Renewable Electricity Futures

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Workshop on Renewables and Energy System Integration

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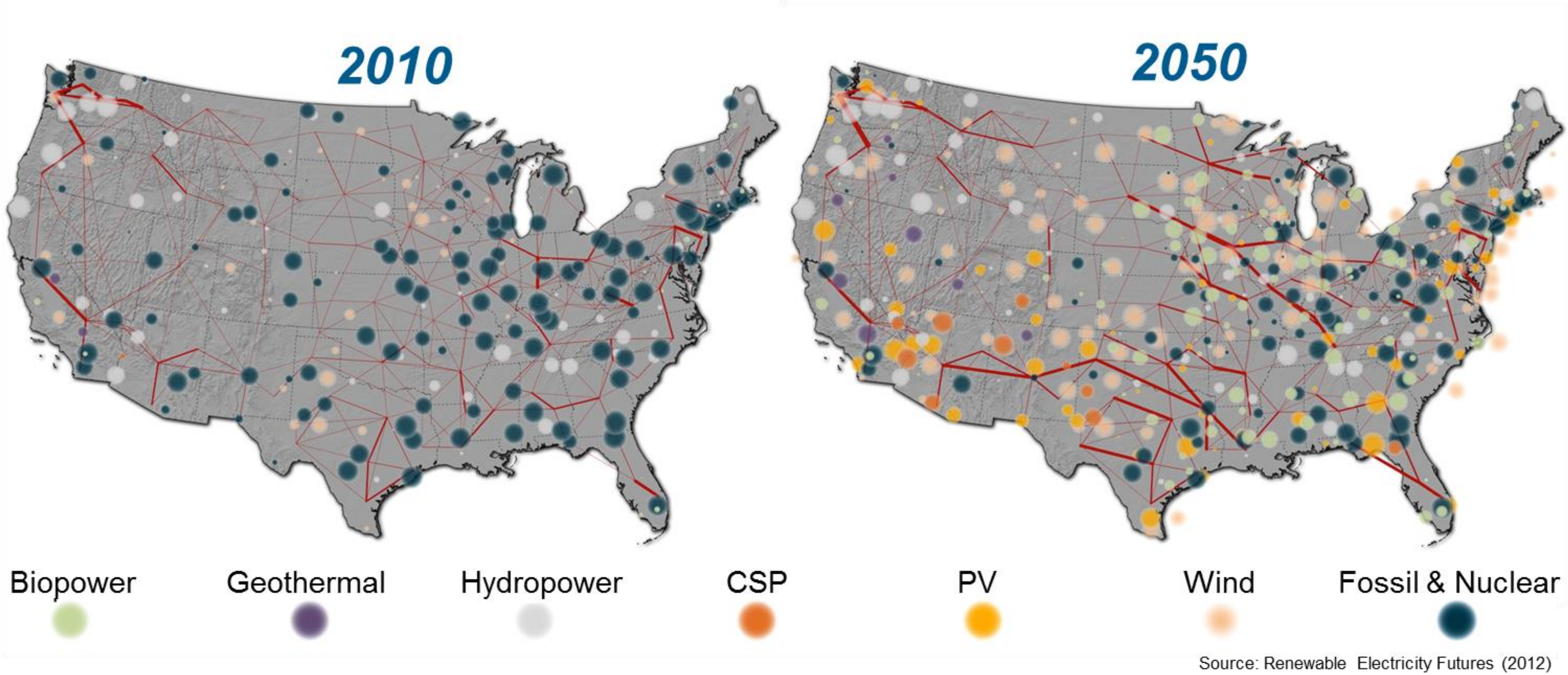
Golden, CO

Renewable Electricity Futures Study (2012). Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; Sandor, D., editors. Lead authors include Mai, T.; Sandor, D.; Wiser, R.; Heath, G.; Augustine, C.; Bain, R.; Chapman, J.; Denholm, P.; Drury, E.; Hall, D.; Lantz, E.; Margolis, R.; Thresher, R.; Hostick, D.; Belzer, D.; Hadley, S.; Markel, T.; Marnay, C.; Milligan, M.; Ela, E.; Hein, J.; Schneider, T.

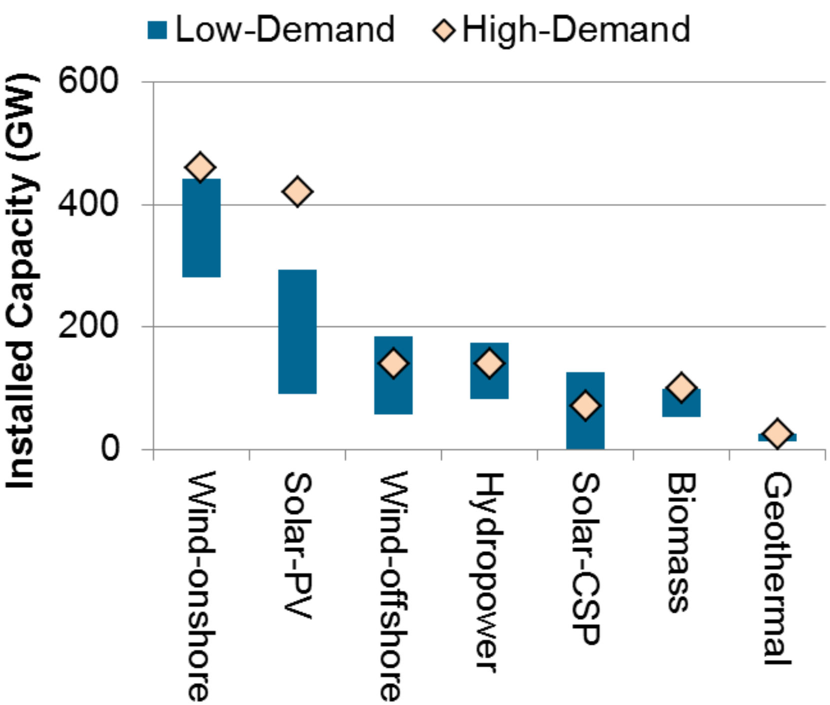
A U.S. DOE-sponsored collaboration among more than 110 individuals from 35 organizations.

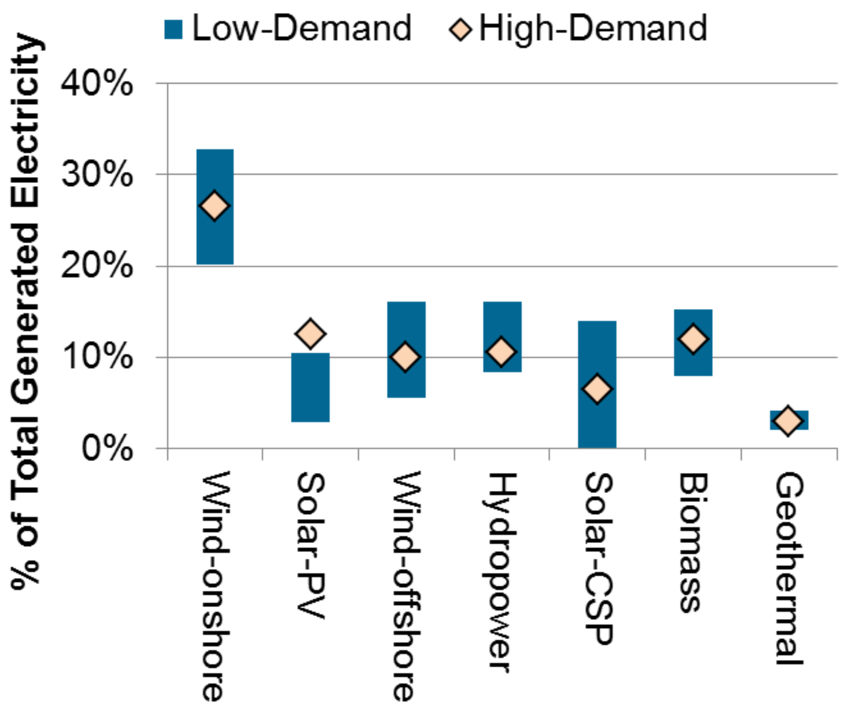
A Transformation of the U.S. Electricity System



RE generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050—while meeting electricity demand on an hourly basis in every region of the country.

