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Innovation for Our Energy Future
A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

Power System Modeling of 20% Wind-Generated Electricity by 2030

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The Analytic Challenge:

- Create technically and economically feasible scenario that estimates:
  - Wind capacity in 2030 to produce 20% of projected electricity demand
  - Geographic distribution of wind capacity
  - Transmission system expansion requirements
  - Direct electric system cost
  - Portfolio of national generation technologies in 2030
  - Potential natural gas price reduction
  - Financial risk of future carbon regulation and avoided carbon emission
  - Reduced water consumption

WinDS Model

(**Win**d **D**eployment **S**ystems Model)

A multi-regional, multi-time-period model of generation capacity and transmission infrastructure expansion in the U.S. electric sector.

Designed to estimate market potential of wind energy in the U.S. for the next 20 – 50 years under different technology development and policy scenarios.

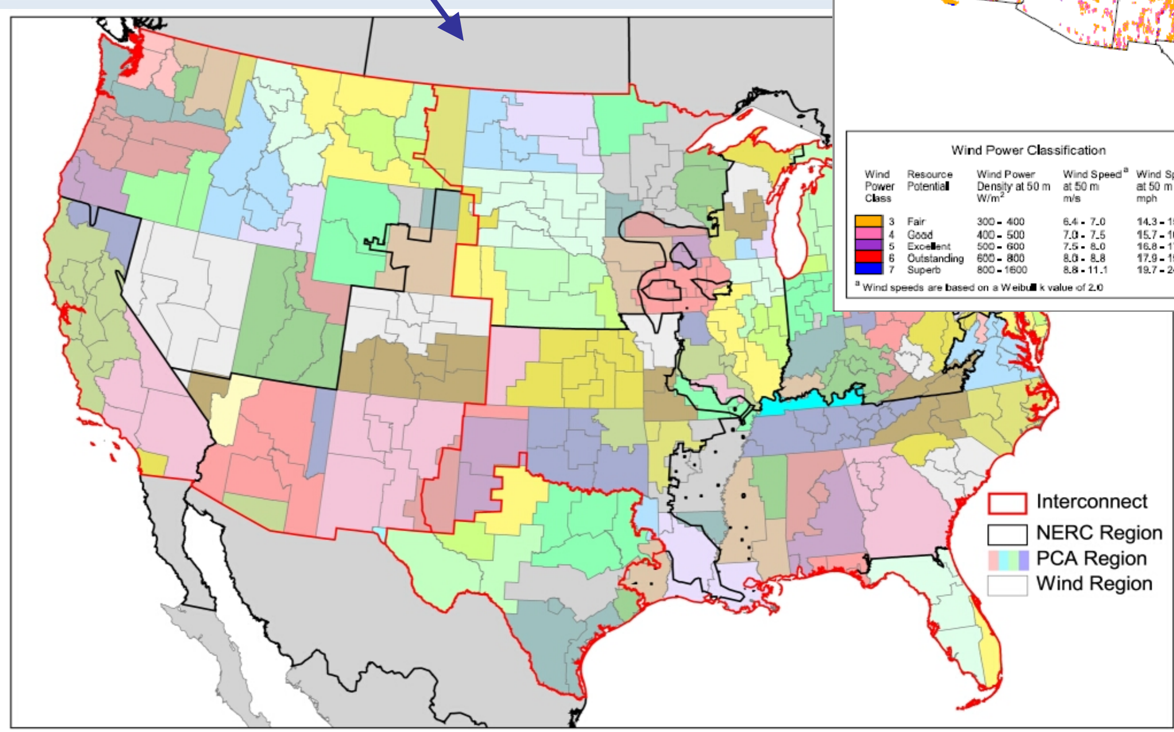
www.nrel.gov/analysis/winds

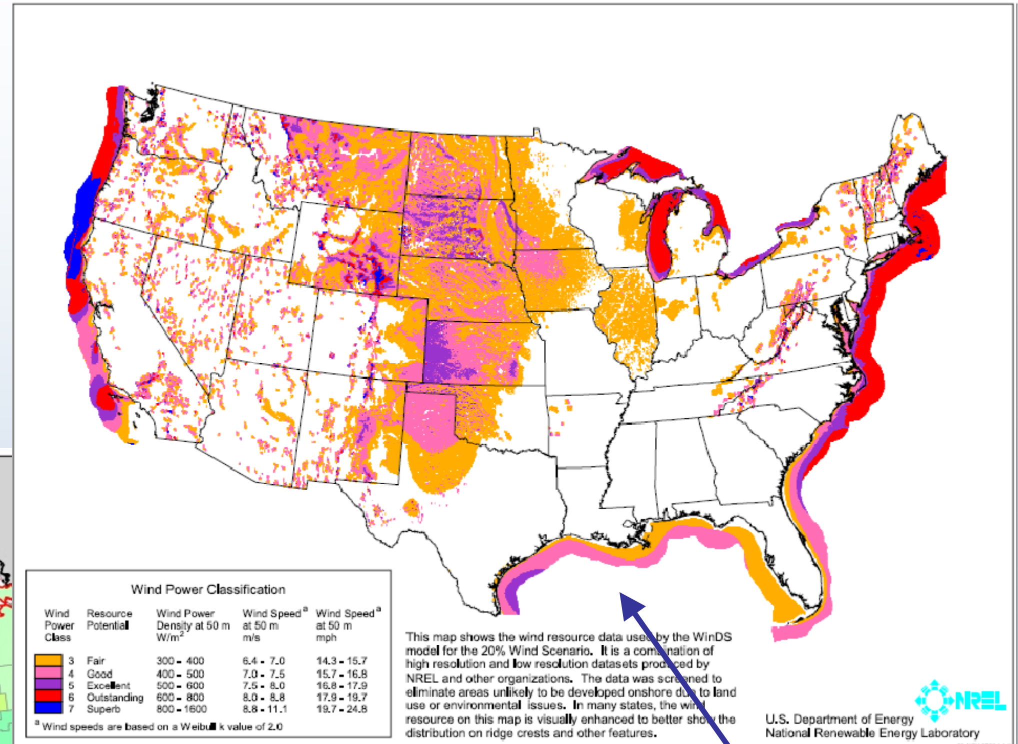
Approach

- Use NREL's Wind Energy Deployment System (WinDS) generation capacity and transmission infrastructure expansion model
- Prescribe annual energy generation from wind technology up to 20% by 2030
- Assume future cost and performance for conventional and wind generation technologies
- Assume electric grid operation and expansion costs
- Select the nationally cost-optimized use of wind resource to meet annual energy production requirements using WinDS
  - Optimizes use of different quality wind resources (Class 3 – 7) in relation to load centers
  - Optimizes use of existing vs. new transmission lines
  - Optimizes relative cost of land-based and offshore wind technology in relation to load centers
  - Optimizes balance of generation technologies without any assumption of future policy changes (e.g. no carbon mitigation policy)

