122 West

Economic Analysis of Bulk Hydrogen Storage for Renewable Utility Applications

Susan M. Schoenung
susan.schoenung@sbcglobal.net
Longitude 122 West, Inc.
10 May 2011

Project ID #
MT-009

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

Overview

Timeline

- Project start date: May 2010
- Project end date: Nov 2011
- Percent complete: 70%

Barriers

- Non-technical barriers to commercializing hydrogen and fuel cells *(per Pete Devlin March 9, 2011)*

Budget

- Total project funding
  - DOE share: $85K
  - Contractor share: $0
- Funding received in FY10: $85K
- Funding for FY11: $ TBD

Partners

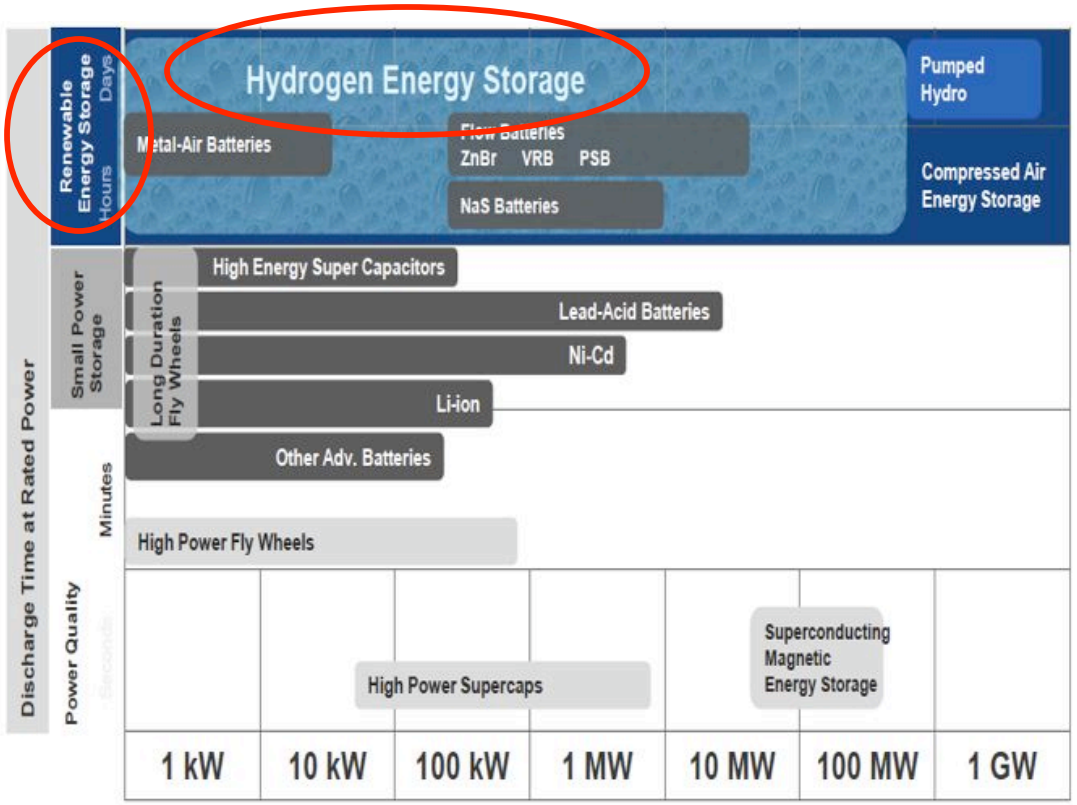
- Lead: Longitude 122 West
- Collaborator: Sandia National Laboratories

Accelerate the commercialization and deployment of fuel cells

Relevance - Objectives

- Address the market for large-scale storage of hydrogen & hydrogen technologies
- Enable greater penetration of clean renewable energy production

- Accelerate the commercialization and deployment of fuel cells

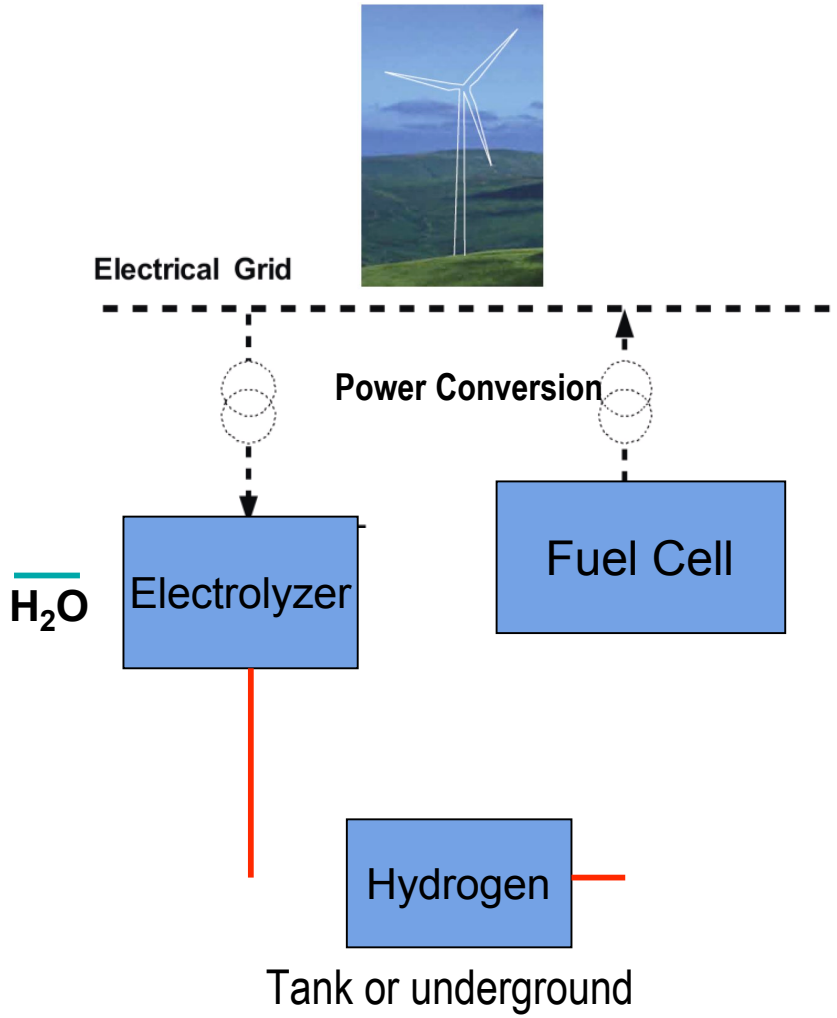


Facilitate the adoption of fuel cells across government and industry.

