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Massachusetts Institute of Technology

Long Duration Storage for Baseload Wind

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Wind Integration—Developer's Perspective

- The bad news
  - Competing against low-cost gas and depreciated coal plants in a over-supplied power market is very tough
  - Wide area integration of multiple wind farms to achieve "capacity" sounds good, but even if true, it is hard for the developer to capture this value
  - Policy supports (ITC, PTC, RPS, Carbon Price) are undependable create wrong incentives
- The Good News
  - Turbine and development costs are coming down fast
  - Turbine designs improving-almost breakthroughs!
  - Wind farm O&M costs-meaningful reductions likely

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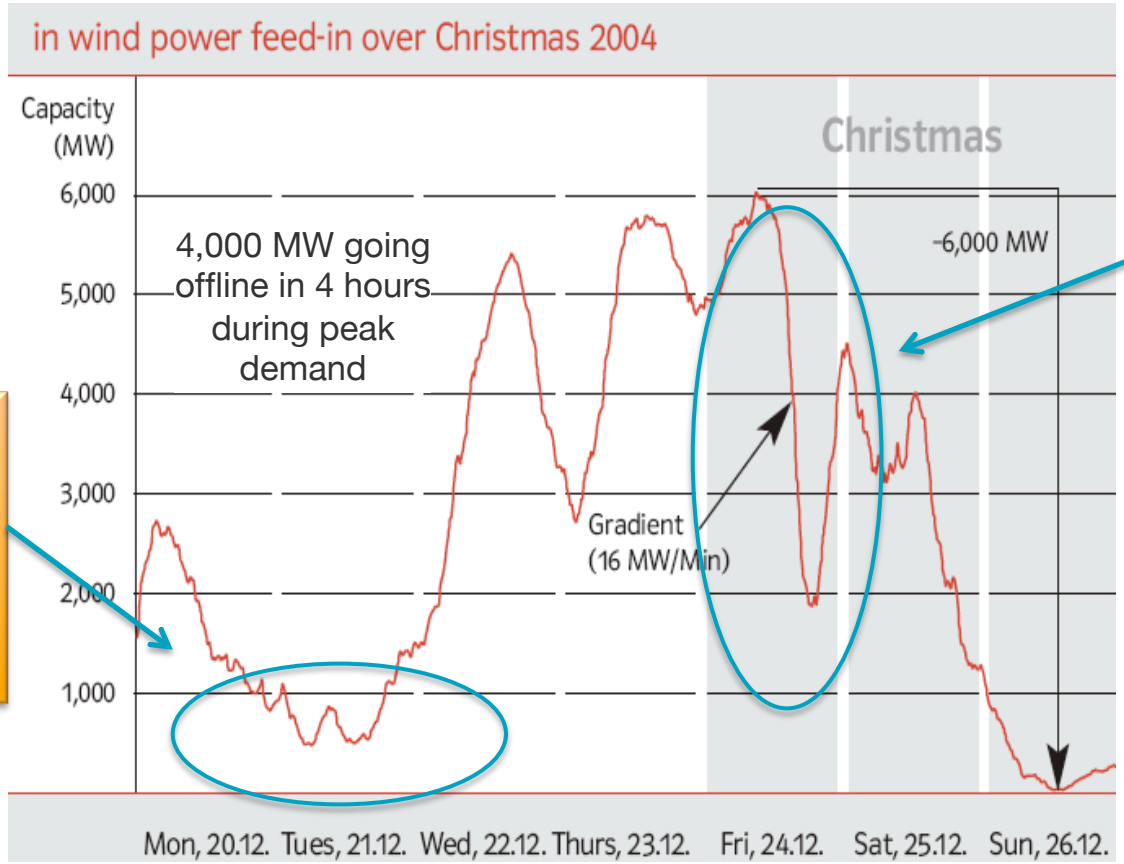
Firming wind is not easy

In addition to large capacity, firming wind requires a system that can constantly switch from storing to generating across large power swings



More granular resolution of wind generation shows that a firming system must be able to alternate frequently between storage and generation if it is going to meet PPA demands with limited loses

The significant swings in wind turbine output, present in all wind farms, drives the need for a system that can address dramatic ramping events

Source: E.ON Netz GmbH 2005 Wind Report

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Can wind be transformed into a firm, baseload resource?

