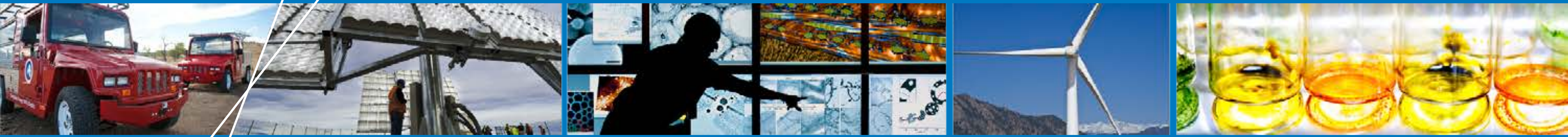
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Hour-by-Hour Cost Modeling of Optimized Central Wind-Based Water Electrolysis Production



Genevieve Saur (PI), Chris Ainscough (Presenter), Kevin Harrison, Todd Ramsden

National Renewable Energy Laboratory

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

Timeline

- Project start date: Sept. 2003
- Project end date: Oct. 2011**

MYPP Barriers Addressed

- G. Cost
- H. System efficiency
- J. Renewable integration

Budget

- Project Funding (2009-2011): $950k
- Funding received in FY11: $425k ($100k Analysis share*)
- Planned Funding for FY12: $450k ($0k Analysis share)

Partners

- Xcel Energy
- Giner Electrochemical Systems
- Avalence
- Proton Onsite
- Univ. of North Dakota/EERC
- DOE Wind/Hydro Program

*Analytical portion of "Renewable Electrolysis Integrated System Development and Testing" (PD031)
**Project continuation and direction determined annually by DOE.

Relevance

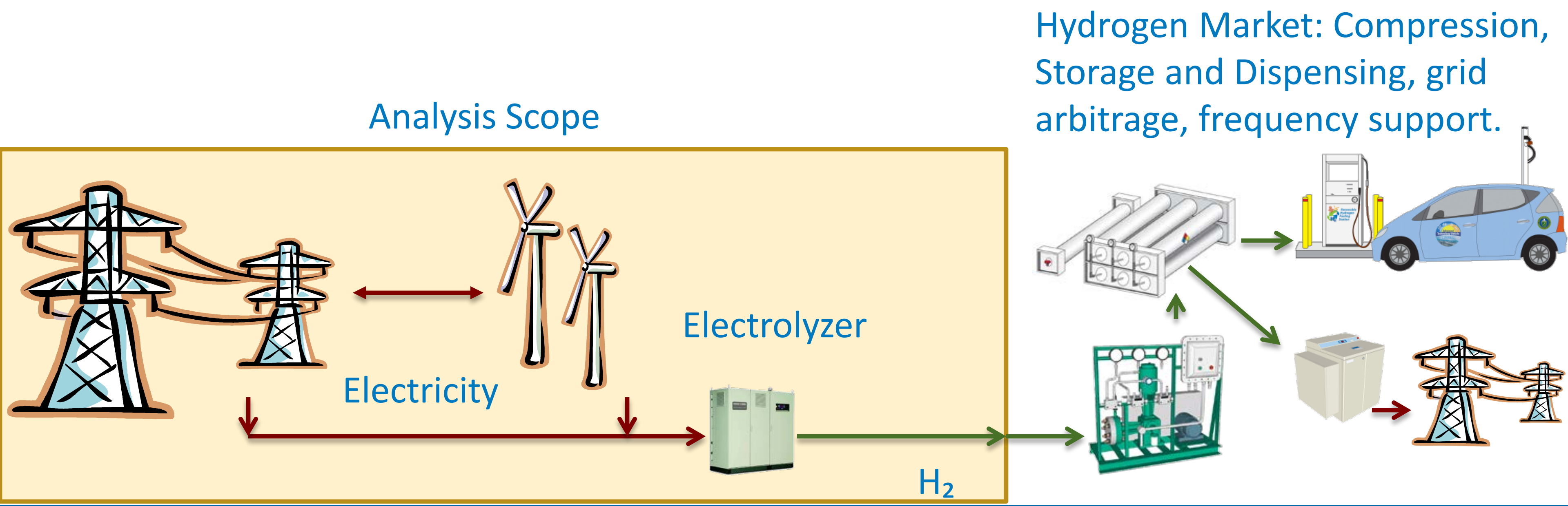
- **Cost**
  - **Problem:** Wind electrolysis production cost estimates are limited geographically.
  - **Solution:** Analyze a variety of wind class sites across the country to show a full range of hydrogen costs based on wind.
- **System efficiency**
  - **Problem:** System efficiency remains a barrier to further cost reductions.
  - **Solution:** Sensitivities examine what components and factors have biggest effect on system performance and efficiency.
- **Renewable integration**
  - **Problem:** Optimal sizing relationships between wind capital and electrolyzer capital are not well understood.
  - **Solution:** Components sized based upon hydrogen demand, wind farm size needed for hydrogen demand, and different operation scenarios

