

# **Economic Analysis of Bulk Hydrogen Storage for Renewable Utility Applications**

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Longitude 122 West, Inc.  
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Project ID #  
MT009

# Overview

## Timeline

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

## Budget

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

## Barriers

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

## Partners

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

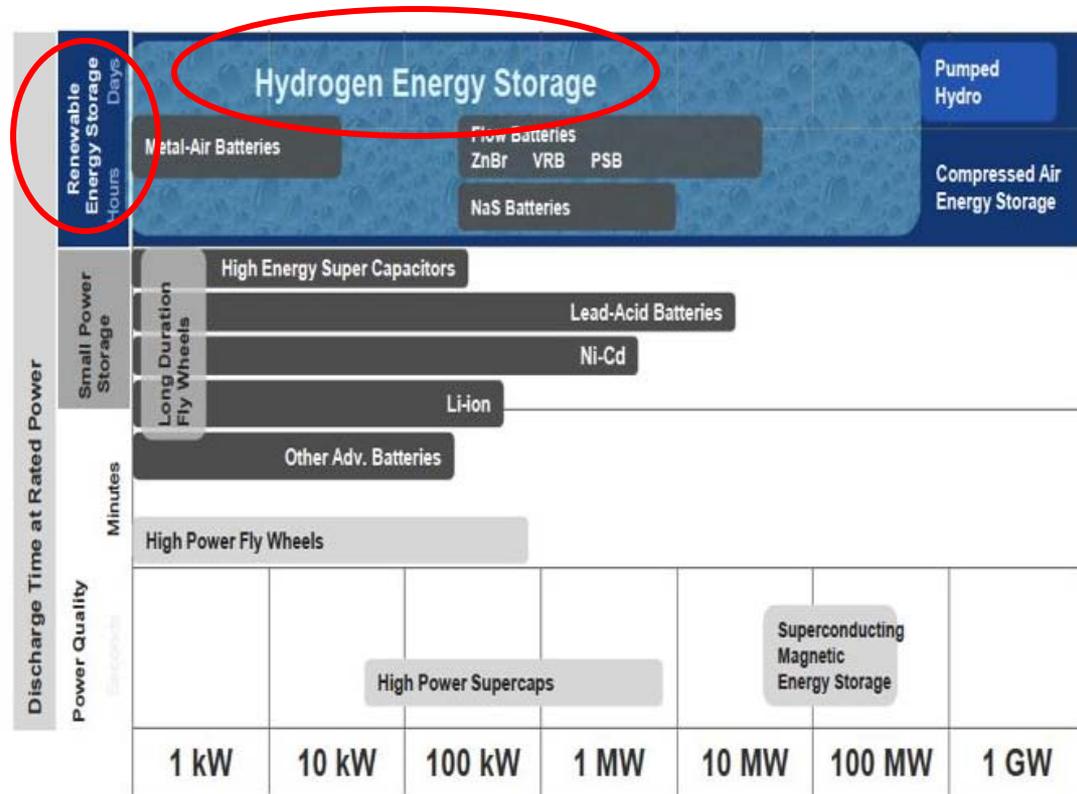
Accelerate the commercialization and deployment of fuel cells

# Relevance - Objectives

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



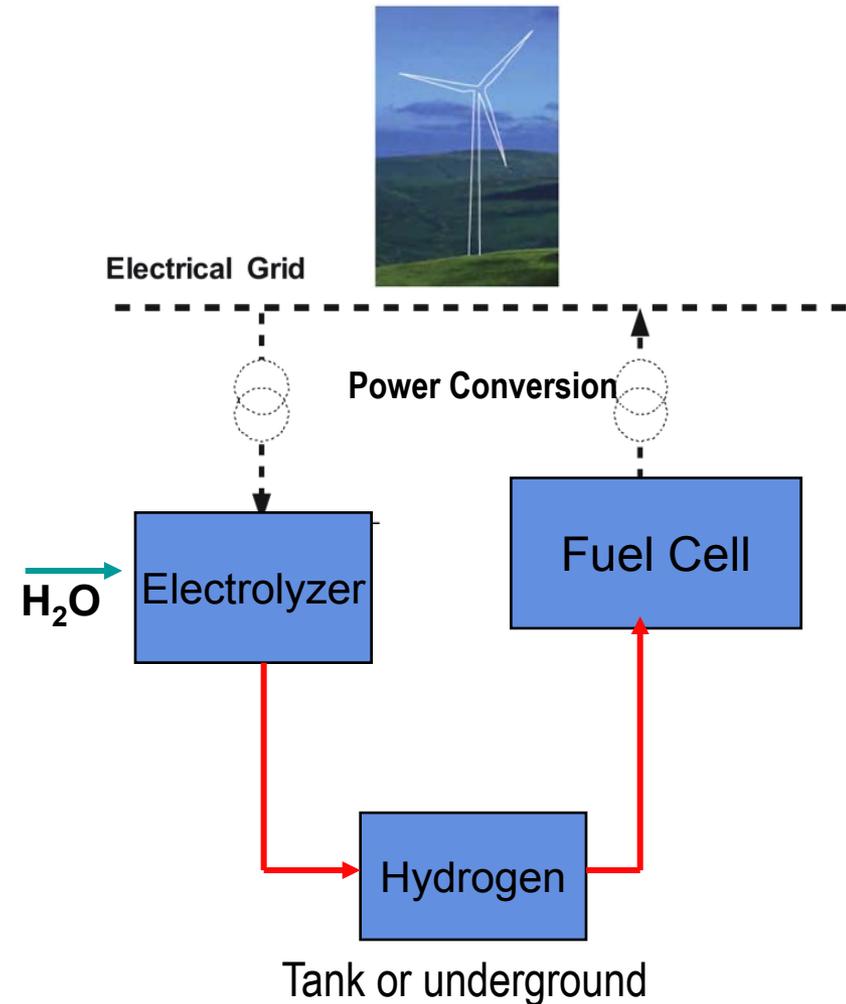
- Accelerate the commercialization and deployment of fuel cells



