Renewable Energy Grid Integration:

Overview of Key Issues

EC-LEDS Grid Integration Team

16 December 2014

This Presentation Reviews

- Grid integration challenges
- Flexible Power Systems
- Myths and Frequently Asked Questions

Learning Objectives

- Understand challenges to renewable energy grid integration
- Define key terms used in grid operations and integration
- Identify sources of power system flexibility
- Understand system impacts of high RE:
  - Stability
  - Storage and Back-Up
  - GHG Emissions
  - Cost

Why is grid integration an important topic?

Introduction

<u>Trends:</u>

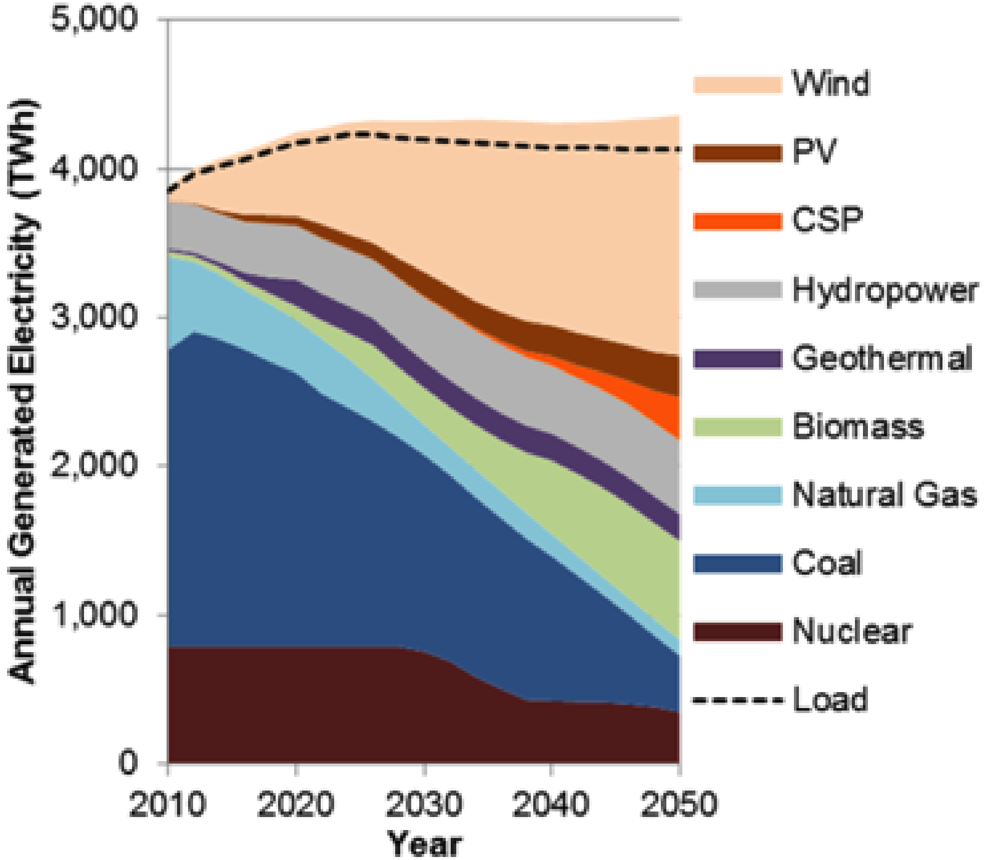
Urbanization

Increasing energy demand

Need to reduce GHG Emissions

Every power system has characteristics that promote and inhibit integration of variable renewable energy (RE)

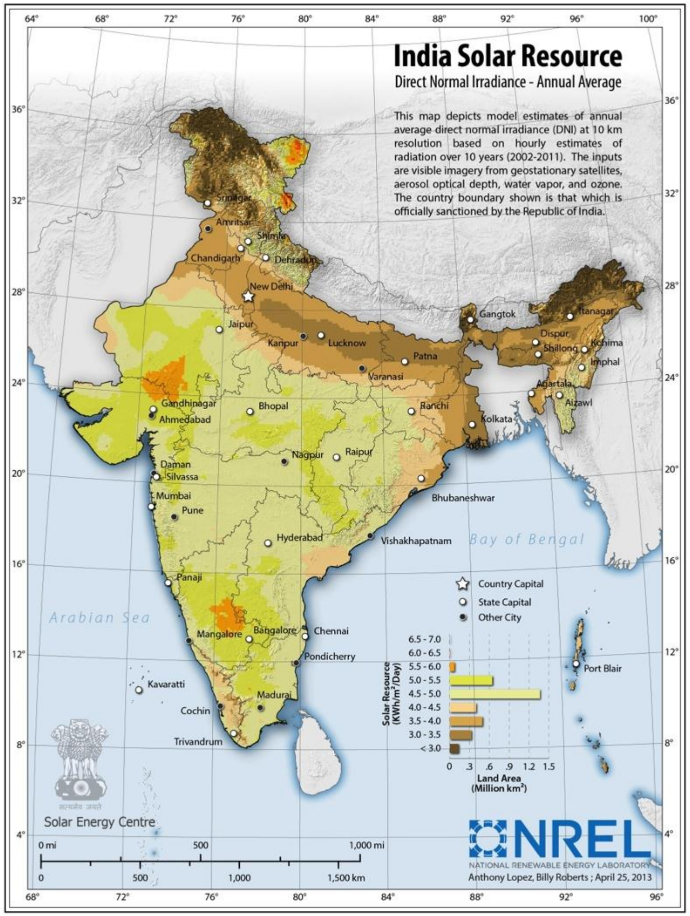
Grid integration is the art of solving challenges associated with variable RE, to enable higher deployment



Source: "Renewable Energy Futures" 2012

Integrating wind and solar energy resources requires an evolution in power system planning

RE is variable, uncertain, and geographically dispersed

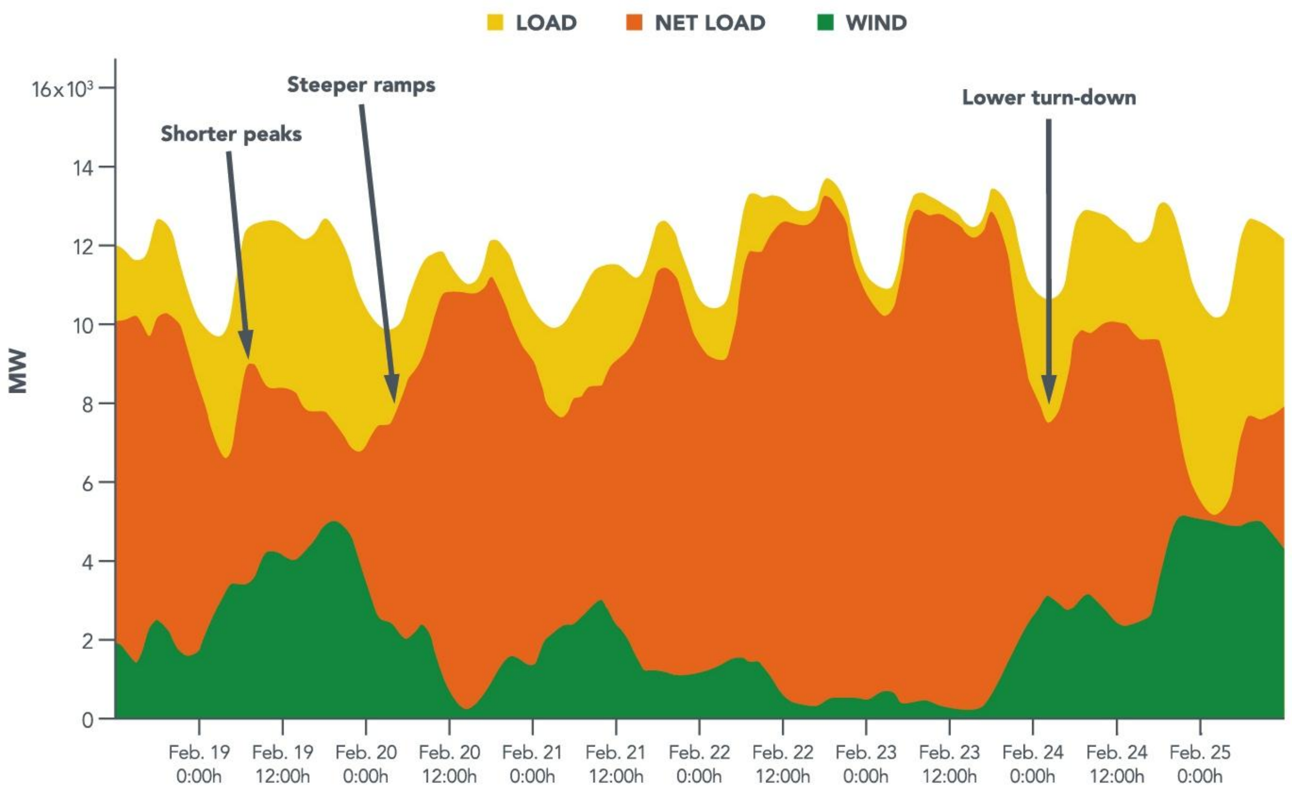


…raising new considerations for grid planning and operations

1. Balancing requires more flexibility
2. More reserves
3. More transmission, better planning needed
4. Voltage control, inertia response come at added cost
5. Existing thermal assets used less frequently, affecting cost recovery