122 West

Approach - Activities / Milestones

Activity	Status
Update utility energy storage model to include purchase of curtailed wind energy	*Complete*
Update costs for fuel cell & hydrogen systems and other storage technologies and compare	*Complete*
Perform sensitivity analyses	*Complete*
Establish utility / renewables business case	*Complete*
Make benefit / cost estimates and draft business model	*In progress*



Step-wise approach to set up business model

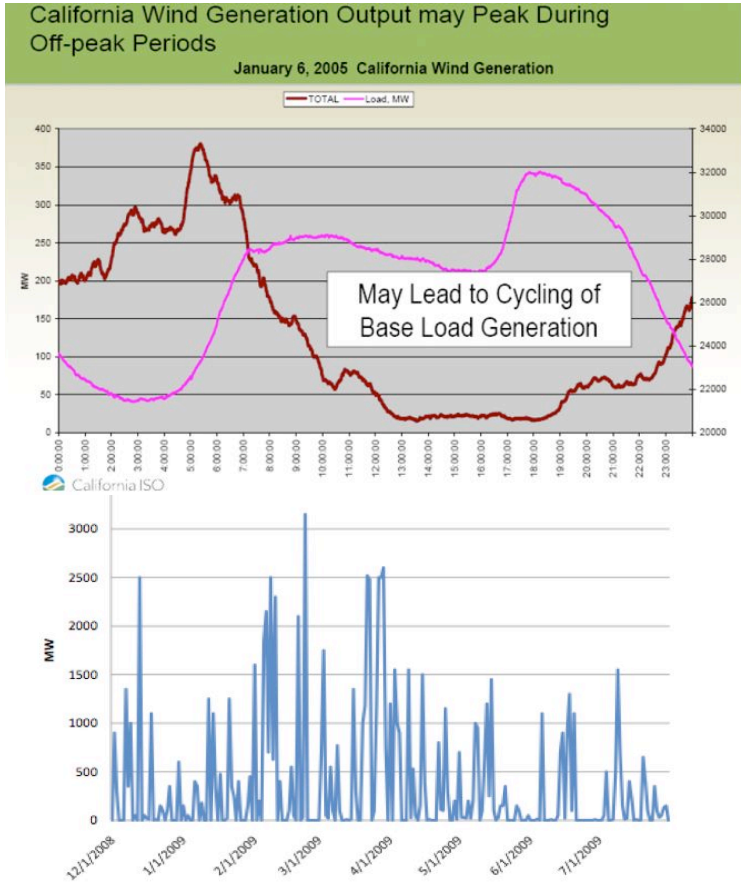
Approach - Lifecycle cost analysis

- Capital cost
  - -Electrolyzer
  - -Storage
  - -Fuel cells
- Annualized life-cycle cost
  - -Capital
  - -O&M
  - -Replacements
  - -Electricity
- Present value cost
  - -20 year life
  - •Duty cycle
  - -7 days/wk

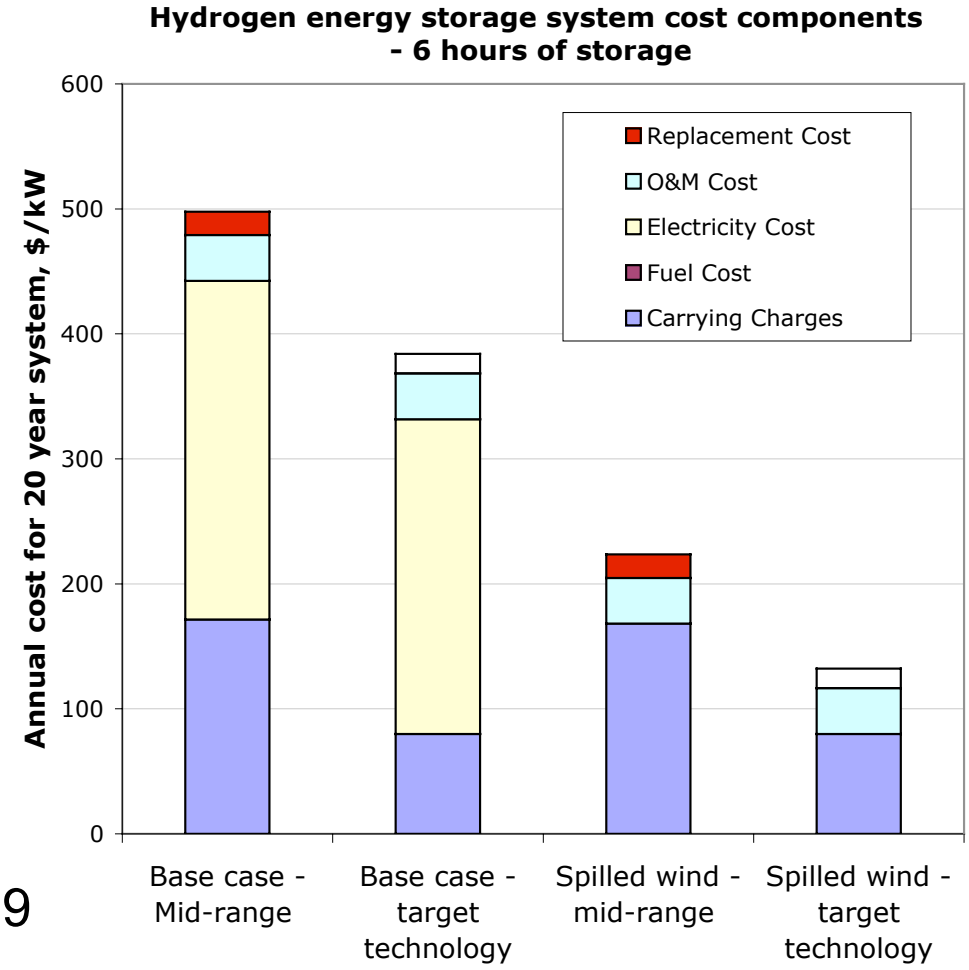
	Current efficiency	Target efficiency	Mid-range cost	Target cost	Reference
Electrolyzer	73%	75%	340 $/kW	125 $/kW	NREL, DOE2010
Gas storage	NA	NA	15 $/kWh	9 $/kWh	MYPP-Delivery
Underground storage	NA	NA	0.3 $/kWh	0.3 $/kWh	H2A, Lord
Fuel cell	55%	58%	700 $/kW	434 $/kW	NREL

Analysis builds on extensive expertise in energy storage and hydrogen. Analysis consistent with DOE MYPP and other lab studies.

