Renewable Electricity Futures

Technical Context for Progress Toward Clean Energy in the West :

Transmission's Critical Role

Rocky Mountain Clean Energy Transmission Summit
History Colorado Center, Denver
Wednesday, January 9, 2012

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.

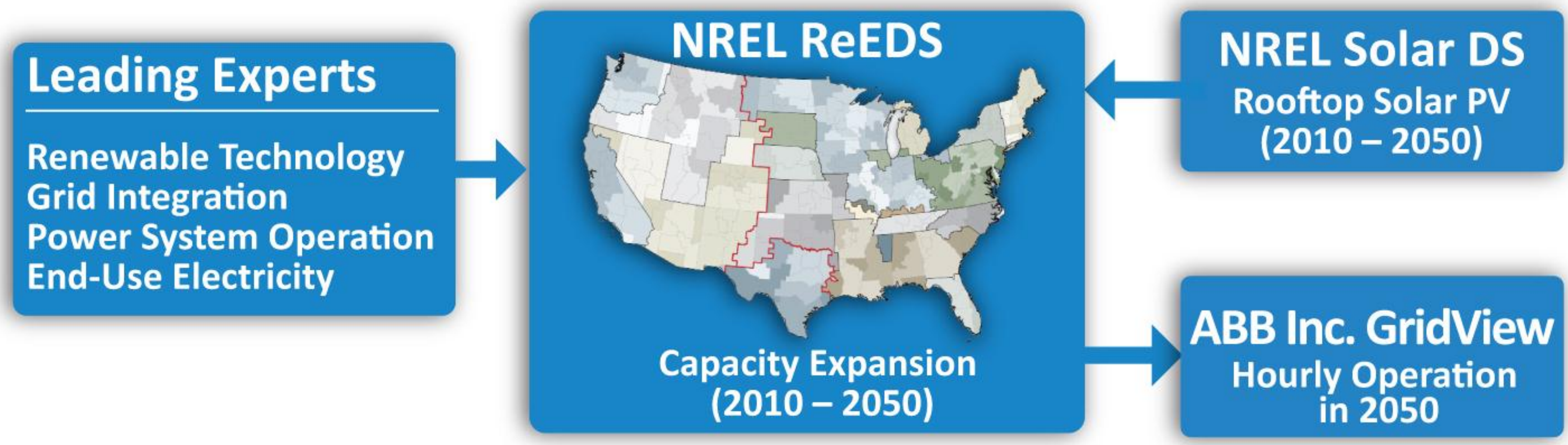
Renewable Electricity Futures Report

To what extent can renewable energy technologies commercially available today meet the U.S. electricity demand over the next several decades?

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.

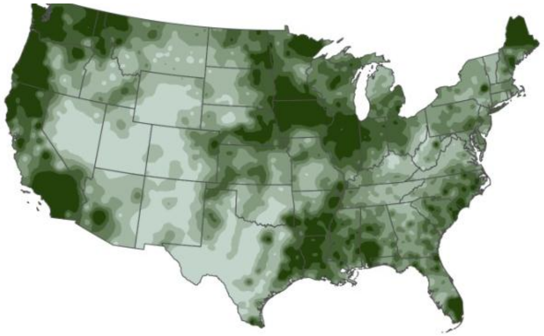
State of the Art Electric System Models

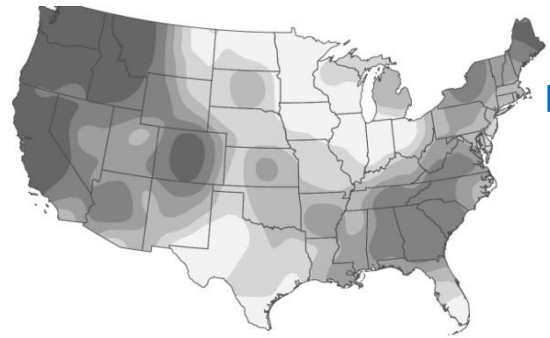


- **Unprecedented <u>geographic</u> and <u>time resolution</u> for the <u>contiguous</u> United States**
- **More than two dozen scenarios of U.S. electric sector focused on 2050.**

Abundant Renewable Energy Resources

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

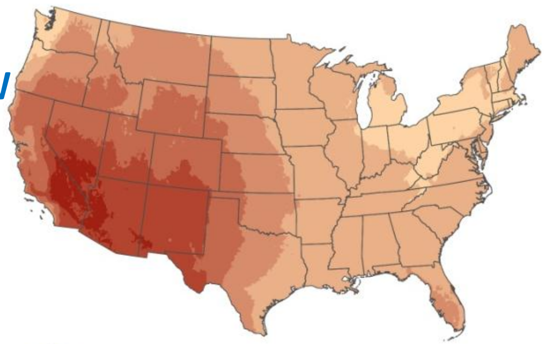


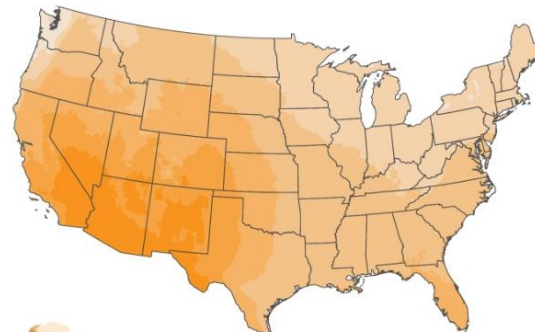


Hydropower ~200 GW
- Run-of-river

Solar CSP ~37,000 GW
- Trough
- Tower

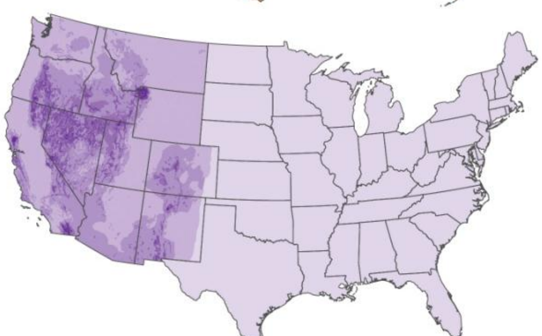
With thermal storage

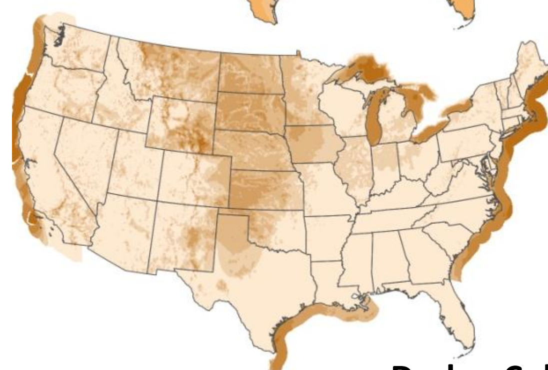




Solar PV ~80,000 GW (rooftop PV ~700 GW)
- Residential
- Commercial
- Utility-scale

Geothermal ~36 GW
- Hydrothermal



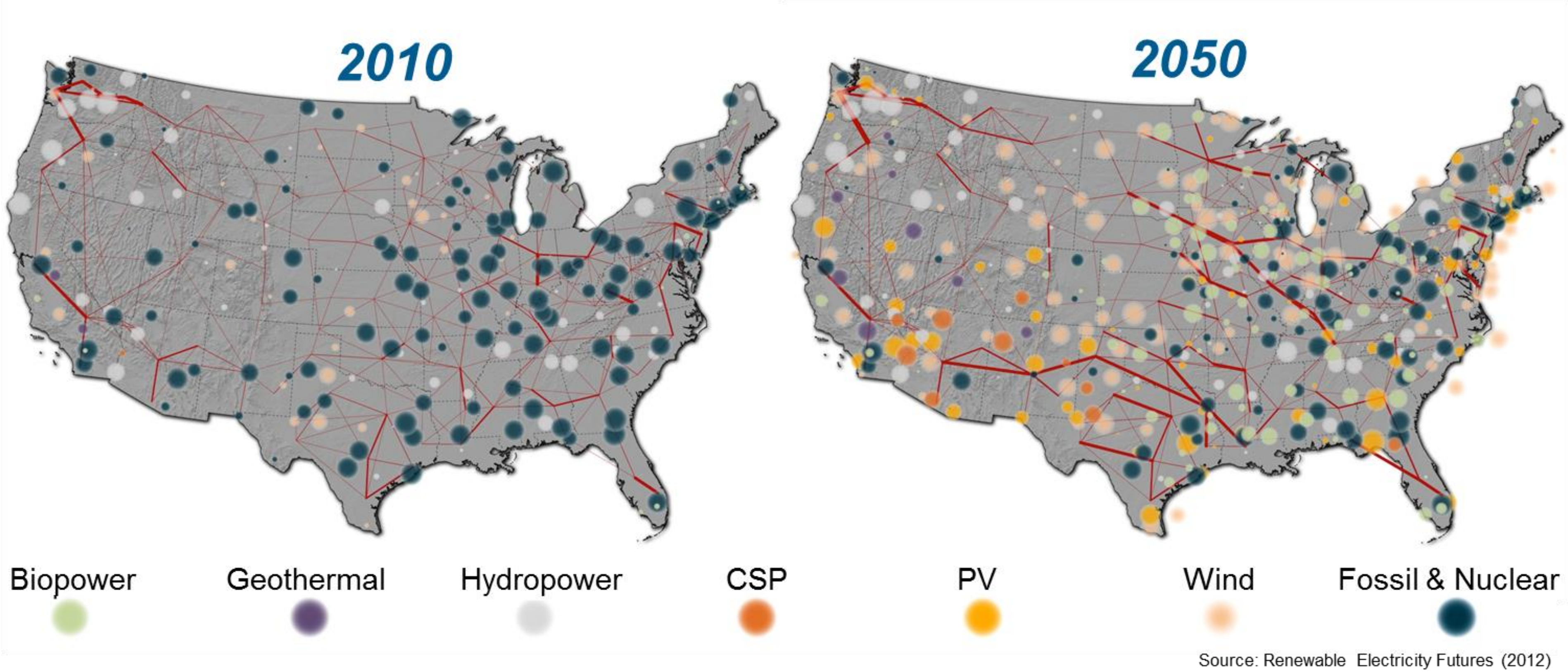


Wind ~10,000 GW
- Onshore
- Offshore fixed-bottom

Darker Colors = Higher Resource

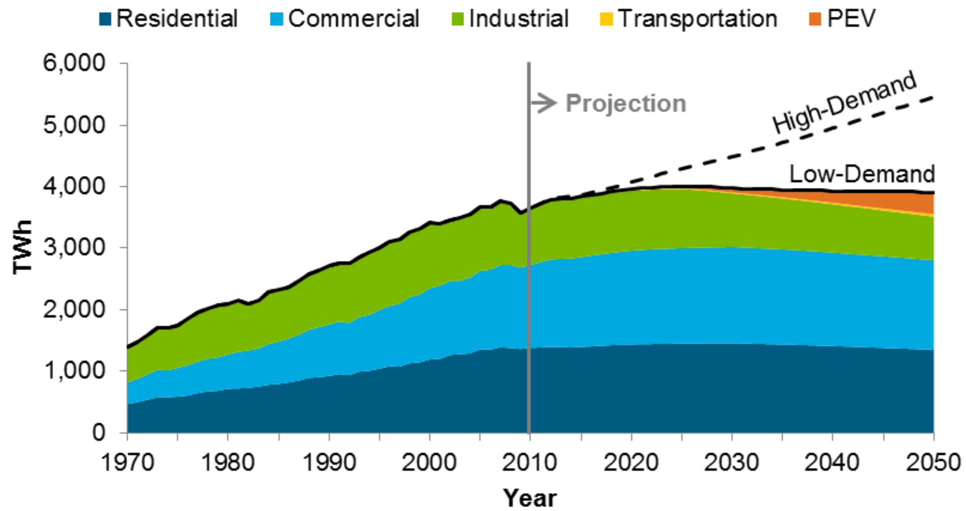
Geographic location, technical resource potential, and output characteristics are unique to each RE generation technology.

