Renewable Electricity Futures

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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.

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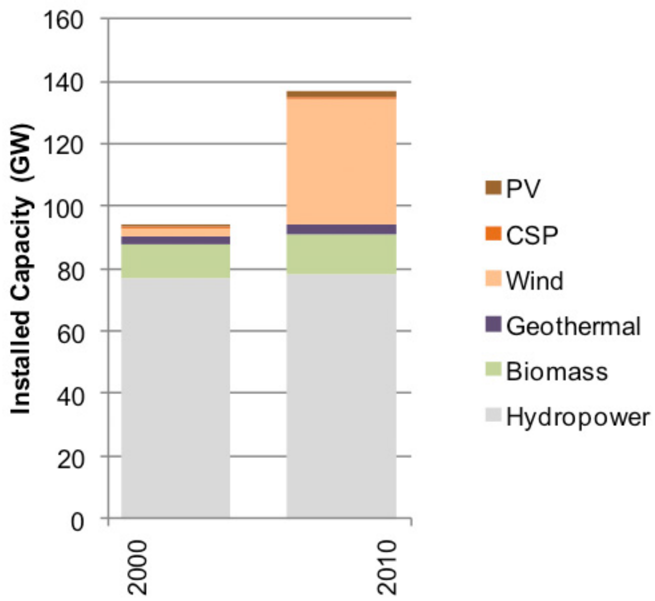
A U.S. DOE-sponsored collaboration among more than 110 individuals from 35 organizations.

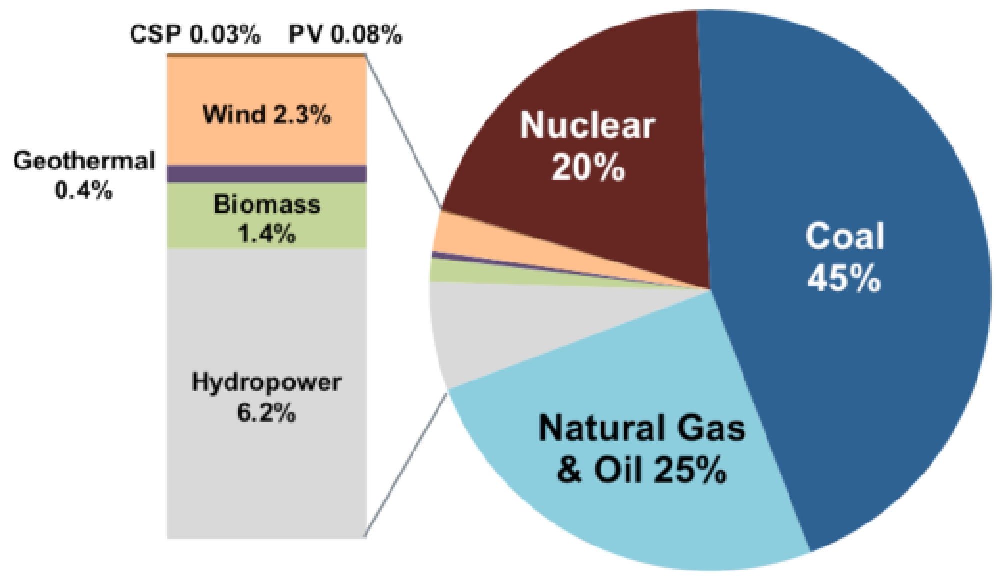
Renewable Electricity Futures Motivation

RE Capacity Growth 2000-2010



Source: RE Data Book (DOE 2011)

2010 Electricity Generation Mix



Source: RE Data Book (DOE 2011)

- RE 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

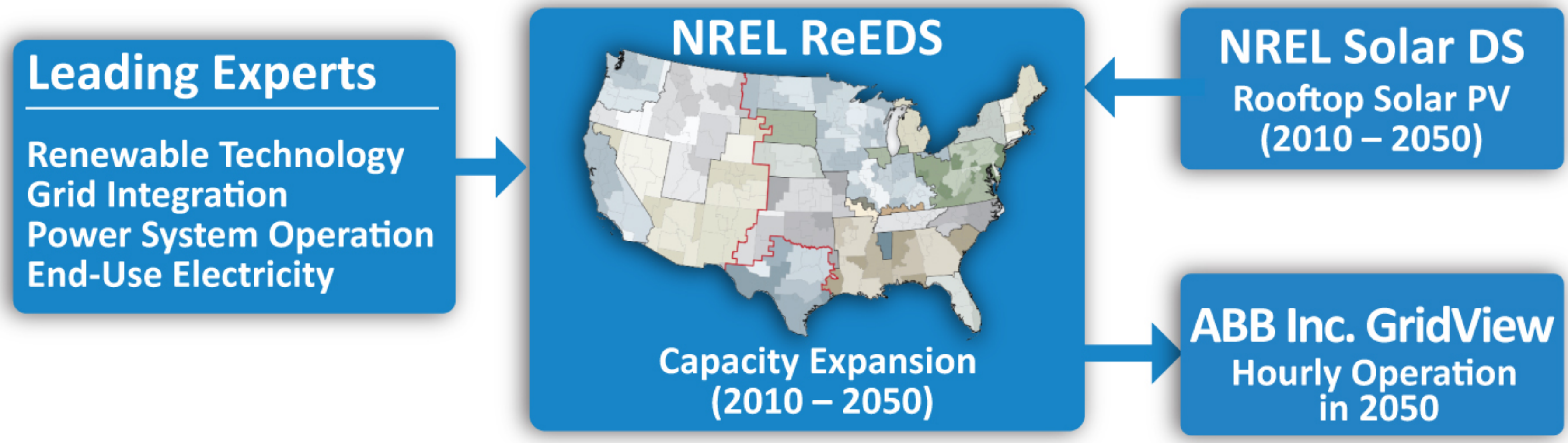
Volume 1	Exploration of High-Penetration Renewable Electricity Futures
Volume 2	Renewable Electricity Generation and Storage Technologies
Volume 3	End-Use Electricity Demand
Volume 4	Bulk Electric Power Systems: Operations and Transmission Planning

REF 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.

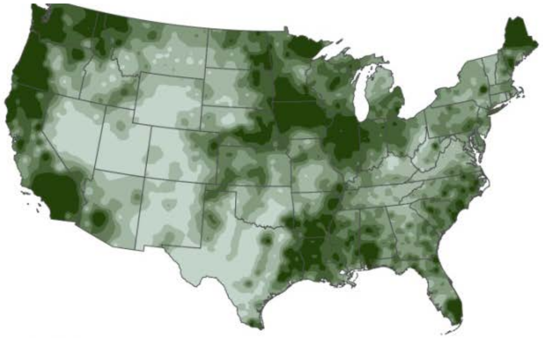
State of the Art Electric System Models

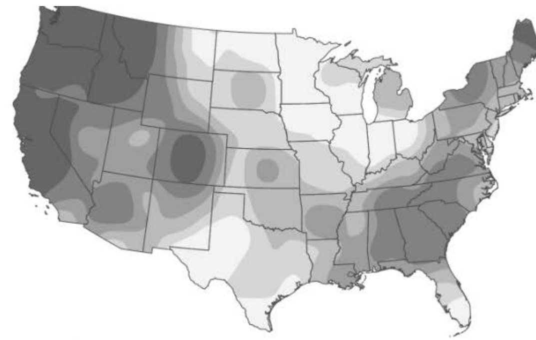


- Unprecedented geographic and time resolution for the contiguous United States
- More than two dozen scenarios of U.S. electric sector focused on 2050.