Multiple Technology Pathways to 80% RE





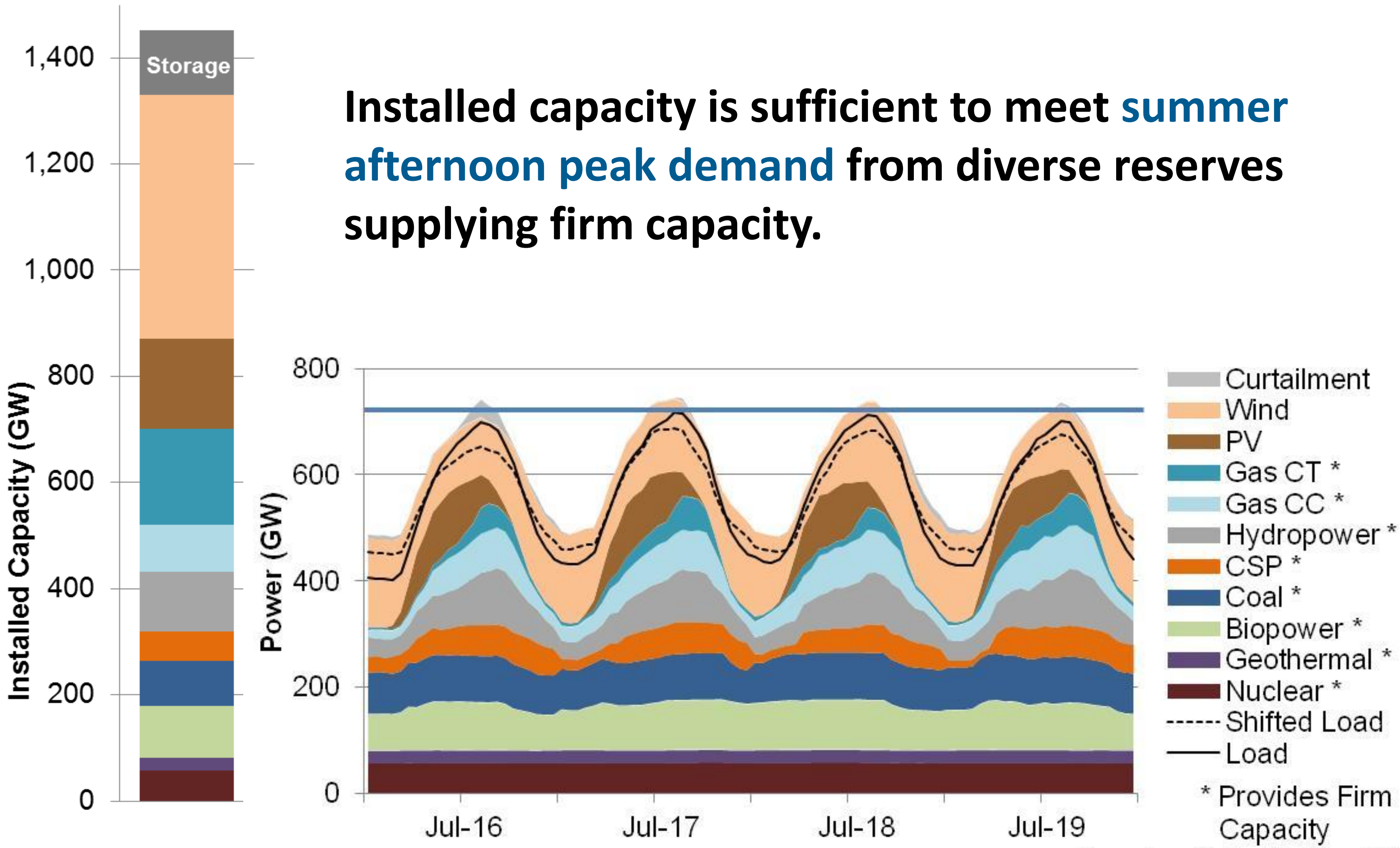
Source: Renewable Electricity Futures (2012)

The capacity of RE generation technologies "built" in 2050 depends on:

- **Future RE technology cost and performance**
- **Electricity demand growth**
- **Presence of constraints that limit new transmission infrastructure, grid flexibility, or the accessibility of renewable resources.**

Supply and Demand Balanced Every Hour of the Year

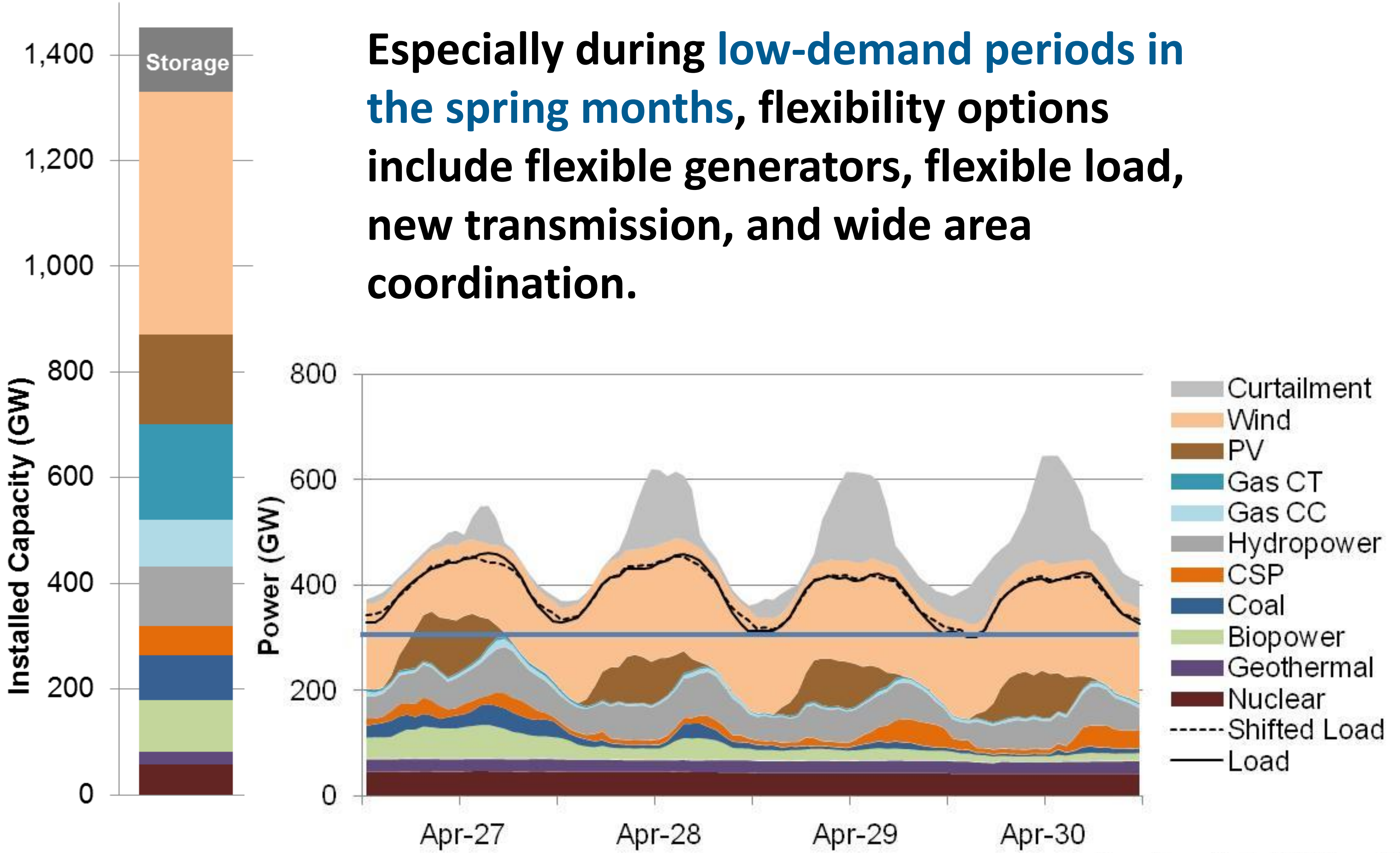
Installed capacity is sufficient to meet summer afternoon peak demand from diverse reserves supplying firm capacity.



