National Renewable Energy Laboratory
Innovation for Our Energy Future

The Role of Energy Storage with Renewable Electricity Generation

Paul Denholm

National Renewable Energy Laboratory

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Outline

- Current Status of Storage
- Impacts of Renewables on the Grid and the Role of Enabling Technologies
- Storage and Flexibility Options for Renewable-Driven Grid Applications
- Conclusions

Current Status of Storage

- ~20GW of pumped hydro storage, 1 CAES plant plus a few batteries and demonstration projects

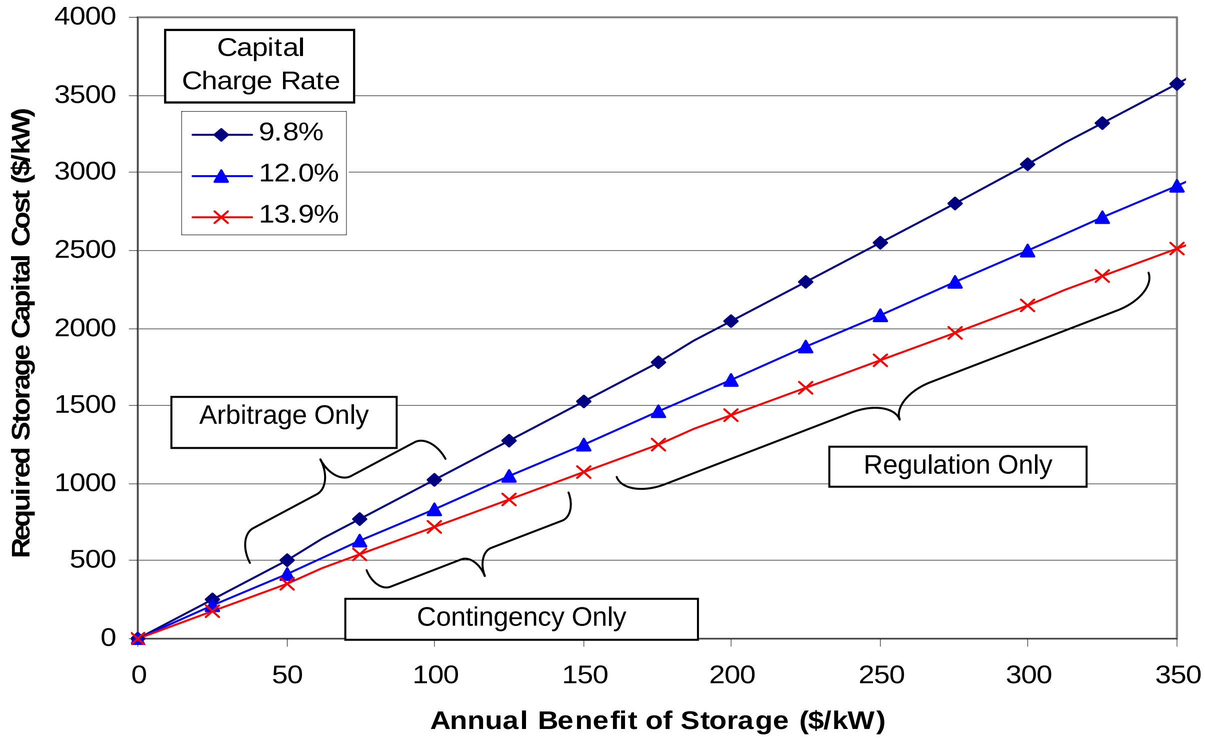
- Revised interest due to a combination of factors including:

  - Advances in storage technologies

  - Energy markets

  - Perceived need for storage with renewables

Value of Energy Storage in U.S. Markets



Relationship between total installed cost and annualized cost

Greatest value is frequency regulation – focus of many applications (flywheels, vehicle to grid). Arbitrage alone is generally insufficient to support most storage technologies, which are generally >$1,000/kW