Facilitate the adoption of fuel cells across government and industry.

# Approach - Activities / Milestones

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



Step-wise approach to set up business model

# Approach - Lifecycle cost analysis

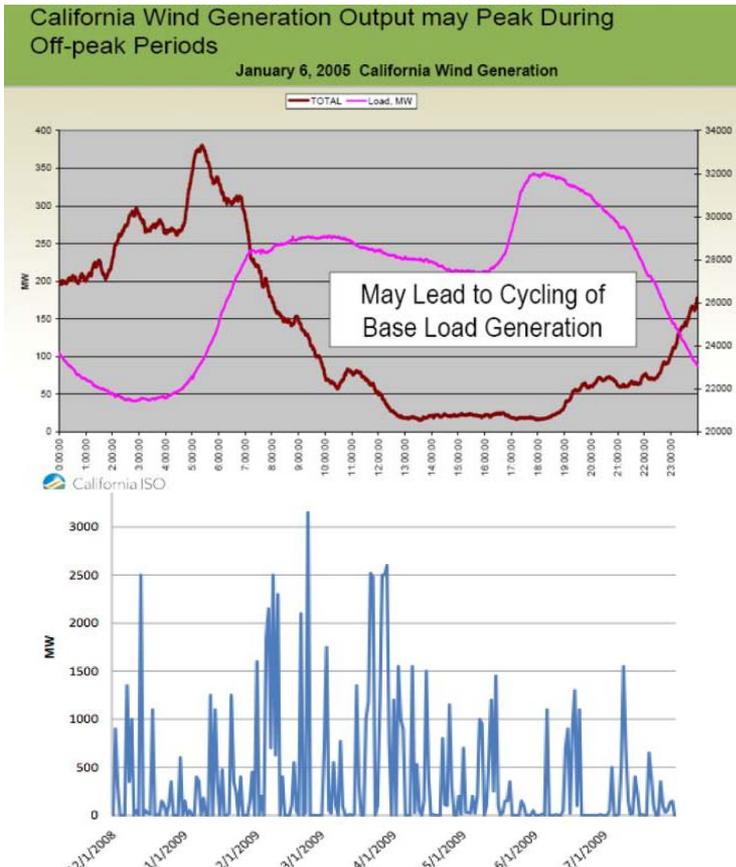
- Capital cost
  - Electrolyzer
  - Storage
  - Fuel cells
- Annualized life-cycle cost
  - Capital
  - O&M
  - Replacements
  - Electricity
- Present value cost
  - 20 year life
  - Duty cycle
  - 7 days/wk

	Current efficiency	Target efficiency	Current cost	Target cost	Reference
<b>Electrolyzer</b>	58%	59%	340 \$/kW	125 \$/kW	NREL, MYPP
<b>Gas storage</b>	NA	NA	15 \$/kWh	2.5 \$/kWh	MYPP
<b>Underground storage</b>	NA	NA	0.3 \$/kWh	0.3 \$/kWh	H2A, Lord
<b>Fuel cell</b>	73.50%	75%	500 \$/kW	100 \$/kW	MYPP

