Renewable Energy Grid Integration:

Challenges and Key Issues

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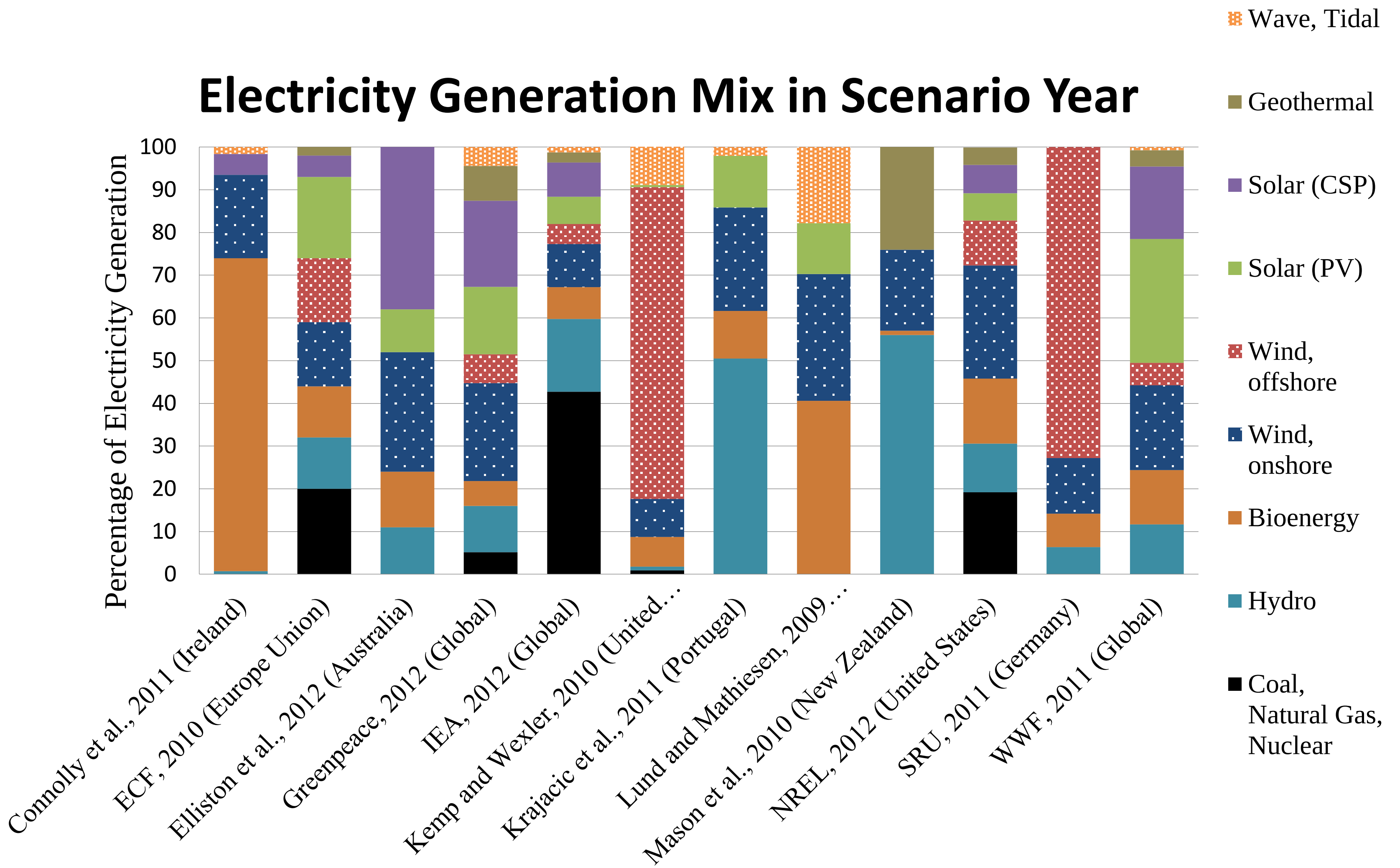
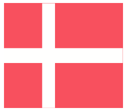
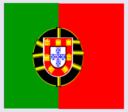
A high RE future is achievable