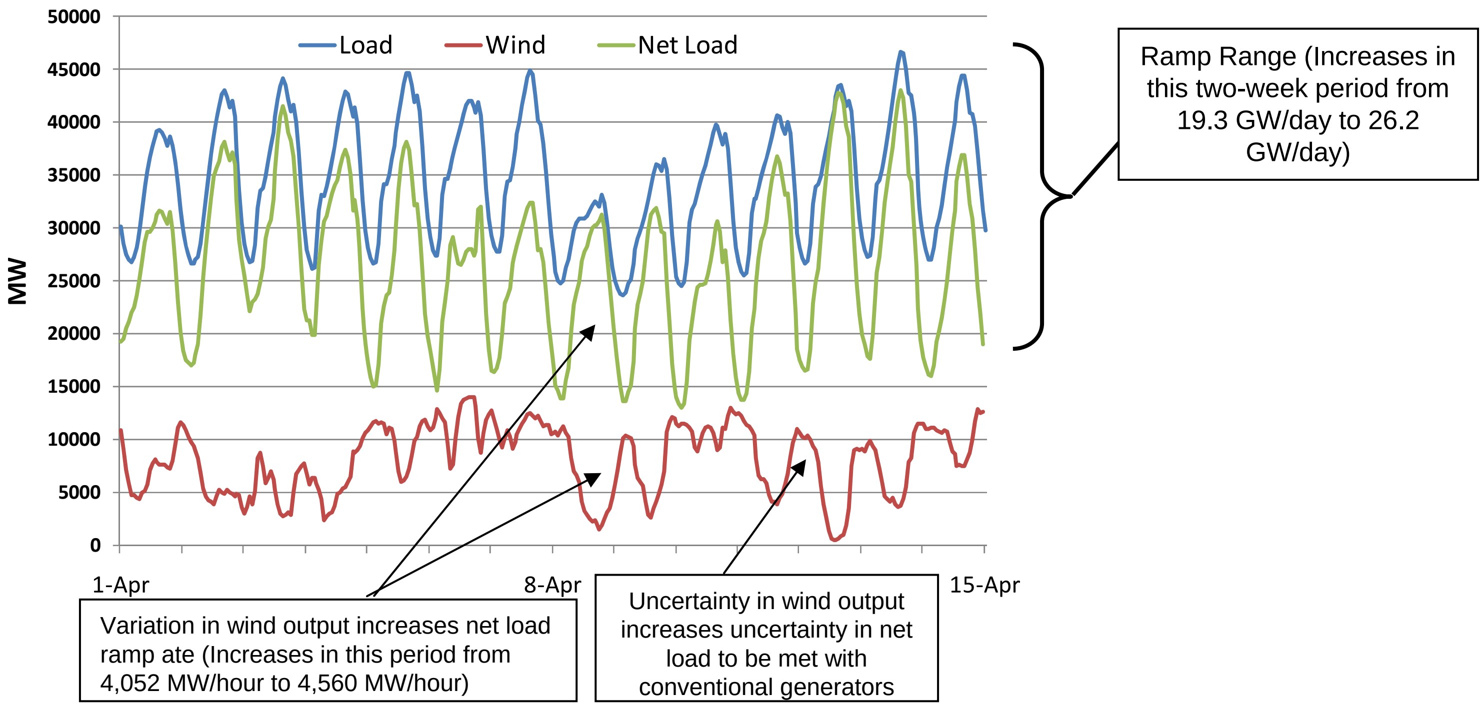
Proper Valuation of Energy Storage

- Energy storage is undervalued in the current grid
  - Largely answers the question (along with high capital costs) “Why isn't their more storage on the grid”
- Many studies start and stop with a basic arbitrage value
  - This will virtually guarantee that no storage technology in existence will be cost effective
- Capture multiple value streams
  - Capacity
  - Load leveling/arbitrage
  - Reducing cycling
  - Ancillary services
- Distribution storage benefits
  - Avoided infrastructure and losses
  - Local congestion

Impacts of Renewables on the Grid

- Storage is often perceived as "necessary" for renewables to achieve a large (>10%? >20%?) penetration.
- Renewables are seen as a source of value for storage
- Can renewables be used without storage?
- How do renewables impact the grid?

Impacts of Renewables on the Grid

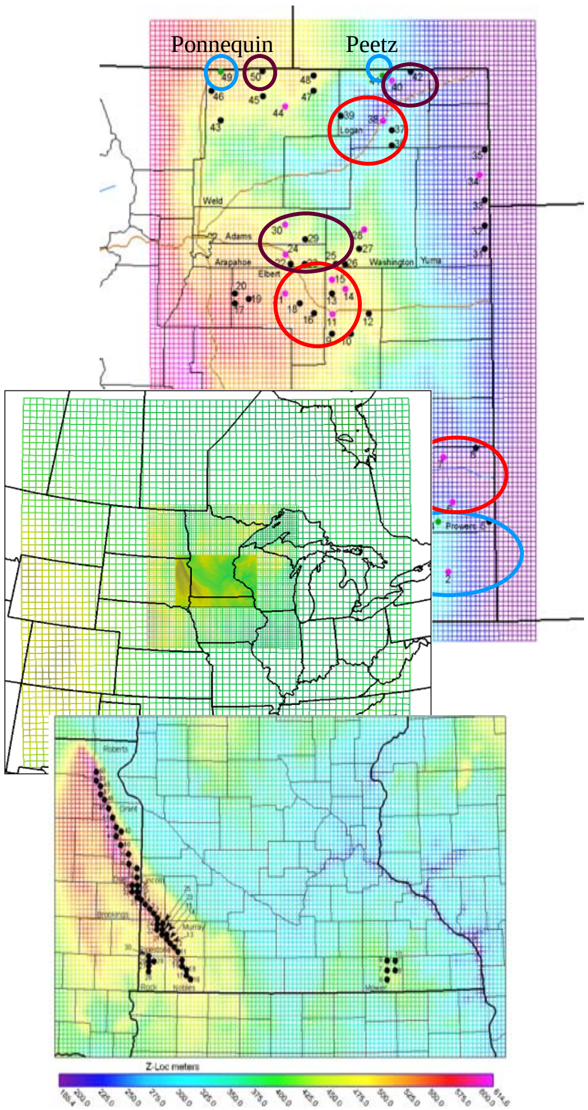


Four major impacts of variable generation (VG) on the grid:

1) Increased need for frequency regulation
2) Increase in hourly ramp rate
3) Increase in uncertainty of net load
4) Increase in ramp range

Costs of Wind Integration

- Simulate system with and without solar and wind
  - Use unit commitment software includes existing generation mix, transmission system
  - Use lots of wind and solar simulations to consider spatial diversity
  - May involve substantial costs
- Evaluate costs of:
  - Additional regulation reserves
  - Additional load following
  - Wind uncertainty