Abundant Renewable Energy Resources

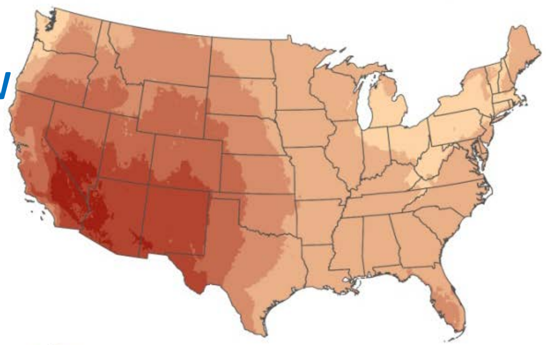
Biopower ~100 GW
- Stand-alone
- Cofired with coal

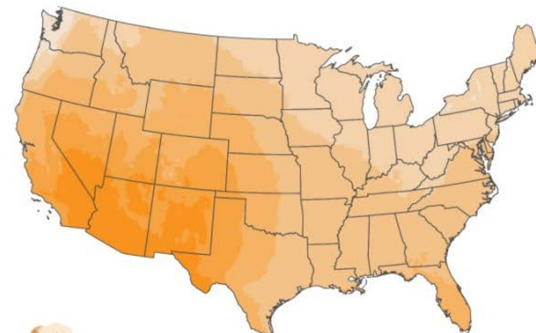




Hydropower ~200 GW
- Run-of-river

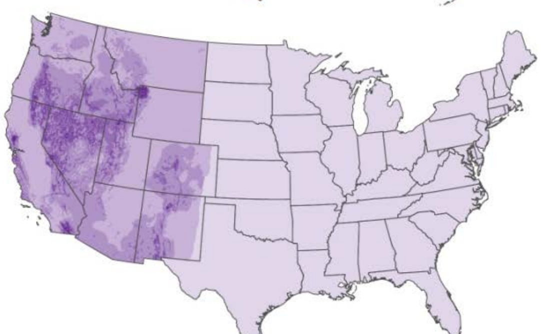
Solar CSP ~37,000 GW
- Trough ⎤ With thermal
- Tower ⎦ storage

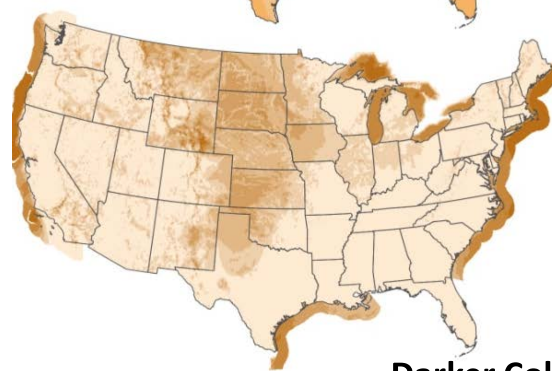




Solar PV ~80,000 GW (rooftop PV ~700 GW)
- Residential
- Commercial
- Utility-scale

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.

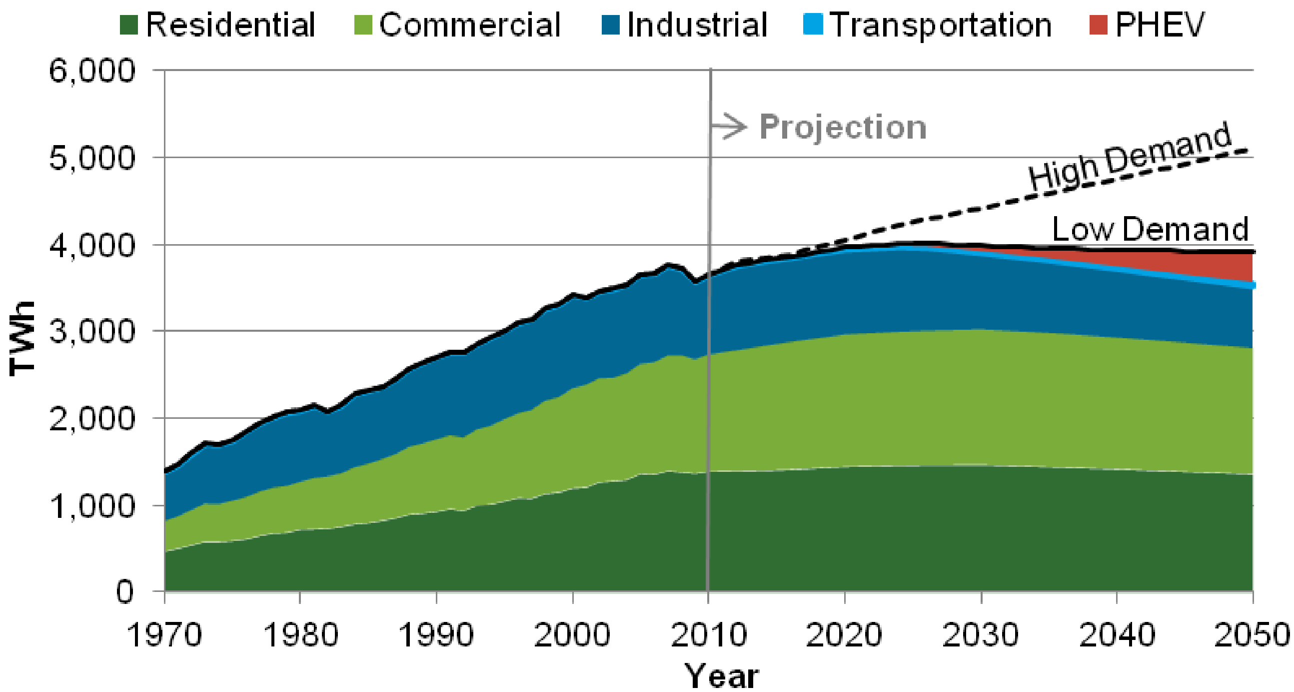
RE Options Have A Wide Range of Characteristics

Technology	Variability Time Scale	Dispatchability	Geographic Diversity Potential	Predictability	Capacity Value Range (%)
Bioenergy	Seasons	+++	+	++	Similar to thermal
PV	Minutes to years	+	++	+	<25–75
CSP (with thermal storage)	Hours to years	++	+	++	90
Geothermal (Hydrothermal)	Years	+++	NA	++	Similar to thermal
Hydropower (run of river)	Hours to years	++	+	++	0–90
Hydropower (reservoir)	Days to years	+++	+	++	Similar to thermal
Wind	Minutes to years	+	++	+	5–40

IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (2011)

