National Renewable Energy Laboratory
Innovation for Our Energy Future

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

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Project ID # PD085

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

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

MYPP Barriers Addressed

G. Cost
H. System efficiency
J. Renewable integration

Budget

- Total Project:
  - $ 200k (FY09)
  - $ 300k (FY10)
  - $ 450k (FY11)
- Analysis Share**:
  - $ 100k (FY11)

Partners

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

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

Collaborations with Industry

Information, technical support, and equipment for overall project from:

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

Wind to Hydrogen

Analysis
Part of Renewable Electrolysis
Task # PD031

Relevance

Cost

- ***Problem:*** Wind electrolysis production cost estimates.
- ***Solution:*** Analyze a variety of wind class sites to show a full range of hydrogen costs based on wind.

System efficiency

- ***Problem:*** Costs linked to both wind farm availability and electrolyzer efficiency.
- ***Solution:*** Sensitivities examine what components and factors have biggest affect on system performance and efficiency.

Renewable integration

- ***Problem:*** Optimal sizing between wind farms and electrolyzers.
- ***Solution:*** Components sized based upon hydrogen demand, wind farm size needed for hydrogen demand, and different operation scenarios.

Wind to Hydrogen

Approach

Background -Previous Cost Studies

Wind electrolysis results from H2A Production model

(1) Levene, J.I., *Economic Analysis of Hydrogen Production from Wind: Preprint. 2005, NREL: Golden, CO.*

(2) Harrison, K.W., et al., *Wind-To-Hydrogen Project: Operational Experience, Performance Testing, and Systems Integration, in NREL/TP-550-44082. 2009, NREL: Golden, CO.*

(3) Genovese, J., et al., *Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis: Independent Review. 2009, NREL: Golden, CO.*

Reference	Year	Hydrogen Cost ($/kg)
(1) H2A v1	2005	5.69
(2) H2A v2	2009	6.25
(3) H2A v2	2009	3.00

Wind2H2 Analysis Objectives

- Corroborate recent wind electrolysis cost studies using a more detailed hour-by-hour analysis
- Examine consequences of different system configuration and operation scenarios
- Initiate understanding of sizing implications between electrolyzers and wind farms
- Identify areas for further analysis and cost reduction

Wind2H2 Analysis Accomplishments

Completed initial hourly analysis of central wind electrolysis production facility (50,000 kg/day)

- Wind class 4-6 sites might produce green hydrogen for between $3.75-5.50/kg

Presented results at FCHEA conference

- Feb 14-16, 2011, Washington, DC

Technical paper (pending)

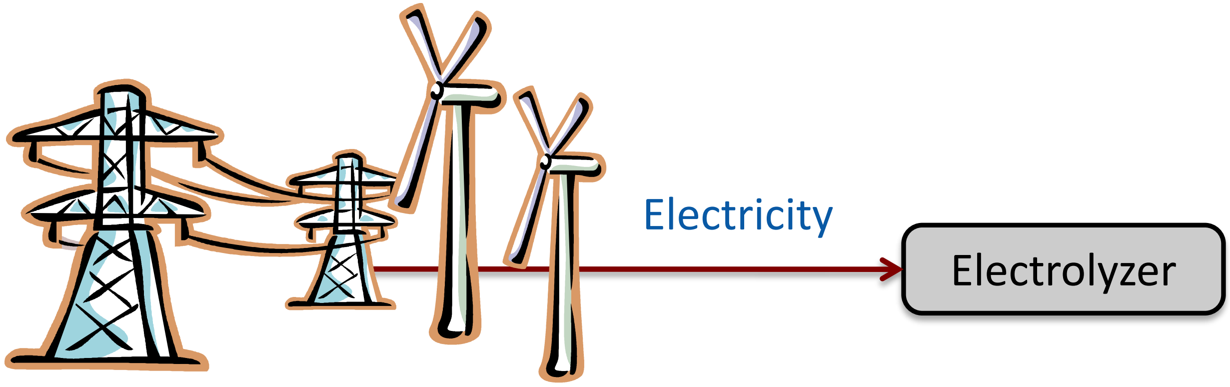
- Saur, G. and T. Ramsden, Wind Electrolysis – Hydrogen Cost Optimization. NREL/TP-5600-50408 . Golden, CO: NREL, 2011.