Technical Accomplishments (1)
Update cost model for utility energy storage

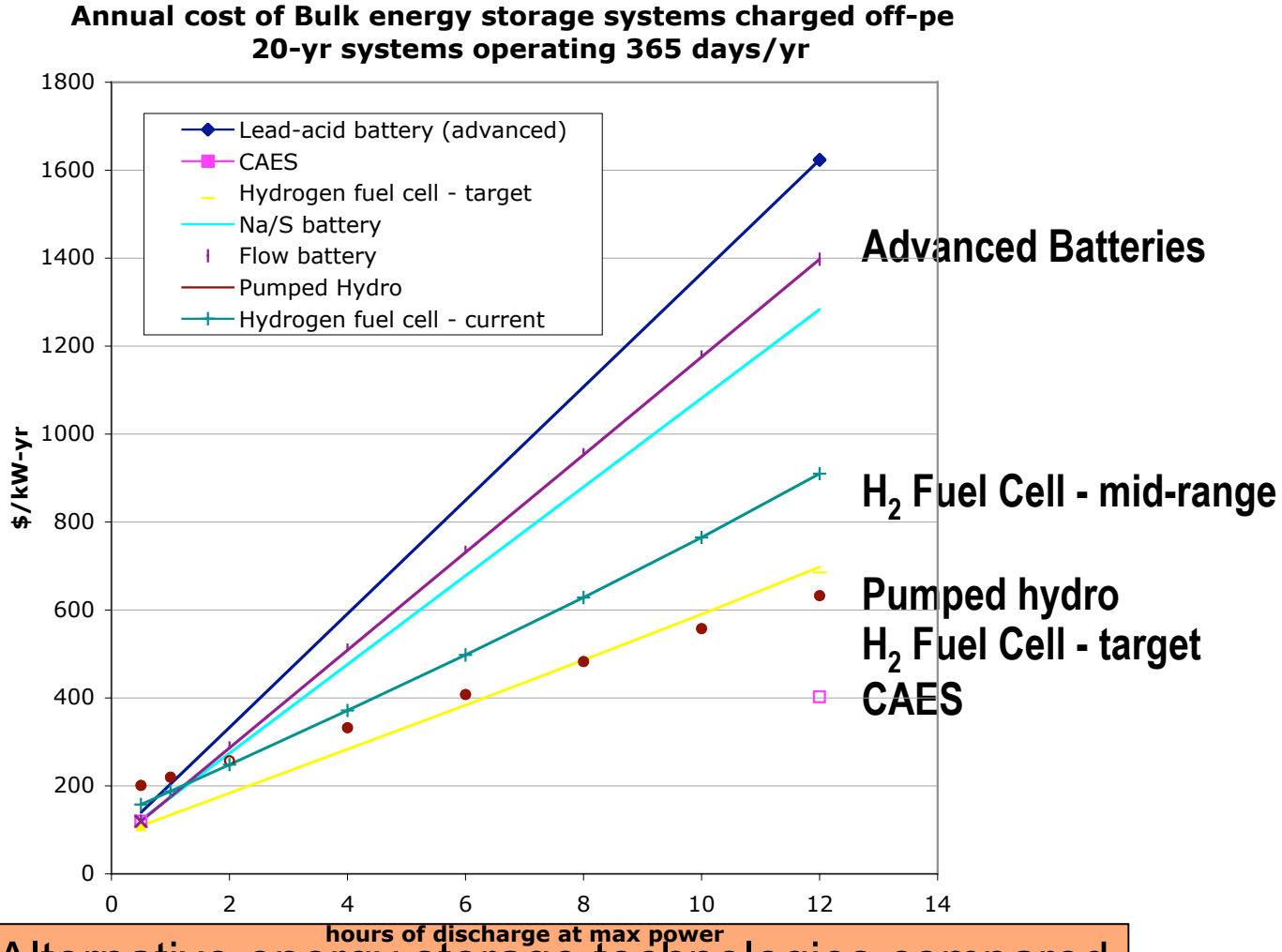


MWs of curtailed wind, TX, 2009



Model addresses storage system size and hours of operation

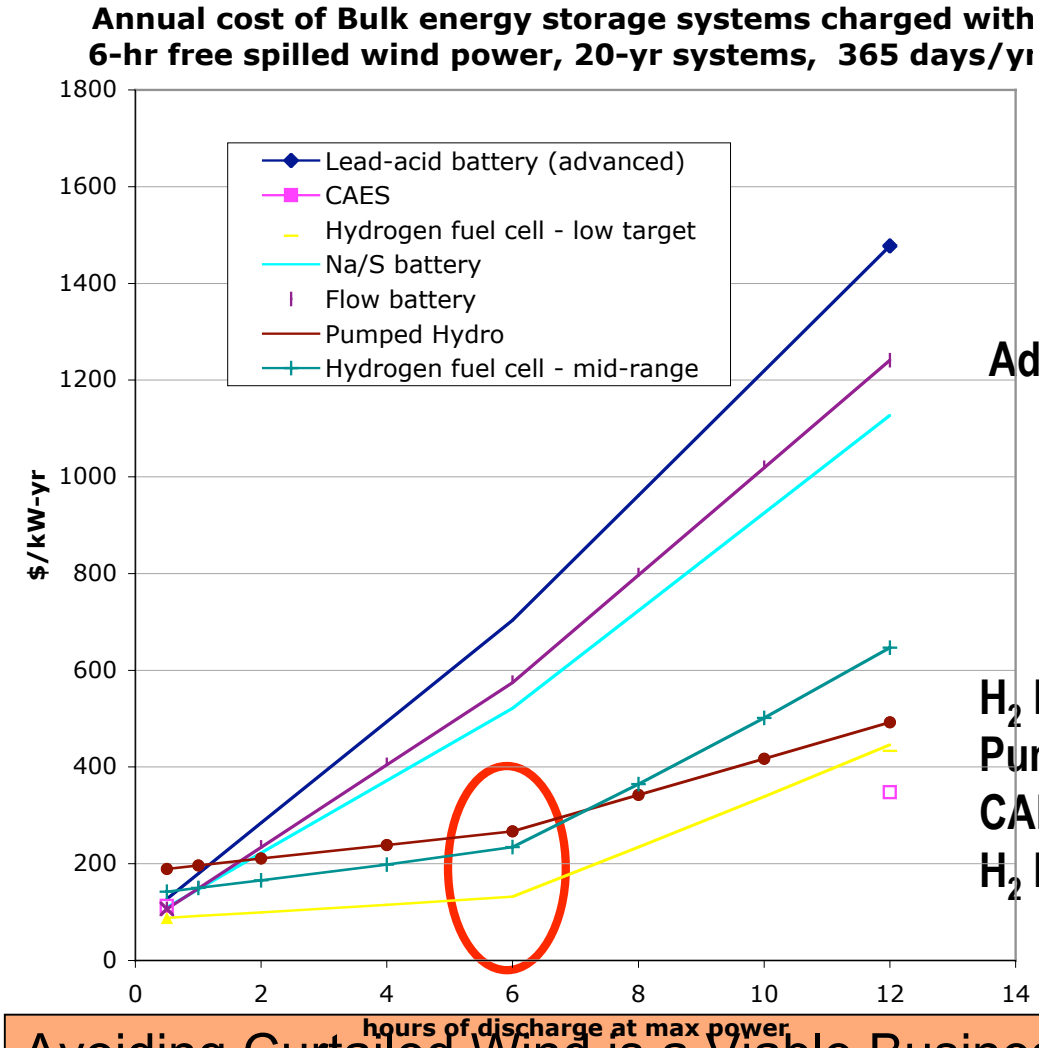
Technical Accomplishments (2)
Update technology costs and compare



