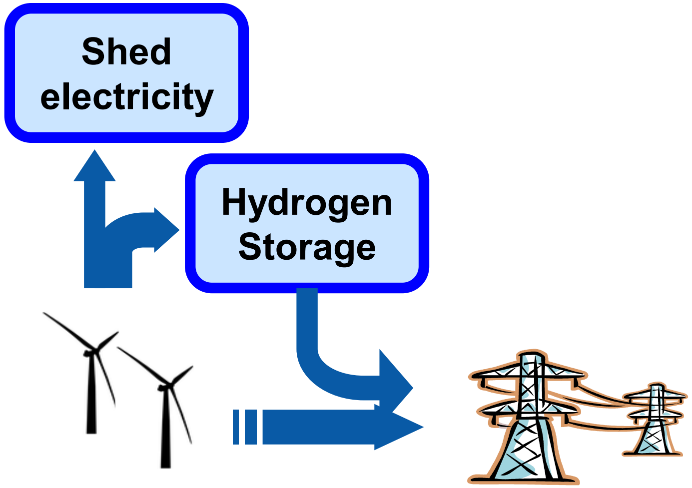

?Is hydrogen a potential solution for utility-scale energy storage



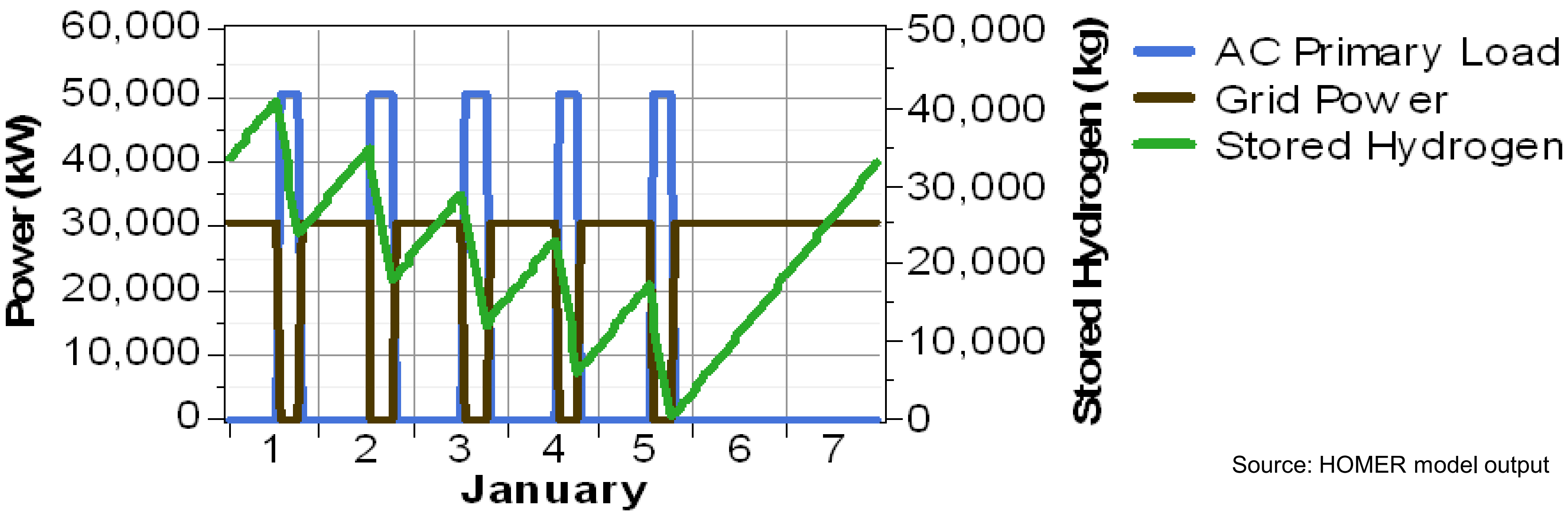

## Study of hydrogen energy storage for a specific renewable resource




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



# Energy Storage Scenario for Comparison Study




Source: HOMER model output

