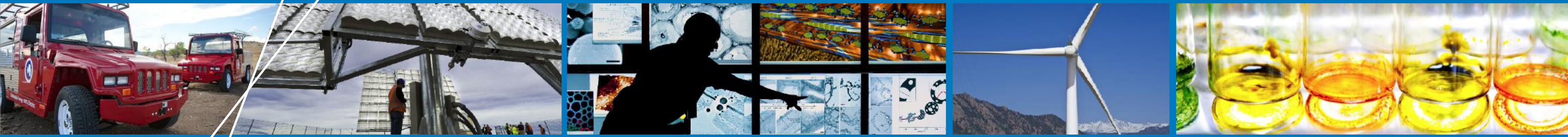
Energy Storage and Renewables: A Cautionary Tale



Presentation to the Harvard Electricity Policy Group

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March 24, 2014

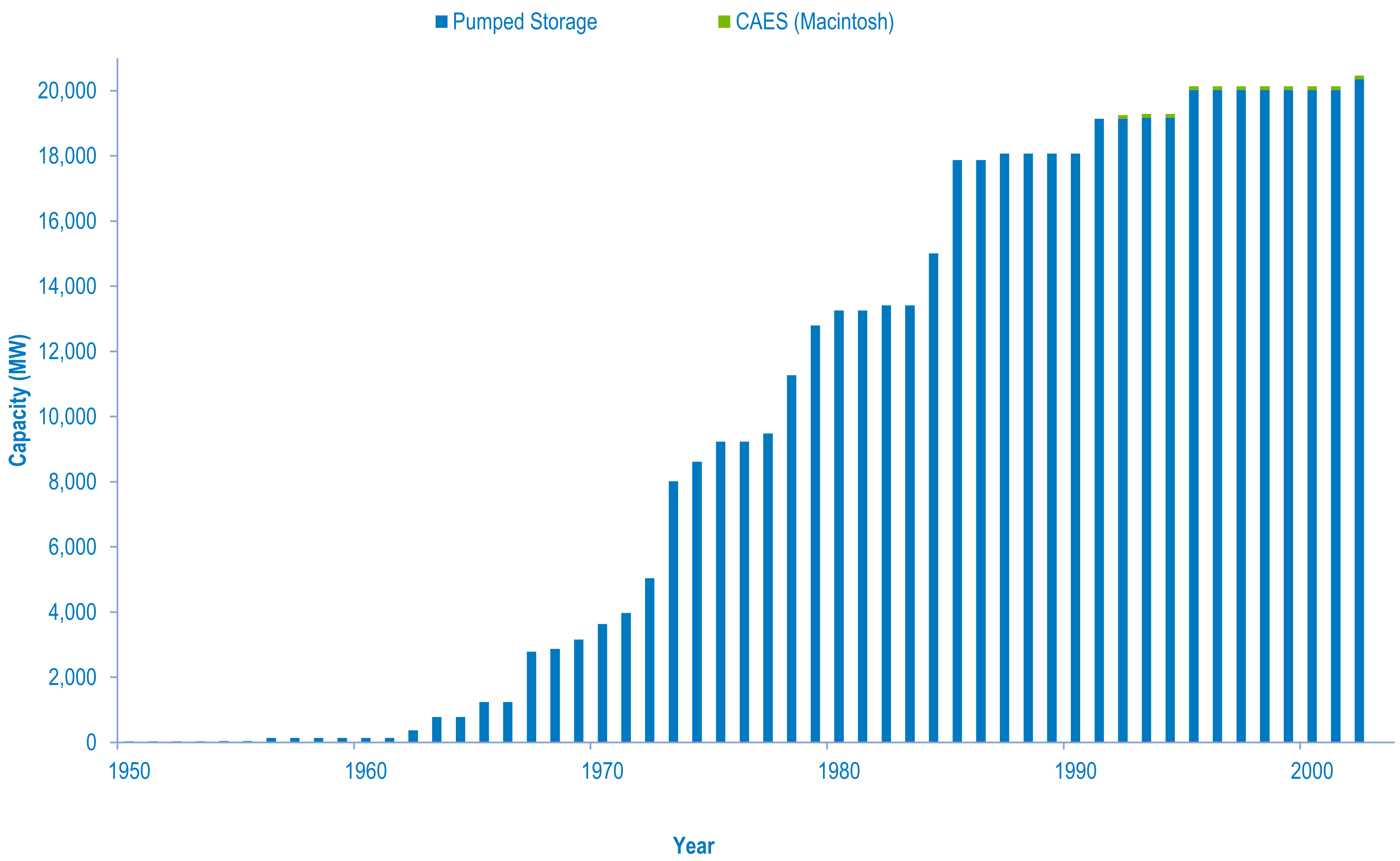
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

My Opinions*

- **Storage is undervalued in today's market place**
- **But at today's prices, storage isn't a no-brainer**
- **Renewables increase the value for storage, but other options are probably more cost effective in the near term**
- **There appear to be substantial market challenges for storage revenue capture**
  - Price-suppression effects
  - Need for ISO optimization of dispatch

*Some of which are actually fact-based

Ancient History



Historical Planning of Storage

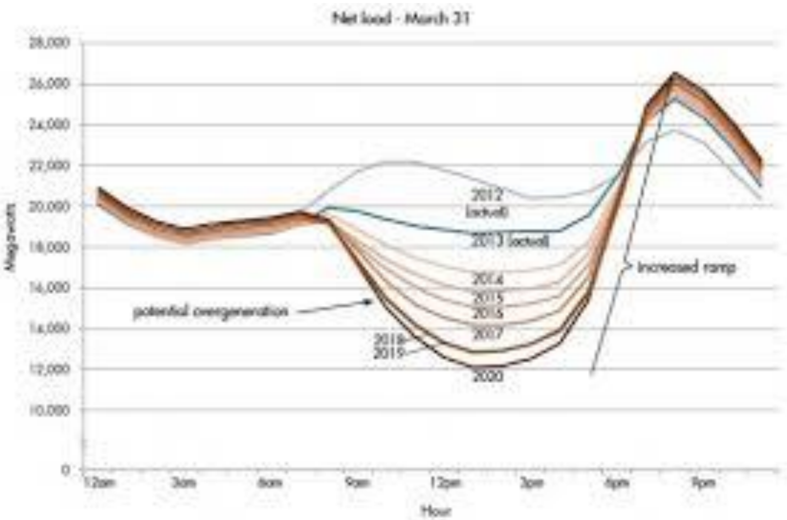
- **Storage as part of the integrated resource planning process**
- **Compares a new storage plant to an alternative generation resource (oil or gas fired steam plant)**
  - Assume approximately equivalent performance (capacity factor, grid services etc)
  - Assume low cost charging from coal or nuclear power
  - Assume increasing cost of natural gas and oil
  - Restrictions on use of oil and natural gas (Power Plant and Industrial Fuel Use Act)
  - Low-efficiency oil and steam gas plants as opposed to today's efficient gas turbines

Revised Interest in Energy Storage

- Advances in storage technologies
- Volatility in fossil fuel prices
- T&D siting challenges
- ***Perceived need for storage with renewables***
- Emergence of electricity markets
  - Puts value on operating reserves
- Mandates

Does wind and solar need storage?

- "The wind doesn't always blow and the sun doesn't always shine"?
- Increased reserves requirements?
- Curtailment and negative LMPs?
- Can the duck pay for energy storage?



So what is storage worth?

1) Identify market opportunities
2) Apply valuation approaches

Applications of Energy Storage

Application	Description	Timescale of Operation
Load Leveling/ Arbitrage	Purchasing low-cost off-peak energy and selling it during periods of high prices.	Response in minutes to hours. Discharge time of hours.
Firm Capacity	Provide reliable capacity to meet peak system demand.	Must be able to discharge continuously for several hours or more.
Operating Reserves		
Regulation	Fast responding increase or decrease in generation (or load) to respond to random, unpredictable variations in demand.	Unit must be able to respond in seconds to minutes. Discharge time is typically minutes. Service is theoretically "net zero" energy over extended time periods.
Contingency Spinning Reserve	Fast response increase in generation (or decrease load) to respond to a contingency such as a generator failure.	Unit must begin responding immediately and be fully responsive within 10 minutes. Must be able to hold output for 30 minutes to 2 hours depending on the market. Service is infrequently called.[2]
Replacement/ Supplemental	Units brought on-line to replace spinning units.	Typical response time requirement of 30-60 minutes depending on market minutes. Discharge time may be several hours.
Ramping/Load Following	Follow longer term (hourly) changes in electricity demand.	Response time in minutes to hours. Discharge time may be minutes to hours.
T&D Replacement and Deferral	Reduce loading on T&D system during peak times.	Response in minutes to hours. Discharge time of hours.
Black-Start	Units brought online to start system after a system-wide failure (blackout).	Response time requirement is several minutes to over an hour. Discharge time requirement may be several to many hours.[3]
End-Use Applications		
TOU Rates	Functionally the same as arbitrage, just at the customer site.	Same as arbitrage.
Demand Charge Reduction	Functionally the same as firm capacity, just at the customer site.	Same as firm capacity. I
Backup Power/ UPS/Power Quality	Functionally the same as contingency reserve, just at the customer site.	nstantaneous response. Discharge time depends on level of reliability needed by customer.

National Renewable Energy Laboratory

Energy Storage in Restructured Markets

Application	Valued in Restructured Markets?
Load Leveling/ Arbitrage	Yes
Firm Capacity	Via scarcity pricing or combined scarcity plus capacity markets. Suffers from missing money problem.
Regulation Reserves	Yes, with potentially increased compensation for fast response through FERC 755 initiated market reforms
Spinning Reserves	Yes
Replacement/Supplemental/ Non-Spinning	Yes but values are very low
Primary Frequency Response / Inertia	No. Early stage proposals
Ramping/Load Following	No. Proposed in several markets
Transmission Replacement and Deferral	Only partially via congestion prices
All Distribution Specific Applications	No. Will likely remain cost of service through regulated entities
Renewable Integration	Captured through other services.
End-Use Applications	Only via rate structure, perhaps combined with aggregated wholesale services (adds transaction costs)

