

# Integrating Variable Renewable Energy into the Grid

Key Issues and Emerging  
Solutions

# Agenda and Learning Objectives

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- ***Part 1: Key Issues***
  - Understand the primary challenges to integrating variable renewable energy (RE) to the grid
- ***Part 2: Flexible Power Systems***
  - Identify sources of power system flexibility
- ***Part 3: Myths and Frequently Asked Questions***
  - Understand system impacts of high RE on reliability, need for storage, and cost
- ***Part 4: Greening the Grid Toolkit***
  - Identify resources and technical assistance available through the Greening the Grid initiative
- ***Part 5: Questions and Panel Discussion***

Part 1

# **KEY GRID INTEGRATION ISSUES**

# Why is grid integration an important topic?

## Introduction

### Trends:

*Increasing energy demand*

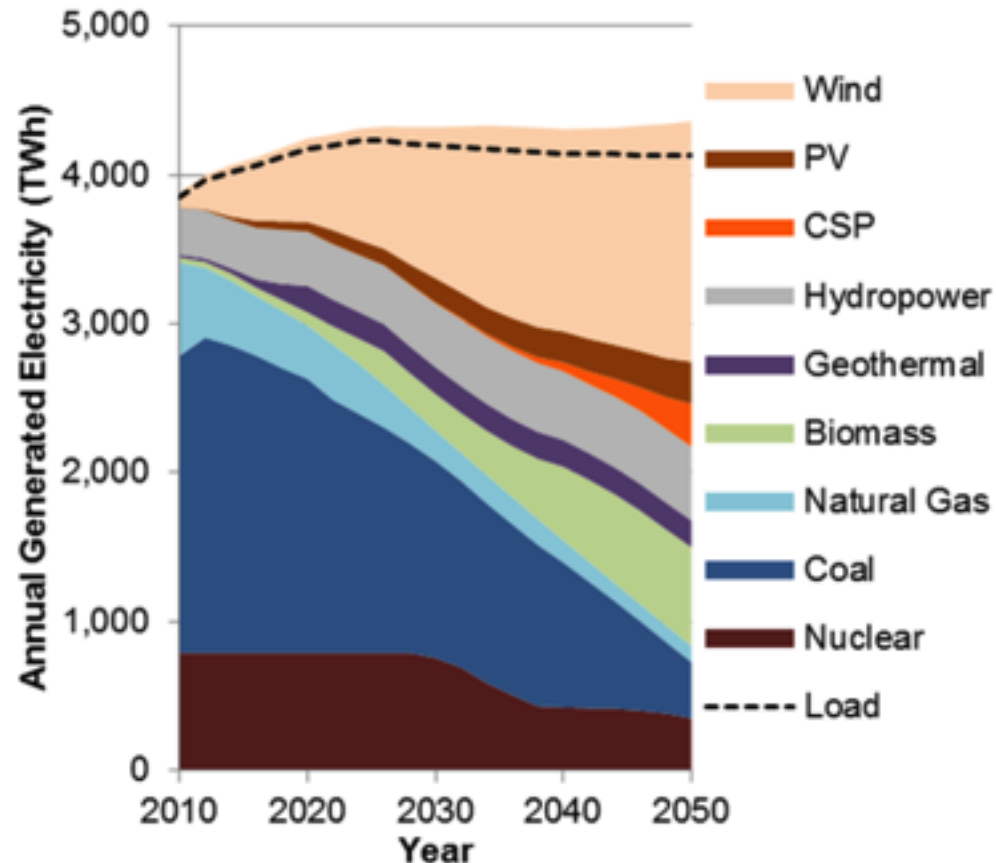
*Urbanization*

*Climate change mitigation targets*

*Need for grid modernization*

Every power system has characteristics that promote and inhibit integration of variable RE

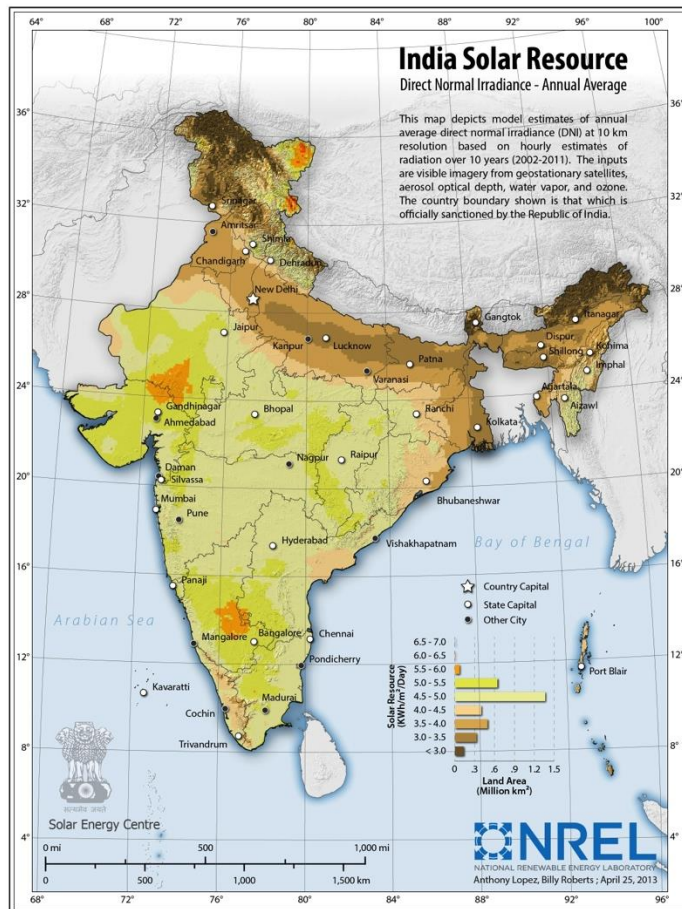
***Grid integration*** is the practice of developing efficient ways to deliver high penetration levels of variable RE to the grid



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

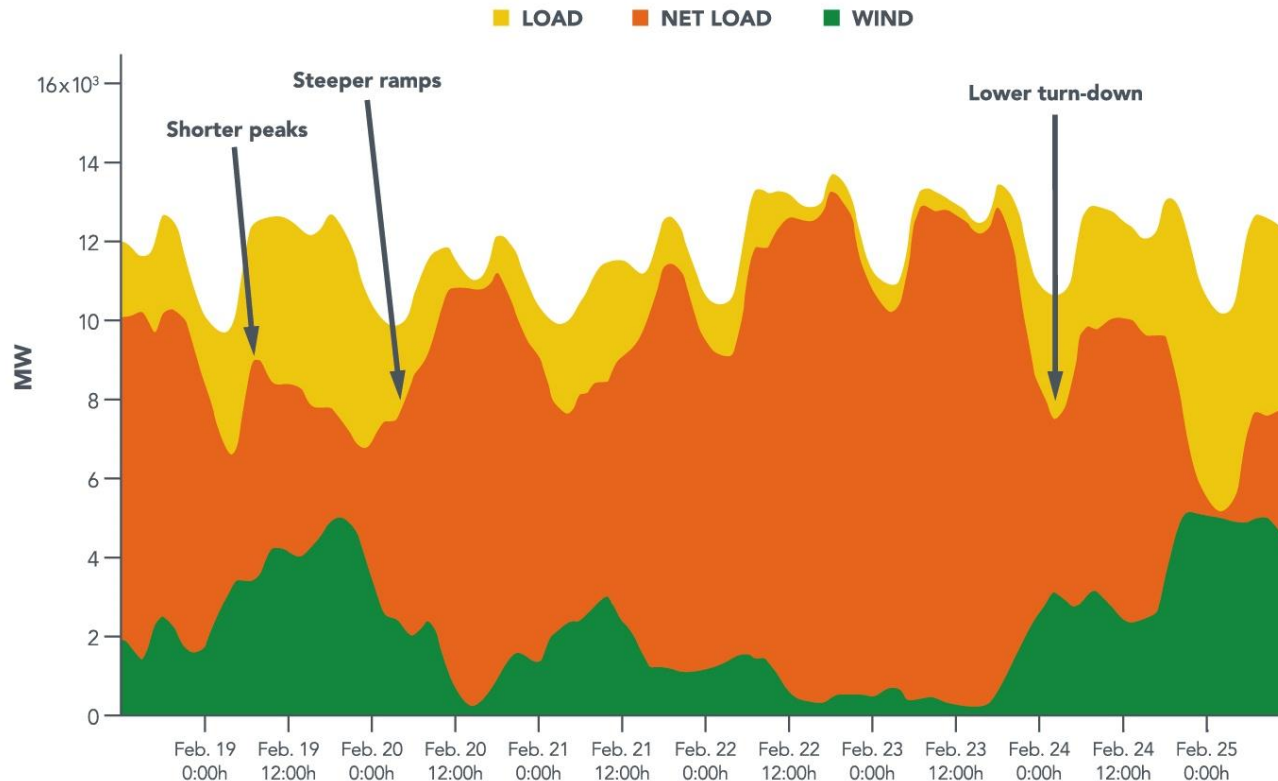
1. Balancing requires more flexibility
2. Existing thermal assets used less frequently, affecting cost recovery
3. More reserves
4. More transmission, better planning needed
5. Voltage control, inertia response come at added cost