Approach: Wind2H2 Analysis Objectives

- **Expand previous analysis beyond California to a variety of wind resources and electricity markets in the U.S.**
- **Examine consequences of different system configurations and operation scenarios**
- **Initiate understanding of sizing implications between electrolyzers and wind farms throughout the country**
- **Identify areas for further analysis and cost reduction**

Approach: Current Analysis

- This task is the analysis part of the Department of Energy's and Xcel Energy's ongoing Wind 2 Hydrogen demonstration project.
- The goal is to examine the viability of wind-generated hydrogen in electricity markets and winds sites throughout the country.
- Four scenarios optimize wind farm size vs. electrolyzer requirements using hour-by-hour modeling.



Approach: Key Parameters – System

- **8,760 hourly analyses based upon NREL's H2A Production and Fuel Cell Power models**
  - Using hourly electricity market pricing and hourly wind data
- **Hydrogen production facility**
  - 50,000 kg H2/day nominal
- **4 grid-connected wind electrolysis scenarios**

Scenarios
A) Cost balanced: $ grid purchased = $ wind sold
B) Power balanced: kWh grid purchased = kWh wind sold ★
C) Same as A) but no summer peak grid electricity purchased
D) Same as B) but no summer peak grid electricity purchased ★

"Net Green" Hydrogen

Approach: Key Parameters – Components

Electrolyzers

- Design capacity of ~51,000 kg/day with 98% capacity factor
- 106 MW electricity requirement (50 kWh/kg)
- $53.2M total depreciable capital cost
- Replacement, O&M costs also included

Wind Farm

- Multiples of 3 MW turbines
- Design performance based on class 4 wind site
- Wind costs updated to reflect latest available costs (2010)

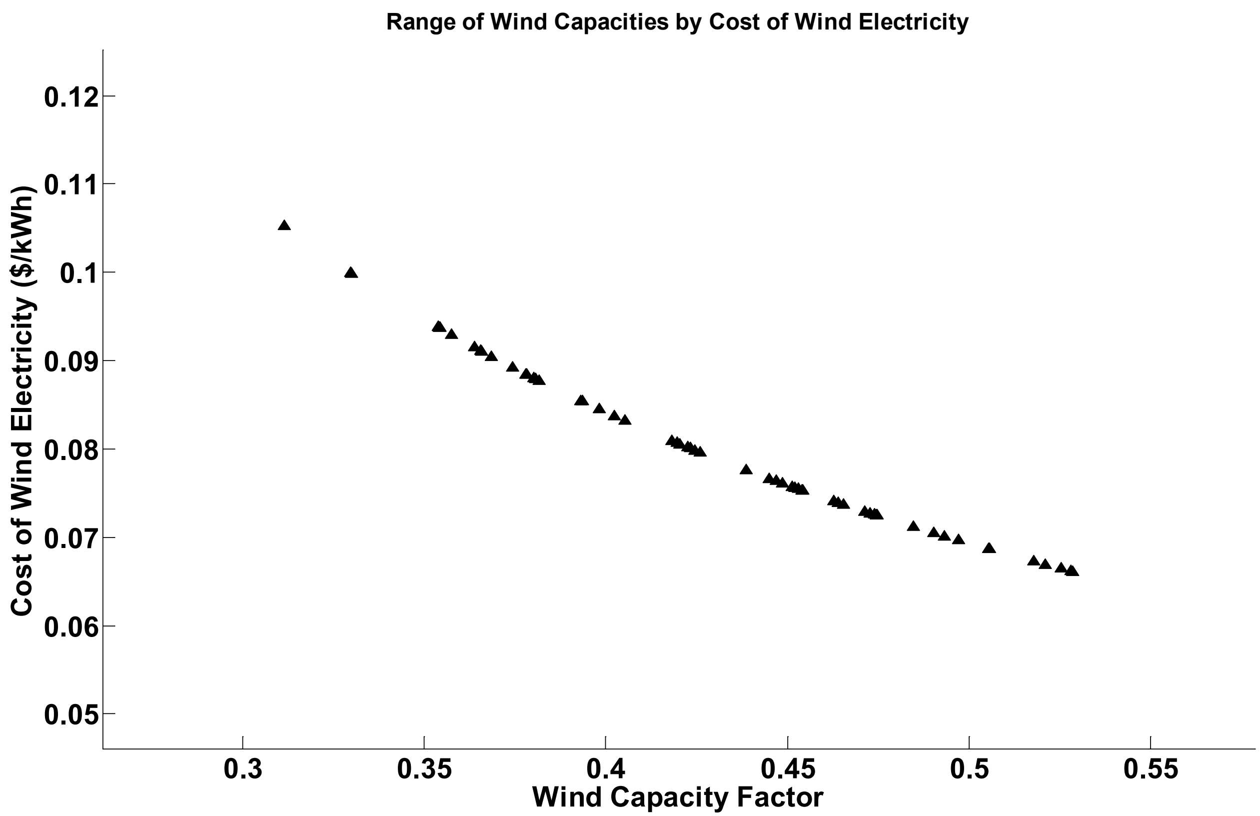
	2009 Cost[1]	2010 Cost[1,2]
Installed wind turbine	$2085/kW	$2067/kW
O&M (incl. replacement)	$0.0078/kWh	$0.0087/kWh

1. Costs adjusted to $2007
2. Wiser, R., Bolinger, M., 2010 Wind Technologies Market Report. DOE/GO-102011-3322. Golden, CO: NREL, 2011.

