Integrating Variable Renewable Energy into the Grid: Sources of Flexibility

Best Practices and Case Studies

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Laboratory Snapshot

- Two major campuses in Colorado
- Physical assets owned by the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy
- Operated by the Alliance for Sustainable Energy under a performance-based contract to DOE
- More than 650 active partnerships, including with internationally-focused organizations
- Activities span basic research, strategic analysis, commercialization, and deployment

Mission: to advance energy efficiency, renewable energy and energy systems integration

Clean Energy Solutions Center Background

CleanEnergySolutions.org

The Clean Energy Ministerial (CEM) launched the Clean Energy Solutions Center in April 2011.

The Solutions Center:

- Is one of several CEM Initiatives, which include:
  - Global Superior Energy Performance Partnership
  - Super-Efficient Equipment and Appliance Deployment initiative
  - Global Lighting and Energy Access Partnership
- Helps governments design and adopt policies and programs that support the deployment of clean energy technologies
- Has more than 35 partners, including IRENA, IEA, IPEEC, Sustainable Energy for All, Bloomberg New Energy Finance and Leonardo Energy
- Is co-chaired by the U.S. Department of Energy and the Australian Department of Industry.

Topics covered by this presentation

- **The role of flexibility in integrating variable renewable energy (RE) to the grid**
  - *Flexibility is a prized characteristic in power systems that have or are working toward significant penetrations of variable renewable energy.*

- **Sources of flexibility**
  - *Sources of flexibility exist across the physical and institutional elements of the power system.*

- **Flexibility case studies**
  - *This presentation provides several snapshots of how a variety of systems are accessing different sources of flexibility.*
  - *These examples are illustrative, not comprehensive. The most successful power systems are implementing multiple strategies for enhancing flexibility.*

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

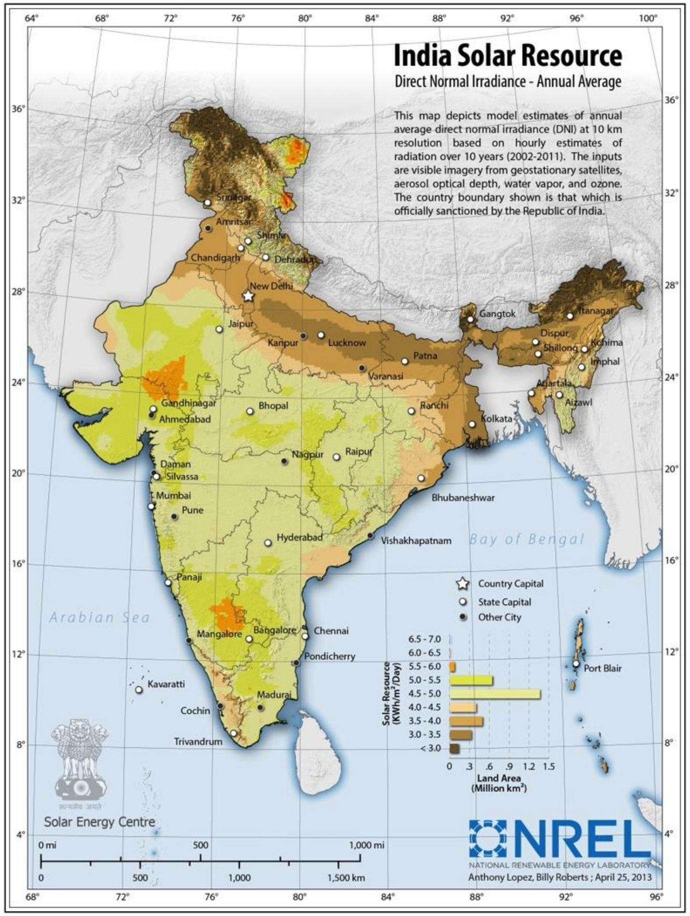
Country	% Electricity from Wind	Balancing
Denmark	**39% in 2014**	Interconnection, flexible generation (including CHP), and good markets
Portugal	**25% in 2013**	Interconnection to Spain, gas, hydro, and good market
Spain	**21% in 2013**	Gas, hydro, and good market
Ireland	**18% in 2013**	Gas and good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

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

RE is variable, uncertain, and geographically dispersed

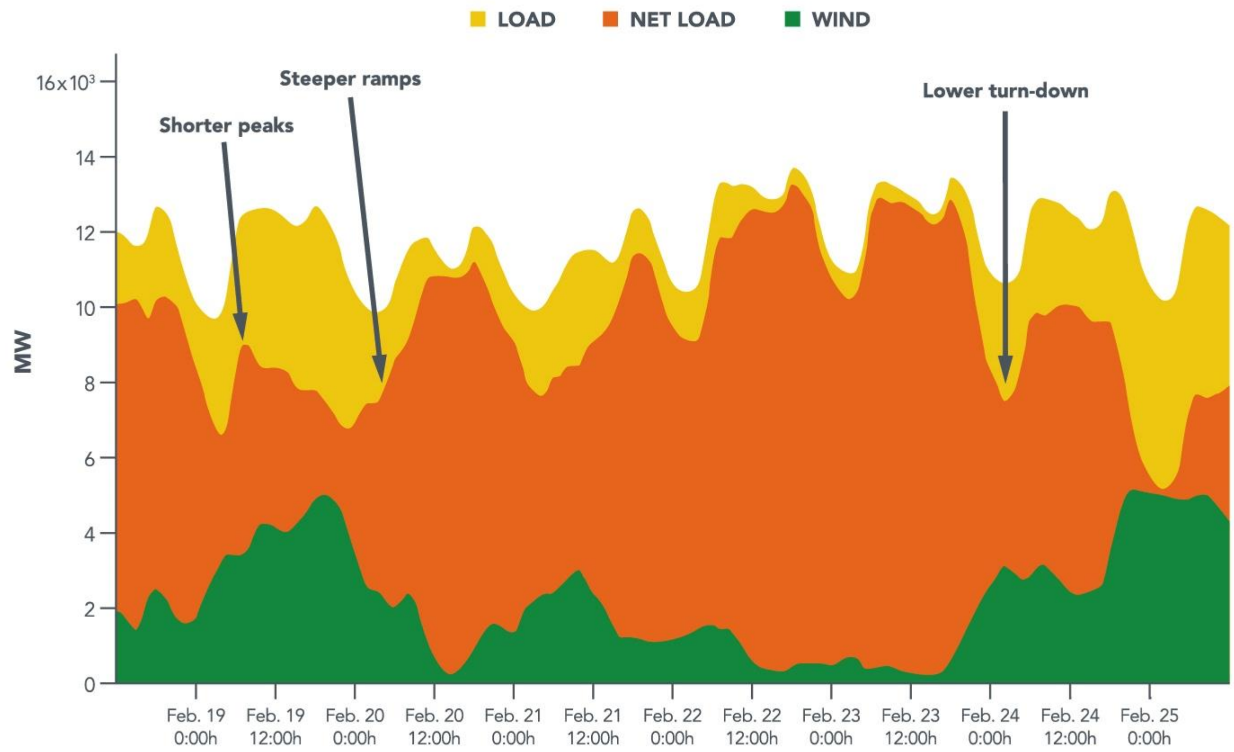


…raising new considerations for grid planning and operations

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

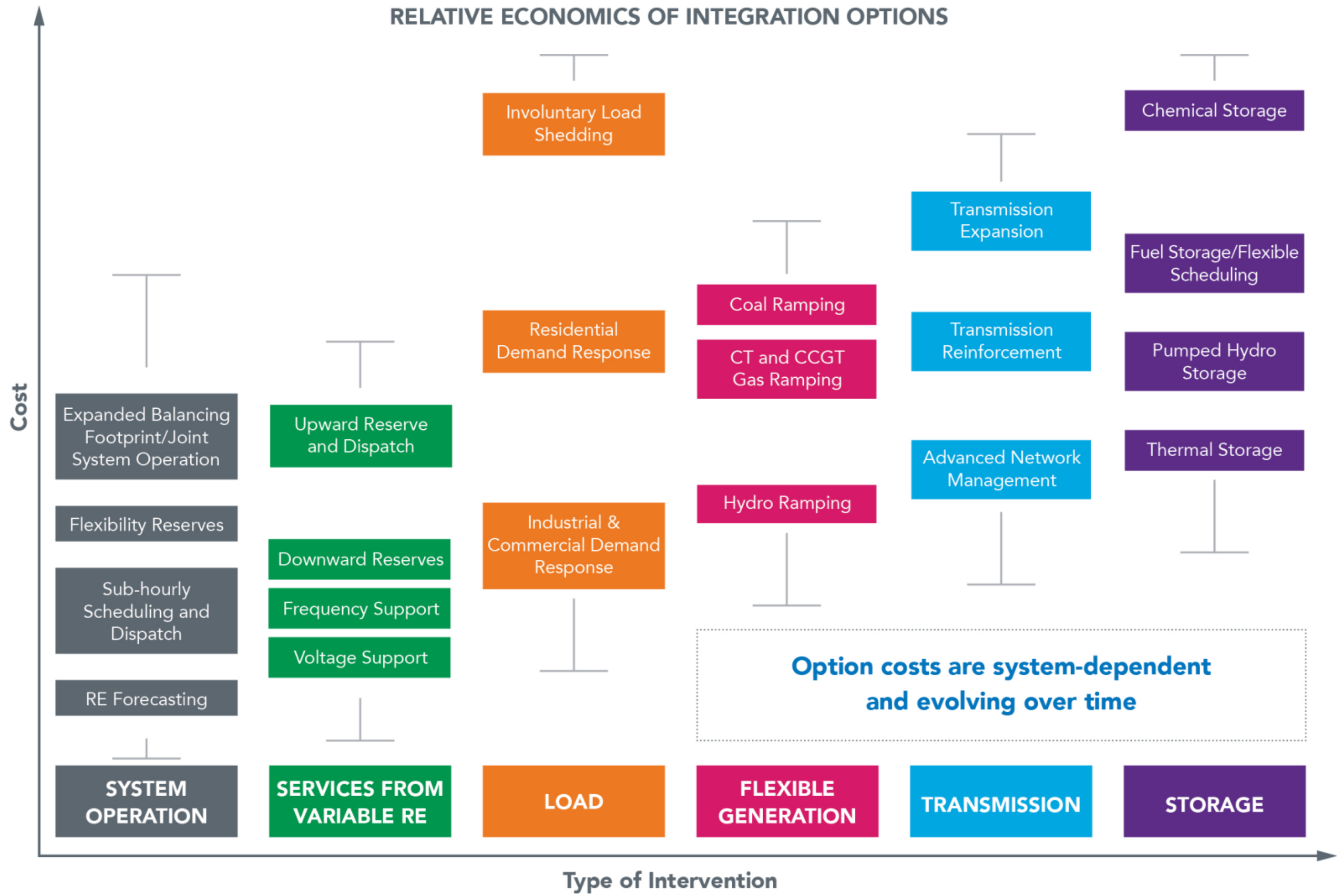
"Flexibility" can help address the grid integration challenges