"Flexibility" can help address the grid integration challenges

***Flexibility**: The ability of a power system to respond to change in demand and supply*



- Increases in variable generation on a system increase the variability of the 'net load'
  - 'Net load' is the demand that must be supplied by conventional generation if all RE is used
- High flexibility implies the system can respond quickly to changes in net load.

Key Terms

Load - An end-use device or customer that receives power from the electric system; electrical demand

Net Load – Load minus the solar and wind output; the demand that must be supplied by conventional generation if all RE is used

Operating Reserve – Extra online capacity to help manage variability in net demand and unforeseen events so that system balance can be maintained

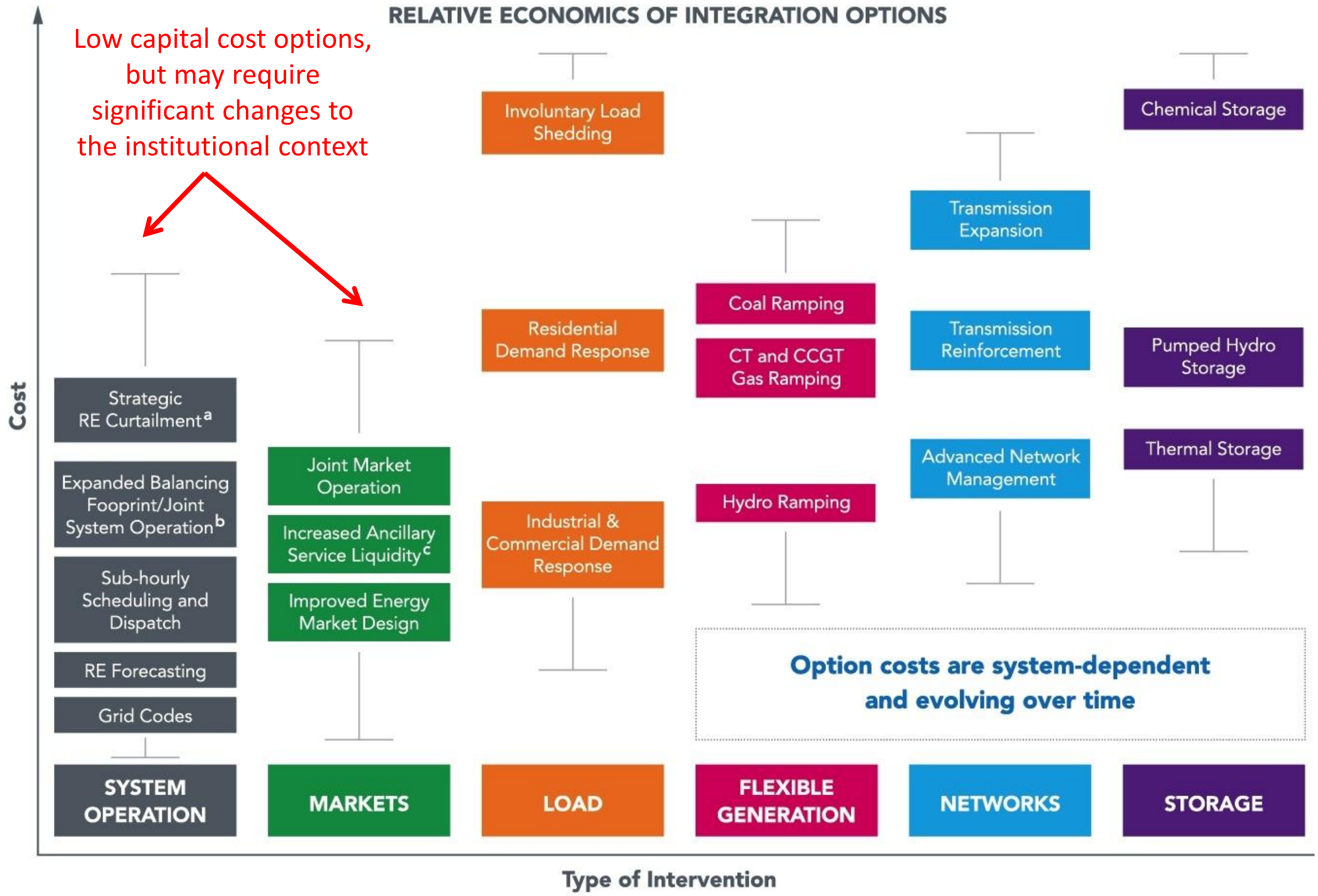
Scheduling/Unit Commitment – Starting and scheduling generators so that they are available when needed

Dispatch (economic dispatch) – A method by which system operators choose among available generators to deliver energy at least operating cost

Flexibility - The ability of the generation fleet to change its output rapidly, start and stop with short notice, and achieve a low minimum turn-down level.

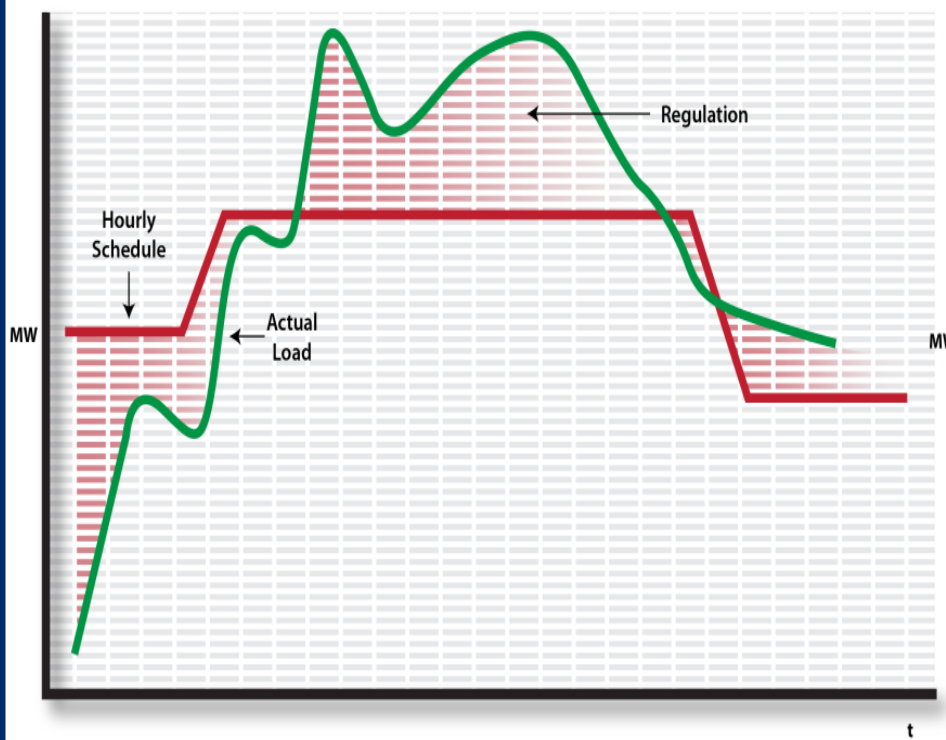
Curtailment - A reduction in the output of a generator from what it could otherwise produce given available resources (e.g., wind or sunlight)