Costs of Wind Integration

Date	Study	Wind Capacity Penetration (%)	Regulation Cost ($/MWh)	Load-Following Cost ($/MWh)	Unit Commitment Cost ($/MWh)	Other ($/MWh)	**Total Oper. Cost Impact ($/MWh)**
2003	Xcel-UWIG	3.5	0	0.41	1.44	Na	**1.85**
2003	WE Energies	29	1.02	0.15	1.75	Na	**2.92**
2004	Xcel-MNDOC	15	0.23	na	4.37	Na	**4.6**
2005	PacifiCorp-2004	11	0	1.48	3.16	Na	**4.64**
2006	Calif. (multi-year)[a]	4	0.45	trace	trace	Na	**0.45**
2006	Xcel-PSCo[b]	15	0.2	na	3.32	1.45	**4.97**
2006	MN-MISO[c]	36	na	na	na	na	**4.41**
2007	Puget Sound Energy	12	na	na	na	na	**6.94**
2007	Arizona Pub. Service	15	0.37	2.65	1.06	na	**4.08**
2007	Avista Utilities[d]	30	1.43	4.4	3	na	**8.84**
2007	Idaho Power	20	na	na	na	na	**7.92**
2007	PacifiCorp-2007	18	na	1.1	4	na	**5.1**
2008	Xcel-PSCo[e]	20	na	na	na	na	**8.56**

[a] Regulation costs represent 3-year average.

[b] The Xcel/PSCO study also examine the cost of gas supply scheduling. Wind increases the uncertainty of gas requirements and may increase costs of gas supply contracts.

[c] Highest over 3-year evaluation period. 30.7% capacity penetration corresponding to 25% energy penetration

[d] Unit commitment includes cost of wind forecast error.

[e] This integration cost reflects a $10/MMBtu natural gas scenario. This cost is much higher than the integration cost calculated for Xcel-PSCo in 2006, in large measure due to the higher natural gas price: had the gas price from the 2006 study been used in the 2008 study, the integration cost would drop from $8.56/MWh to $5.13/MWh.

Conclusions of Wind Integration Studies

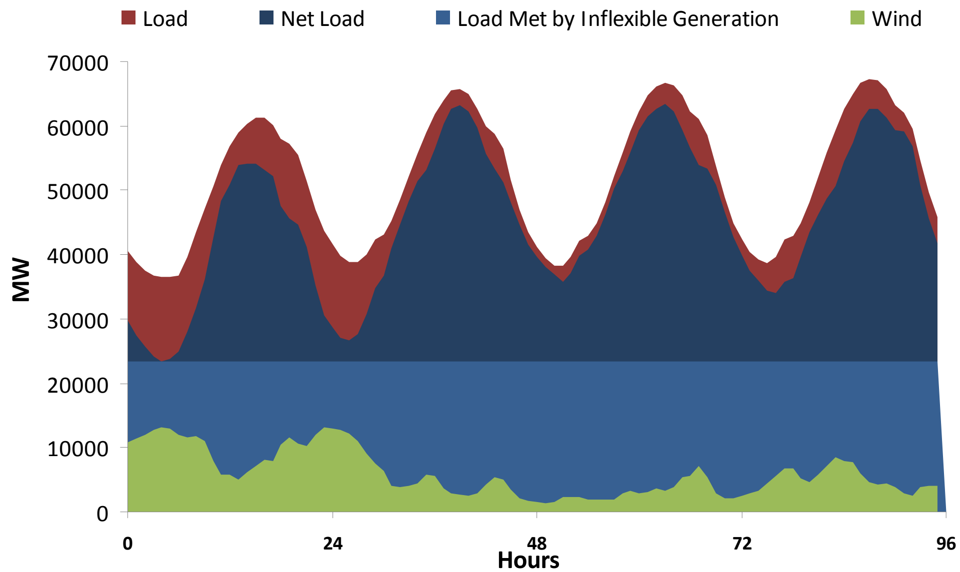
(<30% Penetration)

- Challenges are unit commitment, regulation and load following
- Integration costs are modest (typically less than $5/MWh)
- Increased variability can be accommodates by existing generator flexibility and other “low-cost” flexibility such as increased balancing area cooperation (balancing wind generation and load over larger areas to “share” the increased variability.
- Spatial diversity smooth's aggregated wind output reducing short-term fluctuations to hour time scales
- Storage would “help” but is not needed, and the integration costs would not “pay” for currently expensive storage technologies.

Limits to VG Penetration - Curtailment

- At high penetration, economic limits will be due to curtailment
  - Limited coincidence of VG supply and normal demand
  - Minimum load constraints on thermal generators
  - Thermal generators kept online for operating reserves
- Results from EWITS and WWSIS, along with other studies, indicate that beyond 30% VG, new sources of flexibility will be needed