Valuation Approaches

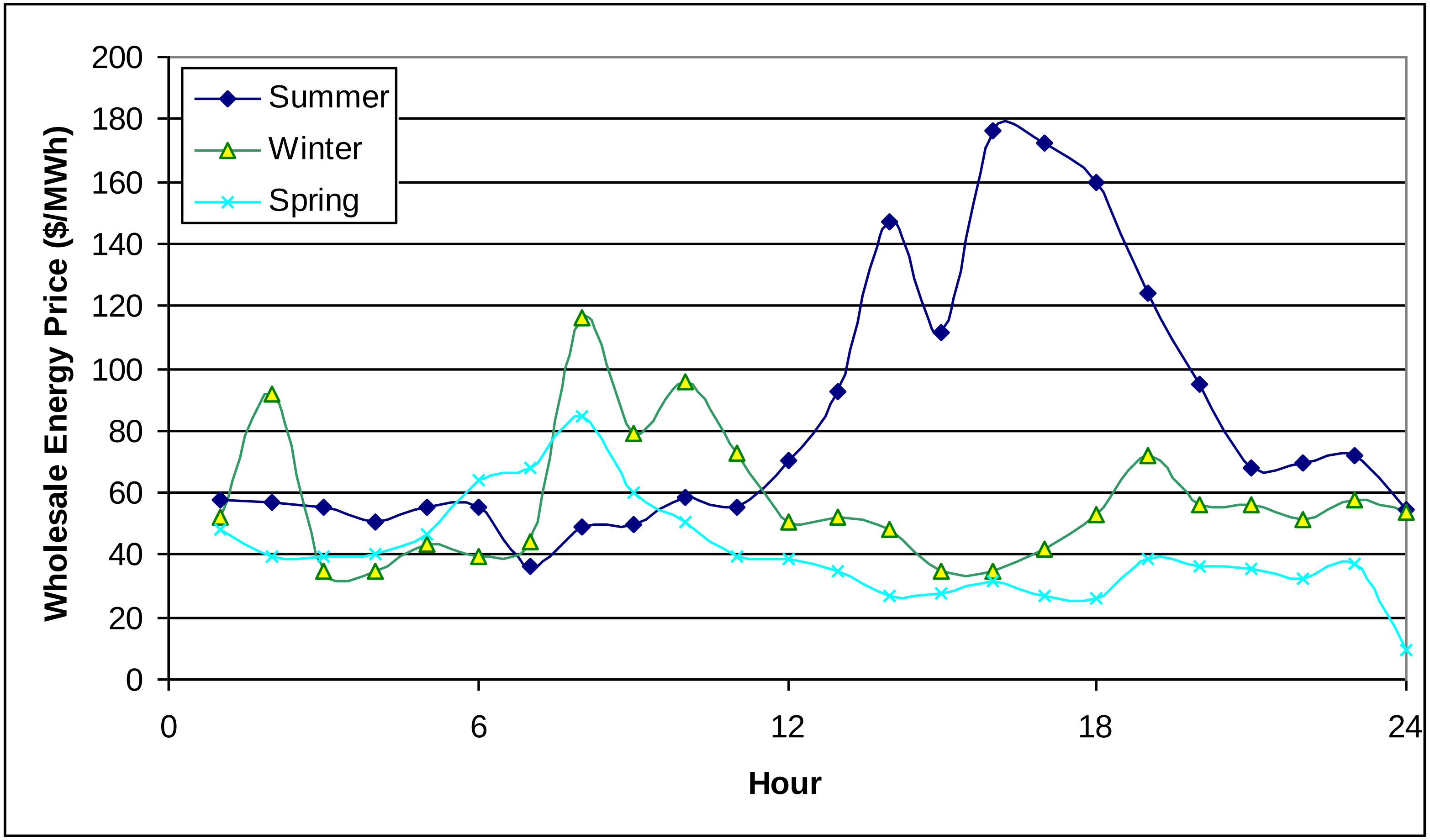
- **Value using historical market data (merchant price-taker)**
- **Full system value using production cost models (operational value to a utility or value to society, with some insight into market value)**

Price-Taker Value in Restructured Markets

- **Use historical market data to estimate what a storage plant would have received if optimally dispatched (big caveat)**

- **Typically Single Unit Optimal Dispatch Simulations (Price Taker)**
  - Based on historical price and load patterns
  - Use a mixed-integer linear program or other optimization routine
  - Typically assumes perfect foresight
  - Can evaluate some price-suppression impacts (using price load relationships)

Example - Load Leveling & Arbitrage



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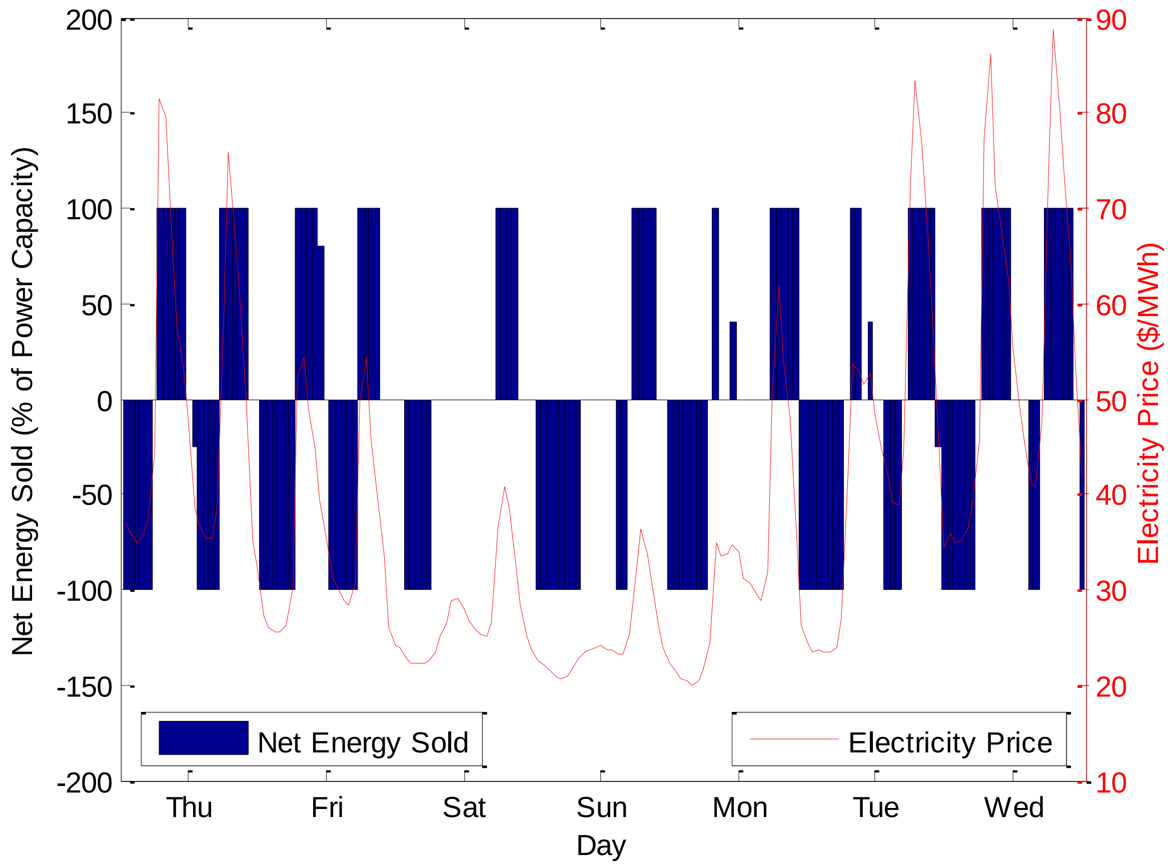
Example: Storage in PJM

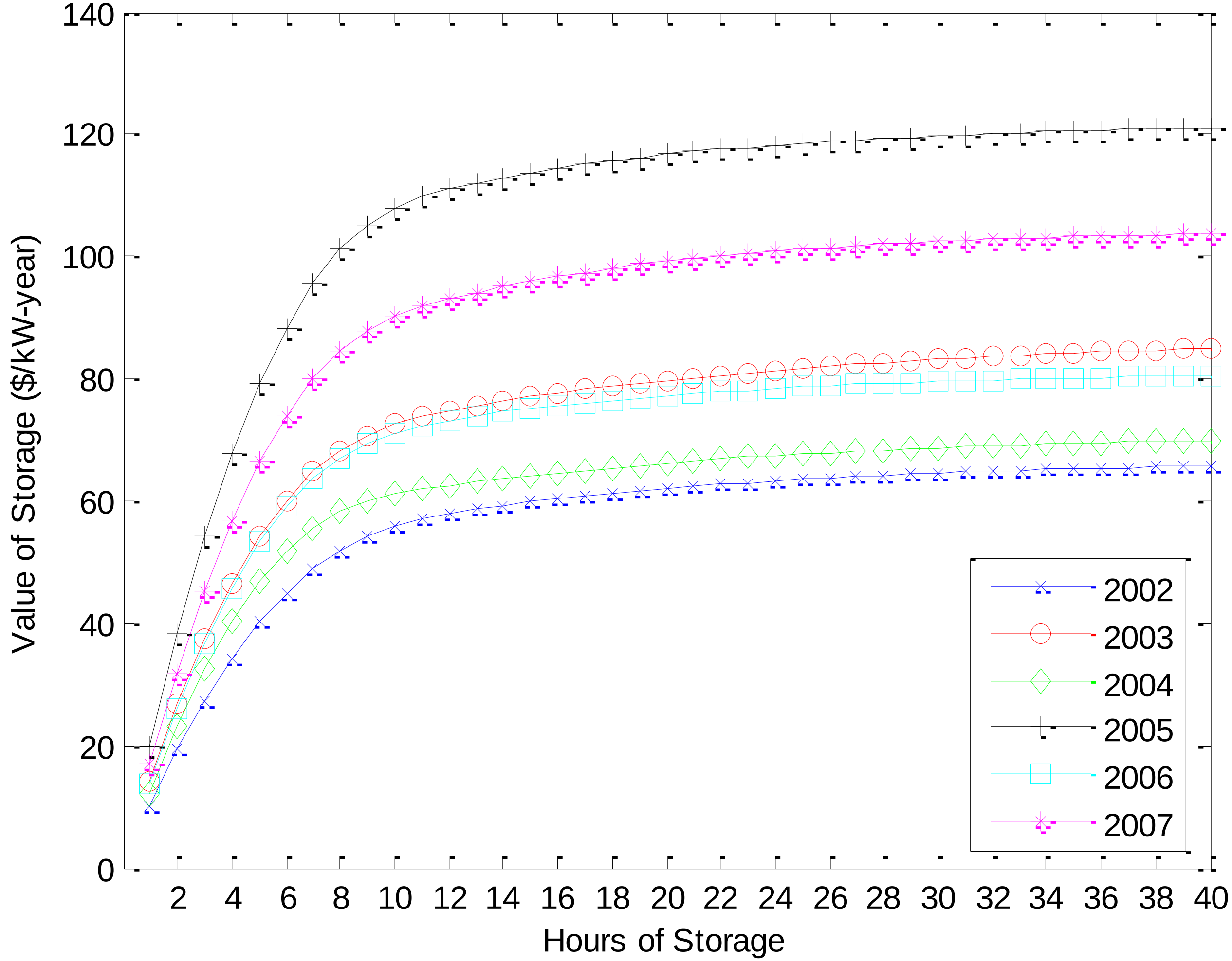
- 75% AC-AC Efficiency
- Perfect foresight of prices for 1 week