- **Some options are dispatchable like conventional fossil plants (e.g., geothermal, bioenergy).**
- **Others show variability and uncertainty (e.g., wind, PV).**
- **Most are widely distributed geographically (except geothermal hydrothermal).**

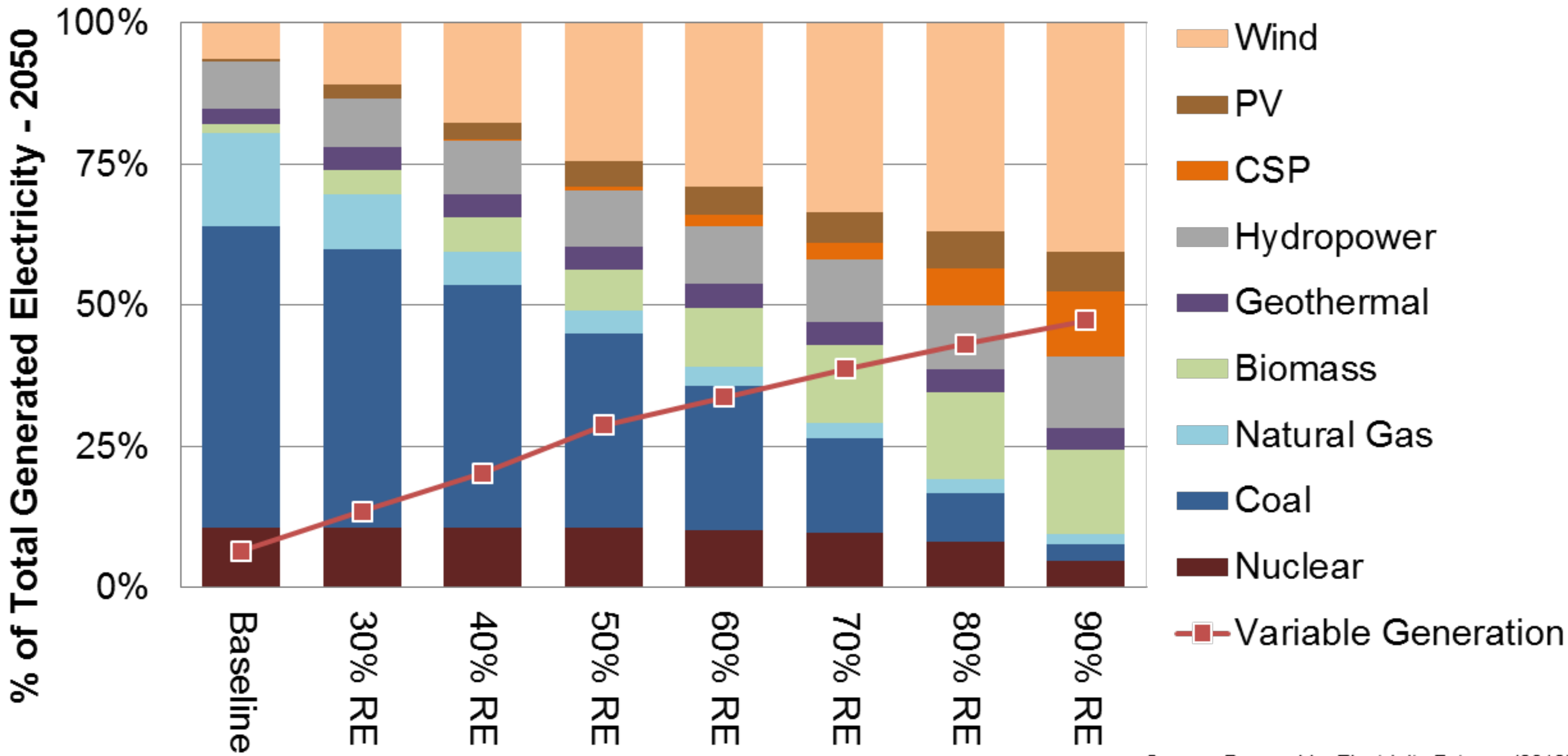
Historical and Projected Demand



Sector	High-Demand Projection	Low-Demand Projection
Residential	2% decline in intensity over 2010 levels	30% decline in intensity over 2010 levels
Commercial	5% increase in intensity over 2010 levels	32% decline in intensity over 2010 levels
Industrial	35% decline in intensity over 2010 levels	50% decline in intensity over 2010 levels
Transportation	<3% PHEV penetration	40% of vehicle sales are PEVs

Key Results

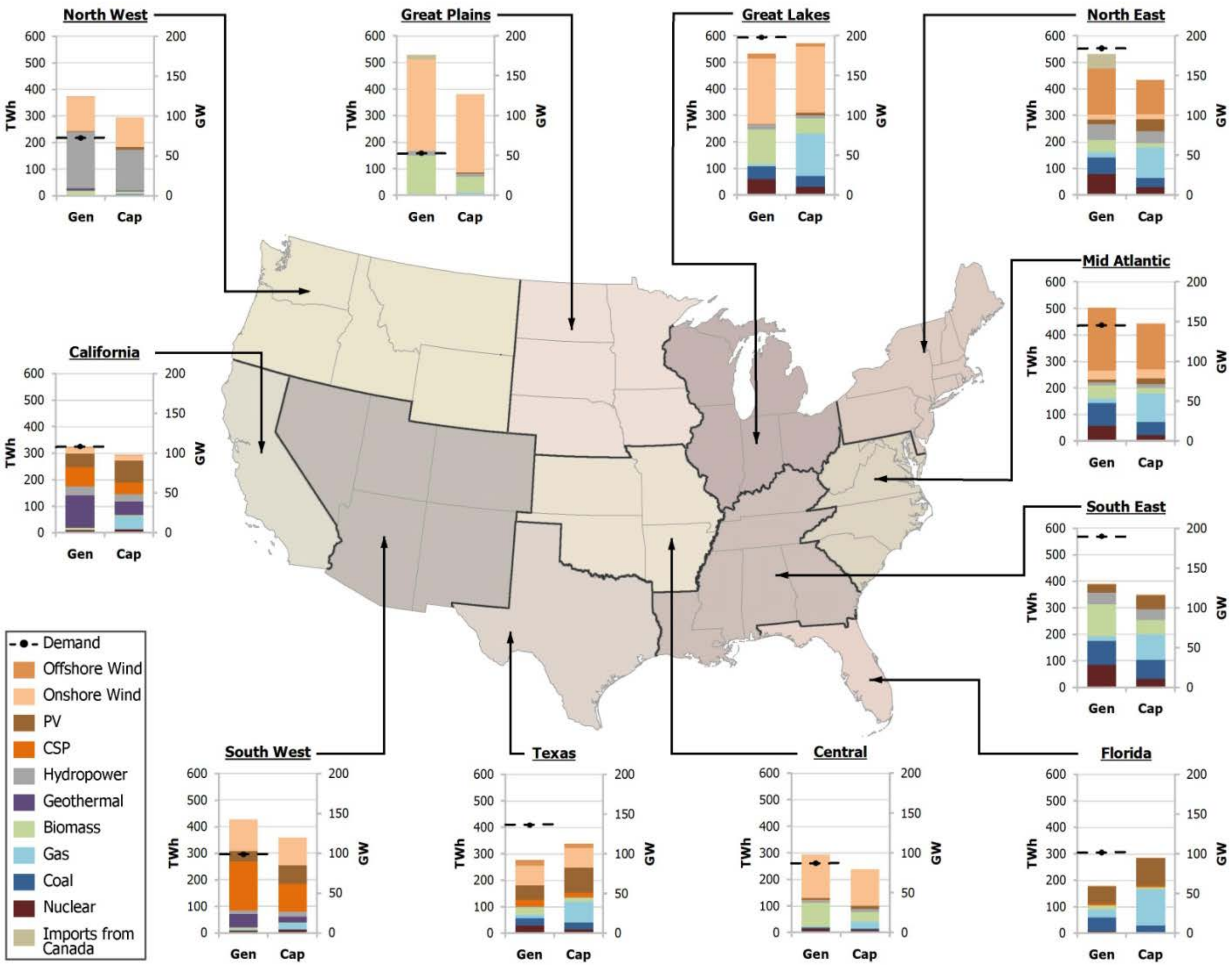
RE Resource Supply from 30% - 90% Electricity