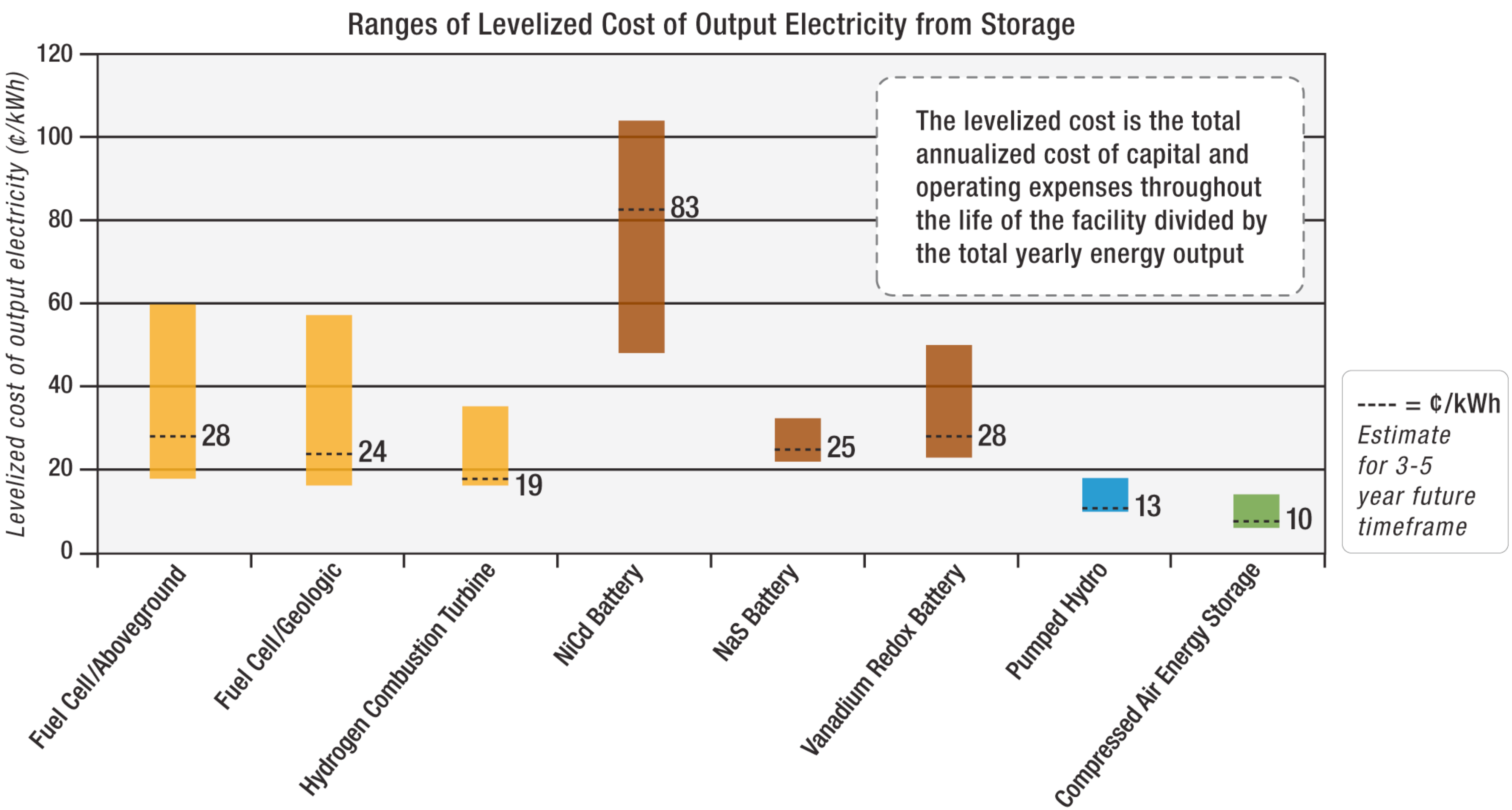
Nominal storage volume is 300 MWh (50 MW, 6 hours)

- 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

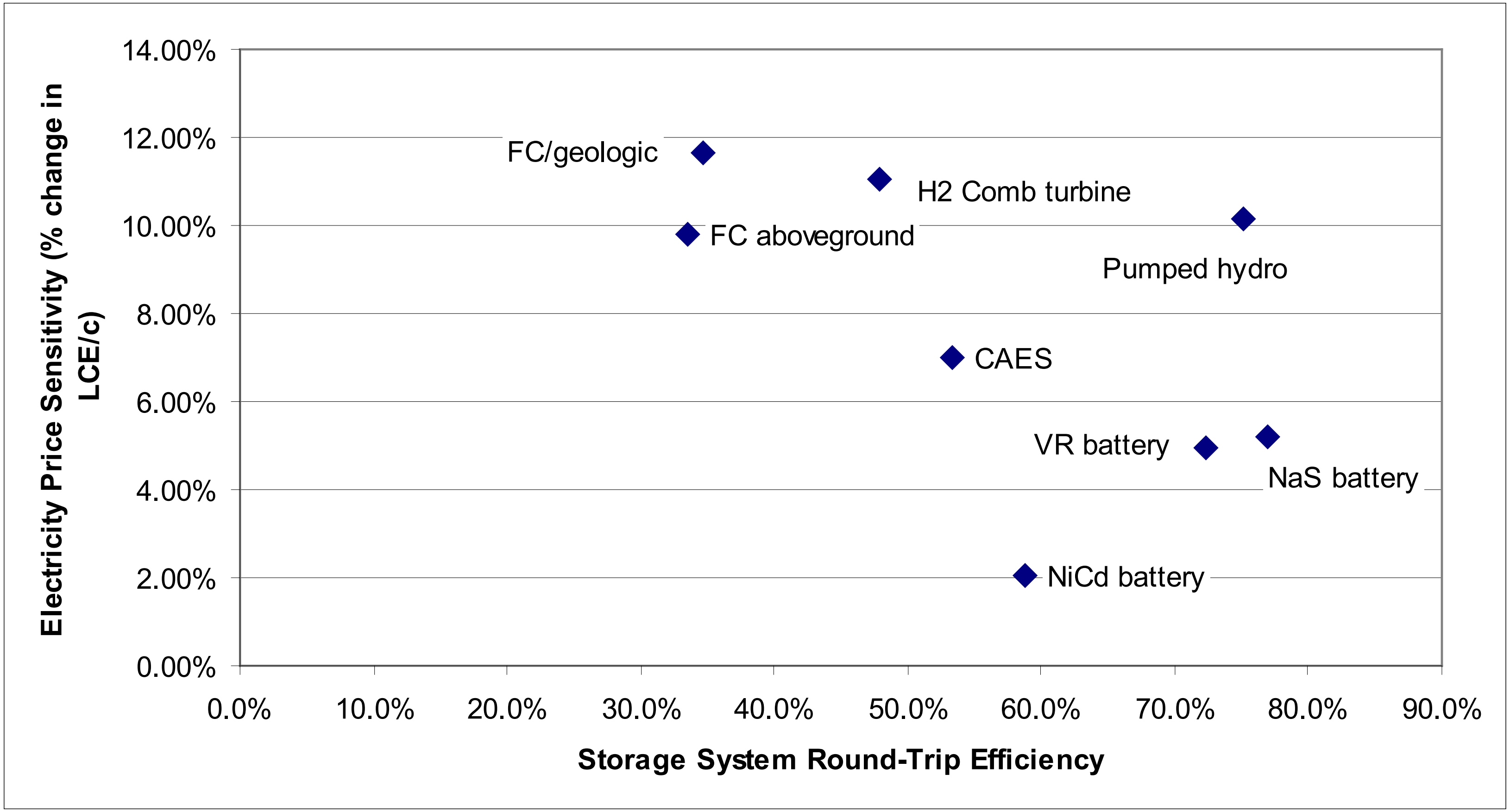
- Assumed steady and unlimited supply during off-peak hours (18 hours on weekdays and 24 hours on weekends)
- Assumed fixed purchase price of off-peak/renewable electricity