WinDS Regions and Wind Resource

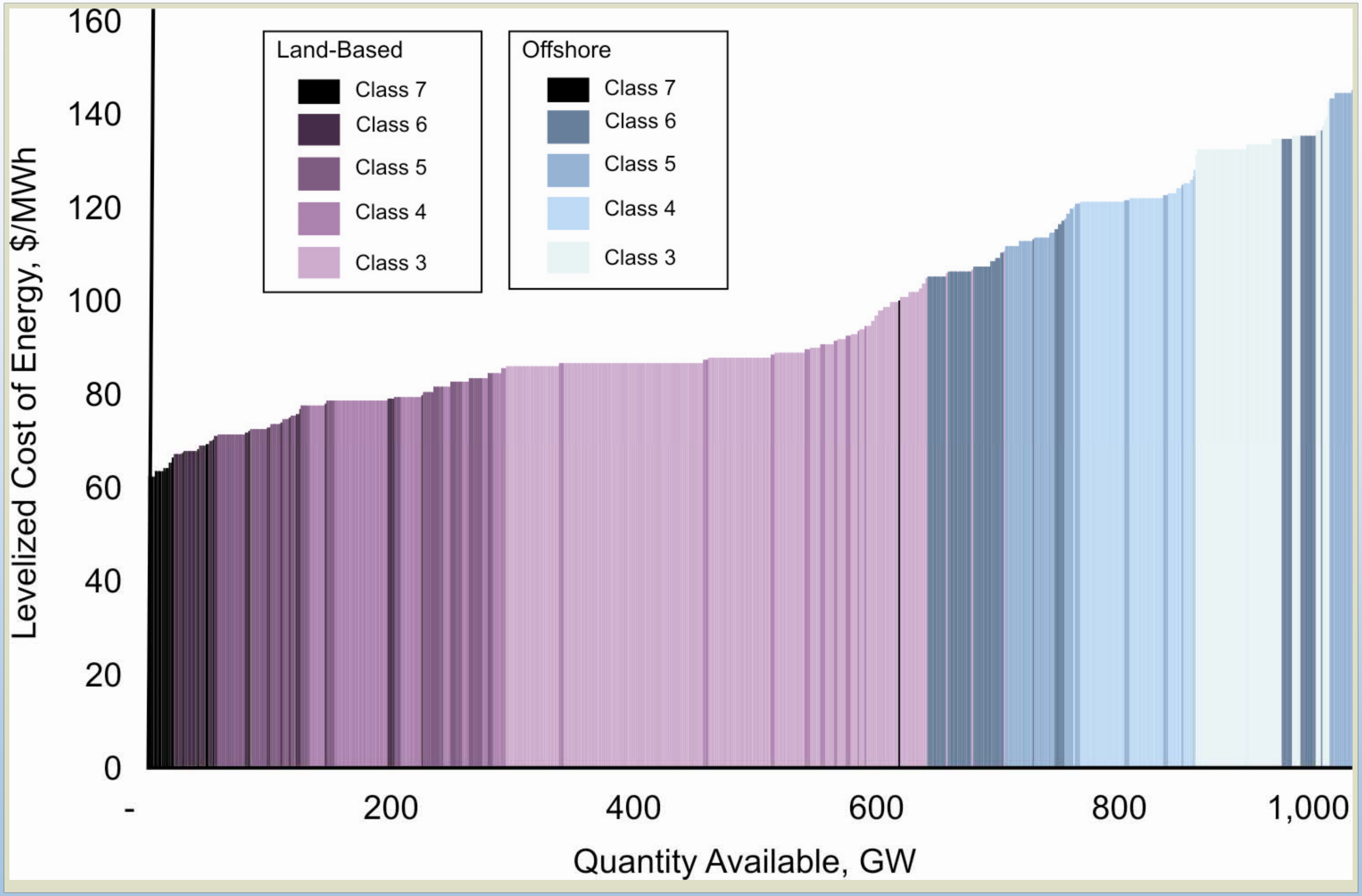
358 WinDS Regions





Wind resource in 9 km^2 cell (0.04 km^2 wind power class delineation within each cell)