Approach: Key Parameters – Wind

Wind Profiles

- Model input from eastern and western wind data sets, and published 2010 wind costs [Wiser & Bolinger, 2010].

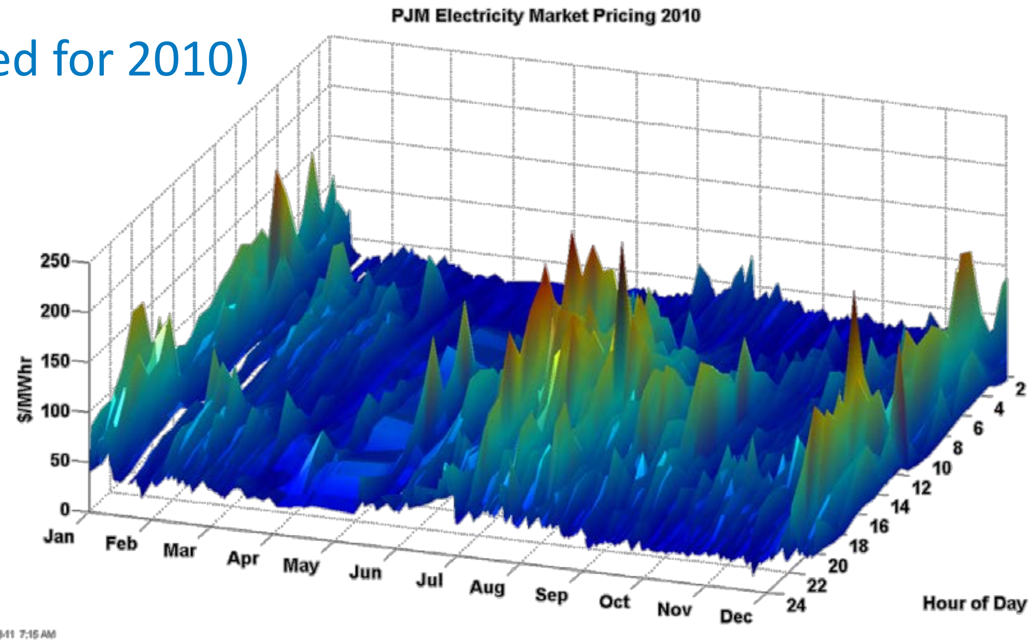


3. Wind Costs shown without any subsidies such as the ITC, PTC, or treasury grant

Approach: Key Parameters – Grid

Grid Electricity Pricing

- Raw Locational Marginal Price (LMP)[4] was gathered for five electricity markets
  - Pennsylvania, Maryland, and New Jersey (PJM)
  - The Electrical Reliability Council of Texas (ERCOT)
  - Midwest ISO
  - ISO New England
  - California ISO (updated for 2010)