Source: Renewable Electricity Futures (2012)

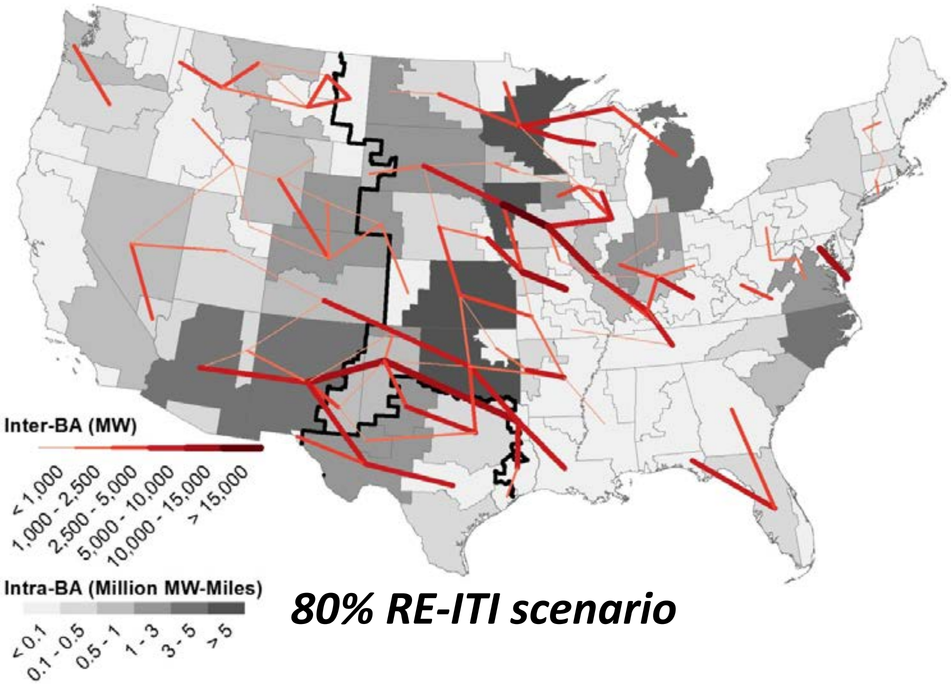
Additional variability challenges system operations, but can be addressed through increased use of supply- and demand-side flexibility options and new transmission.

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



80% RE-ITI scenario

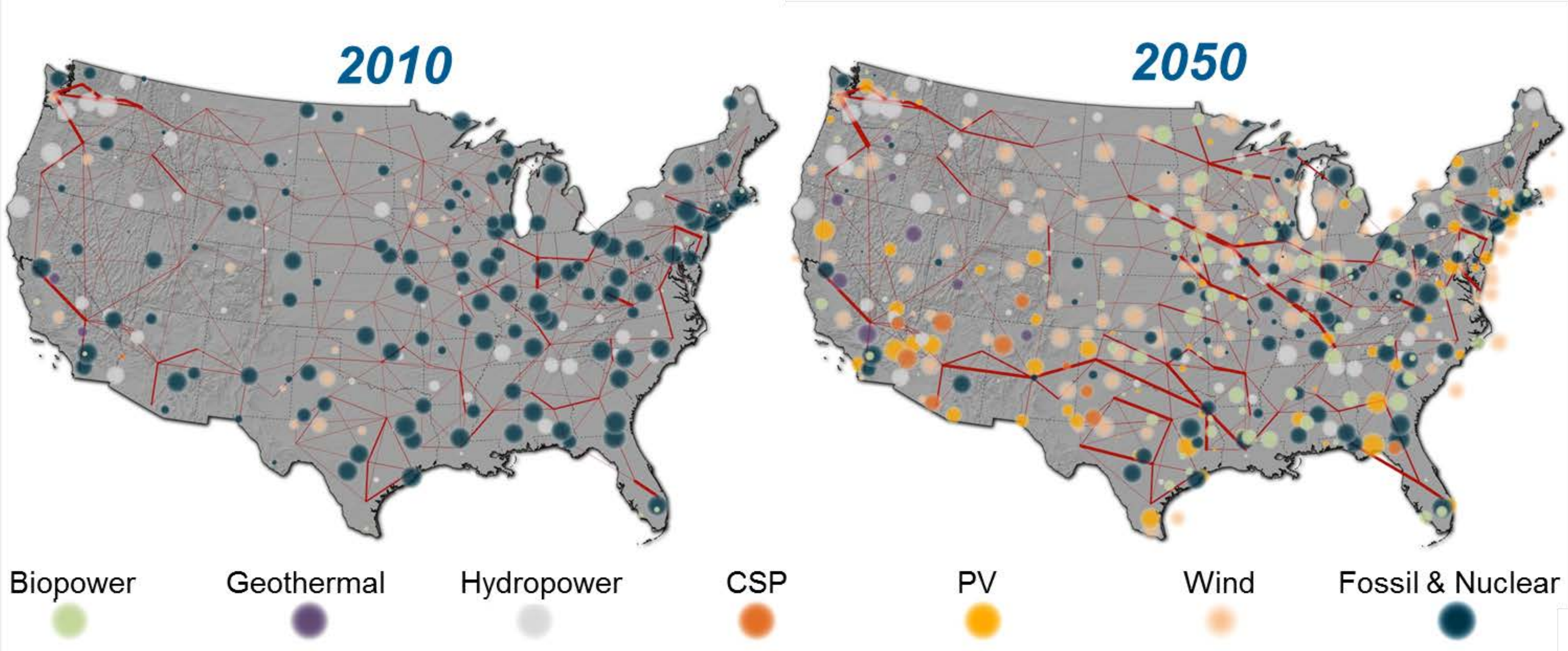
As RE deployment increases, additional transmission infrastructure is required



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 to allow greater power transfer between asynchronous interconnects.**
- **However, 80% RE is achievable even when transmission is severely constrained (30 million MW-miles)—which leads to a greater reliance on local resources (e.g. PV, offshore wind).**
- **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.**