Part 2

# **FLEXIBLE POWER SYSTEMS**

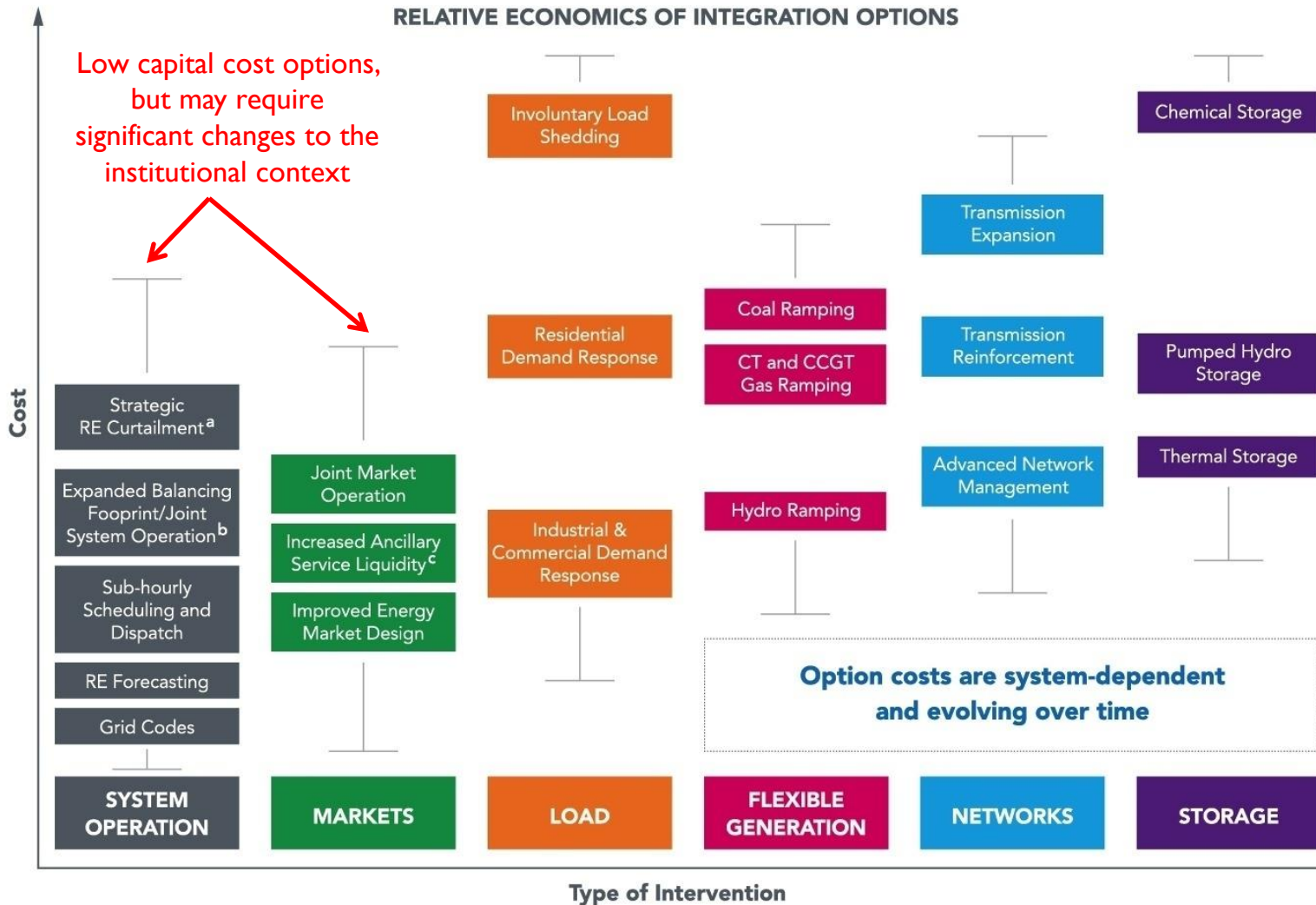
# “Flexibility” can help address the grid integration challenges

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



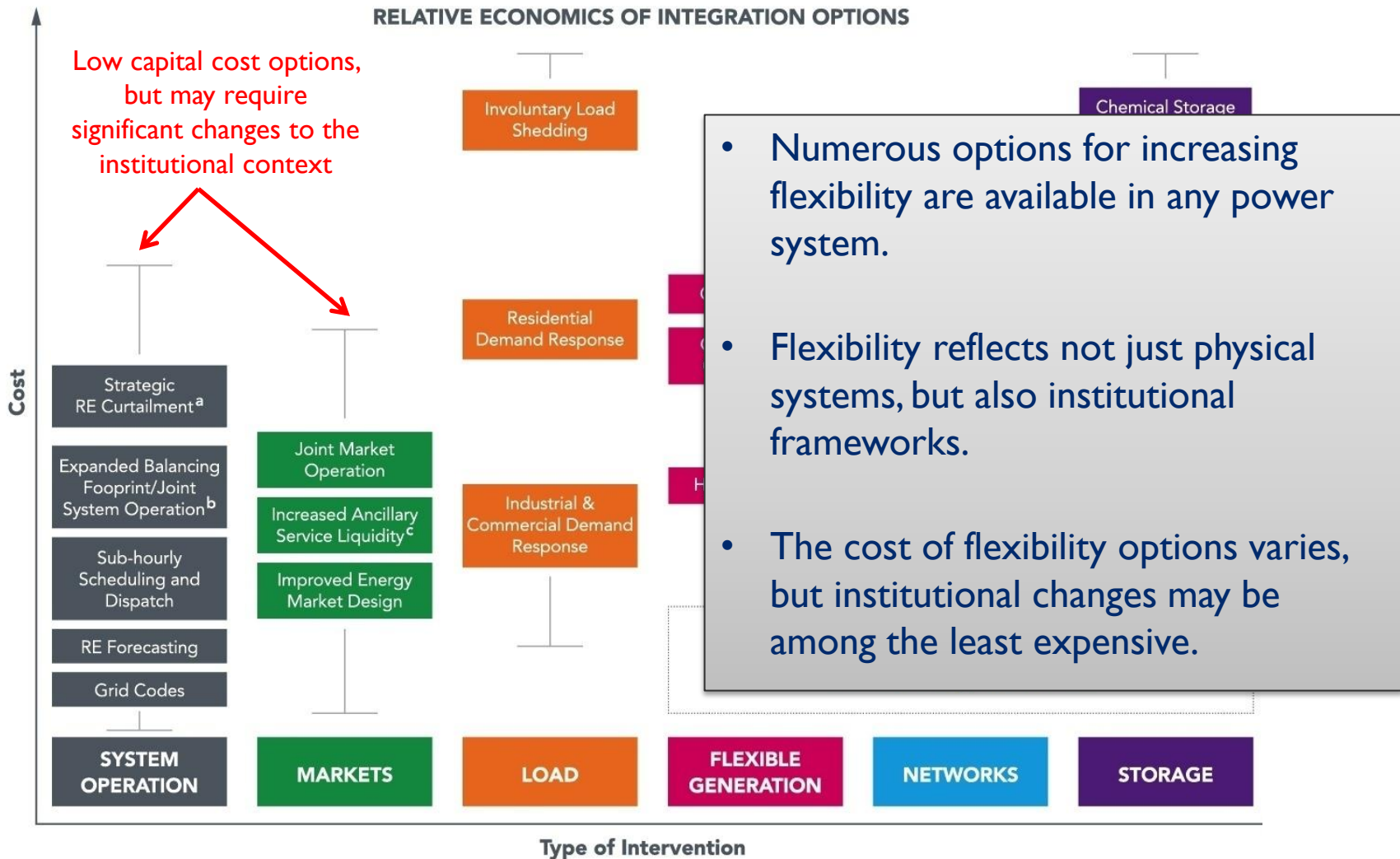
- Increases in variable generation on a system increase the variability of the ‘net load’
  - ‘Net load’ is the demand that must be supplied by conventional generation unless RE is deployed to provide flexibility
- High flexibility implies the system can respond quickly to changes in net load.