If cost effective—this would address many issues

- Compete in the firm power market—much bigger
- Viable alternative to replace retiring coal
- Doesn't require spinning reserve backup
- Increases utilization of existing and new long-distance transmission
- Incidentally, firm baseload is one of the things Utilities WANT to buy

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Transforming intermittent resource into baseload raises many issues

- Hourly, daily, weekly, monthly, seasonal energy distribution in the wind resource
- Duration of storage
- Responsiveness of storage (ramping)
- Penalties for missing dispatch
- Transmission/interconnection size

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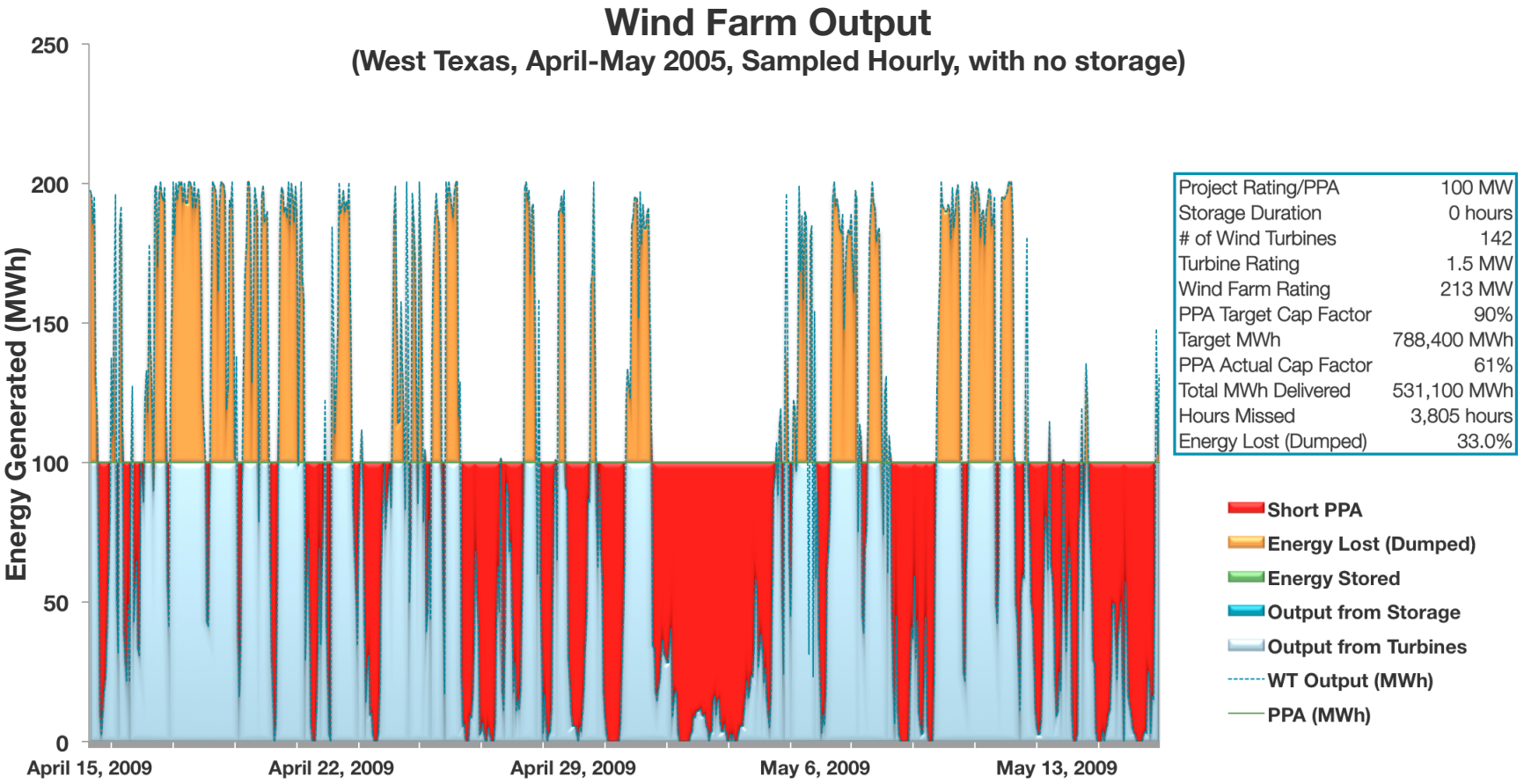
No Storage