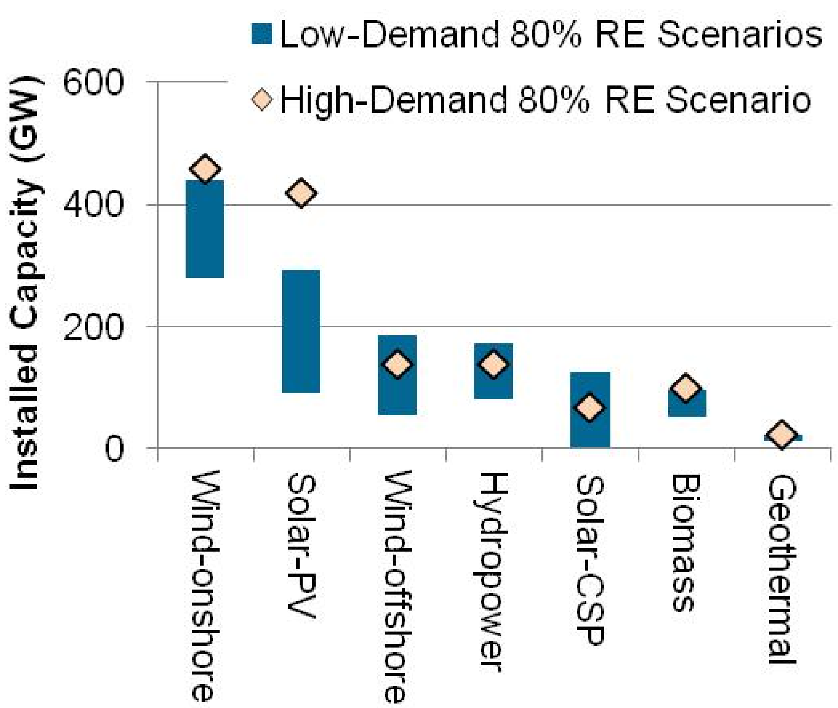
A Transformation of the U.S. Electricity System

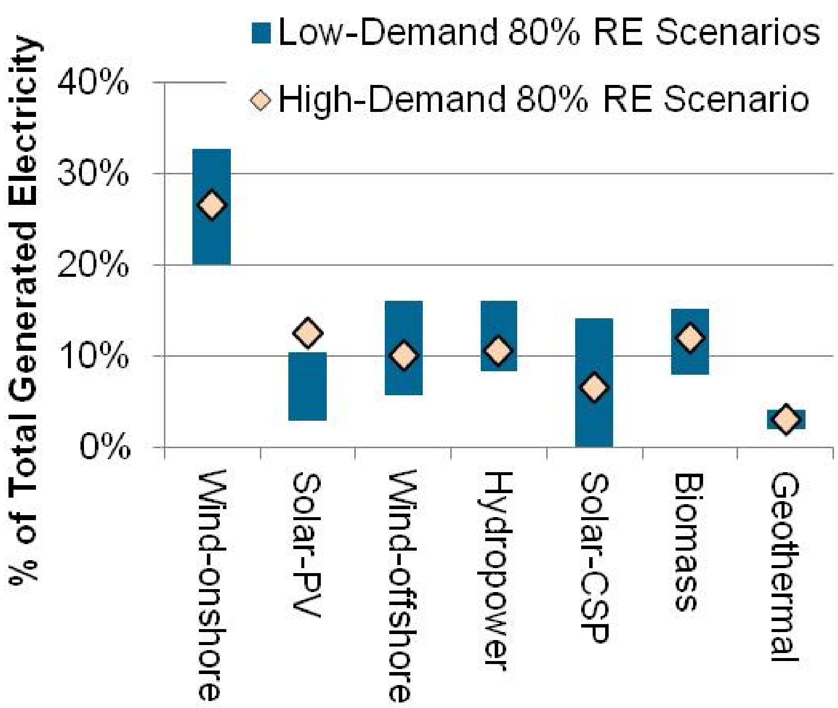


Source: Renewable Electricity Futures (2012)

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



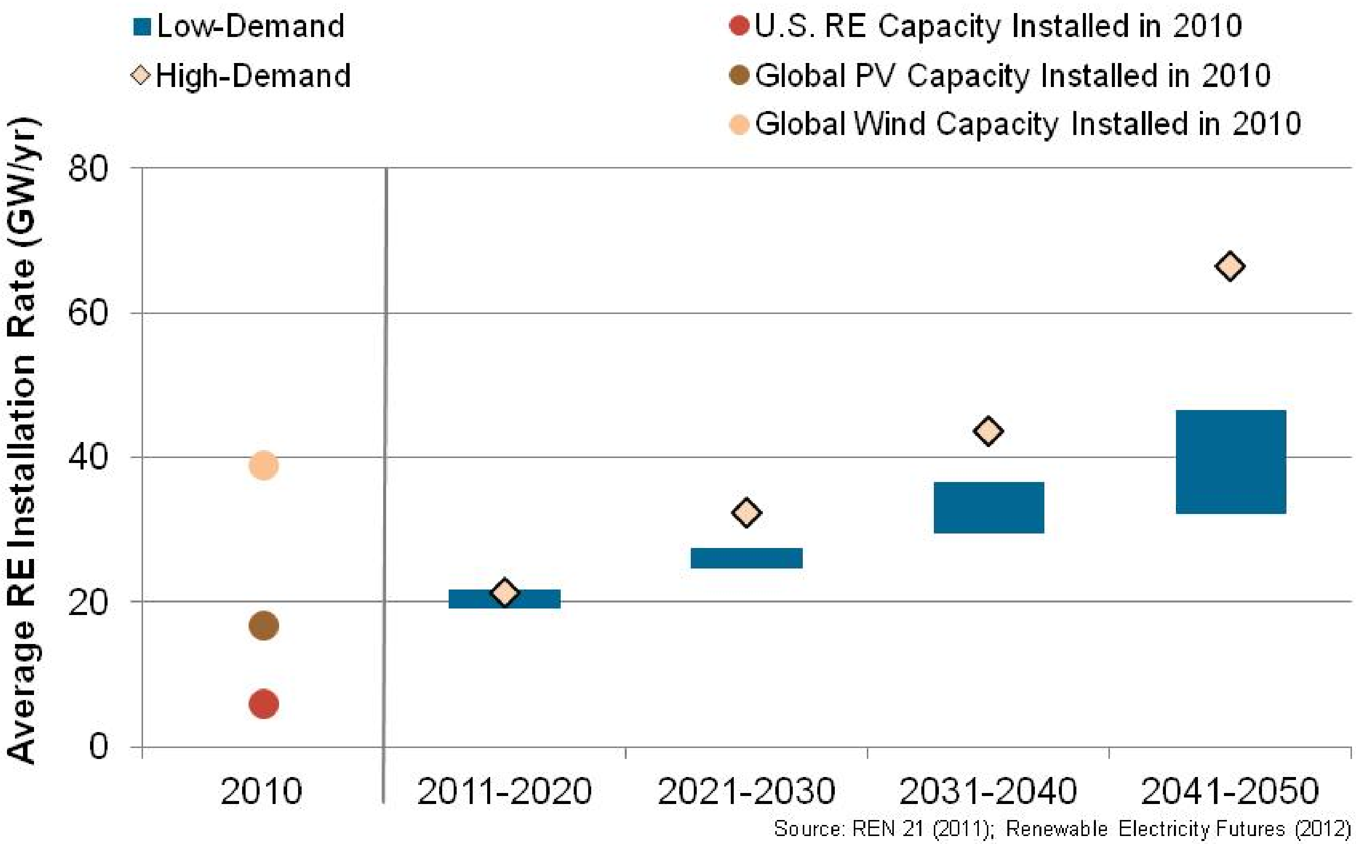


Source: Renewable Electricity Futures (2012)

