RE Futures Modeling Framework

Only currently commercial technologies were modeled, with incremental and evolutionary improvements.

rooftop PV penetration

2050 mix of generators

does it balance hourly?

ITI Projection
(by Black & Veatch)

ETI Projections
(by Tech Teams)

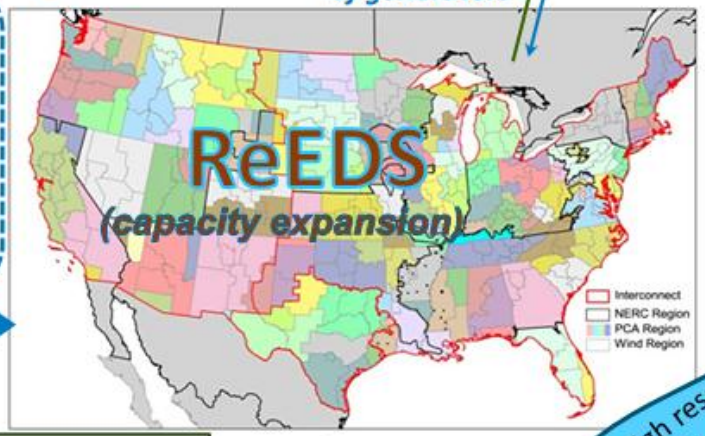
Flexible Resources

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**

Capacity & Generation 2010-2050

Implications
GHG Emissions
Water Use
Land Use
Direct Costs

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.; Brinkman, G.; 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.; et al. - A U.S. DOE sponsored collaboration among more than 110 individuals from about 35 organizations.

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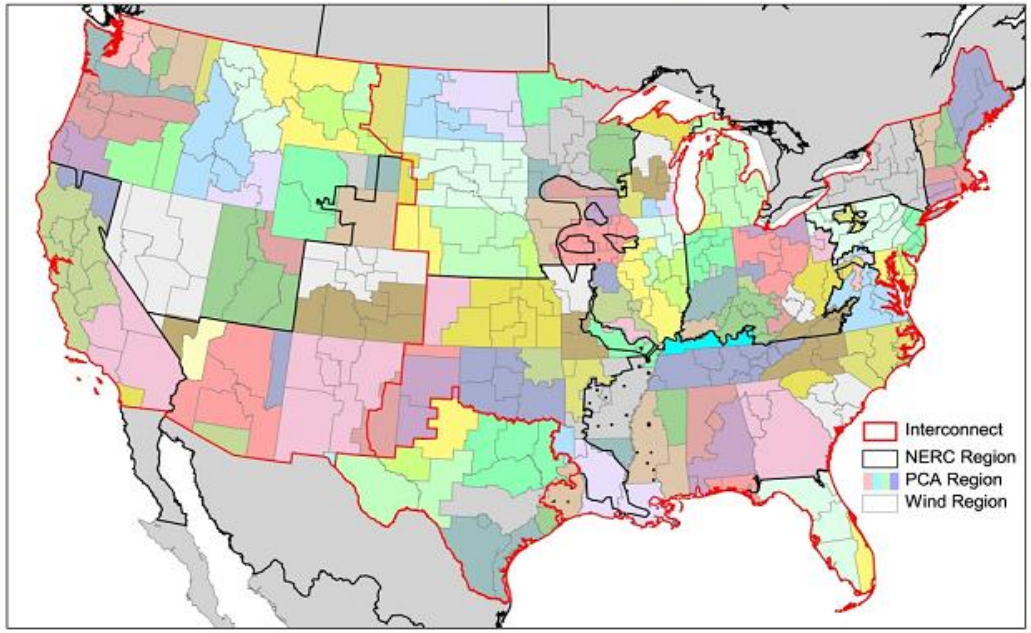
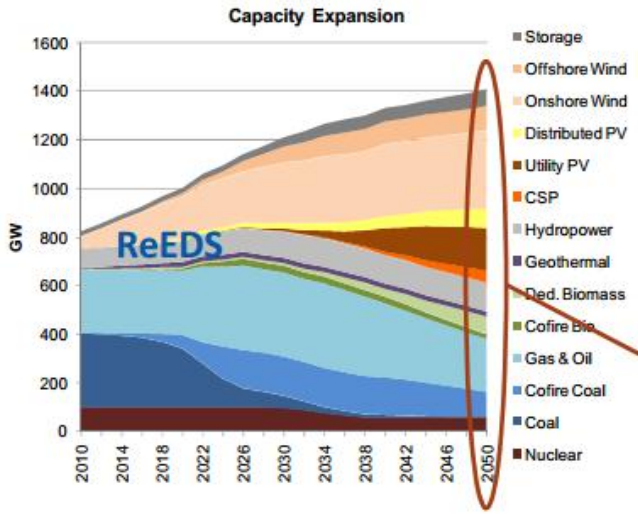
Regional Energy Deployment Systems Model (ReEDS)

