NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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.

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

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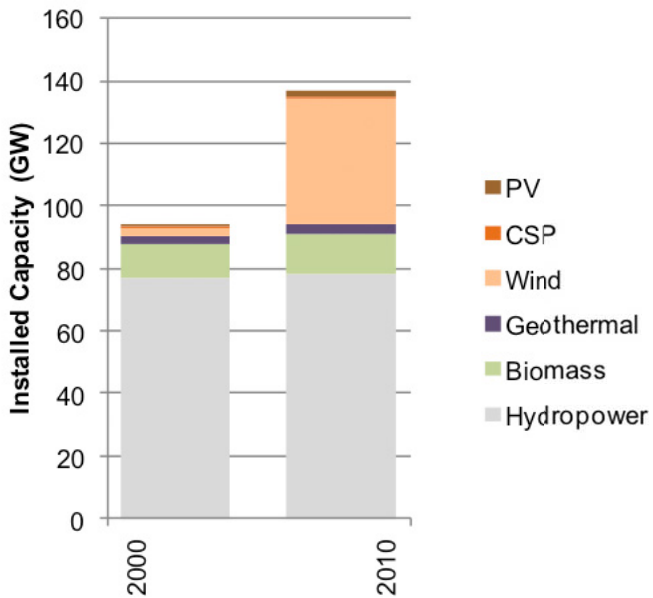
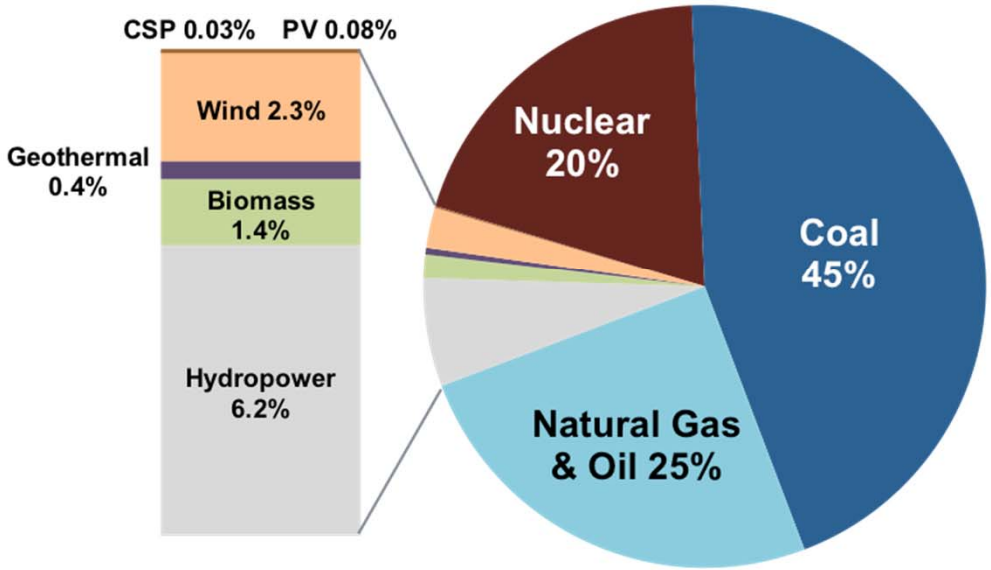
Renewable Electricity Futures Motivation

RE Capacity Growth 2000-2010



Source: RE Data Book (DOE 2011)

2010 Electricity Generation Mix



Source: Renewable Electricity Futures (2012)

- **RE 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

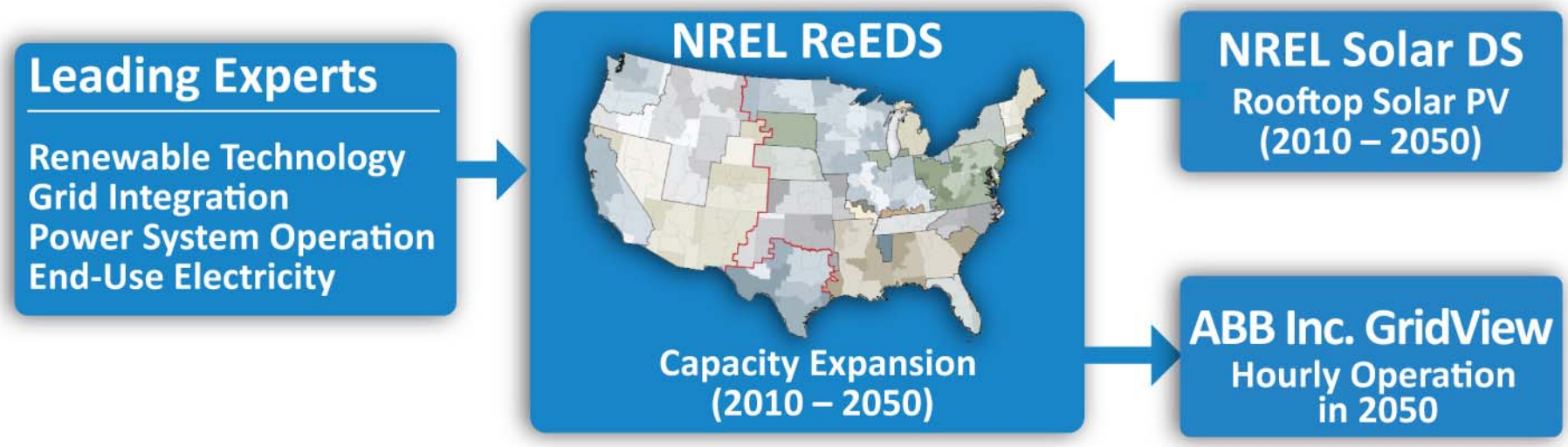
Volume 1	Exploration of High-Penetration Renewable Electricity Futures
Volume 2	Renewable Electricity Generation and Storage Technologies
Volume 3	End-Use Electricity Demand
Volume 4	Bulk Electric Power Systems: Operations and Transmission Planning

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.