Source: Renewable Electricity Futures (2012)

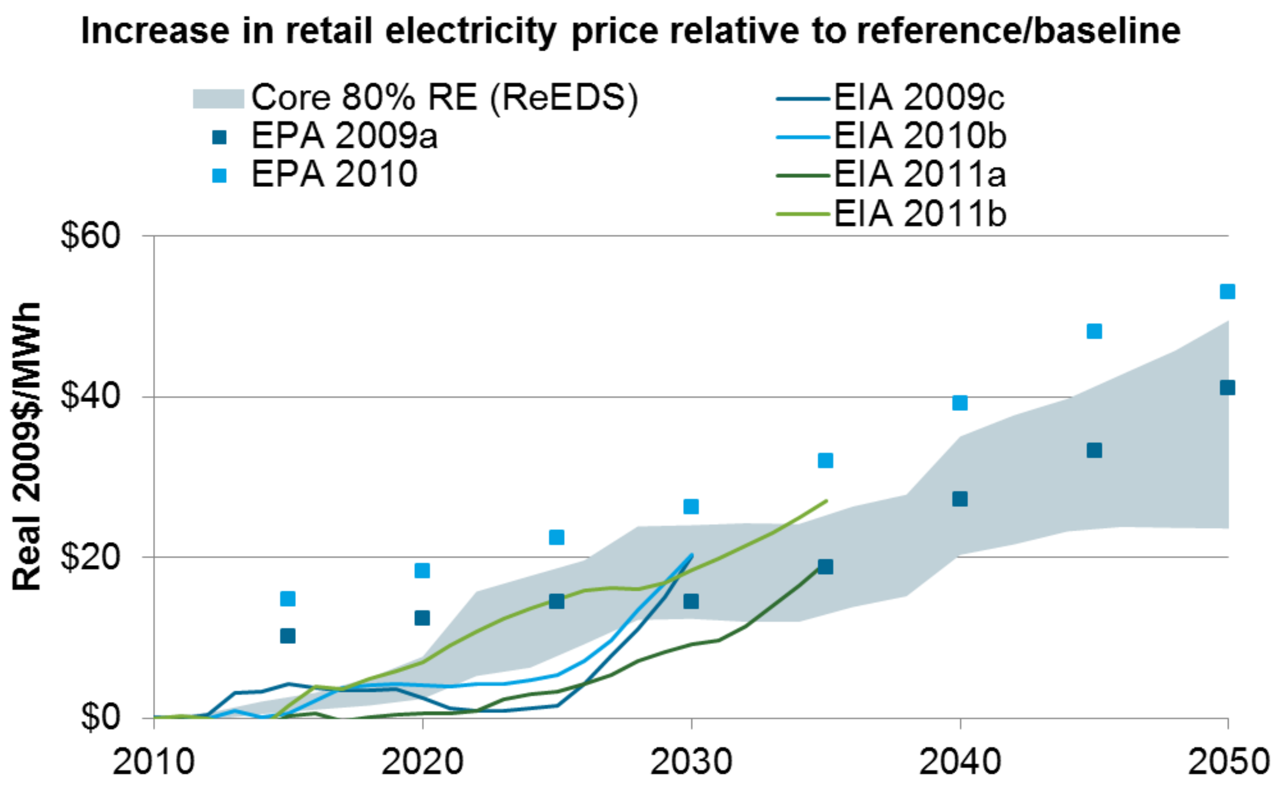
Flexible Electricity System Manages Variability

Especially during low-demand periods in the spring months, flexibility options include flexible generators, flexible load, new transmission, and wide area coordination.



Source: Renewable Electricity Futures (2012)

RE Futures Cost Comparisons



Source: Renewable Electricity Futures (2012)

- **The incremental cost of high RE scenarios is comparable to published cost estimates of other clean energy scenarios.**
- **Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost.**

Key Results

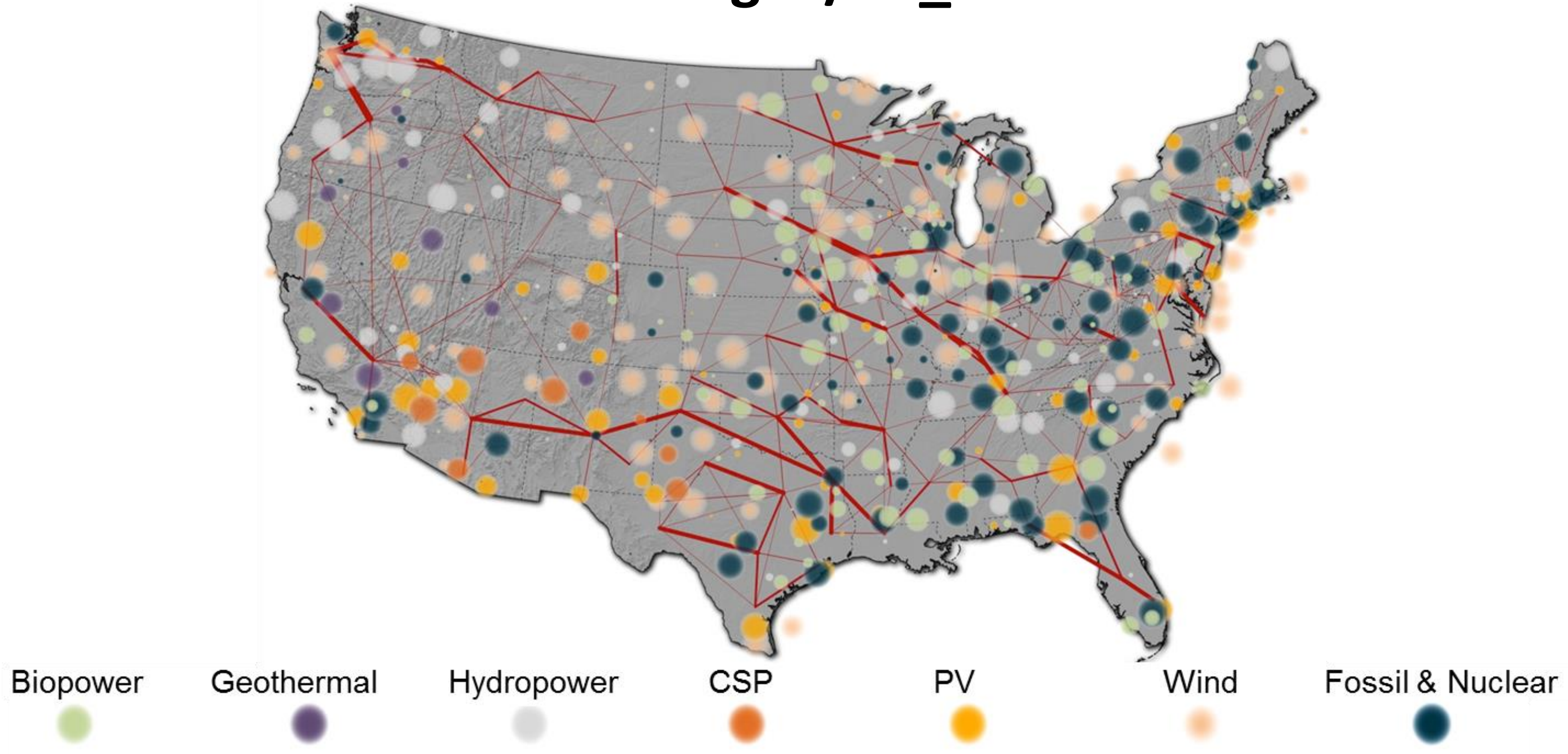
- **Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050–while meeting electricity demand on an hourly basis in every region of the country.**

- **Increased electric system flexibility, needed to enable electricity supply-demand balance with high levels of renewable generation, can come from a portfolio of supply- and demand-side options, including flexible conventional generation, grid storage, new transmission, more responsive loads, and changes in power system operations.**

- **The abundance and diversity of U.S. renewable energy resources can support multiple combinations of renewable technologies that result in deep reductions in electric sector greenhouse gas emissions and water use.**

- **The direct incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost.**

www.nrel.gov/RE_Futures



Source: Renewable Electricity Futures (2012)

A future U.S. electricity system that is largely powered by renewable sources is possible, and further work is warranted to investigate this clean generation pathway.