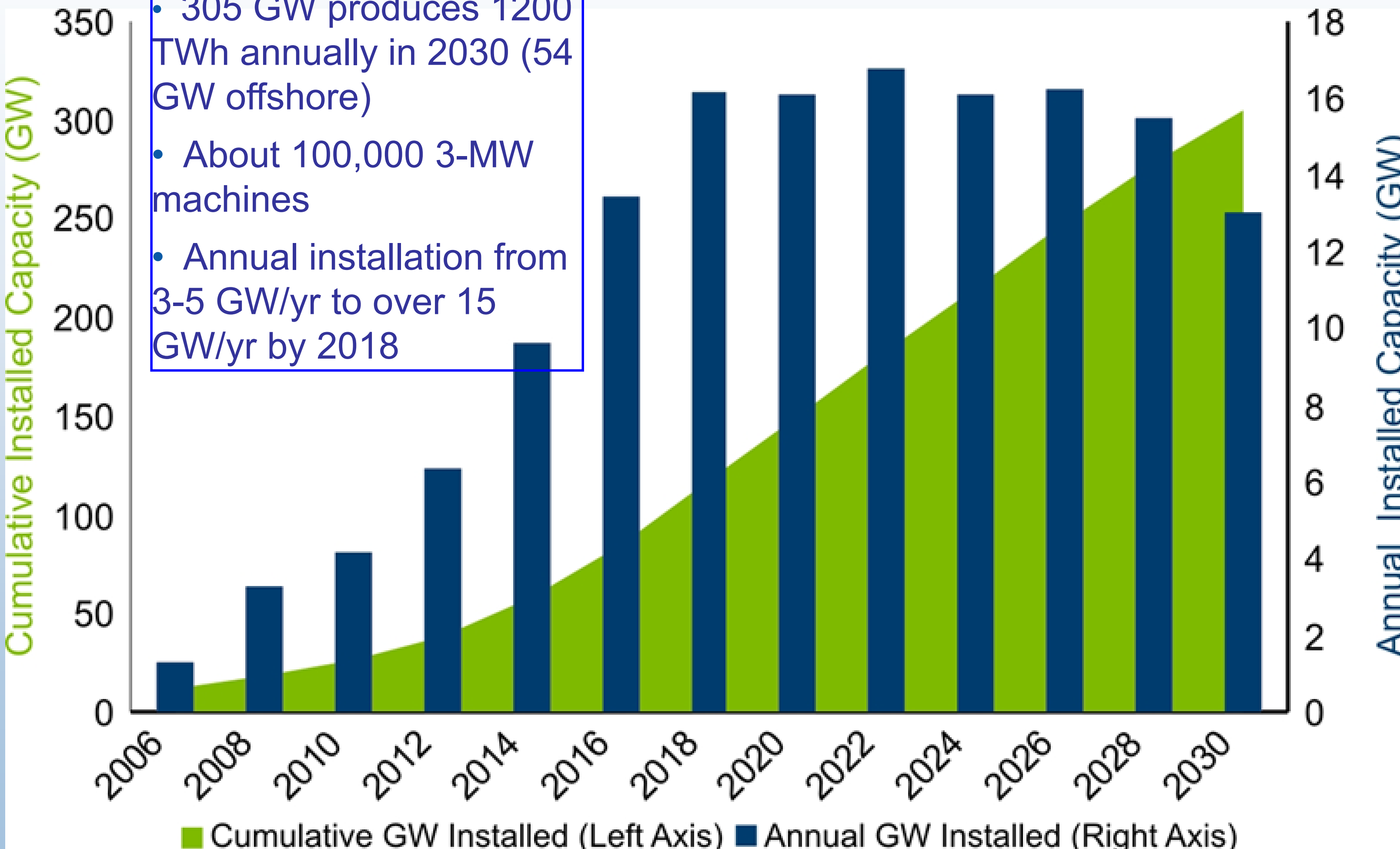
Wind Energy Supply Curve



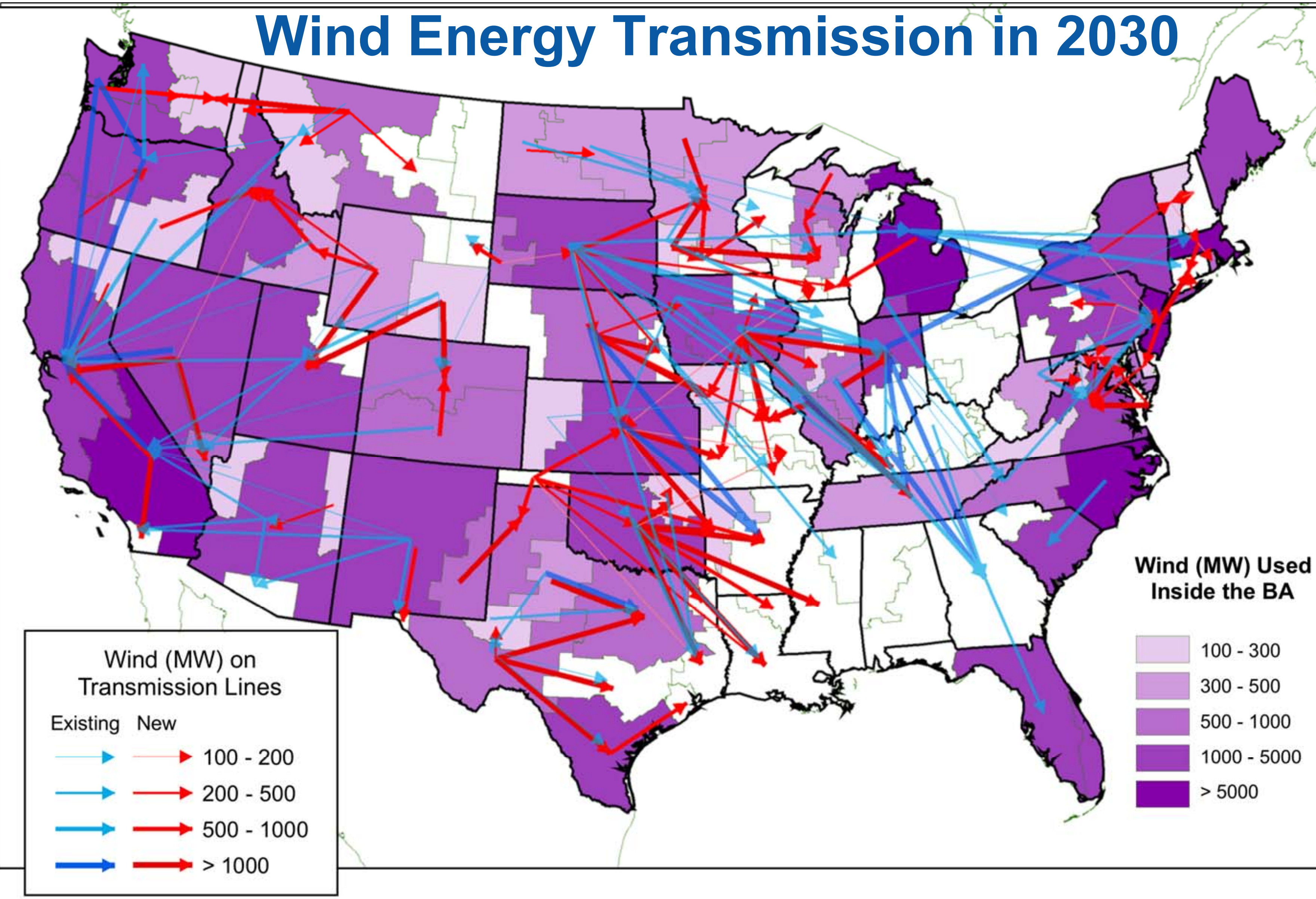
Excludes PTC, includes transmission costs to access 10% existing electric transmission capacity within 500 miles of wind resource.