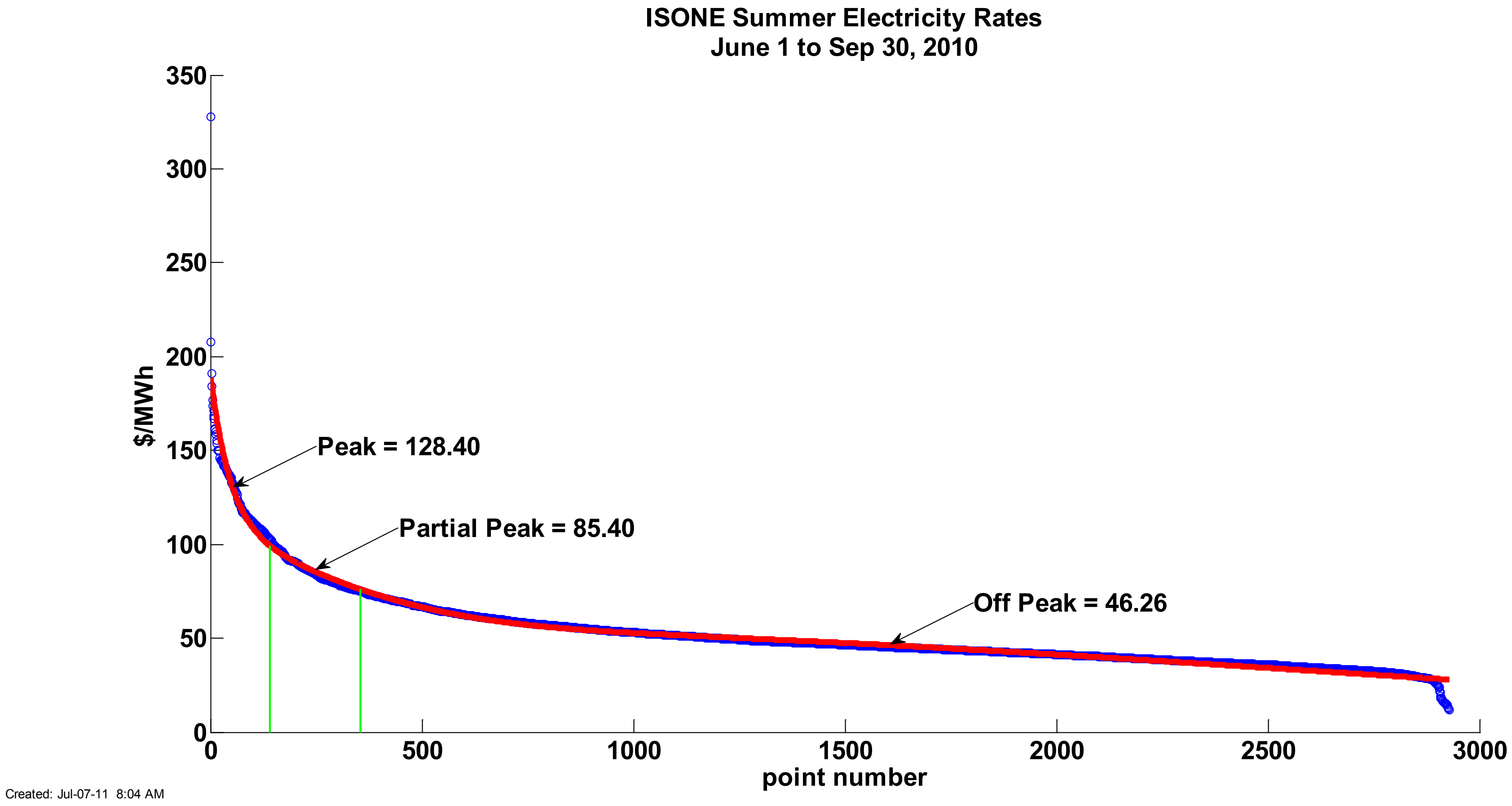


4. ERCOT used market clearing price since it switched pricing methods during the analysis year.

Approach: Key Parameters – Grid

Grid Electricity Pricing

- Raw data were classified into six tiers; peak, partial peak, and off peak for both summer and winter