REF Capacity Expansion

REF Hourly Operation

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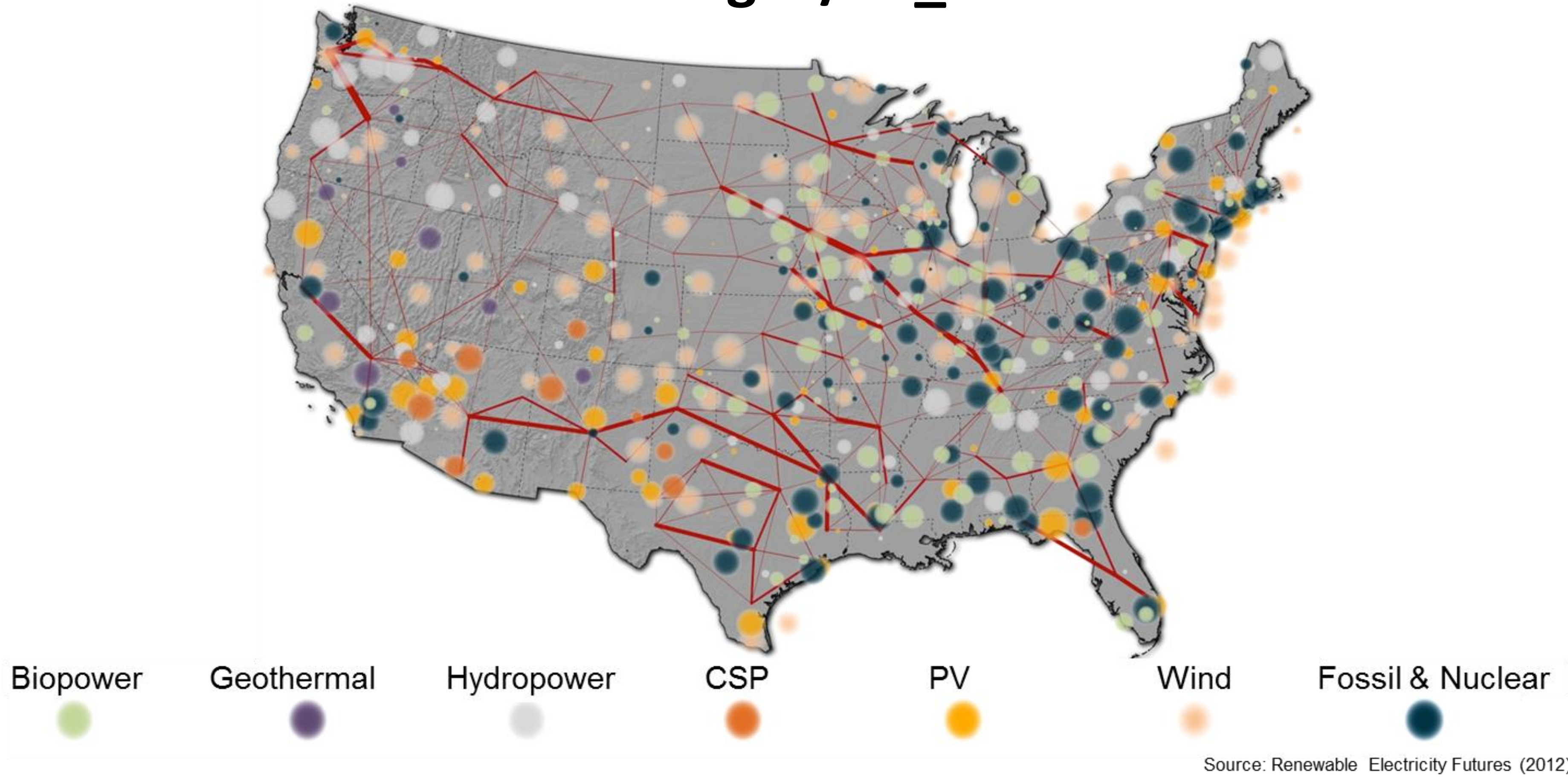

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[REF Capacity Expansion]

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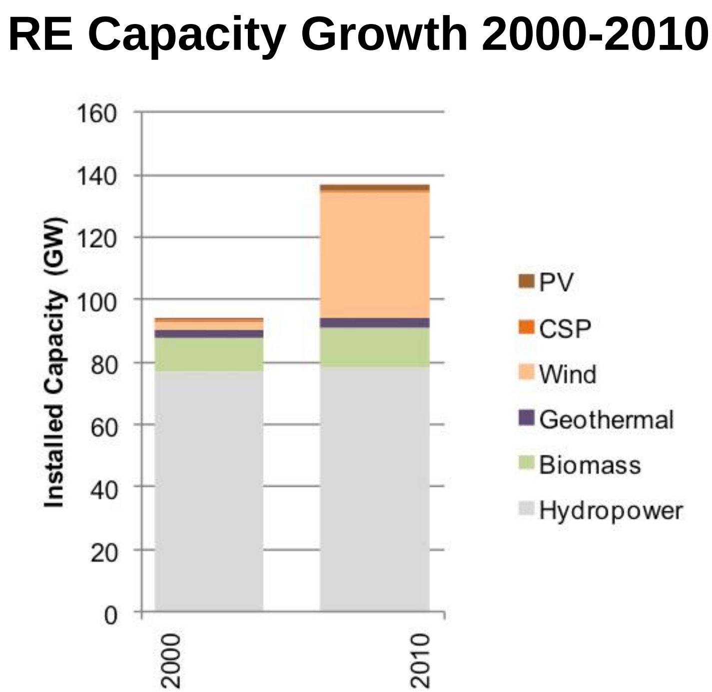
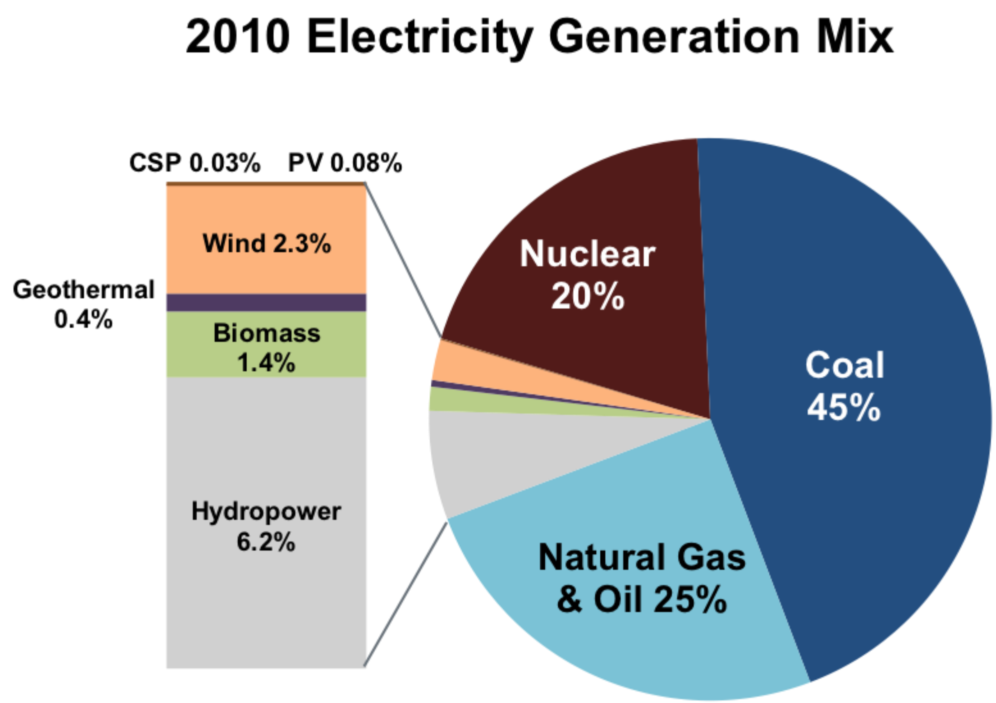
Back-up slides

Renewable Electricity Futures Motivation



Source: RE Data Book (DOE 2011)



Source: Renewable Electricity Futures (2012)