# 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.***

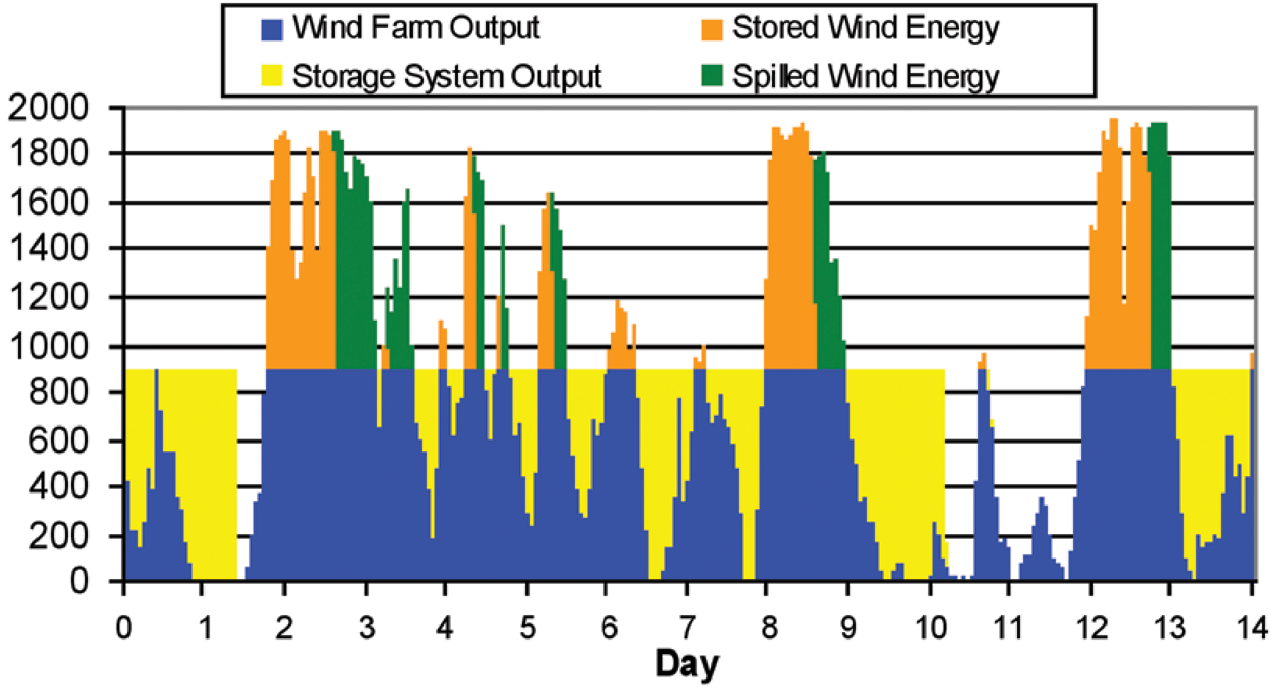
# Round-Trip Efficiency and Electricity Price Sensitivity