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



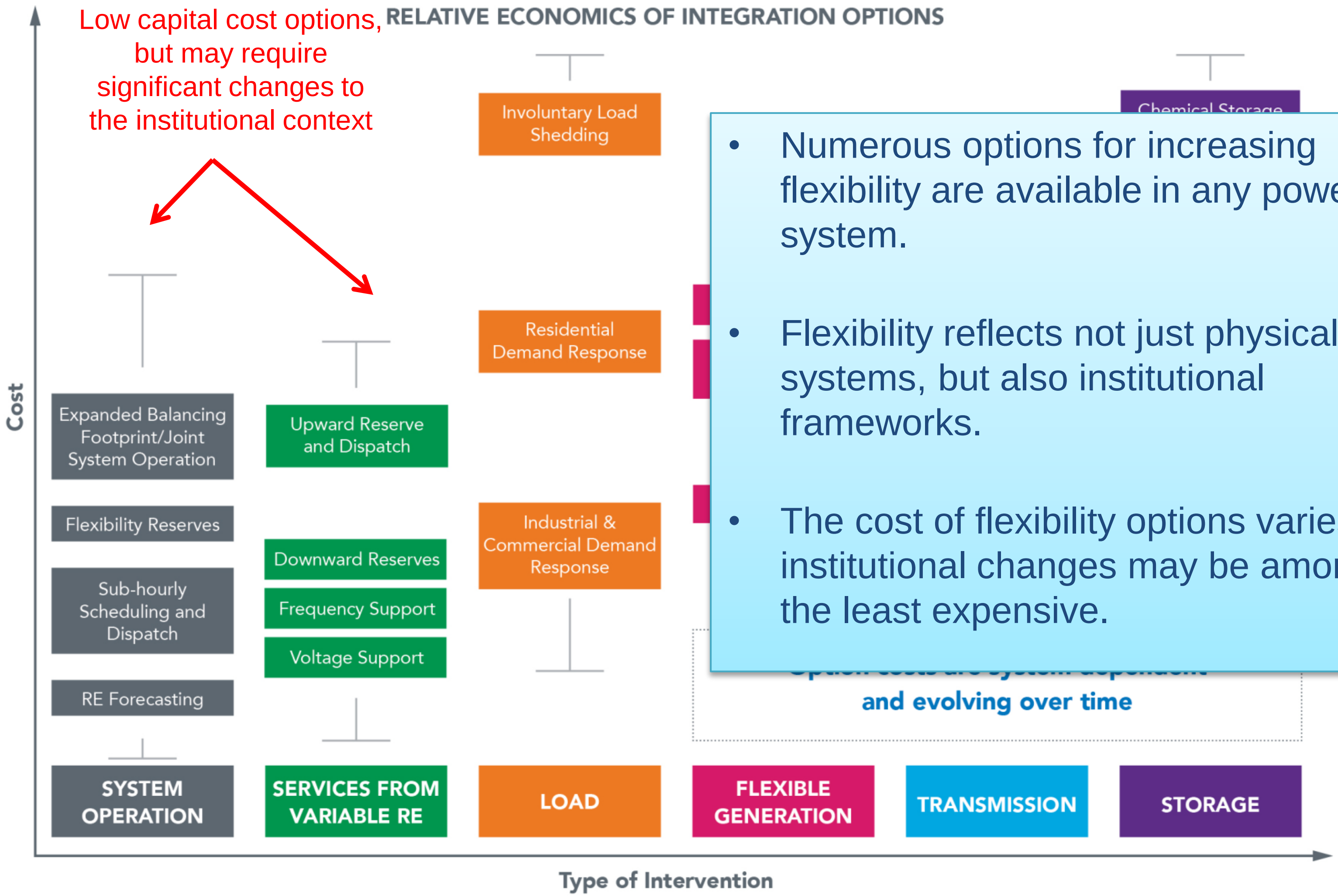
- Increases in variable generation on a system increase the variability of the 'net load'
  - 'Net load' is the demand that must be supplied by conventional generation unless RE is deployed to provide flexibility
- High flexibility implies the system can respond quickly to changes in net load.

Frequently used options to increase flexibility



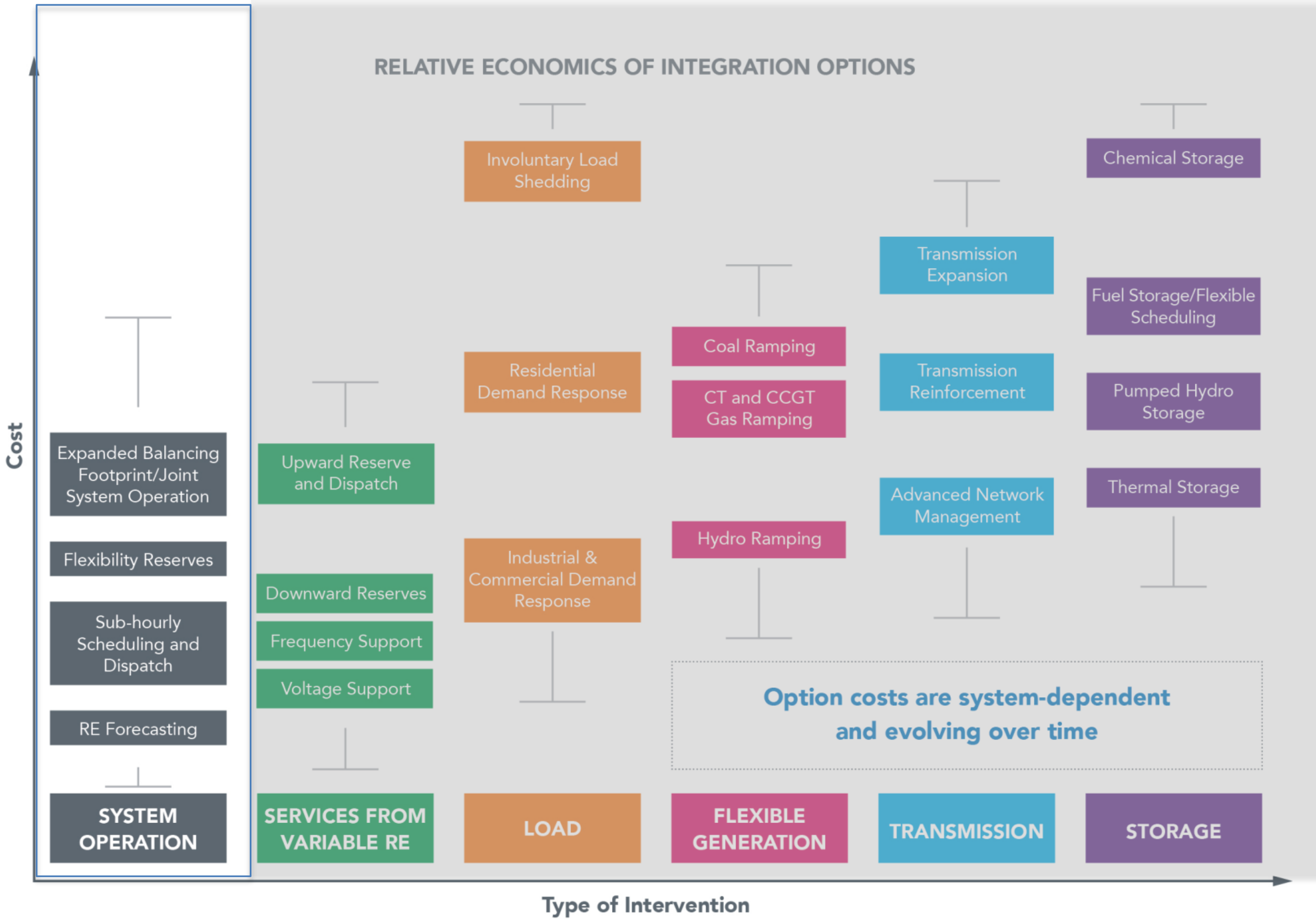
Frequently used options to increase flexibility

Low capital cost options, but may require significant changes to the institutional context



- Numerous options for increasing flexibility are available in any power system.
- Flexibility reflects not just physical systems, but also institutional frameworks.
- The cost of flexibility options varies, but institutional changes may be among the least expensive.