- **RE Futures is a low carbon, low air pollutant, low fuel use, low water use, domestic, and sustainable electricity source.**
- **To what extent can renewable energy technologies commercially available today meet the U.S. electricity demand over the next several decades?**

Renewable Electricity Futures Report

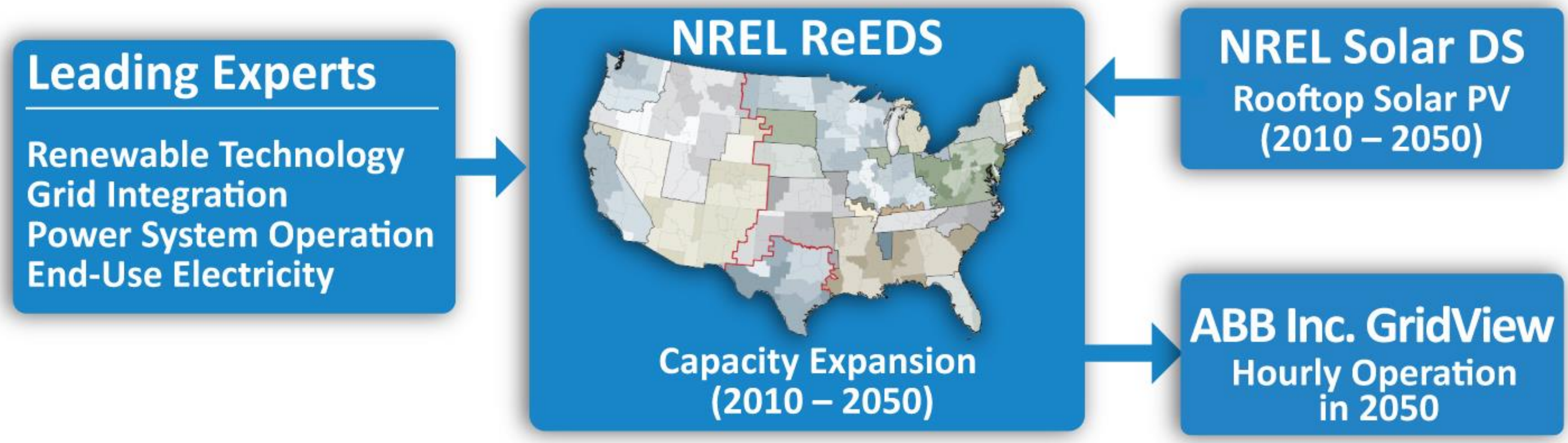
Volume 1	Exploration of High-Penetration Renewable Electricity Futures
Volume 2	Renewable Electricity Generation and Storage Technologies
Volume 3	End-Use Electricity Demand
Volume 4	Bulk Electric Power Systems: Operations and Transmission Planning

RE Futures is a U.S. DOE-sponsored collaboration with more than 110 contributors from 35 organizations including national laboratories, industry, universities, and non-governmental organizations.

Renewable Electricity Futures Introduction

RE Futures does….	RE Futures does not…
Identify commercially available RE generation technology combinations that meet up to 80% or more of projected 2050 electricity demand in every hour of the year.	Consider policies, new operating procedures, evolved business models, or market rules that could facilitate high levels of RE generation.
Identify electric sector characteristics associated with high levels of RE generation.	Fully evaluate power system reliability.
Explore a variety of high renewable electricity generation scenarios.	Forecast or predict the evolution of the electric sector.
Estimate the associated U.S. electric sector carbon emissions reductions.	Assess optimal pathways to achieve a low-carbon electricity system.
Explore a select number of economic, environmental and social impacts.	Conduct a comprehensive cost-benefit analysis.
Illustrate an RE-specific pathway to a clean electricity future to inform the development of integrated portfolio scenarios that consider all technology pathways and their implications.	Provide a definitive assessment of high RE generation, but does identify areas for deeper investigation.

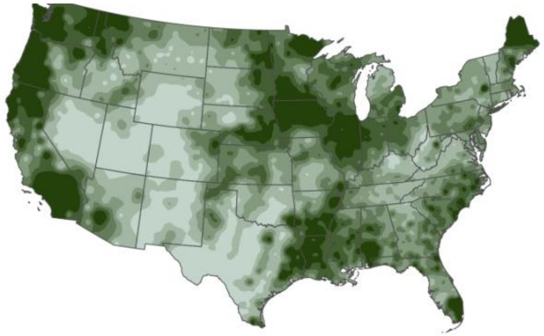
State of the Art Electric System Models

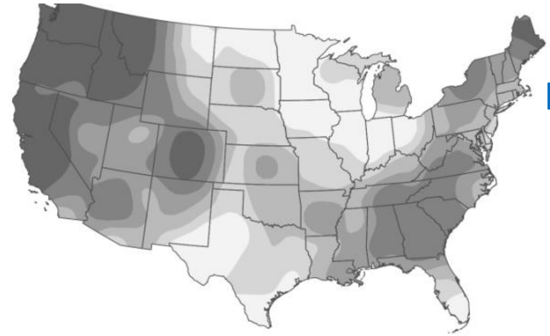


- **Unprecedented <u>geographic</u> and <u>time resolution</u> for the <u>contiguous</u> United States**
- **More than two dozen scenarios of U.S. electric sector focused on 2050.**

Abundant Renewable Energy Resources

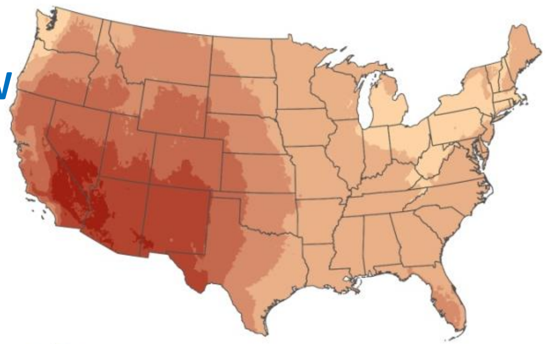
Biopower ~100 GW
- Stand-alone
- Cofired with coal

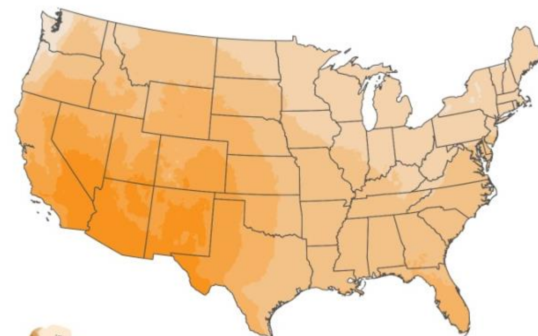




Hydropower ~200 GW
- Run-of-river

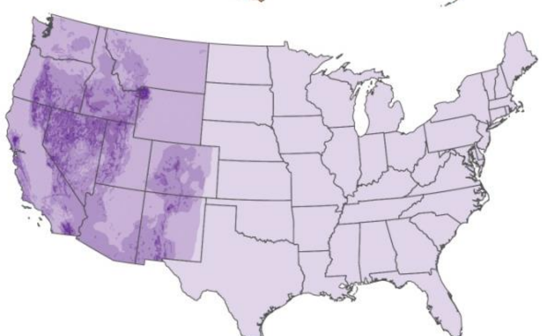
Solar CSP ~37,000 GW
- Trough ⎤ With thermal
- Tower ⎦ storage

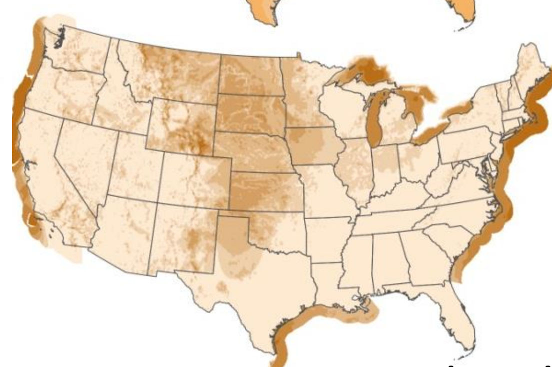




Solar PV ~80,000 GW (rooftop PV ~700 GW)
- Residential
- Commercial
- Utility-scale