20% Wind Scenario

- 305 GW produces 1200 TWh annually in 2030 (54 GW offshore)
- About 100,000 3-MW machines
- Annual installation from 3-5 GW/yr to over 15 GW/yr by 2018

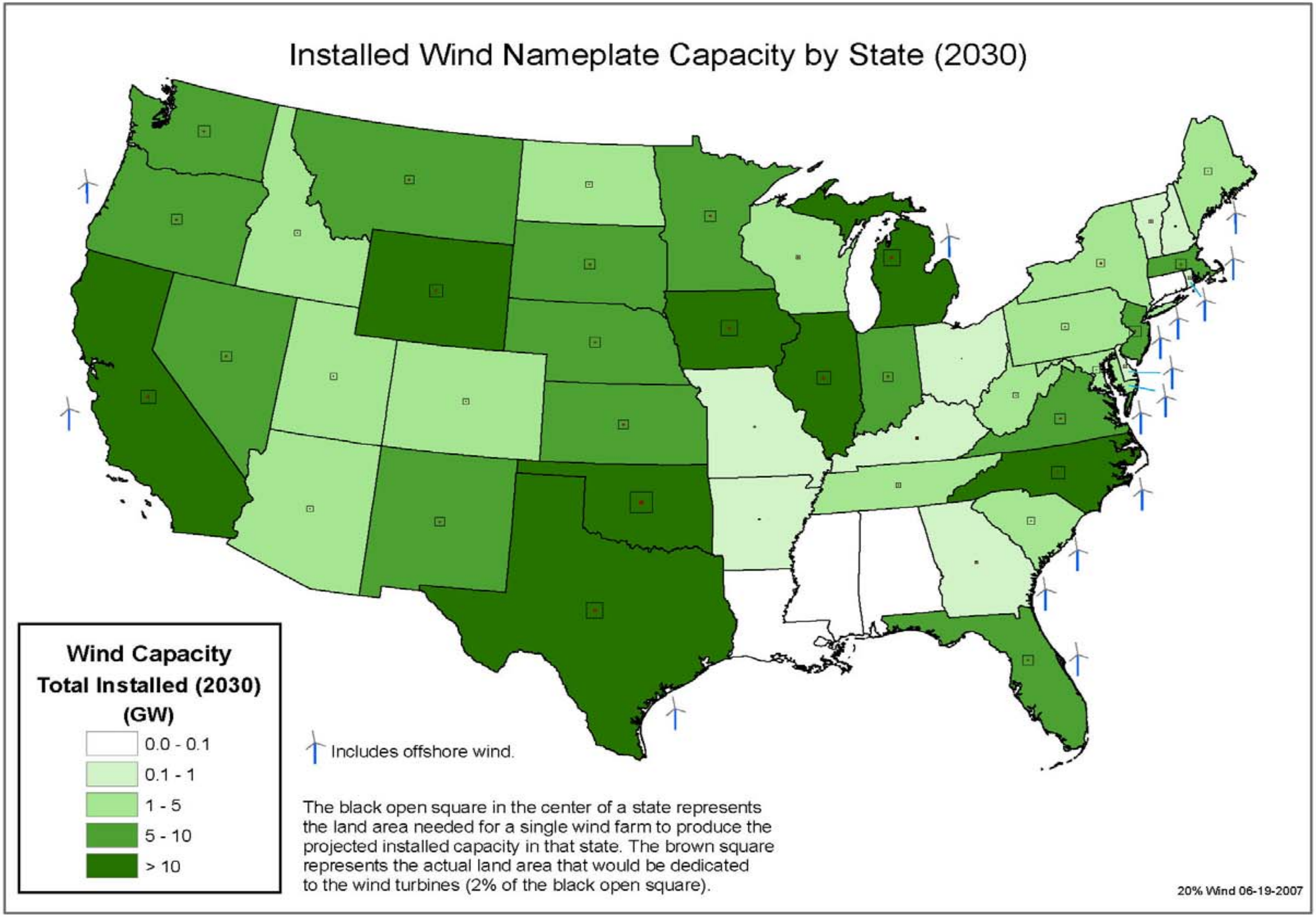


Wind Energy Transmission in 2030



Total Between BA Transfer >= 100 MW (all power classes, land-based and offshore) in 2030. Arrows originate and terminate at the centroid of the BA for visualization purposes; they do not represent physical locations of transmission lines.