Frequently Used Options to Increase Flexibility

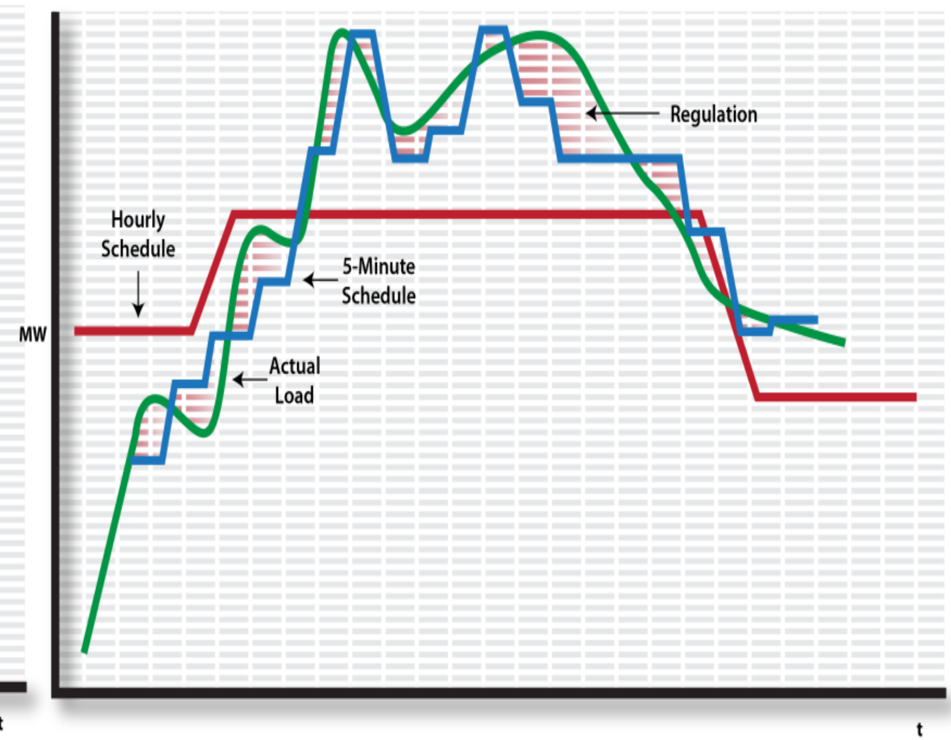


Faster Scheduling to Reduce Expensive Reserves

Hourly schedules and interchanges



Sub-hourly scheduling

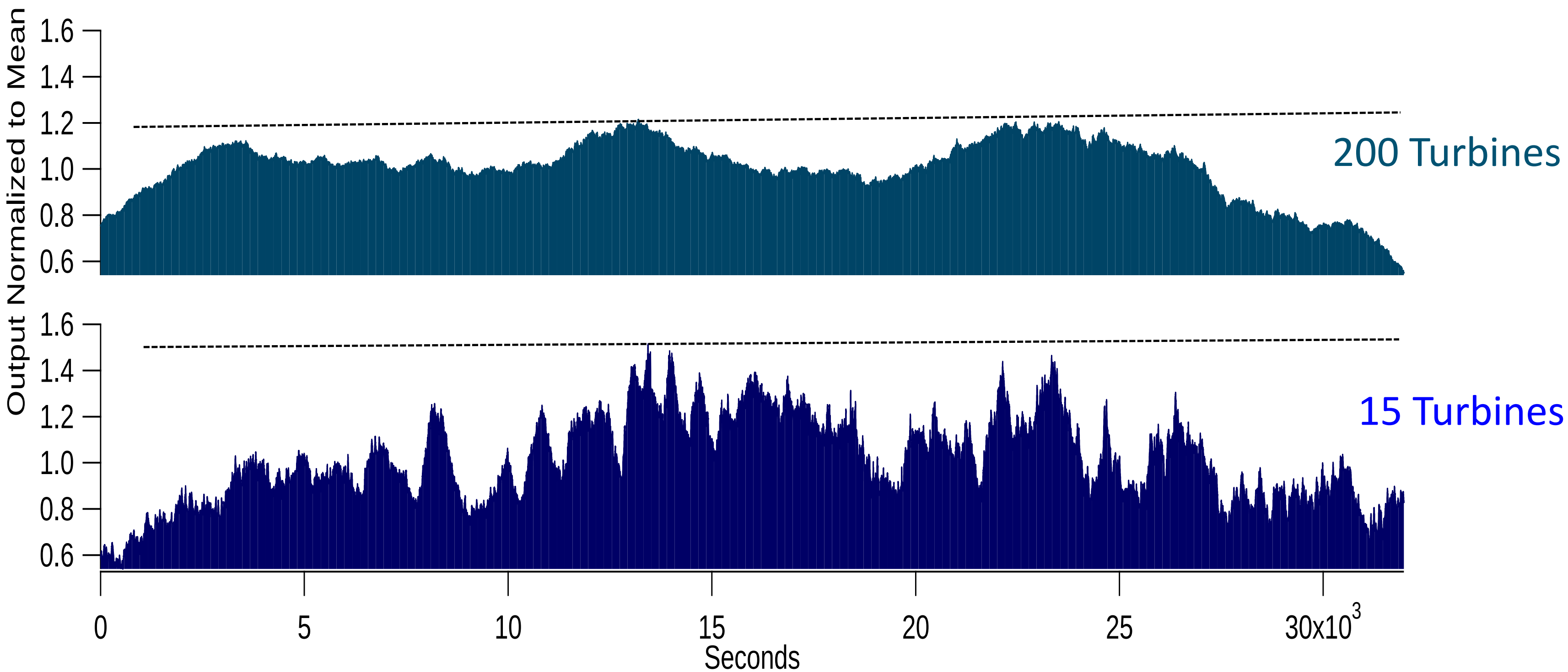


Source: NREL

Dispatch decisions closer to real-time (e.g., intraday scheduling adjustments; short gate closure) reduce uncertainty.

Expand Balancing Footprint

Broader balancing areas and geographic diversity can reduce variability and need for reserves