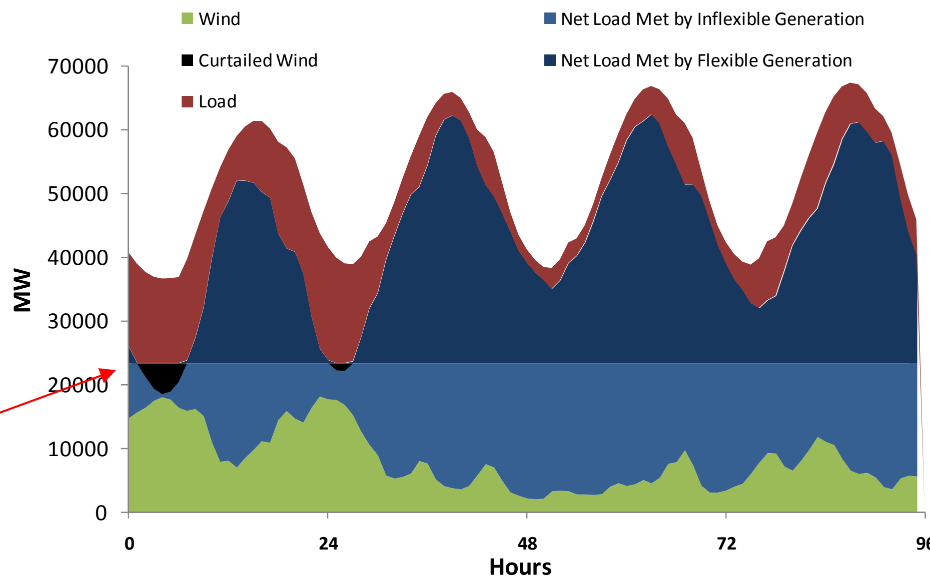
High Penetration Limits



Dispatch with low VG penetration (wind providing 8.5% of load)

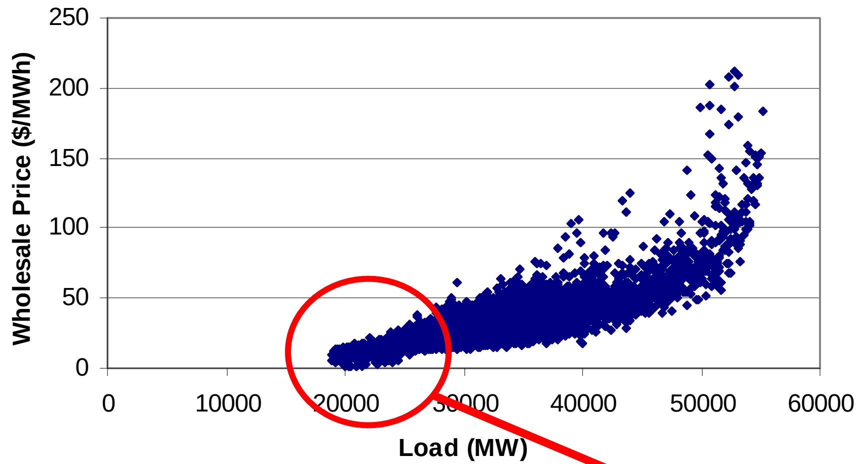
Dispatch with higher VG penetration (wind providing 16% of load)