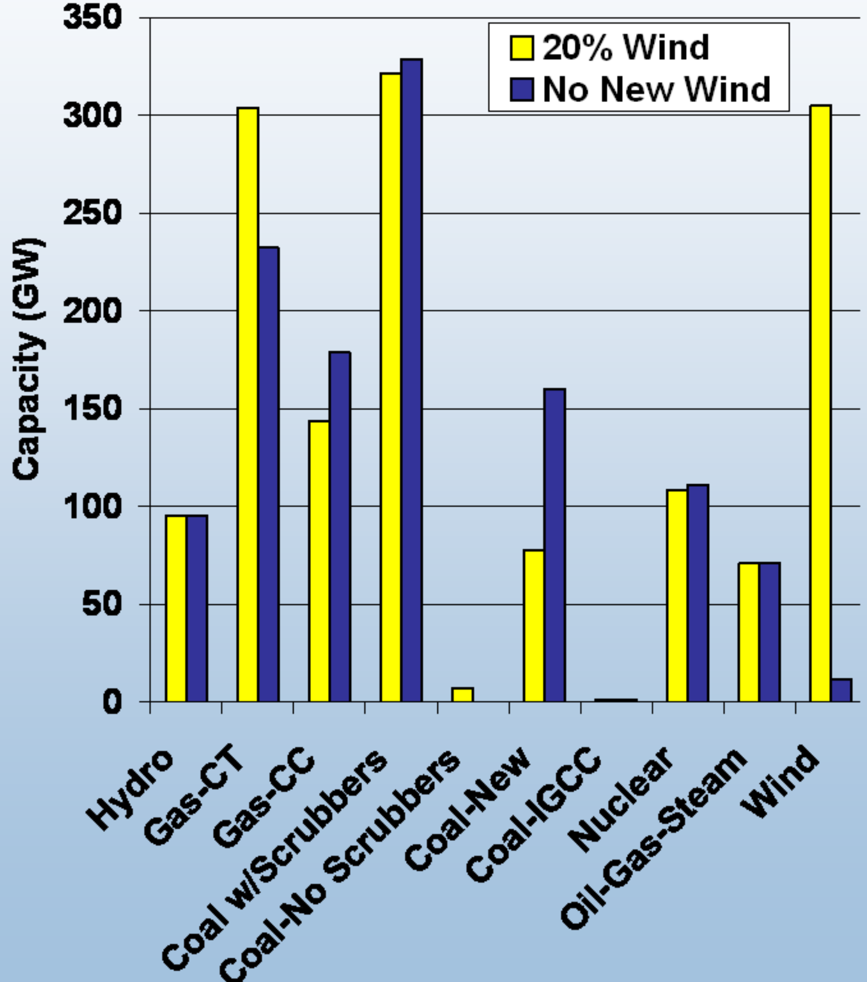
20% Wind 06-19-2007

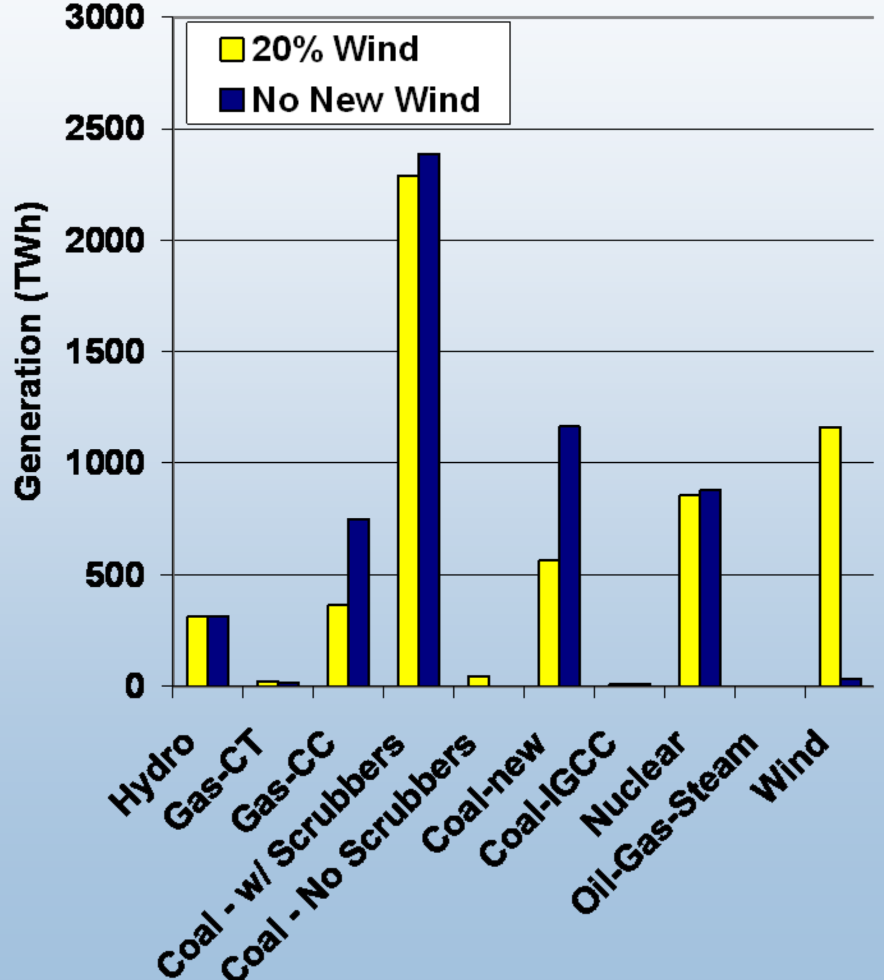


Installed Wind Nameplate Capacity by State (2030)
Wind Capacity
Total Installed (2030)
(GW)
0.0 - 0.1
0.1 - 1
1 - 5
5 - 10
> 10
Includes offshore wind.
The black open square in the center of a state represents the land area needed for a single wind farm to