A Transformation of the U.S. Electricity System



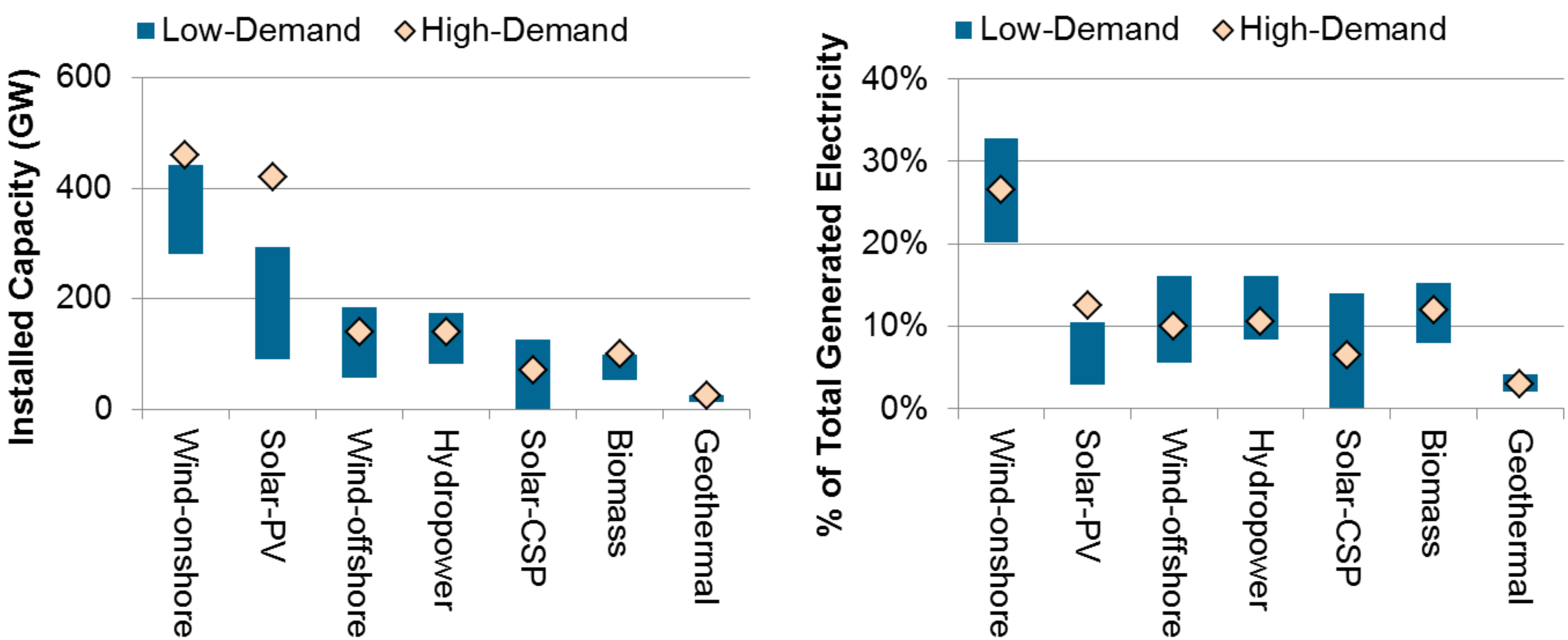
RE generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050—while meeting electricity demand on an hourly basis in every region of the country.

General Assumptions



- **Energy Efficiency**: Most of the scenarios assumed significant adoption of energy efficiency (including electricity) measures in the residential, commercial, and industrial sectors.
- **Transportation**: Most of the scenarios assumed a shift of some transportation energy away from petroleum and toward electricity in the form of plug-in hybrid or electric vehicles, partially offsetting the electricity efficiency advances that were considered.
- **Grid Flexibility**: Most scenarios assumed improvements in electric system operations to enhance flexibility in both electricity generation and end-use demand, helping to enable more efficient integration of variable-output renewable electricity generation.
- ***Transmission***: Most scenarios expanded the transmission infrastructure and access to existing transmission capacity to support renewable energy deployment. Distribution-level upgrades were not considered.
- **Siting and Permitting**: Most scenarios assumed project siting and permitting regimes that allow renewable electricity development and ***transmission expansion*** with standard land-use exclusions.

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.**

Key Results

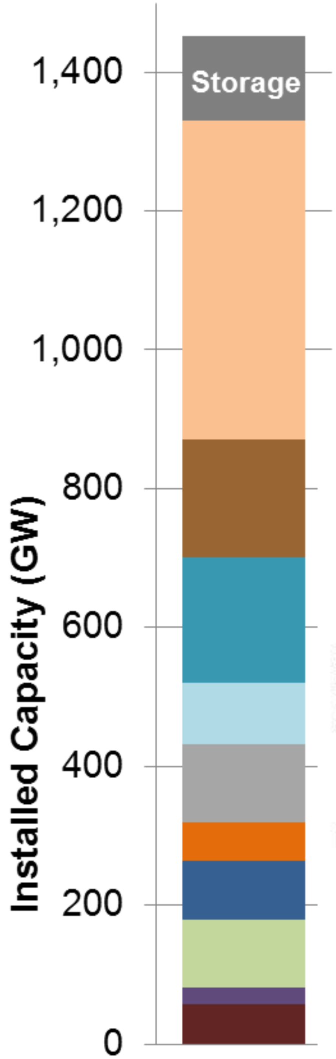
- **Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050–while meeting electricity demand on an hourly basis in every region of the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

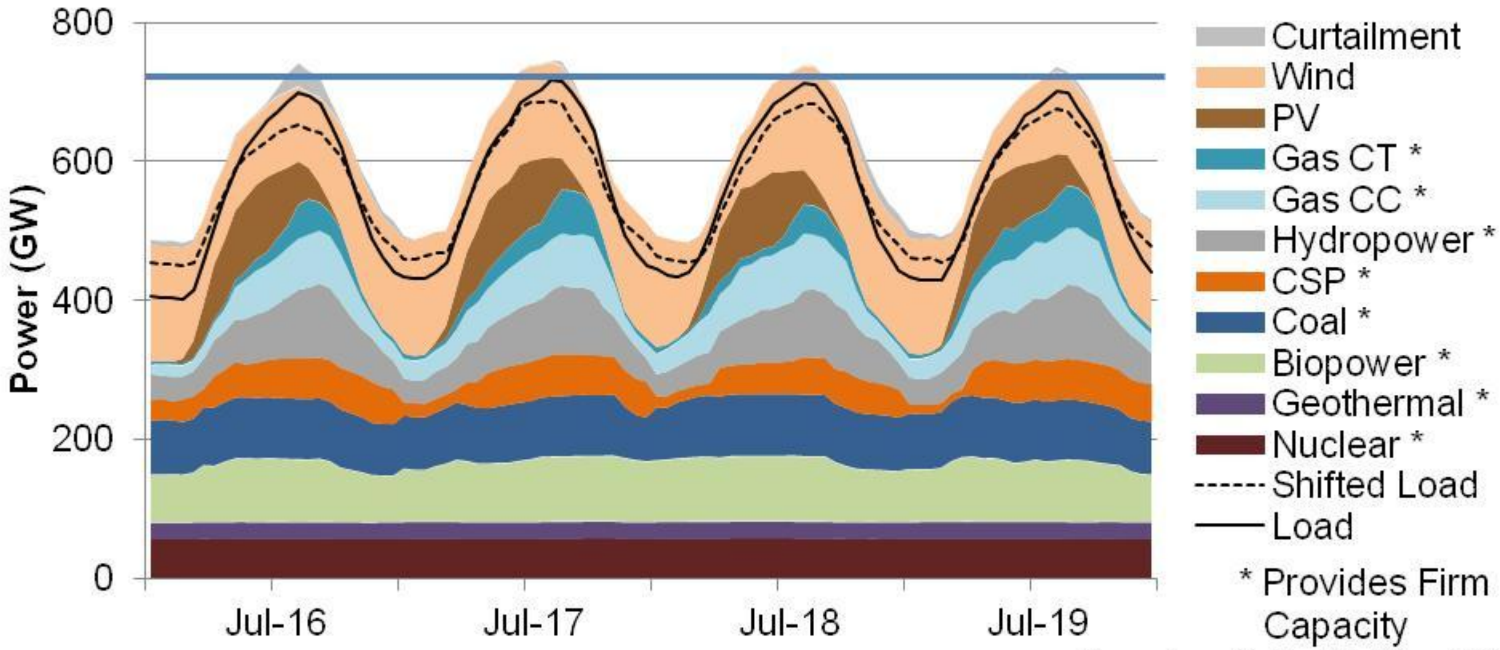
- **The abundance and diversity of U.S. renewable energy resources can support multiple combinations of renewable technologies that result in deep reductions in electric sector greenhouse gas emissions and water use.**

- **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.**

Supply and Demand Balanced Every Hour of the Year

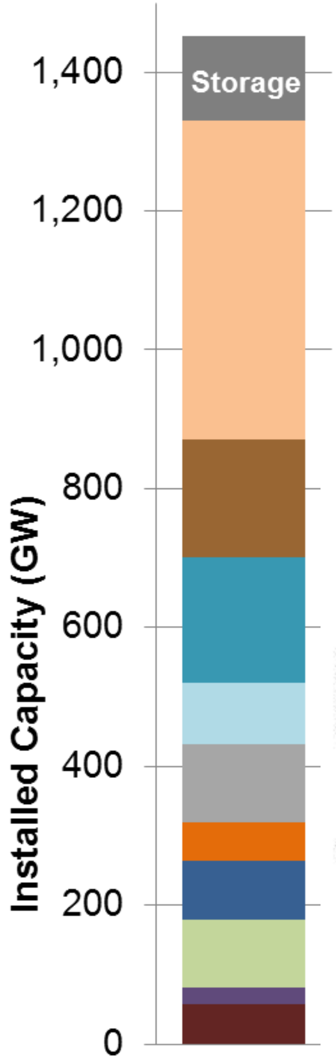


Installed capacity is sufficient to meet summer afternoon peak demand from diverse reserves supplying firm capacity.

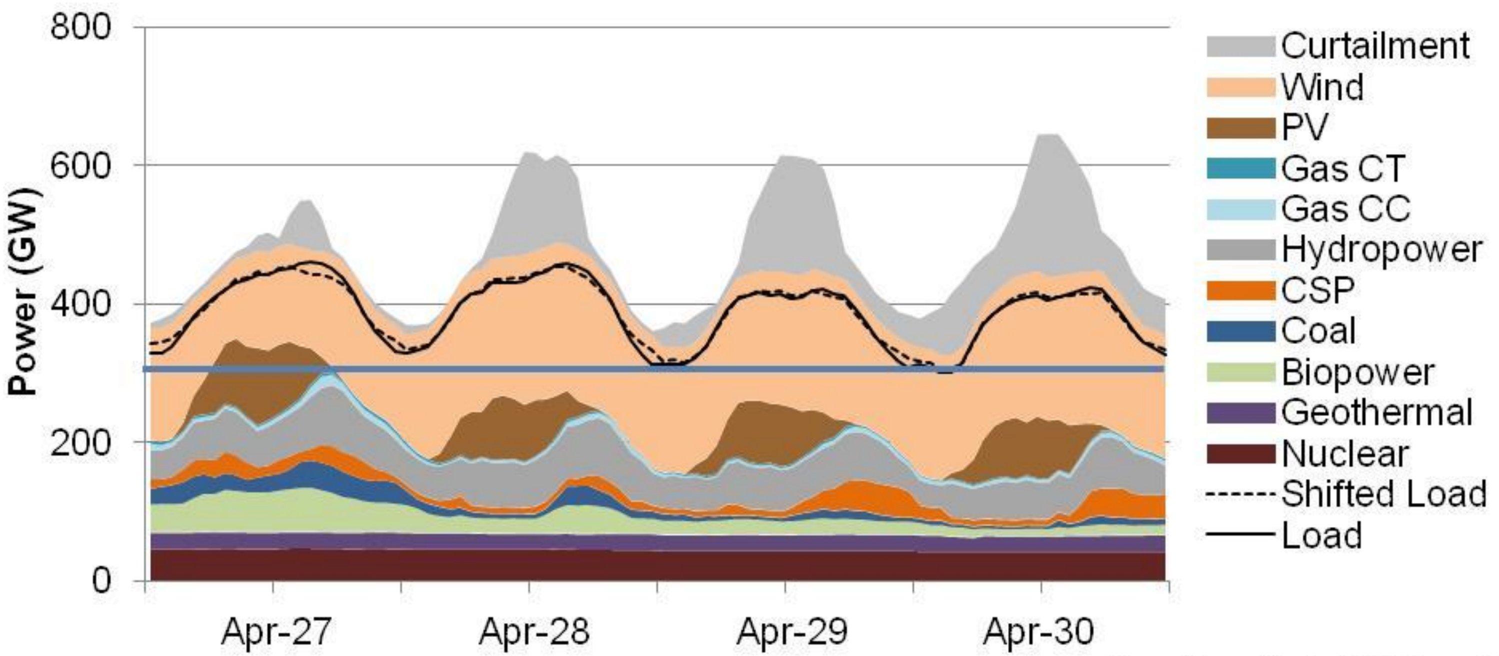


Source: Renewable Electricity Futures (2012)

Flexible Electricity System Manages Variability

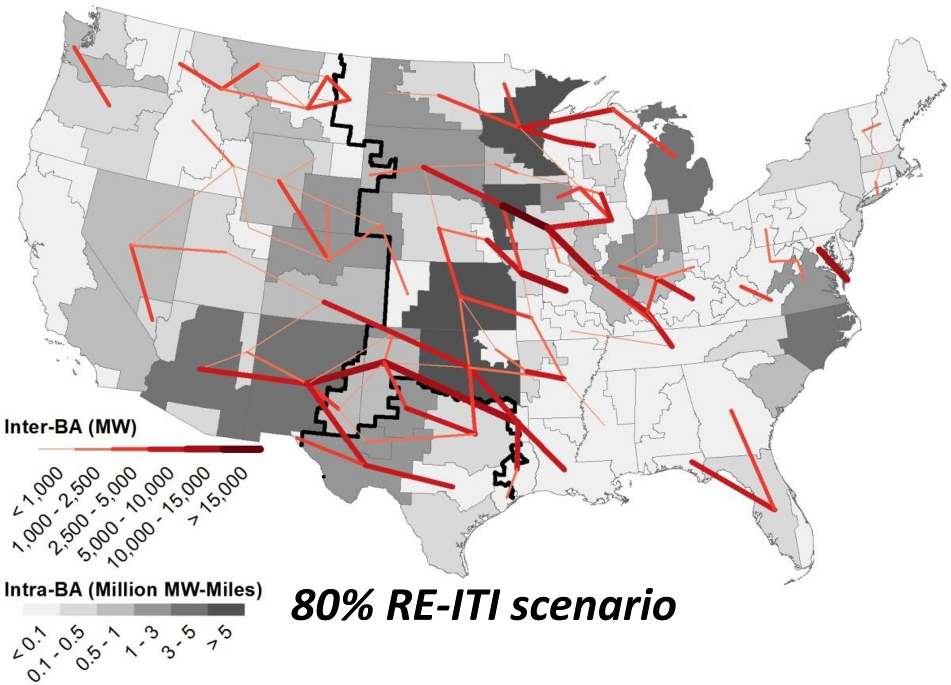


Especially during low-demand periods in the spring months, flexibility options include flexible generators, flexible load, *new transmission*, and wide area coordination.