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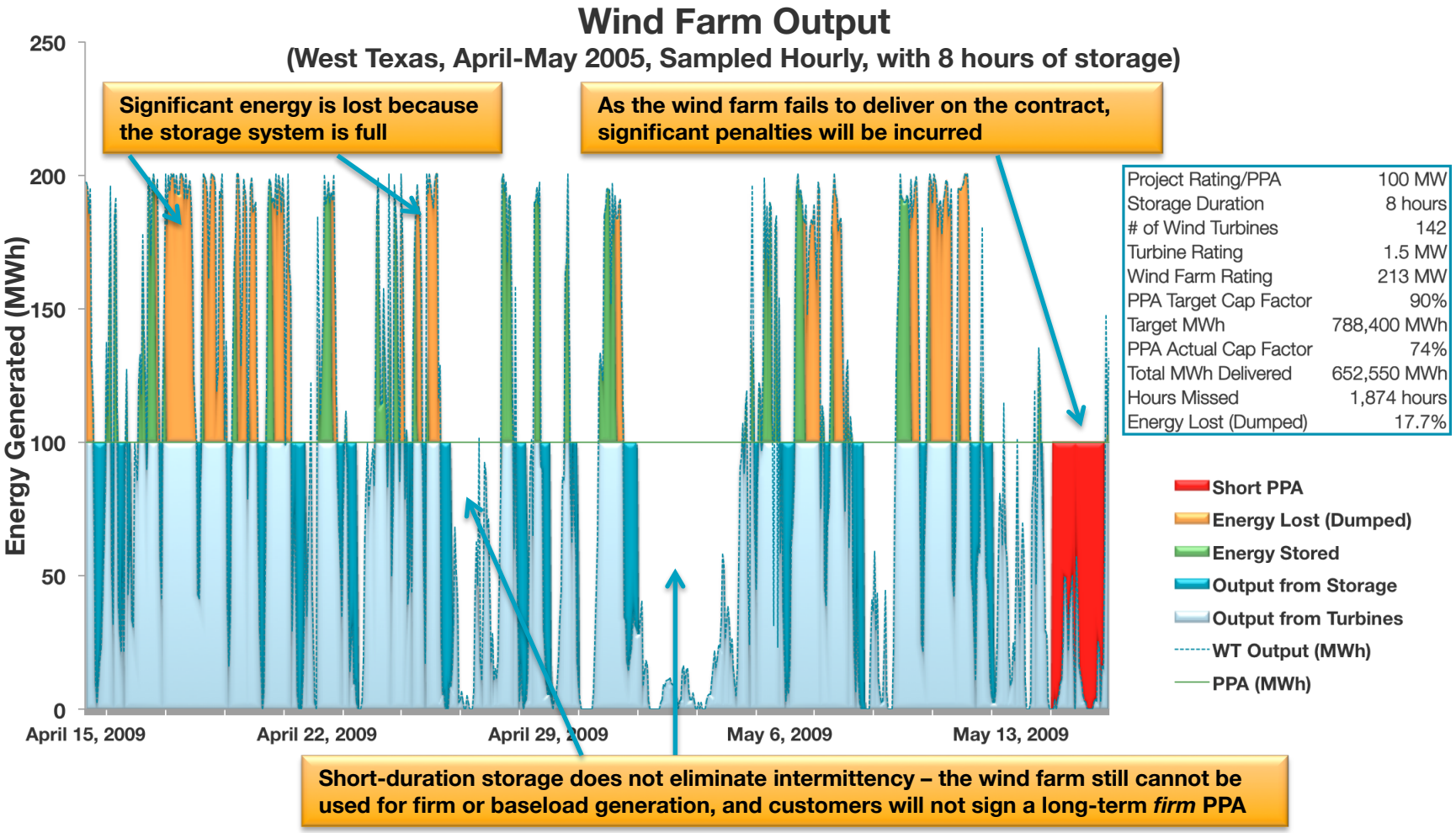
Short Duration Storage Is Insufficient For Firm PPAs

Battery storage can provide smoothing, but will not prevent significant curtailment, causing energy losses and triggering penalties for being unable to meet firm power contract