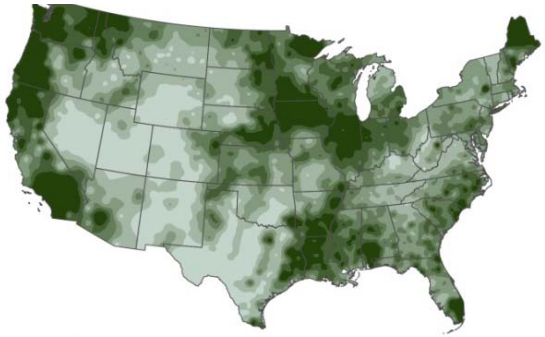
State of the Art Electric System Models

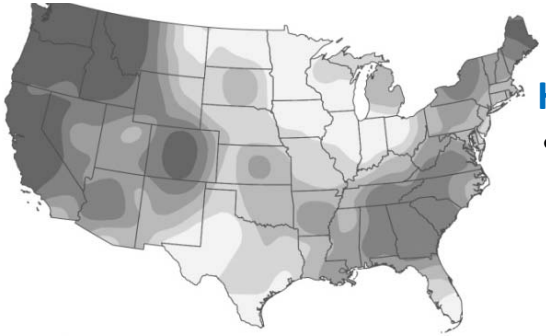


- **Unprecedented <u>geographic</u> and <u>time resolution</u> for the <u>contiguous</u> United States**
- **More than two dozen scenarios of U.S. electric sector focused on 2050.**

Abundant Renewable Energy Resources

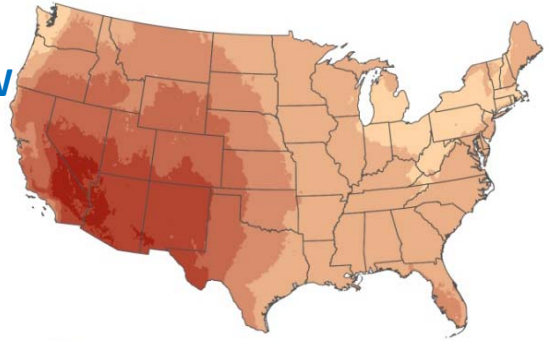
Biopower ~100 GW
- Stand-alone
- Cofired with coal

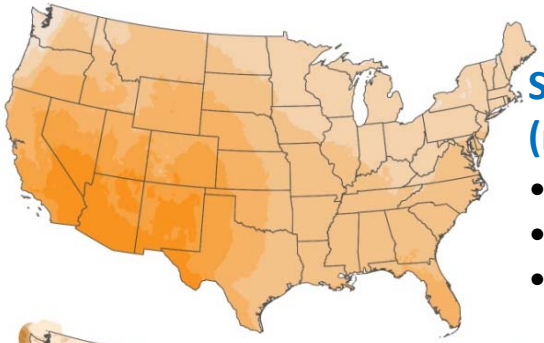




Hydropower ~200 GW
- Run-of-river

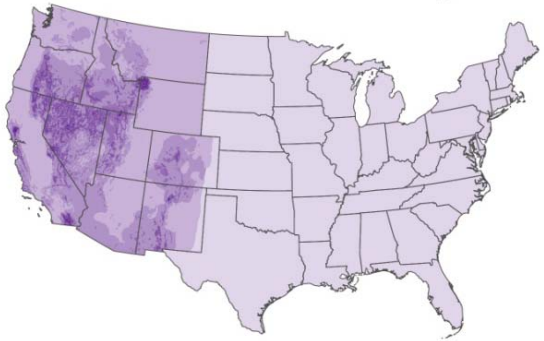
Solar CSP ~37,000 GW
- Trough } With thermal storage
- Tower } With thermal storage

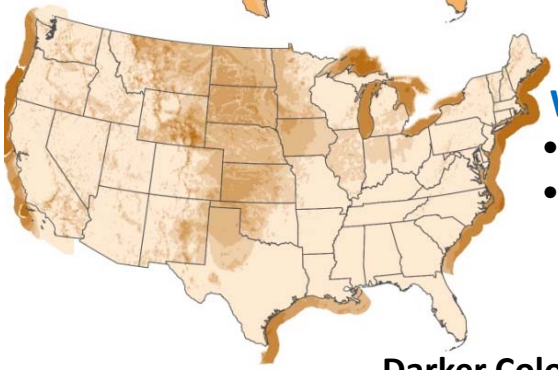




Solar PV ~80,000 GW (rooftop PV ~700 GW)
- Residential
- Commercial
- Utility-scale