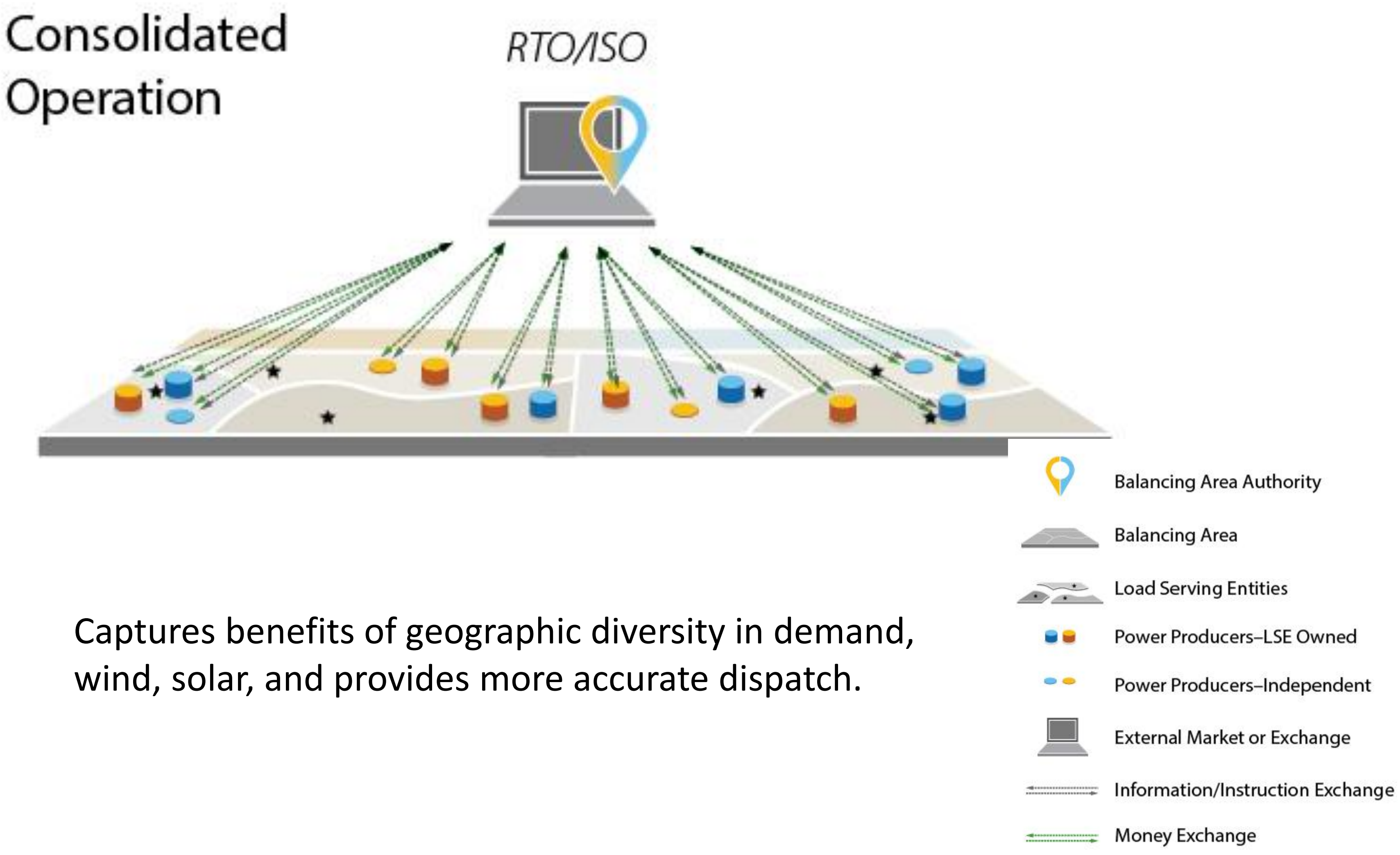
Source: NREL wind plant data

Approximately 8 hours

Revise Energy Market Designs

Markets

Larger balancing region; more frequent dispatch

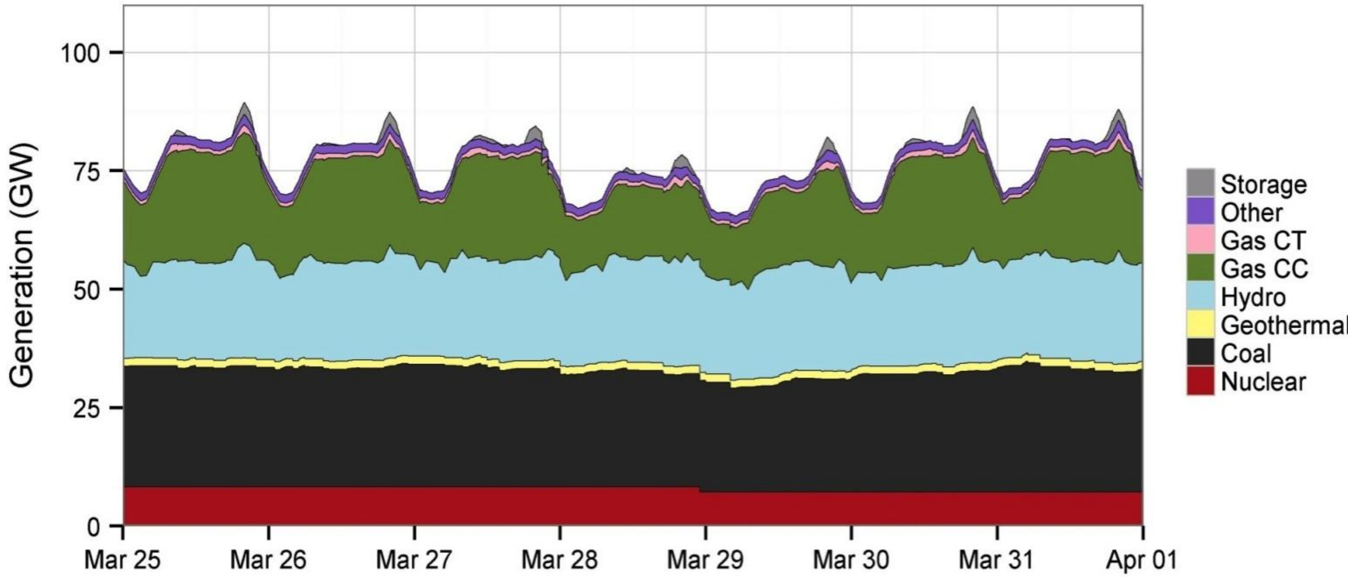


Captures benefits of geographic diversity in demand, wind, solar, and provides more accurate dispatch.

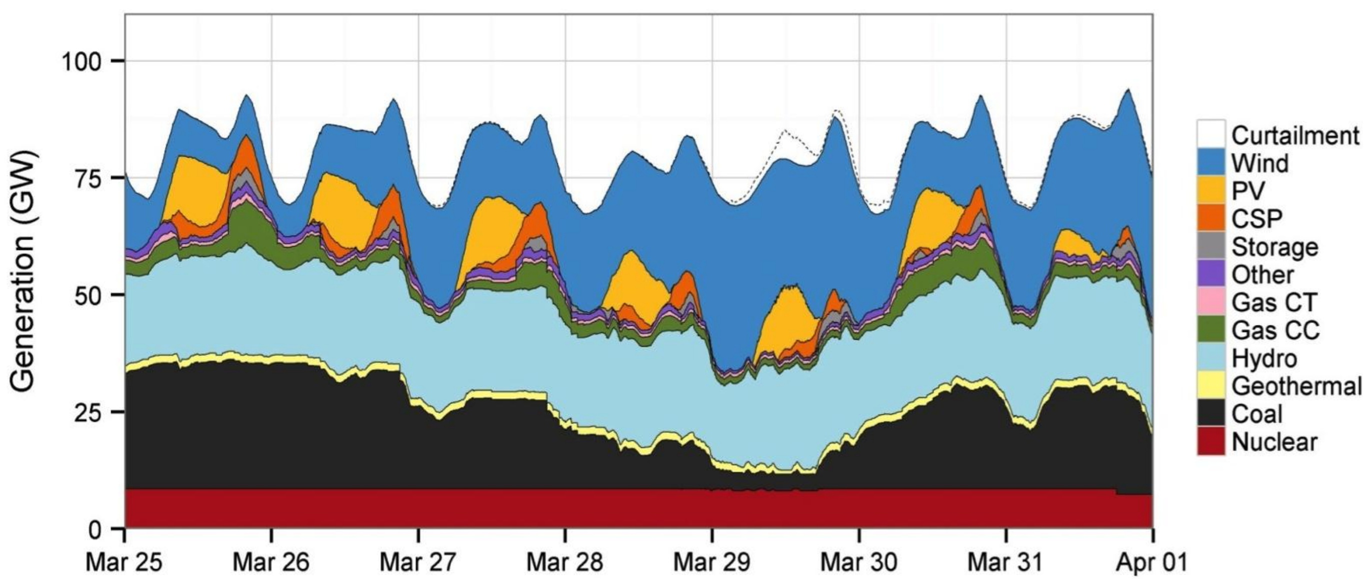
Increase Thermal Plant Cycling

Flexible Generation

0% wind and solar



33% wind and solar energy penetration



Generation dispatch for challenging spring week in the U.S. portion of WECC

Source: WWSIS Phase 2 (2013)

Load

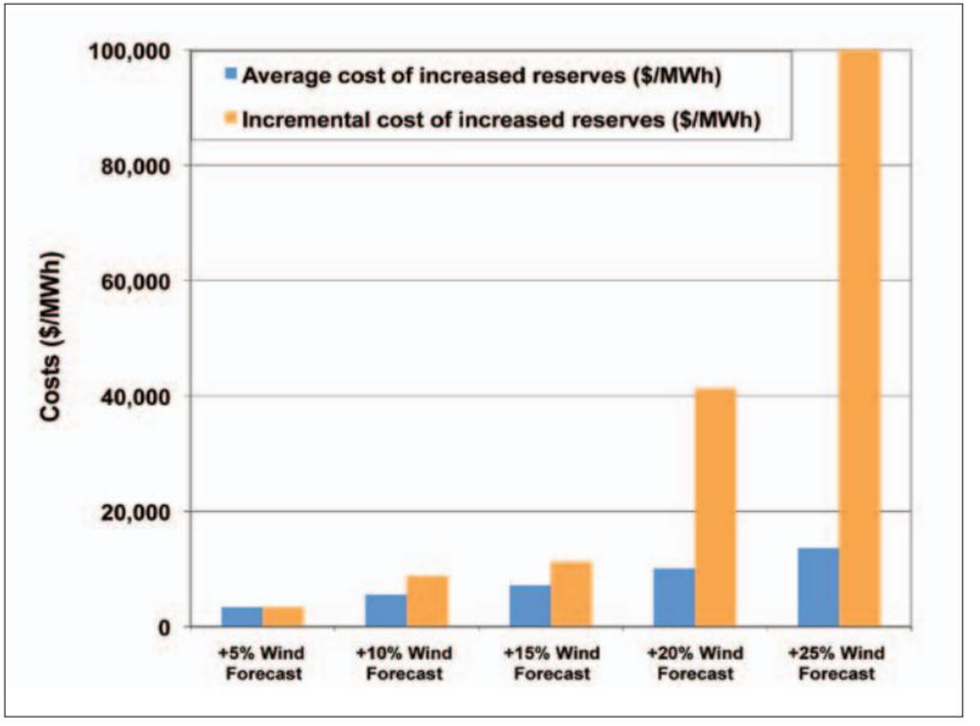
Flexible Demand

Demand response (DR)