Alternative energy storage technologies compared

122 West

Technical Accomplishments (3)
Establish business case based on curtailed wind



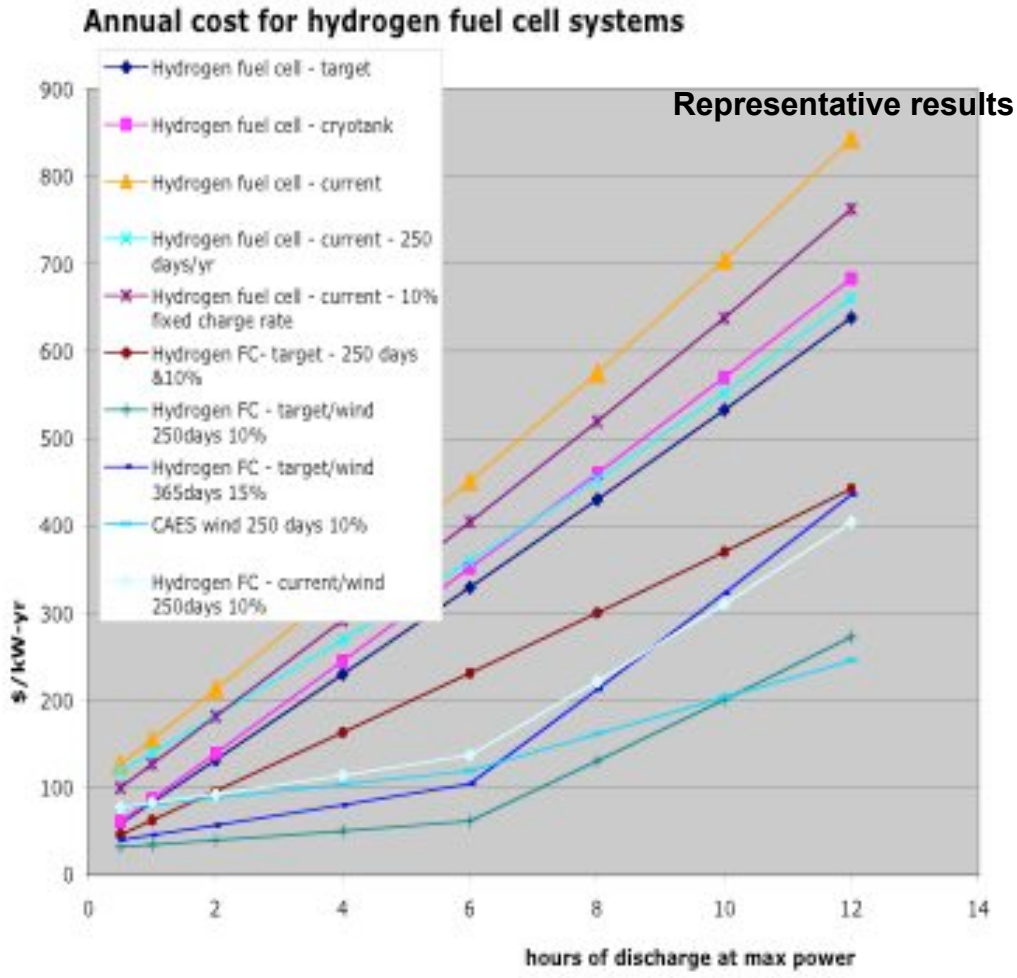
Advanced Batteries

H_2 Fuel Cell - mid-range
Pumped hydro
CAES
H_2 Fuel Cell - target

Avoiding Curtailed Wind is a Viable Business Case

122 West

Technical Accomplishments (4)