Geothermal ~36 GW
- Hydrothermal



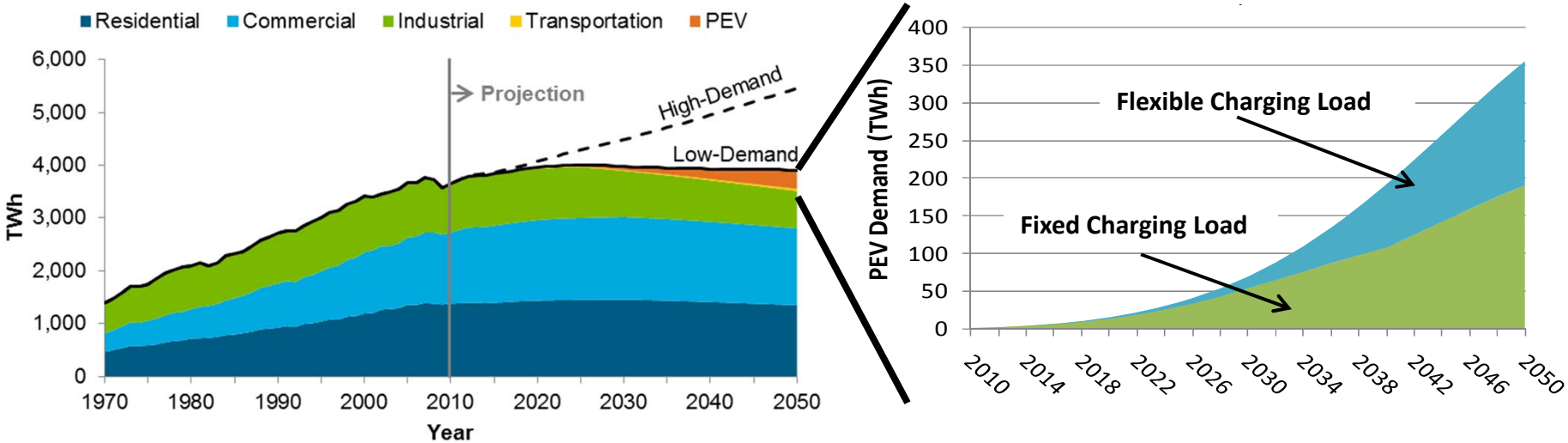


Wind ~10,000 GW
- Onshore
- Offshore fixed-bottom

Darker Colors = Higher Resource

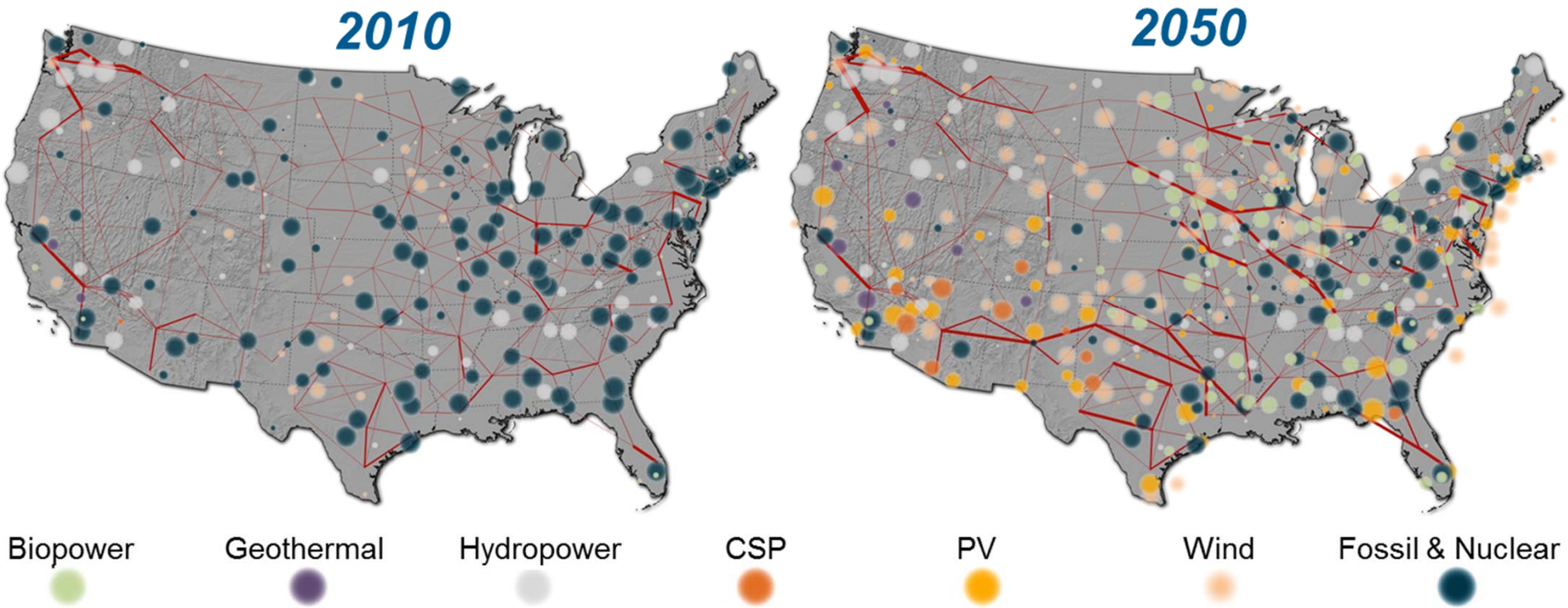
Geographic location, technical resource potential, and output characteristics are unique to each RE generation technology.

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.

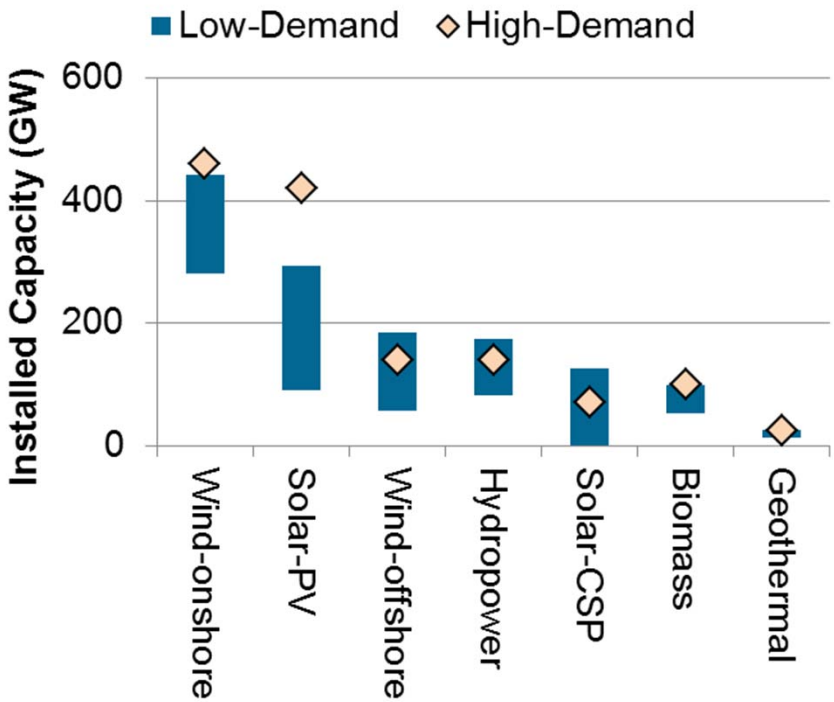
A Transformation of the U.S. Electricity System