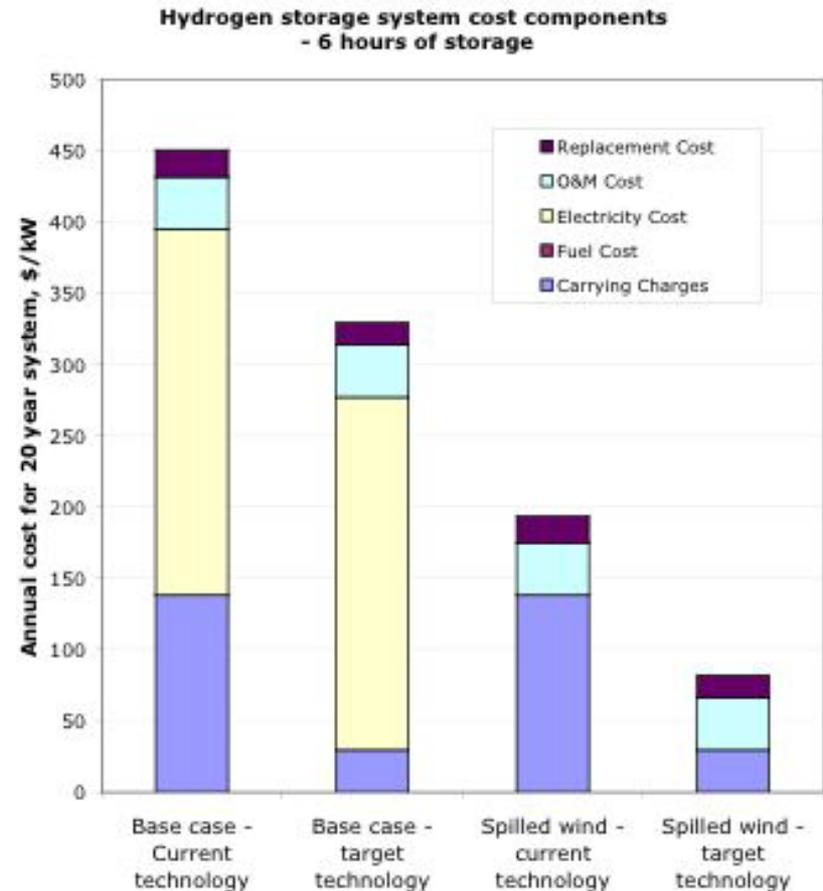
Analysis builds on extensive expertise in energy storage and hydrogen.  
 Analysis consistent with DOE MYPP and other lab studies.