Geothermal ~36 GW
- Hydrothermal



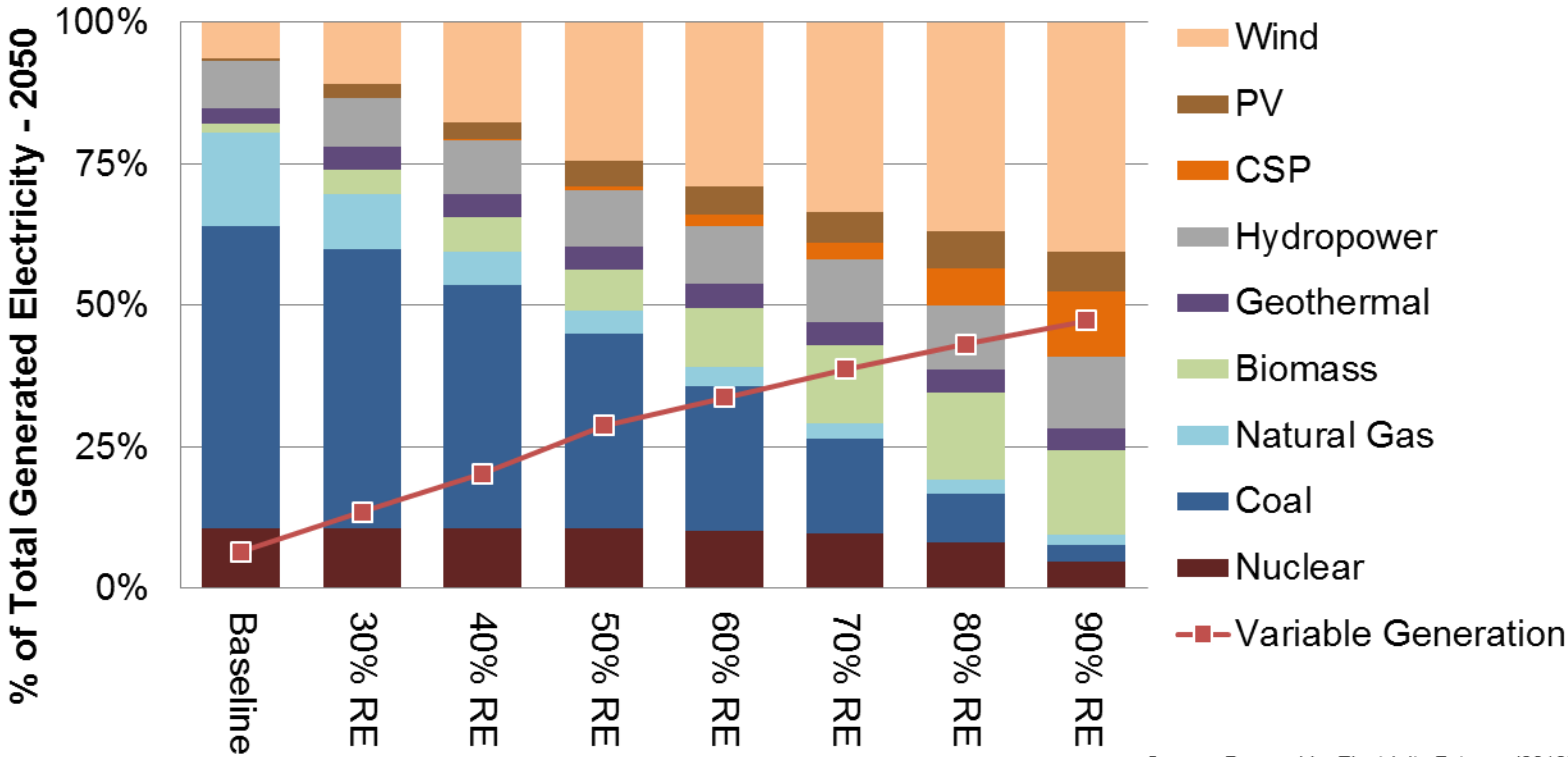


Wind ~10,000 GW
- Onshore
- Offshore fixed-bottom

Darker Colors = Higher Resource

Geographic location, technical resource potential, and output characteristics are unique to each RE generation technology.

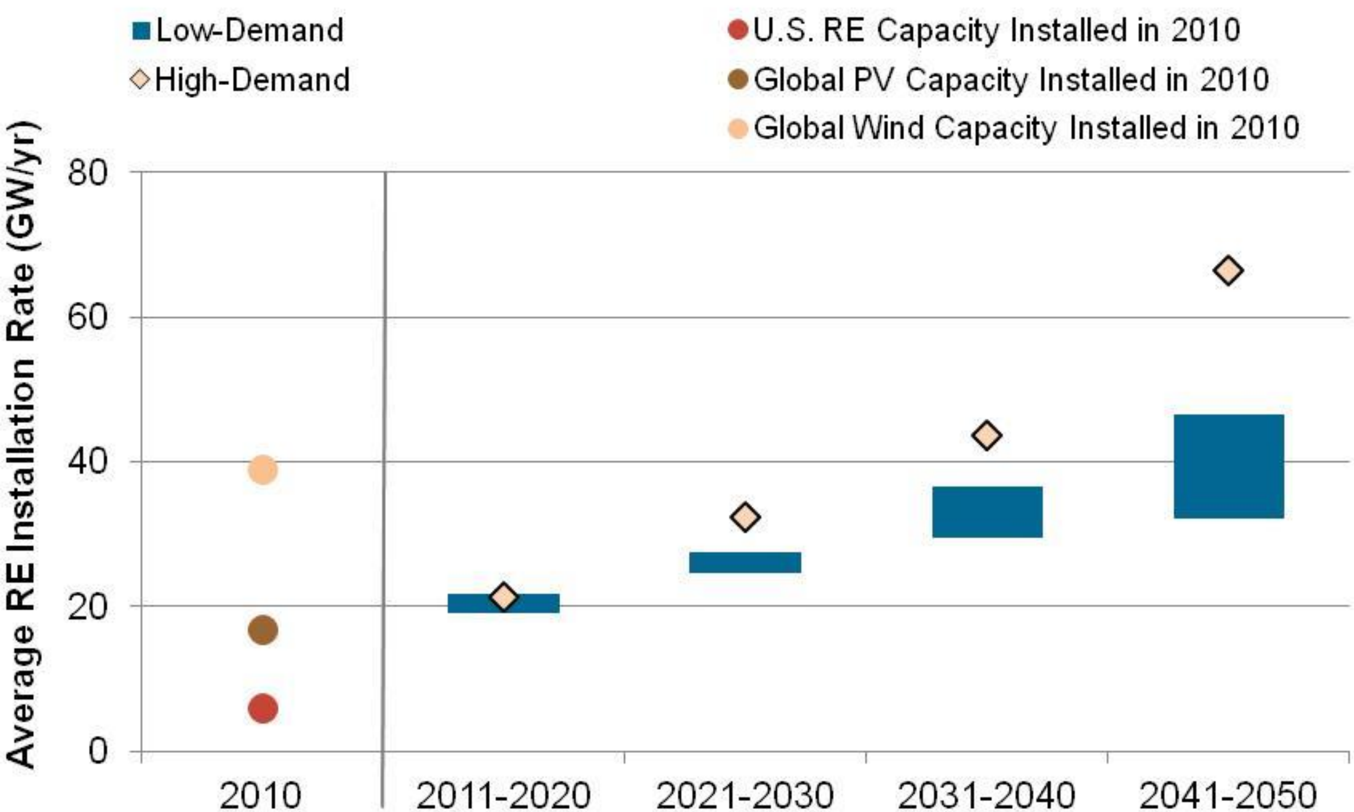
RE Resource Supply from 30% - 90% Electricity



Source: Renewable Electricity Futures (2012)

Additional variability challenges system operations, but can be addressed through increased use of supply- and demand-side flexibility options and new transmission.

Significant Long-Term RE Industry Growth



Source: REN 21 (2011); Renewable Electricity Futures (2012)

No insurmountable long-term constraints to RE technology manufacturing capacity, materials supply, or labor availability were identified.