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

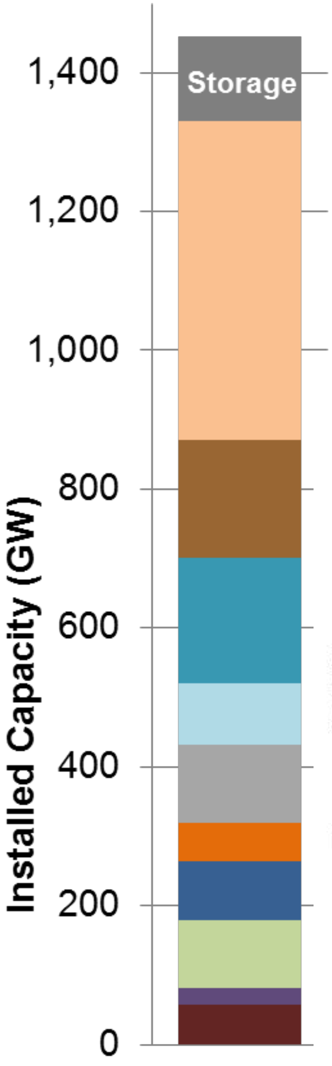
- **Future RE technology cost and performance**
- **Electricity demand growth**
- **Presence of constraints that limit new transmission infrastructure, grid flexibility, or the accessibility of renewable resources.**

Significant Long-Term RE Industry Growth

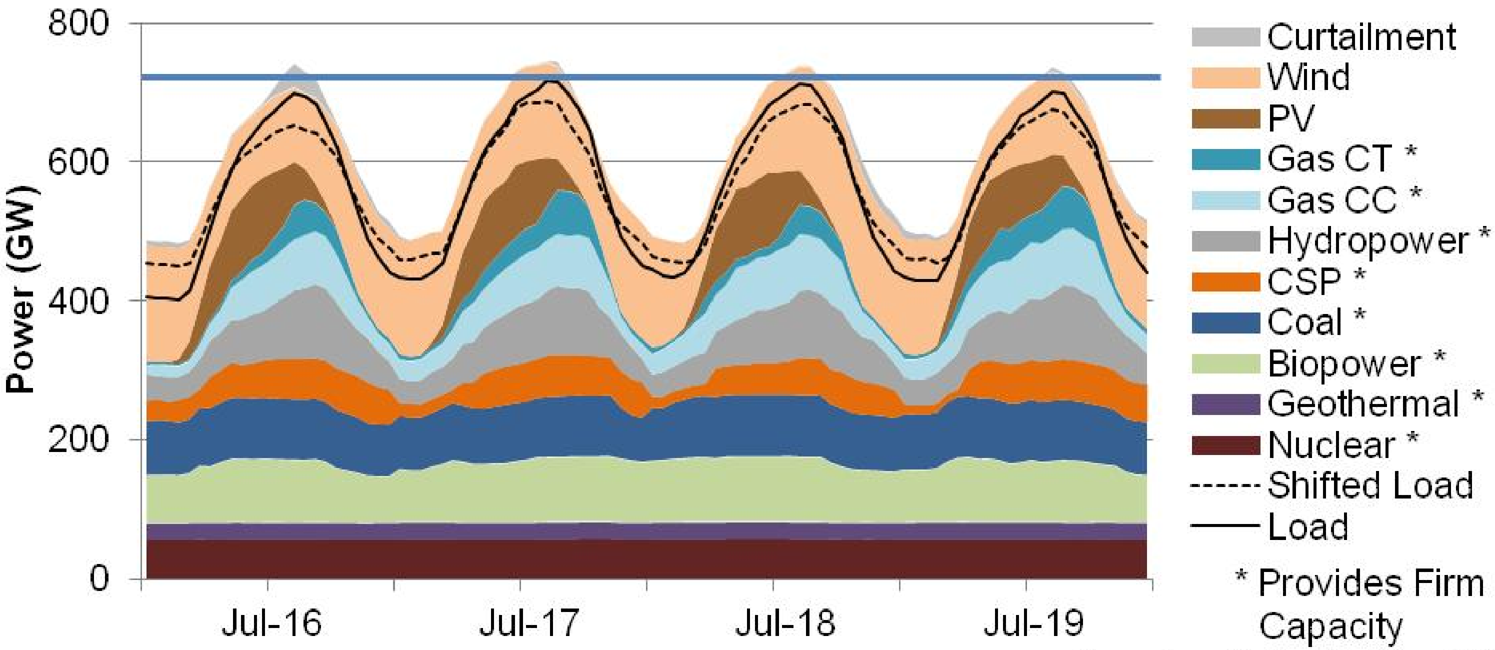


No insurmountable long-term constraints to RE technology manufacturing capacity, materials supply, or labor availability were identified.

Supply and Demand Balanced Every Hour of the Year



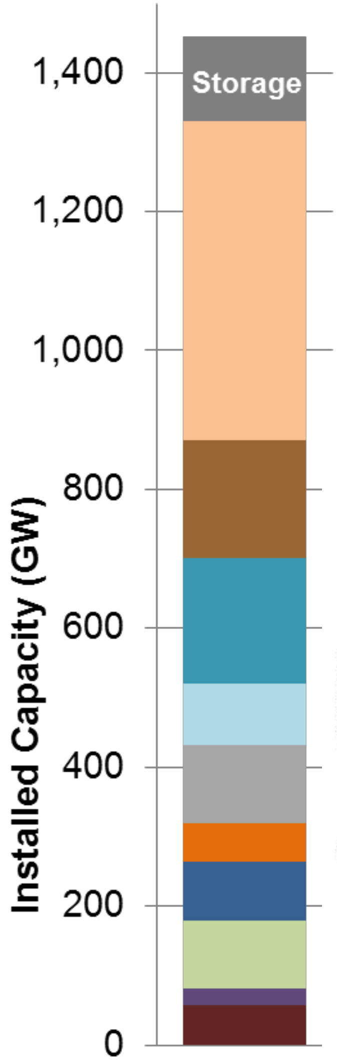
Installed capacity is sufficient to meet summer afternoon peak demand from diverse reserves supplying firm capacity.