Optimal Dispatch



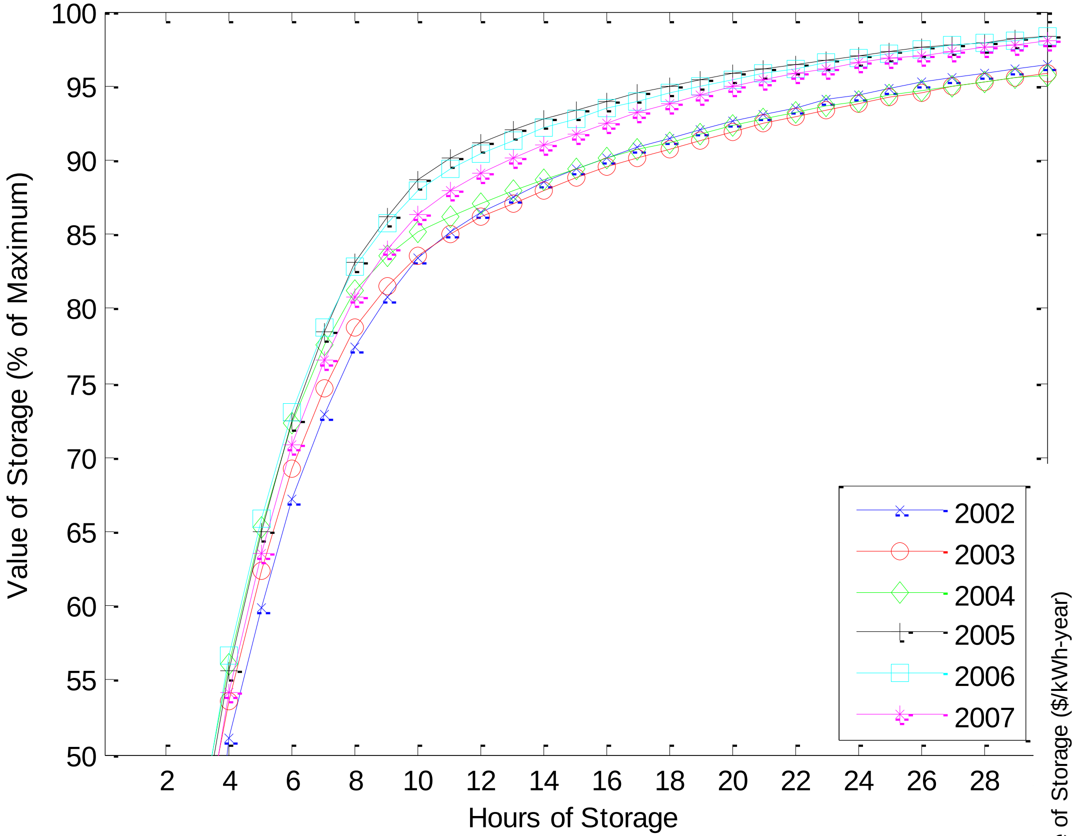
Energy Arbitrage in PJM

Value

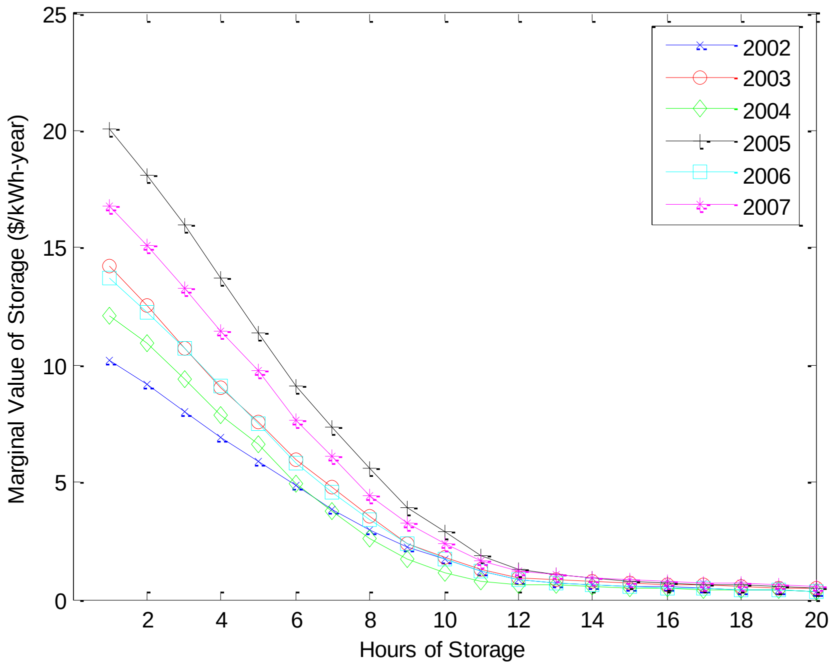


Energy Arbitrage in PJM

Sizing Optimization

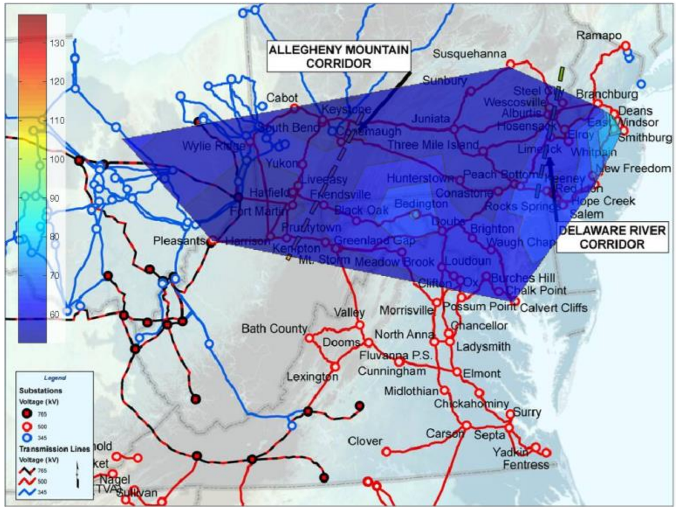


Total Value

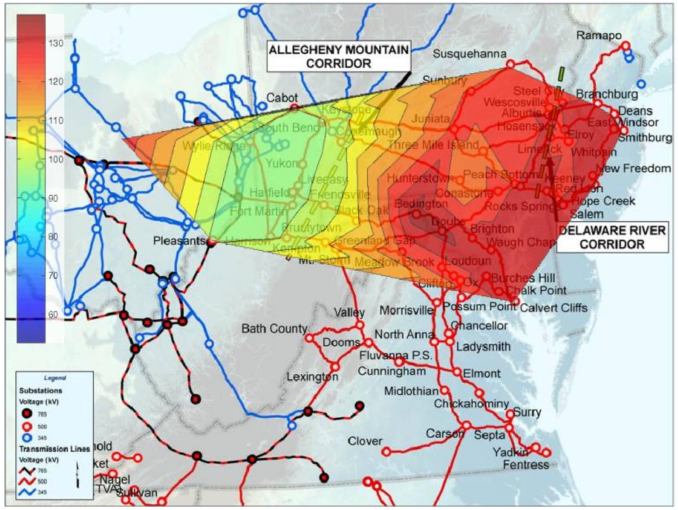


Marginal Value

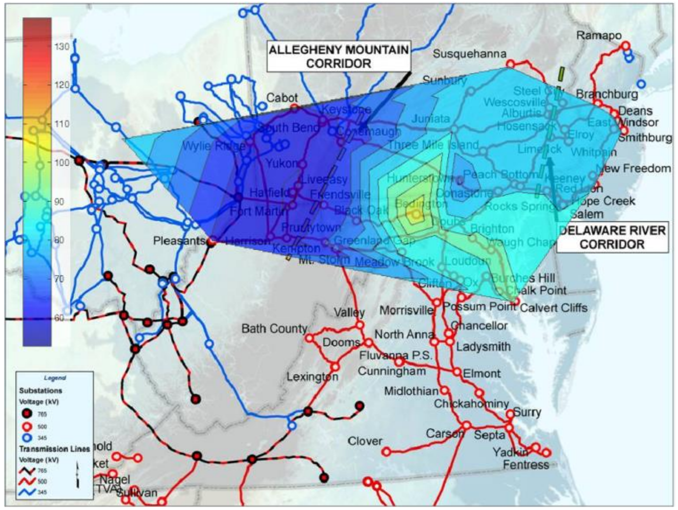
Locational Variation – Arbitrage Value



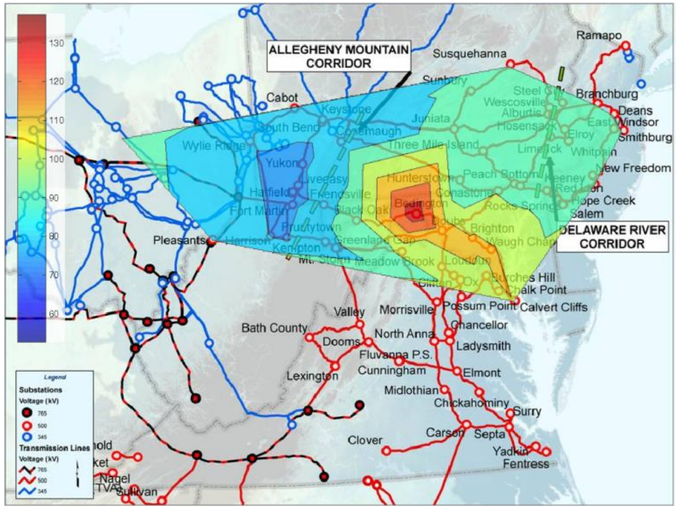
2004



2005



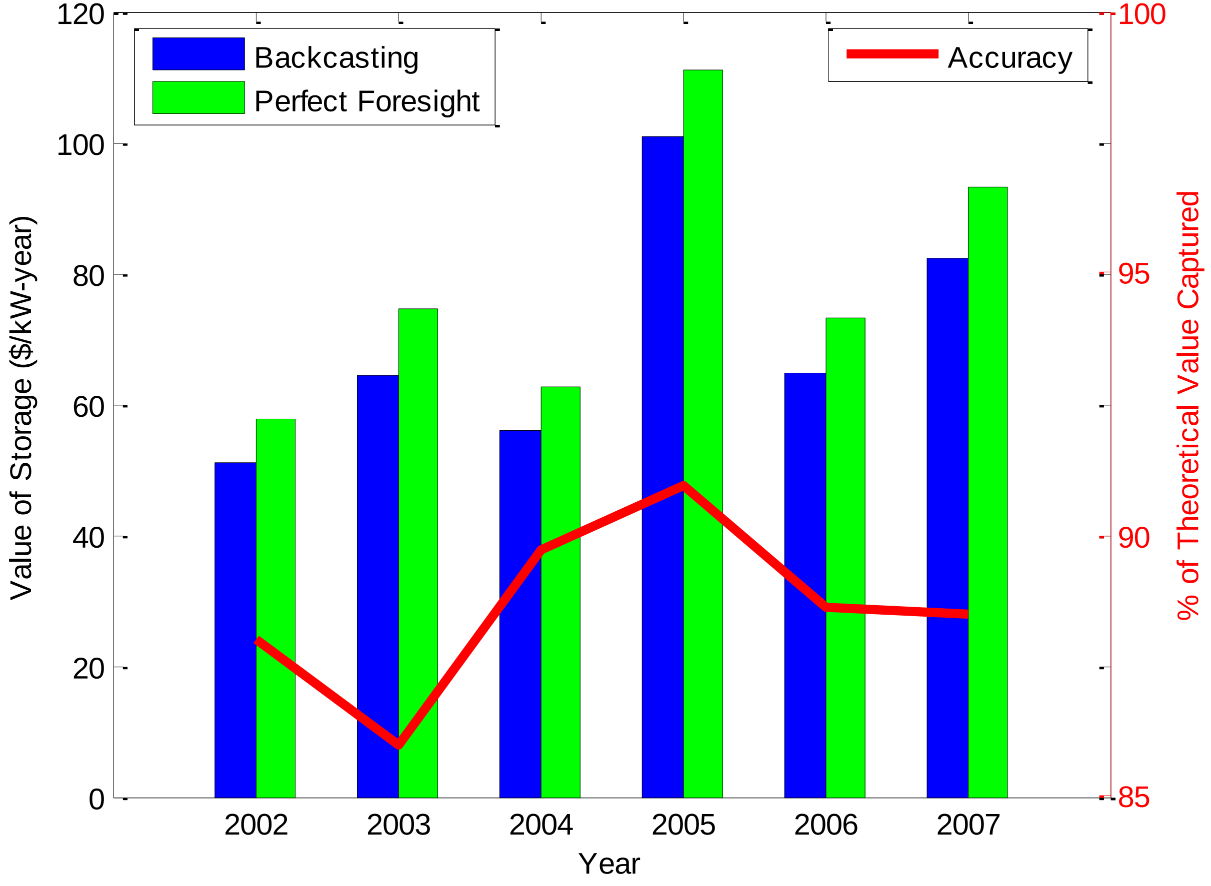
2006



2007

Sioshansi, Denholm & Jenkin (2009) The Value of Electricity Storage in PJM: Arbitrage and Some Welfare Effects.