# Technical Accomplishments (1)

## Update cost model for utility energy storage



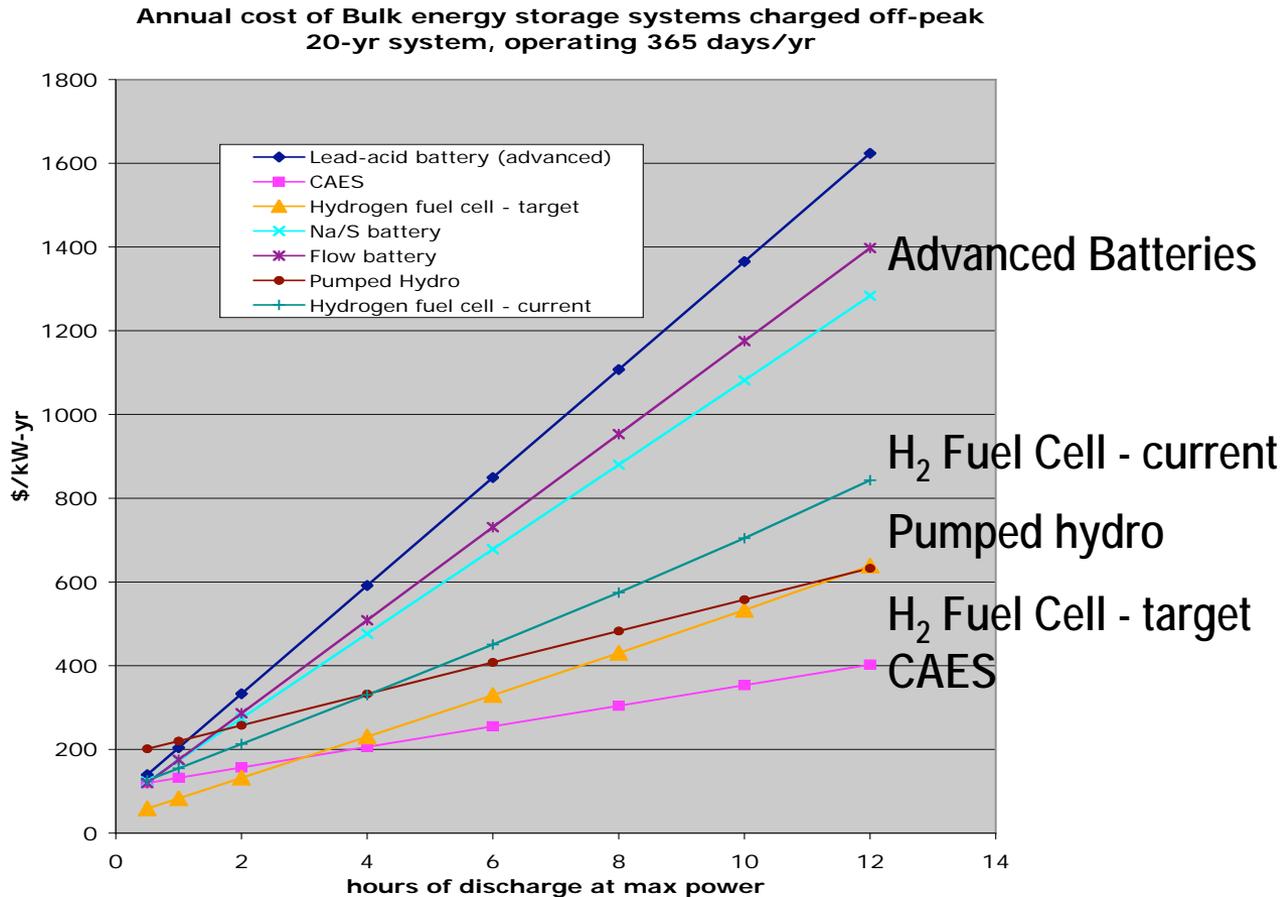
MWs of curtailed wind, TX, 2009



Model addresses storage system size and hours of operation

# Technical Accomplishments (2)

## Update technology costs and compare

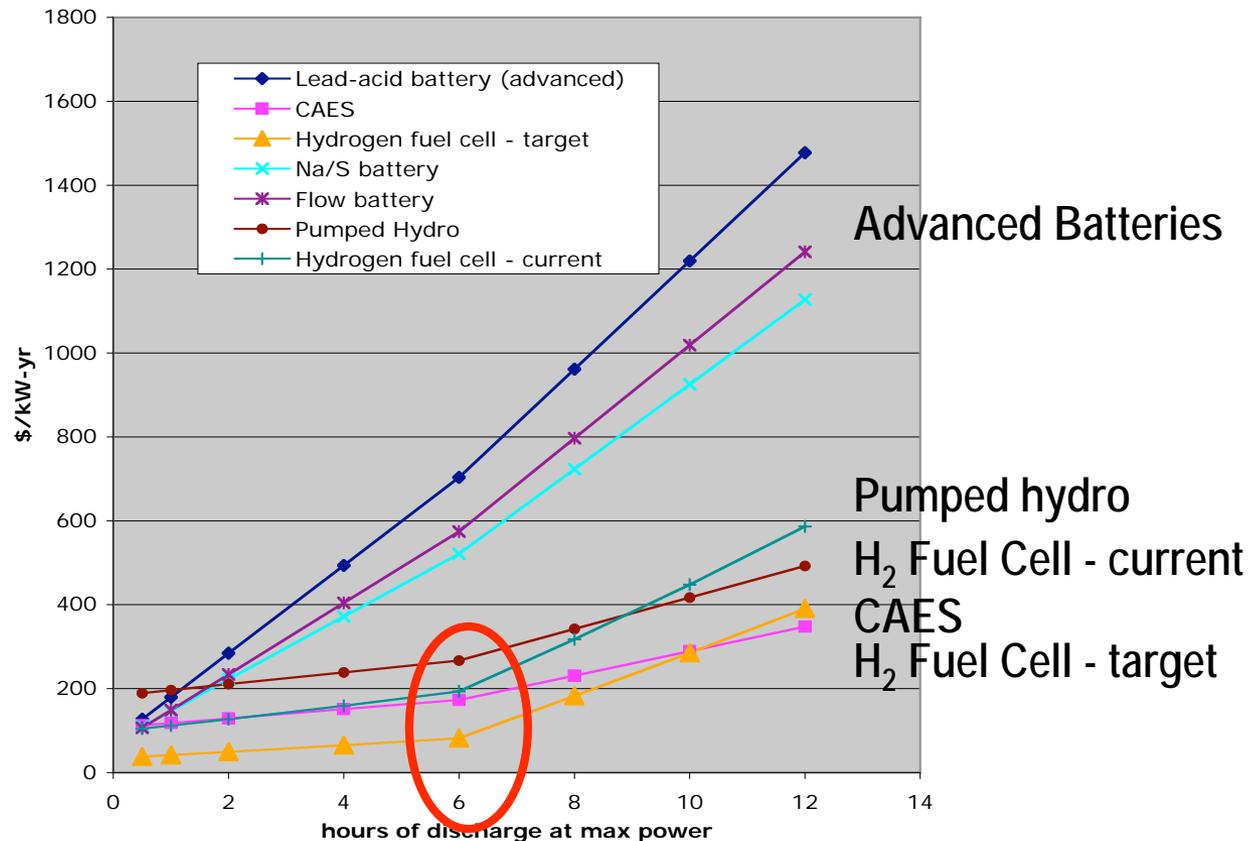