Source: Renewable Electricity Futures (2012)

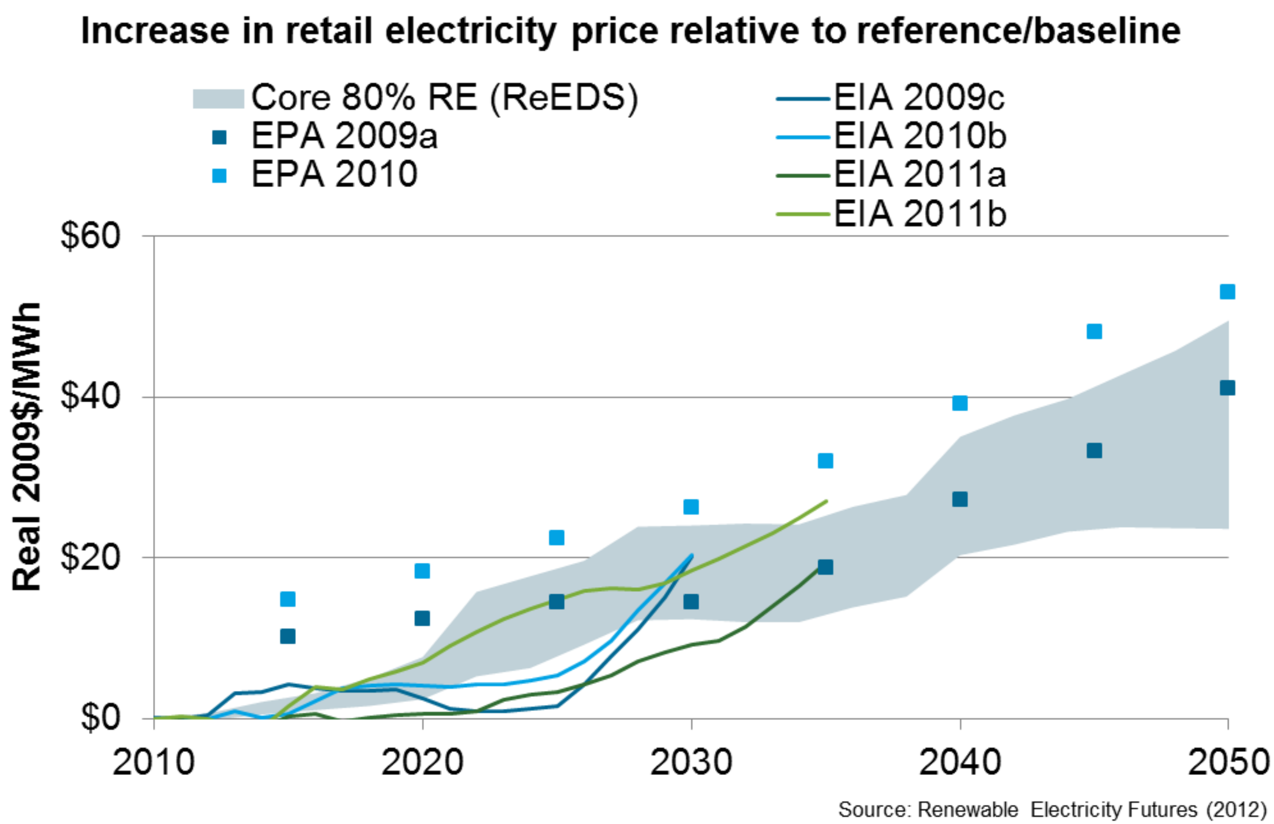
As RE deployment increases, additional transmission infrastructure is required



80% RE-ITI scenario

- **In most 80%-by-2050 RE scenarios, 110-190 million MW-miles of new transmission lines are added.**
- **AC-DC-AC interties are expanded (50,000-80,000 MW) to allow greater power transfer between asynchronous interconnects.**
- **Annual transmission and interconnection investments in the 80%-by-2050 RE scenarios range from B$5.7-8.4/year, which is within the range of recent total investor-owned utility transmission expenditures.**
- **High RE scenarios lead to greater transmission congestion, line usage, and transmission and distribution losses.**

RE Futures Cost Comparisons



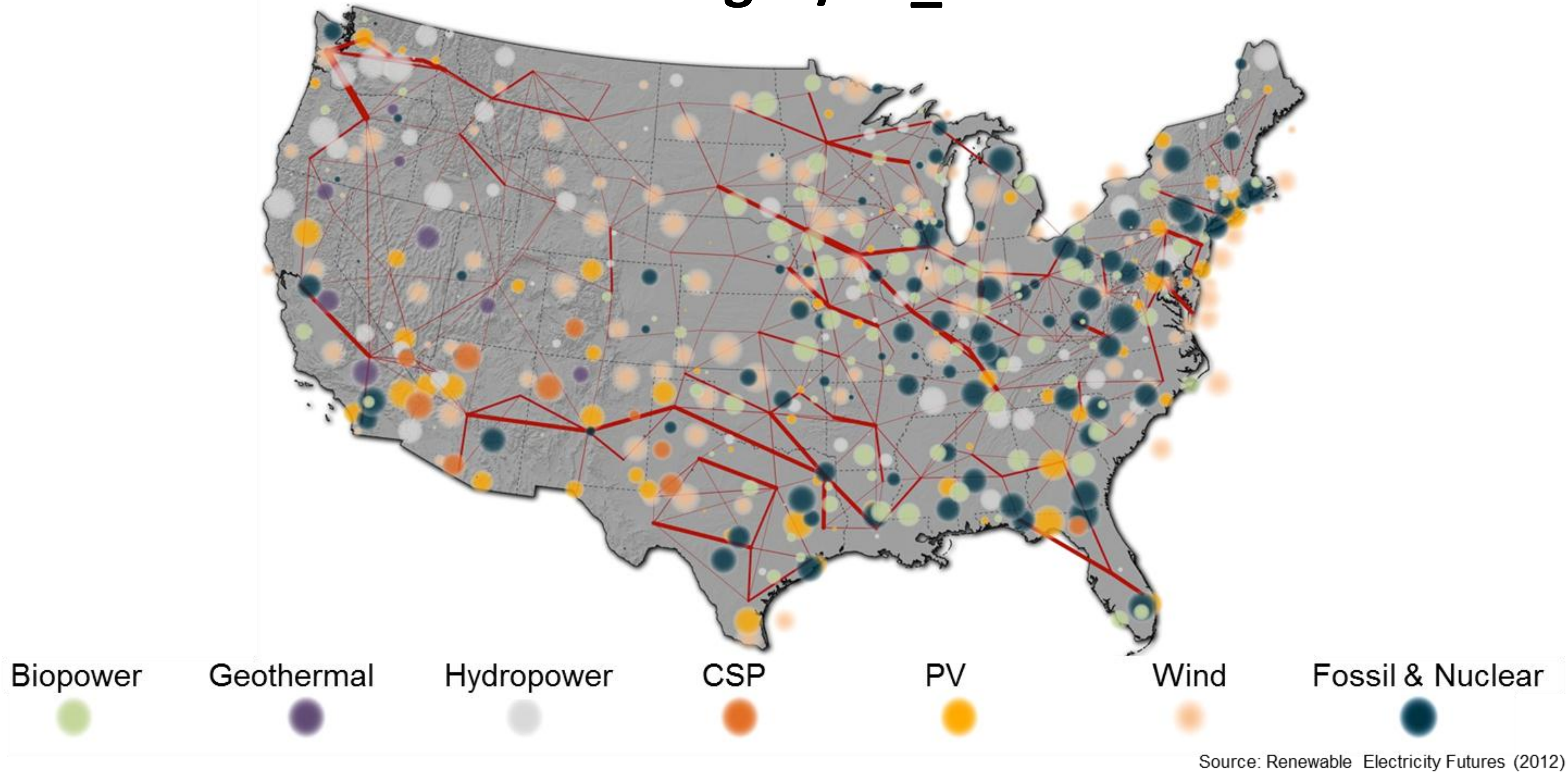
- **The incremental cost of high RE scenarios is comparable to published cost estimates of other clean energy scenarios.**
- **Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost.**

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.**

www.nrel.gov/RE_Futures



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.

Thanks to REF Analysis and Review Teams

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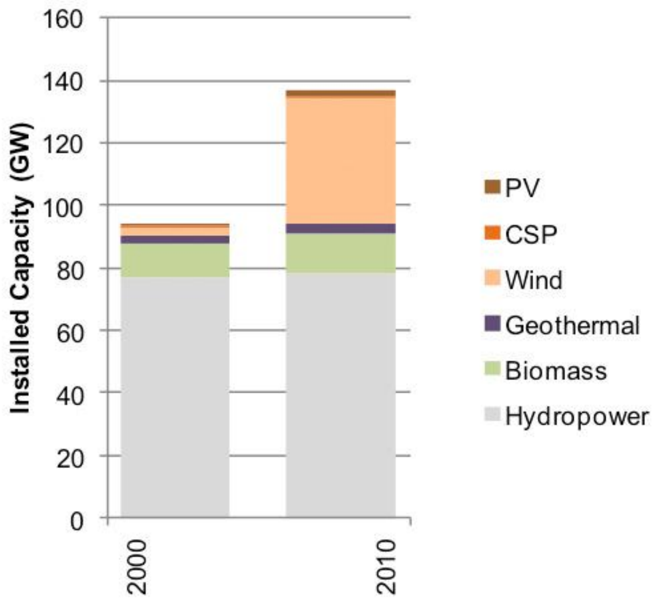
Backup Slides

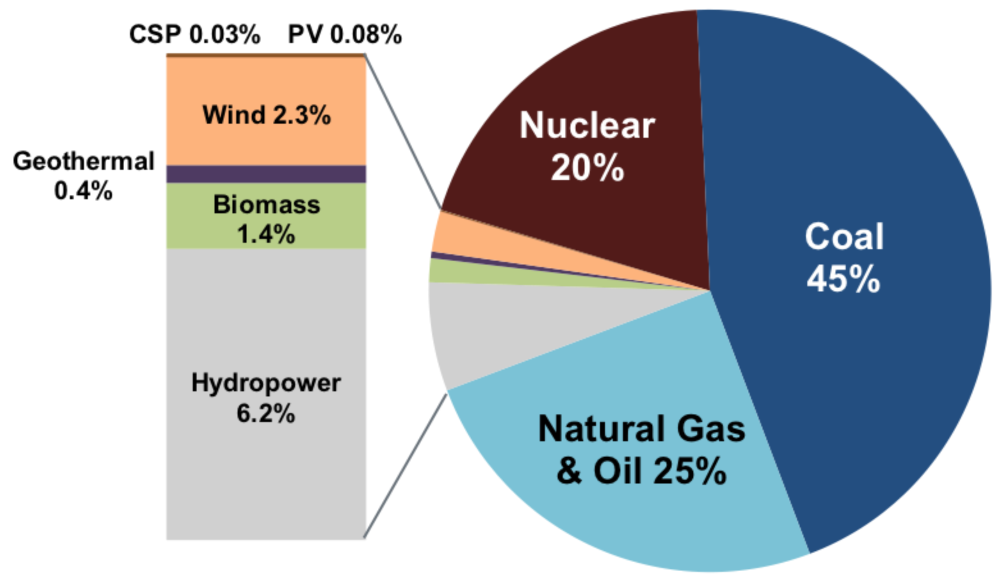
Renewable Electricity Futures Motivation

RE Capacity Growth 2000-2010



Source: RE Data Book (DOE 2011)