# Frequently used options to increase flexibility



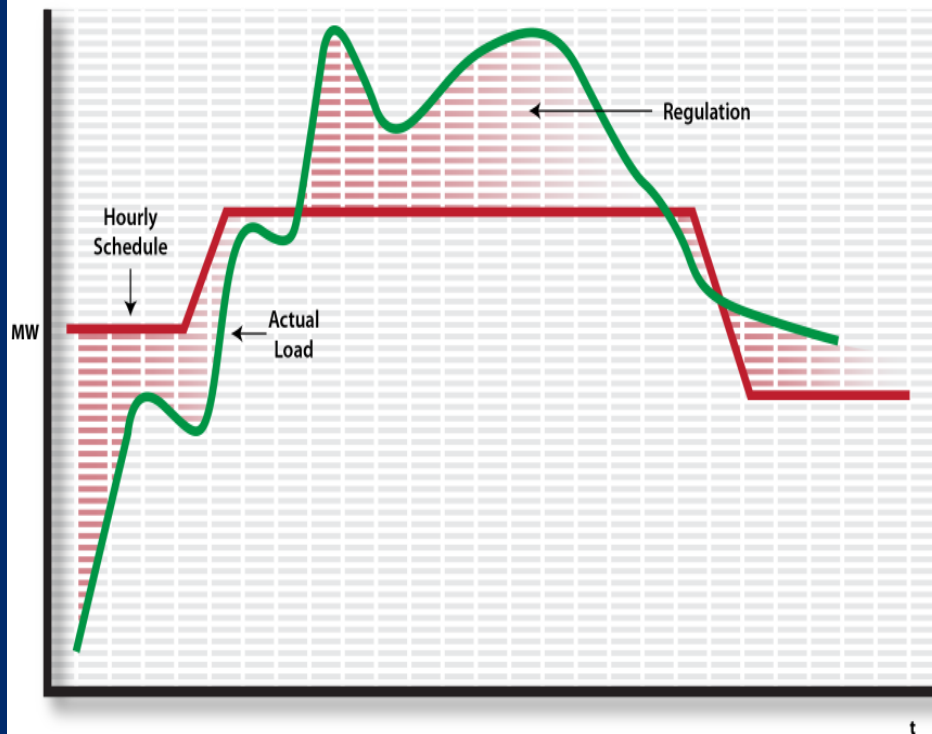


# Frequently used options to increase flexibility

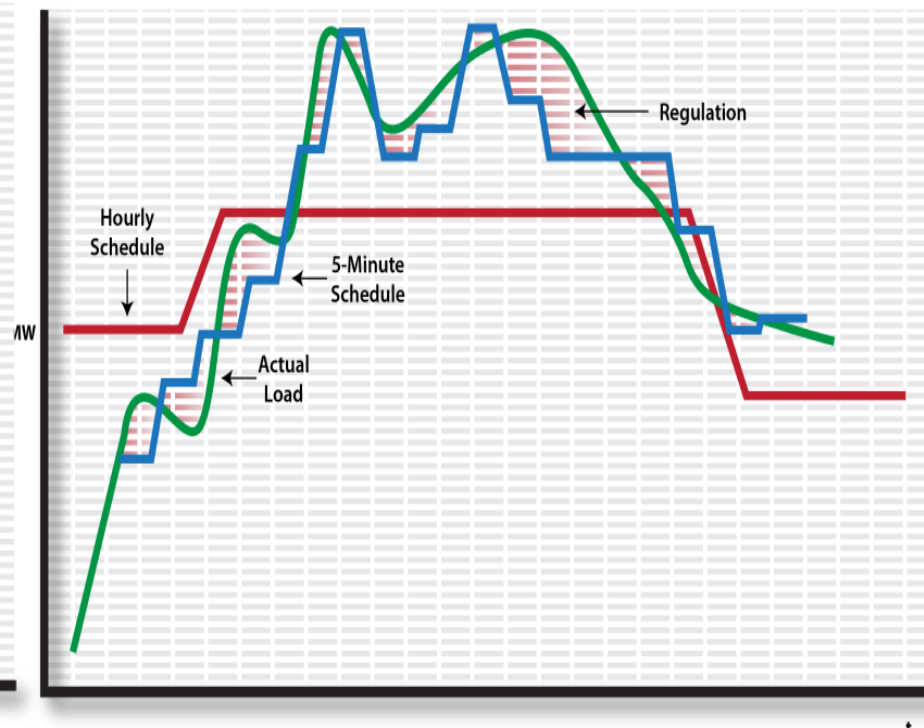


# Faster dispatch to reduce expensive reserves

## Hourly dispatch and interchanges



## Sub-hourly dispatch

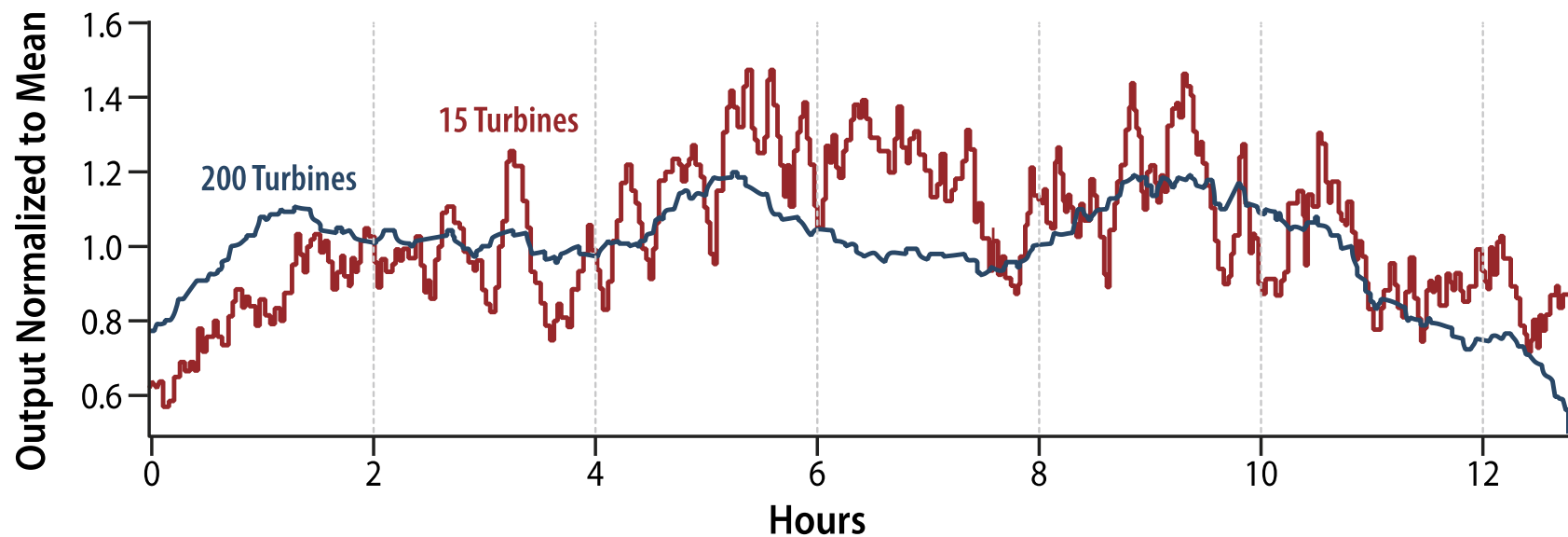


Source: NREL

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

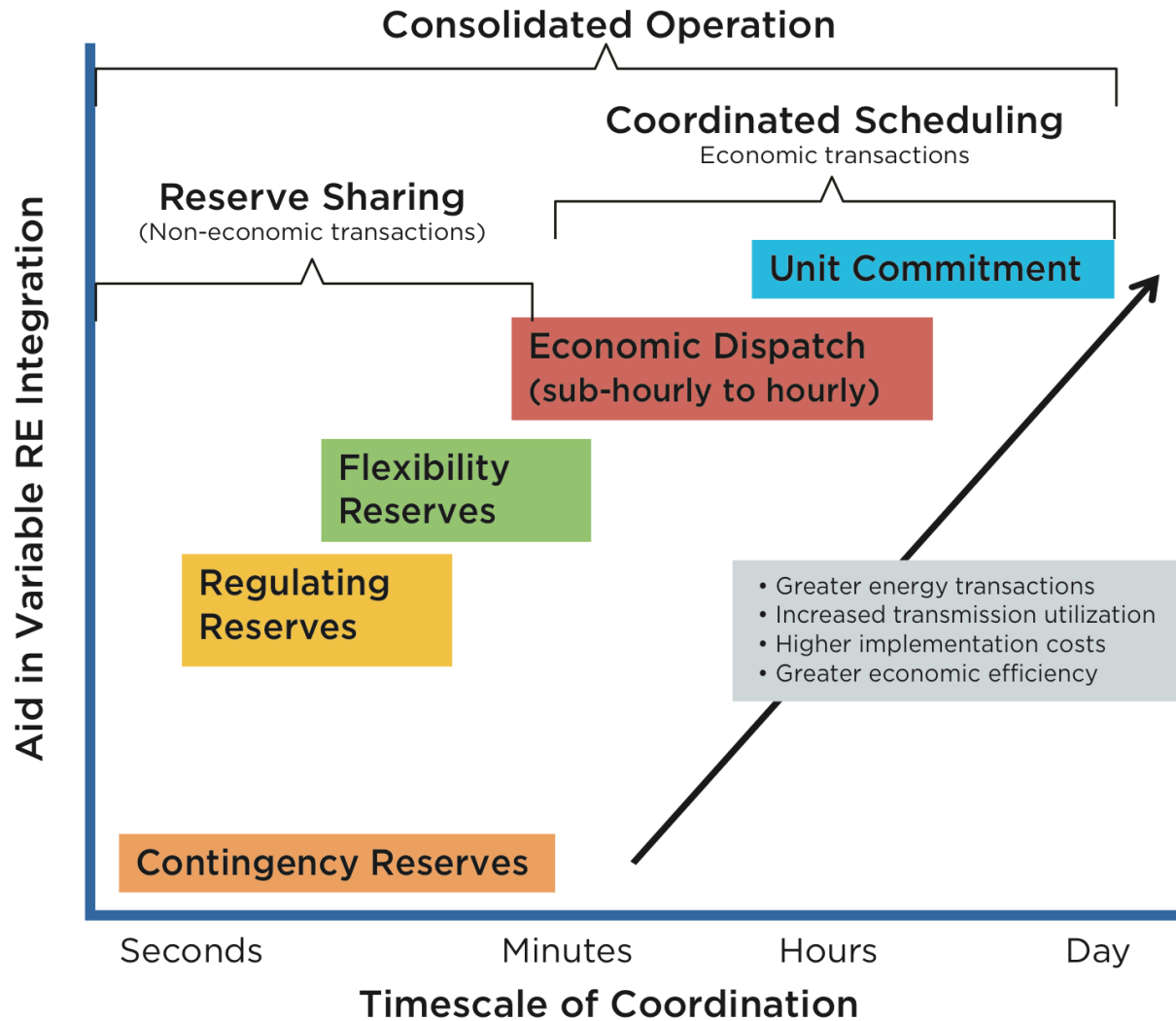
# Expand balancing footprint

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



Source: NREL/FS-6A20-63037

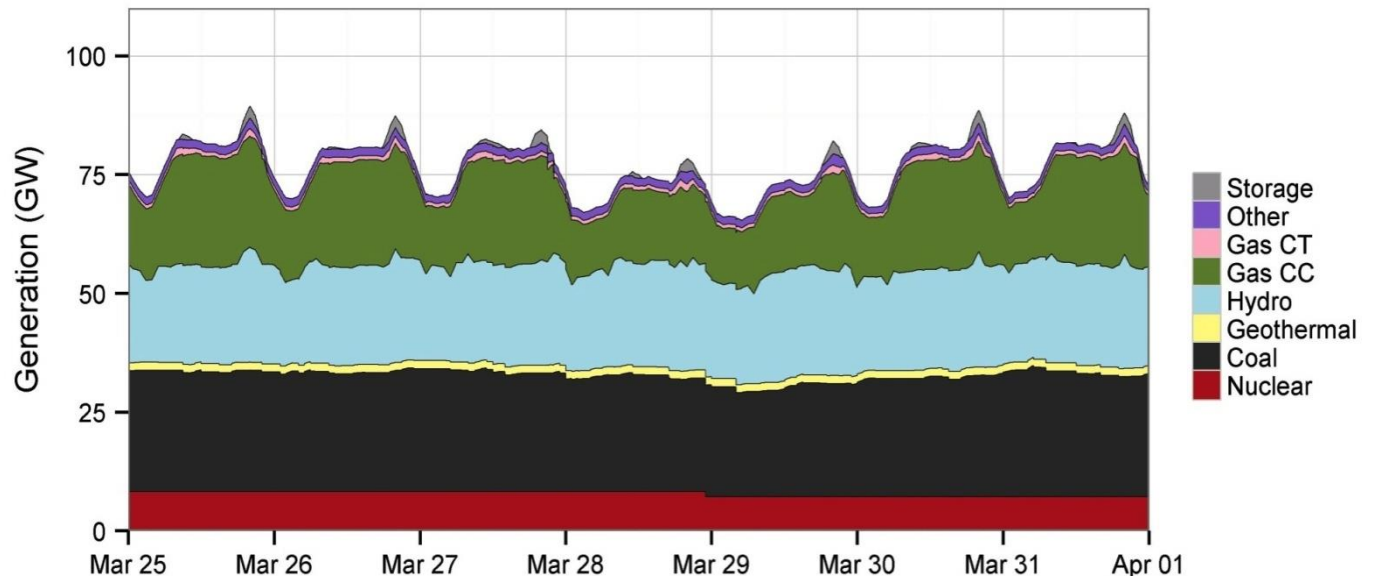
# Increase balancing area coordination



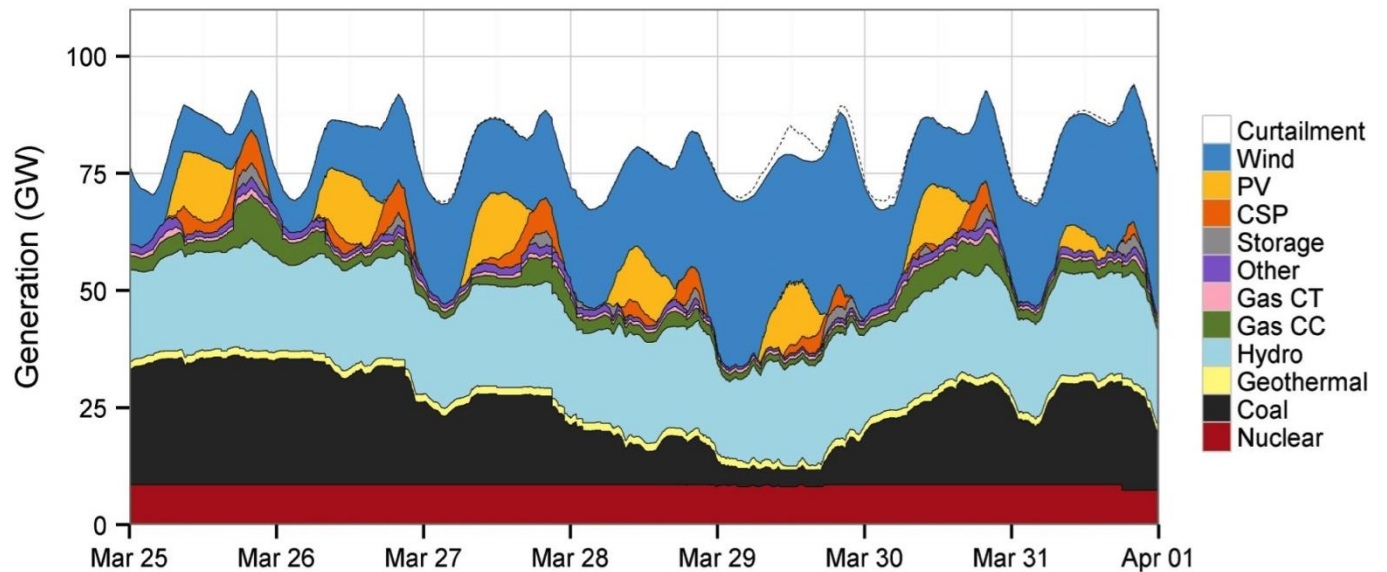
# Increase thermal plant cycling

Flexible  
Generation

0% wind  
and solar



33% annual  
wind and  
solar energy  
penetration



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

*Source: WWSIS Phase 2  
(2013)*

# Flexible generation from wind

- Wind can provide synthetic inertial control and primary and secondary frequency response
- Wind can follow economic dispatch signals, and can be incorporated into economic dispatch or market operations
- This example shows how Public Service Company of Colorado improved its Area Control Error using controllable wind energy during a period of very high wind and low demand