Current Analysis

- U.S. Department of Energy (DOE) and Xcel Energy's Wind-to-Hydrogen Project at NREL, part of the Renewable Electrolysis task

- Examination of a grid-tied, co-located wind electrolysis hydrogen production facility

- 4 scenarios optimize wind farm size vs electrolyzer requirements using hour-by-hour modeling



Key Parameters - System

8,760 hourly analysis 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

- Grid supplements wind to power electrolyzers

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

Key Parameters - Components

Electrolyzers

- Design capacity of ~51,000 kg/day with 98% capacity factor
- 106 MW electricity requirement (50 kWh/kg)
- $50.1M 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

	Low Cost	Current Cost
Installed wind turbine	$1,148/kW	$1,964/kW
O&M (incl replacement)	$0.012/kWh	$0.0074/kWh
Fixed charge rate	12.1%	12.1%

Key Parameters - Infrastructure

Grid Electricity Pricing

- 6 tiered structure; 3 summer, 3 winter
- $0.039/kWh to $0.099/kWh
- “hotter” hours = higher price

Summer rates definitions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sunday	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6
Monday	6	6	6	6	6	6	6	6	5	5	5	5	5	4	4	4	4	4	4	5	5	5	5	6
Tuesday	6	6	6	6	6	6	6	6	5	5	5	5	5	4	4	4	4	4	4	5	5	5	5	6
Wednesday	6	6	6	6	6	6	6	6	5	5	5	5	5	4	4	4	4	4	4	5	5	5	5	6
Thursday	6	6	6	6	6	6	6	6	5	5	5	5	5	4	4	4	4	4	4	5	5	5	5	6
Friday	6	6	6	6	6	6	6	6	5	5	5	5	5	4	4	4	4	4	4	5	5	5	5	6
Saturday	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6