2010 Electricity Generation Mix



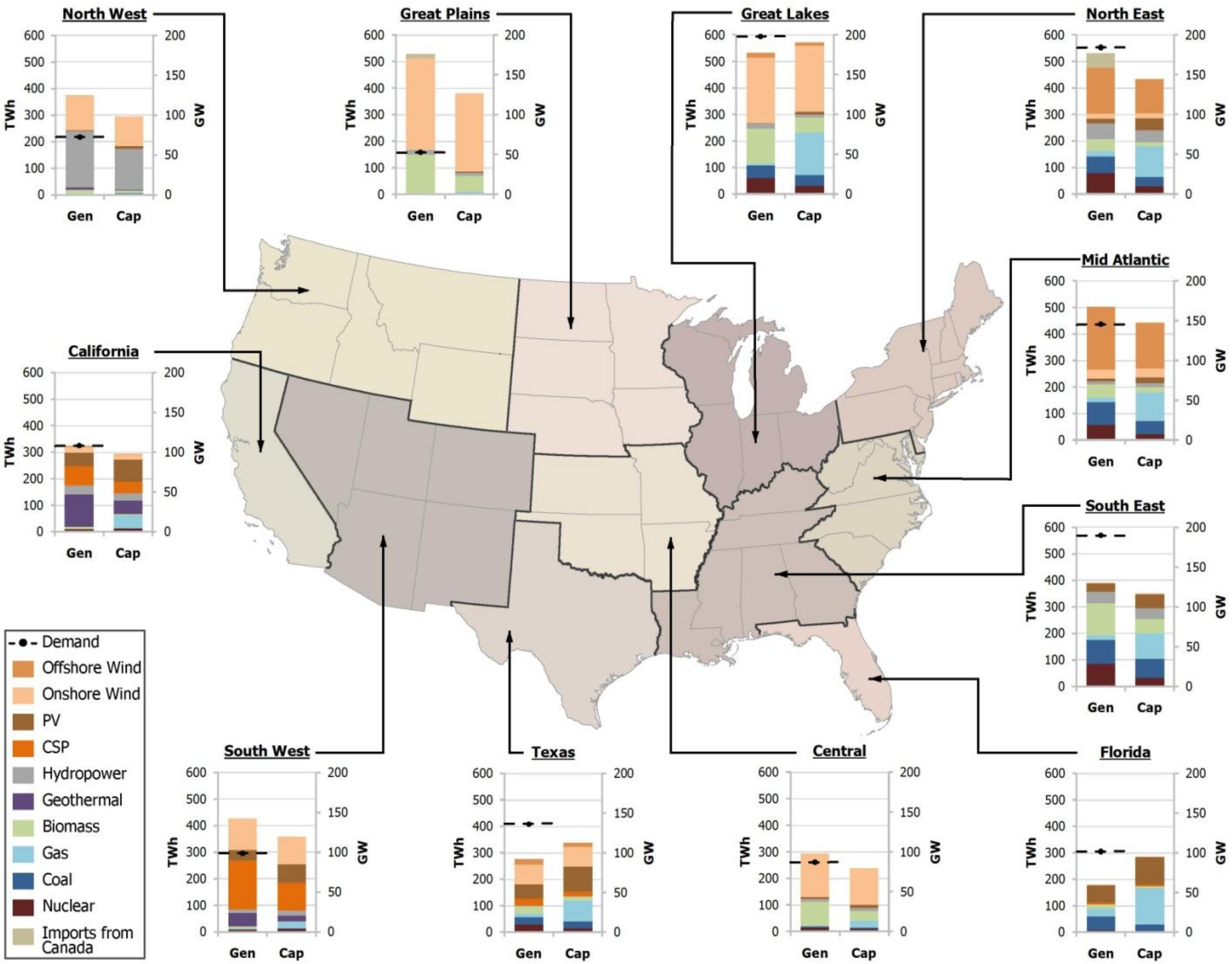
Source: Renewable Electricity Futures (2012)

- **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 Introduction

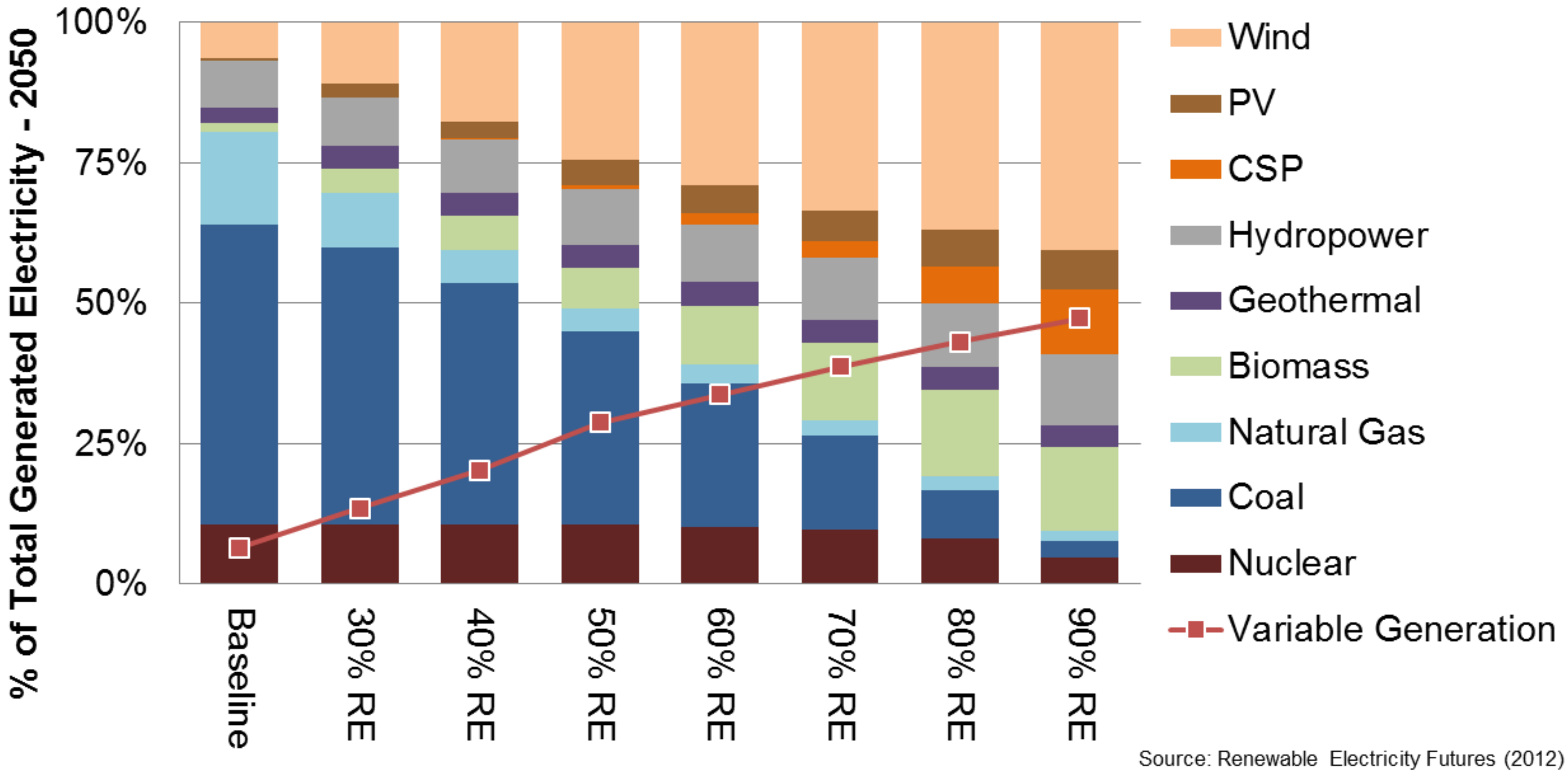
RE Futures does….	RE Futures does not…
Identify commercially available RE generation technology combinations that meet up to 80% or more of projected 2050 electricity demand in every hour of the year.	Consider policies, new operating procedures, evolved business models, or market rules that could facilitate 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.

All regions of the country could contribute substantial renewable electricity supply in 2050



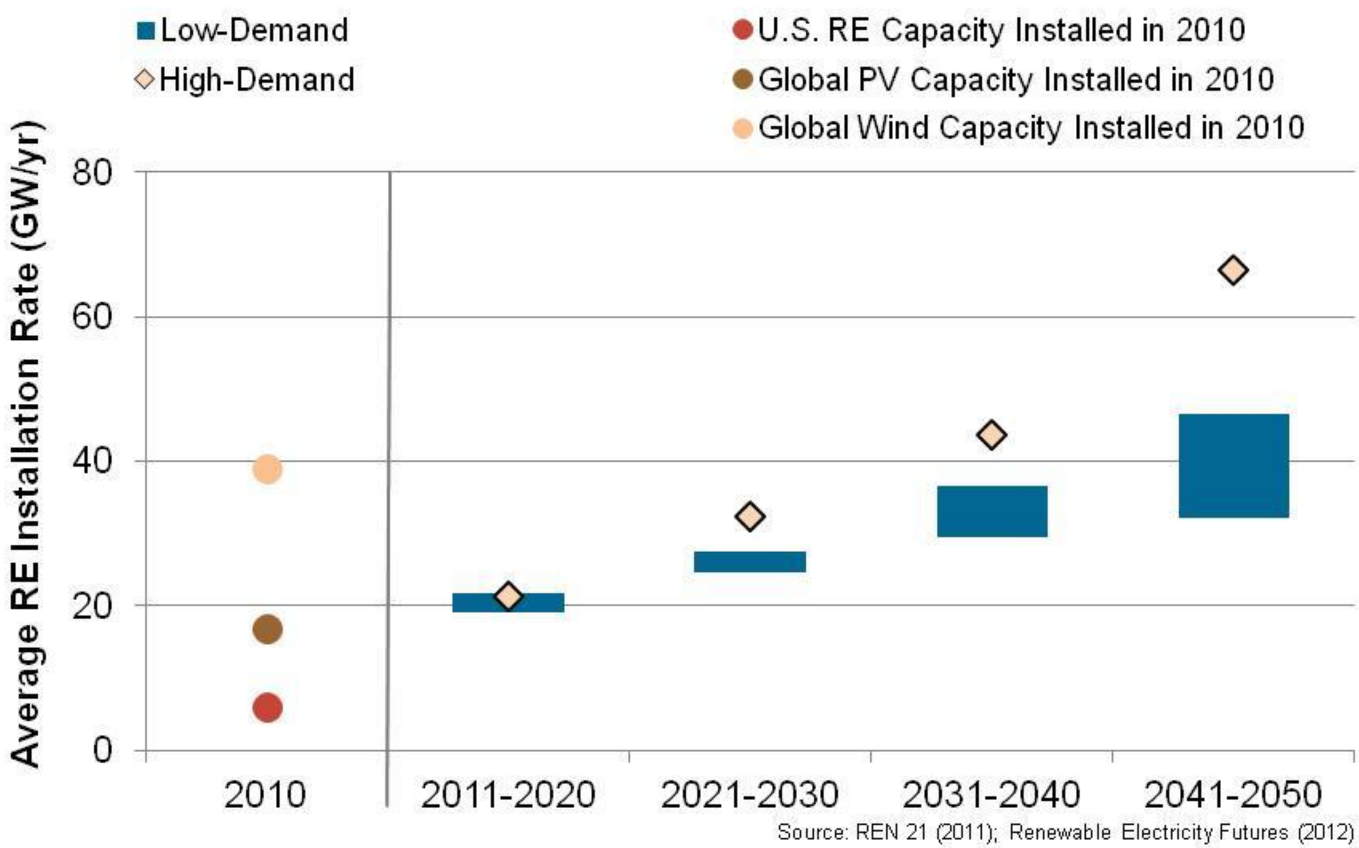
80% RE-ITI scenario

RE Resource Supply from 30% - 90% Electricity



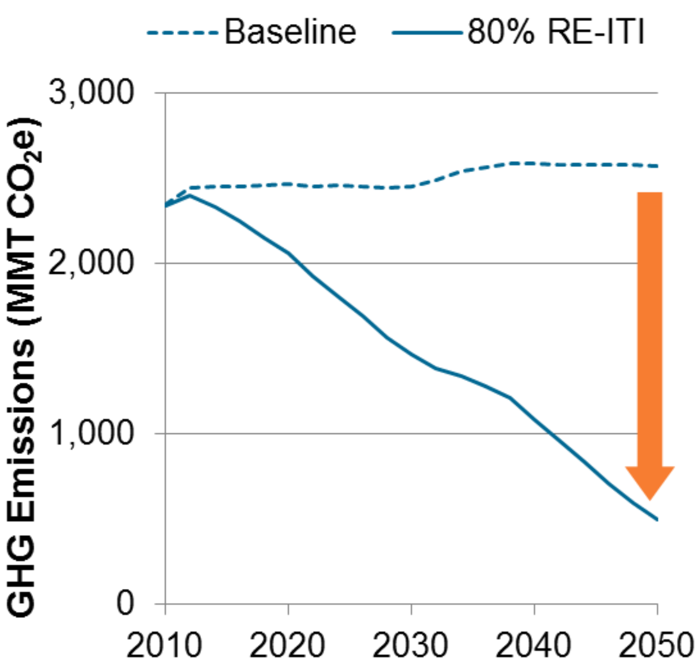
Additional variability challenges system operations, but can be addressed through increased use of supply- and demand-side flexibility options and new transmission.