Cochran, Mai, and Bazilian (2014)

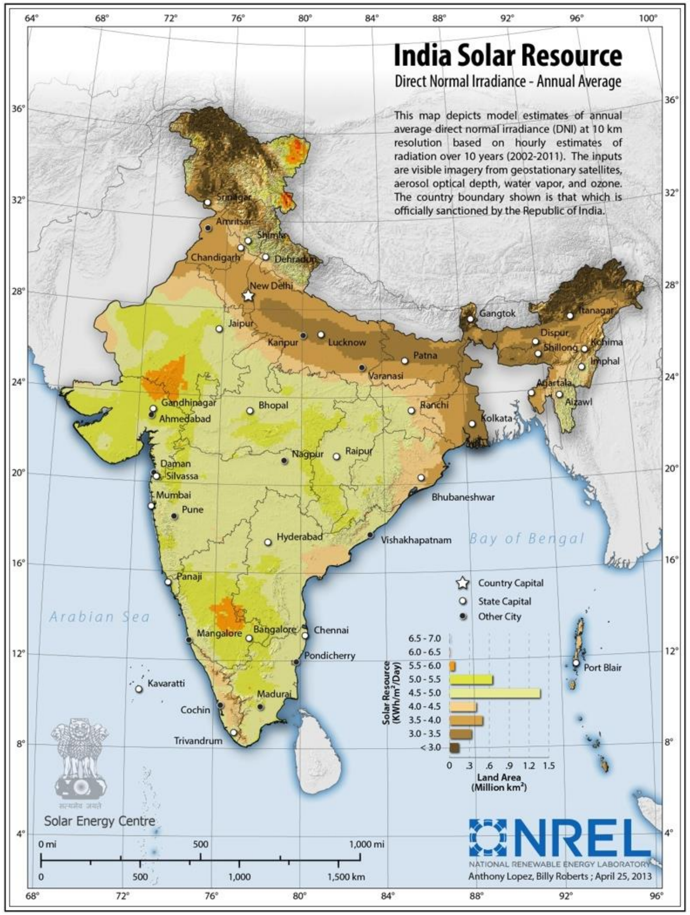
Many countries have <u>already</u> integrated high levels of variable RE

Country		% Electricity from Wind	Balancing
Denmark		**39% in 2014**	Interconnection, f exible 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

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

Achieving power systems with high RE requires an evolution in power system planning