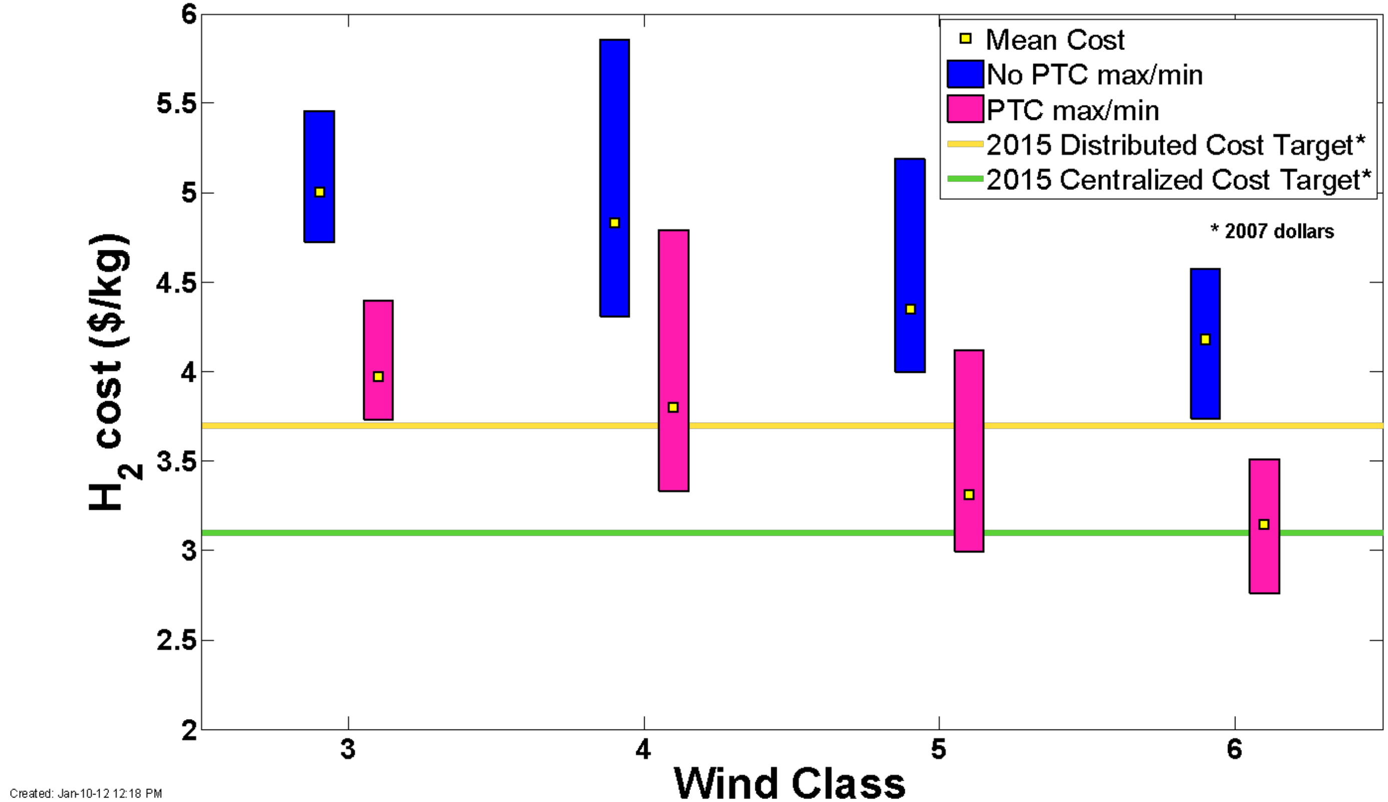
Wind2H2 Analysis Accomplishments

- **Expanded analysis to include 42 sites in 11 states, spanning five electricity markets**
  - Wind classes ranged from 3 to 6
  - System size ranged from 1,000 to 50,000 kg/day
  - Updated financial year to 2007 to harmonize with upcoming DOE targets

Model Parameter	Range in 2011	Range in 2012
Regional grid pricing structures and location(area)	CA	CA ISO, Midwest ISO, ISO New England, ERCOT (TX), Pennsylvania, New Jersey, Maryland (PJM) ISO
Sites (number)	8	42
Size (kg/Day)	50,000	1,000 to 50,000
Wind Capital Costs	$2086/kW Installed	$2067/kW Installed

Wind2H2 Analysis Accomplishments

- **Base hydrogen costs ranged from \$3.74/kg to \$5.86/kg**
- **Hydrogen costs accounting for the combined effects of tax credits for wind power of 0.02 \$/kWh[5] resulted in hydrogen costs of \$2.76/kg to \$4.79/kg**



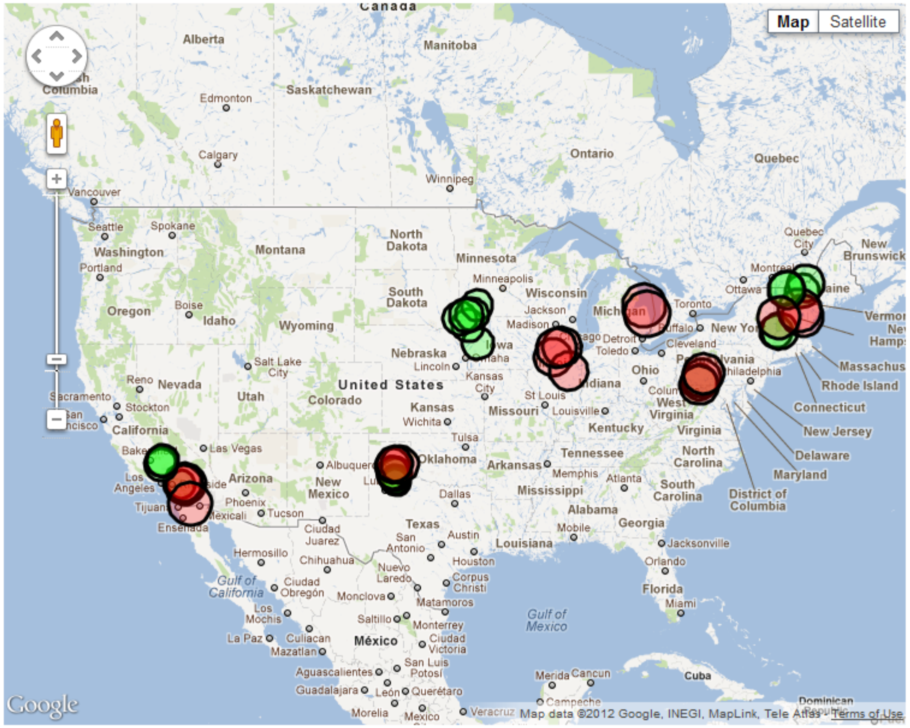
5. The combined effects of the production tax credit (PTC), Investment Tax Credit (ITC), and Treasury Grant reduce wind electricity prices \$0.02/kWh. Refer to: Wiser, R., Bolinger, M., 2010 Wind Technologies Market Report. DOE/GO-102011-3322. Golden, CO: NREL, 2011.