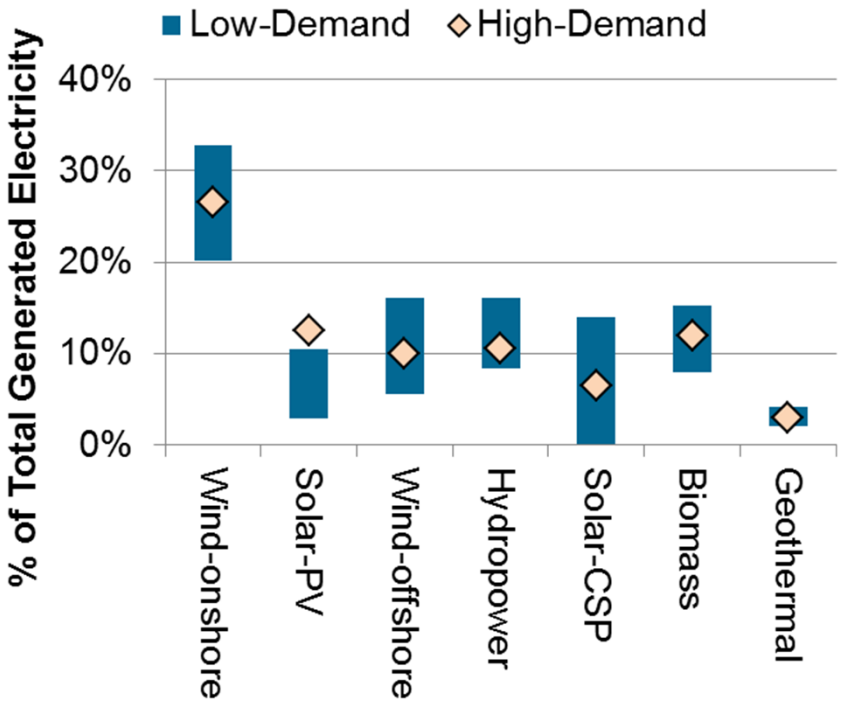


Source: Renewable Electricity Futures (2012)

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



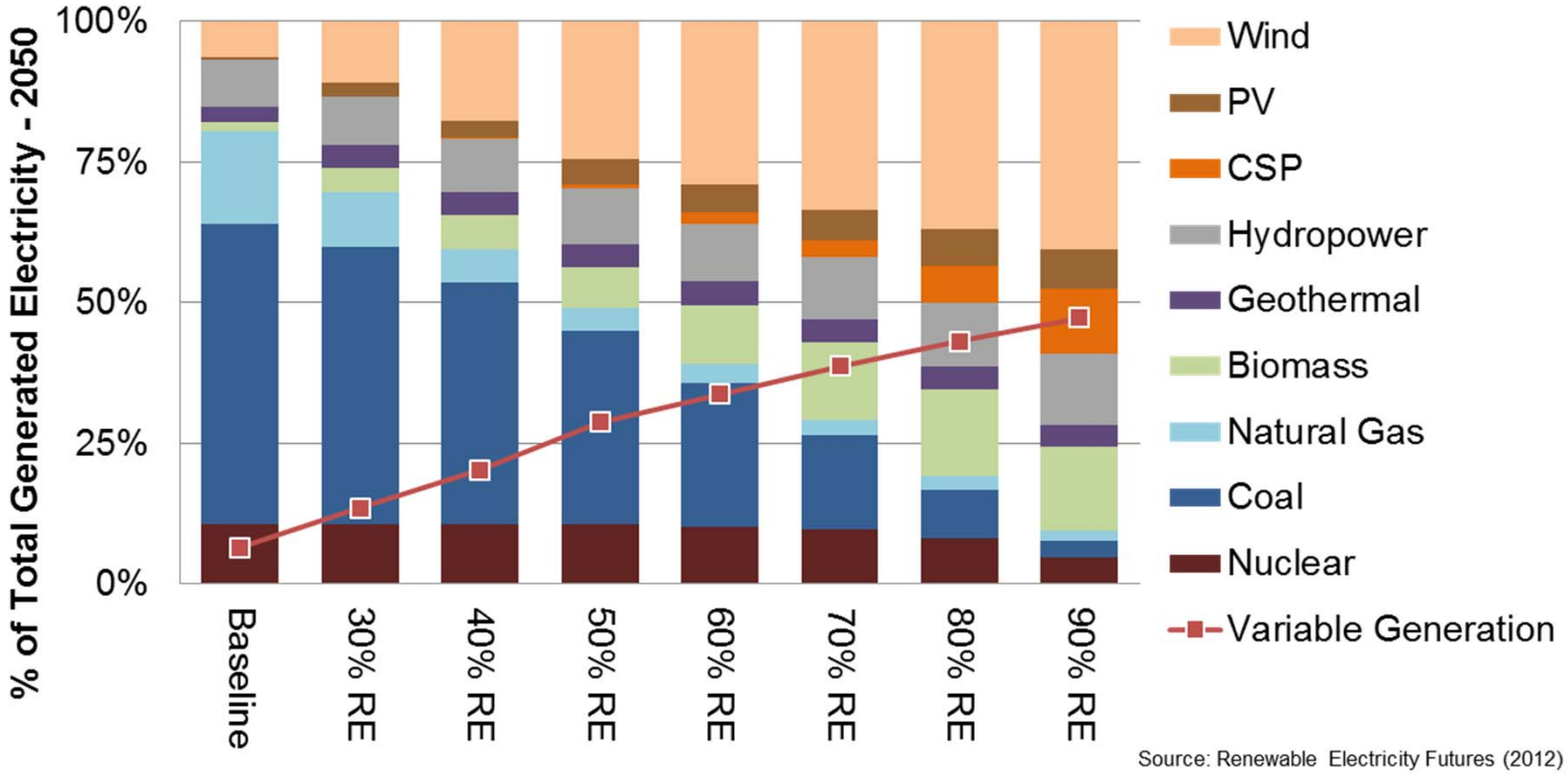


Source: Renewable Electricity Futures (2012)