Wind and solar generation are variable, uncertain, and location-constrained

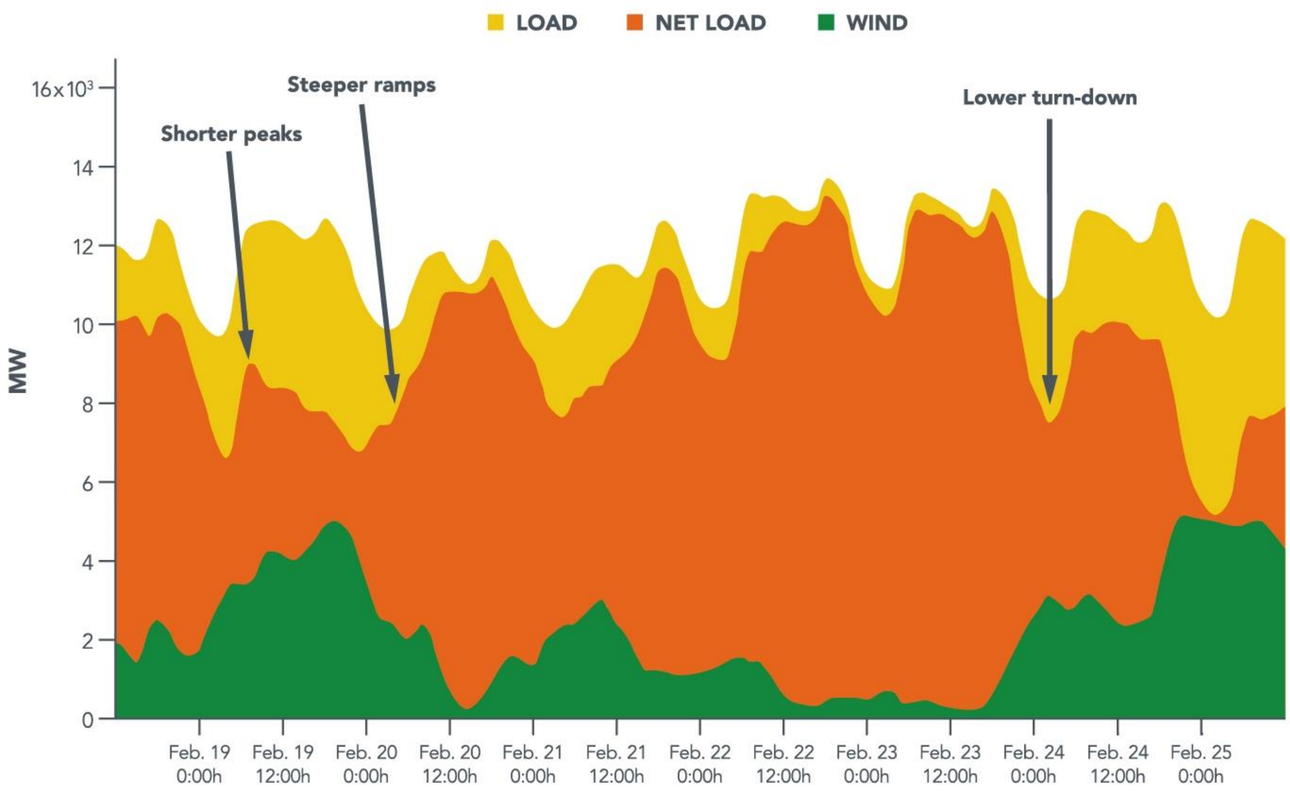


…raising new considerations for grid planning and operations

1. Balancing requires more flexibility
2. More reserves
3. More transmission, better planning needed
4. Grid services (e.g., inertia response) from wind/solar or other equipment come at added cost
5. Existing conventional generators needed, but run less, 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.

How much variable RE can power systems handle?

Technically: No limit

Technological fixes exist for voltage and frequency stability, but at a cost.

Economically: Limit = point at which additional variable RE is no longer economically desirable.