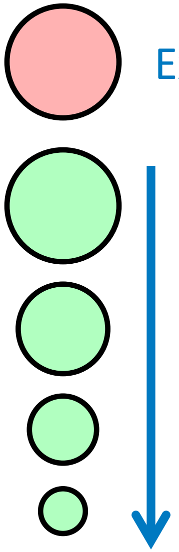
Wind2H2 Analysis Accomplishments

- **NREL created an interactive website to allow exploration of the results**

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

Summer Peak Purchase	Yes	No	Other Variables		
Power Balanced	◉	○	Target Cost[1]	○ Central $3.10/kg	◉ Distributed $3.70/kg
Cost Balanced	○	○	Enable PTC/ITC/Treasury Grant [2]	☑ Reduces wind power cost $0.02/kWh	
			Compression, Storage, and Dispensing Costs[3]	☐ $2.00/kg H_2	$ ____ /kg H_2





Exceeds DOE H_2 cost target

Meets DOE H_2 cost target

Circle size scales with H_2 cost

Smaller=cheaper

Wind2H2 Analysis Accomplishments

Users can:

- Explore the effects of the four different balance scenarios

Summer Peak Purchase

	Yes	No
Power Balanced	◉	○
Cost Balanced	○	○

- Compare site hydrogen costs to DOE targets

Target Cost[1]	○ Central \$3.10/kg	◉ Distributed \$3.70/kg

- Compare the effects of the PTC/ITC and Treasury Grant on hydrogen costs

Enable PTC/ITC/Treasury Grant [2]	☑ Reduces wind power cost \$0.02/kWh

- Add compression, storage, and dispensing (CSD) costs

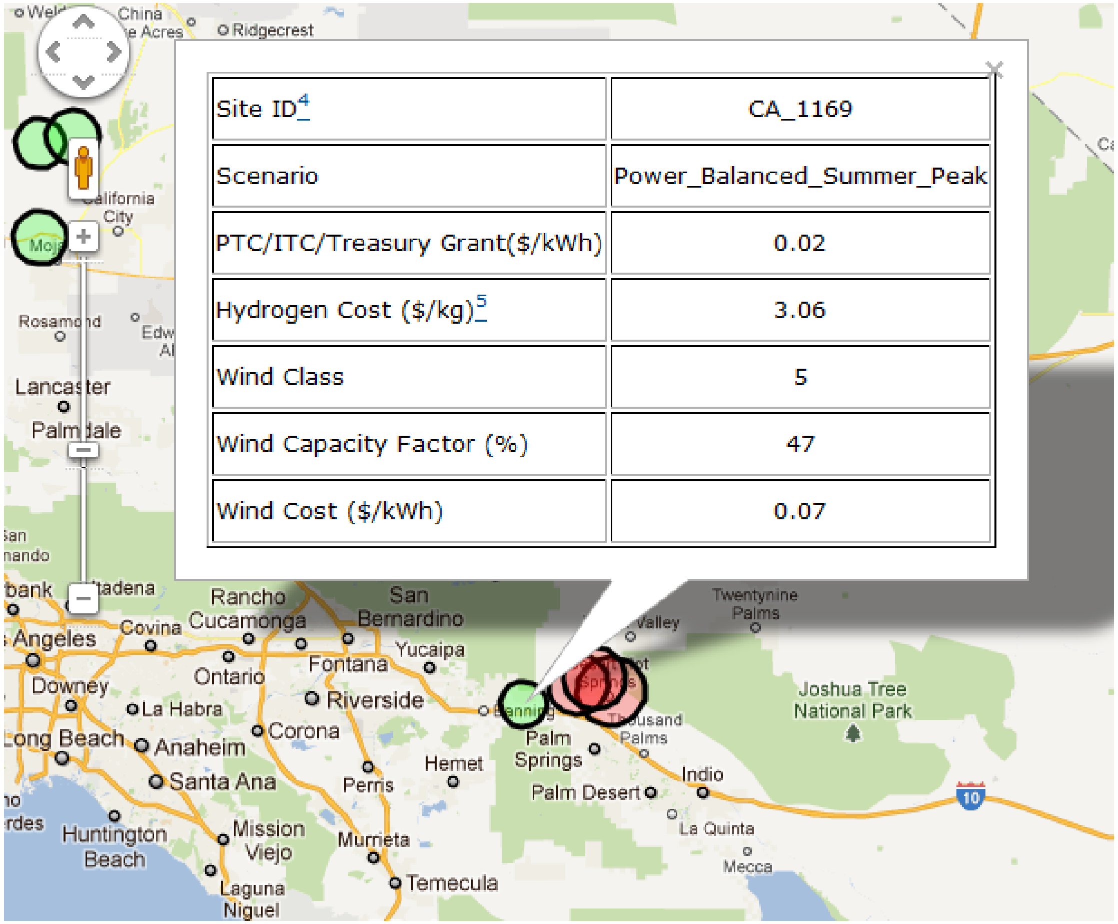
Compression, Storage, and Dispensing Costs[3]	☐ \$2.00/kg H_2	\$ ____ /kg H_2