Inflexible systems may be unable to accommodate large amounts of wind



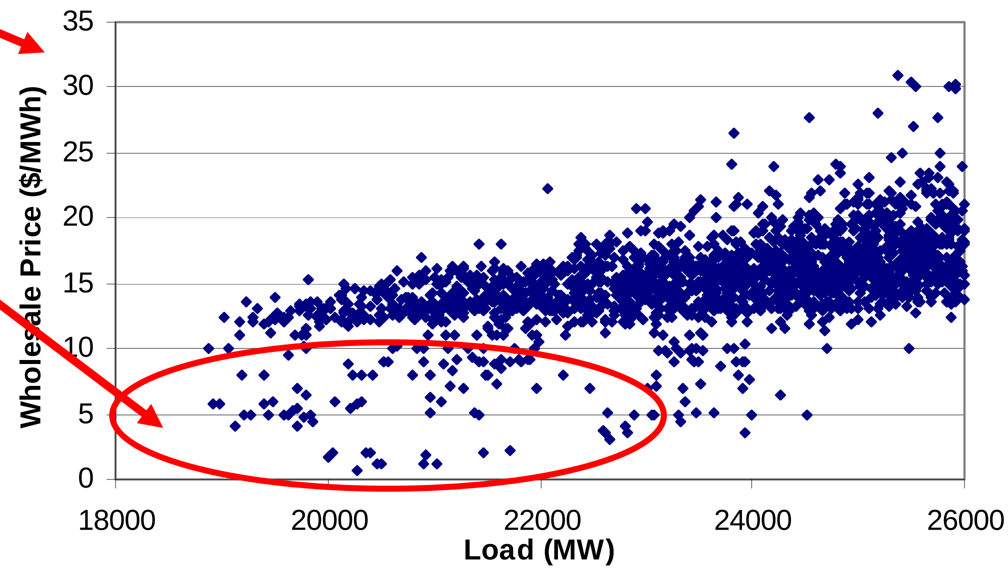
Current System Flexibility

Limited by Baseload Capacity



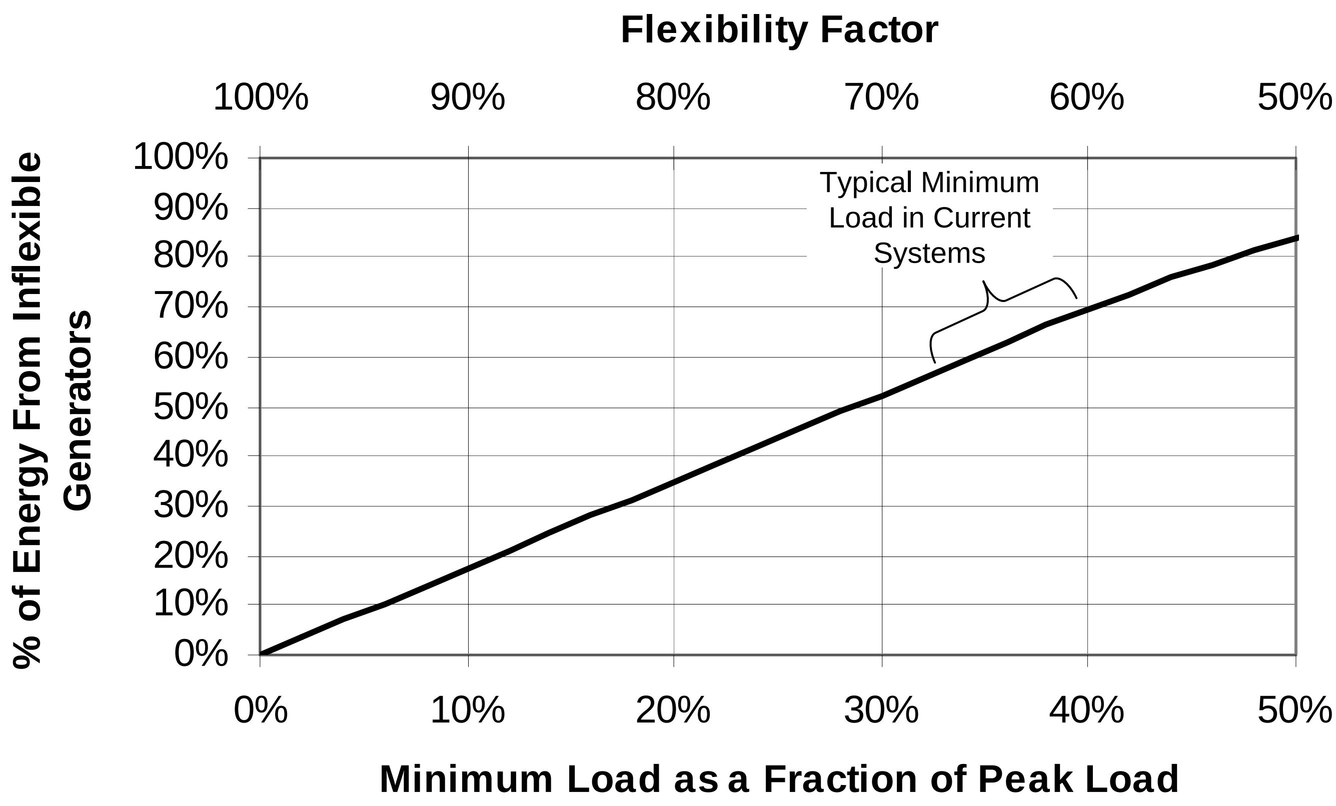
Price/Load Relationship in PJM

Below Cost Bids



Plant operators would rather sell energy at a loss than incur a costly shutdown. Wind may be curtailed under these conditions

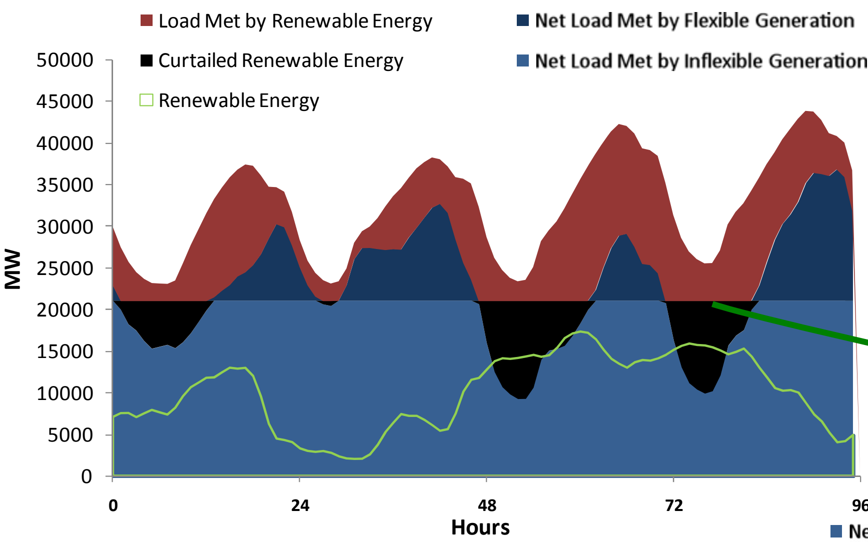
Increased Flexibility is Required



At current minimum loads, baseload generators provide 60-70% of generation, leaving only 30%-40% for VG.