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.**

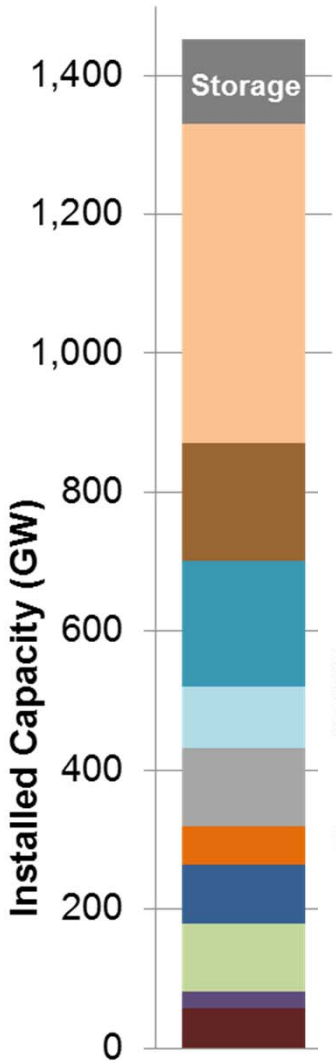
RE Resource Supply from 30% - 90% Electricity

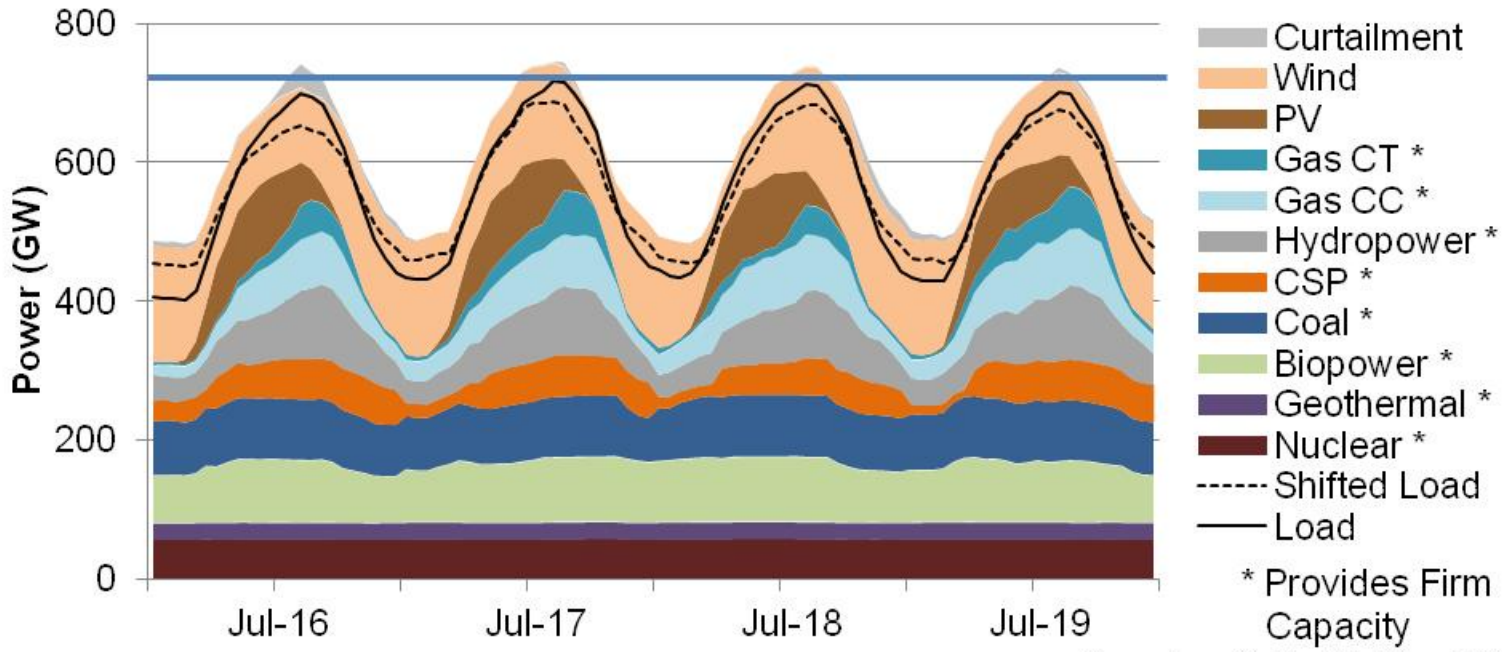


Additional variability challenges system operations, but can be addressed through increased use of supply- and demand-side flexibility options and new transmission.

Supply and Demand Balanced Every Hour of the Year

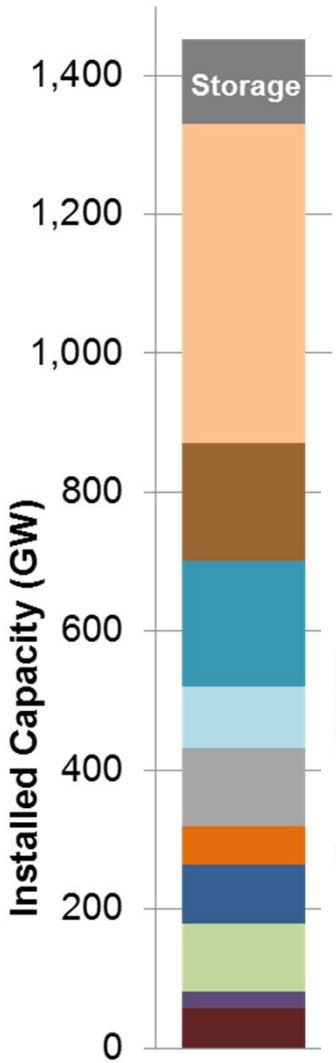
Installed capacity is sufficient to meet summer afternoon peak demand from diverse reserves supplying firm capacity.