Forecasting & Uncertainty Analysis

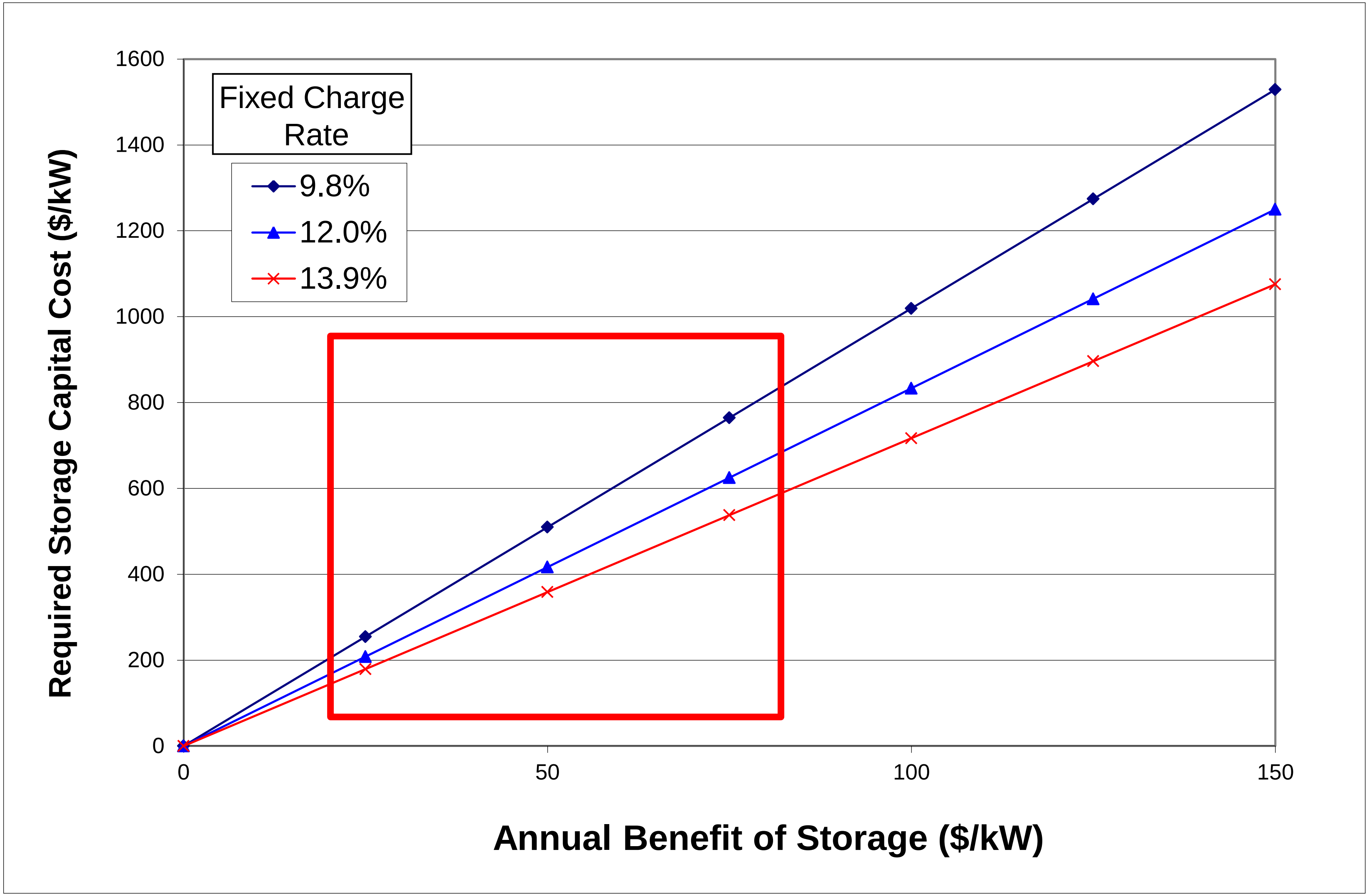


Arbitrage Estimates

Location	Years Evaluated	Annual Value ($/kW)	Assumptions
PJM[a]	2002-2007	$60-$115	12 hour, 80% efficient device. Range of efficiencies and sizes evaluated
NYISO[b]	2001-2005	$87-$240 (NYC) $29-$84 (rest)	10 hour, 83% efficient device. Range of efficiencies and sizes evaluated.
USA[c]	1997-2001	$37-$45	80% efficient device, Covers NE, No Cal, PJM
CA[d]	2003	$49	10 hour, 90% efficient device.
CA[f]	2010-2011	$25-41	4 hour, 90% efficient device

[a] Sioshansi et al. 2009
[b] Walawalkar et al. 2007
[c] Figueiredo et al. 2006
[d] Eyer et al. 2004
[f] Byrne and Silva-Monroy 2012

Supported Capital Cost



Current focus on regulation applications

- Higher Value
- Capacity factor closer to 100%
- Cheaper device (shorter duration)
- But very small market

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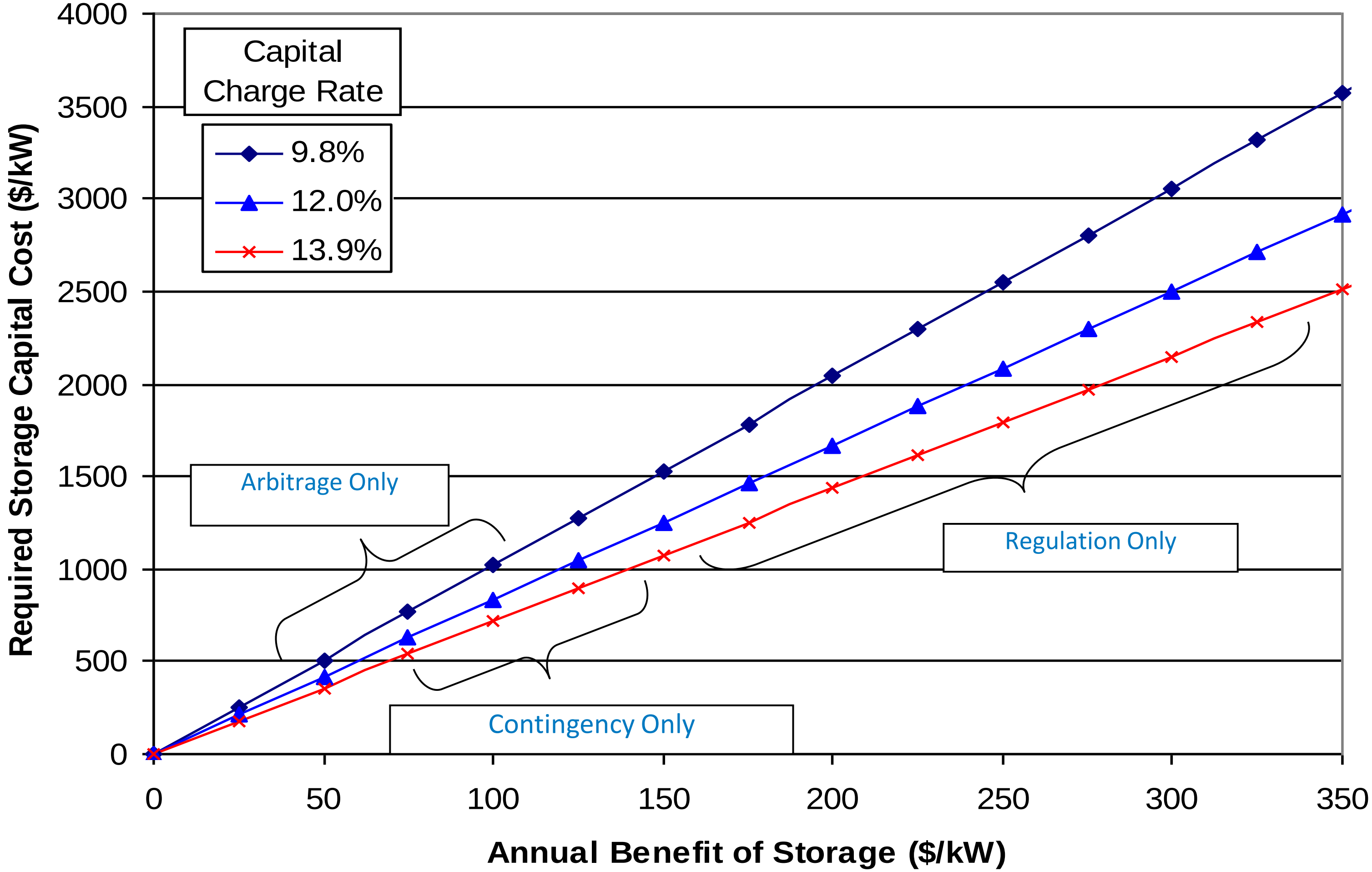
Example Market Prices for Spin and Regulation

	Average Market Clearing Price $/MW-hour							
	2005	2006	2007	2008	2009	2010	2011	2012
	California ISO							
Regulation (Up + Down)	35.2	38.5	26.1	33.4	12.6	10.6	16.1	10.0
Spinning	9.9	8.4	4.5	6.0	3.9	4.1	7.2	3.3
	Electric Reliability Council of Texas							
Regulation (Up + Down)	38.6	25.2	21.4	43.1	17.0	18.1	31.3	9.2
Responsive	16.6	14.6	12.6	27.2	10.0	9.1	22.9	9.1
	New York ISO (east)							
Regulation	39.6	55.7	56.3	59.5	37.2	28.8	11.8	10.4
Spinning	7.6	8.4	6.8	10.1	5.1	6.2	7.4	6.0
30 Minute	0.4	0.6	0.9	1.1	0.5	0.1	0.1	0.3
	Midwest ISO (day ahead)							
Regulation					12.3	12.2	10.8	7.8
Spinning					4.0	4.0	2.8	2.3
	ISO New England							
Regulation + mileage	30.2	22.7	12.7	13.8	9.3	7.1	7.2	6.7
Spinning		0.3	0.4	1.7	0.7	1.8	1.0	1.7
10 Minute		0.1	0.3	1.2	0.5	1.6	0.4	1.0
30 Minute		0.0	0.1	0.1	0.1	0.4	0.3	1.0

Historical Value of Energy Storage in U.S. Markets



Limits of Price-Taker Analysis

1. **Examines a static historic system**
   - Difficult to examine impact of fuel prices, renewables, extract impact of scarcity prices etc.
2. **Depth of Market**
3. **Doesn't consider values not captured in today's markets**
   - Capacity payments, avoided start costs….

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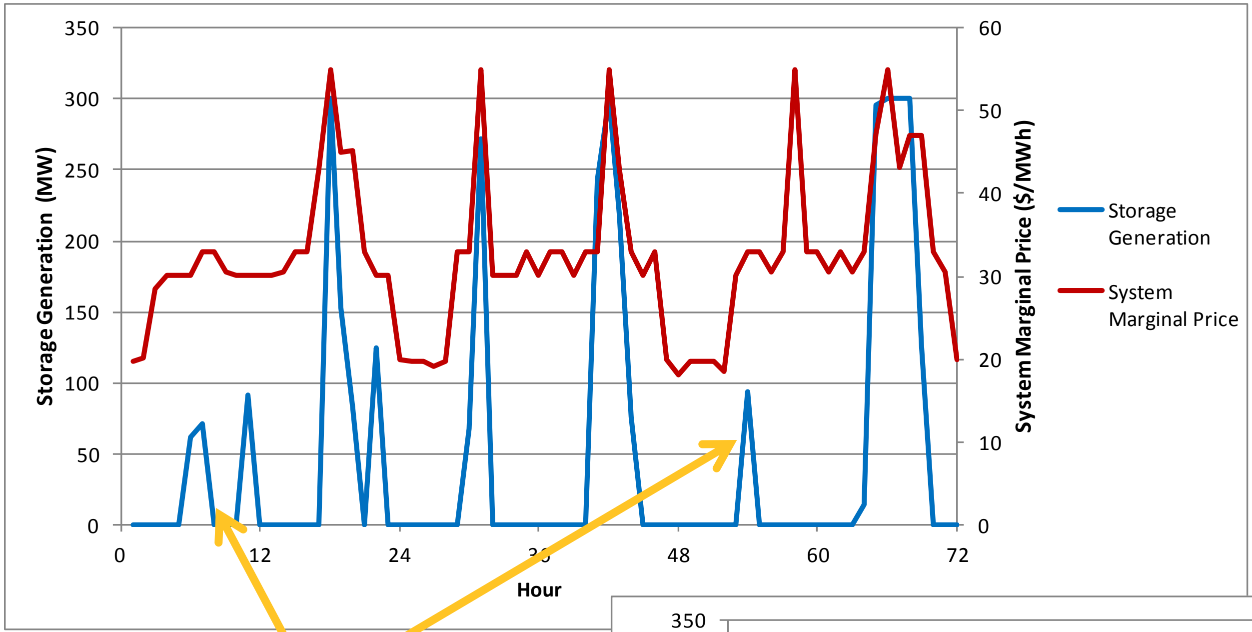
System Value Analysis Example