- Examples: direct load control, real-time pricing
- Cost effective for extreme events and for reserves

Policy and Regulatory Options

- Allow DR to compete on a par with supply-side alternatives in utility resource planning and acquisition
- Consider potential value of enabling DR when evaluating advanced metering
- Examine ratemaking practices for features that discourage cost-effective DR – e.g., demand charges that penalize large customers for higher peaks which could occur when providing DR



Cost of increasing spinning reserves

WWSIS Phase 1 (2010)

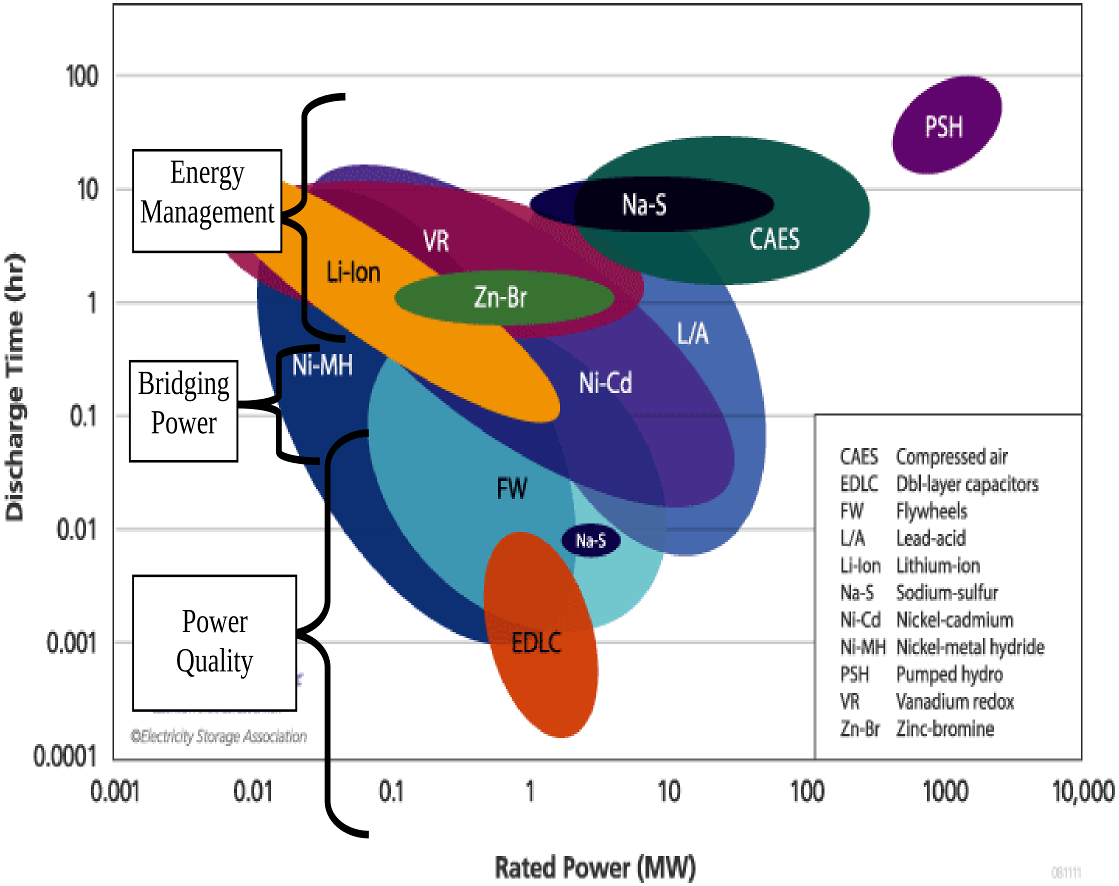
It's cheaper to pay load to turn off (demand response) for the 89 problem hours (1%) than to increase spinning reserves for 8760 hours/year.

Increased supply of flexibility: Storage

ENERGY STORAGE can support: Load Leveling/ Arbitrage; Provide Firm Capacity and Operating reserves; Ramping/Load Following; T&D Replacement and Deferral; and Black-Start

Three types of Energy Storage:

- Power quality – Used for transient stability and frequency regulations (seconds to minutes)
- Bridging Power – Used for contingency reserves and ramping (minutes to hours)
- Energy Management – Used for load leveling, firm capacity and T&D Deferral (hours)



Factors limiting energy storage: Cost

Flexible Transmission Networks

Transmission networks can access flexibility by:

- Improving the capacity and geographic extent of existing networks
- Interconnecting with neighboring networks
- Employing smart network technologies and advanced management practices to minimize bottlenecks and optimize transmission usage

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Can Grids Support High Levels (>5-10%) of Variable RE?

	% Electricity from wind (IEA, 2011)	% Wind Energy Curtailed	Balancing	Notes
Denmark	28.0 **33% in 2013**	< 1 %	Interconnection, flexible generation (including CHP) & good markets	Renewable target (mainly wind) is 50 % by 2020 and 100% by 2050
Portugal	18.0 **25% in 2013**	Low	Interconnection to Spain, gas, hydro & good market	Iberian peninsula: Spain & Portugal all well connected to one another but operate a single market MIEBEL
Spain	16.4 **21% in 2013**	< 1 % (but increasing due to excess hydro and low demand)	Gas, hydro & good market	
Ireland	15.6 **18% in 2013**	2.3 % in 2011 EirGrid and SONI, 2012; "2011 Curtailment Report"	Gas & good market	Curtailment reduced in 2012 to 2.1 %

Denmark has already experienced 97% instantaneous wind and solar penetration levels

Goals:
50% RE by 2020
100% RE by 2035

Many grids are operating with 20%–30% variable renewables

Do Individual Renewable Energy Plants Require Backup by Conventional Plants?

- <u>Reserves</u> are already a part of every system
- <u>Individual</u> plants do not require backup
  - Reserves are optimized at system level.
- Wind and solar could increase need for operating reserves.
  - This increase is not a constant amount (Depends on what wind/solar are doing)
  - Many techniques are available to reduce needed reserves.
- Wind and solar might displace conventional generation, freeing up that generation to provide energy and reserves (if economic).
- Wind can also provide reserves; in both directions when curtailed.

Photo from iStock 72283000

Does Variable Renewable Energy Generation Require Storage?

- Storage is always useful, but may not be economic.
- Detailed simulations of power system operation find no need for electric storage up to 30% wind penetration (WWSIS, CAISO, PJM, EWITS).
- 50% wind/solar penetration study in Minnesota found no need for storage (MRITS, 2014)
- At higher penetration levels, storage could be of value.
    - Recent E3 integration study for 40% penetration in California: storage is one of many options.

Does Variable Renewable Energy Require New Gas Capacity to Provide Flexibility?

If wind is added to an already reliable system, there is no need for new gas or new reserves; existing generation will back down, providing up-reserves.

Wind can increase the need for system flexibility

(Due to more cycling, faster ramps, lower turn-downs).

Wind/solar can often *provide* flexibility if incentives exist

But, flexibility is not new—conventional systems are also designed for flexibility.

Low wind penetrations:

Most systems sufficiently flexible

Medium wind penetrations:

Likely least-cost source of flexibility is to change how the system is operated

e.g., faster schedules, forecast integration, deeper cycling of coal, demand response

Wind turbines may provide frequency support

High wind penetrations:

Might need new physical sources of flexibility

e.g., new natural gas turbines, additional services from wind/solar

What Impact Does Variable Renewable Energy Have on Emissions (Due to Thermal Cycling)?