RE Land Use Implications

- **Area requirements:**
  - **The gross estimate for RE Futures scenarios = < 3% of U.S. land area.**
  - **About half of that land area is used for biopower.**
  - **The majority of the remainder is used for wind, but only about 5% is actually disrupted.**

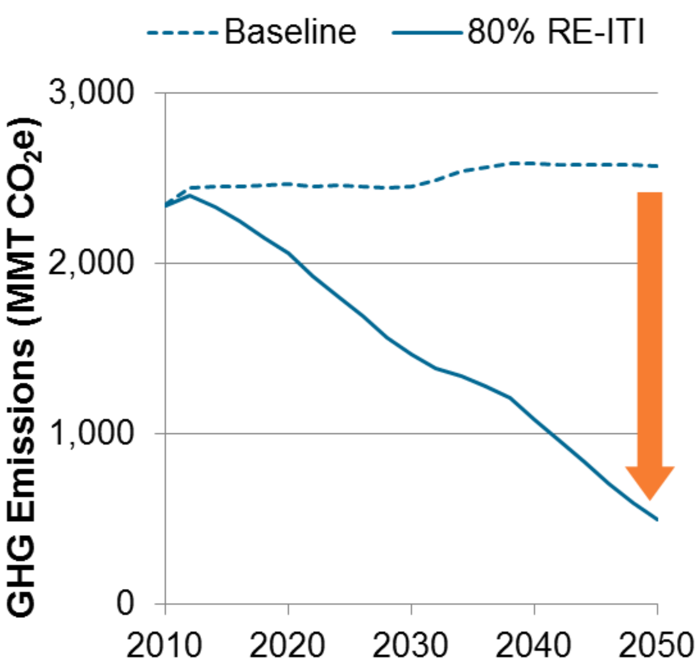
80% RE scenarios

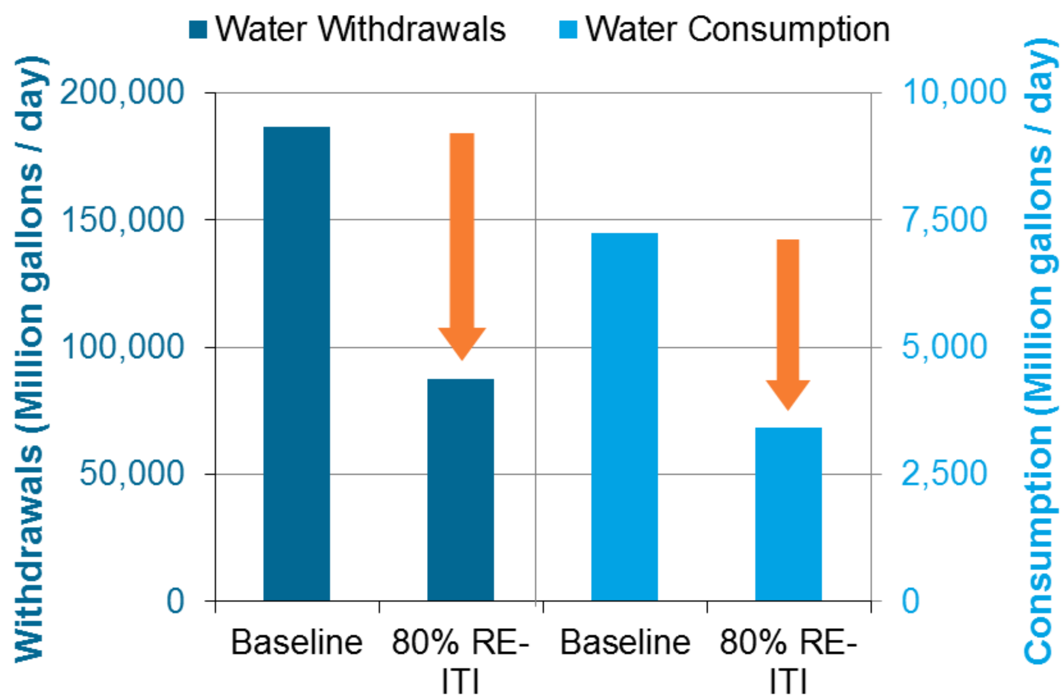
Gross Land Use Comparisons ($000\ km^2$)	
Biomass	44-88
All Other RE	52-81
All Other RE (disrupted)	4-10
Transmission & Storage	3-19
Total Contiguous U.S.	7,700
2009 Corn Production*	350
Major Roads**	50
Golf Courses **	10

** USDA 2010, ** Denholm & Margolis 2008*

- **Other siting issues:**
  - **Permitting processes that vary with technology and location**
  - **Wildlife and habitat disturbance concerns**
  - **Public engagement for generation and transmission**

High RE Reduces Emissions and Water Use





Source: Renewable Electricity Futures (2012)

80% renewable electricity in 2050 could lead to:

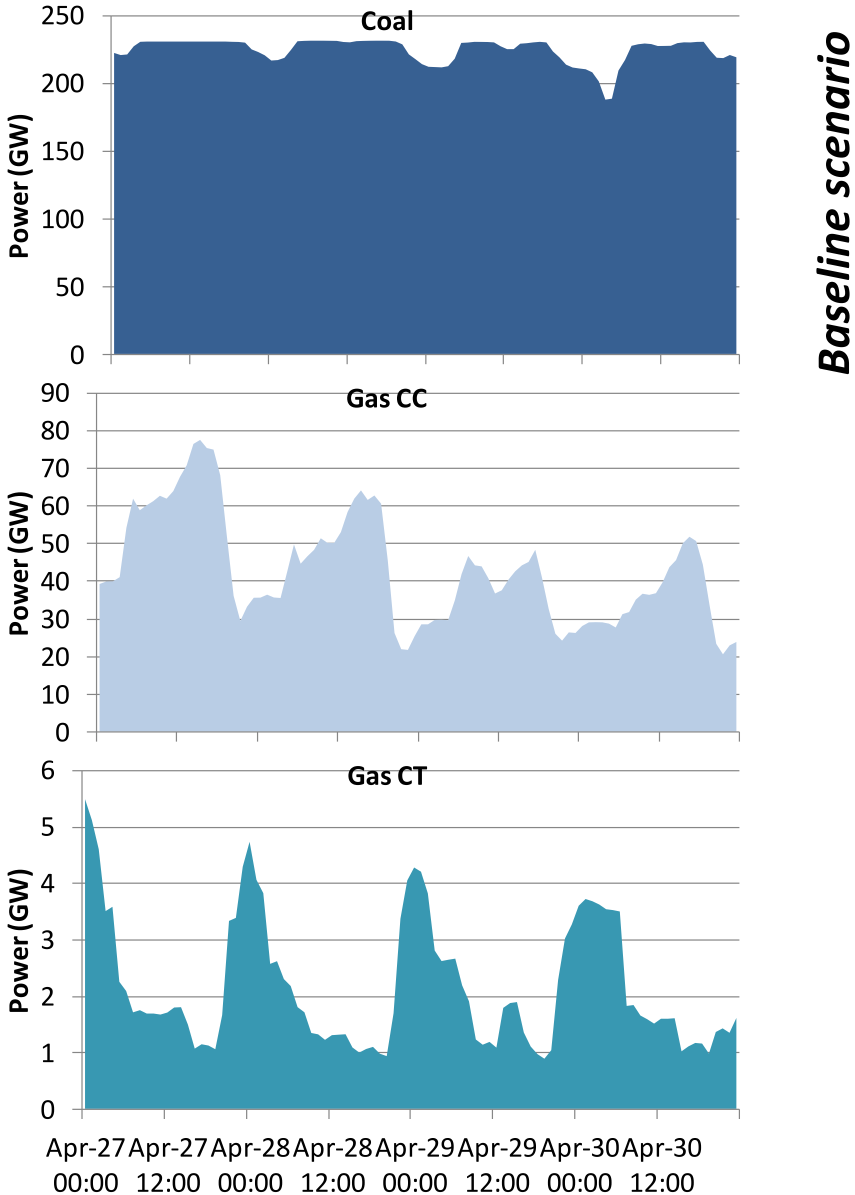
- **~ 80% reduction in GHG emissions (combustion-only and full life-cycle)**
- **~ 50% reduction in electric sector water use (withdrawals and consumption).**