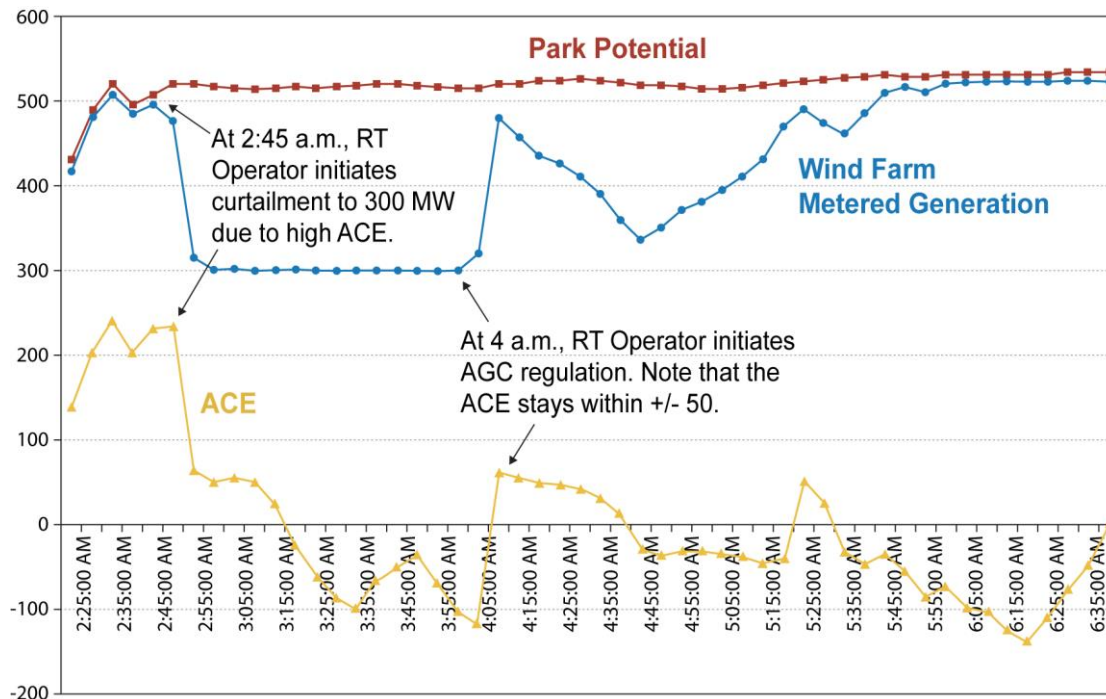


Figure: Impact of wind power controls regulation, dispatch, and area control error

Public Service Company of Colorado

# 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
- Introduce ratemaking practices—such as time-varying electricity pricing—that encourage cost-effective demand response, even in communities without significant deployment of smart meters.
- Consider potential value of enabling DR when evaluating advanced metering



Photo credit: Susan Bilo





Studies have found that it is cheaper to pay load to turn off (demand response) for the 89 problem hours (1%) than to increase spinning reserves for 8760 hours/year.

Part 3

# **MYTHS AND FREQUENTLY ASKED QUESTIONS**



# Can grids support high levels (>5-10% annually) of variable RE?

Country	%Electricity from Wind	Balancing
Denmark 	<b>39% in 2014</b>	Interconnection, flexible generation (including CHP), and good markets
Portugal 	<b>25% in 2013</b>	Interconnection to Spain, gas, hydro, and good market
Spain 	<b>21% in 2013</b>	Gas, hydro, and good market
Ireland 	<b>18% in 2013</b>	Gas and good market

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

Their experiences demonstrate that actions taken to integrate wind and solar are unique to each system, but do follow broad principles.

# Do individual renewable energy plants require backup by conventional plants?

- Reserves are already a part of every system
- Individual plants do not require backup
  - Reserves are optimized at system level.
- Wind and solar could increase need for operating reserves.
  - But this reserve can usually be provided from other generation that has turned down to accommodate wind/solar
  - This reserve is not a constant amount (depends on what wind/solar are doing)
  - Many techniques are available to reduce needed reserves.
- Wind can also provide reserves; in both directions when curtailed, but it may not be economic to obtain up-reserve from wind or solar.



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)



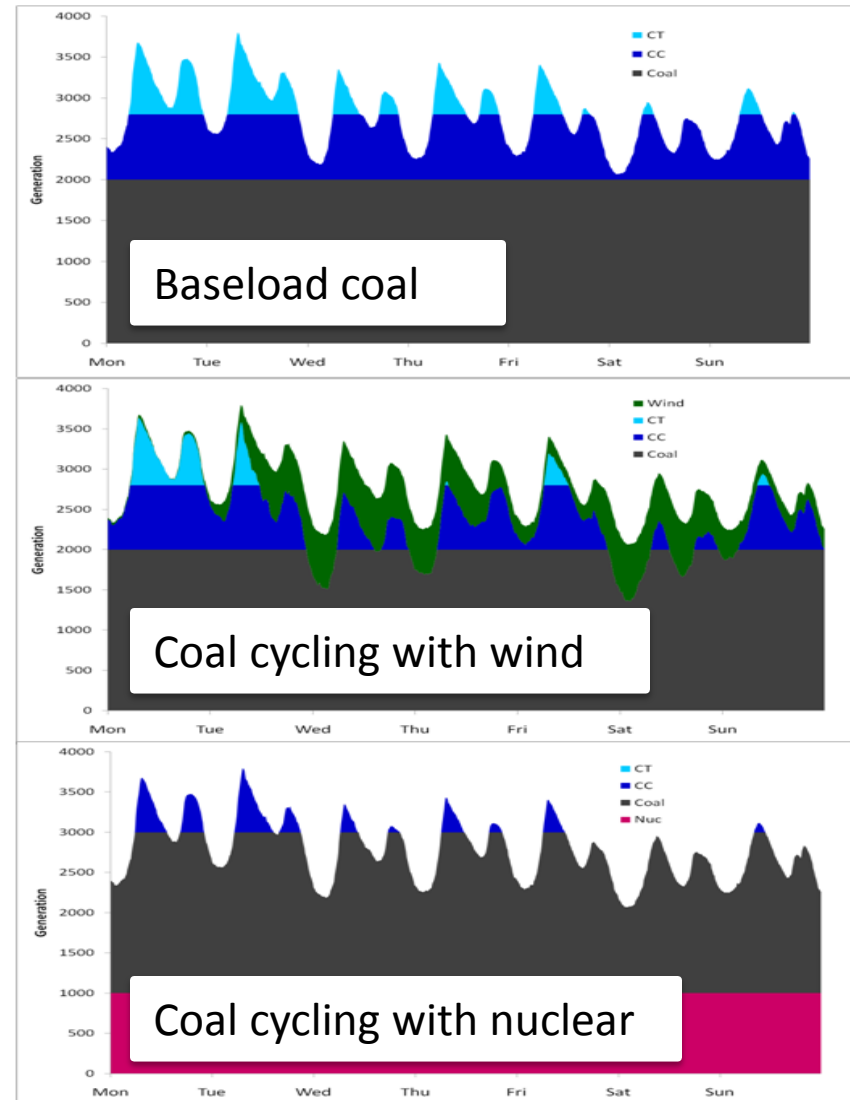
Source: Adrian Pingstone (Wikimedia Commons)

- At higher penetration levels, storage could be of value.
  - Recent E3 integration study for 40% penetration in California: storage is one of many options.

# 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



# Key Takeaways

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- Wind and solar generation increase variability and uncertainty
- Actual operating experiences from around the world have shown up to 39% annual penetrations are possible
- Often most the cost effective changes to the power system are institutional (changes to system operations and market designs)
- 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



NREL/PIX 10926

Part 4

# **GREENING THE GRID TOOLKIT**

# What is Greening the Grid?

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***Greening the Grid provides technical assistance to energy system planners, regulators, and grid operators to overcome challenges associated with integrating variable renewable energy to the grid.***

# What We Do

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Offer a **toolkit** of information and guidance materials to inform the development and implementation of grid integration roadmaps



Facilitate direct **technical assistance** tailored to the unique power system characteristics and priorities of each partner country

*Greening the Grid is a component of the U.S. Government's Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) program*



# The Greening the Grid Toolkit

- HOME
- OVERVIEW
- TRAININGS
- INTEGRATION TOPICS
- ASK AN EXPERT
- GLOSSARY
- RESOURCES



## Understand Grid Integration Basics

Review concise fact sheets covering a variety of key issues. [Read more](#)

## Greening the Grid

### What is Grid Integration?



*The Challenge:*  
*Large-Scale, Grid  
Connected Clean  
Energy*

Power grids are complex networks that balance electricity supply and demand around the clock, every day of the year. Renewable energy, such as solar and wind, can significantly reduce greenhouse gas emissions from electricity generation.

[Read more](#)

### What We Do



*Technical  
Assistance and  
Collaboration*

Greening the Grid offers a toolkit of information, guidance materials, and technical assistance to support countries in significantly scaling up the amount of variable renewable energy connected to the electricity grid.

[Read more](#)

### Ask an Expert



*Request information  
and assistance*

Greening the Grid connects power system stakeholders to experts from our grid integration expert network to provide no-cost, remote consultation and advice.