Perform sensitivity analysis

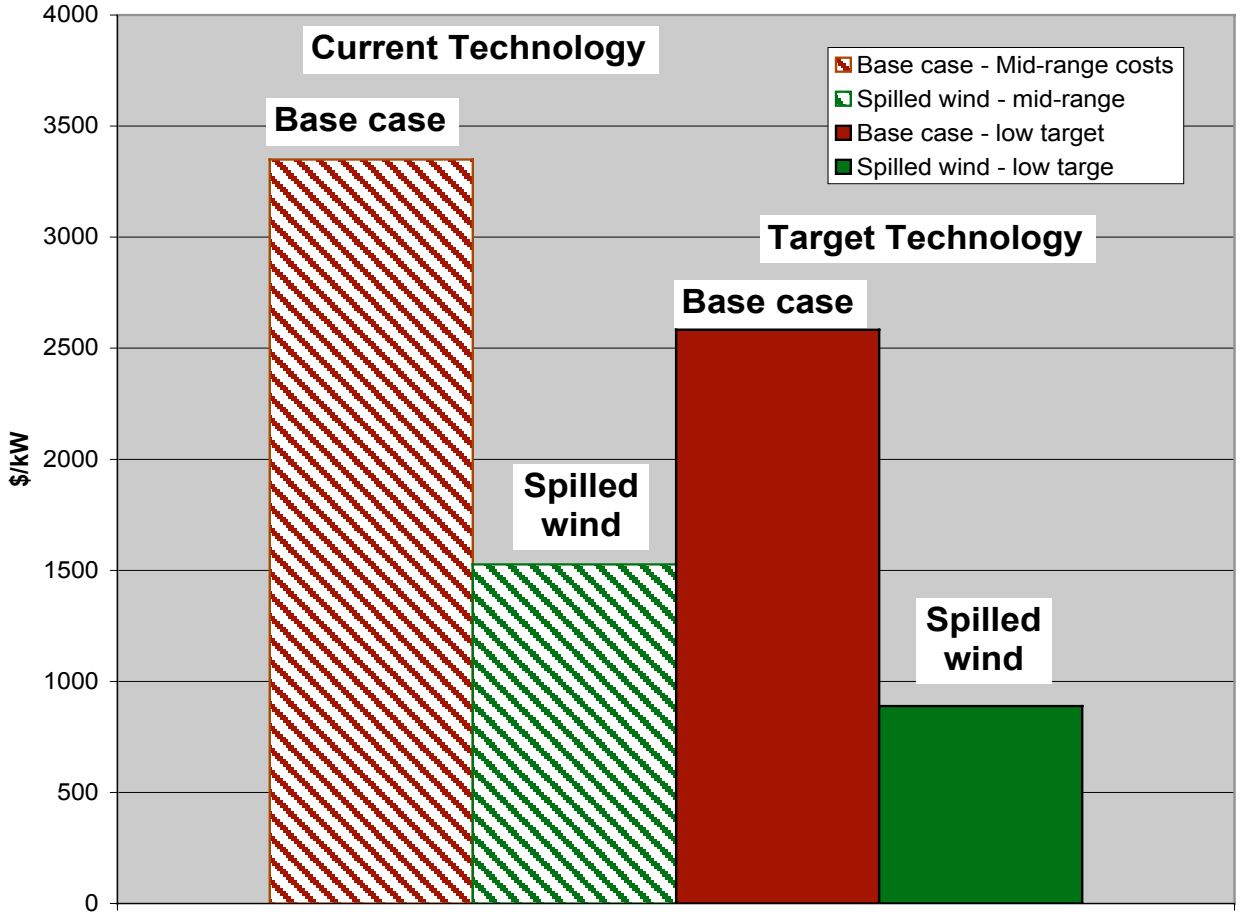


Results are sensitive to operational & economic assumptions

122 West

Technical Accomplishments (5)
Perform sensitivity analysis for business case

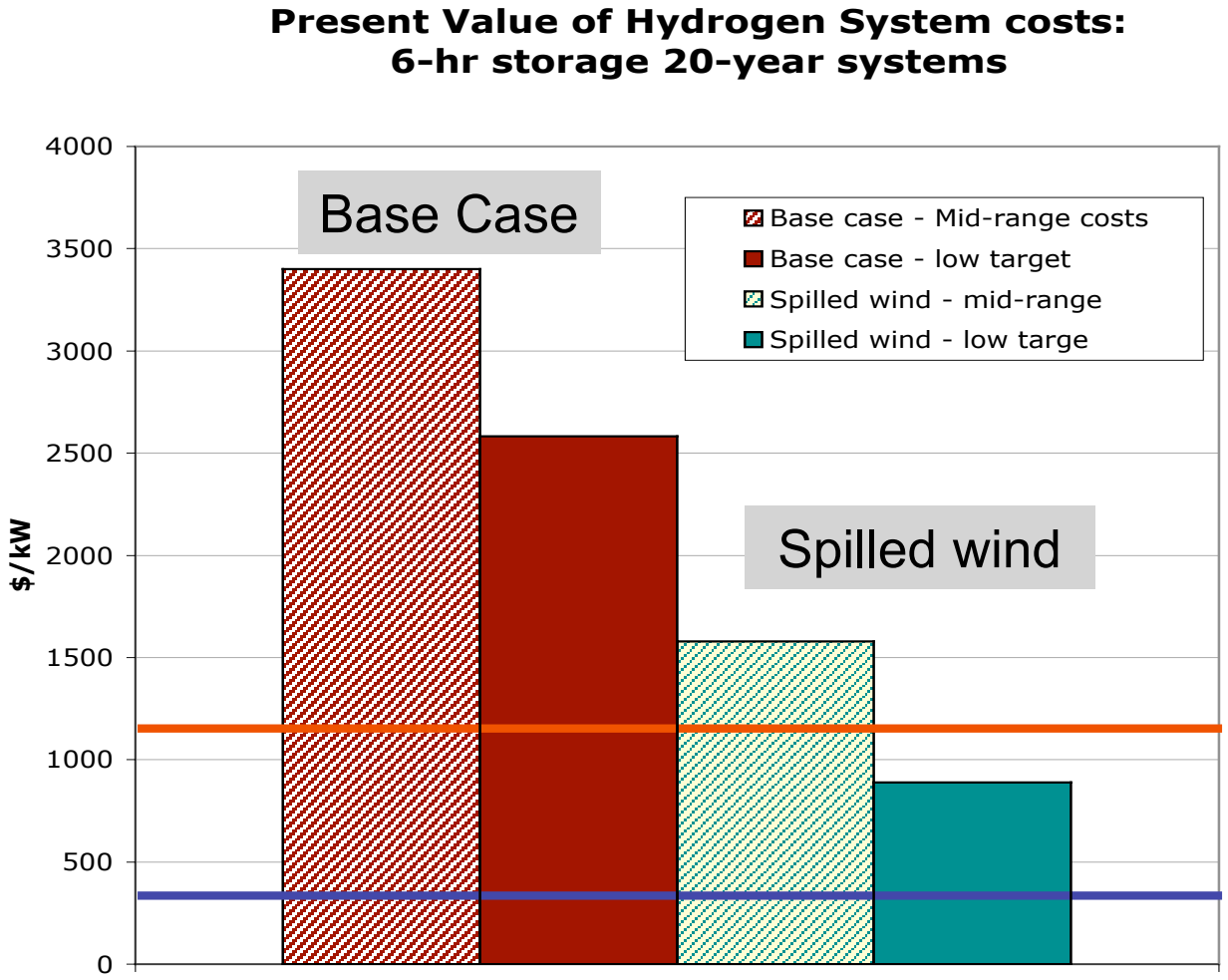
Present value of 20 yr costs for 6-hr hydrogen storage system with wind