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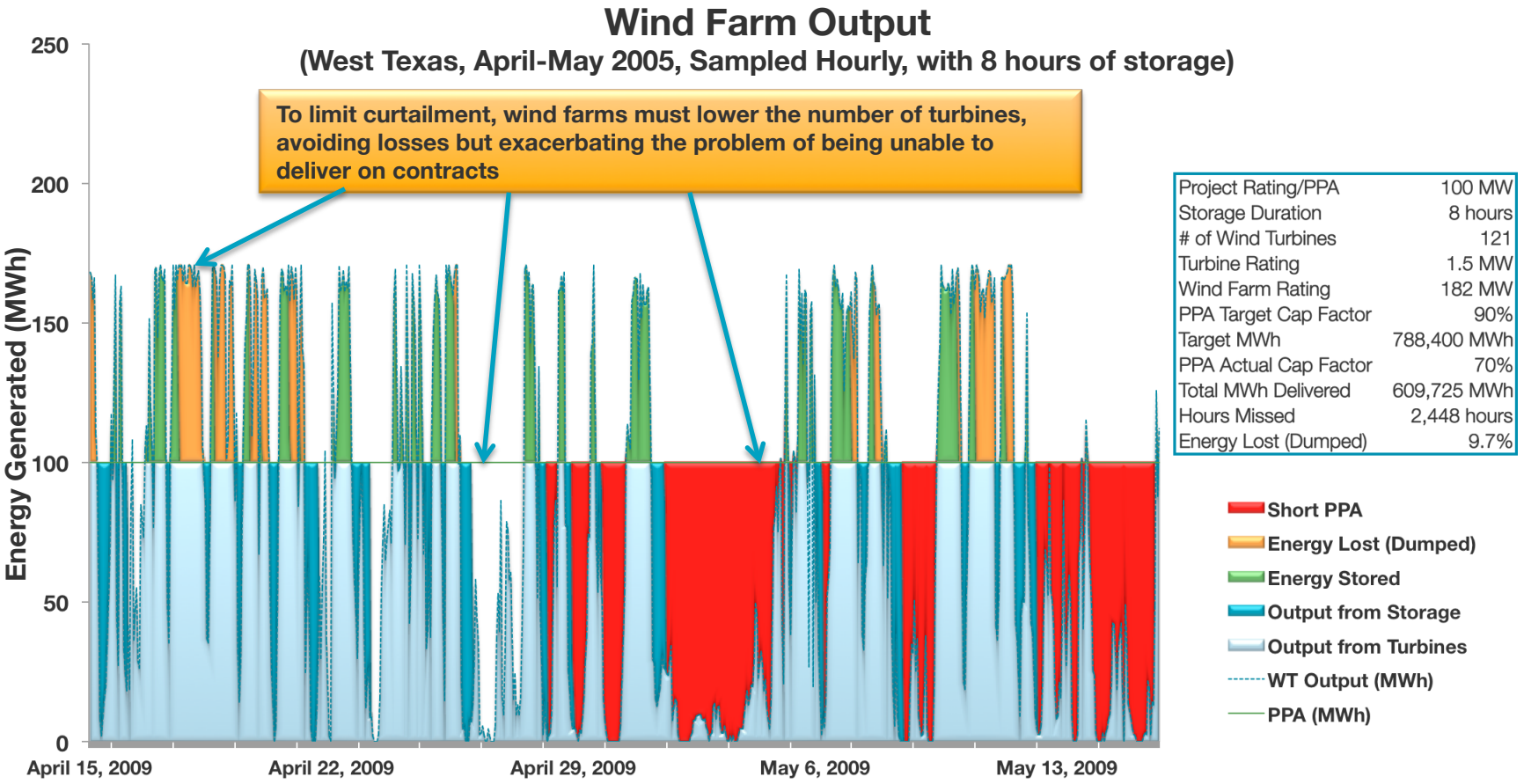
Short Duration Storage Controlled for Energy Losses

While increasing the number of turbines could help to meet PPA requirements, as storage hits capacity, energy losses due to curtailment become infeasible