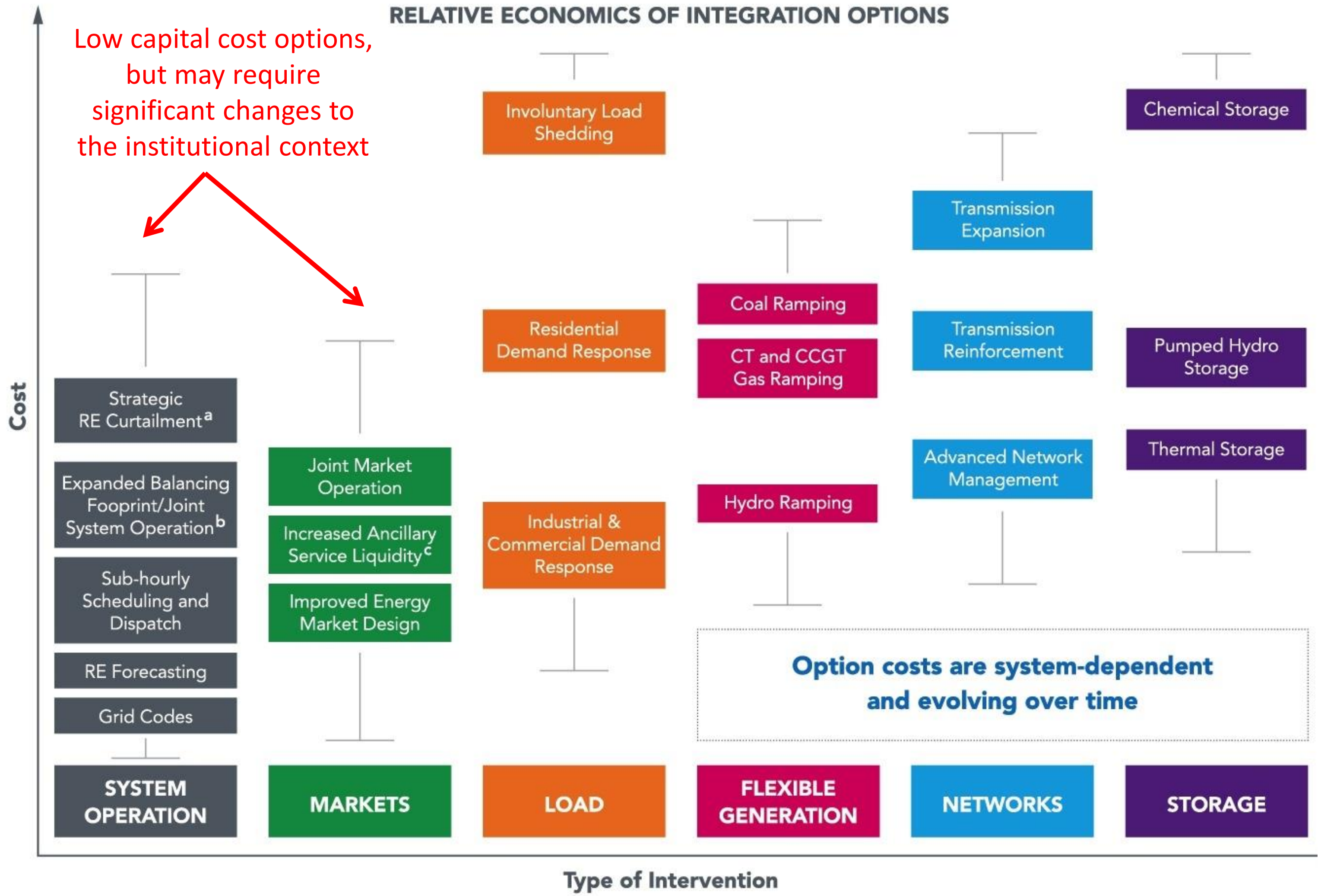
Benefit-cost ratio can reflect a variety of inputs:

- Avoided energy costs, carbon pricing
- Benefits of energy security
- Costs of technological fixes (e.g., new transmission)

NREL PIX 20689

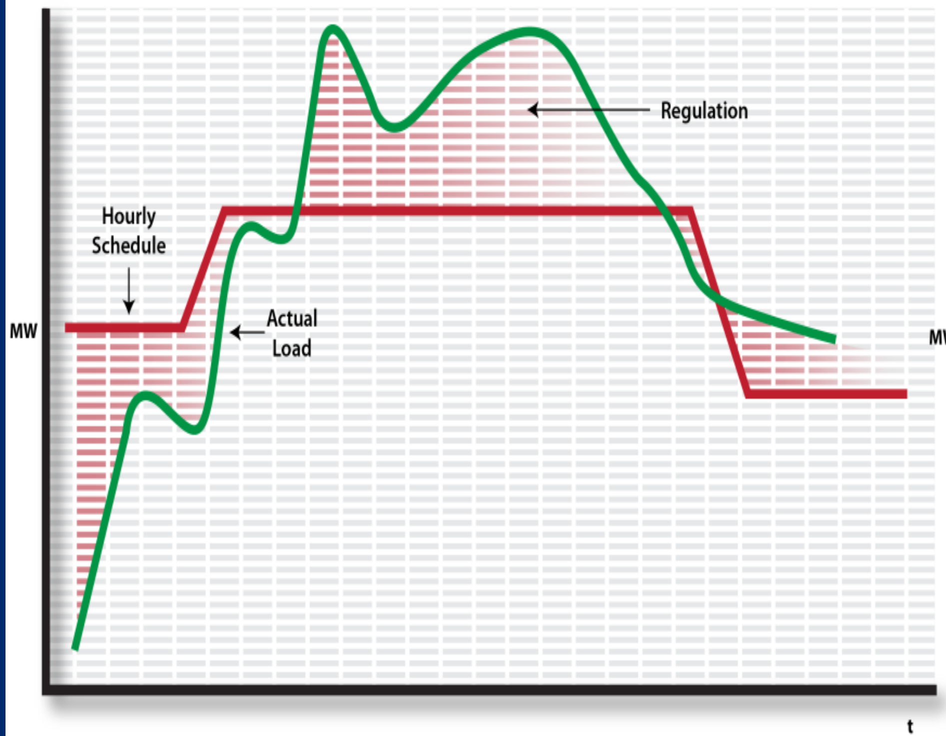
This limit is not fixed but can change over time. For example, technology costs can drop, carbon policies can make RE more competitive…