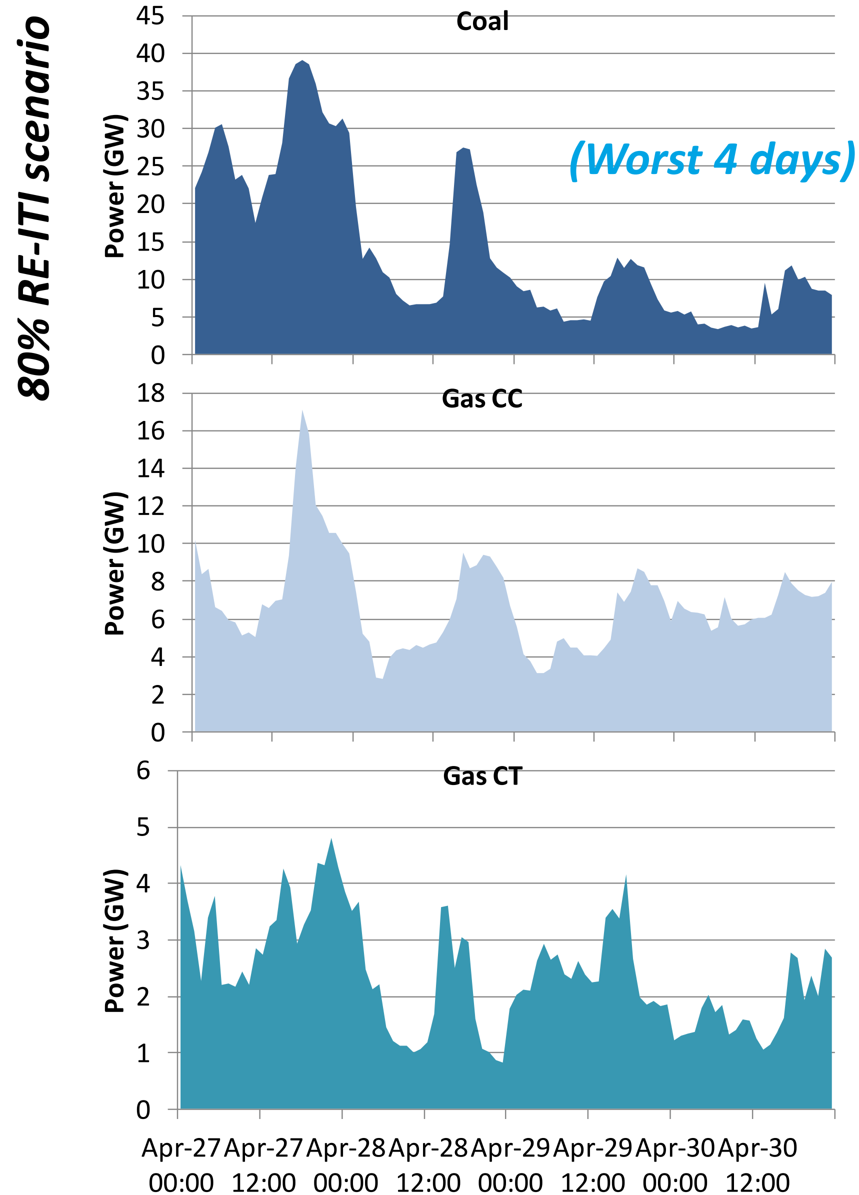
A more flexible electric power system is needed to enable electricity supply-demand balance with high levels of RE generation

System flexibility can be increased using a broad portfolio of supply- and demand-side options, including:

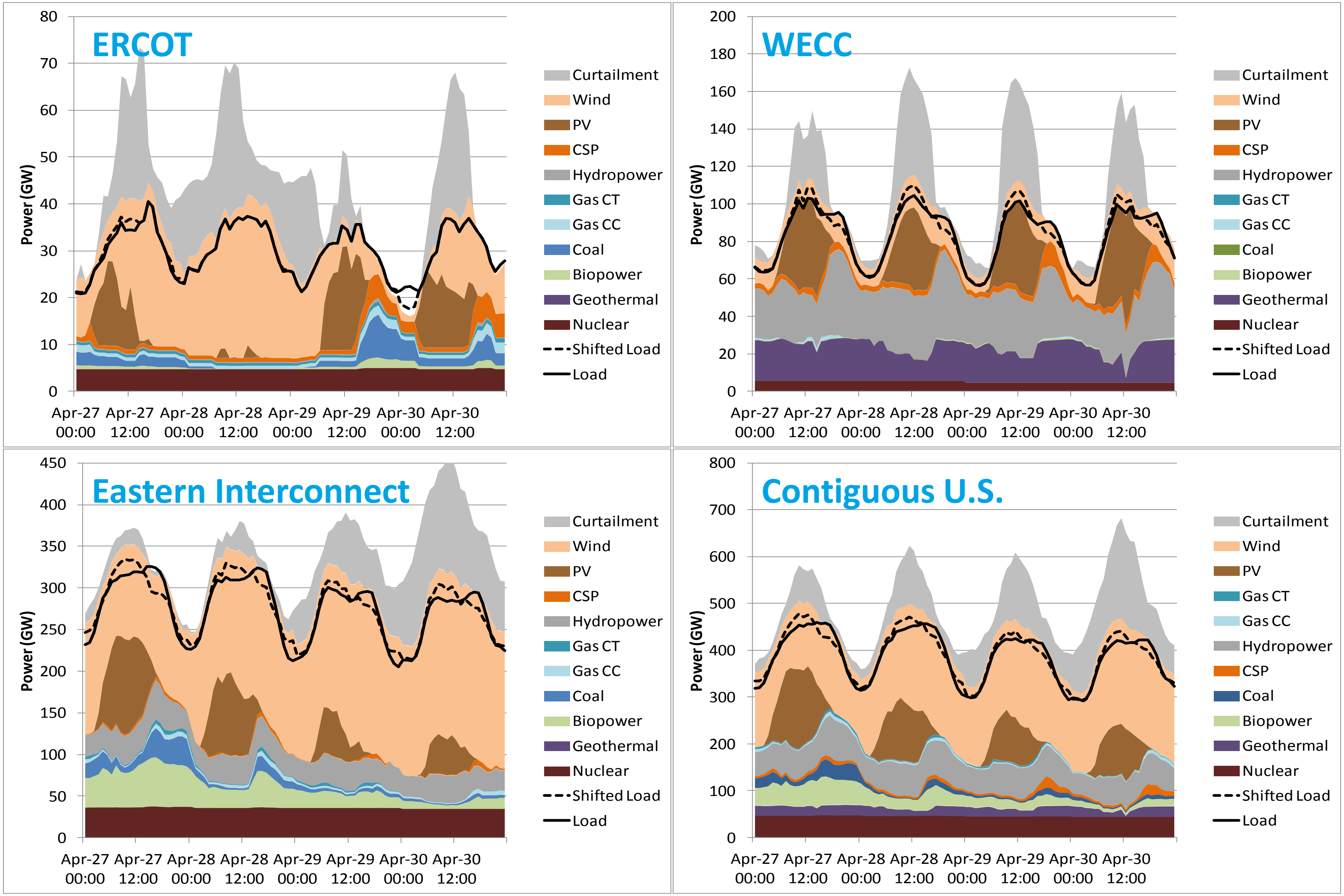
- **Maintaining sufficient capacity on the system for planning reserves**
- **Relying on demand-side interruptible load, conventional generators (particularly natural gas generators), and storage to manage increased operating requirements**
- **Mitigating curtailment with storage and controlled charging of electric vehicles**
- **Operating the system with greater conventional power plant ramping**
- **Relying on the dispatchability of certain renewable technologies (e.g., biopower, geothermal, CSP with storage and hydropower)**
- **Leveraging the geospatial diversity of the variable resources to smooth output ramping**
- **Transmitting greater amounts of power over longer distances to smooth electricity demand profiles and meet load with remote generation**
- **Coordinating bulk power system operations across wider areas.**

Flexible generation for conventional and dispatchable RE technologies through increased ramping and startup-shutdowns





Coordination across wider areas and faster markets help to manage variability *(see WWSIS 2, Energy Imbalance Market, & other studies for better examples)*



Constrained Transmission Scenario (Worst 4 days)