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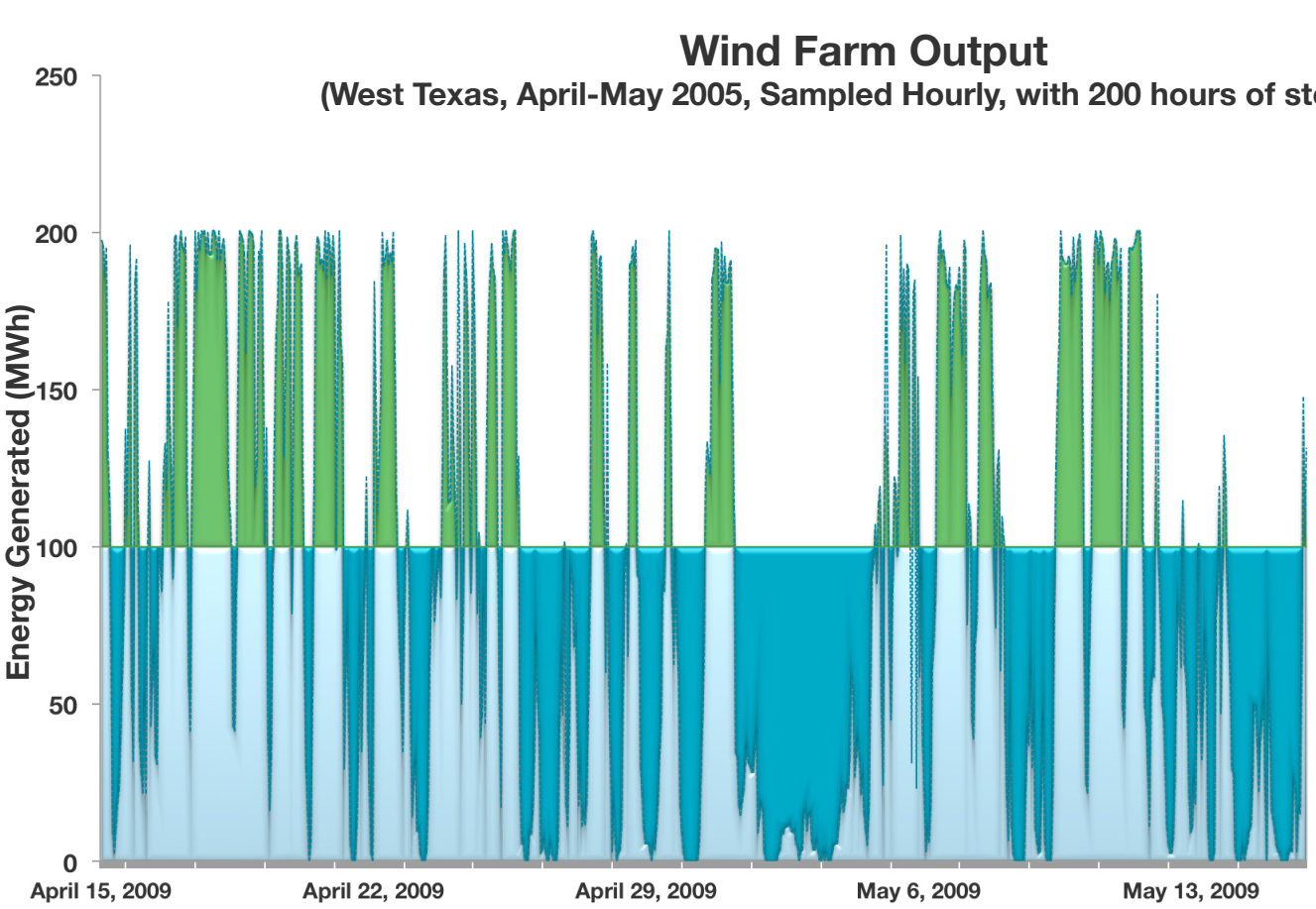
Baseload Wind Projects Can Sign Firm Power Contracts

Large storage durations transform intermittent renewable generation into dispatchable power with a predictable output profile similar to fossil-fuel generators



Large duration storage systems limit losses, enabling more than 90% of energy generated by the wind turbines to be used

Project Rating/PPA	100 MW
Storage Duration	200 hours
# of Wind Turbines	142
Turbine Rating	1.5 MW
Wind Farm Rating	213 MW
PPA Target Cap Factor	90%
Target MWh	788,400 MWh
PPA Actual Cap Factor	90%
Total MWh Delivered	791,602 MWh
Hours Missed	0 hours
Energy Lost (Dumped)	0.0%

The wind farm is able to meet the firm PPA required output year-round

- Energy Stored
- Output from Storage
- Output from Turbines
- WT Output (MWh)
- PPA (MWh)

Long duration storage enables wind farms to provide dispatchable power at much higher contracted prices