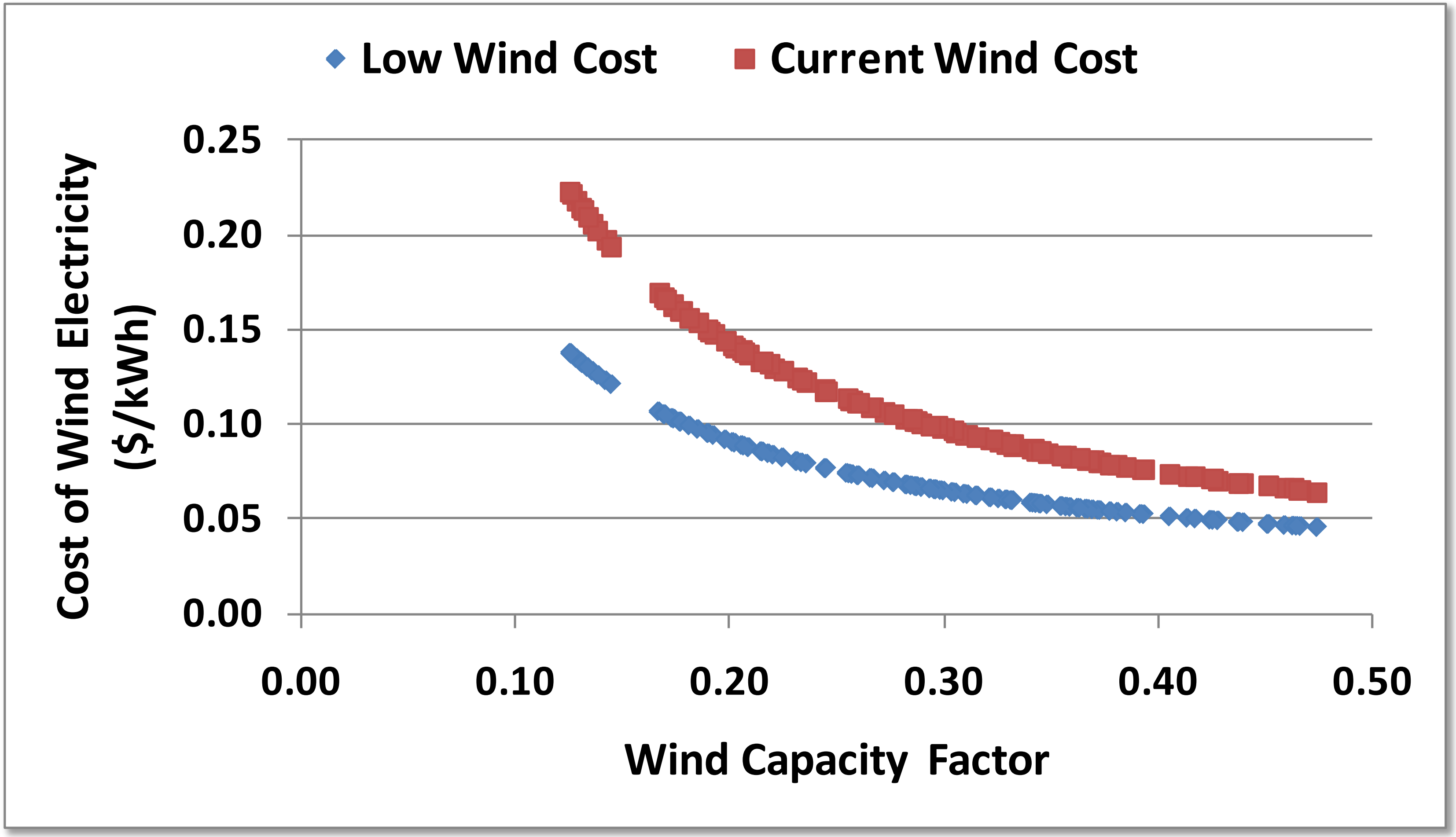
Hour

Winter rates definitions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sunday	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	2	2
Monday	3	3	3	3	3	2	2	2	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	3
Tuesday	3	3	3	3	3	2	2	2	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	3
Wednesday	3	3	3	3	3	2	2	2	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	3
Thursday	3	3	3	3	3	2	2	2	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	3
Friday	3	3	3	3	3	2	2	2	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	3
Saturday	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	2	2