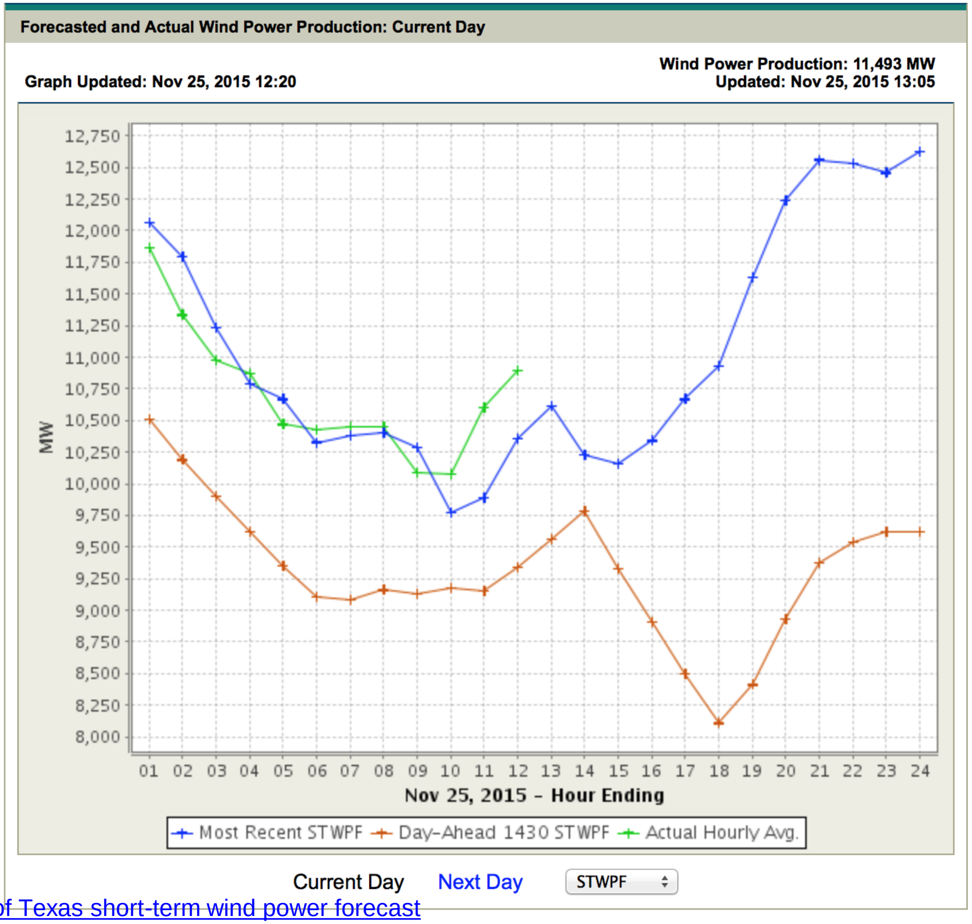
Flexibility from system operations



Forecasting reduces uncertainty and improves scheduling

System Operation

Wind and solar forecasting improves scheduling of other resources to reduce reserves, fuel consumption, and operation and maintenance costs

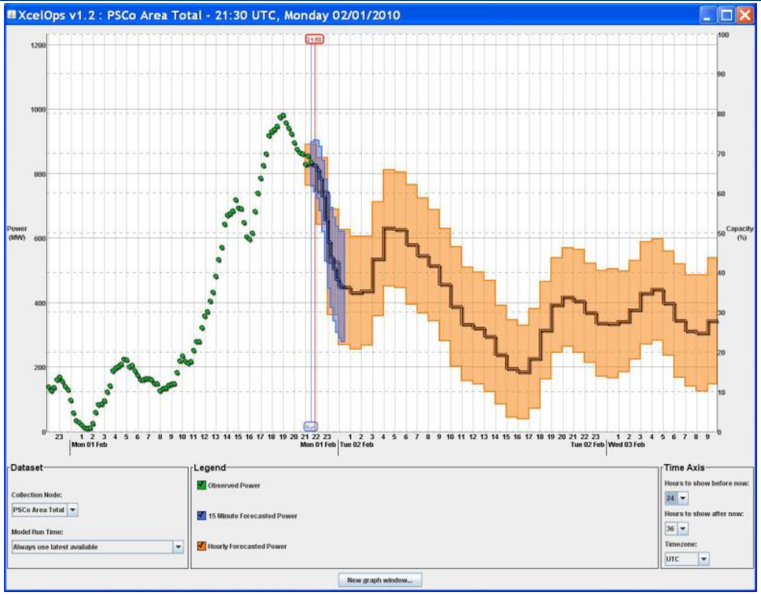


Source: [Electricity Reliability Council of Texas short-term wind power forecast]

Improved variable RE forecasting reduces uncertainty and costs: Xcel Energy case study

System Operation

- Partnered with two national laboratories to develop a state-of-the art forecasting model, which is maintained by a third party
- Uses real-time, turbine-level operating data to generate wind energy forecasts every 15 minutes out to 3 hours and on an hourly basis out to 168 hours
- Outcomes:
  - Reduced forecast error from 16.8% in 2009 to 10.10% in 2014
  - Saved ratepayers US $49.0 million over the 2010-2014 period



Grid Integration Achievements

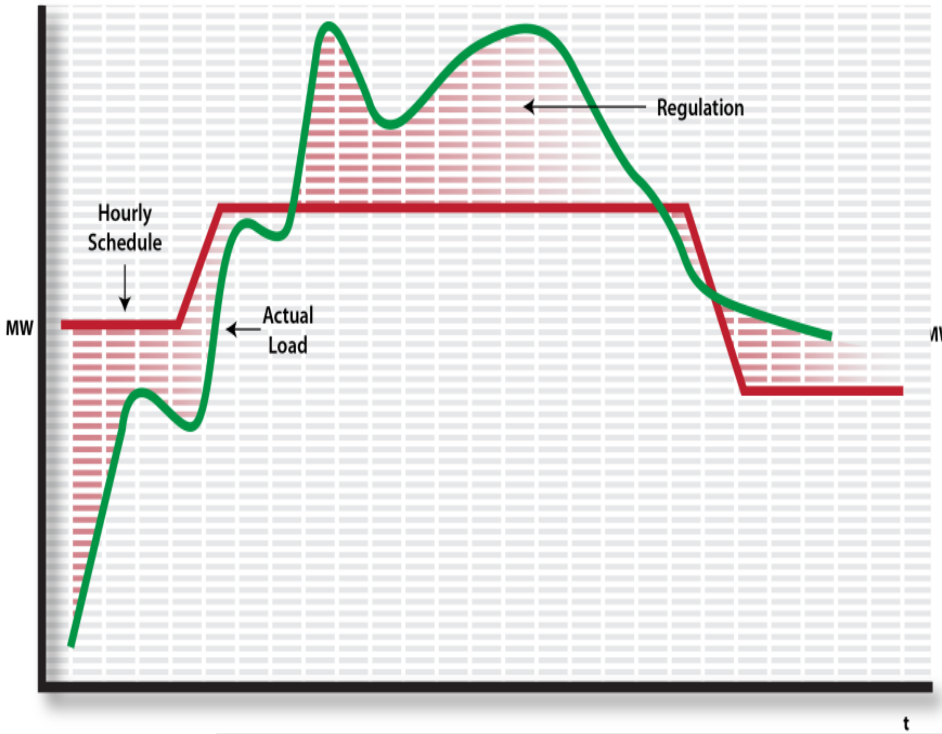
- #1 utility wind provider in the United States, and top 10 for solar.
- Wind generated 15% of energy supply in 2014 (a five-fold increase over 2006 levels); 5,794 MW wind capacity installed.
- Public Service Company of Colorado experienced instantaneous wind penetration of 61% in 2014.

Sources: Staton 2015; NCAR 2015; Xcel Energy 2015

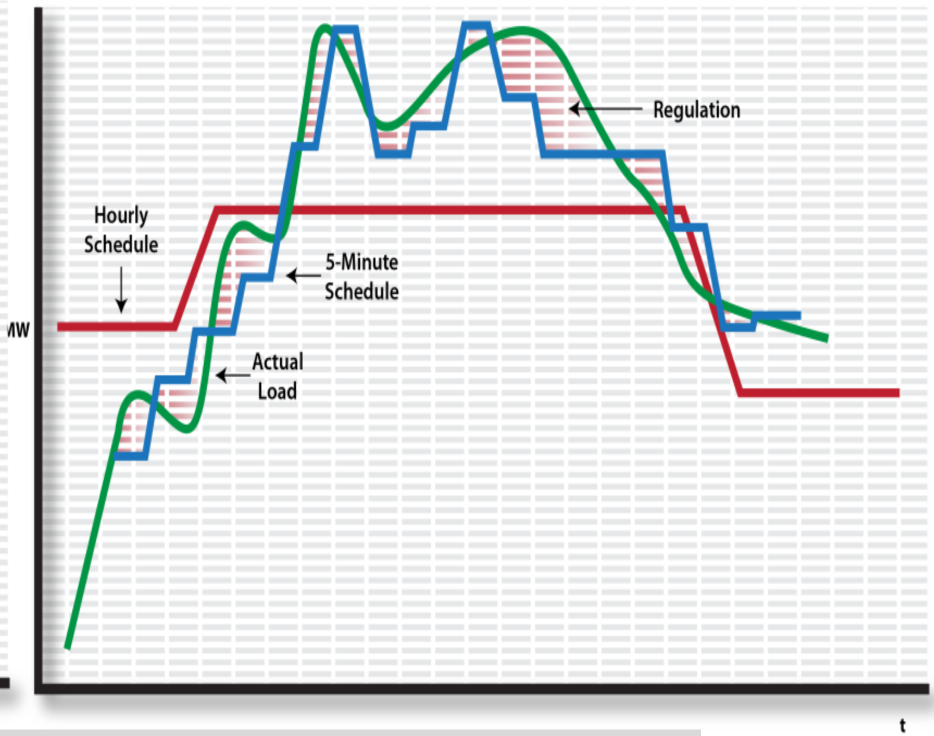
Faster dispatch reduces expensive reserves

System Operation

Hourly dispatch and interchanges



Sub-hourly dispatch



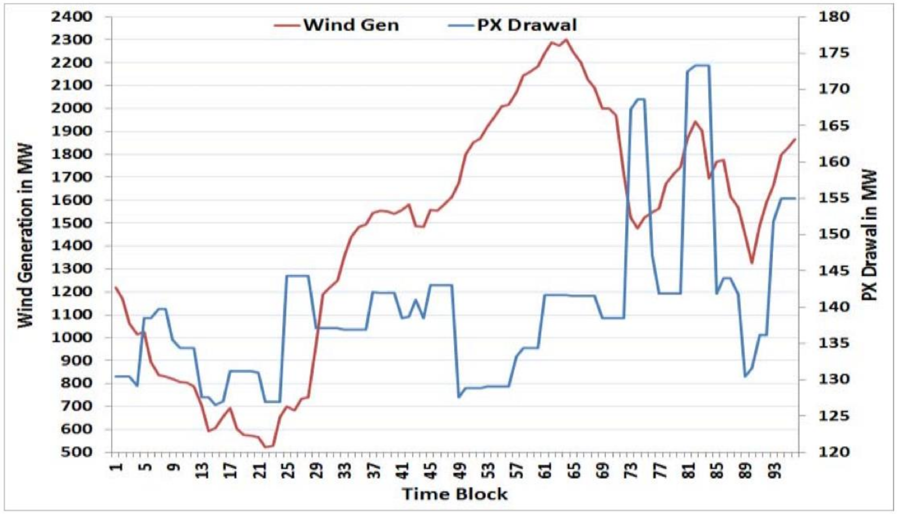
Dispatch decisions closer to real-time (e.g., intraday scheduling adjustments; short gate closure) reduce uncertainty.