- And see results updated immediately…

Wind2H2 Analysis Accomplishments

Results are updated instantaneously

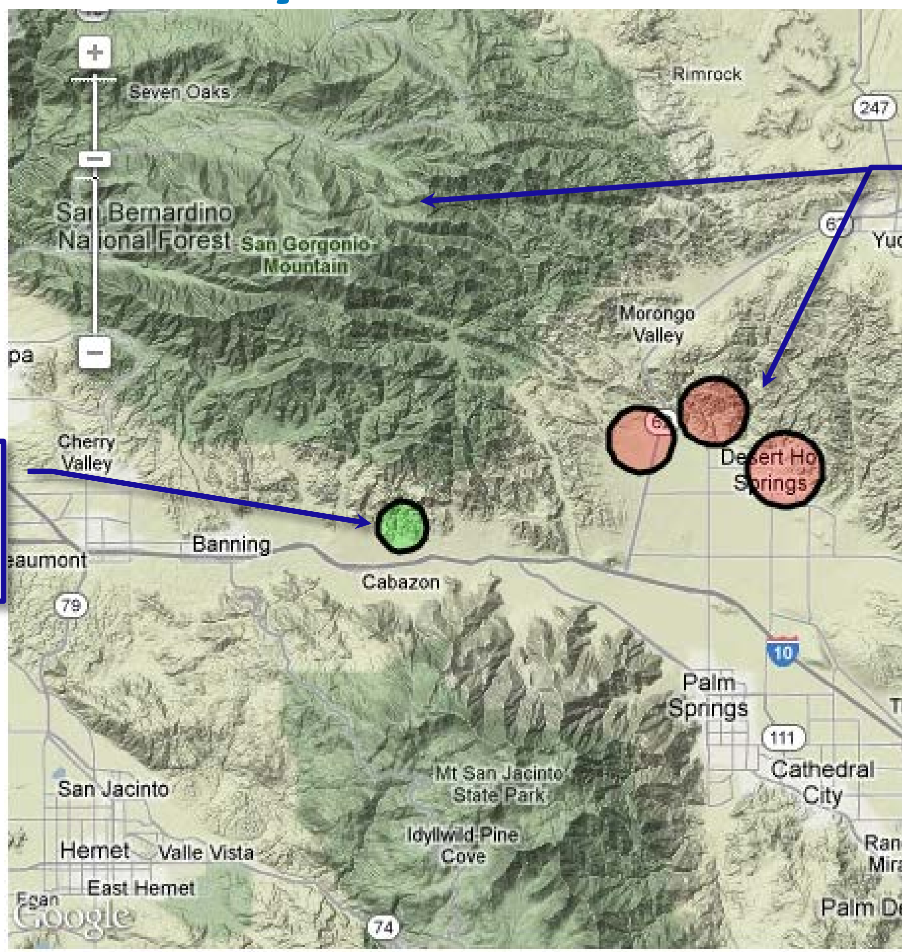
Mouse hover will display: The site ID from the NREL Eastern & Western Wind Datasets, balance scenario, the status of the PTC/ITC, hydrogen cost, wind class, wind capacity factor, wind electricity cost



Site ID[4]	CA_1169
Scenario	Power_Balanced_Summer_Peak
PTC/ITC/Treasury Grant($/kWh)	0.02
Hydrogen Cost ($/kg)[5]	3.06
Wind Class	5
Wind Capacity Factor (%)	47
Wind Cost ($/kWh)	0.07