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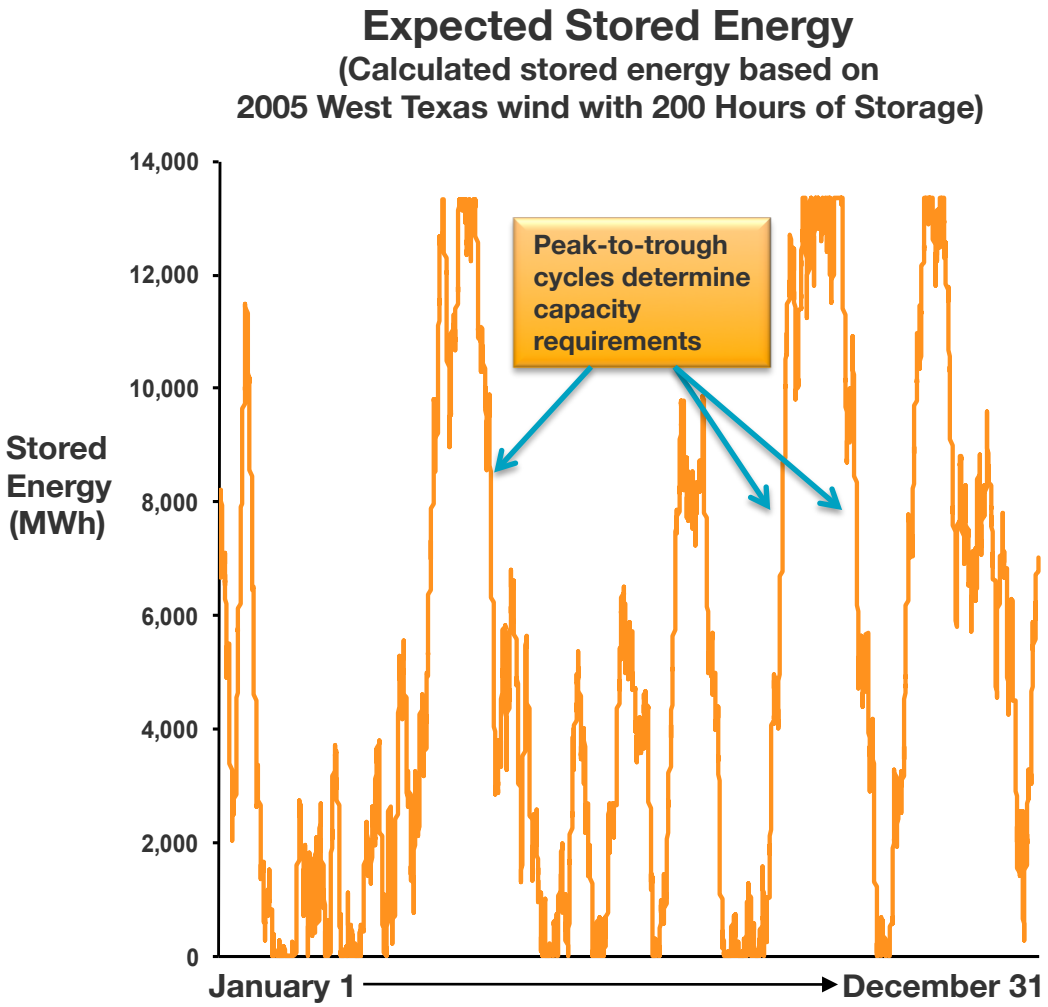
Wind variability drives storage capacity requirements

Long duration (100-300 hours) enables energy storage to transform intermittent renewables into firm baseload generation



- Seasonal, monthly, and week-to-week variation in wind generation output causes long periods of under or over-production
- During low wind periods, storage must generate power from reserves for long durations, nearly exhausting its stored capacity of energy
- During high wind periods, storage systems must absorb large quantities of excess energy for long periods of time

The ability to transform a wind farm into dispatchable output requires 100 to 300 hours of storage capacity