Source: NREL

Sub-hourly markets enable more efficient utilization of the generation fleet: India case study

System Operation

- Modified the bidding time block from one hour to 15-minutes in 2012
- Outcomes:
  - Better portfolio management by utilities
  - More gradual ramping and smoother morning and evening peaks
  - Better utilization of maneuvering capabilities of conventional generation to manage variability in renewable-rich states



Source: Barpanda et al. 2015

Grid Integration Achievements

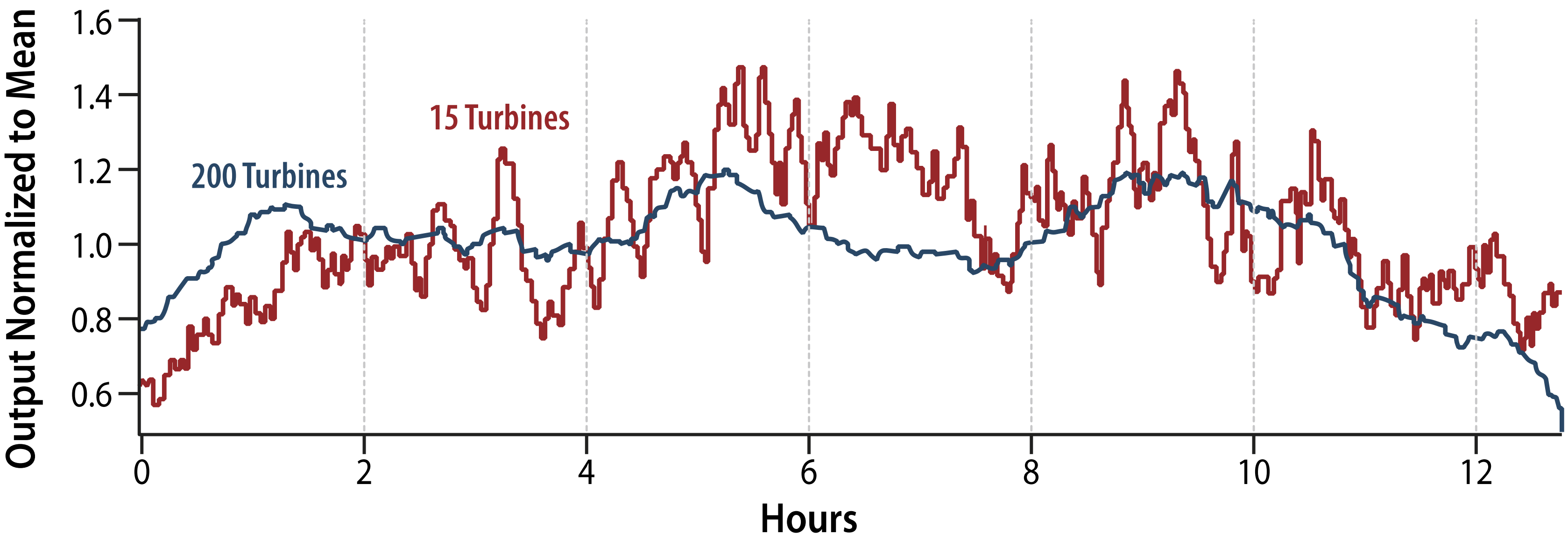
- More than 22.4 GW of wind and 3.0 GW of solar installed (2014).
- Government of India has set some of the world's most ambitious installation targets: 160 GW of wind and solar by 2022.

Sources: Barpanda et al. 2015; MNRE 2015

Larger balancing footprint reduces variability

System Operation

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



Source: NREL/FS-6A20-63037

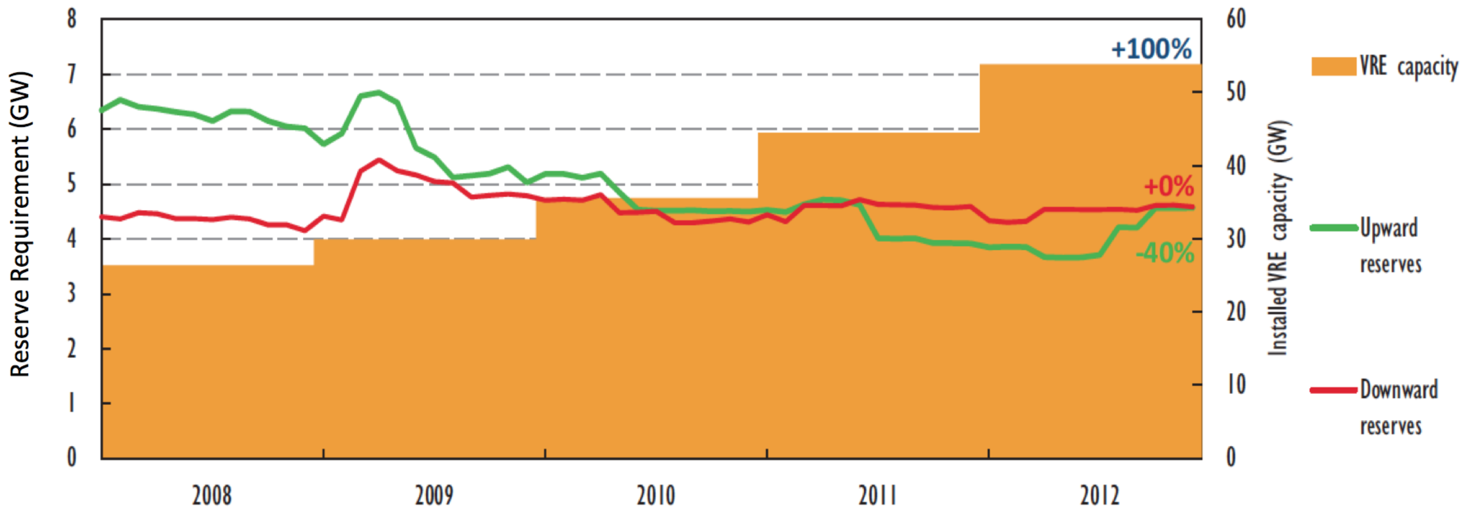
Balancing area cooperation decreases the need for reserves: Germany case study

System Operation

- Germany's four TSOs began cooperating to jointly allocating and activating reserves in 2009
- The TSOs also use a common procurement platform
- Outcomes
  - More than doubled variable RE capacity between 2008 and 2013 but decreased balancing reserves by 20%.

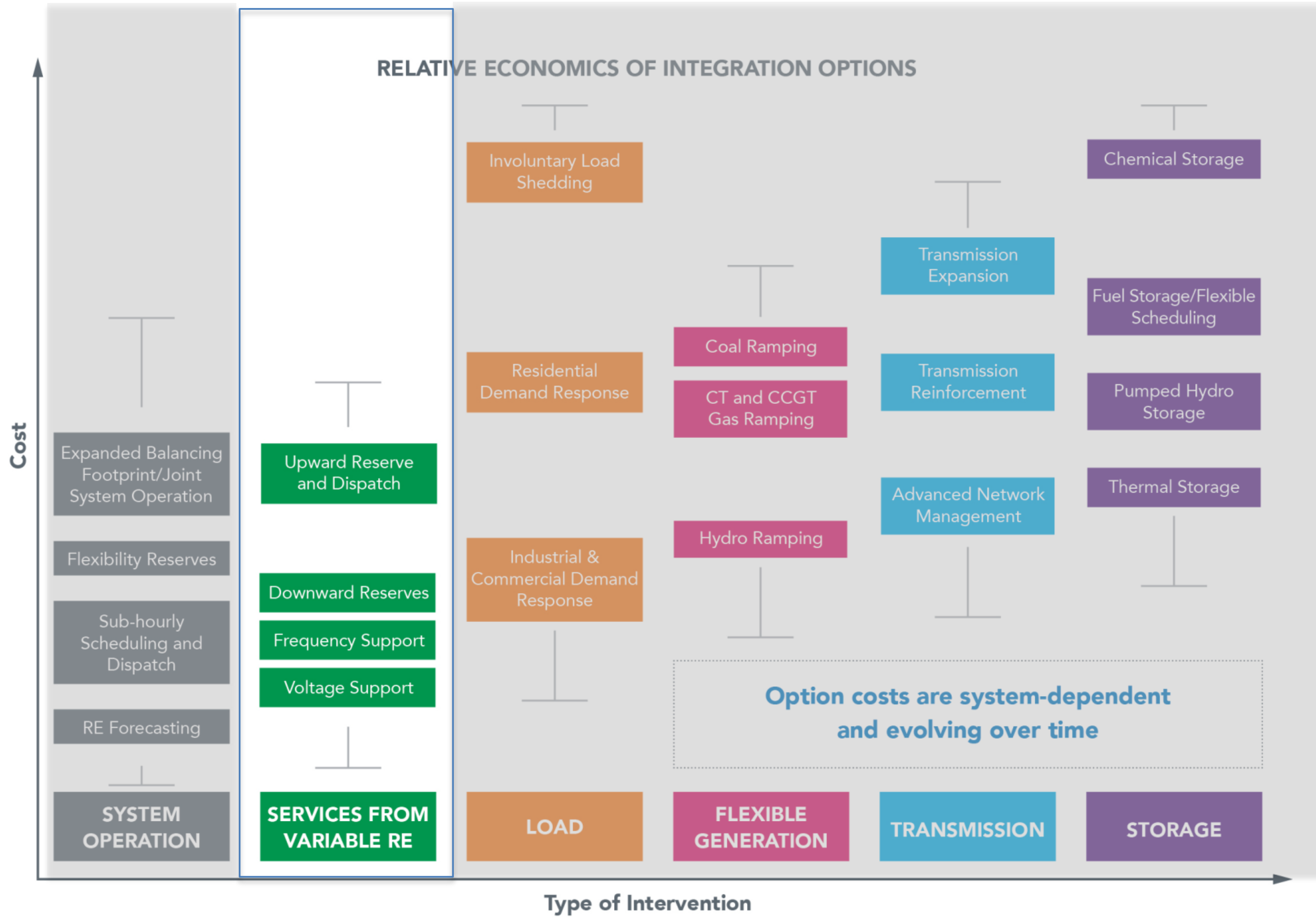
Grid Integration Achievements

- More than 35.6 GW wind and 38.1 GW solar installed (2014).
- Wind and solar supplied more than 15.8% of demand in the first 11 months of 2014.
- Maximum instantaneous penetration levels reached over 56% (including 40-50% from distributed generation.