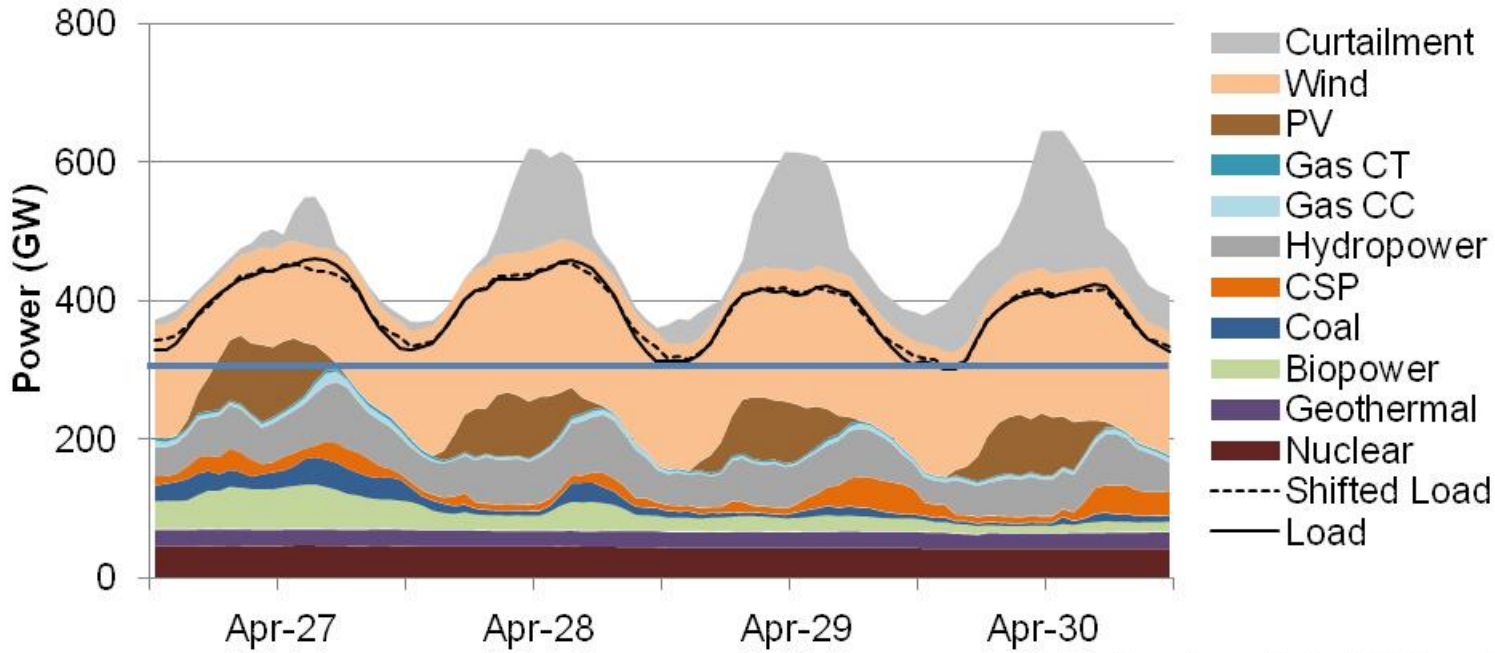


Source: Renewable Electricity Futures (2012)

Flexible Electricity System Manages Variability

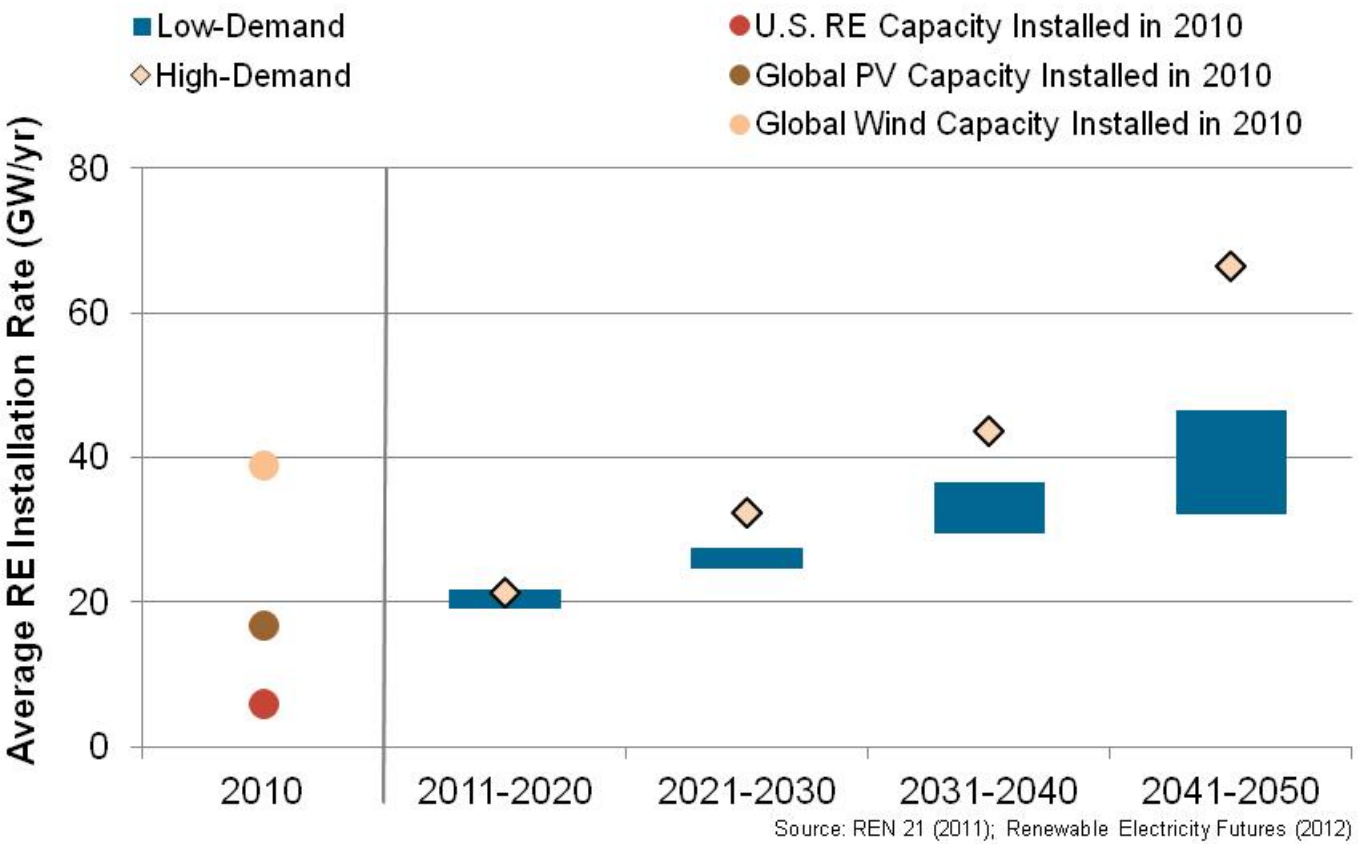


Especially during low-demand periods in the spring months, flexibility options include flexible generators, flexible load, new transmission, and wide area coordination.