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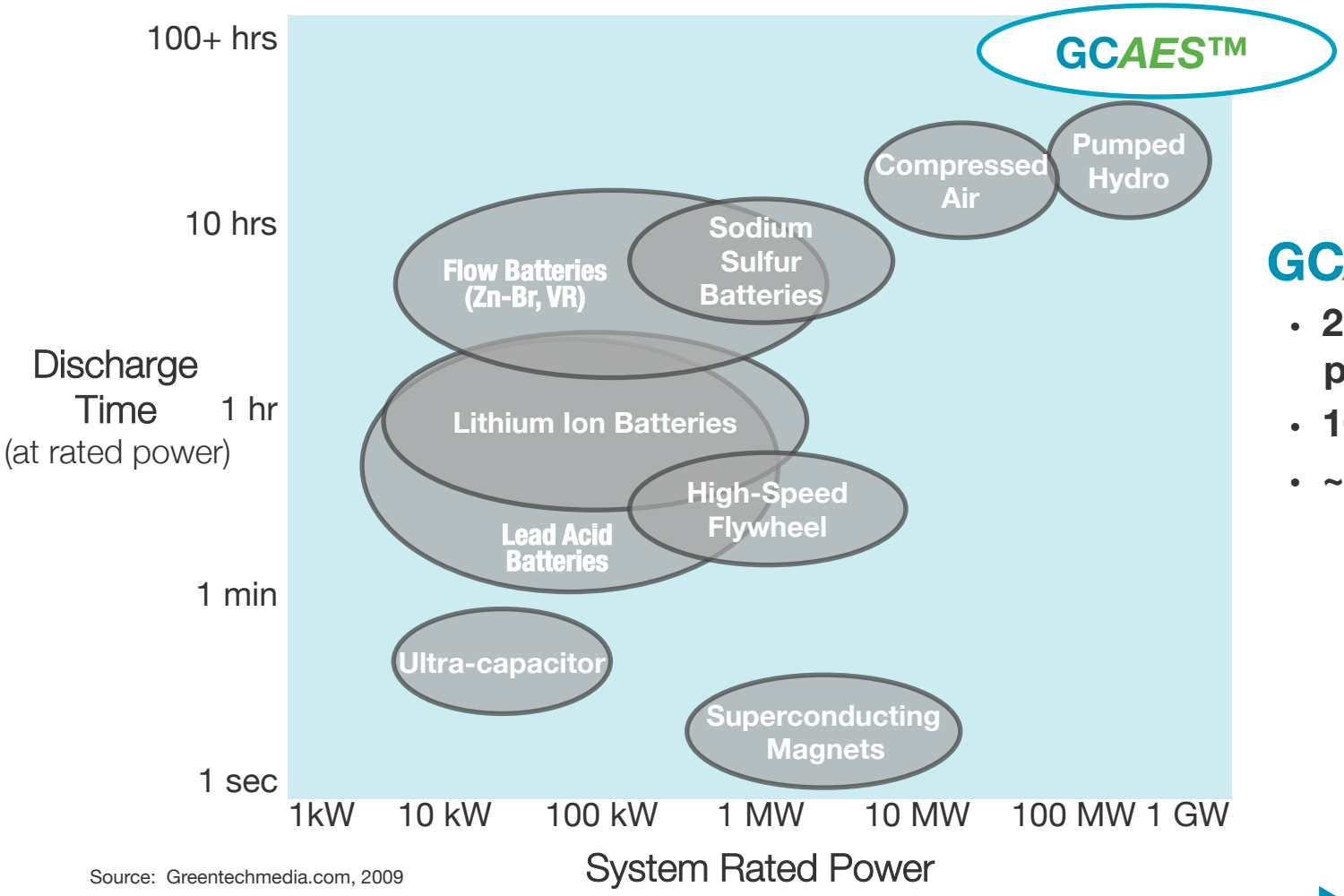
Energy Storage Power and Discharge Times

GC*AES*™ is the only proven storage technology that combines high system-rated power with long discharge time capabilities



GC*AES*™

- **2MW Rated Power per module**
- **100+ hours storage**
- **~$1,200/kW CapEx**

Source: Greentechmedia.com, 2009

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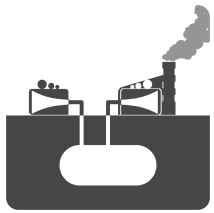
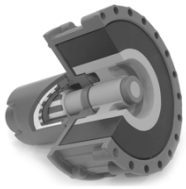
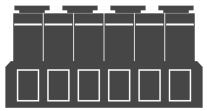
Comparison of Utility-Scale Storage Technologies*



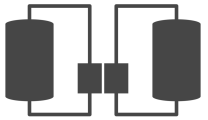
conventional CAES



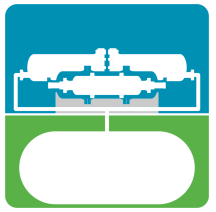
flywheel



NaS battery



flow battery



GC*AES*™

CO2-free generation	no	yes	yes	yes	yes
efficiency rating	**	80% - 85%	75% - 80%	70% - 75%	70% - 75%
response time	~15 minutes	< 1 second	< 1 second	< 1 second	< 1 second
energy storage duration	100+ hours	~10 minutes	6-8 hours	< 6 hours	100+ hours
ancillary services	No	limited	yes	yes	yes
modularity	limited	yes	yes	yes	yes
cap ex $/kW	$800 - $1,200/kW	$3,000/kW	$2,500 - $3,500/kW	$2,000 - $2,500/kW	$1,000/kW
cap ex $/kWh	N/A	~12,000/kWh	~$500/kWh	~$400/kWh	$10 - $15/kWh