Frequently Used Options to Increase Flexibility

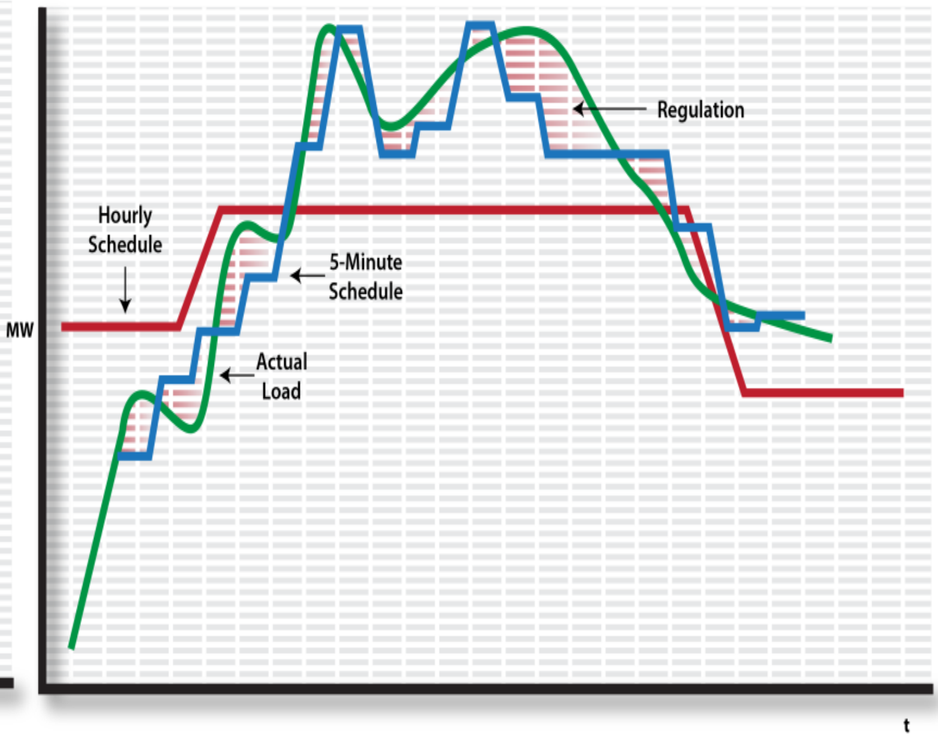


Faster Scheduling to Reduce Expensive Reserves

Hourly schedules and interchanges



Sub-hourly scheduling

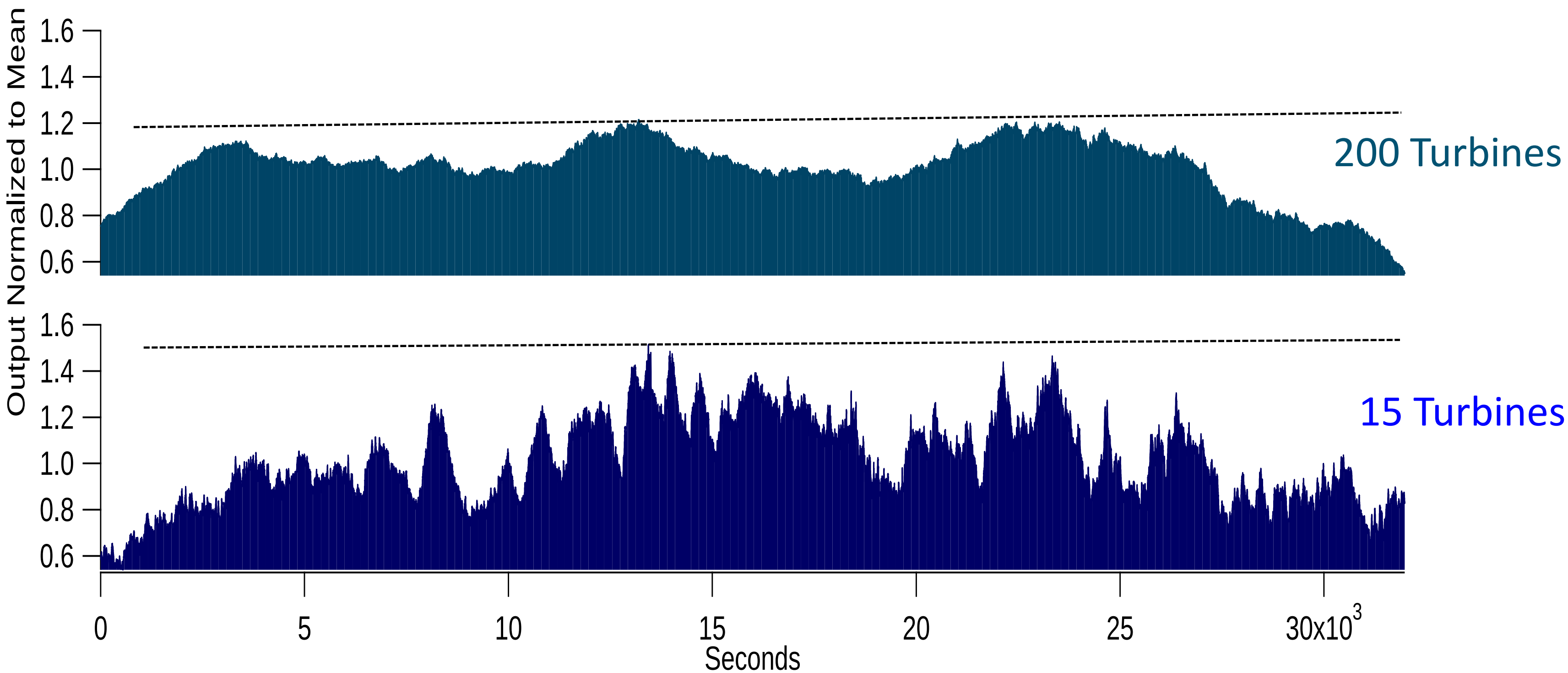


Source: NREL

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



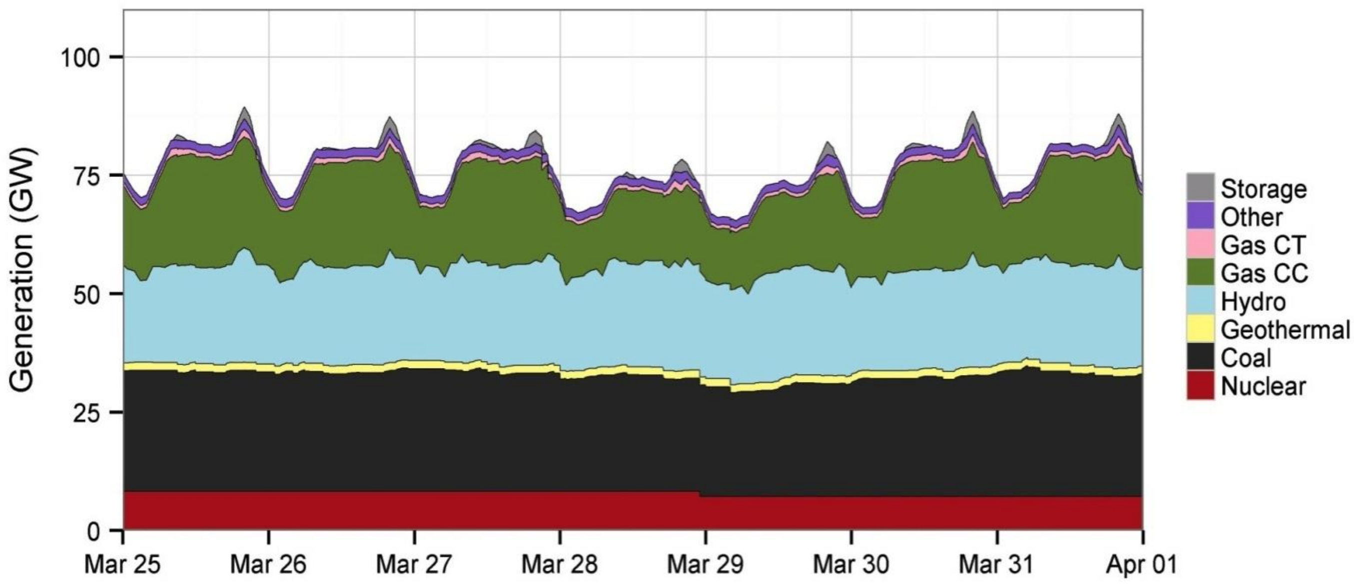
Source: NREL wind plant data