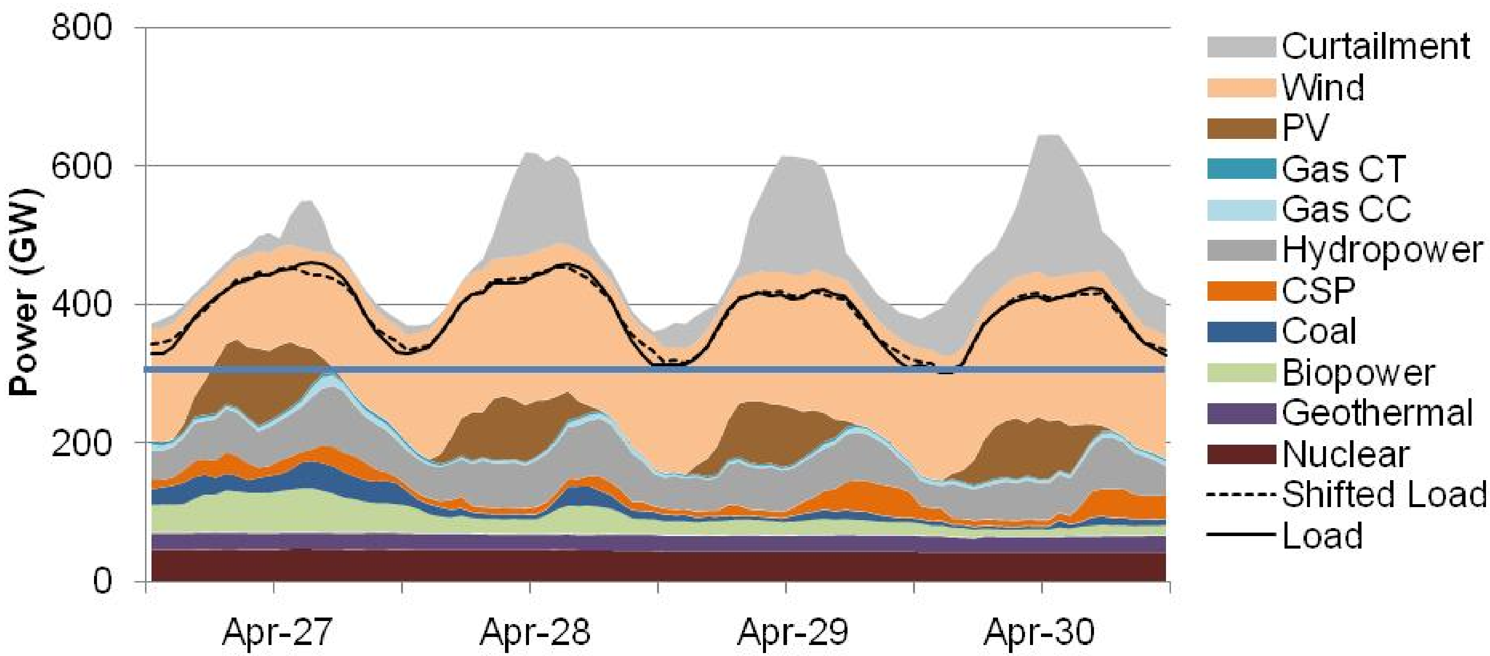


Source: Renewable Electricity Futures (2012)

Flexible Electricity System Manages Variability

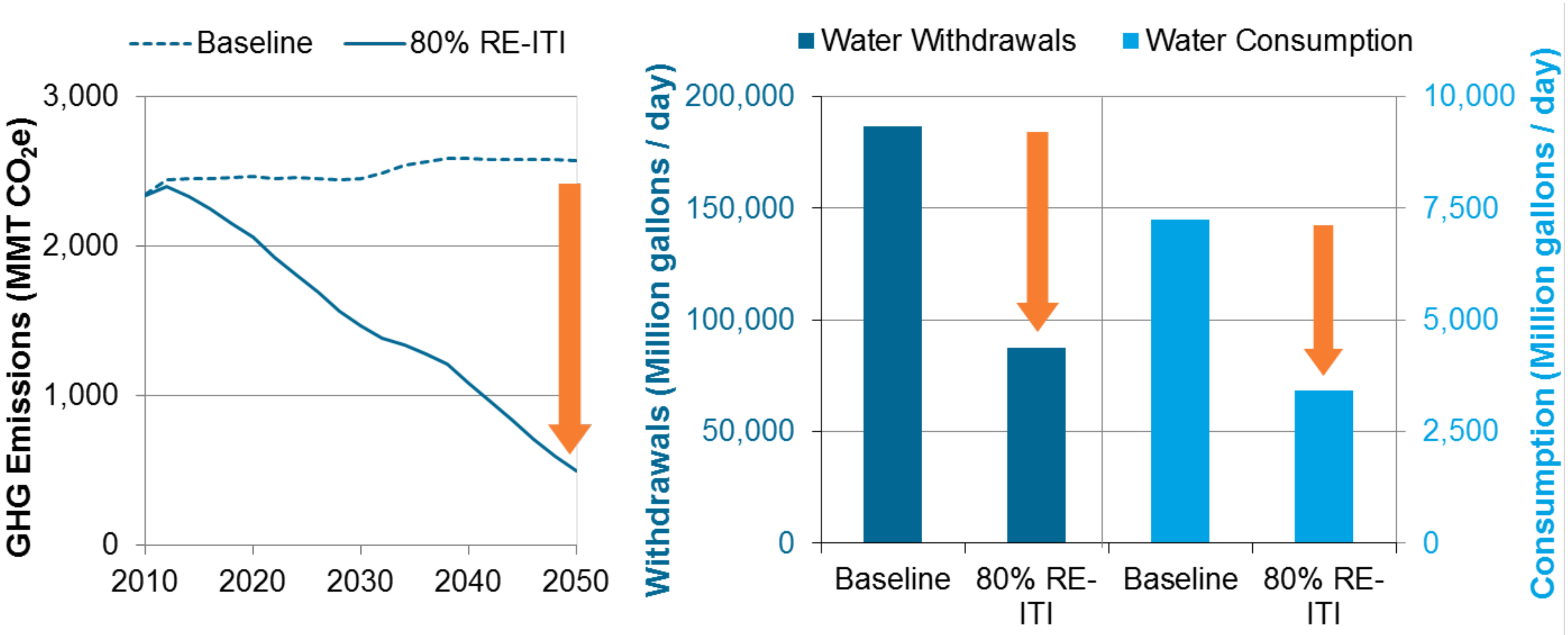
Especially during low-demand periods in the spring months, flexibility options include flexible generators, flexible load, new transmission, and wide area coordination.