[Submit a Request](#)

# Greening the Grid Factsheets

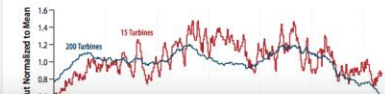
## Topics Now Available:

- *Integrating Variable RE into the Grid: Key Issues*
- *Scaling Up Renewable Energy Generation*
- *Balancing Area Coordination*
- *Using Wind and Solar to Reliably Meet Electricity Demand*
- *Sources of Operational Flexibility*
- *Methods for Procuring Power System Flexibility*
- *Wind and Solar on the Power Grid: Myths and Misperceptions*
- *Grid Integration Studies: Data Requirements*

## Coming Soon:

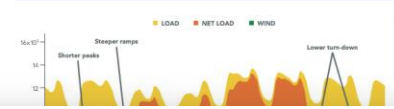
- *The Evolution of Power System Planning*
- *Grid Expansion and Upgrades*
- *Demand Response and Storage*
- *Integrating Distributed Solar*
- *Evaluating Costs of Grid Integration*

### WIND AND SOLAR ON THE POWER GRID: MYTHS AND MISPERCEPTIONS



Employing the inherent flexibility present in the power system helps mitigate the most impacts of renewables. Although ramp rates (rate of change) of the aggregated wind and solar output can still be significant, power systems—even before the development of VRE technologies—are often in a better position to manage variability in heavily variable and seasonal, a variety of designed but (4) observed elements, ch of the longer of which can log (offline).

### SOURCES OF OPERATIONAL FLEXIBILITY



**VARIABLE RENEWABLE ENERGY INCREASES THE NEED FOR FLEXIBILITY**  
Operational flexibility refers to the ability of a power system to respond to changes in electricity demand and generation. Flexibility is particularly important for power systems with high shares of solar and wind.

### INTEGRATING VARIABLE RENEWABLE ENERGY INTO THE GRID: KEY ISSUES



"Greening the Grid" aims to modernize the power system so that it can accommodate large-scale integration of variable renewable energy resources. Photo from flickr/photos/17722781 and flickr/photos/12466265.

To foster sustainable, low-emission development, many countries are establishing ambitious renewable energy targets for their electricity supply. Because solar and wind tend to be more variable and uncertain than conventional sources, meeting these targets will involve changes to power system planning and operations. Grid integration is the practice of developing efficient ways to deliver variable renewable energy (VRE) to the grid. Good integration methods maximize the cost-effectiveness of incorporating VRE into the power system while maintaining or increasing system stability and reliability.

- When considering grid integration, policymakers, regulators, and system operators consider a variety of issues, which can be organized into four broad topics:
- New renewable energy generation
  - New transmission
  - Increased system flexibility
  - Planning for a high RE future.

**NEW RENEWABLE ENERGY GENERATION**  
Power system planners can secure and sustain investment in new VRE generation by aligning targets and incentives with grid integration considerations. Long-

term, aspirational renewable energy targets in the policies and system operations that support clean energy. Also critical are "grid-aware" incentives (e.g., rewarding wind and solar generators that incorporate technologies that contribute to grid stability), which both motivate investment in renewable energy and mitigate negative impacts of integrating these resources to the grid.

As planners consider scaling up VRE generation, the inherent variability of wind and solar resources complicates evaluations of whether a system with significant VRE has adequate supply to meet long-term electricity demand. A variety of approaches exist for estimating the capacity value of VRE, as well as techniques that enable utilities and power system operators to use wind and solar to reliably meet electricity demand.

**Integrating distributed photovoltaic (PV) solar power** results in unique benefits and challenges compared to the integration of utility-scale wind and solar power. Significant localized growth in PV can raise concerns such as voltage violations and reverse power flow in low-voltage distribution systems. However, various studies have shown that positive impacts (e.g., reduced line losses and avoided generation costs) can also result

#### GRID INTEGRATION TERMINOLOGY

**Balancing area:** the collection of generation, transmission, and loads within the metered boundaries of the responsible entity (i.e., the balancing authority) that maintains balance between electricity supply and demand within this boundary.

**Capacity value:** the contribution of a power plant to reliably meet demand, measured either in terms of physical capacity (kW, MW, or GW) or as a fraction of the power plant's nameplate capacity (%).

**Flexibility:** the ability of a power system to respond to changes in electricity demand and supply.

**Demand response:** voluntary (and compensated) load reduction used as a system reliability resource.

**Grid integration of renewable energy:** the practice of power system planning, interconnection, and operation that enables efficient and cost-effective use of renewable energy while maintaining the stability and reliability of electricity delivery.

**Grid integration study:** an analysis of a set of scenarios and sensitivities that seeks to inform the stakeholders on the ability and needs of a power system to accommodate significant VRE.

**Storage:** technologies capable of storing electricity generated at one time and for use at a later time.

**Variable renewable energy (VRE):** electricity generation technologies whose primary energy source varies over time and cannot easily be stored. VRE sources include solar, wind, ocean, and some hydropower generation technologies.

**Variability:** the changes in power demand and/or the output of a generator due to underlying fluctuations in resource or load.

**Uncertainty:** the inability to perfectly predict electricity demand and/or generator output.

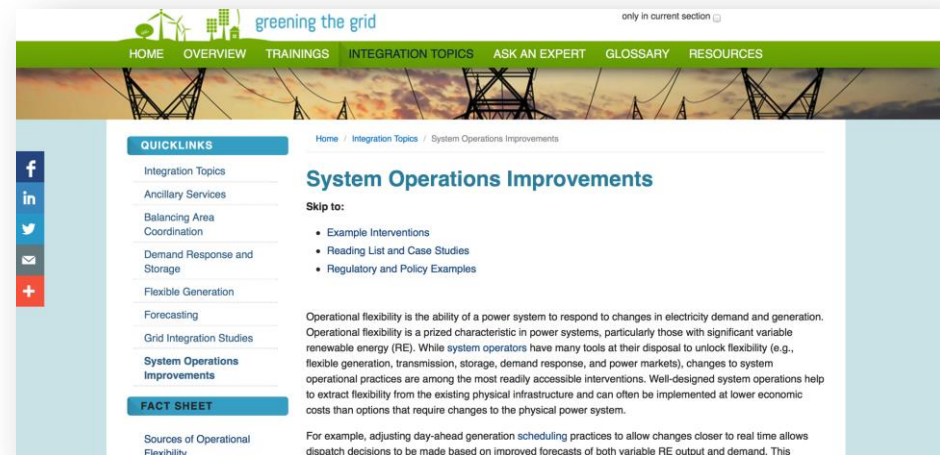
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two uses of backup wind. The first is used by. As ty and increase. This system is dedicated to reduce emissions and that reduce needed. This power system rig and the additional date  
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# Integration Topics

- Ancillary Services
- Balancing Area Coordination
- Demand Response and Storage
- Flexible Generation
- Forecasting
- Grid Integration Studies
- System Operations Improvements

## *Coming Soon*

- Resource Adequacy
- Distributed Generation
- Target-Setting



## **Resources in the Toolkit:**

- *Background information*
  - *Tools*
  - *Methodologies*
  - *Videos*
- *Technical reports*
  - *Case studies*
- *Model policies and regulations*
- *Example grid integration studies*

# Greening the Grid Technical Assistance Opportunities

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## Ask an Expert Service

- No cost, remote expert consultation on grid integration questions
- High-level guidance; review of drafts of strategies; examples from other systems
- Supported by experts from the National Renewable Energy Laboratory and the Clean Energy Solutions Center expert network

## Demonstration Projects

- In-depth USAID-funded direct assistance to partner countries to identify and implement actions to increase variable RE penetration
- Examples:
  - Support for grid integration studies and roadmaps
  - Integrating forecasting into system operation controls
  - Addressing technical and regulatory challenges of distributed solar PV

***We welcome requests!***

# Coming Soon

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- Additional factsheets and integration topics
- Webinar series
  - Next topic: Best Practices in Grid Integration Studies (September 2015)
- Integration demonstration projects with partner countries
- More case studies and examples from developing countries
  - Please let us know of resources that you would like to see highlighted!