Decreased Minimum Load

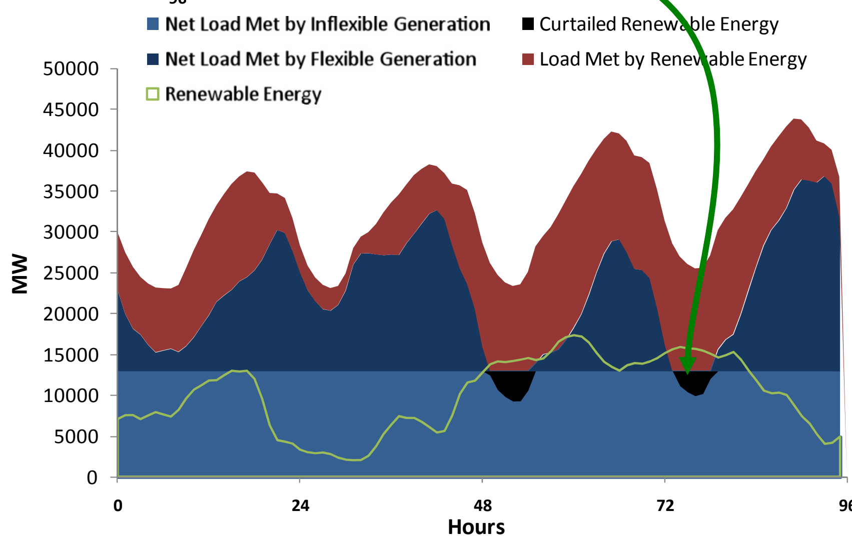
Needed to accommodate greater amounts of VG without significant curtailment



Inflexible System - Minimum Load of 21 GW (65% FF)

Decreased curtailment

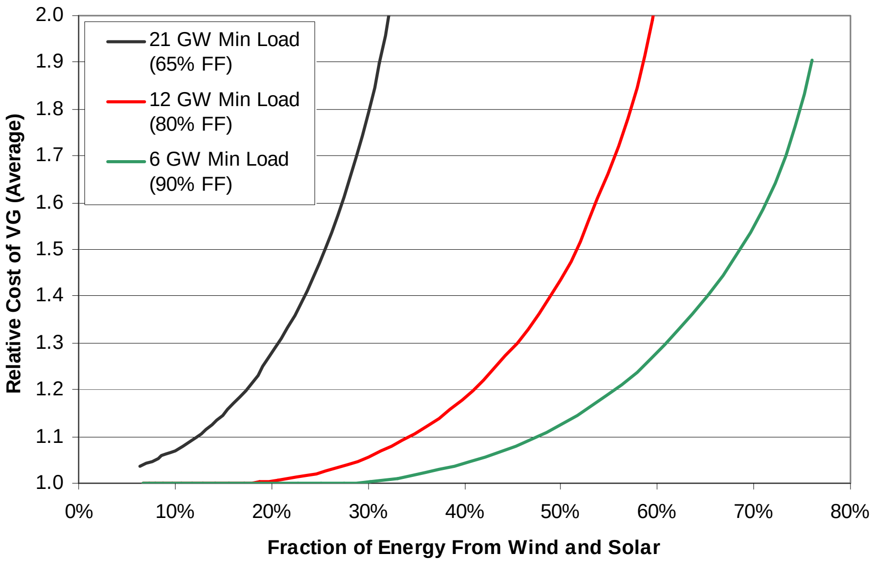
More Flexible System -Minimum Load of 13 GW (80% FF)



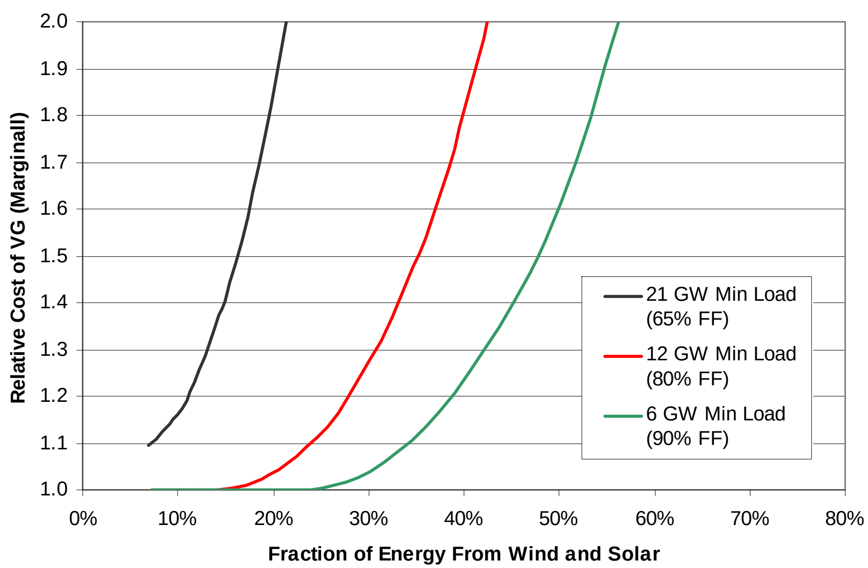
Simulations based on 2005 load and weather

VG Curtailment

May Result In Unacceptably High Costs at High Penetration



Relative cost of VG – average (top chart) and marginal (bottom chart) – as a function of VG penetration for different system flexibilities in ERCOT