Key Parameters - Infrastructure

Wind Profiles

- NREL's Western Wind data set
- 136 sites in California, class 1 to class 6

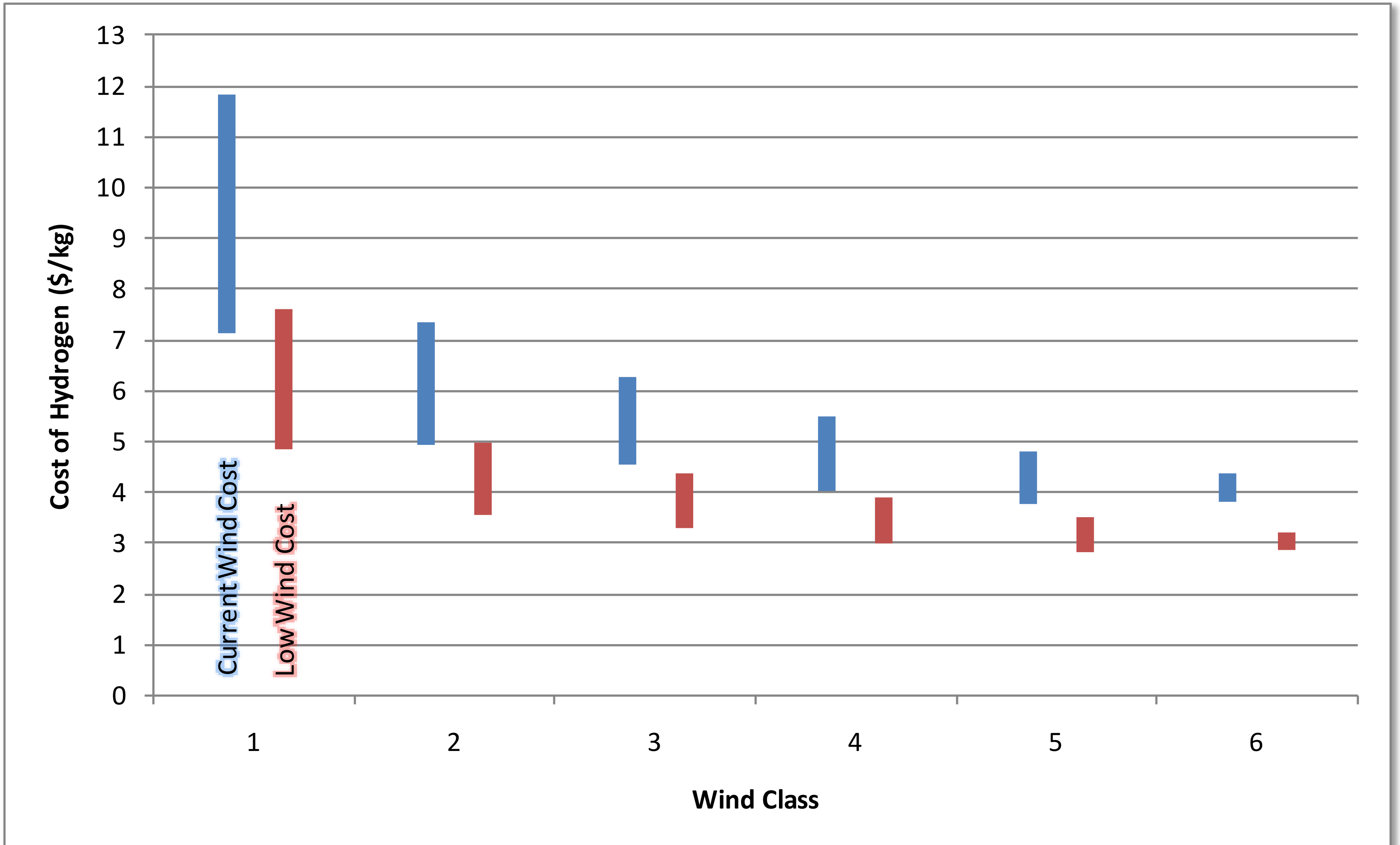


Wind to Hydrogen