- **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

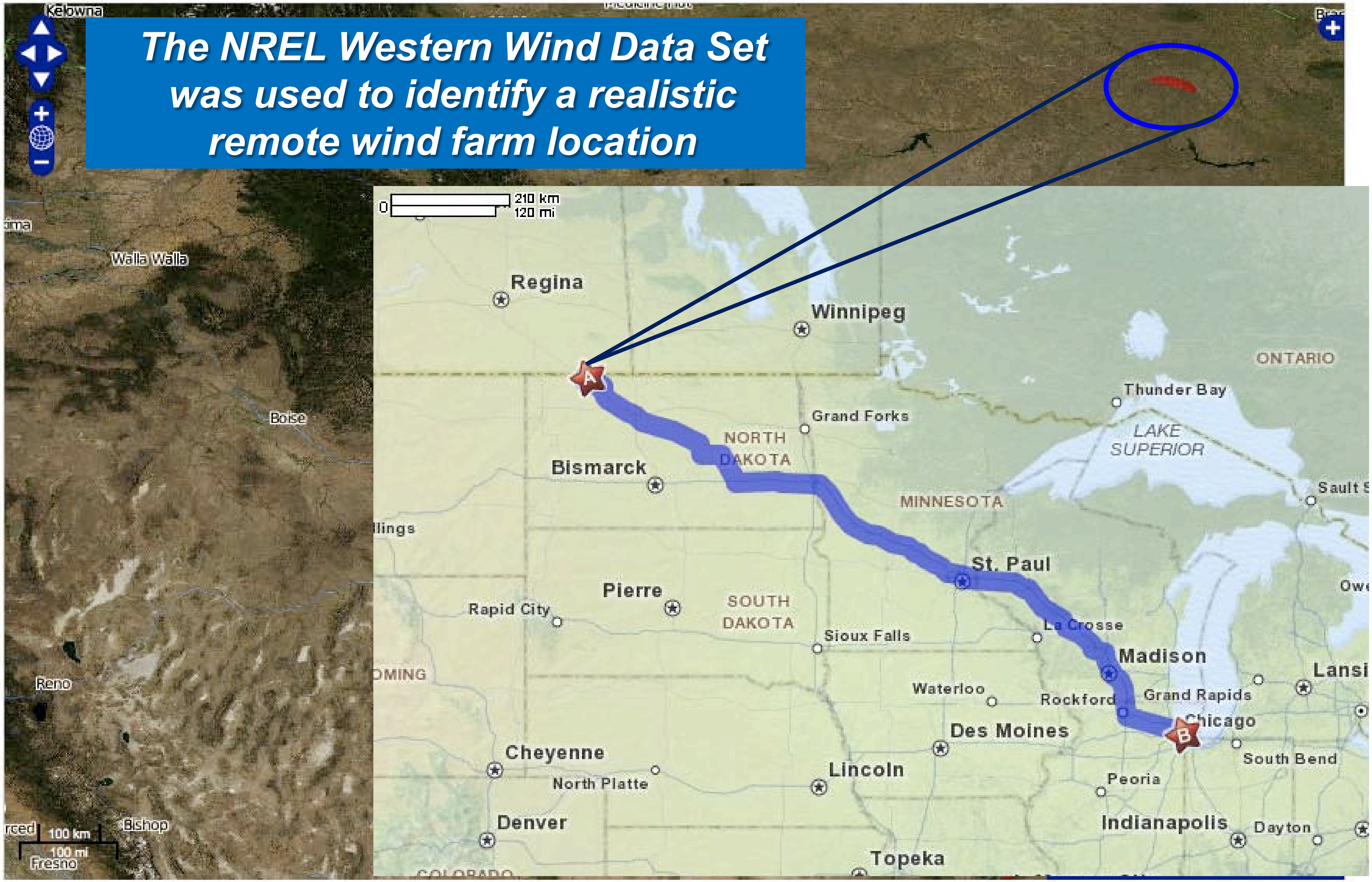
| + | - |
|---|---|
| Additional energy from the windfarm can be captured for later use | Efficiency losses incurred by routing wind energy through the storage system reduce the greenhouse gas benefit of wind |