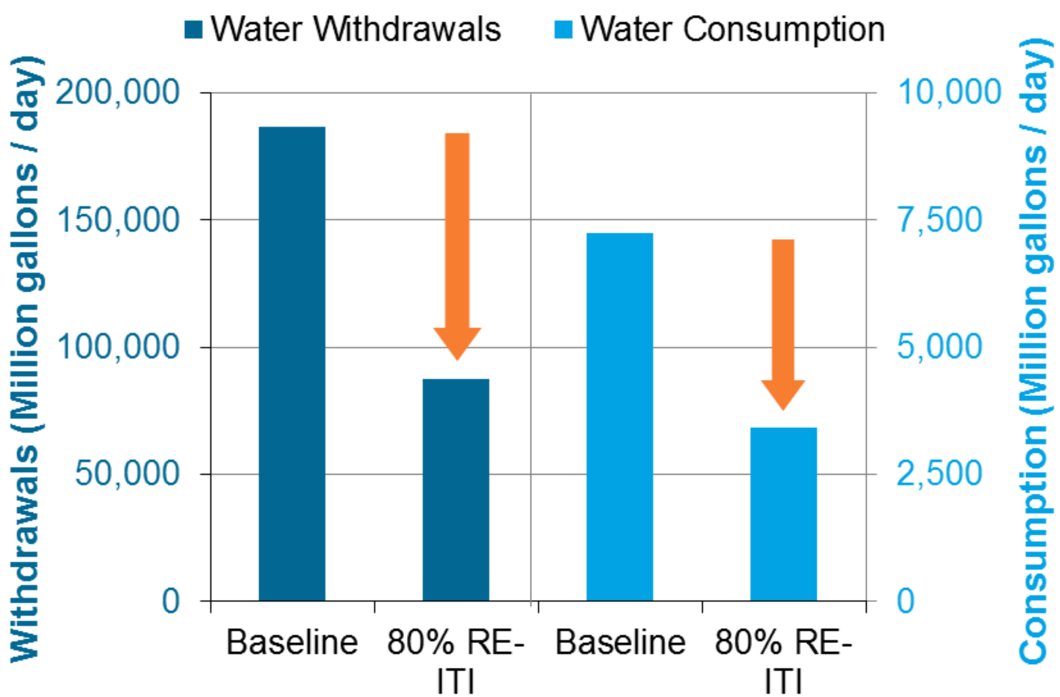
Significant Long-Term RE Industry Growth



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

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).**

RE Land Use Implications

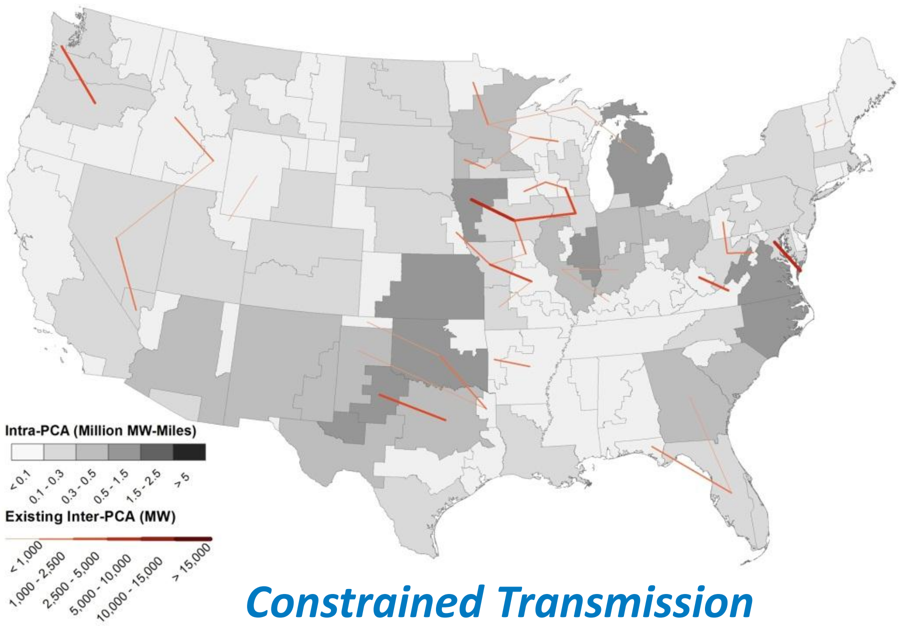
- Area requirements:
  - The gross estimate for RE Futures scenarios = < 3% of U.S. land area.
  - About half of that land area is used for biopower.
  - The majority of the remainder is used for wind, but only about 5% is actually disrupted.

	Gross Land Use Comparisons (000 km^2)	
80% RE scenarios	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

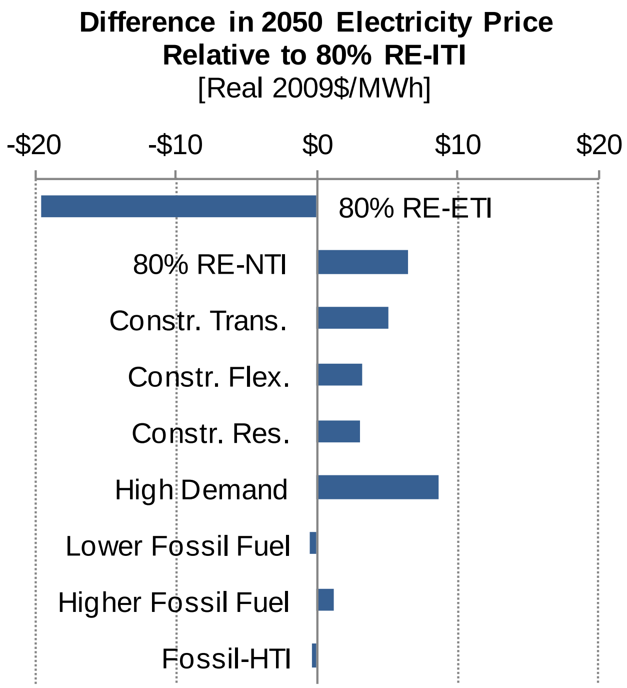
However 80% RE was achievable even when transmission is severely constrained

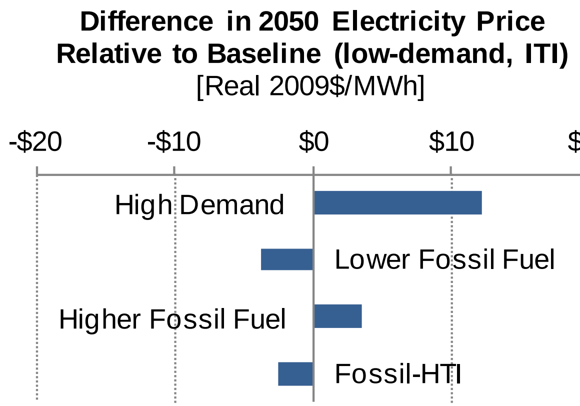


Constrained Transmission

- **A Constrained Transmission scenario was also evaluated, where**
  - **Triple cost of transmission lines**
  - Disallow new intertie capacity
  - Double transmission losses
  - Double the deployment of rooftop PV
  - + other minor assumption modifications
- **As a result, only 30 million MW-miles of new transmission lines are added**
- **Greater reliance on more local resources (e.g. PV, offshore wind)**

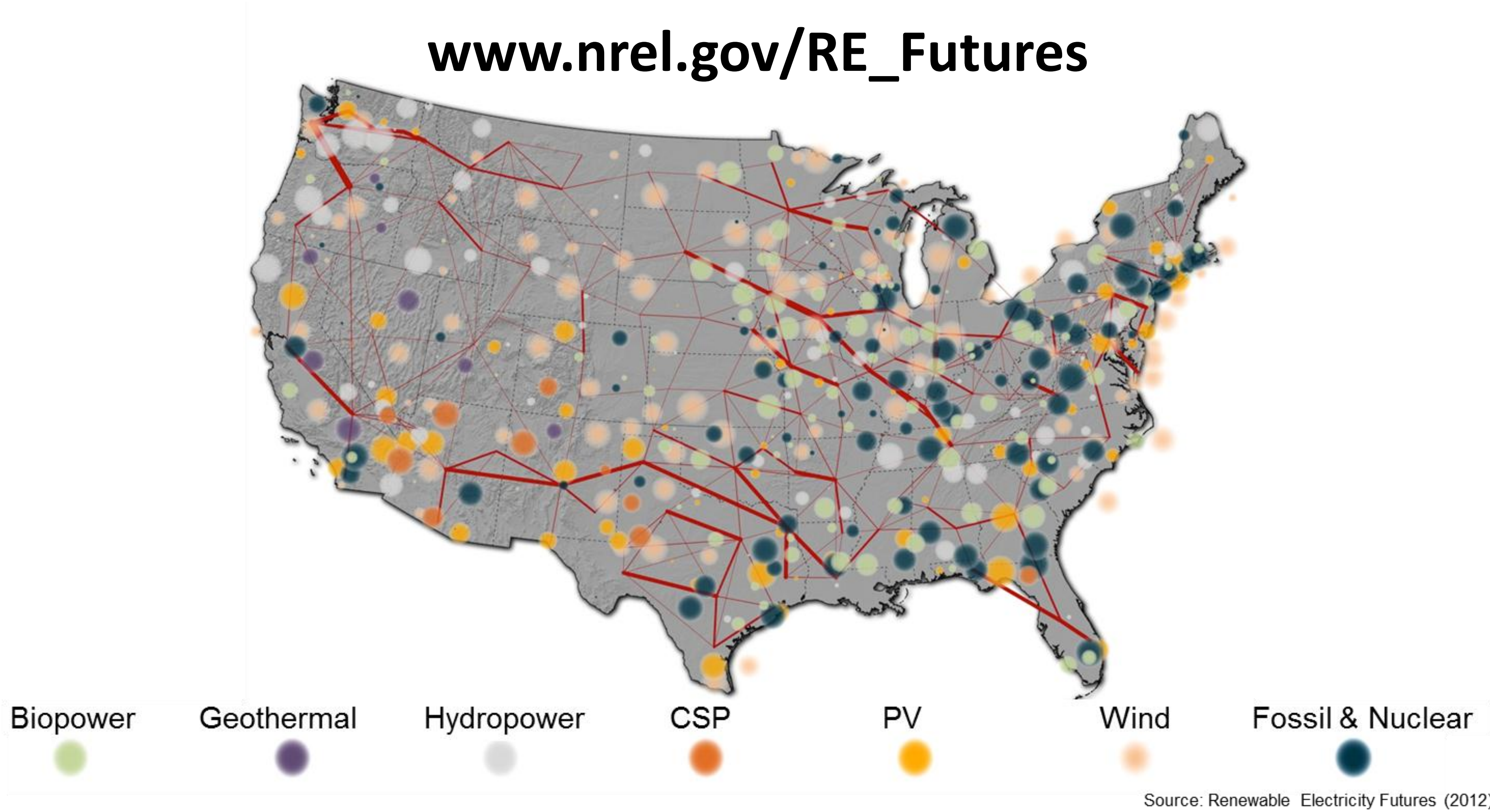
Improvement in cost and performance of RE technologies is the most impactful lever for reducing the incremental cost





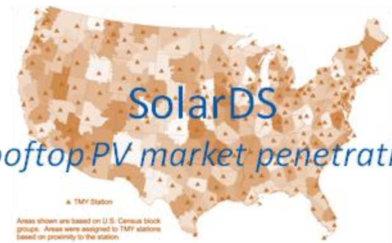
- **Cost is less sensitive to the assumed electric system constraints (transmission, flexibility, RE resource access).**
- **Electricity prices in high RE scenarios are largely insensitive to projections for fossil fuel prices and fossil technology improvements.**
- **Lower RE generation levels result in lower incremental prices (e.g., 30% RE-ETI scenario shows no incremental cost relative to the baseline scenario).**
- **Cost figures do not reflect savings or investments associated with energy efficiency assumptions in the low-demand *Baseline* and *80% RE* scenarios.**

www.nrel.gov/RE_Futures



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.

Modeling Framework



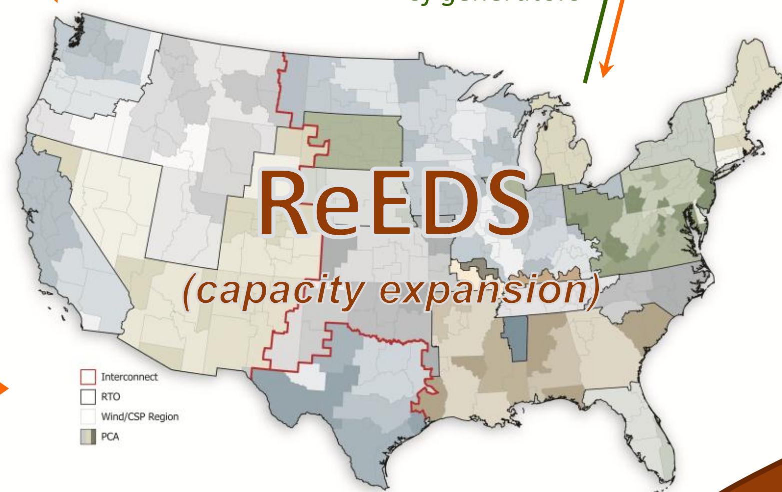
rooftop PV penetration

2050 mix of generators

does it balance hourly?