- **PLEXOS SCUC Simulation**
- **Can examine production costs as well as simulated market revenue**
- **Example Energy Only Device**
  - 75% AC-AC efficiency
  - No minimum generation, ramp constraints
  - 8 hours
  - Base device is 300 MW

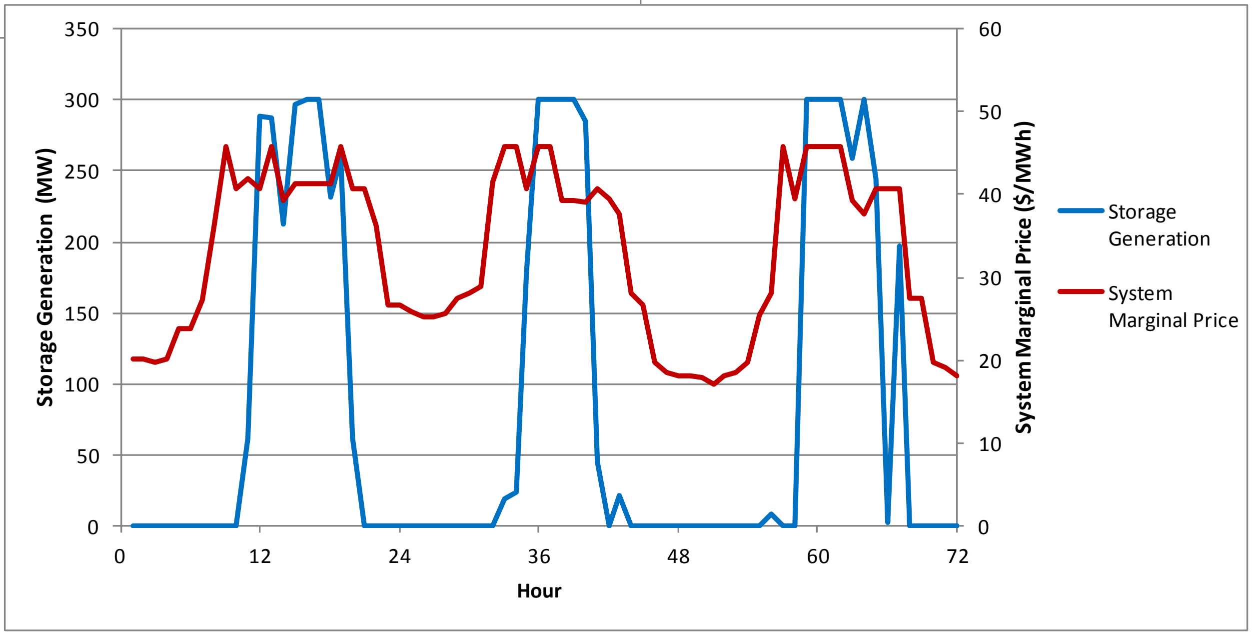
Results – Storage Dispatch (Energy)



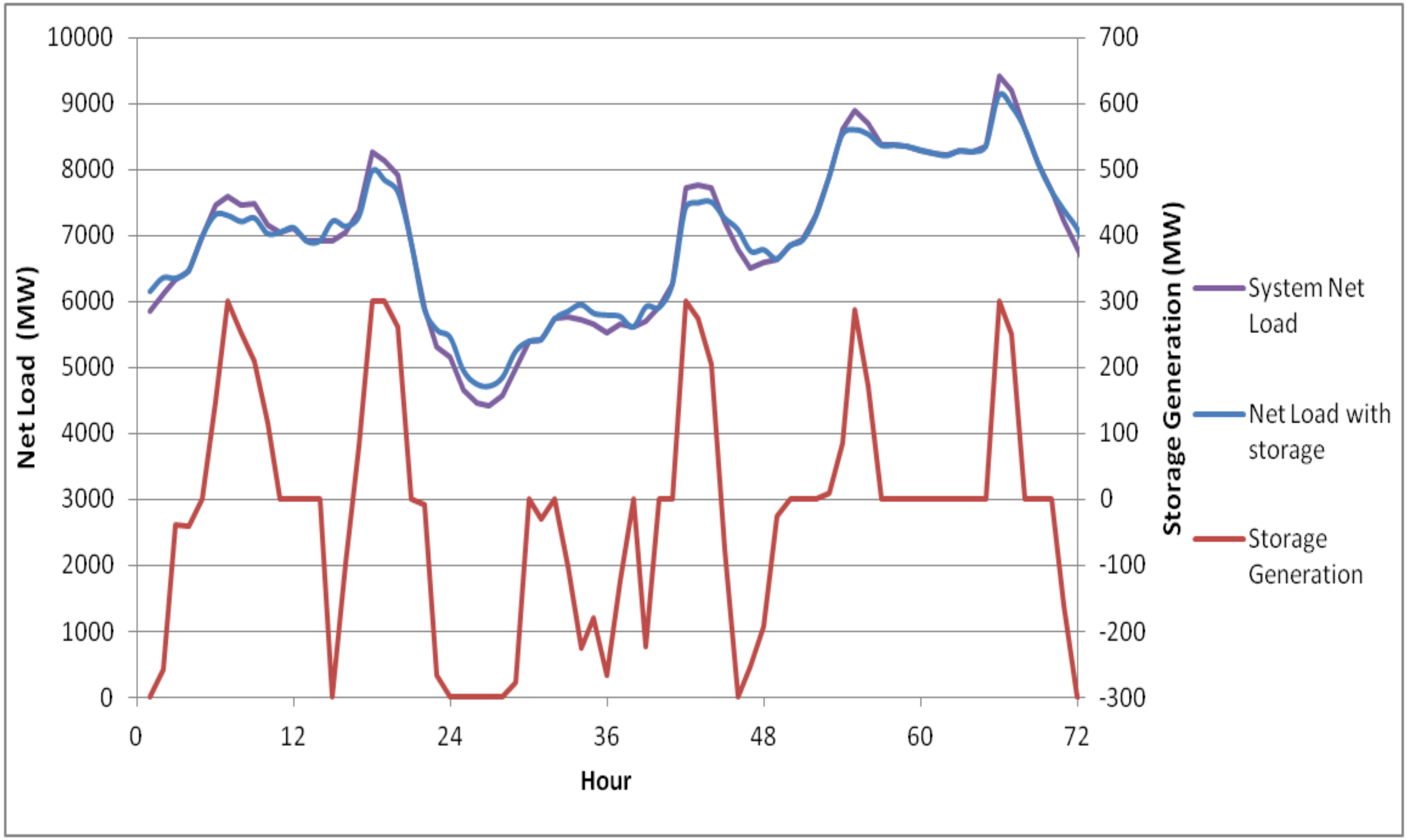
February 3-5

What's going on here?

July 19-21



Value of Avoided Starts



Results – Fuel/Generation

	Base Case	With Storage (300 MW)	Increase with Storage
Generation (GWh)			
Coal	46,134	46,375	241
Hydro	3,792	3,792	-
Gas CC	14,761	14,947	186
Gas CT	1,024	763	-260
Other	103	89	-14
Existing Pumped Storage	1,054	1,050	-4
New Storage	-	465	465
PV	1,834	1,834	0
Wind	10,705	10,705	0
Total Generation (GWh)	79,407	80,020	613
Fuel Use (1,000 MMBtu)			
Coal	488,140	490,930	2,790
Gas	126,651	124,728	-1,923
Total Fuel	614,719	615,658	867

Results – Change in Production Costs (300 MW Device)

	Base Case	With Storage (300 MW)	Increase with Storage
Total Fuel Cost (M$)	1,210.5	1,204.7	-5.8
Total Variable Operations and Maintenance Cost (M$)	152.1	152.8	0.7
Total Start Cost (M$)	58.2	52.8	-5.5
Total Regulation “Adder” Cost (M$)	4.7	4.8	0.1
Total Production Cost (M$)	1,425.6	1,415.1	-10.5

~50% of value from avoided starts

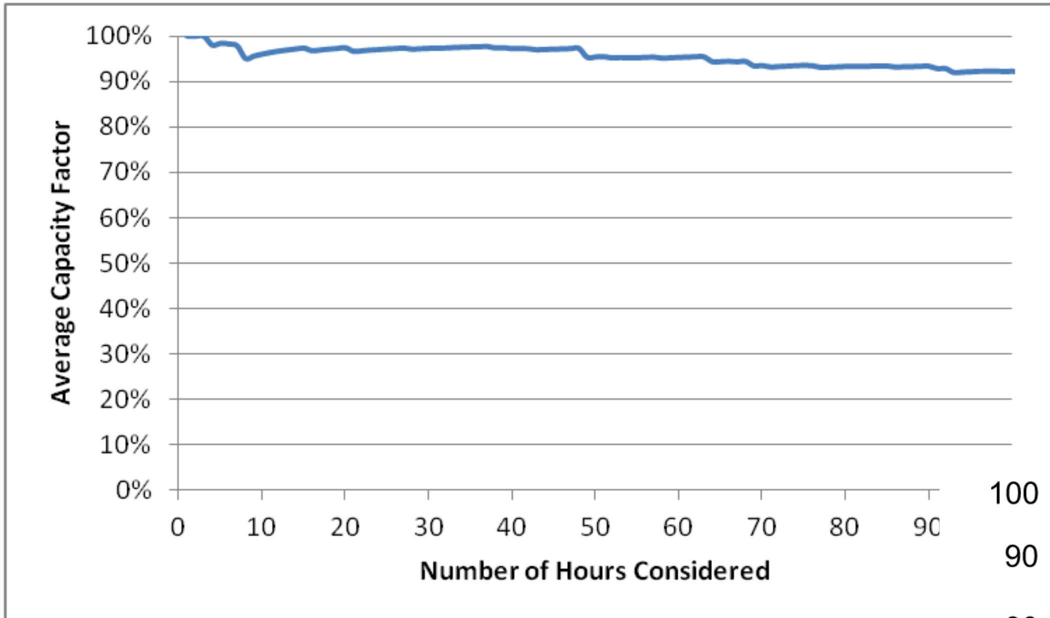
Price taker value - $8.5 million

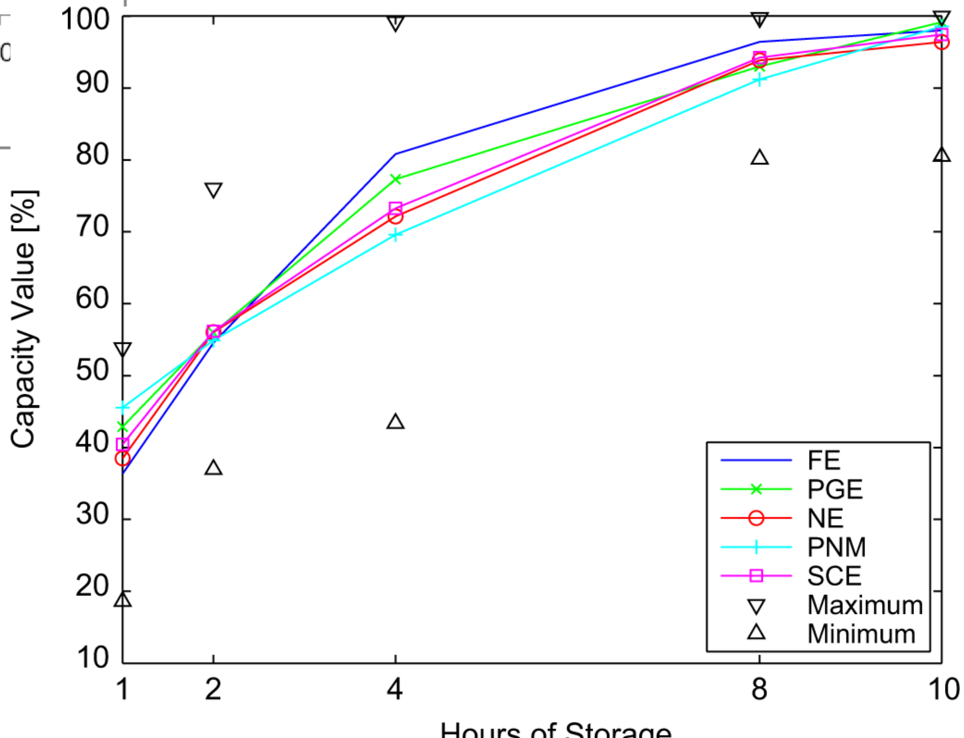
Market value - $5.2 million

Market Challenge 1: Starts and Scheduling

- Large fraction of storage value may come from avoided starts, which are not captured in LMPs
- You can’t self-schedule to avoid starts
- I don’t see any way to maximize value without complete ISO optimization of storage

Capacity Value – Storage is a Peaker





A storage plant with 6- 8 hours of capacity is functionally equivalent to a CT for capacity planning purposes. But should short duration A/S devices receive capacity payments?