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

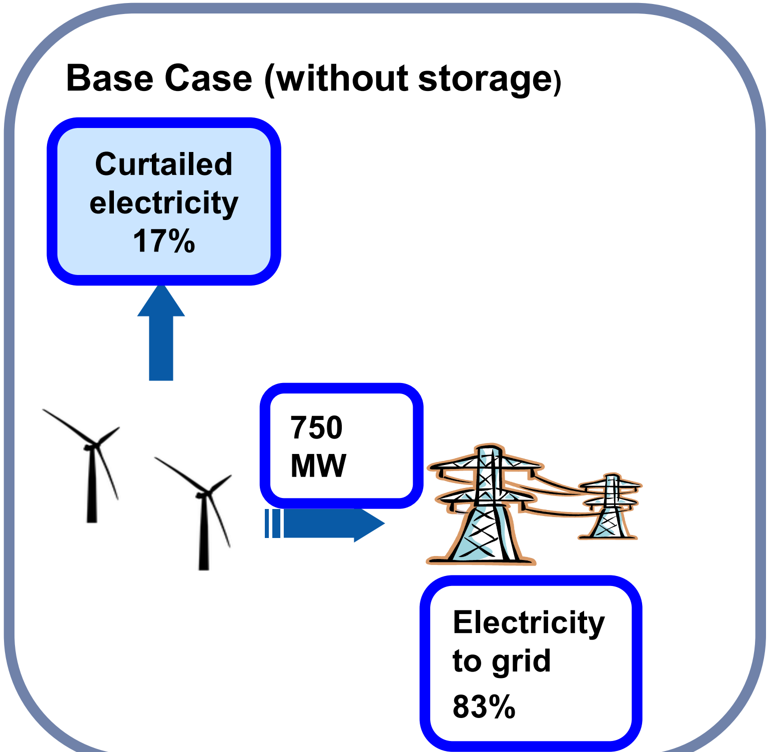
# Wind Farm Location

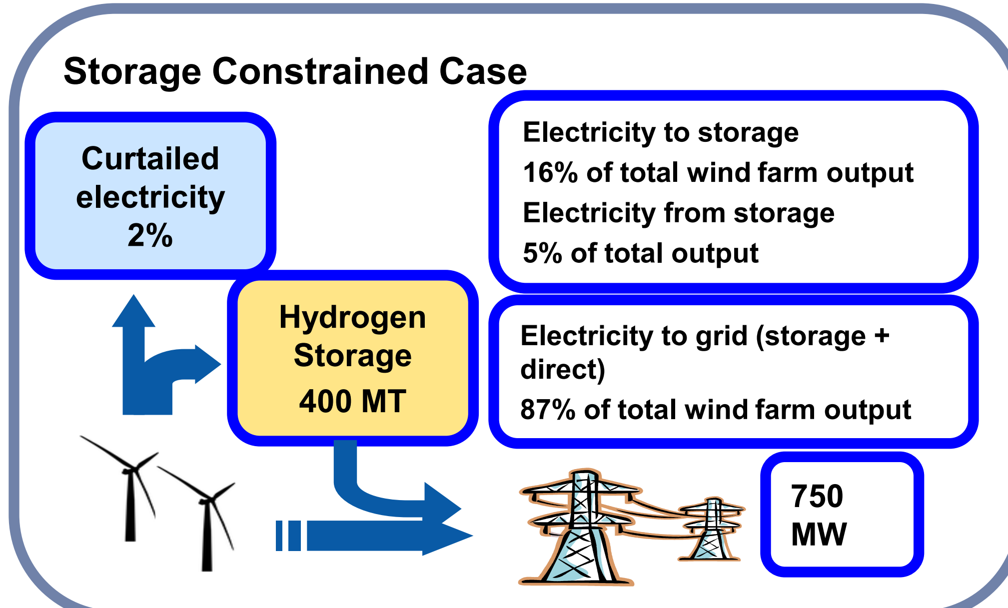
*The NREL Western Wind Data Set was used to identify a realistic remote wind farm location*

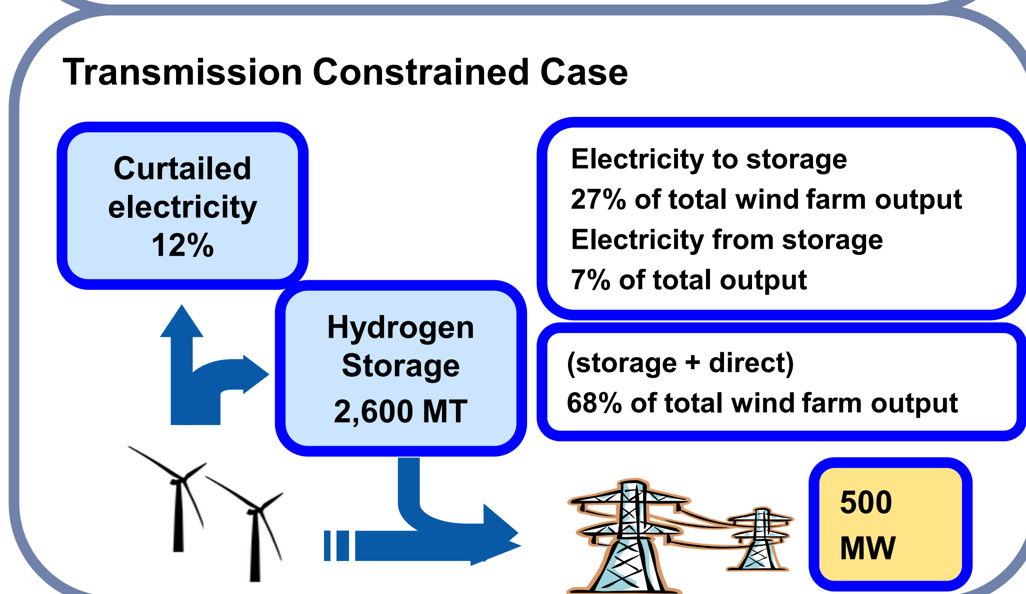


# Study Framework - Add Hydrogen Storage to a Base Case Without Storage

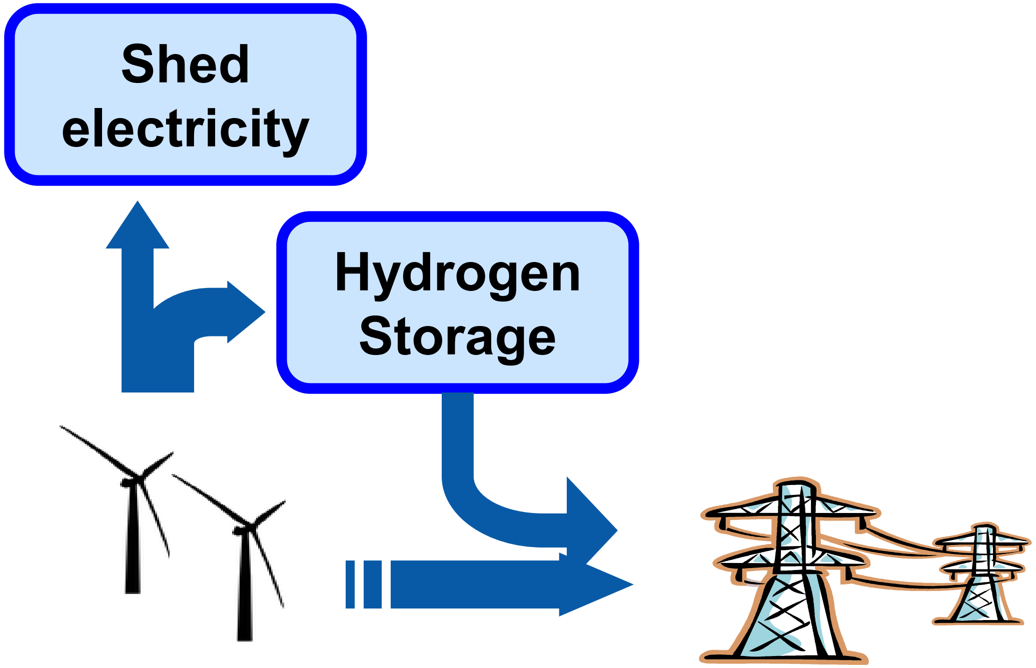
***Analysis of the base case provides LCOE and avoided emissions for comparison***