Approximately 8 hours

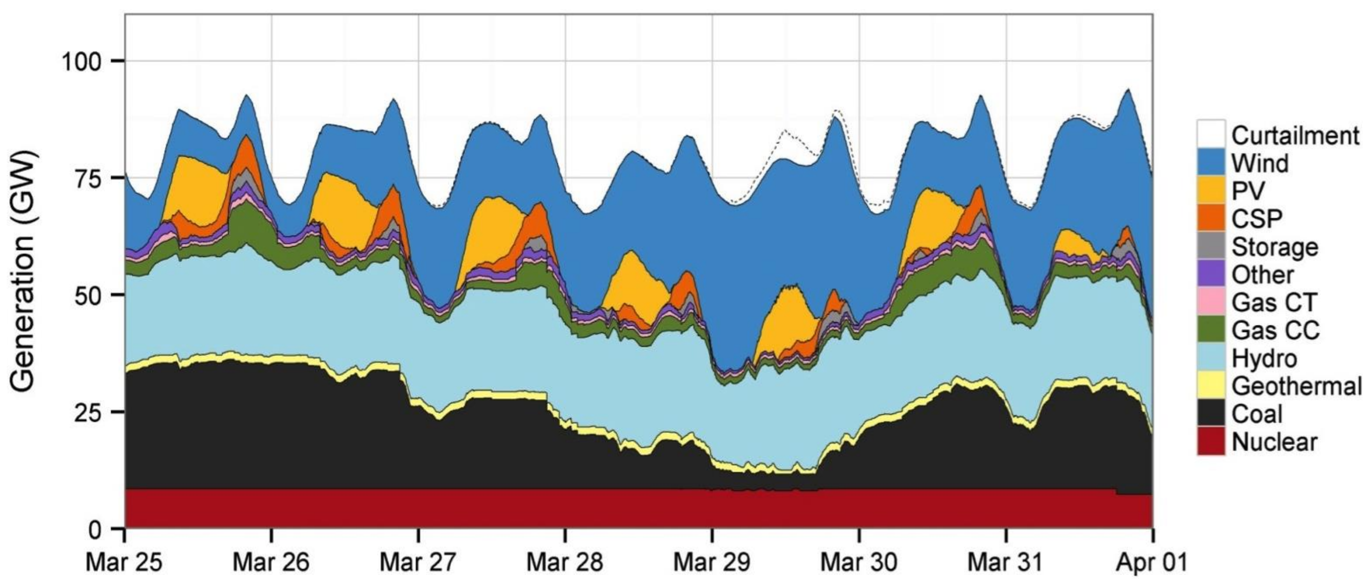
Increase Thermal Plant Cycling

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)

Key Takeaways

- Wind and solar generation increase variability and uncertainty
- A wide variety of systems worldwide show 10%+ annual RE penetrations achievable
- There are no technical limits: investments in flexibility and transmission will enable higher penetration levels of RE
- Often the most cost effective changes to the power system are institutional (changes to system operations and market designs)
- Specific back-up generation is not required because the system is

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Thank You!

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