Sources: Hirth and Ziegenhagen 2013; Miller et al. 2015

Flexibility from services provided by variable RE



Utilizing flexible generation from wind: Xcel Energy case study

Services from Variable RE

- 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

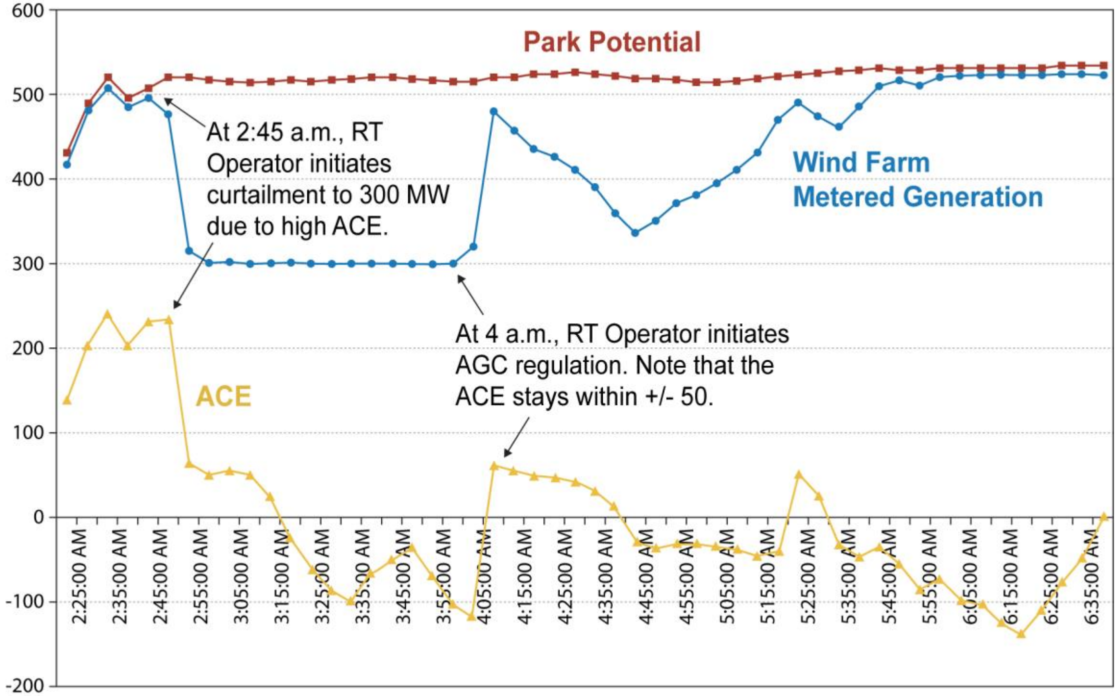


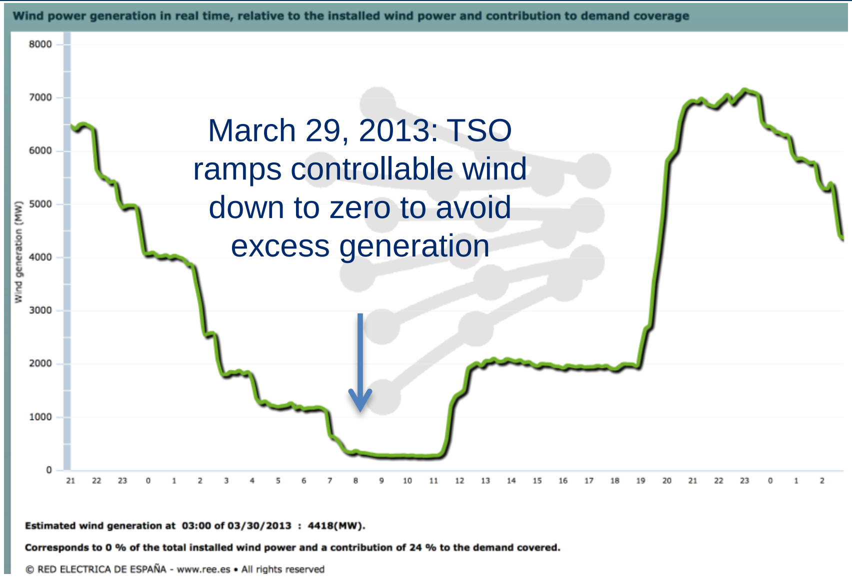
Figure: Impact of wind power controls regulation, dispatch, and area control error

Source: Public Service Company of Colorado

Enabling renewables to contribute grid services: Spain case study

Services from Variable RE

- Strict grid codes specify:
  - Frequency control (required)
  - Reactive power supply; fault ride through capabilities; plant operation in line with forecast (incentivized/penalized)
- Complemented by the capabilities of the Control Centre for Renewable Energy, which observes generators larger than 1MW in real time and can control generators over 5MW within 15 minutes
- Outcomes:
  - Reduced the number wind power losses of more than 100 MW from 87 in 2007 to 30 in 2009

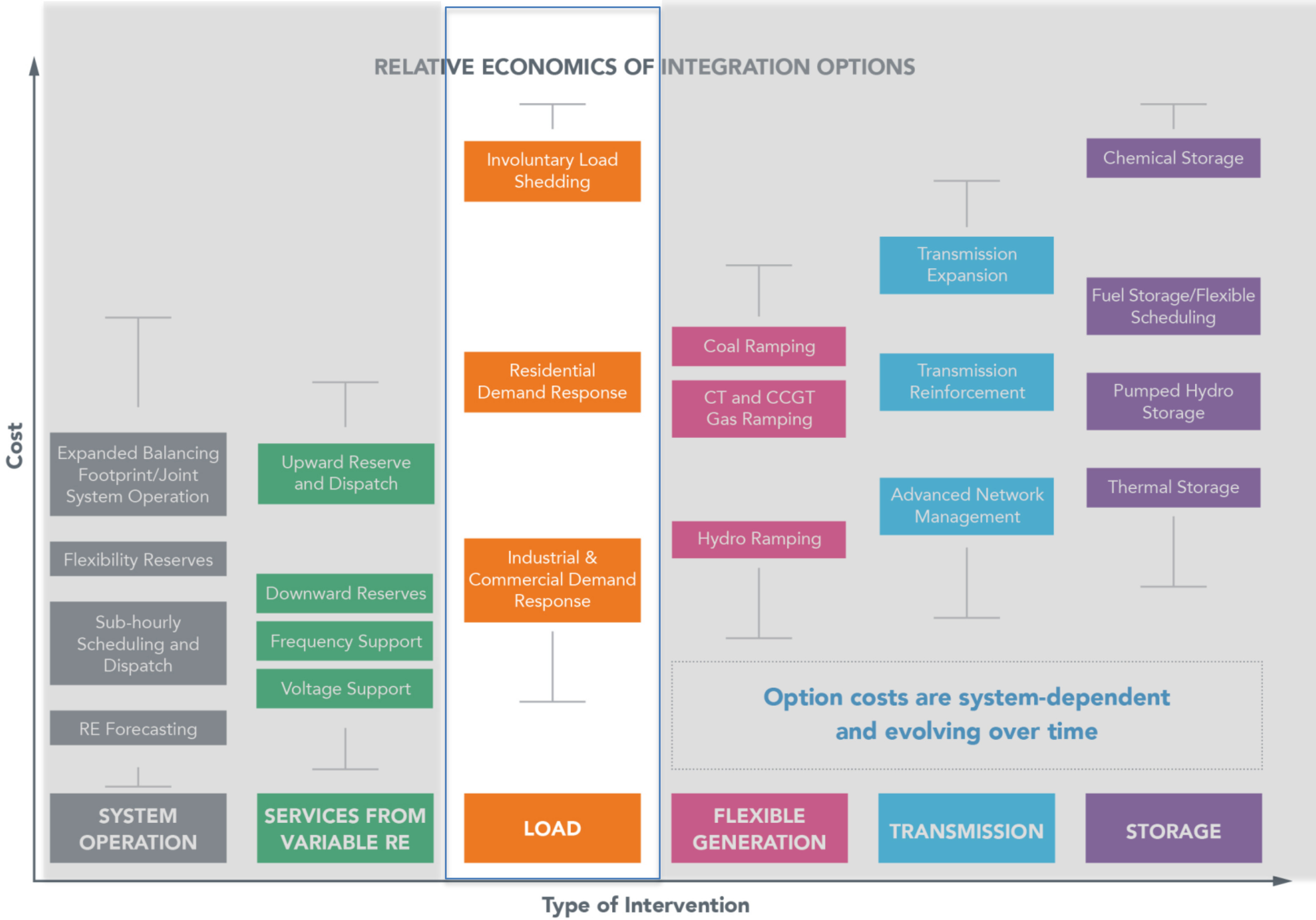


Grid Integration Achievements

- First country to rely on wind as top energy source (in 2013). Wind energy met 20.4% of demand in 2014.
- Over 2,000 MW solar PV installed, meeting 3.1% of demand in 2014.
- Instantaneous wind penetrations can reach more than 60% of power demand.
- Curtails less than 1.5% of variable RE generation (2013).