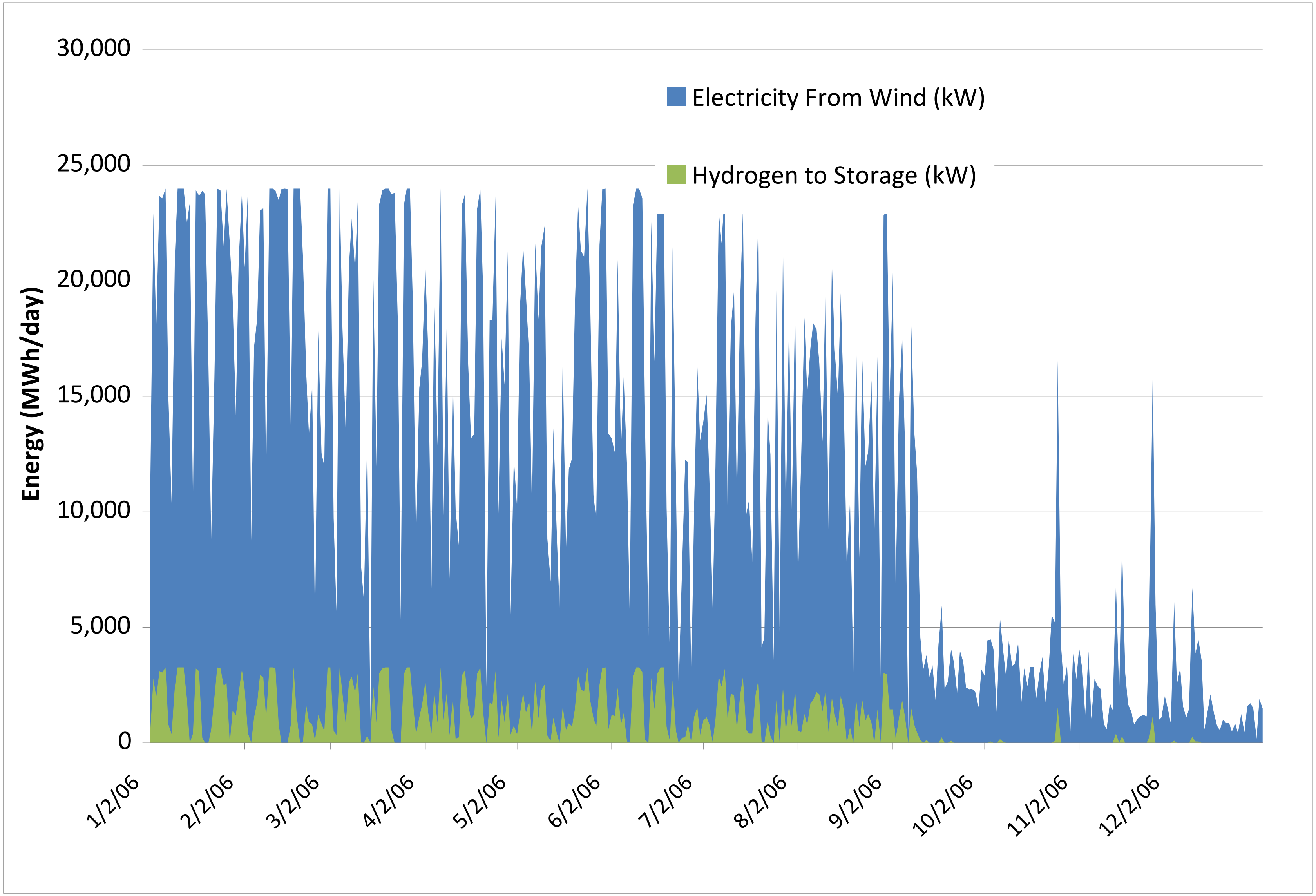
# Primary Study Assumptions



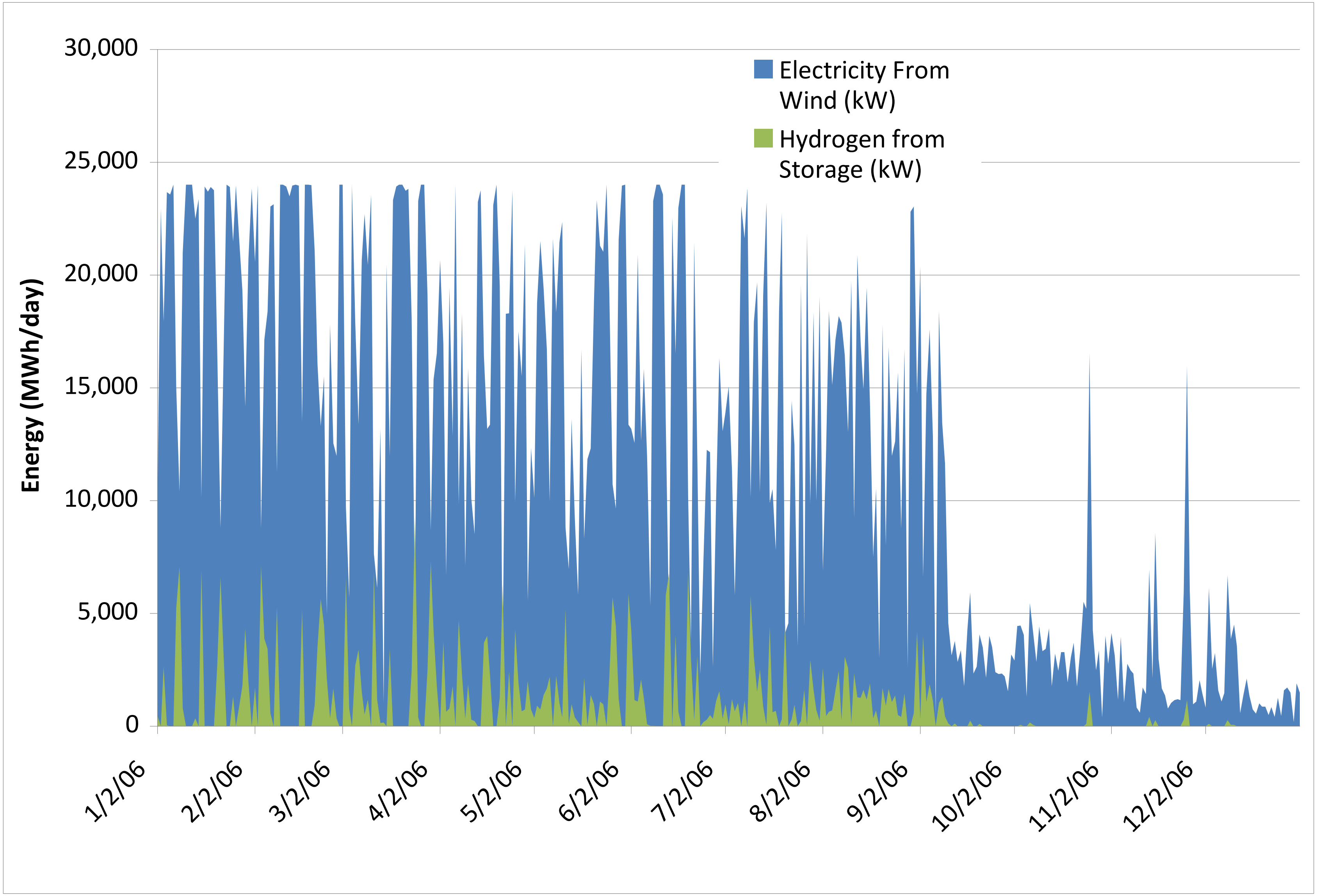

## Major Assumptions

- 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



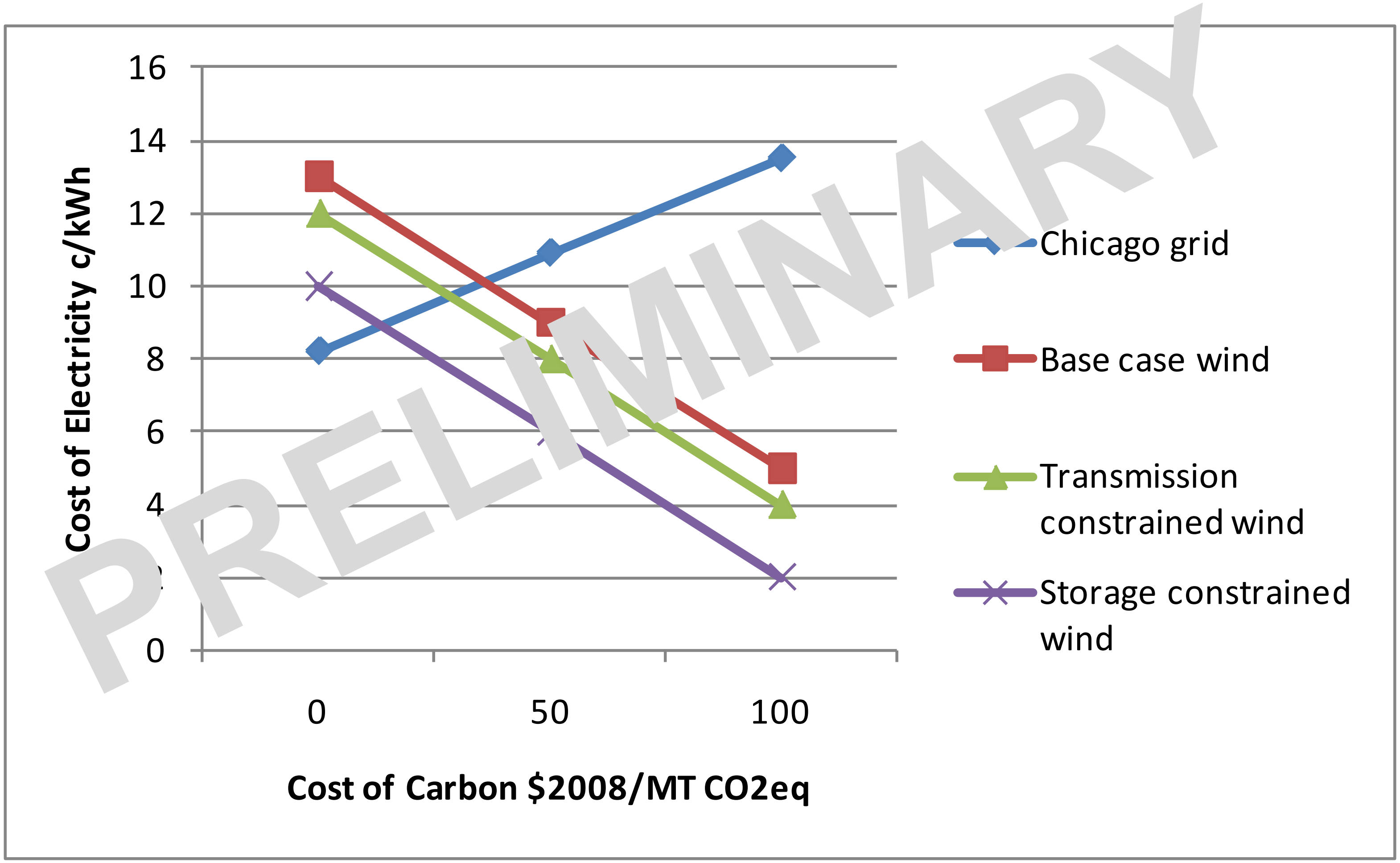