Alternative energy storage technologies compared

# Technical Accomplishments (3)

## Establish business case based on curtailed wind

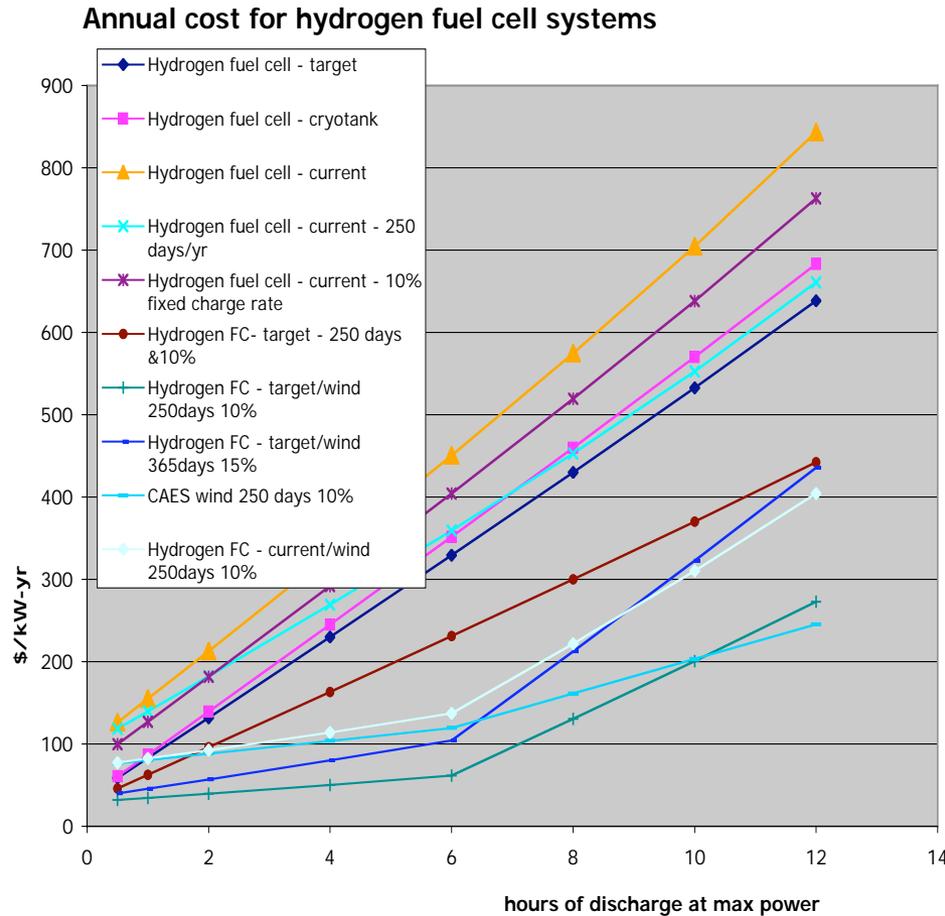
Annual cost of Bulk energy storage systems charged with 6-hr free spilled wind power, 20-yr systems, 365 days/yr