Wind2H2 Analysis Accomplishments

Users can see the effects of local topography on the viability of a site



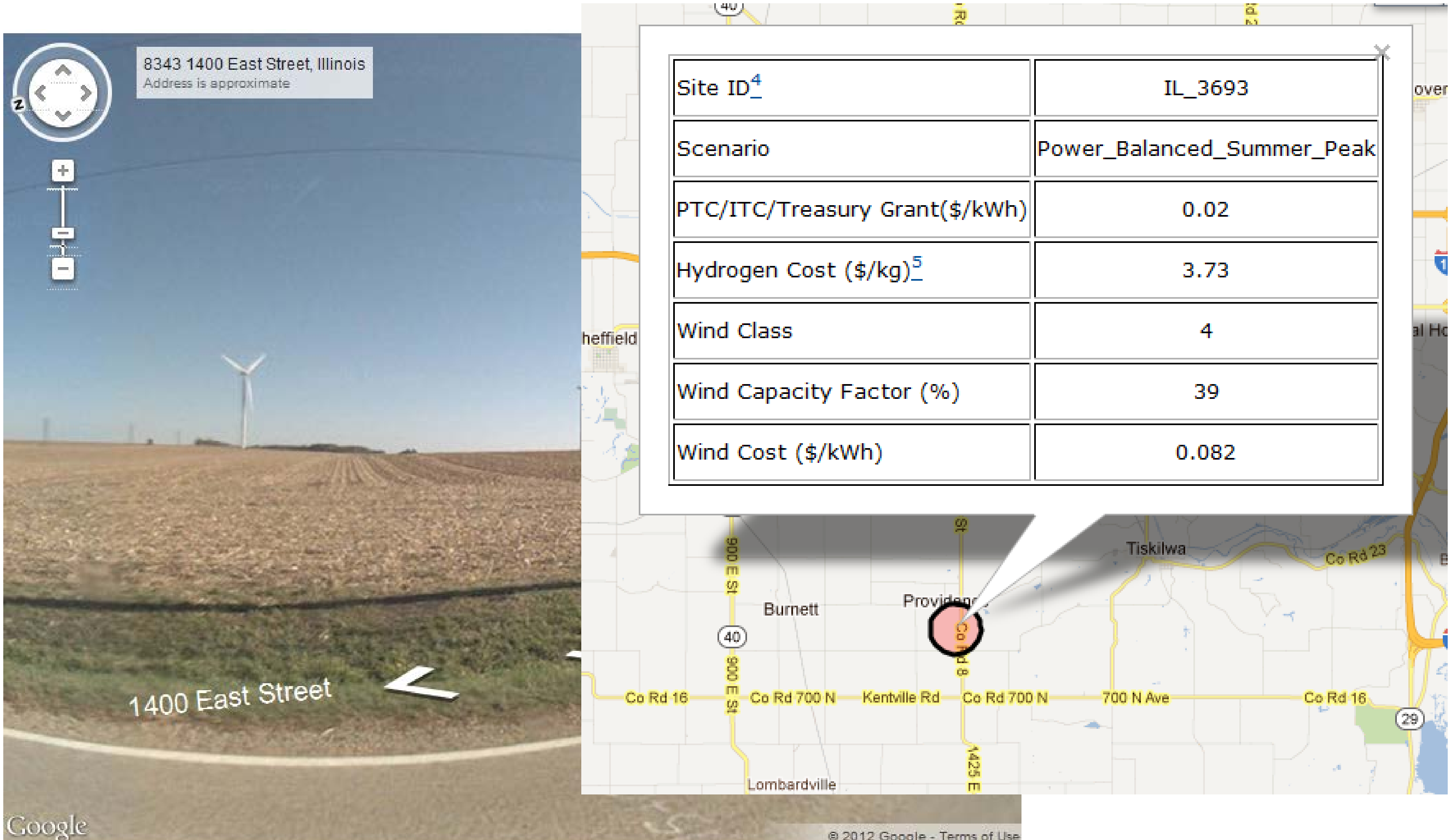
Site meets DOE target

Nearby mountains degrade the wind resource making these sites less viable. Despite being in the same electricity market, hydrogen cost is increased from \$3/kg to more than \$4.5/kg

Wind2H2 Analysis Accomplishments

Users can see the street view of many sites

Site IL_3693 is already a developed wind site southwest of Chicago



Site ID[4]	IL_3693
Scenario	Power_Balanced_Summer_Peak
PTC/ITC/Treasury Grant($/kWh)	0.02
Hydrogen Cost ($/kg)[5]	3.73
Wind Class	4
Wind Capacity Factor (%)	39
Wind Cost ($/kWh)	0.082

Collaborations with Industry

- **Information, technical support, and equipment for overall project from:**
  - Xcel Energy
  - Giner Electrochemical Systems
  - Avalence
  - Proton Onsite
  - DOE Wind/Hydro Program

Analysis – Proposed Future Work

- Add more sites on land
- Add additional electricity markets
- Add offshore wind sites
- Examination of solar integration
- More emphasis on smaller or forecourt sized renewable electrolysis targeted to the vehicle end use market, with 700 bar storage
- Other optimal electricity/hydrogen production balance scenarios
- Explore other electrolyzer types in close collaboration with manufacturers

Wind2H2 Analysis Summary

- Wind classes 3-6 can produce hydrogen in the range of $3.74–$5.86/kg, unsubsidized by wind or renewable fuel tax credits.
- This does not yet meet DOE centralized or distributed production targets.
- The effect of the PTC/ITC/Treasury Grant on the cost of hydrogen is significant. $0.02/kWh = ~$1/kg drop in H_2 cost. Including these effects, the cost of hydrogen drops into the range of $2.76–$4.79/kg.
- Site viability is very dependent on the quality of the local wind resource.
- Further reductions in the cost of wind electricity and electrolyzer capital are needed to make this type of plant widely applicable.

Summary

RELEVANCE Project addresses barriers of cost, efficiency, and renewable integration.

APPROACH Project has expanded geographical region and included CSD costs.

ACCOMPLISHMENTS Project has identified needs for cost improvement of renewable electrolysis and developed an interactive site to help view and interpret results.

COLLABORATION Project has strong collaboration with industry.

FUTURE WORK Project has a clear direction for future work, if funded.