# Summary of Preliminary Results

***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

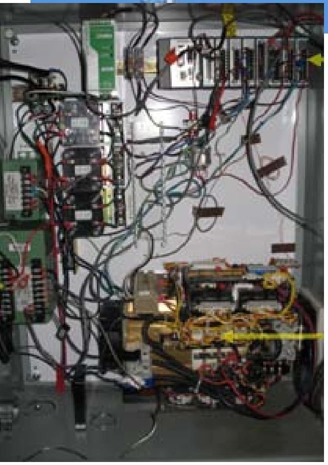
***Credit for avoided emissions reduces LCOE for wind electricity below grid price***

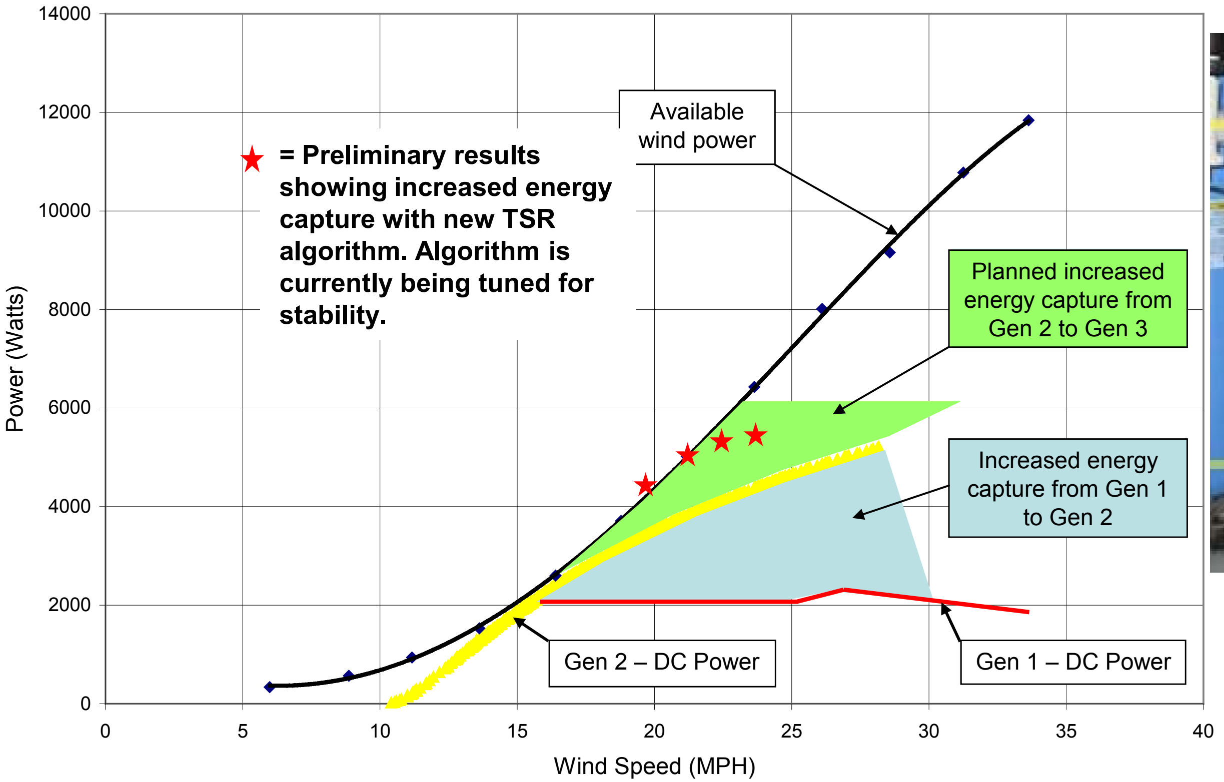



Cost comparison for Chicago Grid Electricity v Wind Electricity for Various Storage Configurations

# 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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