Avoiding Curtailed Wind is a Viable Business Case

# Technical Accomplishments (4)

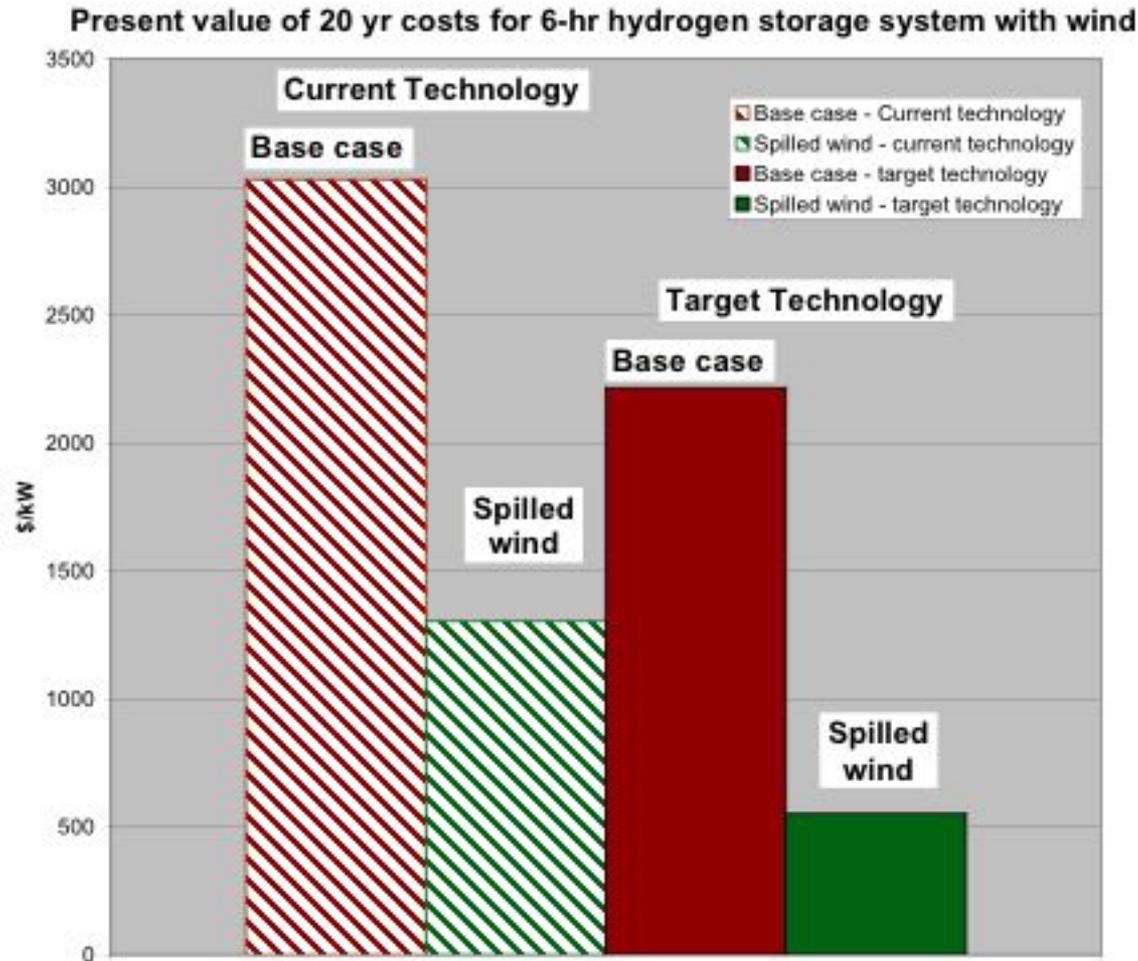
## Perform sensitivity analysis



Results are sensitive to operational & economic assumptions

# Technical Accomplishments (5)

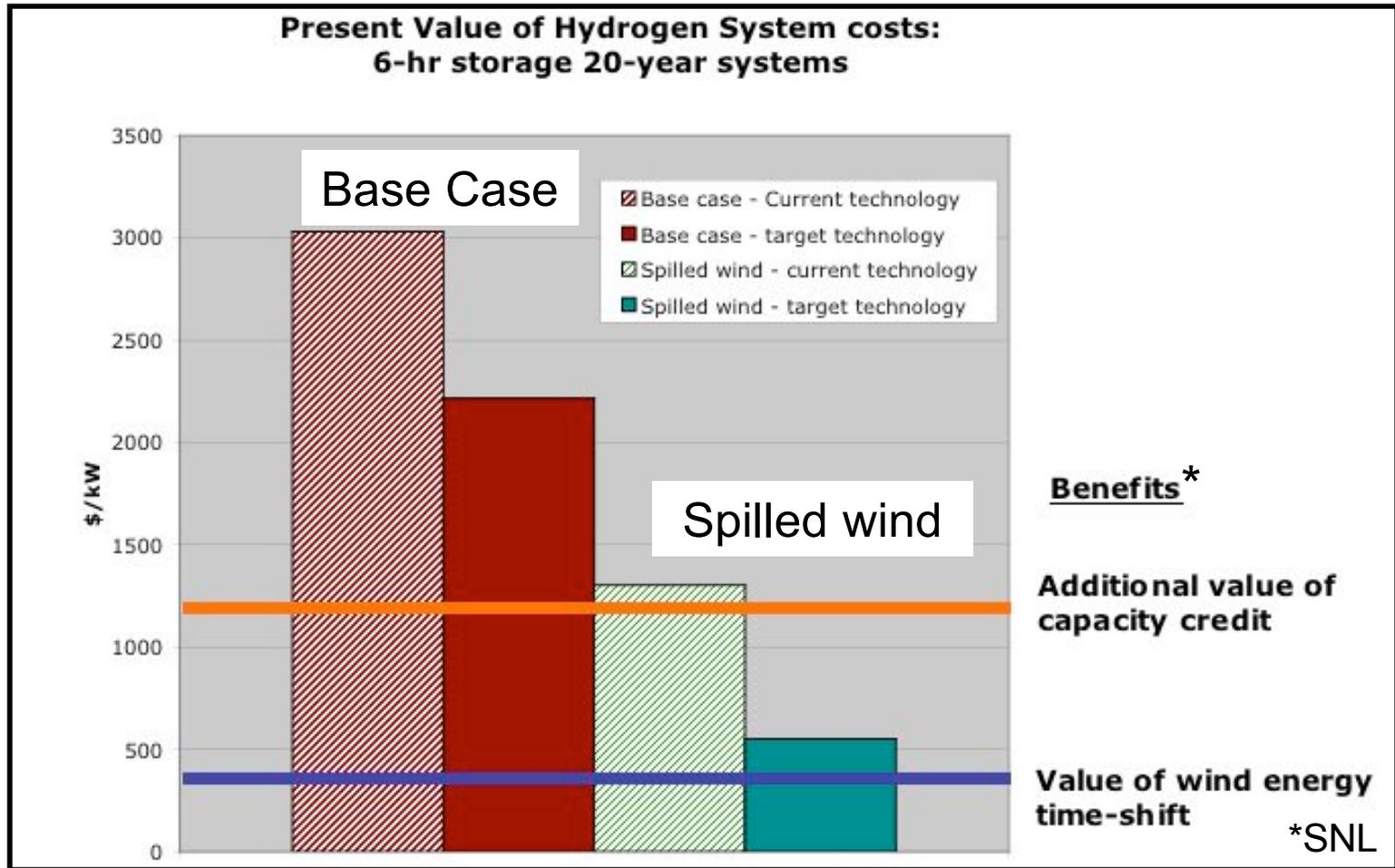
## Perform sensitivity analysis for business case