Sources: Amenedo 2010; Red Eléctrica de España 2014; Milligan et al. 2015; Fichtner 2010 ; Ackermann et al. 2015 (Figure: Red Eléctrica de España 2015)

Flexibility from load



Implementing demand side management to improve system flexibility: Republic of Korea case study

Load

- Offers financial incentives to customers who reduce peak consumption
- Runs a demand resource market when operation reserves are predicted to be <5GW
- Enables load shifting through time-of-use tariffs and incentives for customers to install thermal storage equipment
- Facilitates emergency voluntary and direct load interruption

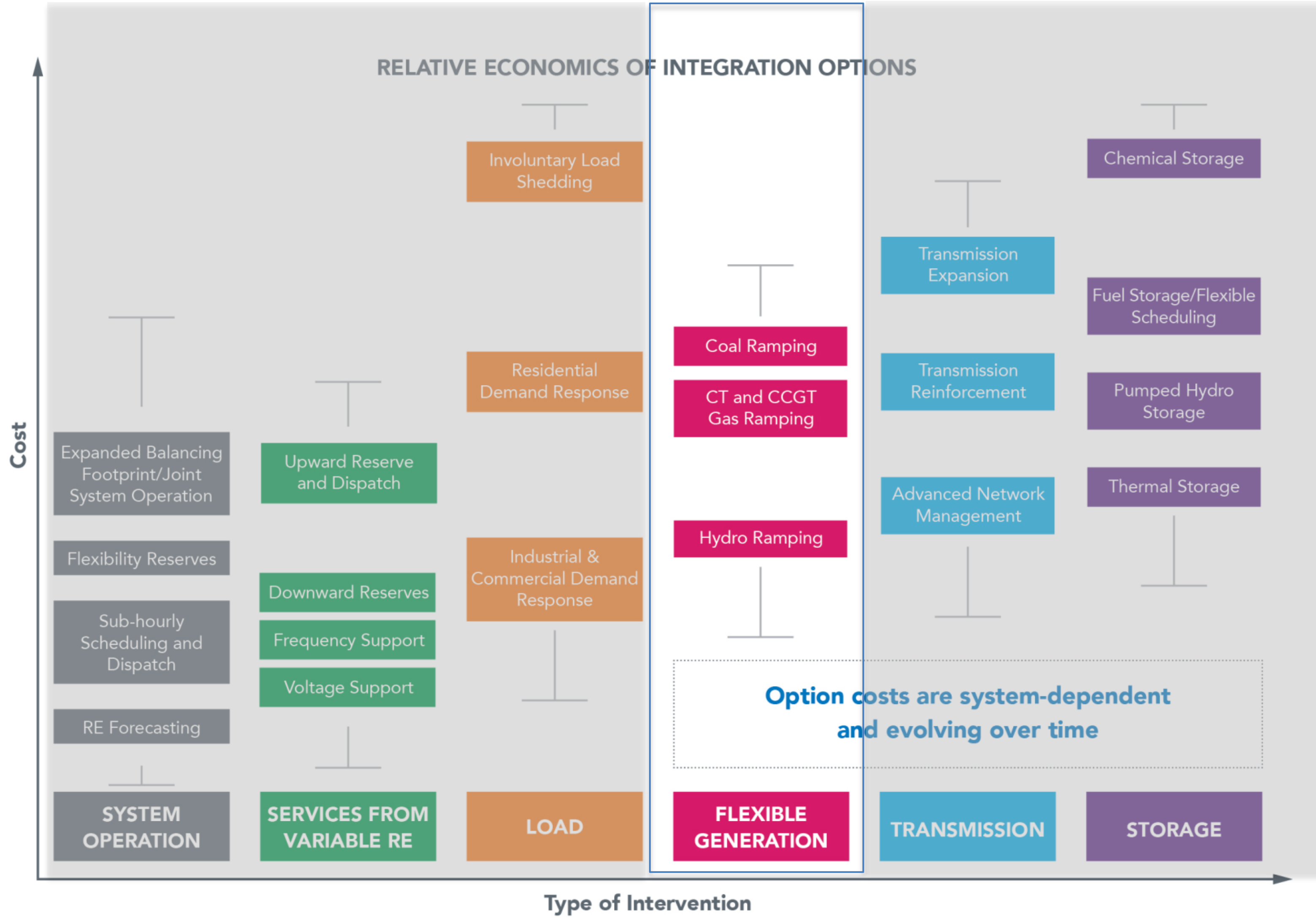
2011 Statistics	
Peak load	73,137 MW
Reserve margin	5.5%
Peak reduction by DSM	3,939 MW
Peak reduction as a percent of peak load	5.4%

Outcomes

- Improved Korea's load factor (the highest in the world) by 4.5% in 2010.
- Reduced peak demand by 3.9GW in 2011 (~5.4% of peak load).

Sources: IRENA 2015; Rhee and Park 20 15

Flexibility from conventional generation

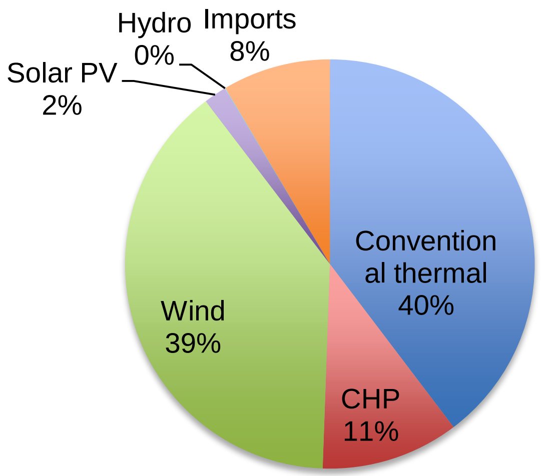


Extracting flexibility from coal and natural gas plants: Denmark case study

Flexible Generation

- Coal plants have been designed explicitly for flexibility over the past 10-15 years
- Combined cycle natural gas can ramp faster than equivalent plants in other countries
- Significant use of combined heat and power (CHP) plants provide dispatchable generation and thermal storage
- Outcomes:
  - Many coal plants able to ramp down to 10% of rated output
  - Coal plants can ramp at up to 3-4% of rated output per minute

Electricity Generation 2014



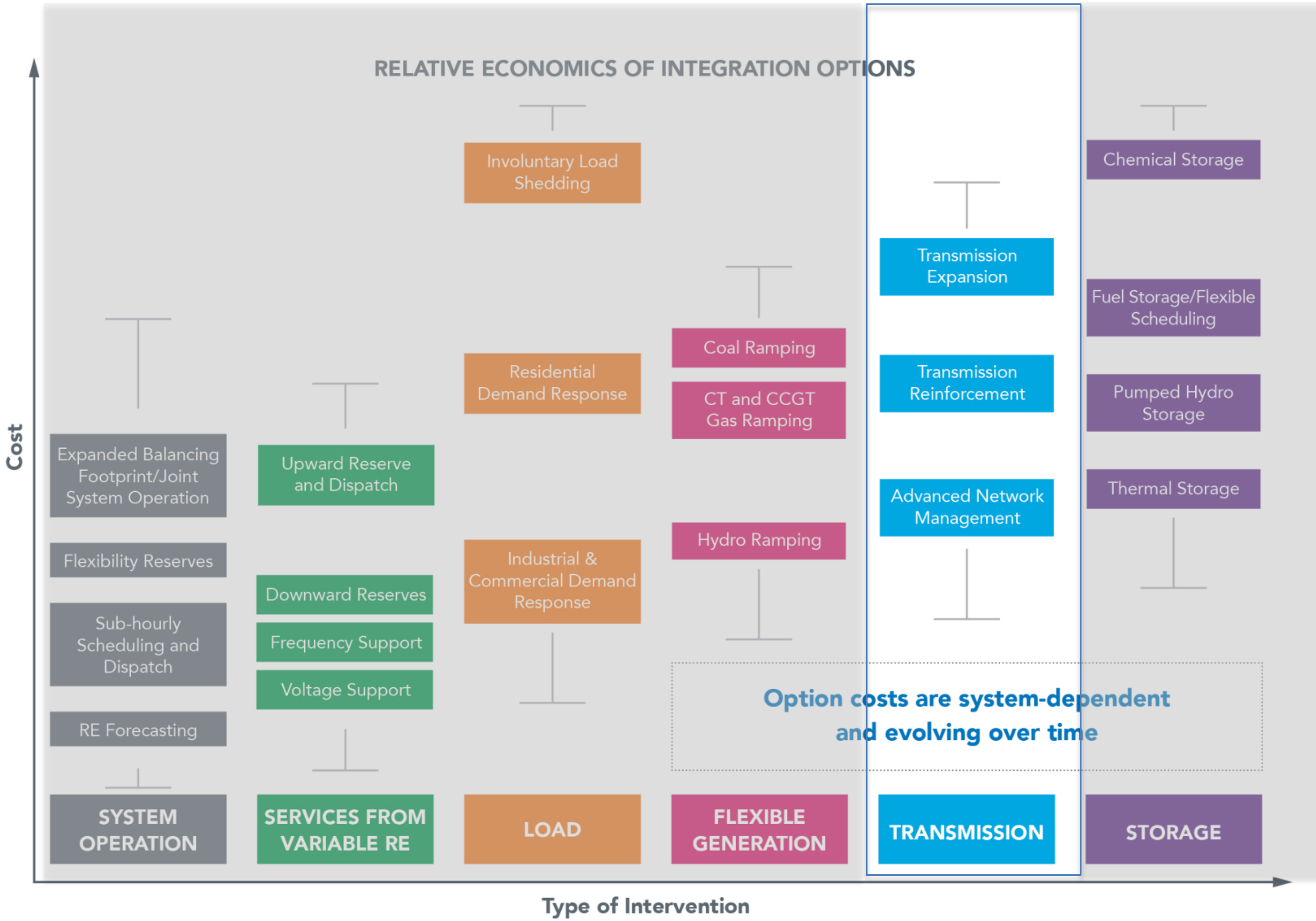
Source: Energinet.dk 2015

Grid Integration Achievements

- Highest penetration of RE in the world, with wind power supplying 39.1% of annual demand.
- Instantaneous penetrations reached 140% in 2015.
- Exports clean energy to Germany, Norway, and other neighbors.