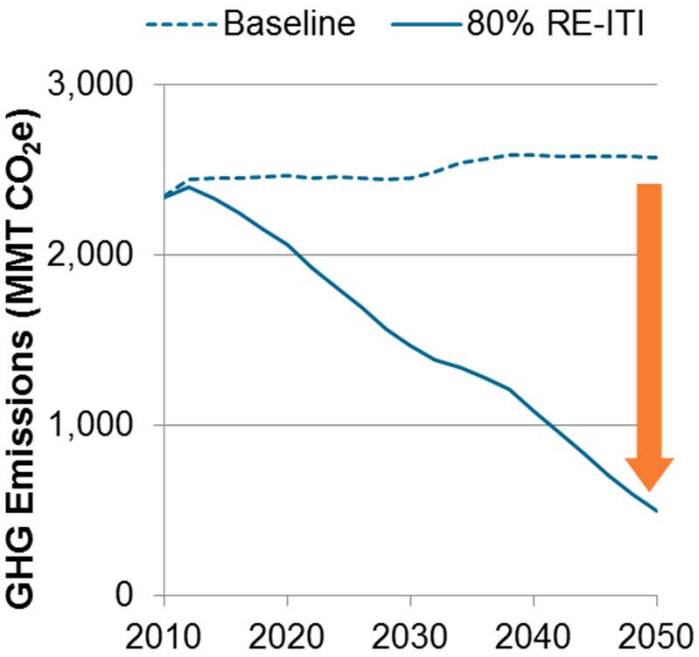
Source: Renewable Electricity Futures (2012)

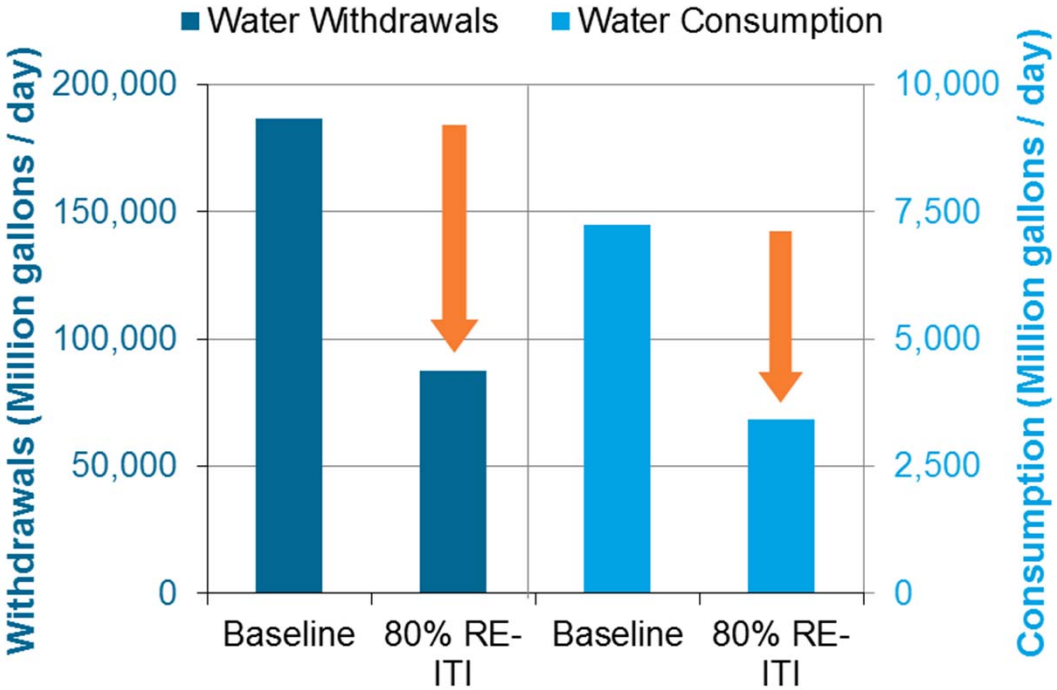
Significant Long-Term RE Industry Growth