Part 5

# **QUESTIONS AND PANEL DISCUSSION**

# Contacts and Additional Information

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## Webinar Panel

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## Greening the Grid

[greeningthegrid.org](http://greeningthegrid.org)  
Email: [greeningthegrid@nrel.gov](mailto:greeningthegrid@nrel.gov)



# **APPENDIX**



# Key Terms

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**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

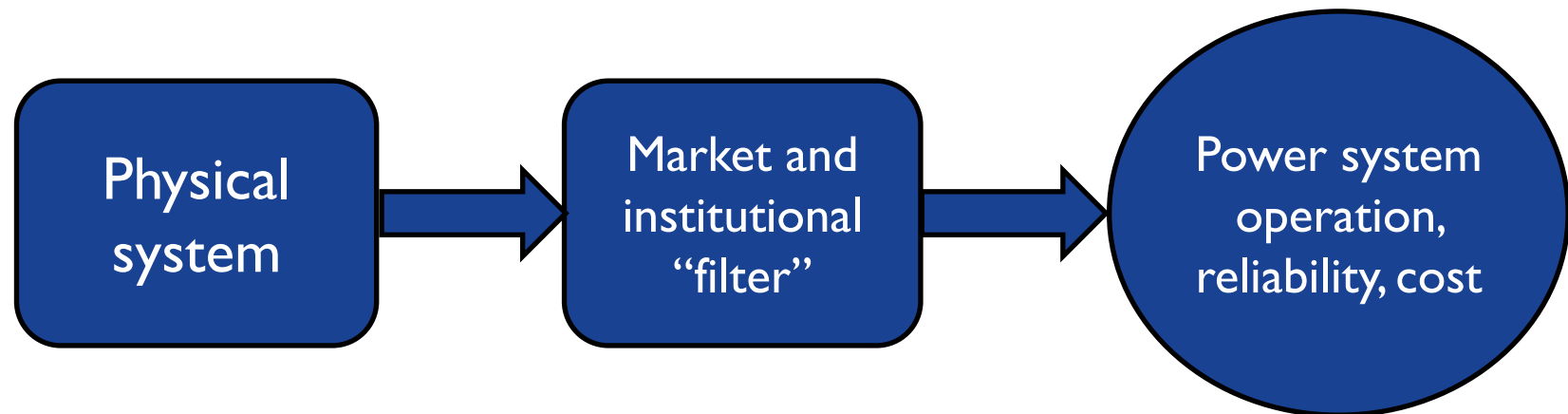
**Flexibility** - The ability of a power system to respond to change in demand and supply

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

# Flexibility reflects not just physical system, but institutional framework

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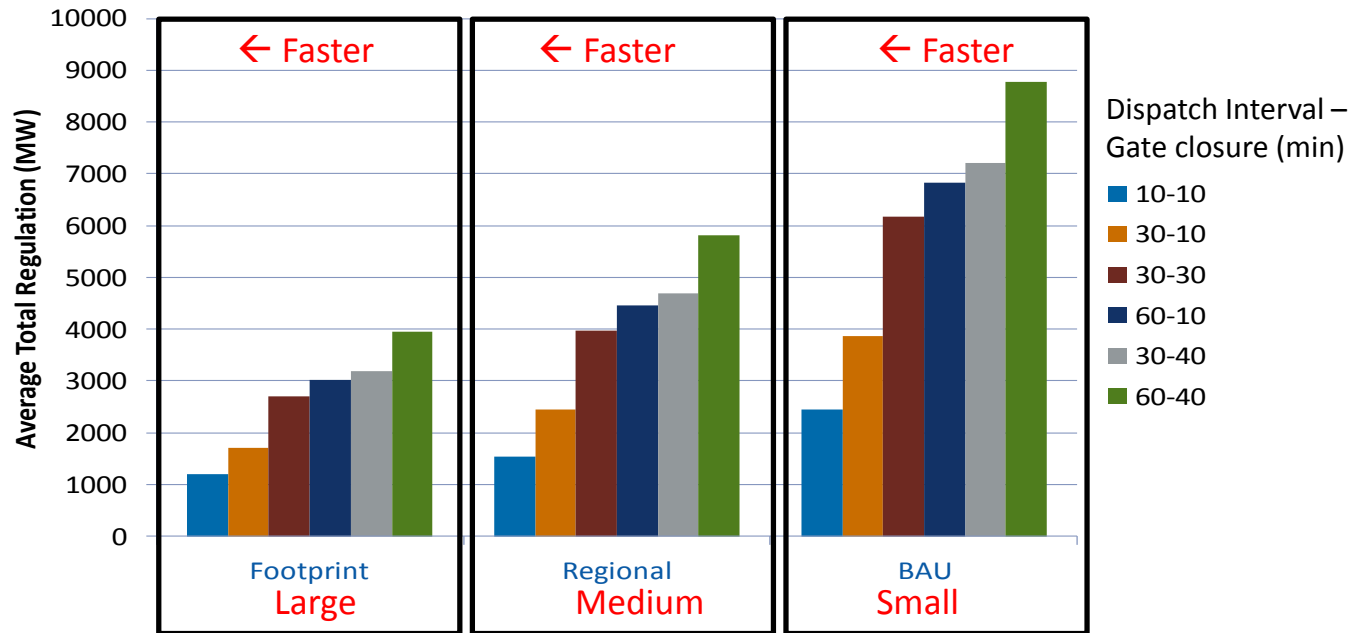
- Flexibility can come from two sources
  - Physical power system: generators, transmission, storage, interconnection
  - Institutional system: making dispatch decisions closer to real time, better use of forecasting, better collaboration with neighbors
- Power system operation must carefully consider both



*Smarter grids require smarter frameworks and markets*

# Impacts of faster dispatch, shorter gate closure, and larger balancing areas

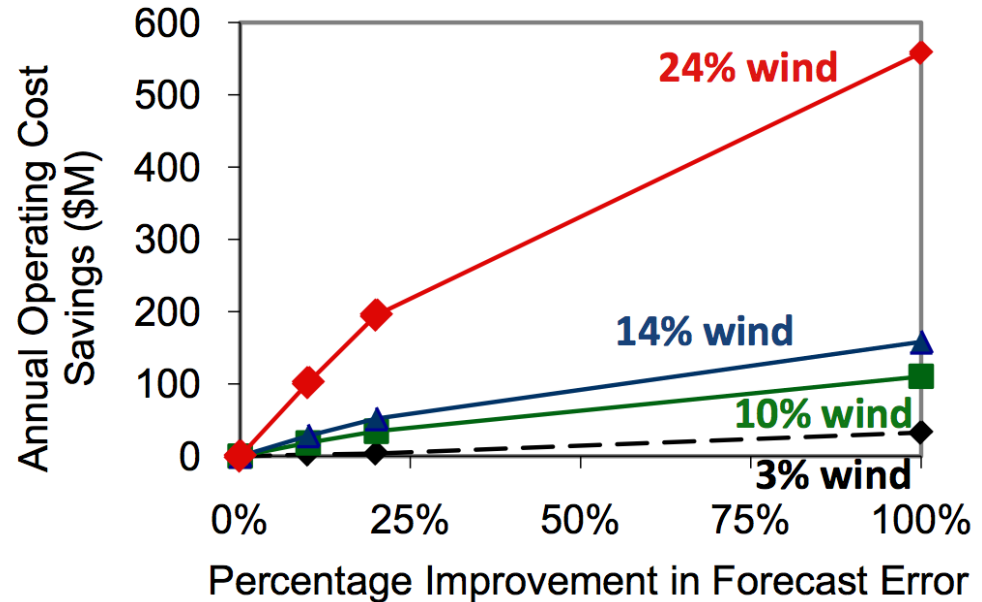
**Average Total Regulation for 6 Dispatch/Lead Schedules by Aggregation (Dispatch interval - Forecast lead time)**



Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October

# 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 may be more important than mean error reduction
- Access to renewable energy plant data is critical



At 24% (annual) 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>

# Strategic curtailment

Costs to  
achieve  
flexibility

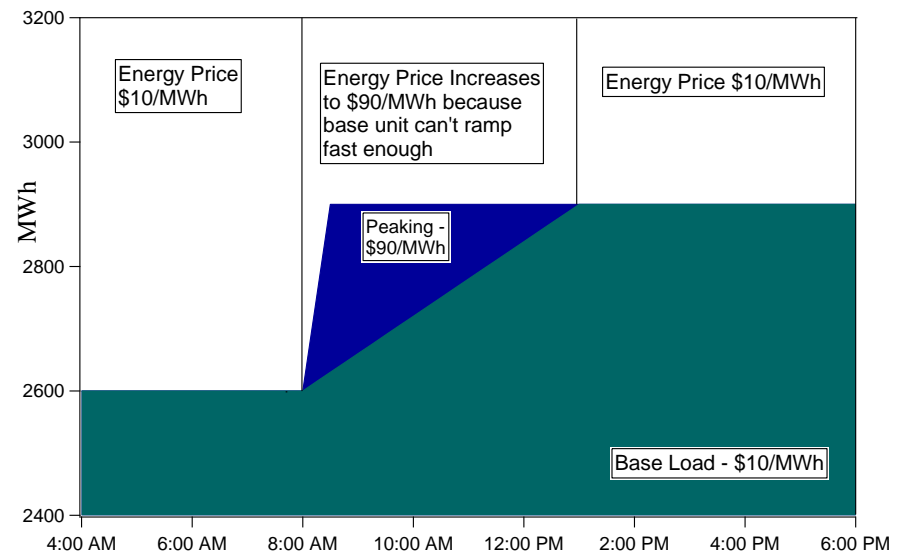


Benefits of  
reduced or no  
curtailment

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

# Revise energy market designs

- Ramp products
  - May 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



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

# 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 synthetic inertial control and primary and secondary frequency response
- Capability to curtail to a set-point command during periods of system stress
- Several regions in the U.S. and elsewhere are beginning to mandate that wind generators provide primary and secondary frequency response.