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

# Technical Accomplishments (6)

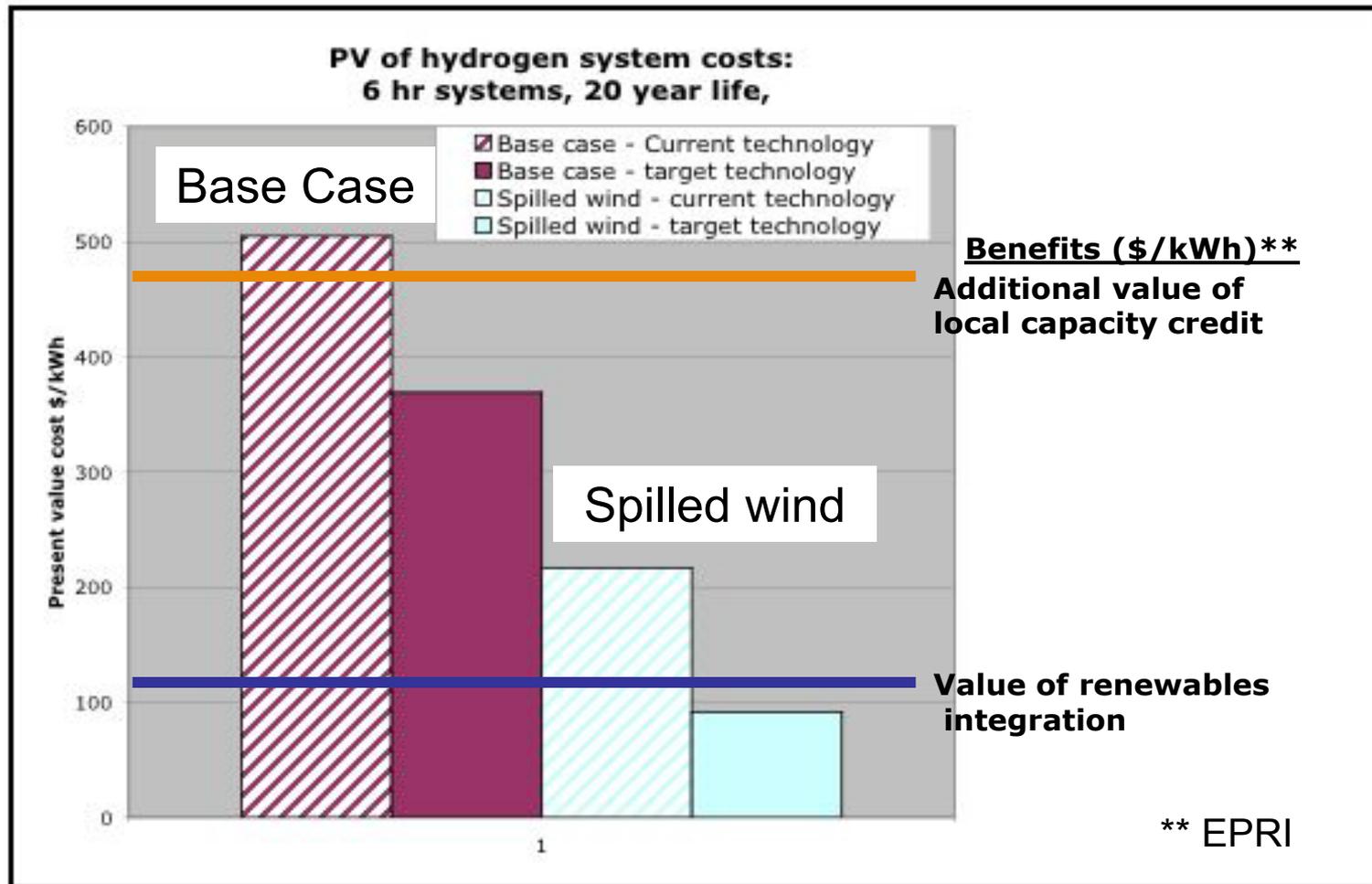
## Benefit / cost analysis on \$/kW basis\*