Increase in plant emissions from cycling to accommodate wind and solar are more than offset by overall reduction in CO_2, NO_x, and SO_2

Scenario: 33% wind and solar energy penetration as percentage of annual load

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs 29%–34%	Negligible Impact
NO_X	170–230 million lbs 16%–22%	3–4 million lbs
SO_2	80–140 million lbs 14%–24%	3–4 million lbs

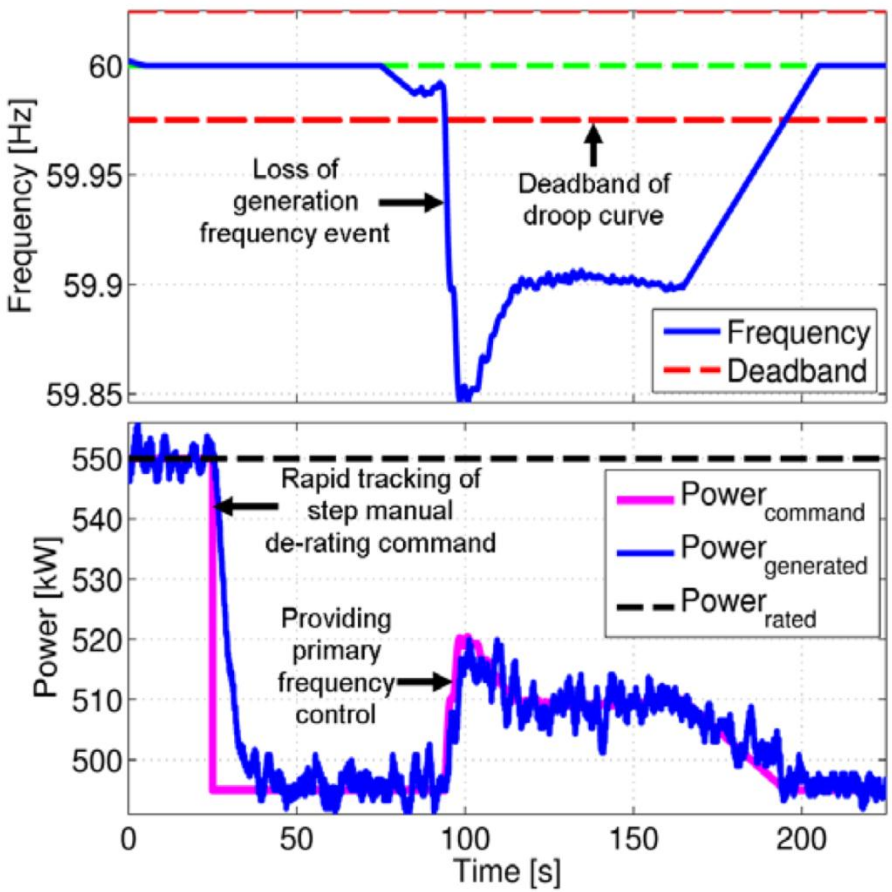
Results from Western Wind and Solar Integration Study (WWSIS), Phase II (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html

What Impact Does Variable Renewable Energy Have on Grid Stability?

Frequency stability (supply-demand balance) is only a potential issue at extremely high penetration levels

- Solution: Wind turbines will need to provide active power controls (synthetic inertia, governor response)
- Example: ERCOT mandates governor response on wind turbines

Voltage stability: potential issue in small and/or weak systems, such as those with long, radial lines



Field test data that shows a single turbine tracking a step change in the de-rating command followed by primary frequency control response to an under-frequency event

http://www.nrel.gov/docs/fy14osti/60574.pdf

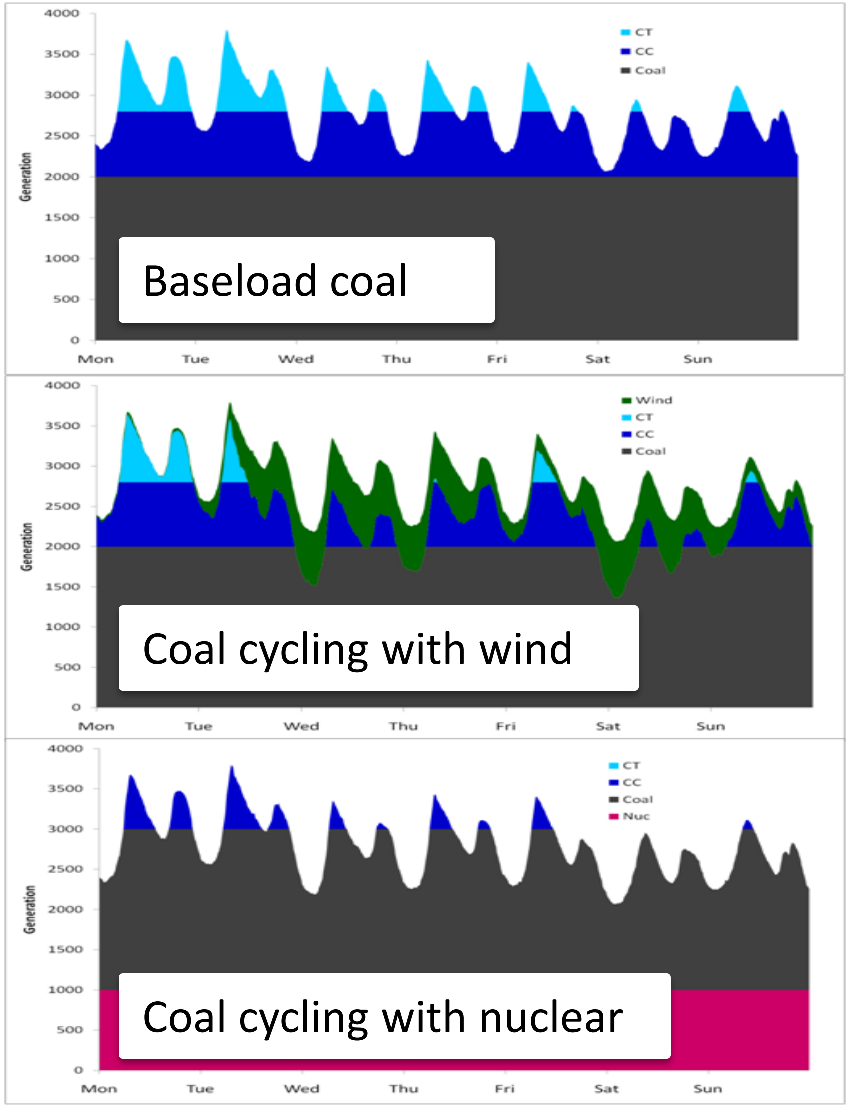
How Expensive is Integrating Variable Renewable Energy Generation to the Grid?

All generation (and load) has an integration cost:

- Any generator can increase cycling for remaining generation
    - E.g., Baseload nuclear can increase coal cycling, as shown in lower figure

- Conventional plants can impose variability and uncertainty costs
    - Contingency reserves sized for largest plant, often thermal
    - Operating reserves needed for plants that cannot follow dispatch signals precisely

- Conventional plants can create conditions that increase need for system flexibility
    - Must-run hydropower, must-run IPP contracts, thermal plants that cannot be turned down