Black & Veatch
Technology Teams
Flexible Resources
End-Use Electricity
System Operations
Transmission

Technology cost & performance
Resource availability
Demand projection
Demand-side technologies
Grid operations
Transmission costs



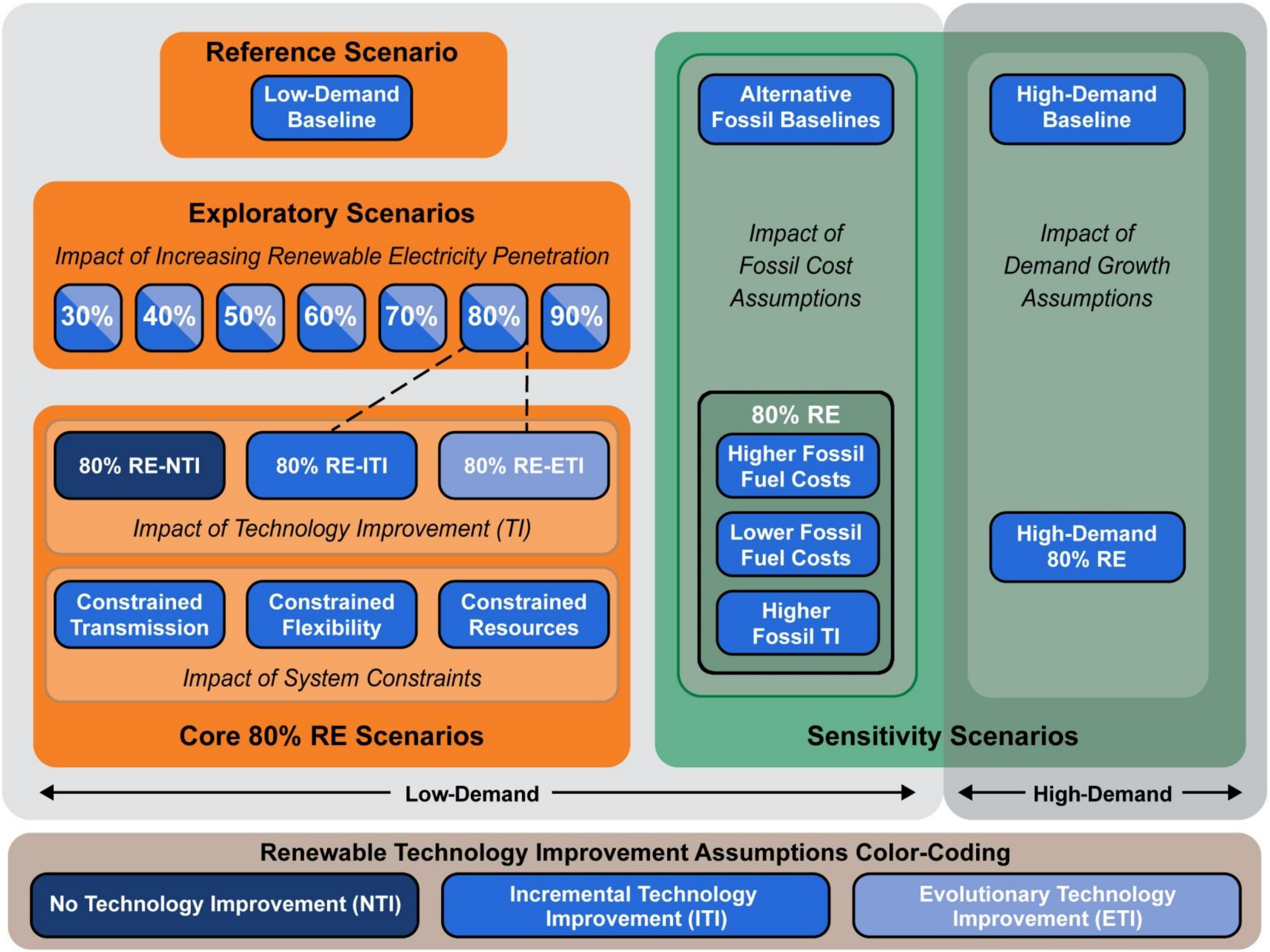
High resolution modeling using **134 nodes** & **hourly time steps**

Implications

GHG Emissions
Water Use
Land Use
Direct Costs

Capacity & Generation 2010-2050

Scenario Framework



Renewable Resources and Technologies

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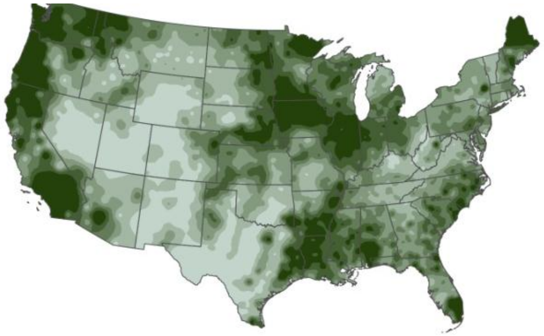

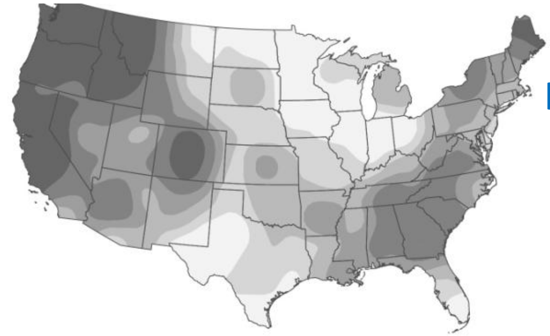

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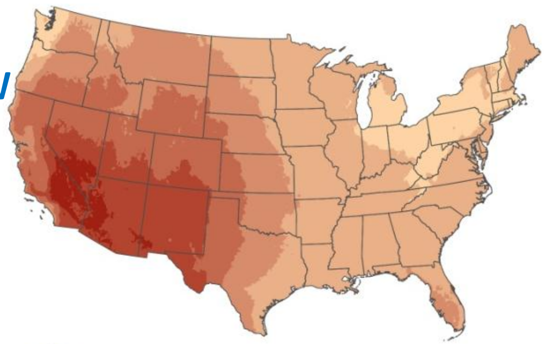

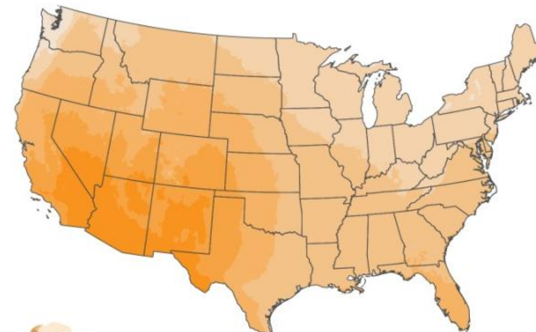

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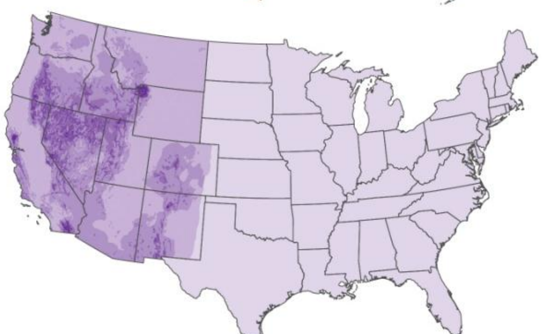
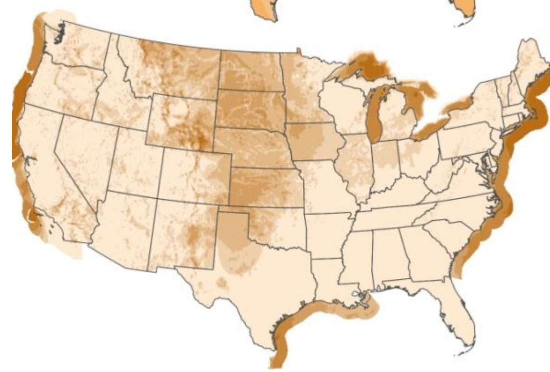
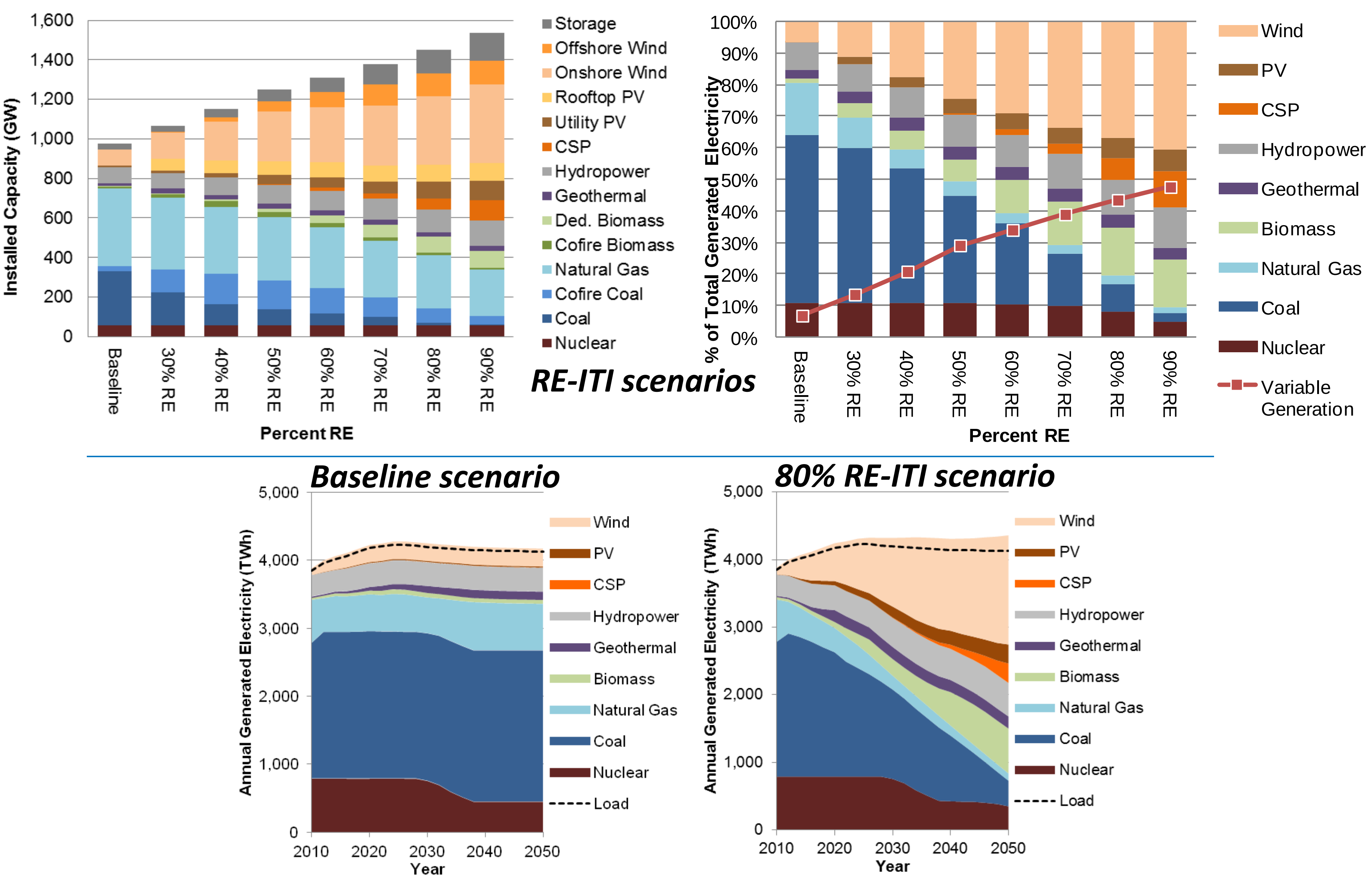