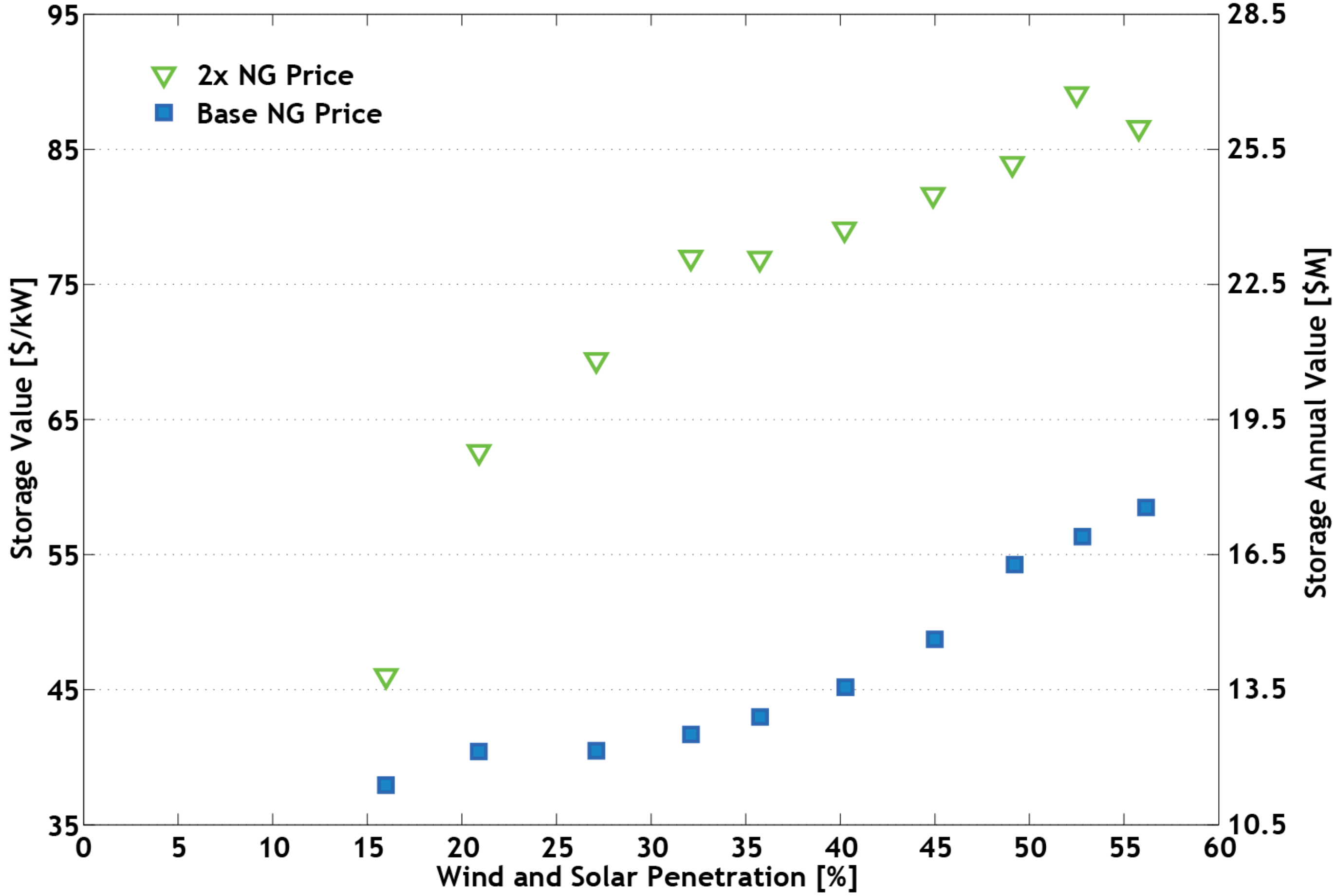
Market Challenge 2: Capacity

- Insert standard discussion of missing money problem
- Scarcity pricing? Perhaps, but how does a storage plant effect on-peak prices?

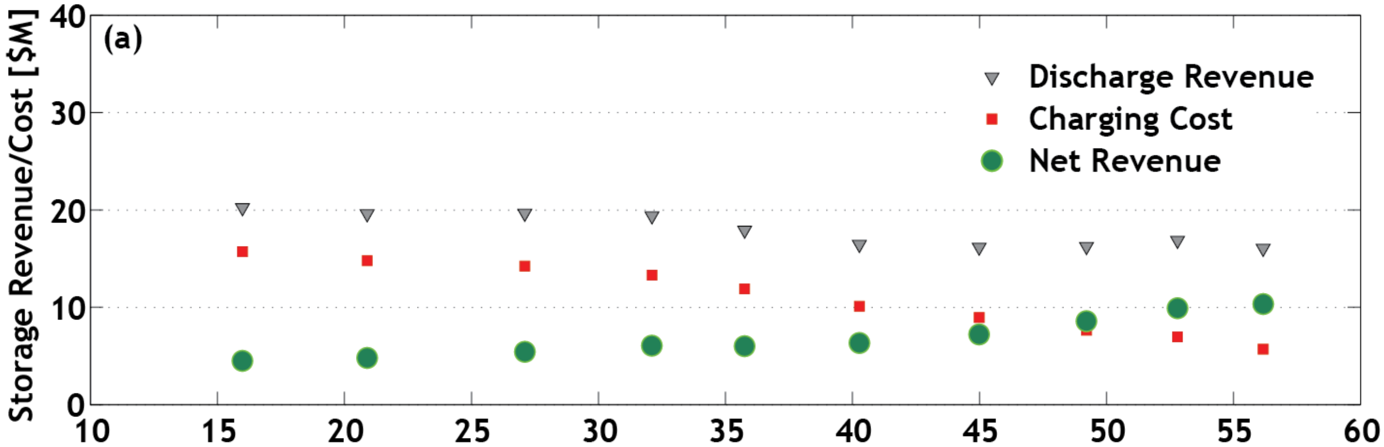
Impact of RE Penetration

- Increased number of starts
- Decrease in both on-peak and off-peak prices
- Increased reserve requirements