Renewables-Driven Grid Applications

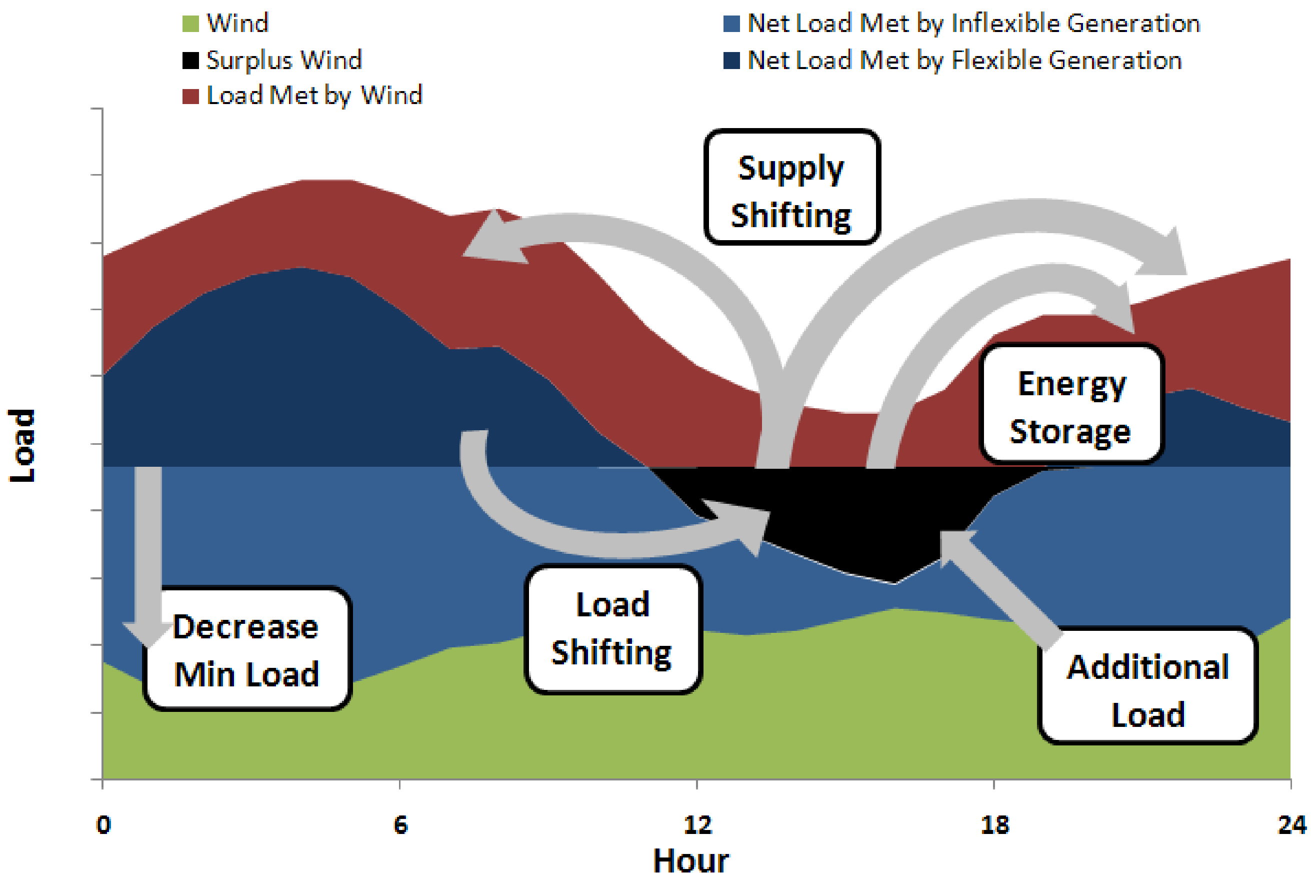
Storage and Flexibility Options

- At high penetration of VG, additional flexibility is required
- What are the options?