Hydrogen storage results are sensitive to current and target costs and applications

122 West

Technical Accomplishments (6)
Benefit / cost analysis on $/kW basis*



Benefits ($/kW)*

Additional value of capacity credit

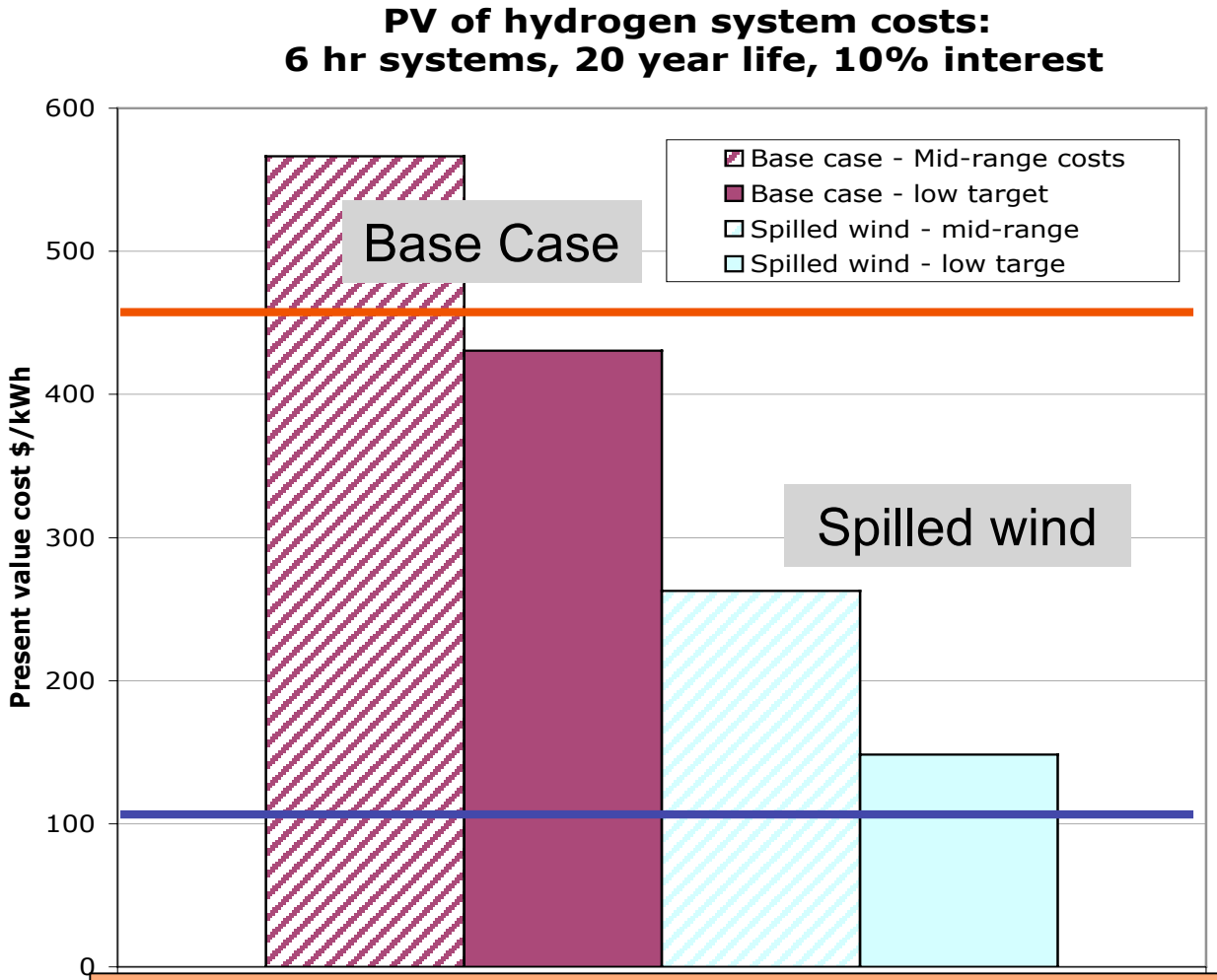
Value of wind energy time-shift

*SNL

The Benefit / Cost ratio is Attractive for Curtailed Wind

122 West

Technical Accomplishments (7)
Benefit / cost analysis on $/kWh basis**



Benefits ($/kWh)**

Additional value of local capacity credit

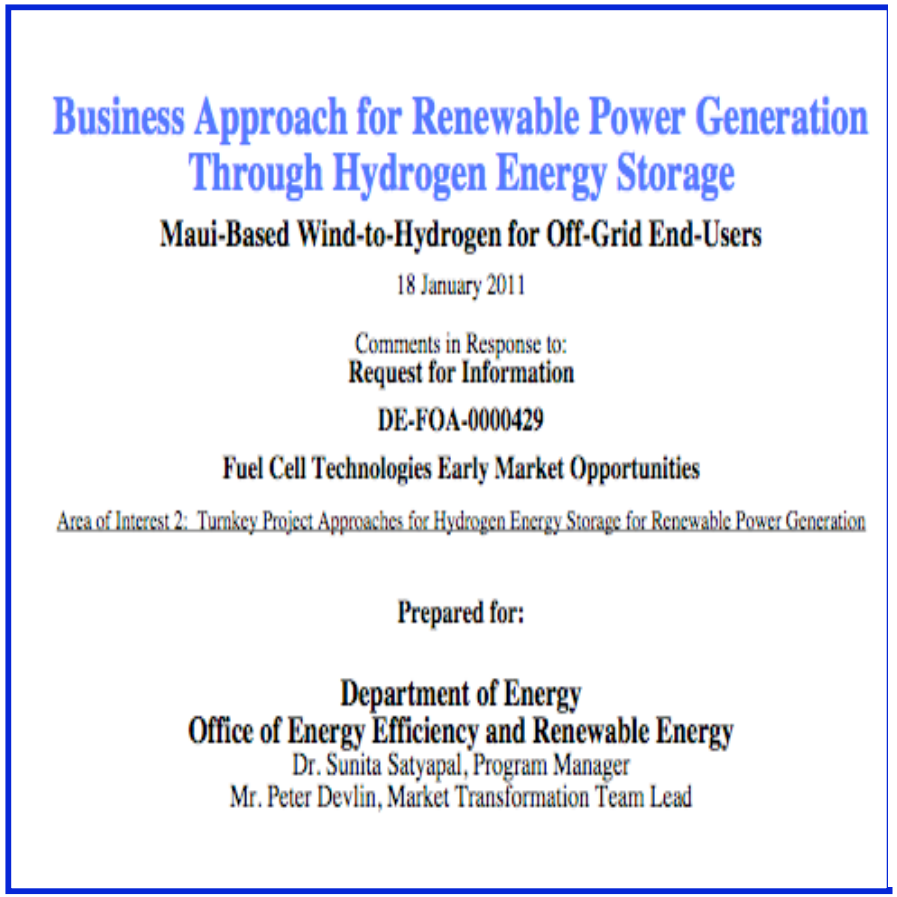
Value of renewables integration

** EPRI

The Benefit / Cost ratio is even more Attractive on an energy basis

122 West

Business model / market analysis (In Progress)



Business Approach for Renewable Power Generation Through Hydrogen Energy Storage

Maui-Based Wind-to-Hydrogen for Off-Grid End-Users

18 January 2011

Comments in Response to:
Request for Information

DE-FOA-0000429

Fuel Cell Technologies Early Market Opportunities

Area of Interest 2: Turnkey Project Approaches for Hydrogen Energy Storage for Renewable Power Generation

Prepared for:

Department of Energy
Office of Energy Efficiency and Renewable Energy
Dr. Sunita Satyapal, Program Manager
Mr. Peter Devlin, Market Transformation Team Lead

		Benefit ($/kW)**		Potential (MW, 10 Years)		Economy ($Million)†	
#	Benefit Type	Low	High	CA	U.S.	CA	U.S.
1	Electric Energy Time-shift	400	700	1,445	18,417	795	10,129
2	Electric Supply Capacity	359	710	1,445	18,417	772	9,838
3	Load Following	600	1,000	2,889	36,834	2,312	29,467
4	Area Regulation	785	2,010	80	1,012	112	1,415
5	Electric Supply Reserve Capacity	57	225	636	5,986	90	844
6	Voltage Support	400		722	9,209	433	5,525
7	Transmission Support	192		1,084	13,813	208	2,646
8	Transmission Congestion Relief	31	141	2,889	36,834	248	3,168
9.1	T&D Upgrade Deferral 50th percentile††	481	687	386	4,986	226	2,912
9.2	T&D Upgrade Deferral 90th percentile††	759	1,079	77	997	71	916
10	Substation On-site Power	1,800	3,000	20	250	47	600
11	Time-of-use Energy Cost Management	1,226		5,038	64,228	6,177	78,743
12	Demand Charge Management	582		2,519	32,111	1,466	18,695
13	Electric Service Reliability	359	978	722	9,209	483	6,154
14	Electric Service Power Quality	359	978	722	9,209	483	6,154
15	Renewables Energy Time-shift	233	389	2,889	36,834	899	11,455
16	Renewables Capacity Firming	709	915	2,889	36,834	2,346	29,909
17.1	Wind Generation Grid Integration, Short Duration	500	1,000	181	2,302	135	1,727
17.2	Wind Generation Grid Integration, Long Duration	100	782	1,445	18,417	637	8,122

Matching the business model and market potential

Collaborations

- Sandia National Laboratories