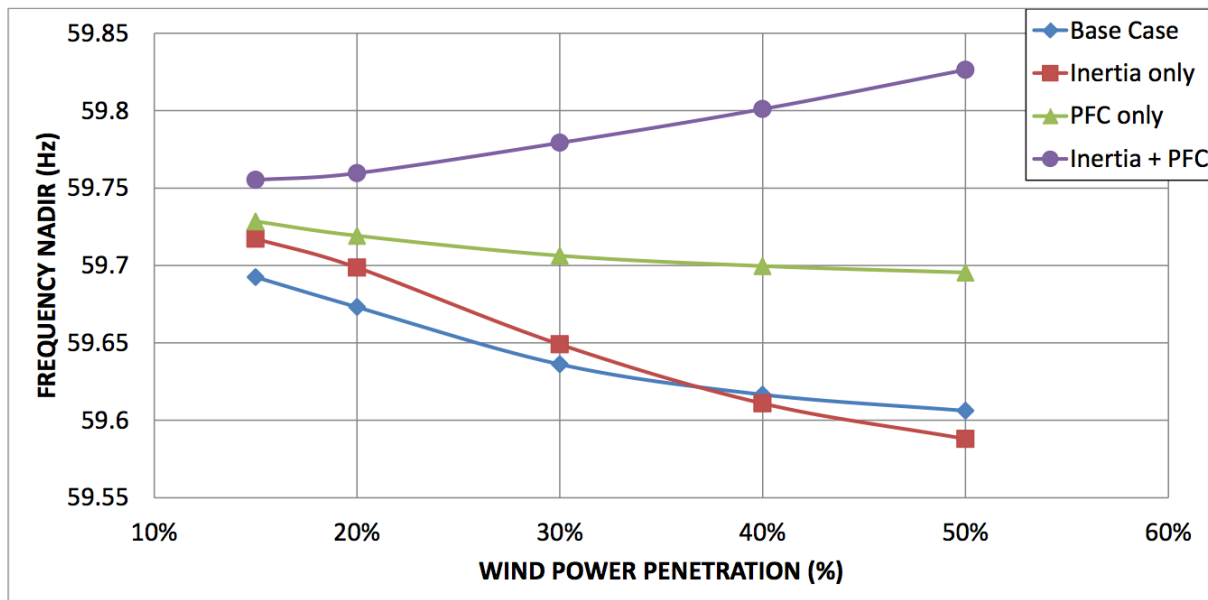


Figure: Impact of wind power controls on frequency nadir

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

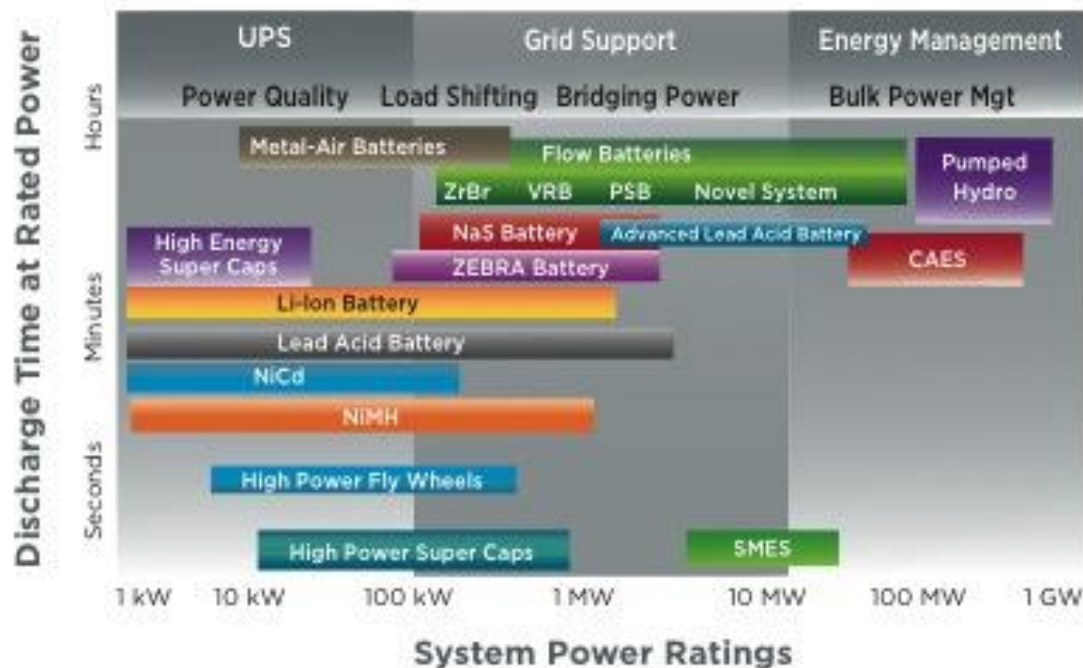


# Increased supply of flexibility: Storage

**ENERGY STORAGE can support:** Load Leveling/ Arbitrage; Provide Firm Capacity and Operating reserves; Ramping/Load Following; T&D Replacement and Deferral; and Black-Start. Storage must compete with other sources of flexibility

## Two applications of energy storage:

- *Operating reserves* – respond within seconds to minutes and provide regulating and contingency reserves.
- *Energy management* – continuous discharge over a period of hours to provide operating reserves as well as firm and system capacity.



Source: DOE/GO-102011-3201

**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



# Does variable renewable energy require new gas capacity to provide flexibility?

- If wind and solar are 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 and solar 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 VRE penetrations:**

Most systems sufficiently flexible

## **Medium VRE 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 VRE 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<sub>2</sub>, NO<sub>x</sub>, and SO<sub>2</sub>

	Emission Reduction Due to Renewables	Cycling Impact
CO <sub>2</sub>	260–300 billion lbs 29%–34%	Negligible Impact 
NO <sub>x</sub>	170–230 million lbs 16%–22%	3–4 million lbs 
SO <sub>2</sub>	80–140 million lbs 14%–24%	3–4 million lbs 

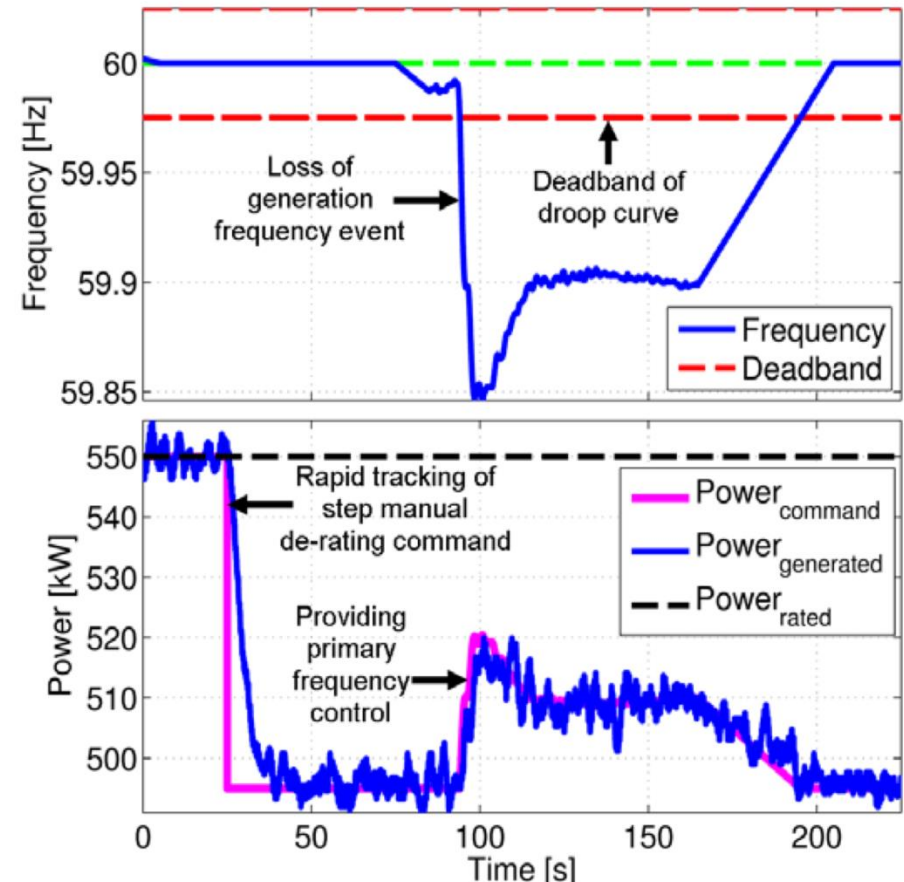
Scenario: 33% wind and solar energy penetration as percentage of annual load

# 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