Sources: Miller 2015; Energinet.dk 2015; Martinot 2015; The Guardian 2015

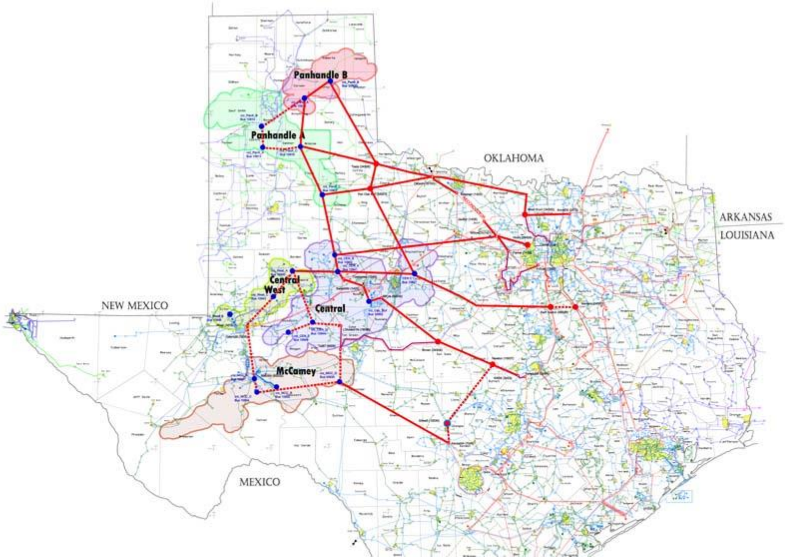
Flexibility from transmission



Transmission planning and locational-pricing reduce transmission congestion: ERCOT case study

Transmission

- Transitioned to a Nodal Market based on locational marginal prices (LMPs), which better reflects congestion
- Implemented a Competitive Renewable Energy Zone process to plan new transmission in areas with high wind potential
- Outcomes:
  - Reduced curtailment from 17% in 2009 to 1.6% in 2013
  - Constructed of enough transmission to accommodate 18.5GW wind capacity
  - Nearly eliminated negative LMPs

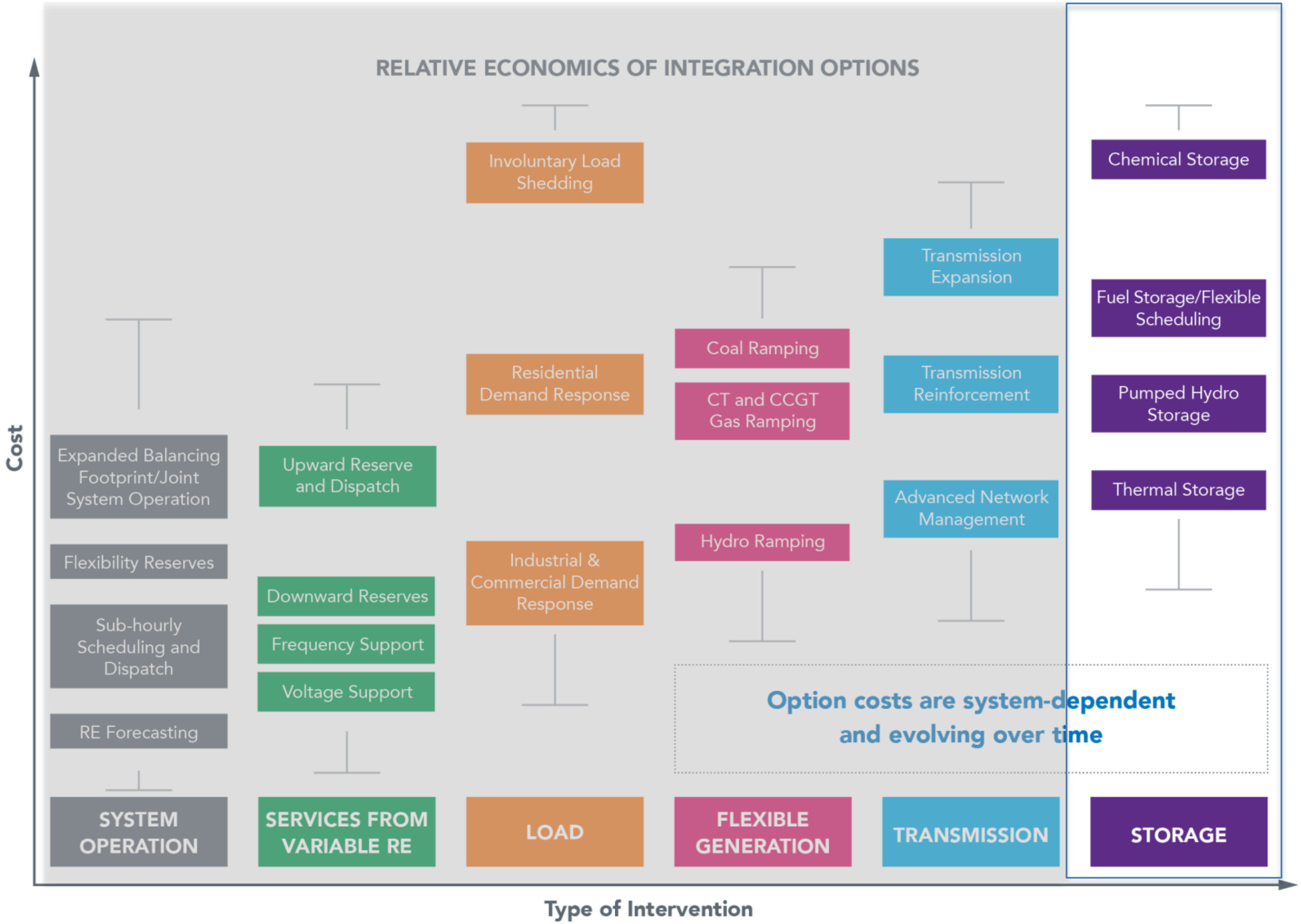


Grid Integration Achievements

- Texas is the state with the largest amount of installed wind in the United States.
- 12.5 GW wind capacity; contributes over 10% to meeting total demand.
- Instantaneous penetration reached 39.4% of load in March 2014.
- Isolated system; weakly connected to other grids.

Sources: Weiss and Tsuchida 2015

Flexibility from storage



Does variable renewable energy generation require storage?

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)

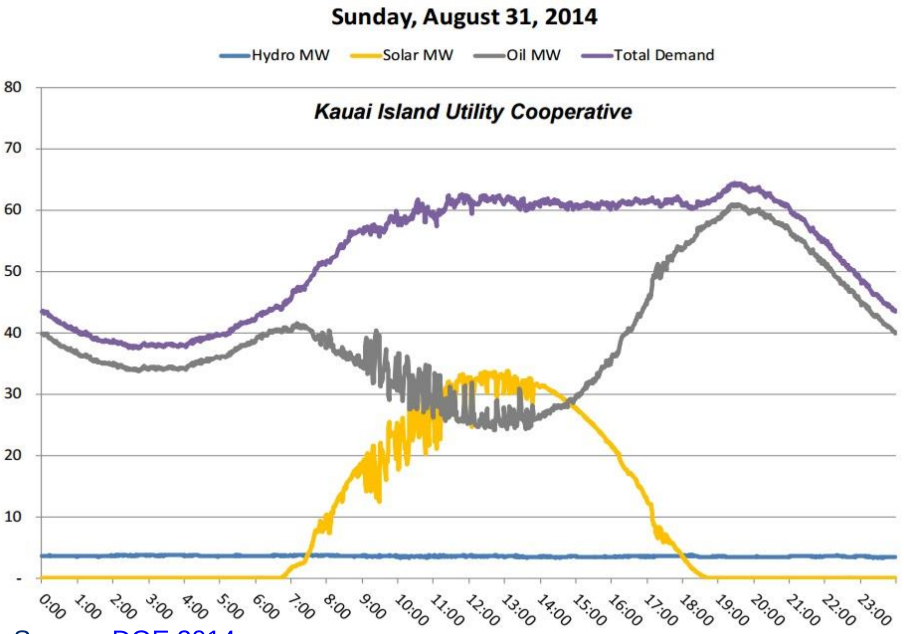
Source: Adrian Pingstone (Wikimedia Commons)

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

Utility-scale batteries support grid balancing: Hawaii case study

Storage

- Proof of concept for a fully-dispatchable utility-scale solar-plus-storage system on Kaua'i (13 MW PV array + 13 MW battery array)
- System is designed specifically to store excess PV generated during mid-day in order to reduce curtailment and use stored energy during the evening peak
- Provides a least-cost means of using more solar to further displace fossil fuel generation



Source: DOE 2014

Grid Integration Achievements

- Kaua'i Island Utility Cooperative transitioned from 91% oil generation in 2009 to 37% RE generation in 2015.
- Solar PV generates 15% of demand (2014), and as much as 95% of the electricity co-op's instantaneous load can be met by solar on a sunny day.

Sources: Miller et al. 2015; Maloney 2015

Key Takeaways

- 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).
- Sources of flexibility are available to all power systems, through specific options depend on power system size, fuel supply, market characteristics, etc.