The Benefit / Cost ratio is Attractive for Curtailed Wind

# Technical Accomplishments (7)

## Benefit / cost analysis on \$/kWh basis\*\*



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

# 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 Type	Benefit (\$/kW)**		Potential (MW, 10 Years)		Economy (\$Million) <sup>†</sup>	
		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**
  - 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

$$\text{Capital Cost} = \boxed{\text{Cost of Power equipment}} + \boxed{\text{Cost of storage}}$$

$$\text{Cost}_{\text{total}}(\$) = \text{Cost}_{\text{pcs}}(\$) + [\text{Cost}_{\text{storage}}(\$) + \text{Cost}_{\text{Bop}}(\$)]$$

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

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

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

**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

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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)

<b>Business case parameters</b>	
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:

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

<b>Economic parameters</b>	
System lifetime	20 years
Capital charge rate	15%
Discount rate	10%
Inflation rate	2%

## 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

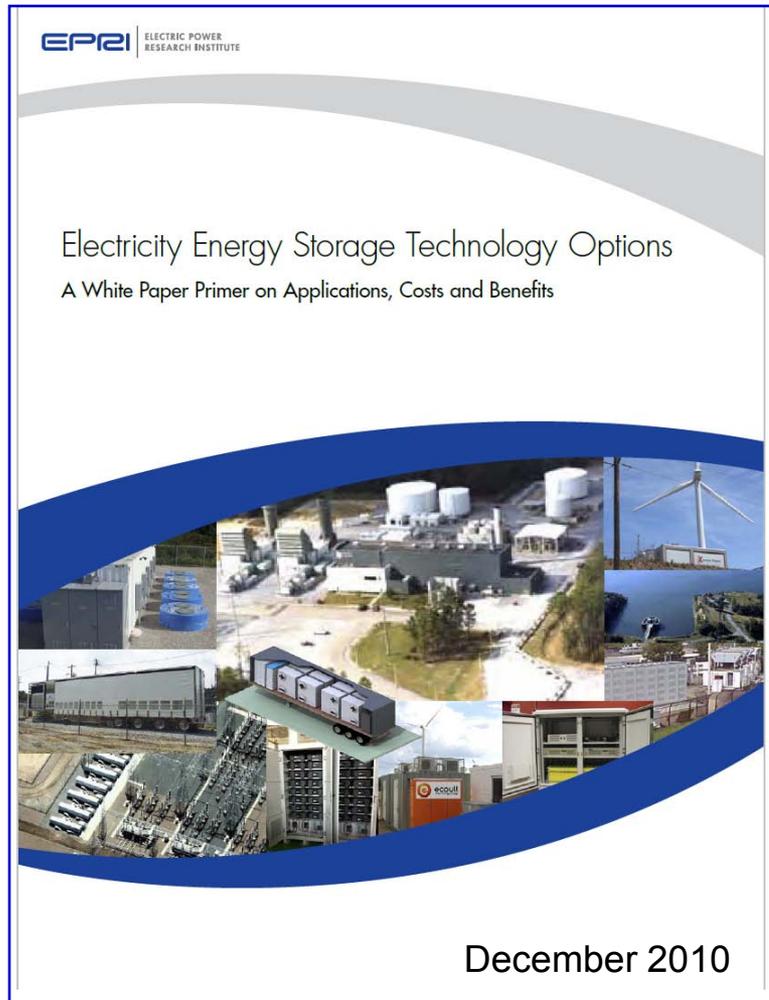
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10	Substation On-site Power	1,800	3,000
11	Time-of-use Energy Cost Management	1,226	
12	Demand Charge Management	582	
13	Electric Service Reliability	359	978
14	Electric Service Power Quality	359	978
15	Renewables Energy Time-shift	233	389
16	Renewables Capacity Firming	709	915
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17.2	Wind Generation Grid Integration, Long Duration	100	782

# Storage Benefits Analysis 122 West



Value Chain	Benefit		PV \$/kW-h	
			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