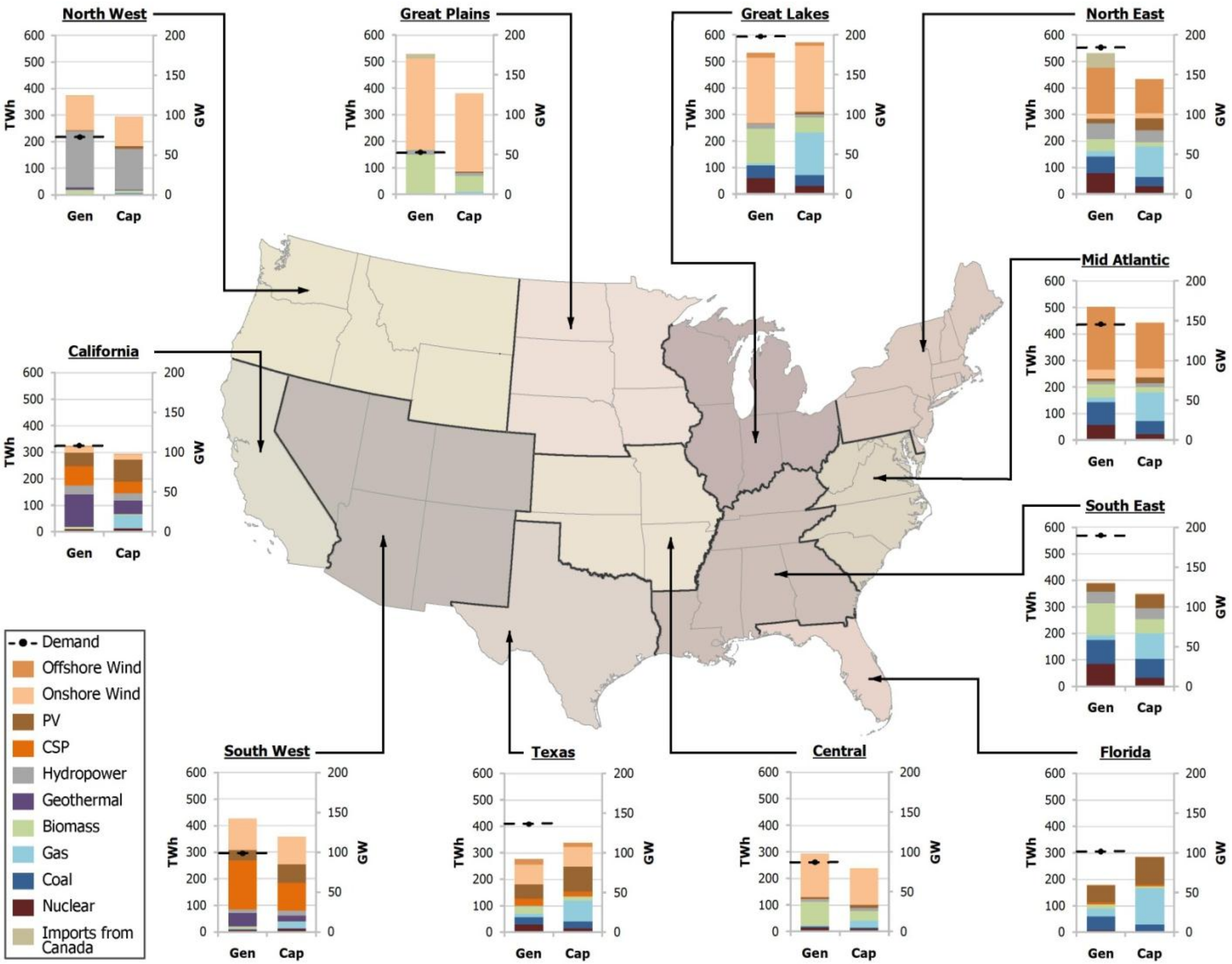
Wind ~10,000 GW
- Onshore
- Offshore fixed-bottom

- **Only currently commercial technologies were modeled (no EGS, ocean, floating wind) with incremental and evolutionary improvements.**
- **RE characteristics including location, technical resource potential, and grid output characteristics were considered.**

Renewable generation resources could adequately supply 80% of total U.S. electricity generation in 2050 while balancing hourly supply and demand



All regions of the country could contribute substantial renewable electricity supply in 2050



80% RE-ITI scenario

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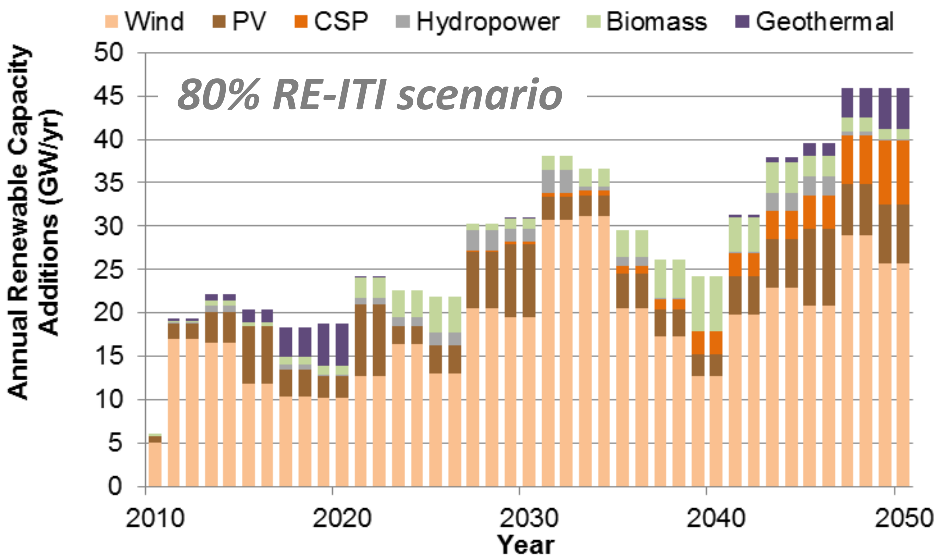
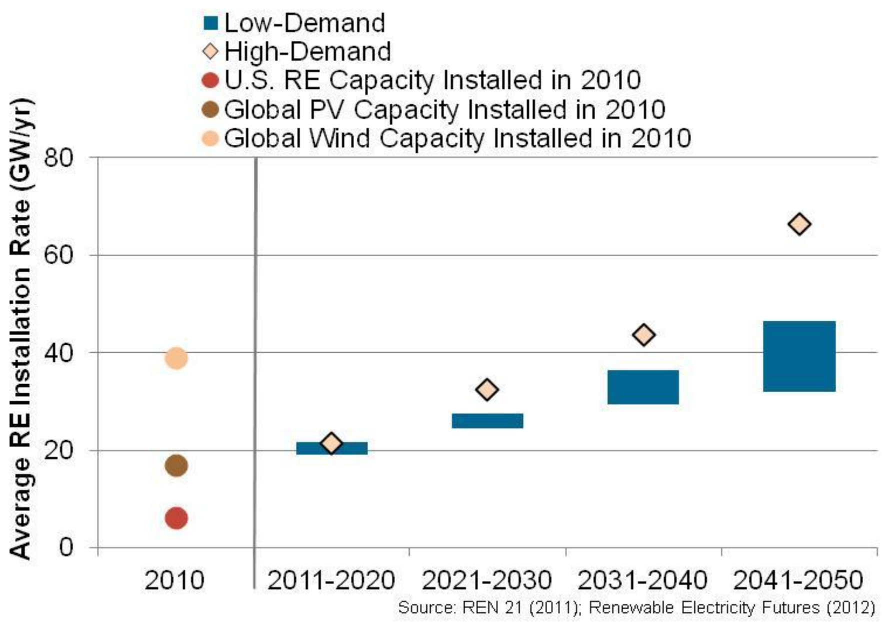
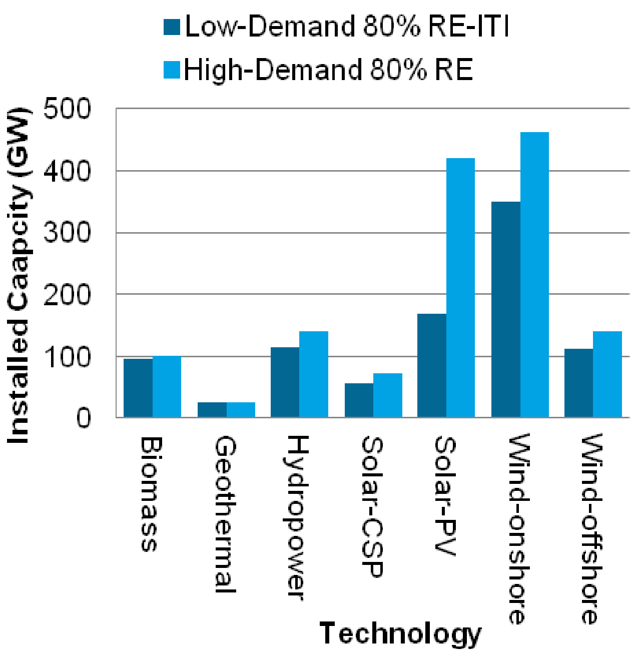




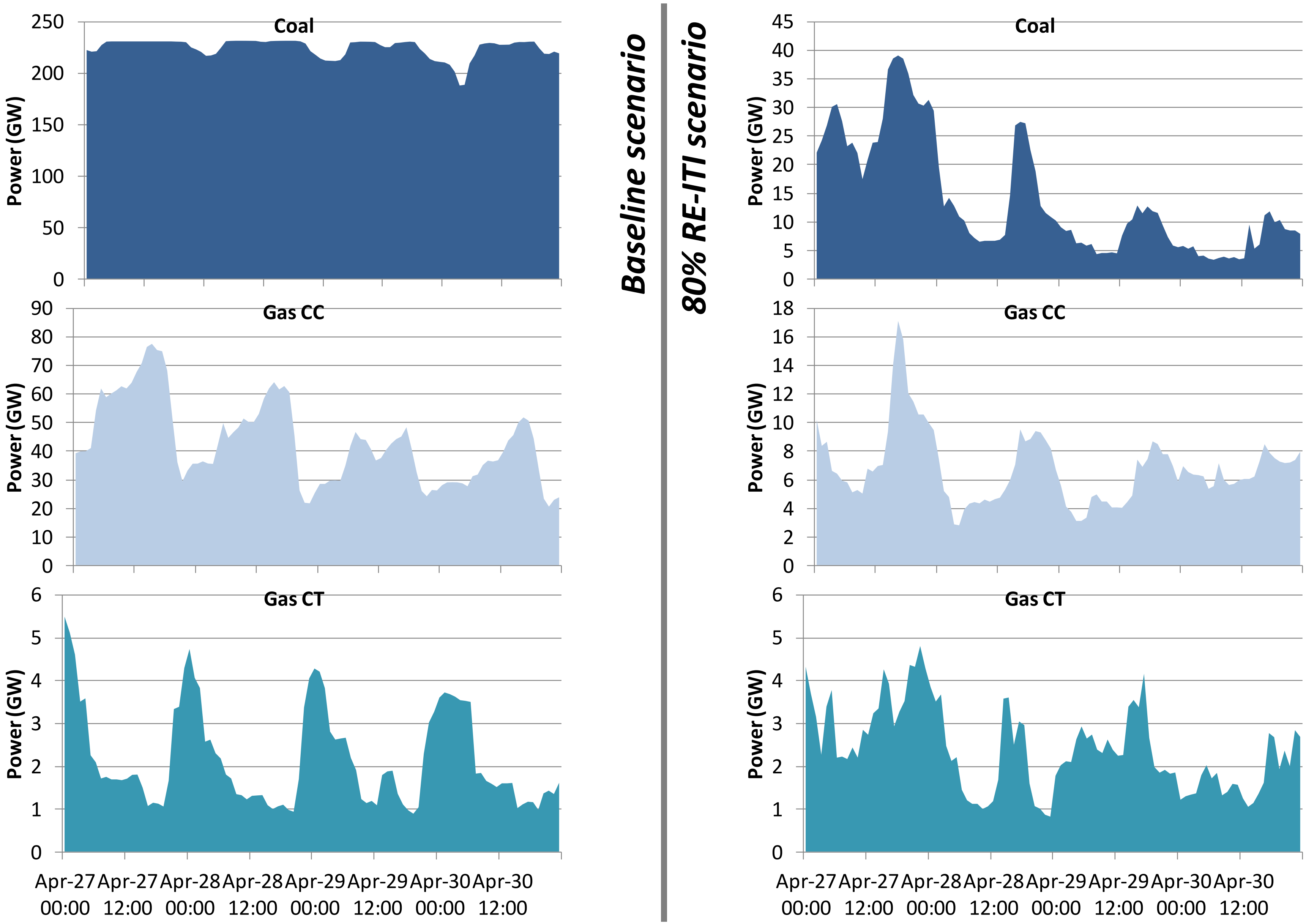
- **80% RE generation in 2050 requires additions of ~20 GW/year in 2011-2020 , ~30/GW/year in 2021-2040, and ~40 GW/year in 2041-2050 (higher under High-Demand scenario).**
- **These installation rates are higher than U.S. capacity additions in 2010 (7 GW) and 2009 (11 GW) and would place challenges on RE industries.**
- **Recent U.S. and worldwide growth demonstrate the scalability of RE industries.**
- **More informed siting practices and regulations can reduce industry scale-up challenges.**

With higher demand growth, high levels of renewable generation present increased resource and grid integration challenges