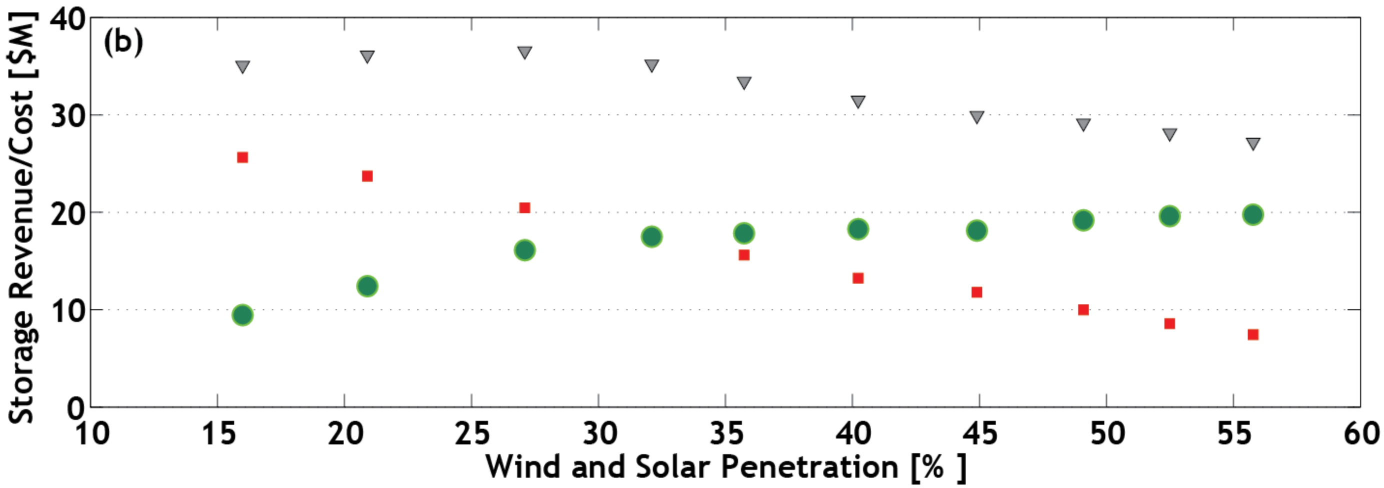
Value as a Function of RE Penetration



Source of Value Difference



$4.1/MMBTU

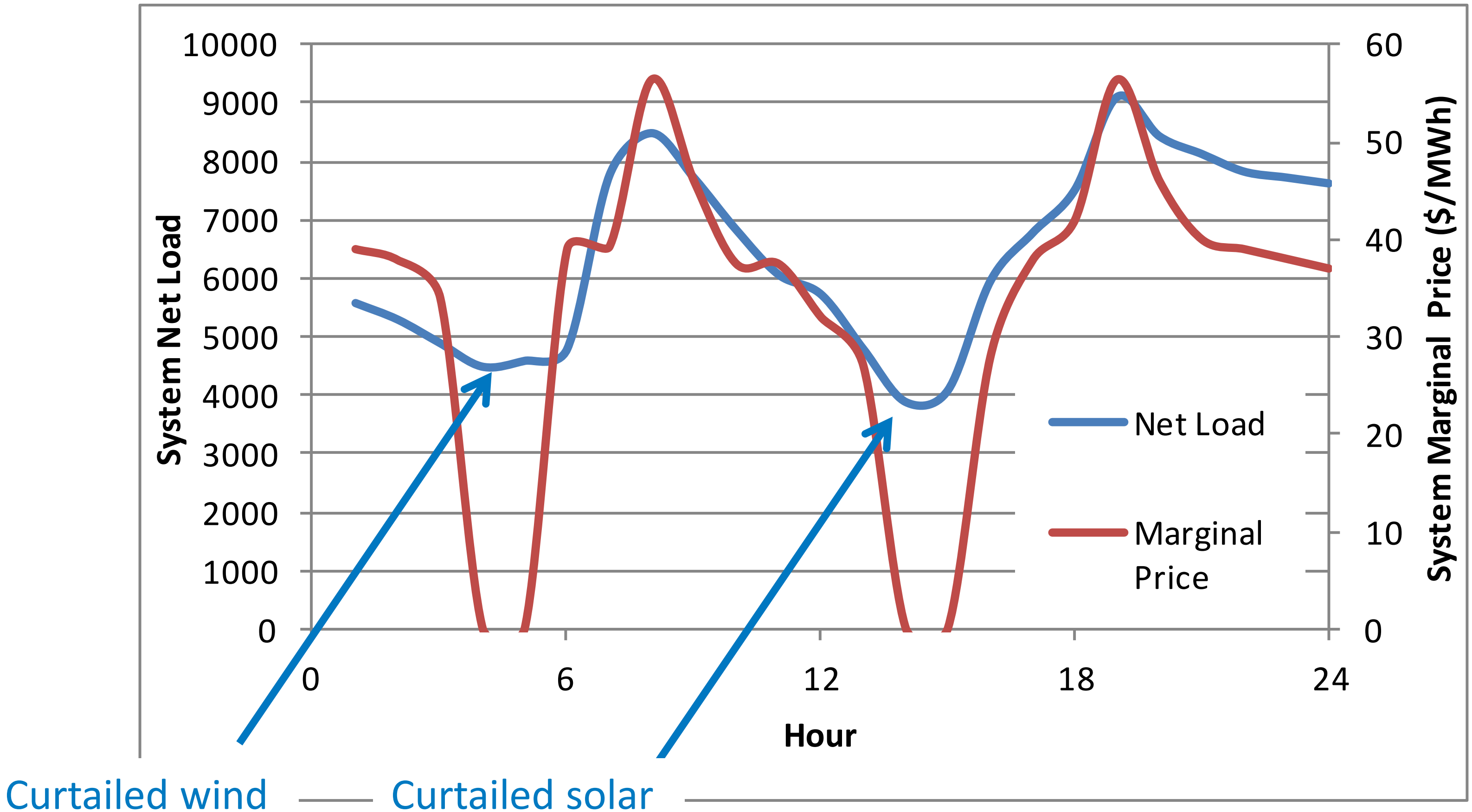


$8.2/MMBTU

Market Challenge 3: Price Suppression

- Storage is uniquely exposed to price suppression in BOTH directions

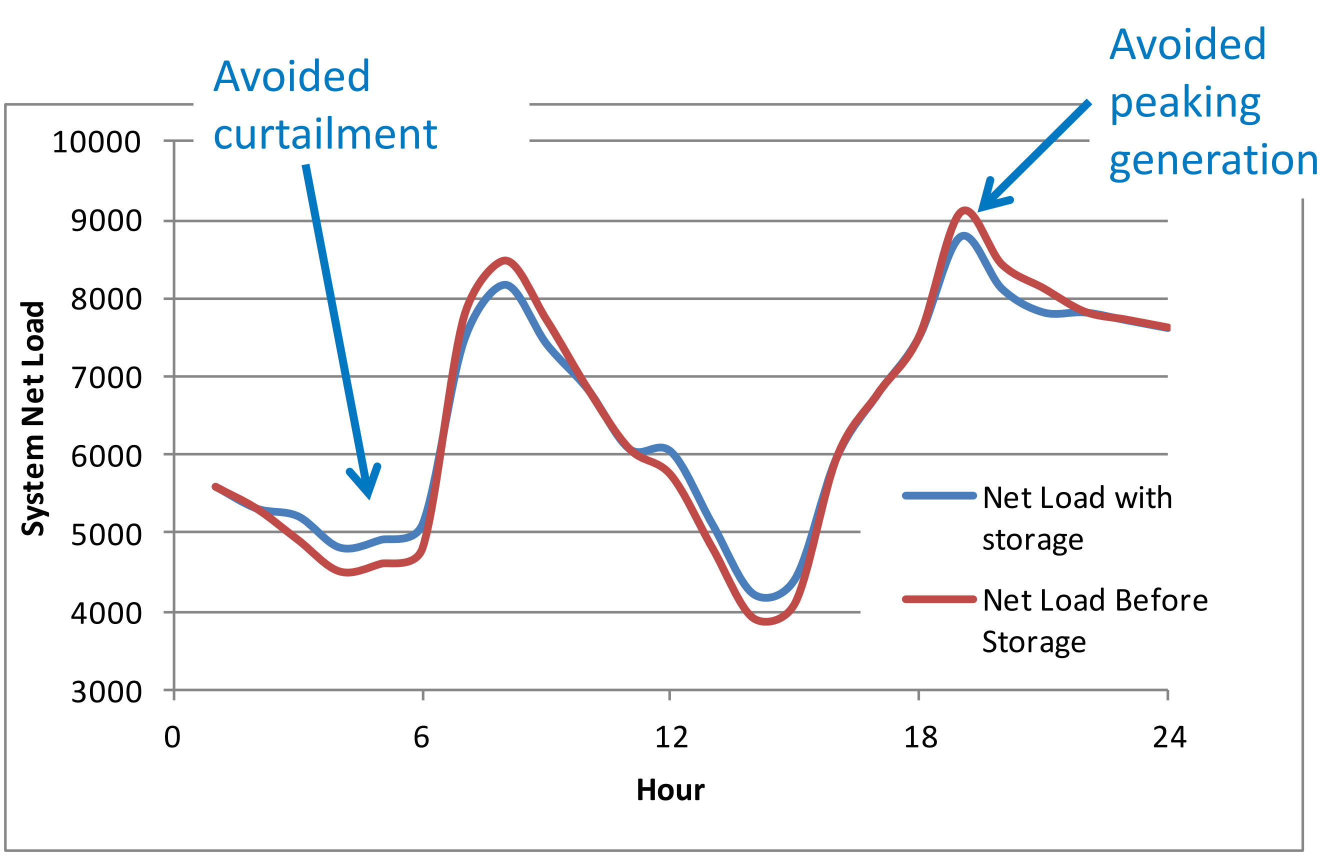
Storage is uniquely exposed to price-suppression effects



A day sometime in the future with a significant penetration of wind and solar…..

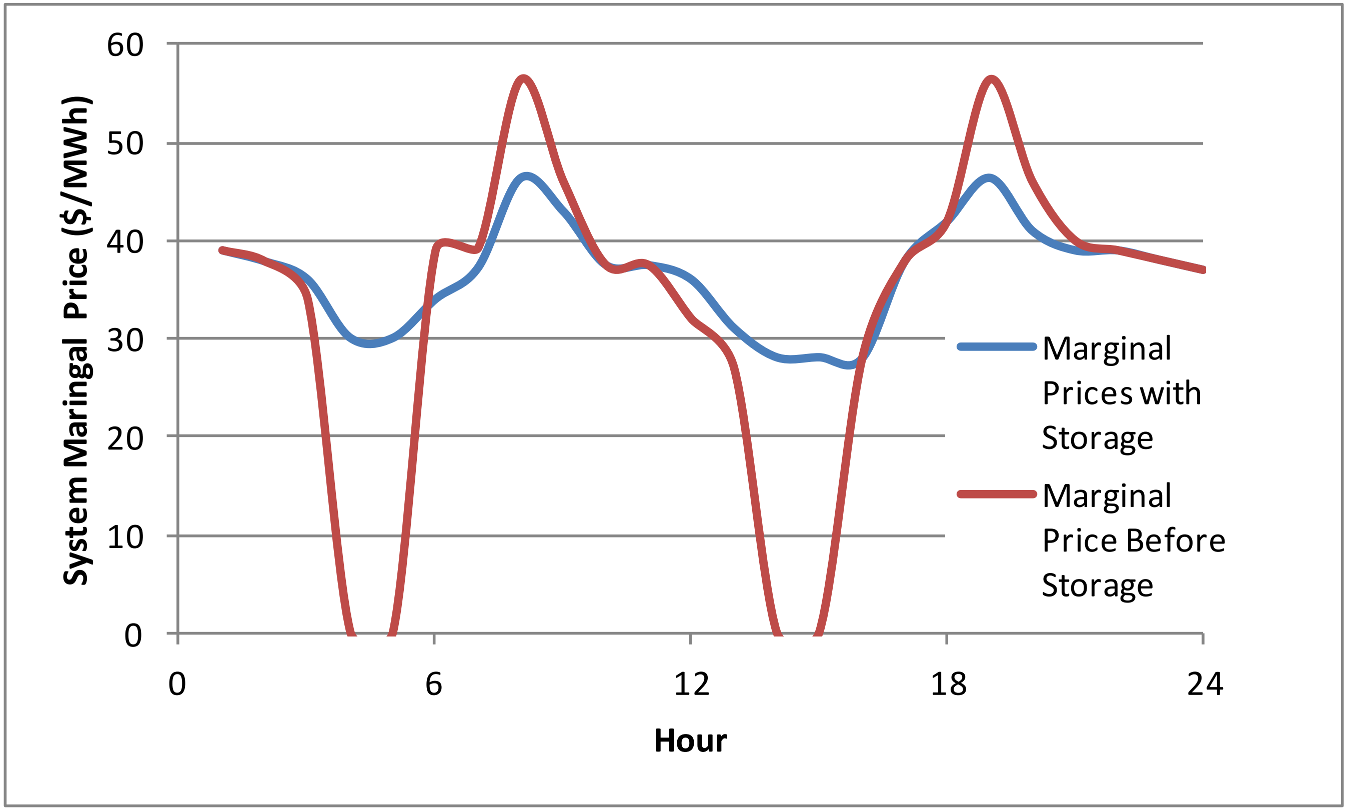
What would the value of storage be on this day?

Storage Impact on Net Load and Value



Added 300 MW storage device.
Absorbs 2,400 MWh of otherwise curtailed solar and wind energy
Avoids 1,800 MWh of combustion turbine generation.
At 9,500 BTU/kWh the storage device saves about 17,000 MMBTU of gas.
At $5/MMBTU this is about $85,500 of system value

Impact on Storage Revenue

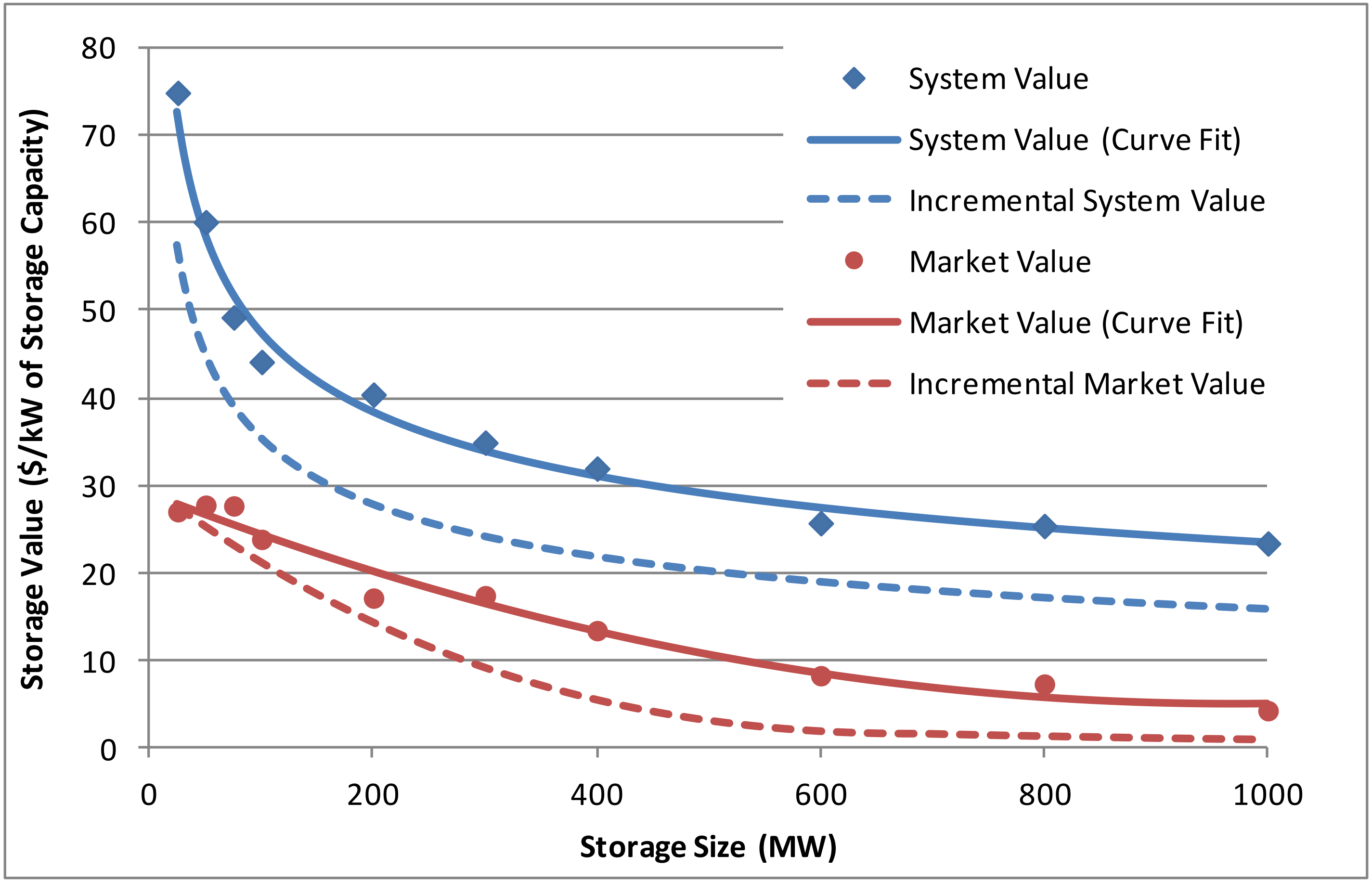


Storage device must purchase 2,400 MWh of energy at marginal cost of a CCGT (even though it absorbed zero cost wind and solar) at $75,900