NREL/PIX 10926

Additional resources on case studies and best practices

- Clean Energy Solutions Center: https://cleanenergysolutions.org*
  - Clean Energy Grid Integration Network (CEGIN): https://cleanenergysolutions.org/cegin
  - Clean Energy Regulators Initiative: https://cleanenergysolutions.org/ceri/resources
- Greening the Grid: http://greeningthegrid.org*
- International Smart Grid Action Network: http://www.iea-isgan.org*
- 21st Century Power Partnership: http://www.iea-isgan.org http://www.21stcenturypower.org

Ask an Expert services offer free, remote, on-demand technical assistance on grid integration (and other) issues

Contacts and Additional Information

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Greening the Grid
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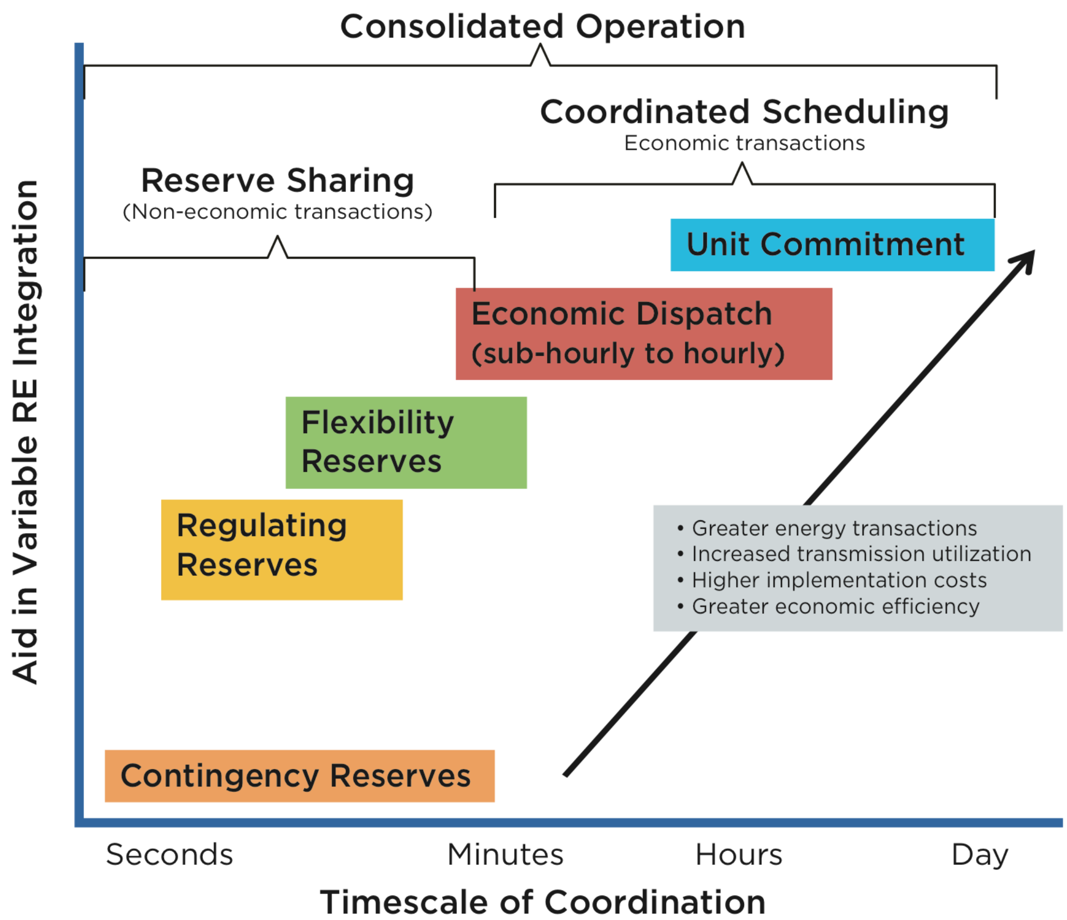
ADDITIONAL SLIDES

Balancing area coordination increases balancing footprint

System Operation



Characteristics of variable RE technologies are evolving to include grid support services

Characteristic	Old Variable RE	New Variable RE
Dispatchability	Uncontrollable, “must take”	Dispatchable through participation in economic dispatch
Forecast/uncertainty	Unpredictable	Increasingly forecastable
Variability	Highly variable over multiple timescales	Short-term variability largely mitigated through spatial diversity
Reserve requirements	Requires dramatic increase in operating reserves from thermal units	Relatively small increase in regulation required. Can self-provide multiple reserves across multiple timescales with selective/economic curtailment
Grid support	Provides no grid support/decreases grid stability	Can provide multiple grid support services

Source: Milligan et al. 2015

Reducing reserve requirements through balancing area coordination: European and Western U.S. case studies

System Operation

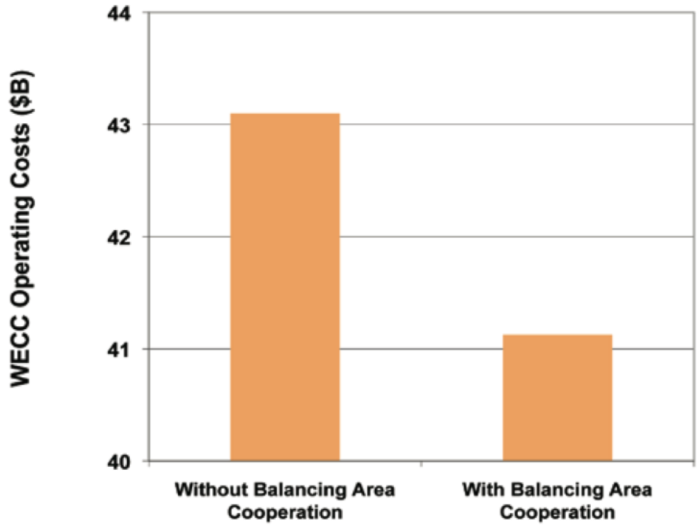
Europe

- Integrating reserve requirements at the European level has the potential to reduce reserve requirements by 40% relative to maintaining national reserves individually (under a 40% variable RE penetration scenario).

- Spain and neighboring TSOs are already participating in a cross-border platform for activating replacement reserves.

Sources: Ackermann et al. 2015 ; EDF R&D 2015

Western U.S.



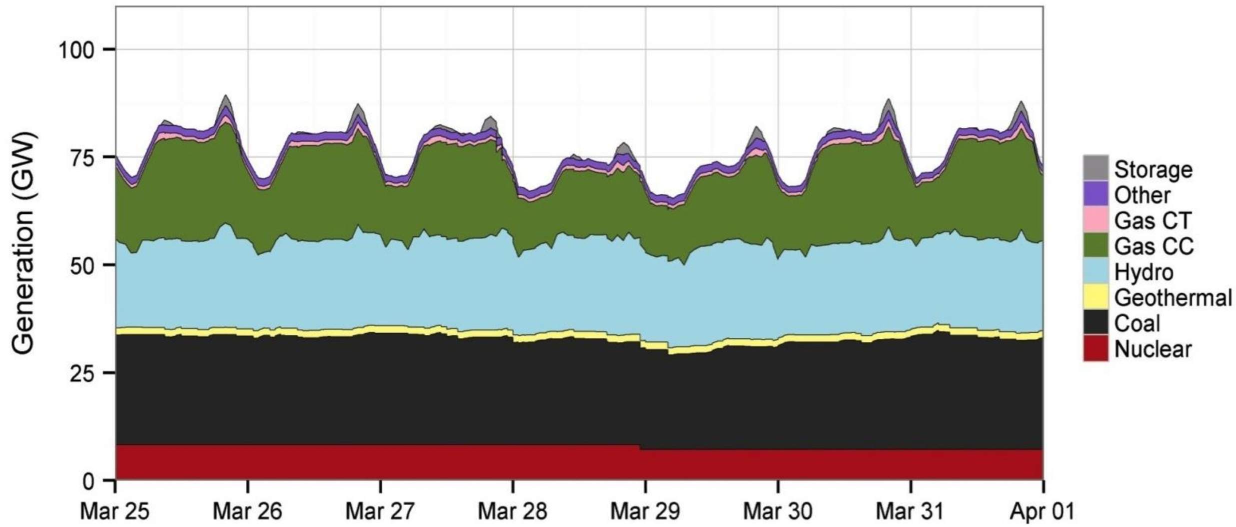
- Holding spinning reserves as five large regions rather than many small zones has the potential to save the Western Electricity Coordinating Council $2 billion.

Source: NREL 2010

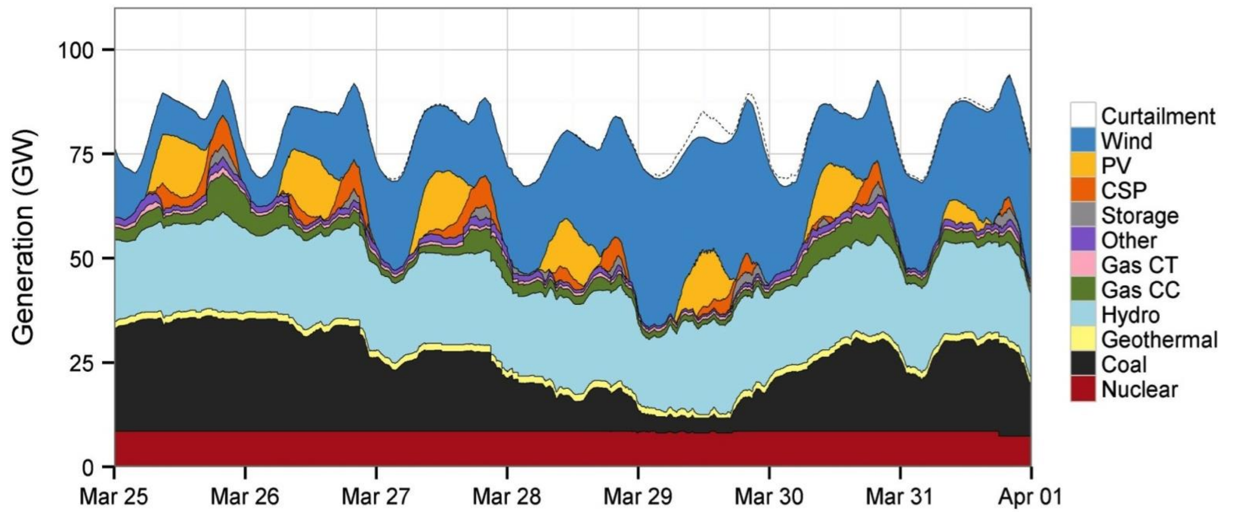
Increased cycling of conventional generators improves flexibility: Western U.S. case study

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)

What impact does variable renewable energy have on emissions (due to thermal cycling)?

Flexible Generation

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)