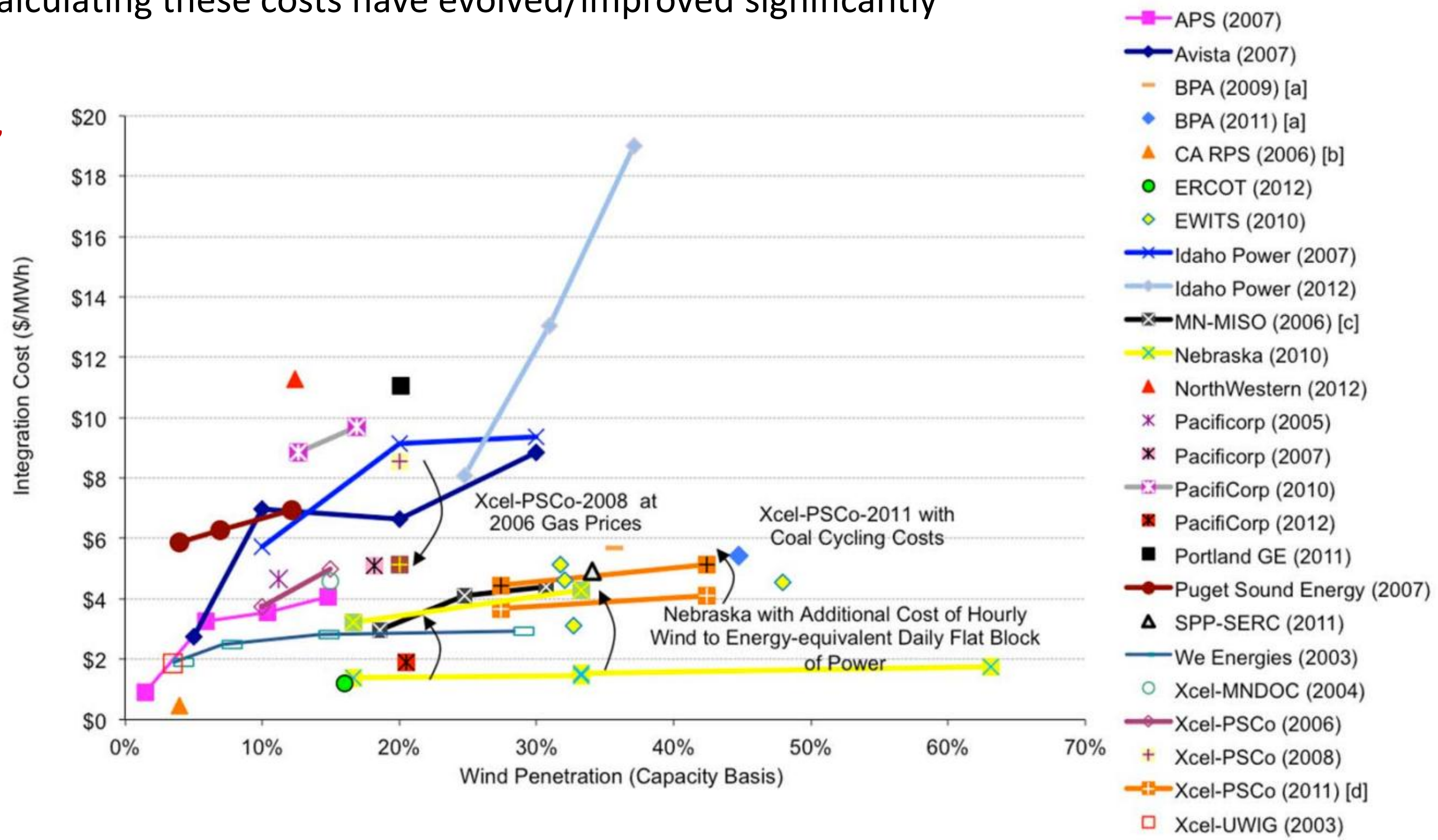
http://www.nrel.gov/docs/fy11osti/51860.pdf

Is Integrating Variable Renewable Energy Generation to the Grid Expensive?

- Large integrations show relatively low costs: under $5 USD/ MWh (0.5cents/kWh)
  e.g., Eastern Wind Integration and Transmission Study (NREL 2011), European Wind Integration Study (EWIS 2010)
- Costs are intrinsically related to how the system is operated
- Methods for calculating these costs have evolved/improved significantly

Many of the small, isolated systems with hourly scheduling have higher costs.

Large, diverse, agile systems can more easily integrate high quantities of wind with little cost difference.



Lawrence Berkeley National Laboratory (2013), http://emp.lbl.gov/sites/all/files/lbnl-6356e-ppt.pdf

Key Takeaways

- Wind and solar generation increase variability and uncertainty
- A wide variety of systems world-wide find 10%+ annual penetrations technically achievable
- Specific back-up generation is not required, but additional reserves may be necessary
- Specific detailed analyses will help identify the most cost effective measures to integrate RE in each power system
- Often most the cost effective changes to the power system are institutional (changes to system operations and

NREL/PIX 10926

QUESTIONS?

Extra Slides

Strategic Curtailment

Costs to achieve flexibility

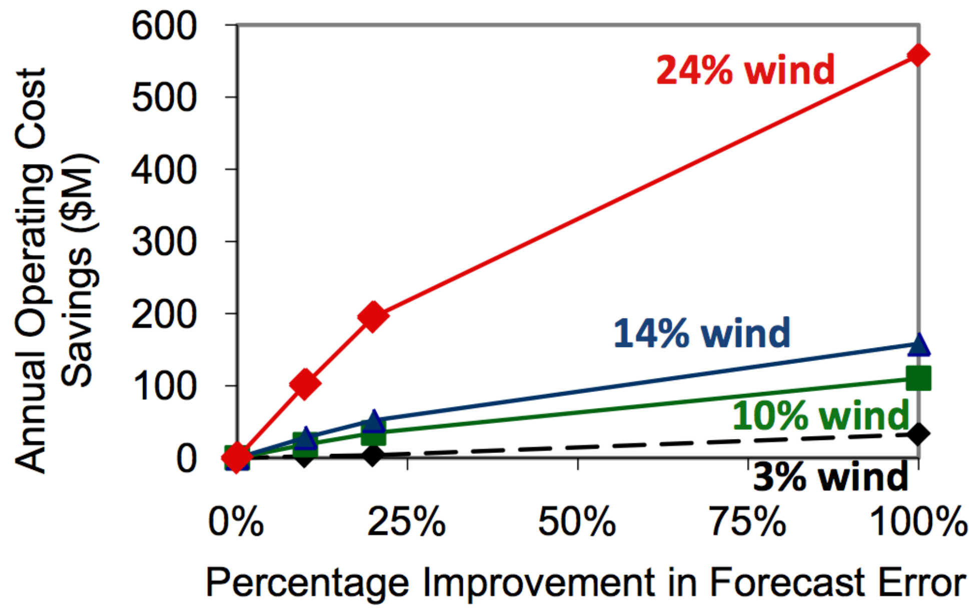
Benefits of reduced or no curtailment

Economically optimal amount of flexibility could include certain level of curtailment.