Sells 1,800 MWh at marginal costs of CT/CCGT at $75,950

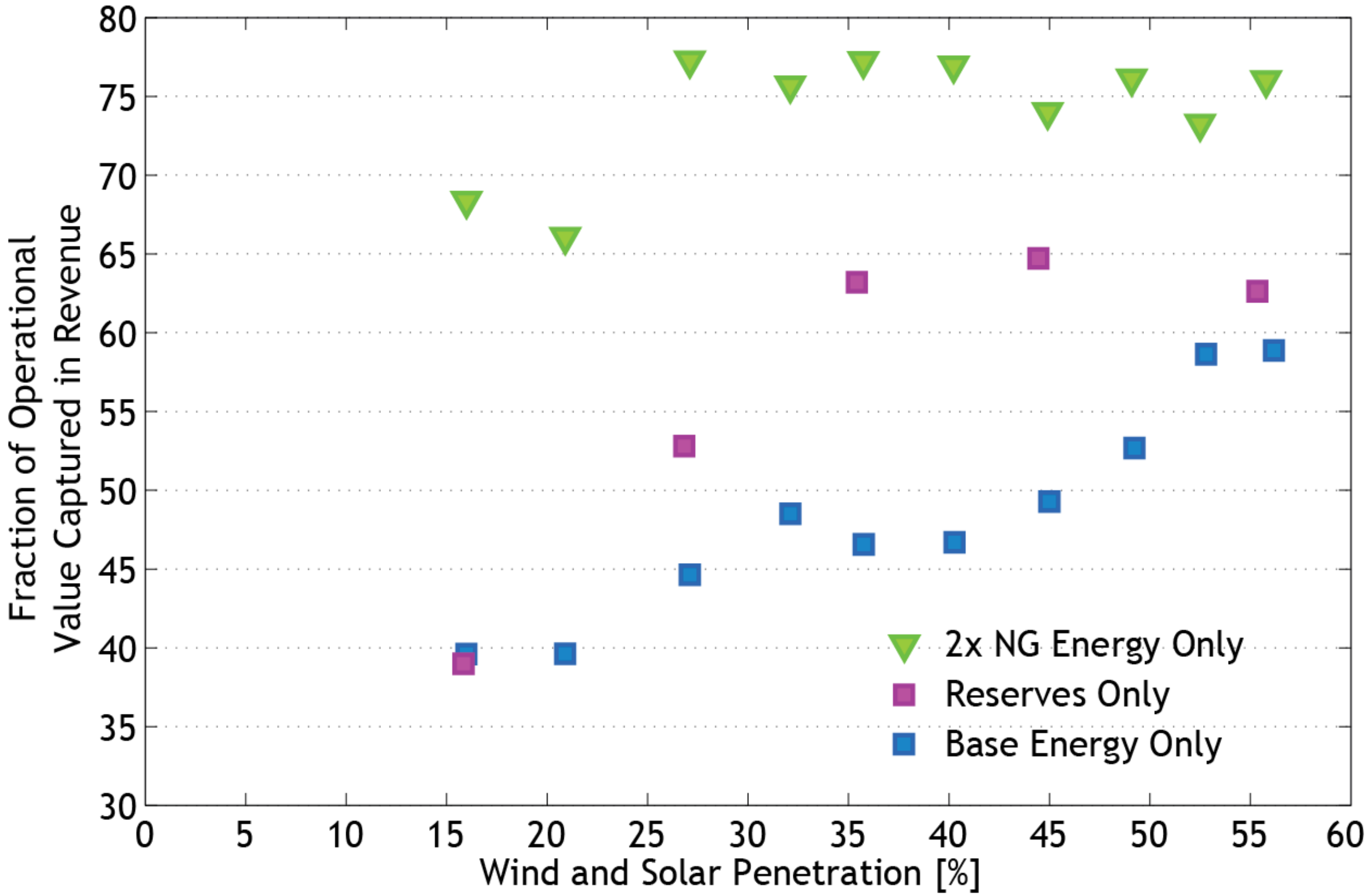
Net revenue is $50, compared to system value of $85,500

System Value vs. Market Capture



Storage is uniquely exposed to price suppression effects in market environments!

Value Capture?



Conclusions / Opinions

1. **The value of storage for energy arbitrage is relatively low and will never pay for almost any storage device in existence.**
   - Arbitrage devices are peaking resources and suffer from the missing money problem.
2. **Ancillary services (regulating reserves) appears to be cost effective for a few storage devices, but how deep is the market?**
   - Capacity payments would help, but should short duration devices get them?
3. **Storage is undervalued in existing markets and it is still difficult to assess the true value and opportunities for energy storage in the current and future grid**
4. **Renewables appear to increase the value of storage, but significant challenges to capture this revenue**
   - Need ISO optimized scheduling in both day ahead and real time
   - Value of avoided starts
   - Impact of price suppression
   - Large benefits do not appear until significant curtailment occurs

Questions?

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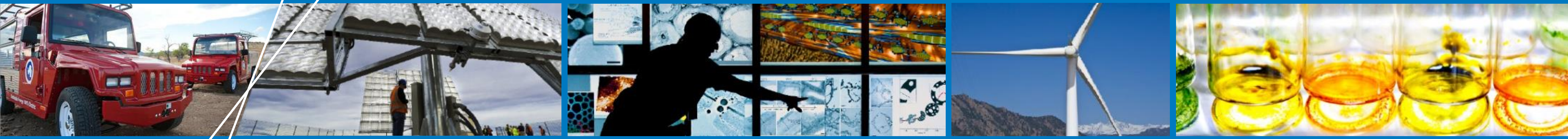

Contact

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Dedicated Renewable Storage?

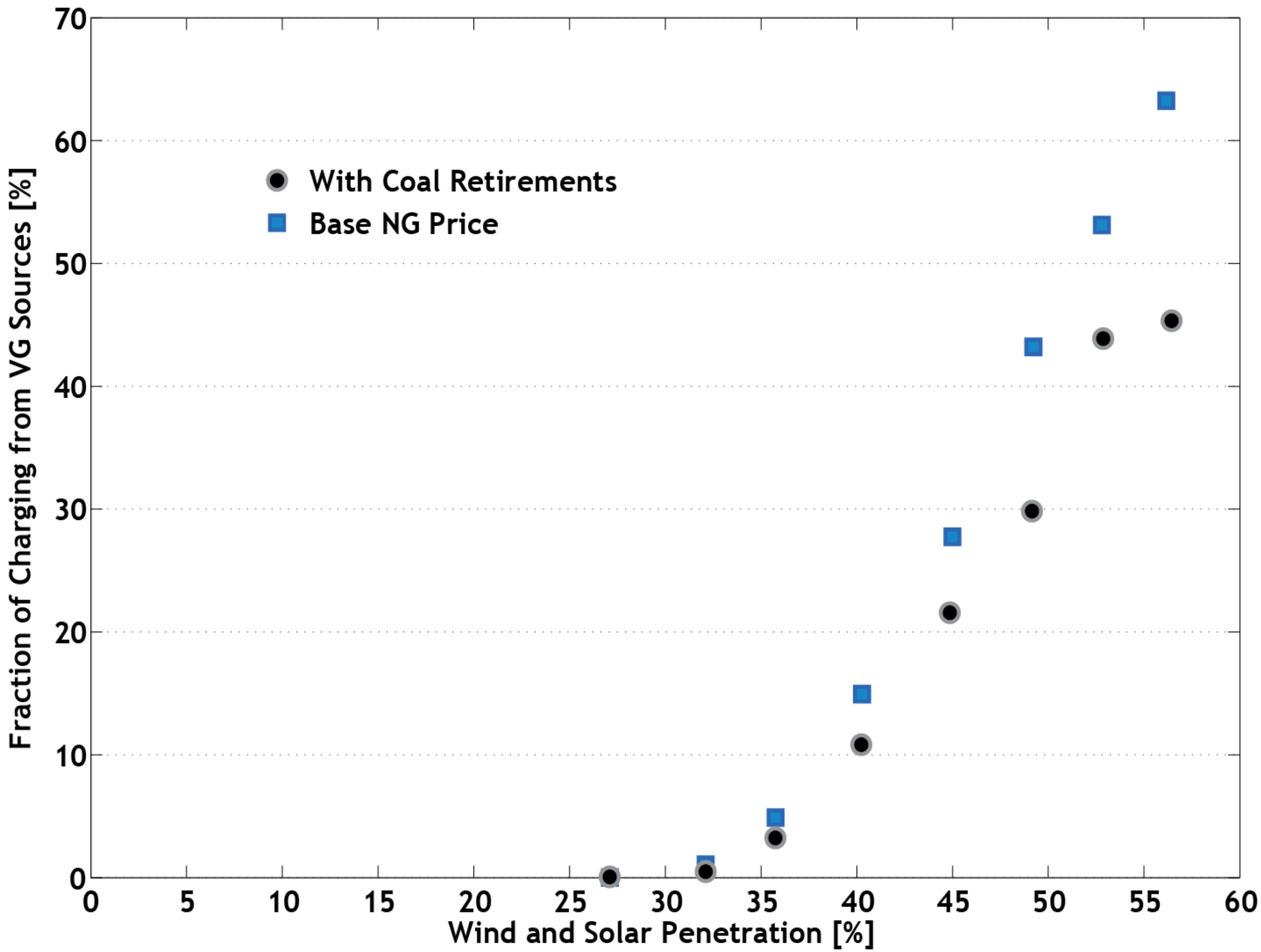
- Dedicated renewable storage is generally a non-optimal use
- Could have scenarios where one storage device is charging while another is discharging simultaneously in the same system
- "Renewable specific" applications are already typically captured in grid operations

RE Specific Application	"Whole Grid" Application
Transmission Curtailment	Transmission Deferral
Time Shifting	Load Leveling/Arbitrage
Forecast Hedging	Forecast Error
Frequency Support	Frequency Regulation
Fluctuation Suppression	Transient Stability

Storage Caveats

- **Efficiency**
  - Not uniformly defined (should be AC-AC, but sometimes stated in terms of DC-DC, which doesn't capture conversion)
  - May not include parasitics
  - CAES (which uses natural gas) and thermal storage cannot be easily compared to pure electricity storage devices such as pumped hydro
- **Cost**
  - Many technologies have not been deployed as large scale, so costs are largely unknown
  - Commodity prices affect estimates from different years
  - Difficult to compare devices that offer different services (power vs. energy)

Charging from Curtailed Wind and Solar



Carbon Emissions