Accomplishments and Results

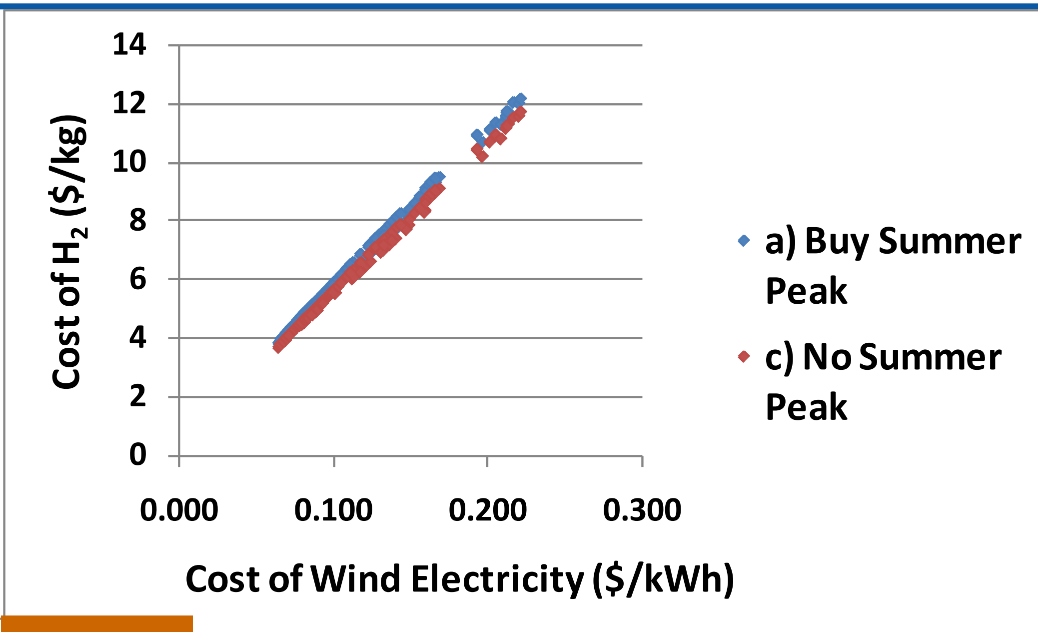
Results - Comparison

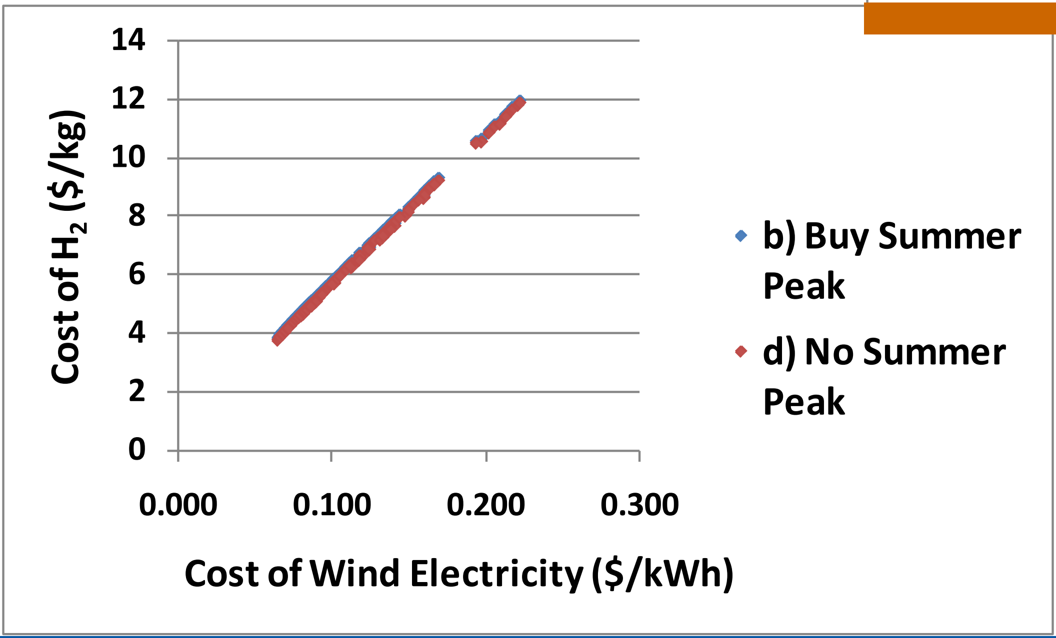
Power Balanced Scenario – range of costs