Image: Commons.wikimedia.org

Incorporate Forecasting in Unit Commitment and Dispatch

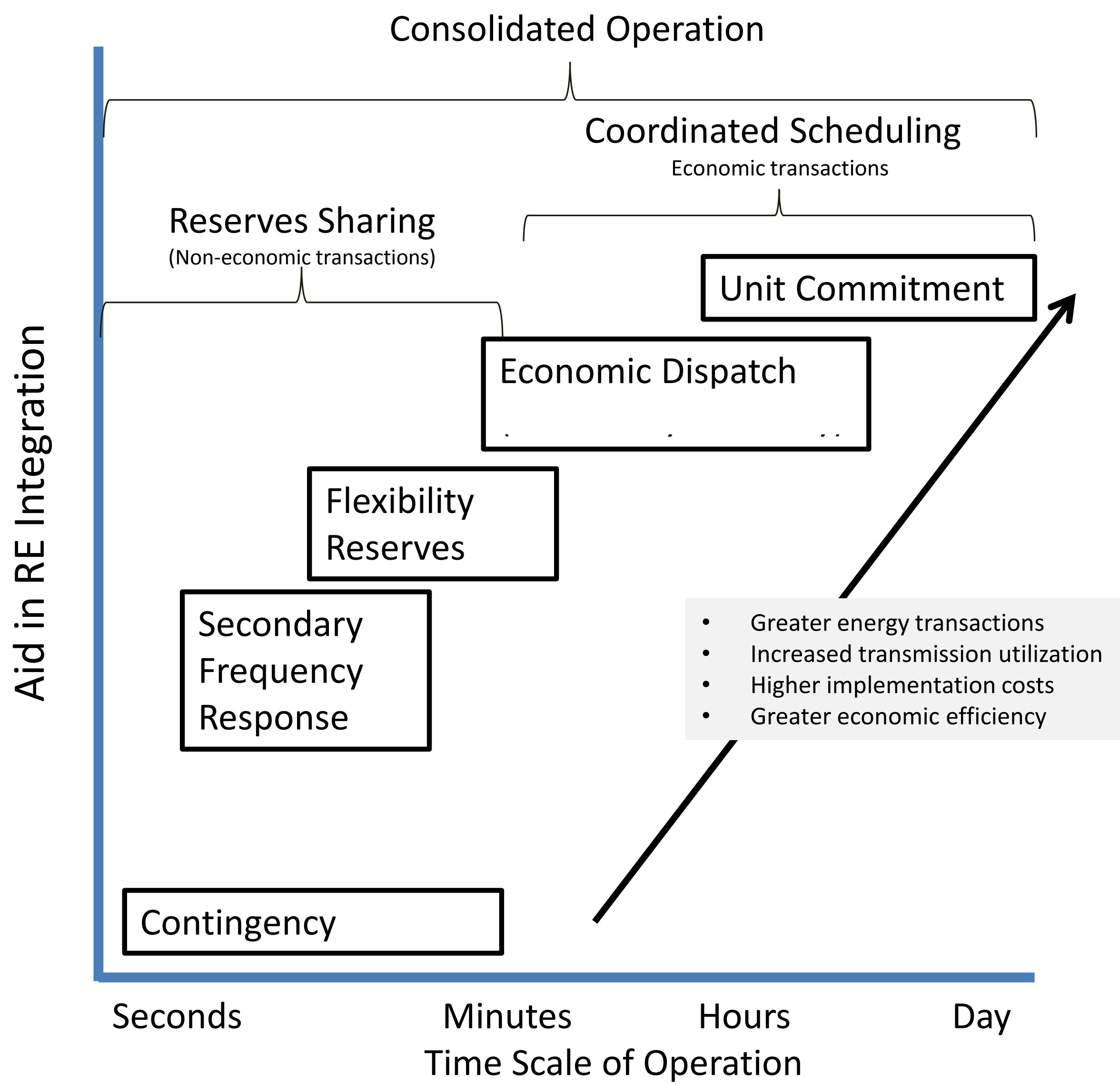
- Reduces uncertainty
- Improves scheduling of other resources to reduce reserves, fuel consumption, and operating, maintenance costs
- More accurate closer to operating hour
- Forecasting of extreme events more important than mean error reduction
- Access to renewable energy plant data is critical (implications for contracts and communications)



At 24% wind penetration levels, improving forecasting by 10%–20% can provide significant savings in annual operating costs in the U.S. West.

http://www.nrel.gov/docs/fy11osti/50814.pdf

Increase Balancing Area Coordination



Revise Energy Market Designs

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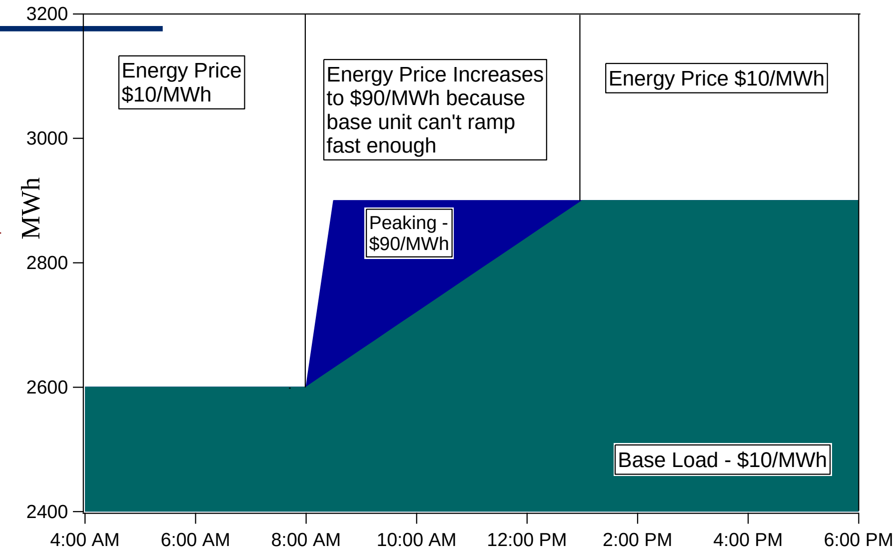

Source: Milligan et al. (2012) NREL/CP-5500-56212

- Ramp products
  - To better value flexibility
- Larger, faster, more frequent markets
- Negative pricing
  - Economically efficient way to reduce output during excess generation
  - Allows curtailment to proceed through scheduling software rather than manual intervention
- Forecast integration and allowing variable RE to participate as dispatchable generators
  - Improves market efficiencies and opportunities for wind/solar

Flexible Generation

New or retrofitted conventional power plants can improve system flexibility by incorporating capabilities to:

- Rapidly ramp-up and ramp-down output to follow net load
- Quickly shut-down and start-up
- Operate efficiently at a lower minimum level during high renewable energy output periods

NREL PIX 06392

Flexible Generation from Wind

- Wind can provide primary and secondary frequency response, e.g., synthetic inertia, down reserves
- Capability to curtail to a set-point command during periods of system stress
- Xcel Colorado example during high wind, low load: fossil fuel generators parked at minimum generation; all reserves come from wind

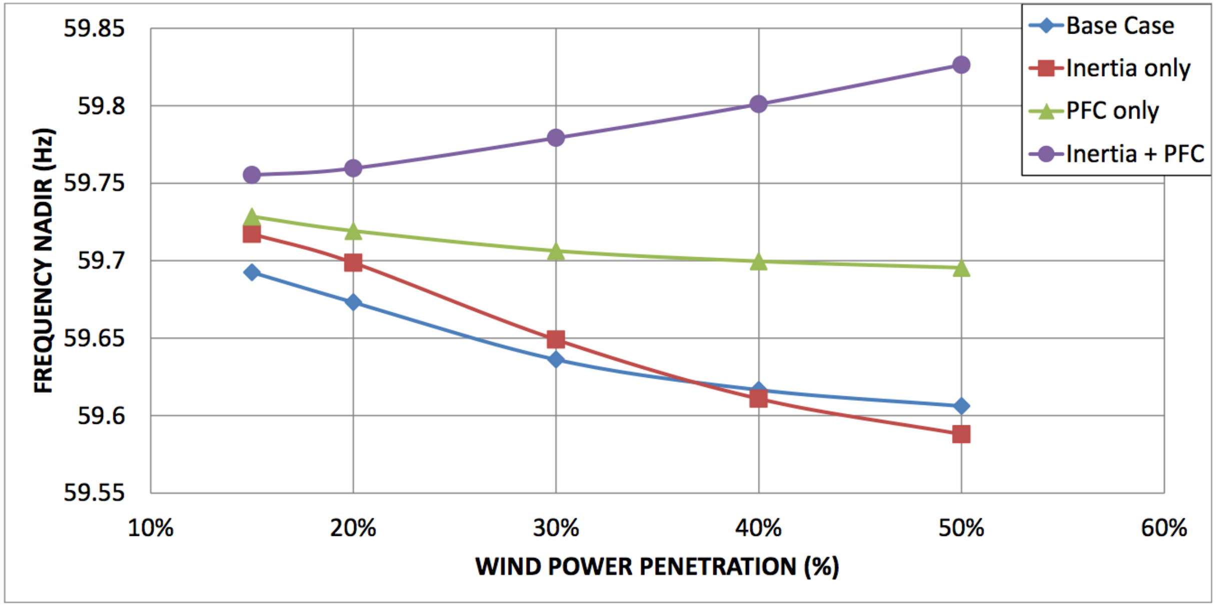

Figure: Impact of wind power controls on frequency nadir

Wind with inertia and primary frequency control (PFC) response significantly improves frequency nadir at 50% penetration levels

http://www.nrel.gov/docs/fy14osti/60574.pdf

Dynamic Reserve Requirements

- Most places typically use static operating reserves.
- Integration studies: reserves should vary hourly with actual and predicted conditions.
- Target high-risk periods of big wind changes and reduce integration costs
- ERCOT changed rules to incorporate wind forecast error statistics in its determination of up- and down-regulation reserve and non-spinning reserve.

Photo by Invenergy LLC, NREL 16037

The Evolution of Planning with High Levels of Variable RE

Adjusting Planning Processes

- For decades, planning has concentrated on orange boxes
  - Covered all aspects of reliable and cost-effective grid
- New planning steps are represented in green boxes
- What changed? Variability
- Implication?
  - Rule of thumb analysis no longer works
  - Now need new data sets, new models
- Grid integration study is the umbrella of power system planning activities to capture difference between then and now