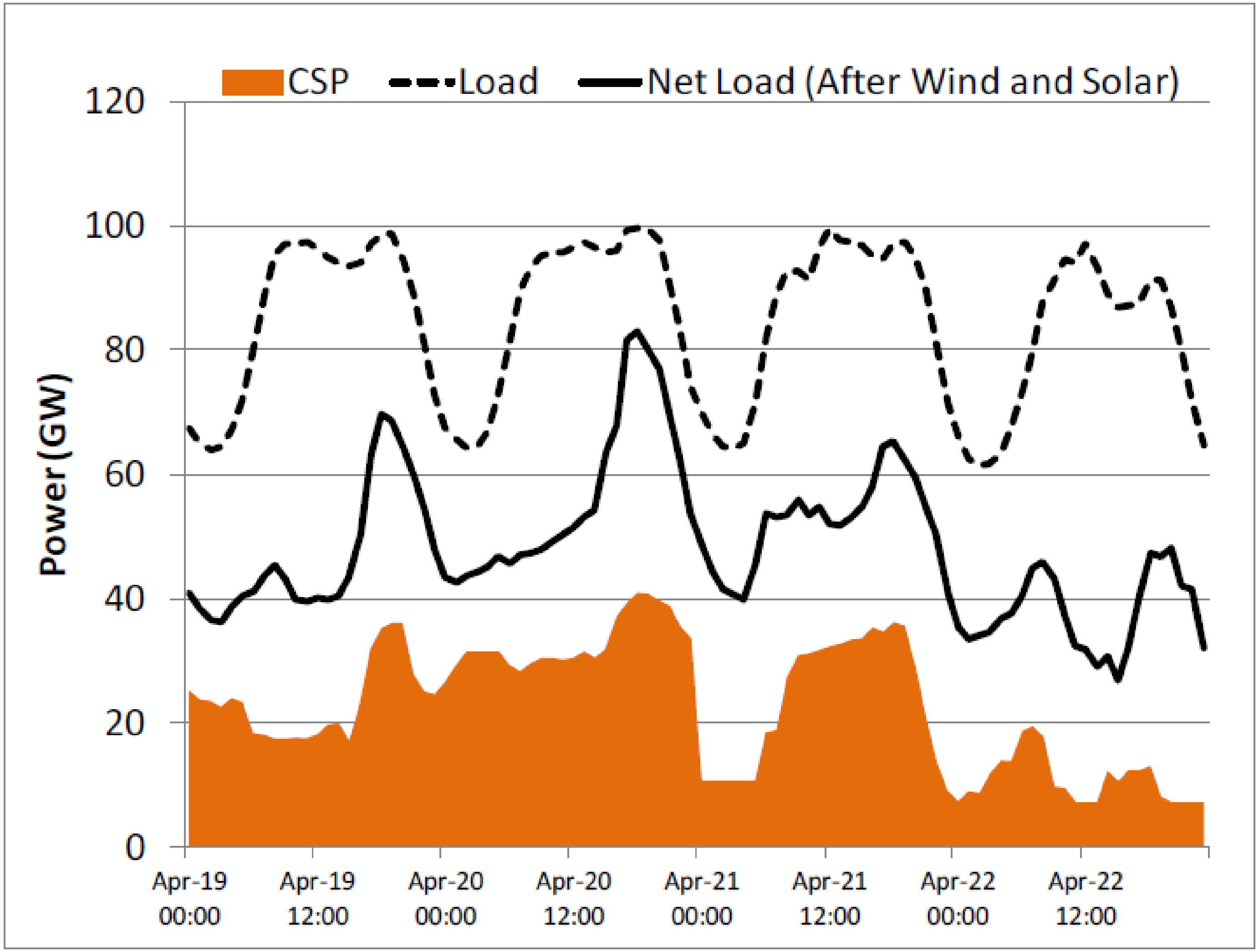


- **Higher demand growth generally implies an increased need for new generation and transmission capacity in both the baseline and 80% RE scenarios.**
- **More renewable generation capacity, particularly wind and PV, is needed; it will result in greater industry scale-up and resource access challenges.**
- **Additional flexible supply- and demand-side capacity (e.g., storage, natural gas combustion turbine power plants, and interruptible load) is also needed.**
- **While higher demand growth shows greater increases in electricity prices, the direct incremental cost associated with high renewable generation levels <u>decreases</u> (the prices in baseline also increase).**
- **Cost-effectiveness of energy efficiency vs. supply-side options was not evaluated.**

System flexibility provided through increased ramping and startup-shutdown of conventional generators, particularly in low-demand periods



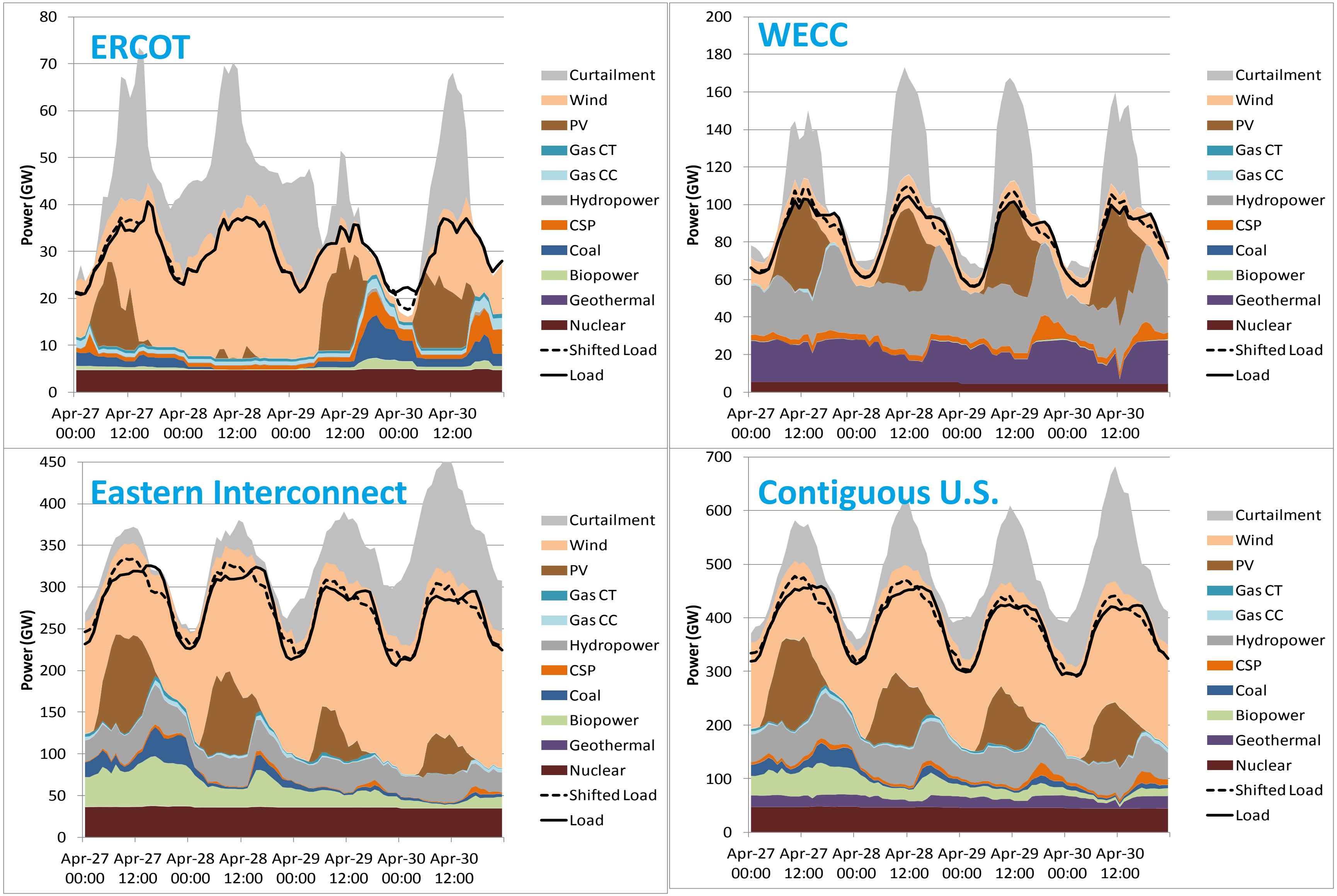
Dispatchable renewable generators and storage provide system flexibility by shifting operation to periods of high net load



Source: Denholm, …….. (2012)

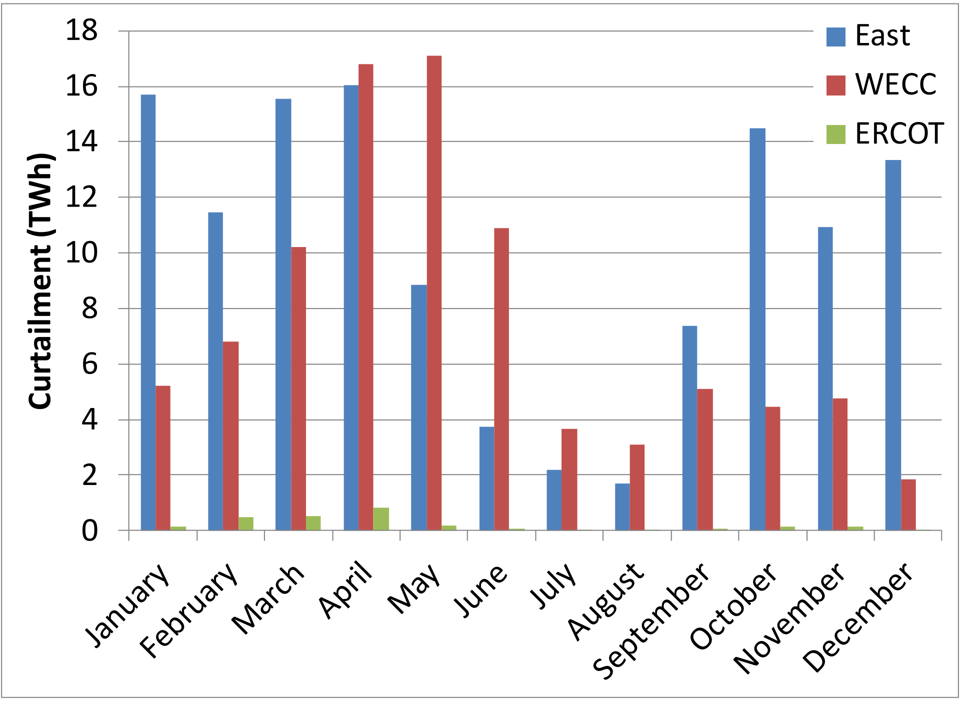
Dispatch of CSP with thermal storage in Western Interconnection (80% RE-ITI)

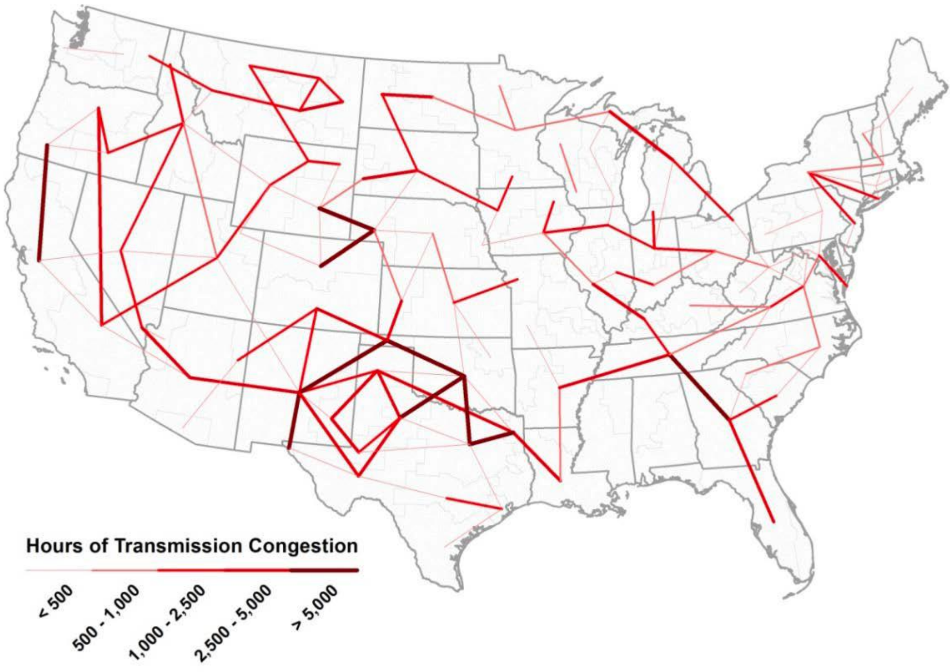
Coordination across wider areas and faster markets help to manage variability *(see Energy Imbalance Market, & other studies for additional examples)*



***Constrained Transmission Scenario** (Worst 4 days)*

Curtailment can be used strategically to reduce variability in the net load





- **8-10% of wind, solar, hydropower curtailed in 2050 under 80% RE scenarios**
- **Curtailment can be reduced through increased transmission capacity, more-flexible generators, storage, and demand-side applications (e.g., controlled PHEV charging)**