Results – Current Wind Costs

Cost Balanced Scenarios

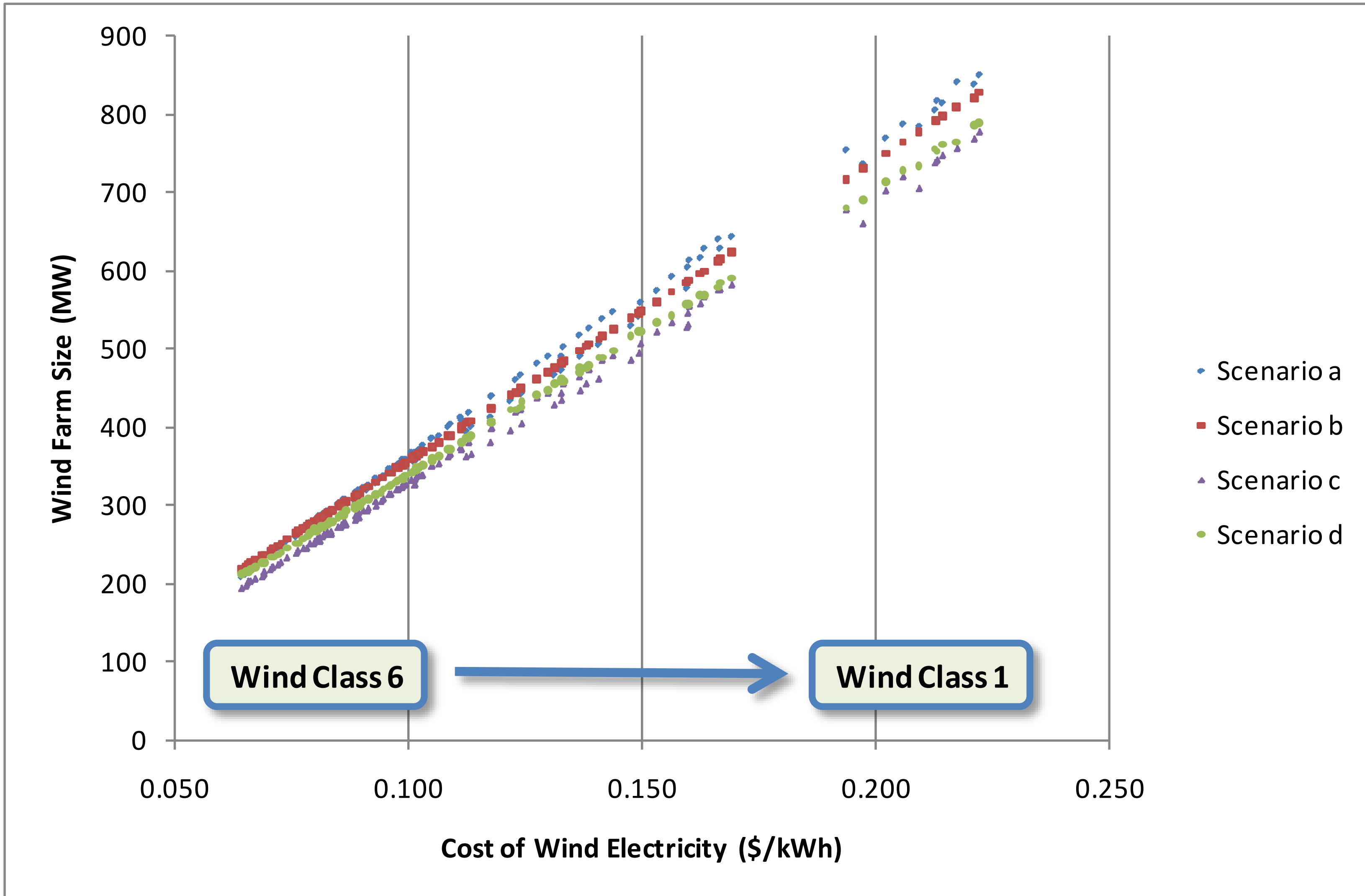




Power Balanced Scenarios

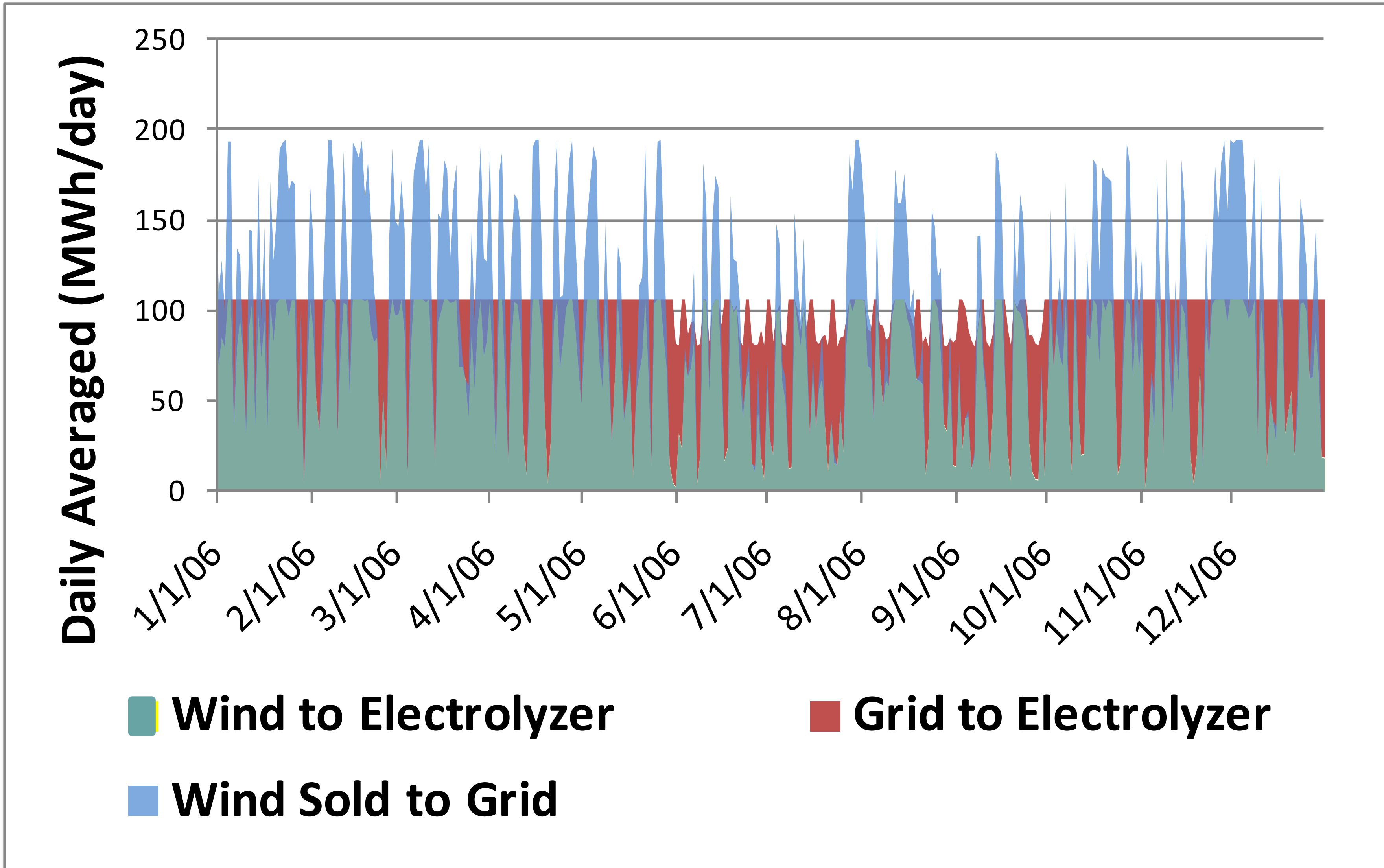
Results – Scenario Details

Wind Farm Sizes to Produce 50,000 kg/day H2



Results – Case Example

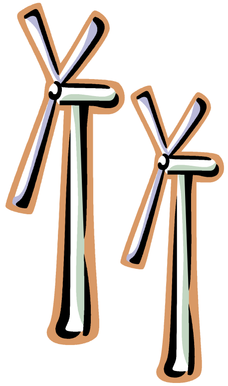
Averaged Yearly Profile



Results – Case Example

Wind Site Details

- Class 5 wind site with capacity factor 47%
- Average wind speed at 100 m 8.5 m/s
- Produces electricity for $0.064/kWh