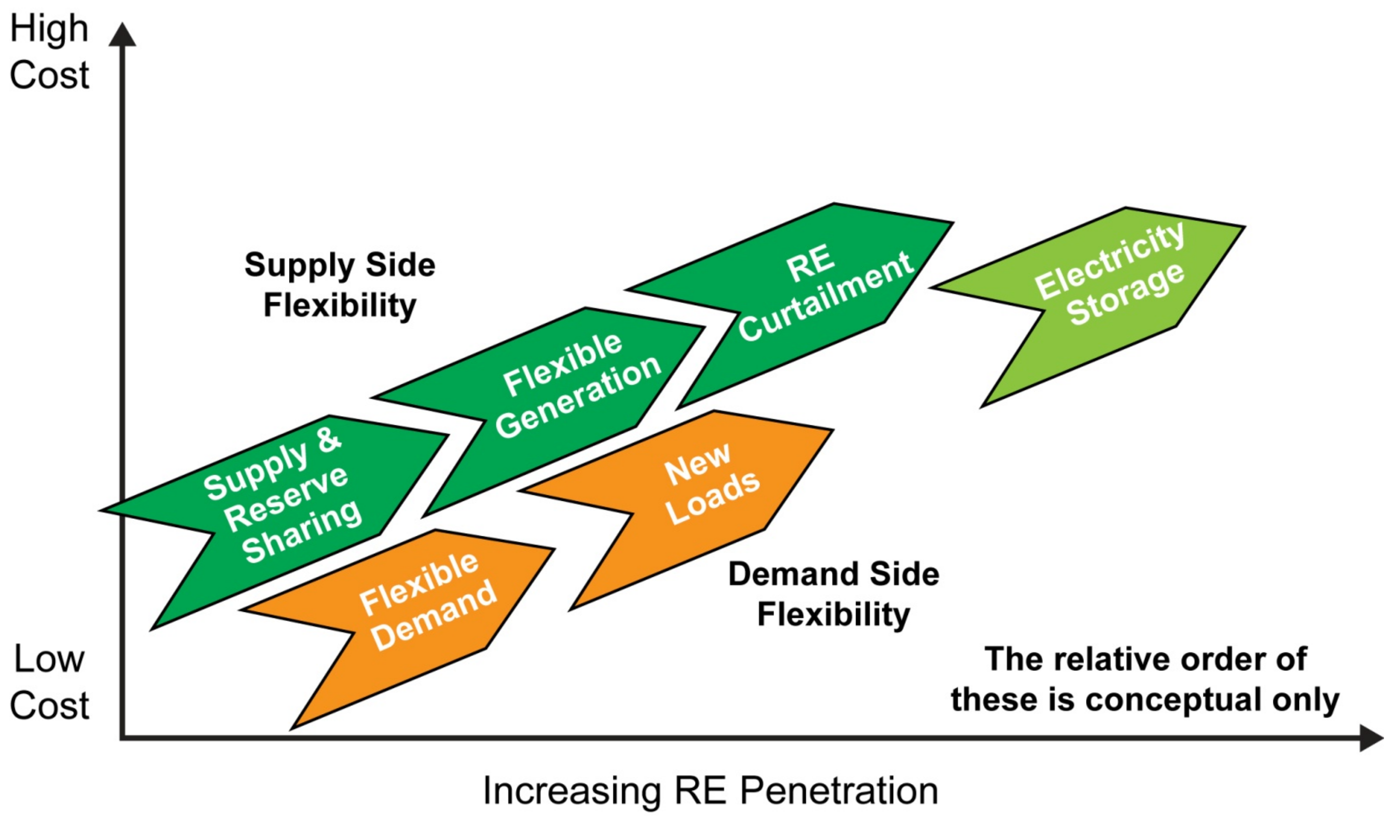
Renewables-Driven Grid Applications

Storage and Flexibility Options *(cont.)*

While storage provides an "obvious" answer to the problem of supply-demand coincidence, there are a number of options



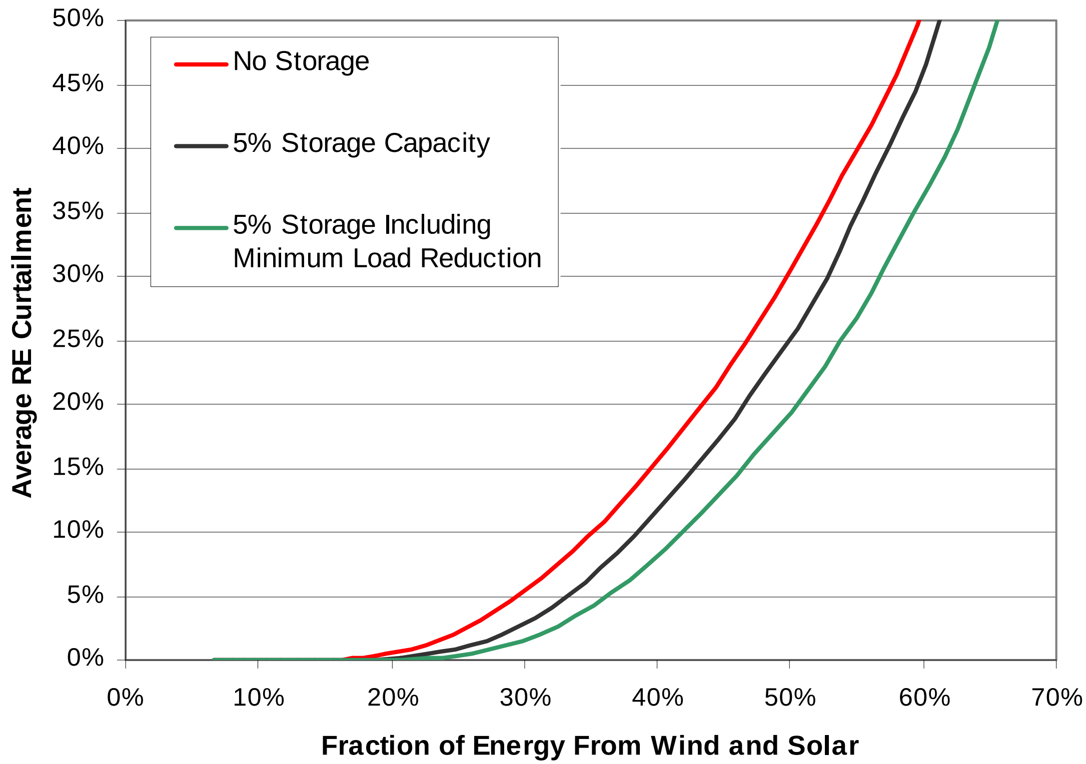
Flexibility Supply Curve



The cost of all options has yet to be determined. Currently, energy storage is expensive and incurs the penalty of round-trip losses.

Based on an original by Nickell 2008

Energy Storage Can Reduce VG Curtailment



FF=80% (12 GW min load)

Energy storage can reduce curtailment both by shifting otherwise unusable generation, and also increase system flexibility by providing reserves (reducing the need for partially loaded thermal generators) and replacing "must-run" capacity

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)

Conclusions

- The role of storage is an economic issue – does the value of storage exceed its benefits?
- 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
- Renewables increase the value of storage, but the current grid can accommodate substantially increased amount of renewables with options that appear to be lower cost than new dedicated storage
- At penetrations of wind and solar that exceed 30%, increased curtailment will require new sources of grid flexibility
- New models and analysis will be required to evaluate the benefits of energy storage in the future electric grid.