Source: Renewable Electricity Futures (2012)

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.**

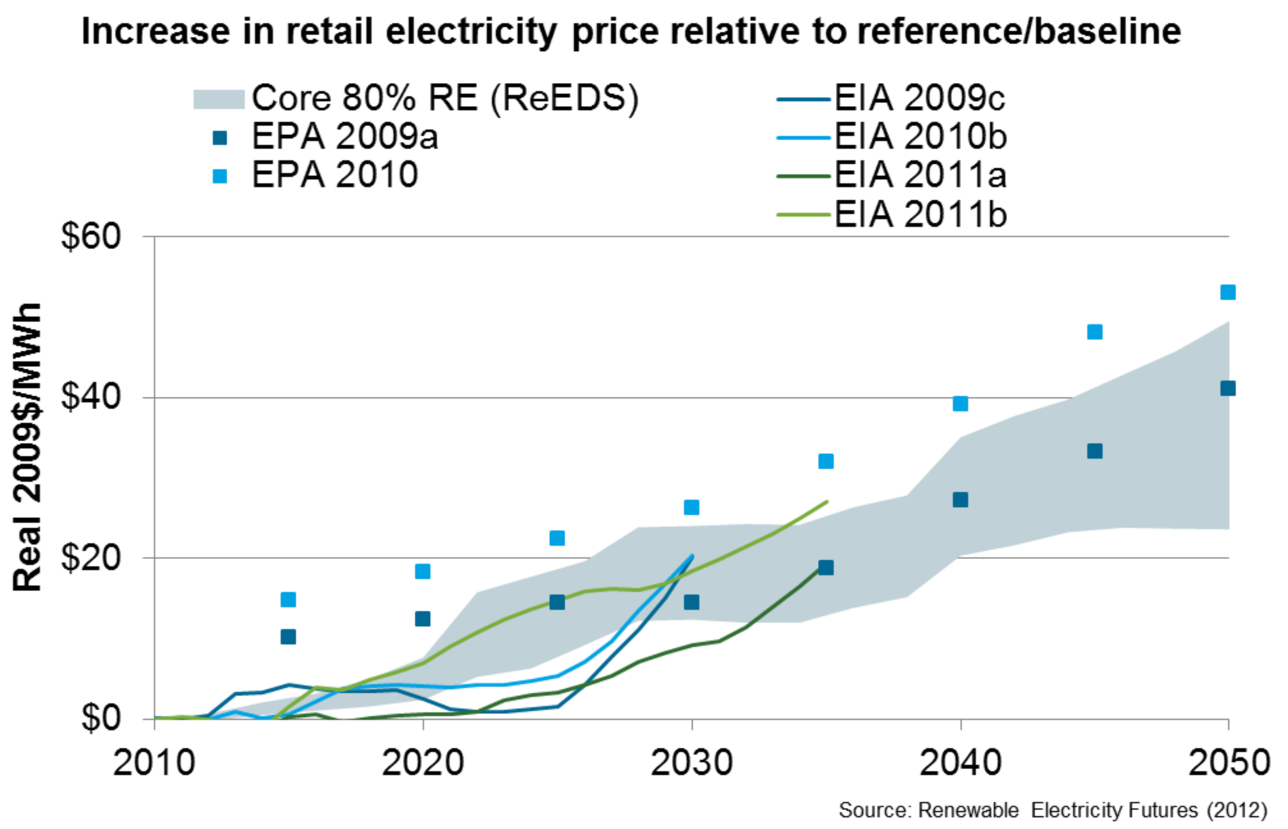
80% RE scenarios

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**

RE Futures Cost Comparisons



- **The estimated 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

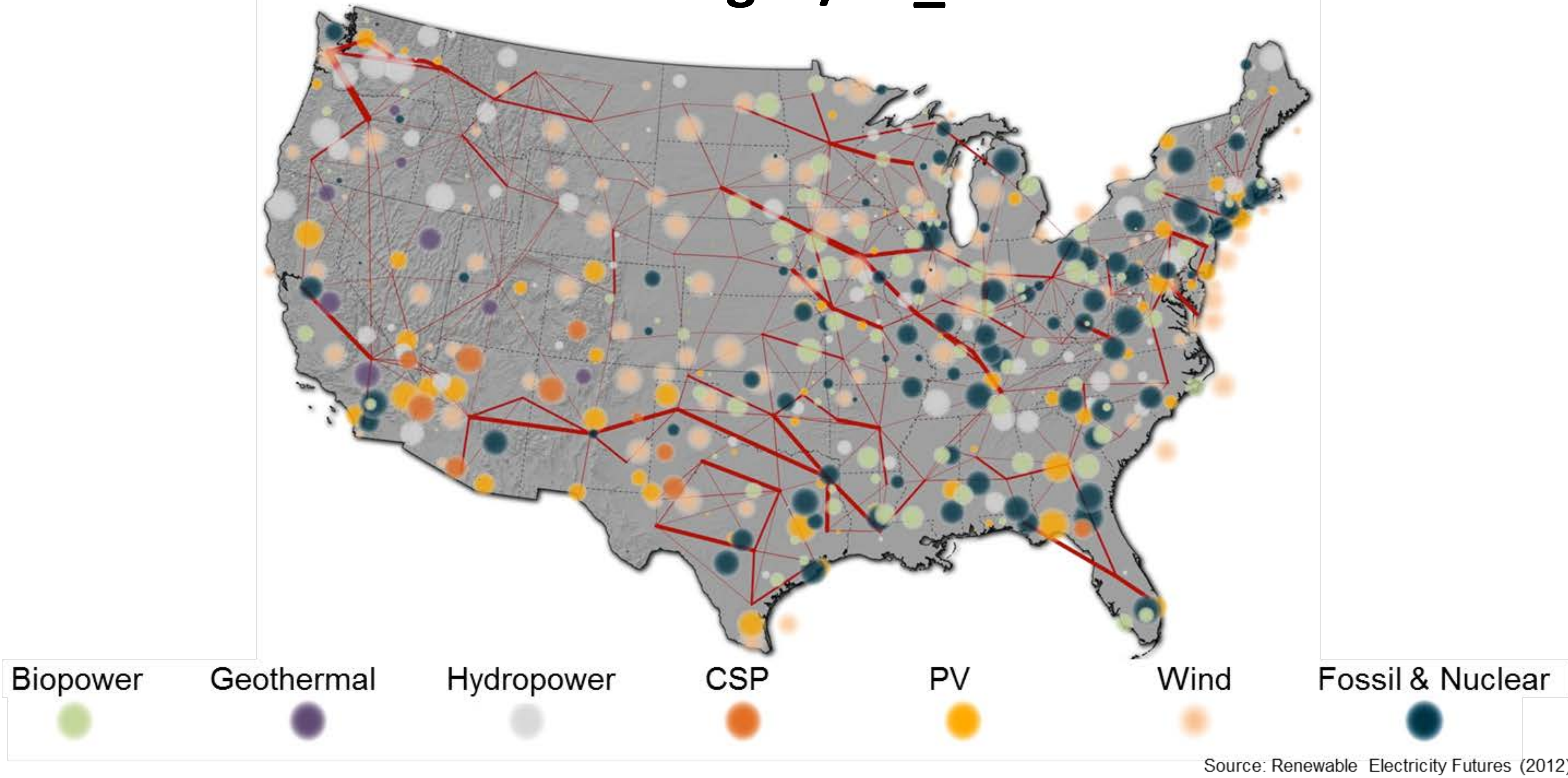
- Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050–while meeting electricity demand on an hourly basis in every region of the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



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.