- **Capacity expansion & dispatch** for the continental U.S. electricity sector, including transmission and all major generator types
- **Minimize total system cost** in each 2-year investment period until 2050. All constraints (e.g. balance load, planning & operating reserves, etc.) must be satisfied. Linear program without inter-temporal optimization (nonlinear calcs between periods)
- **Multi-regional**: 356 regions in continental US; 134 power control areas; RTOs; States; NERC areas; Interconnection areas.
- **Temporal Resolution**: 17 time slices in each year: 4 daily x 4 seasons, 1 super-peak

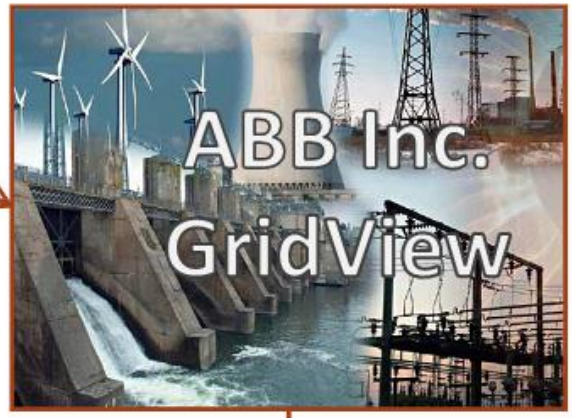


Operating the Electricity System



- Used by ISOs, utilities, others for planning—transmission/generation expansion; total production cost, prices, congestion, etc.
- 11,000 Generators; 85,000 Transmission lines; 34,000 Buses with load; 65,000 nodes; 136 transmission zones
- Commits/Dispatches generating units based on electricity demand, operating characteristics of generators, transmission grid parameters.

- Commercial production cost model
- Hourly chronological model, 8760 hours
- Realistic plant flexibility parameters
- Directly simulates plant outages and forecast error events, unserved load
- Transmission: DC power flow

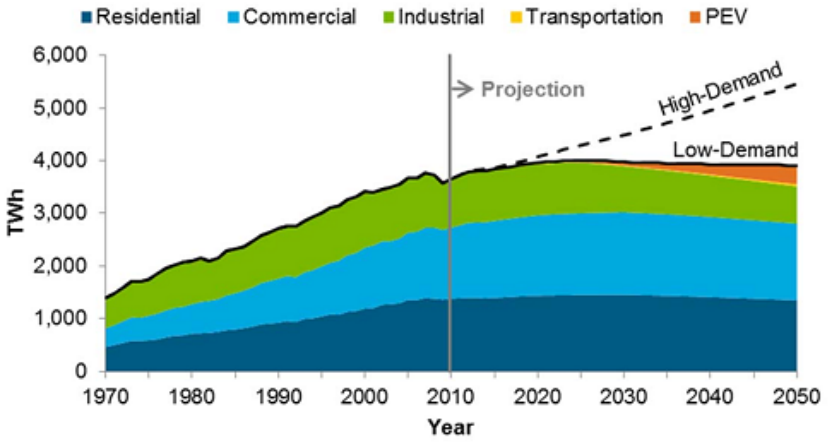


Does the system operate (hourly)?

Scenarios and Assumptions

- **Renewable Technology Improvements: NTI, ITI, ETI**
- **Exploratory Scenarios: 30%, 40%, 50%, 60%, 70%, 80%, 90%**
- **System Constraints: Transmission, Flexibility, Resources**
- **Sensitivities: Demand—High/Low, Fossil Fuel Costs—High/Low, Fossil Technology**

- **Energy Efficiency**: Most scenarios assumed significant energy efficiency measures in the residential, commercial, industrial sectors.
- **Transportation**: Most scenarios assumed a shift toward plug-in hybrid or electric vehicles, partially offsetting the electricity efficiency advances that were considered.



- **Grid Flexibility**: Most scenarios assumed improved 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 transmission infrastructure and access to support renewable energy deployment. Distribution-level upgrades were not considered.
- **Siting and Permitting**: Most scenarios assumed project siting/permitting that allows RE development and transmission expansion with standard land-use exclusions.

Renewable Resources and Technologies

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

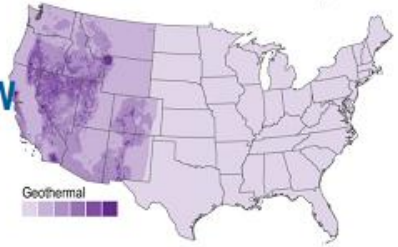
Hydropower ~200 GW
- Run-of-river

CSP ~37,000 GW
- Trough
- Tower

} With thermal storage

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

Geothermal ~36 GW
- Hydrothermal



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

Resource
Dark = Higher
Light = Lower

- **Only currently commercial technologies were modeled (no EGS, ocean, floating wind) with incremental and evolutionary improvements.**
- **RE characteristics, including location (exclusions), technical resource potential, and grid output (dispatchability), were considered**
- **Technical resource potential shown, not economic potential**

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