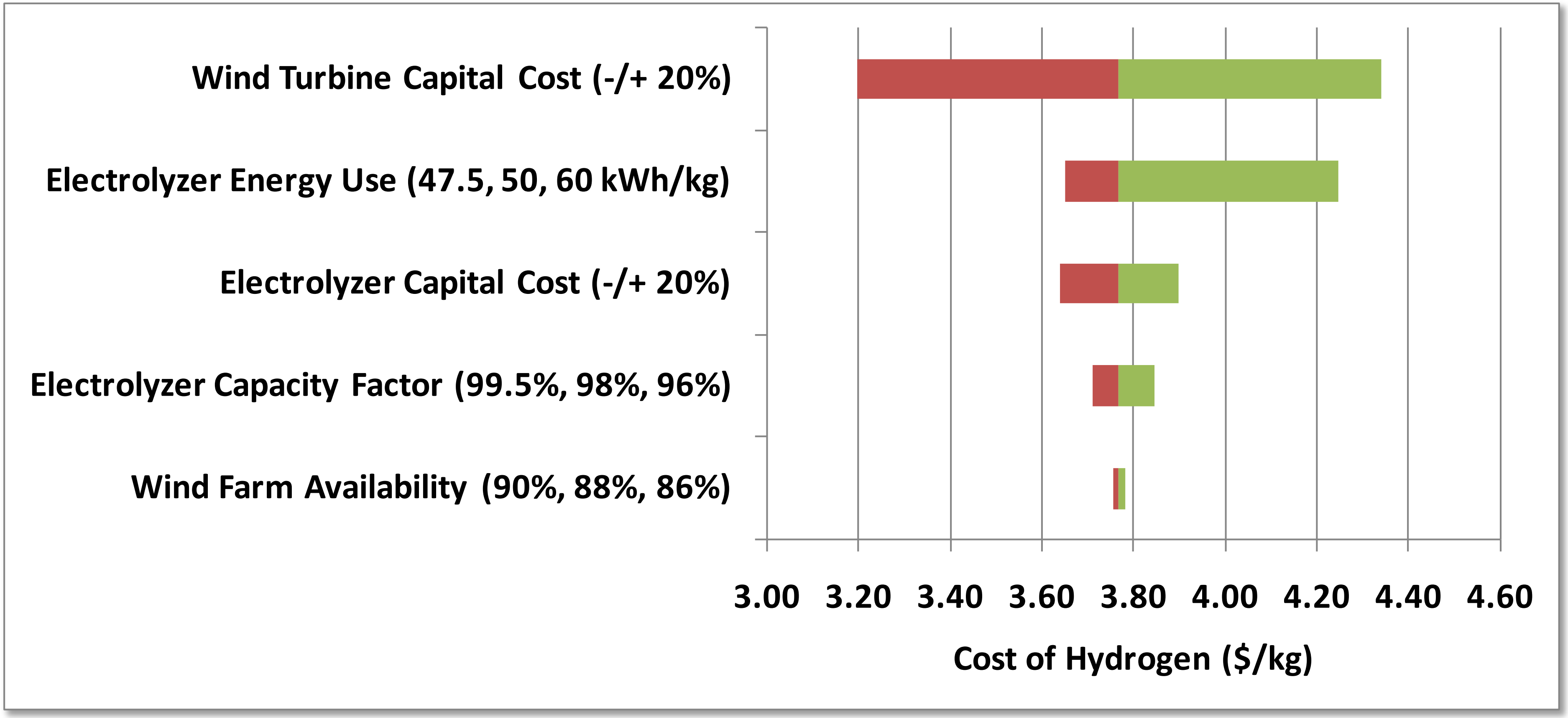


Scenario	Wind Farm Size (MW)	# 3-MW Turbines	Grid Utilization (%)	Unmet H2 Production (kg/yr)	Cost of H2 ($/kg)
(a) Cost-Balanced—Buy Summer Peak	210	70	94	0	3.80
(b) Power-Balanced—Buy Summer Peak	219	73	102	0	3.82
(c) Cost-Balanced— No Summer Peak	195	65	100	622,000	3.72
(d) Power-Balanced—No Summer Peak	213	71	120	602,000	3.77

Results – Case Sensitivity

Sensitivity for power balanced case

- Baseline optimization and sizing held constant
- Other scenarios show similar ranges

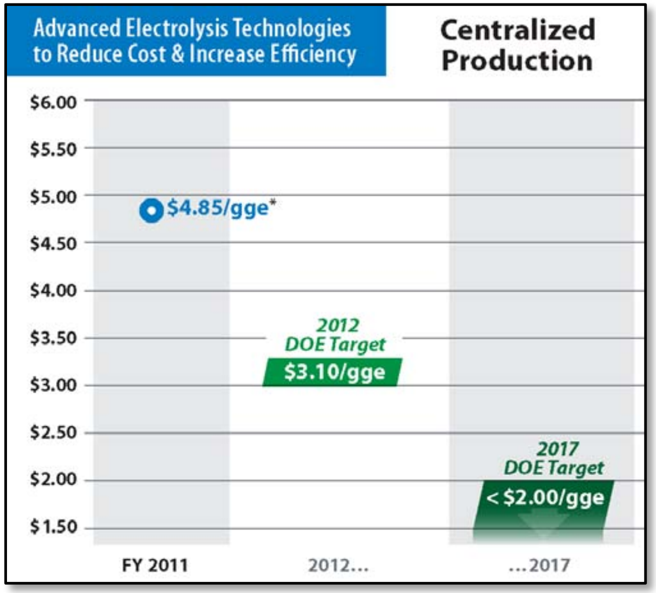


Analysis – Proposed Future Work

- More sensitivities to various inputs possibly including grid pricing, wind farm size, PTC
- Use of curtailed wind
- Uses of different bulk storage technologies
- Year-to-year wind variation uncertainty
- Regionally expanded grid pricing structures
- Examination of solar integration
- Smaller or forecourt sized renewable electrolysis
- Other optimal electricity/hydrogen production balance scenarios.

Wind2H2 Analysis Summary

- Using current wind costs hydrogen could be produced at some class 4-6 wind sites for $3.75-5.50/kg.
- Less ideal wind sites should be considered if they are closer to demand centers; reduced delivery cost may offset increased production cost.



** Average cost is for Class 4 Wind Resource Cost differs with quality of wind resources.*

- There are trade-offs for buying or not buying summer peak electricity – lower hydrogen cost but some unmet hydrogen demand.
- Including hydrogen production at wind sites may increase flexibility of system and have other beneficial consequences.