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.**

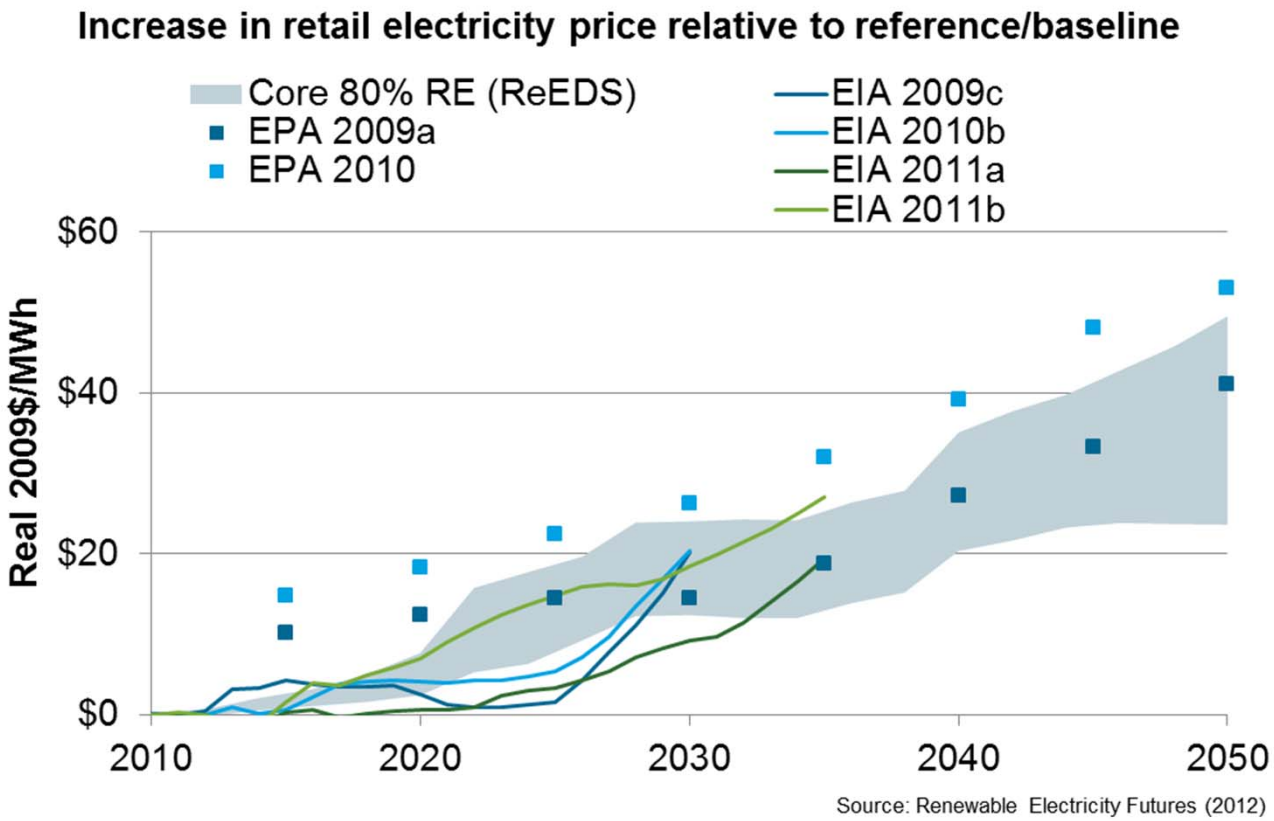
Gross Land Use Comparisons (000 km^2)	
Biomass	44-88
All Other RE	52-81
All Other RE (disrupted)	4-10
Transmission & Storage	3-19
Total Contiguous U.S.	7,700
2009 Corn Production*	350
Major Roads**	50
Golf Courses **	10

80% RE scenarios

** 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 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

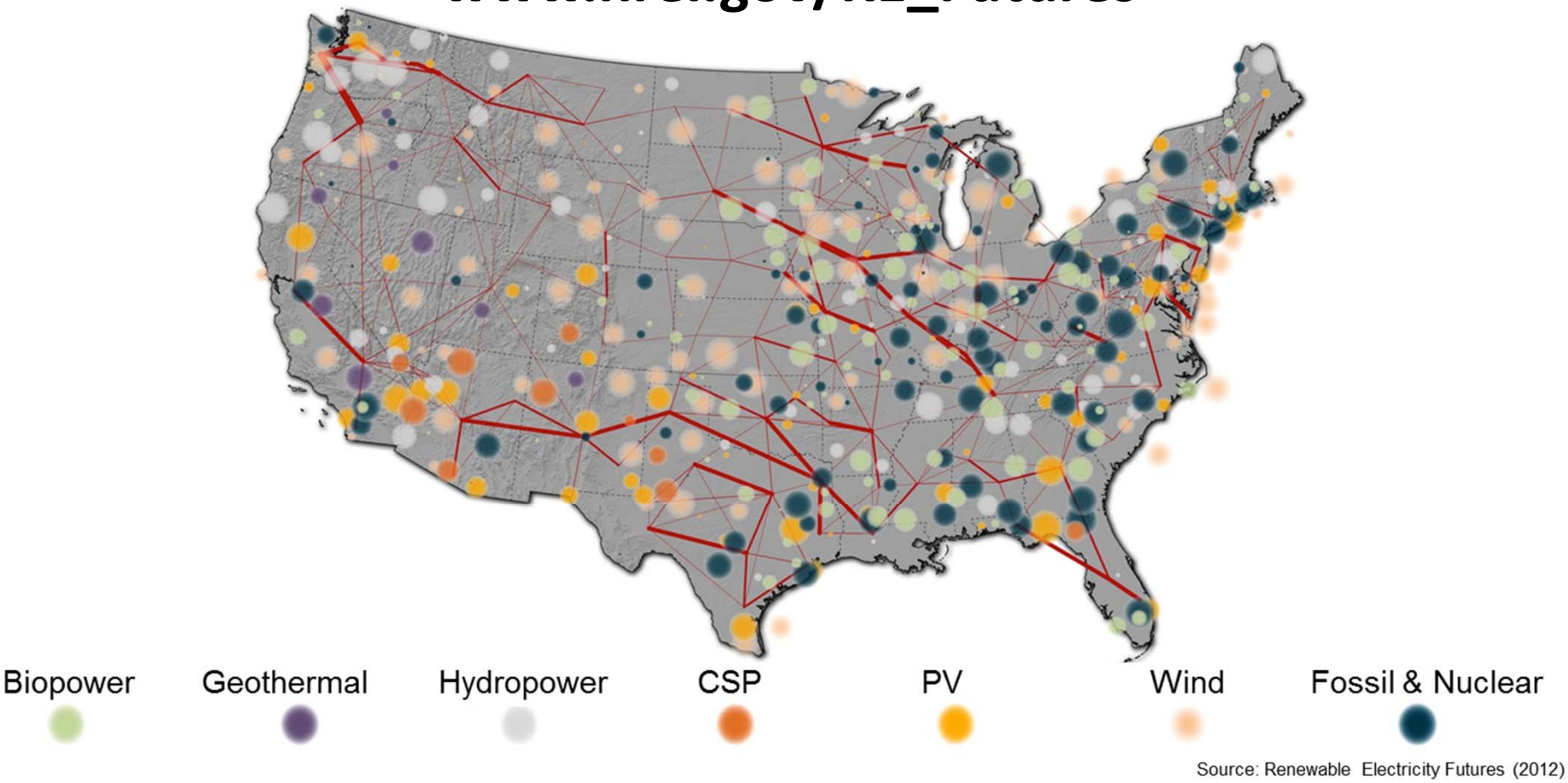
- **Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050–while meeting electricity demand on an hourly basis in every region of the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