**0.8kWH + 4300 btu = 1kWh (approximately $25 - $35/MWh)

*Source: Technology Insights February 2009 Report — *Assessment of the GC Advanced Energy Storage System*

- In order to be effective in any power market, a utility-scale storage system for wind must be highly efficient across a wide operating range, low-cost, and extremely durable
  - ***to date no system has satisfied all three requirements***

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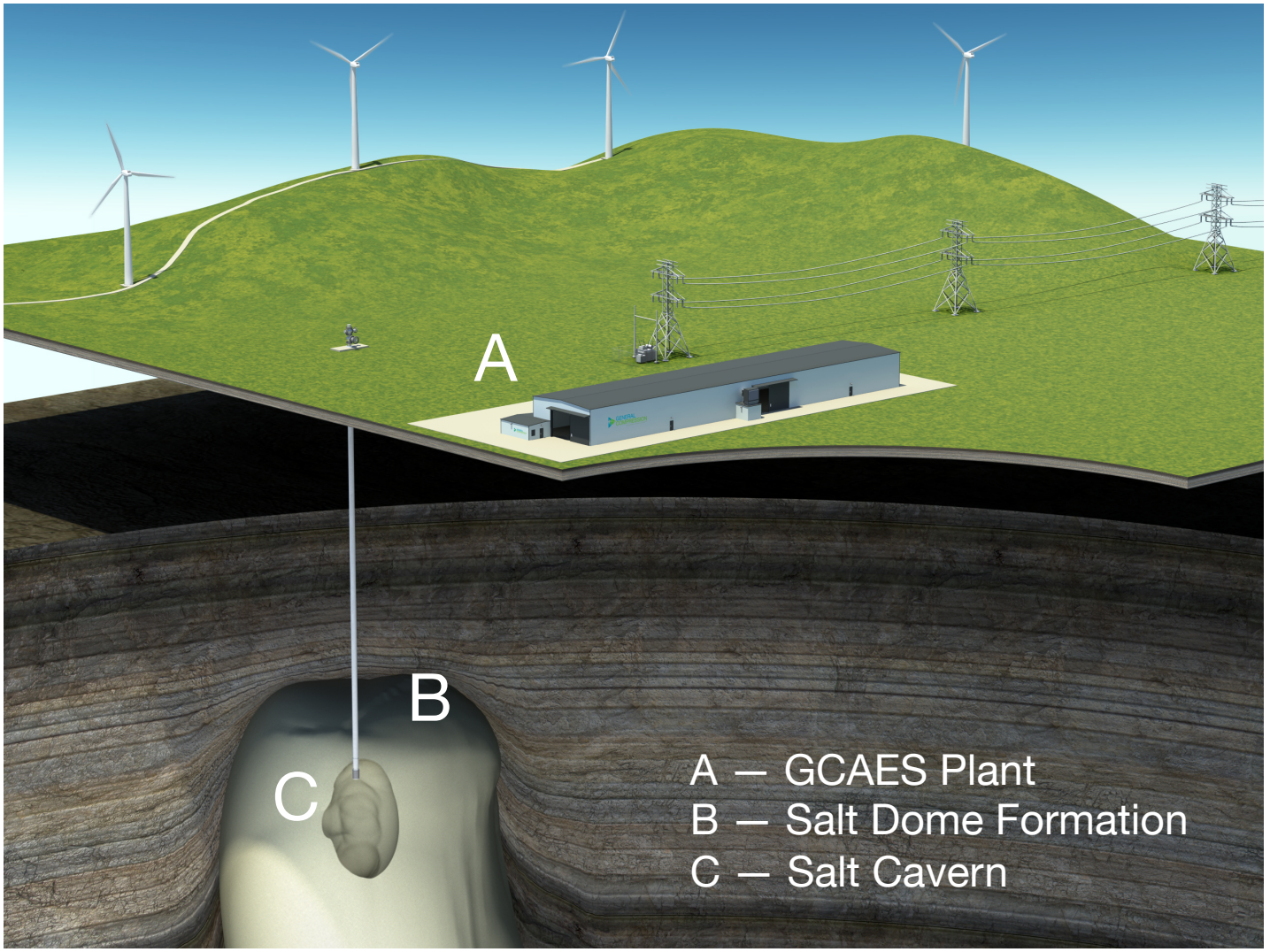
Illustrative GC*AES*™ Wind Integration Project



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