  - Collaborator on geologic cost estimates
- Austin Energy
  - Utility company with excess wind resources - informal advisor
- Schafer Corporation
  - Industry with industry clients needing innovative energy solutions - informal partner
- Hydrogen Utility Group (HUG)
  - Reports to HTAC - exchanging data on opportunities for grid storage, preparing hydrogen energy storage model
- Hydrogenics

  - Industrial provider of large-scale electrolyzers - interested party

Utilities and industry are interested in this opportunity

Proposed Future Work

FY11

- Complete benefit / cost analysis; market potential framework
- Finish report

FY12

- Add **scaling** considerations to utility business model, considering spectrum of value propositions
- Add **location** considerations to cost and benefit analysis
- Build **third-party** (non-utility) opportunities business model
- Continue discussions and deliberations with **commercial** interests, market potential

Detailed considerations and discussions are needed

Summary

- **Relevance:** Market growth for hydrogen technology
- **Approach:** Benefit / cost analysis for hydrogen to enable penetration of dispatchable renewables
- **Technical accomplishments**
  - Model and database updates for cost analysis
  - Comparisons with other large-scale energy storage
  - Sensitivity, focusing on DOE target costs
  - Benefit / cost analysis of viable business case
  - Fostering commercial conversations
- **Collaborations / contacts**
  - Within the DOE fuel cell program: SNL, Hydrogen Utility Group
  - External / commercial contacts: Austin Energy, Schafer Corp., Hydrogenics, Ballard, Next Hydrogen, Nebraska Public Power
- **Proposed future work:** Additional real-world considerations for market development

This work is on schedule and meeting objectives

Technical Back-Up Slides

Capital Cost

122 West

Capital Cost = Cost of Power equipment + Cost of storage

$Cost_{total}(\$) = Cost_{pcs}(\$) + [Cost_{storage}(\$) + Cost_{Bop}(\$)]$

$E_{storage}(kWh) = Power(kW) \times time\ (hr)$

$Cost_{total}(\$) = [P(kW) \times Cost_{pcs}(\$/kW)] + [Cost_{storage+BOP}\ (\$/kWh) \times time\ (hr) \times Power(kW)]$

$Cost_{total}(\$/kW) = Cost_{pcs}(\$/kW) + Cost_{storage+BOP}\ (\$/kWh) \times time\ (hr)$

Total Cost = Cost of hydrogen tanks or reservoir + Cost of electrolyzer + cost of fuel cell + balance of plant

Annual Life-cycle and Present Value Costs

Levelized annual cost ($/kw-yr)

= Cost of capital (carrying charge on initial purchase)
+ cost of fixed O&M
+ cost of variable O&M
+ annualized replacement costs
+ consumables (fuel and electricity)

Business case parameters

Storage charging	6 hours
Storage discharging	Min 6 hrs
Cost of charging electricity	0.00 $ / kWh for 6 hrs
Cost of charging electricity	0.05 $ / kWh thereafter
Days of operation per year	365
Cost of natural gas (for CAES)	5 $/ BTU

Present Value Calculation:

$$PV = F_0 / (1 + i)^0 + F_1 / (1 + i)^1 + F_2 /(1 + i)^2 + ... + F_n /(1 + i)^n$$

Economic parameters

System lifetime	20 years
Capital charge rate	15%
Discount rate	10%
Inflation rate	2%

Storage Benefits Analysis

122 West

SANDIA REPORT
SAND2010-0815
Unlimited Release
Printed February 2010

Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide

A Study for the DOE Energy Storage Systems Program

Jim Eyer

Garth Corey

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

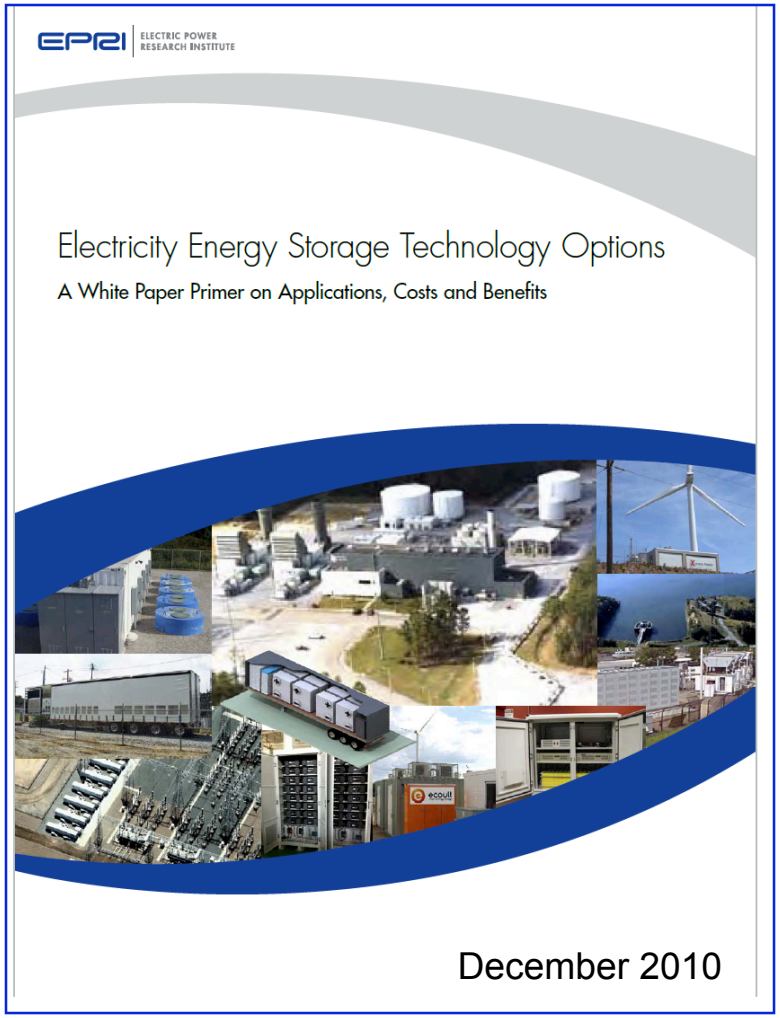
Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Sandia National Laboratories

#	Benefit Type	Benefit ($/kW)** Low	High
1	Electric Energy Time-shift	400	700
2	Electric Supply Capacity	359	710
3	Load Following	600	1,000
4	Area Regulation	785	2,010
5	Electric Supply Reserve Capacity	57	225
6	Voltage Support	400	
7	Transmission Support	192	
8	Transmission Congestion Relief	31	141
9.1	T&D Upgrade Deferral 50th percentile††	481	687
9.2	T&D Upgrade Deferral 90th percentile††	759	1,079
10	Substation On-site Power	,800	3,000
11	Time-of-use Energy Cost Management	1,226	
12	Demand Charge Management	582	
13	Electric Service Reliability	359	978
14	Electric Service Power Quality	359	978
15	Renewables Energy Time-shift	233	389
16	Renewables Capacity Firming	709	915
17.1	Wind Generation Grid Integration, Short Duration	500	1,000
17.2	Wind Generation Grid Integration, Long Duration	100	782

Storage Benefits Analysis

122 West



			PV $/kW-h	
Value Chain	**Benefit**		**Target**	**High**
End User	1	Power Quality	19	96
	2	Power Reliability	47	234
	3	Retail TOU Energy Charges	377	1,887
	4	Retail Demand Charges	142	708
Distribution	5	Voltage Support	9	45
	6	Defer Distribution Investment	157	783
	7	Distribution Losses	3	15
Transmission	8	VAR Support	4	22
	9	Transmission Congestion	38	191
	10	Transmission Access Charges	134	670
	11	Defer Transmission Investment	414	2,068
System	12	Local Capacity	350	1,750
	13	System Capacity	44	220
	14	Renewable Energy Integration	104	520
ISO Markets	15	Fast Regulation (1 hr)	1,152	1,705
	16	Regulation (1 hr)	514	761
	17	Regulation (15 min)	4,084	6,845
	18	Spinning Reserves	80	400
	19	Non-Spinning Reserves	6	30
	20	Black Start	28	140
	21	Price Arbitrage	67	335

Note: each benefit is modeled in isolation using a consistent battery configuration of capacity and 2 MWh of energy storage capacity, with a 15-year life and a 10% disco

Publications and Presentations

- Eyer and Schoenung, “A comprehensive survey of utility-related storage: value propositions and technology,” Electric Utility Consultants, Inc., *Electricity Storage: Business and Policy Drivers Conference*, 24-25 January 2011, Houston, TX

- Schoenung, “Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications,” *International Colloquium on Environmentally Preferred Advanced Generation*, sponsored by the National Fuel Cell Research Center, 8-10 February, 2011, Costa Mesa,CA

- Schoenung, “Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications,” *International Conference on Sustainable Energy Storage*, 22-24 February, 2011, Belfast, UK

- SNL (SAND) Report - in process

Presentations well received by industry, utility and academic communities