produce the projected installed capacity in that state. The brown square represents the actual land area that would be dedicated to the wind turbines (2% of the black open square).
20% Wind 06-19-2007

Fig 1-6

Generation Technologies in 2030 with and without 20% Wind





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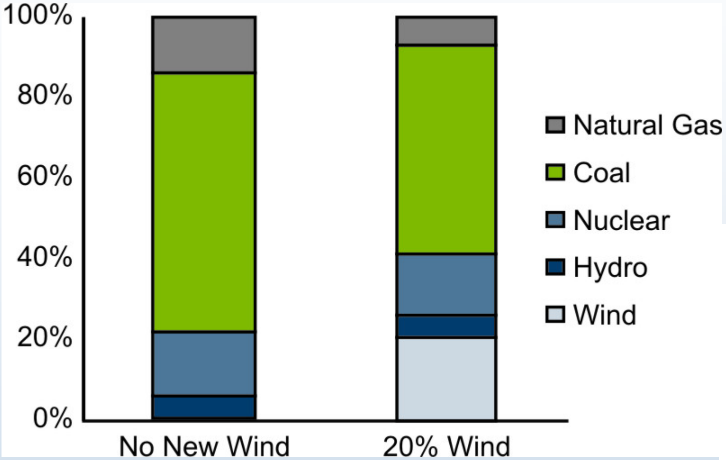
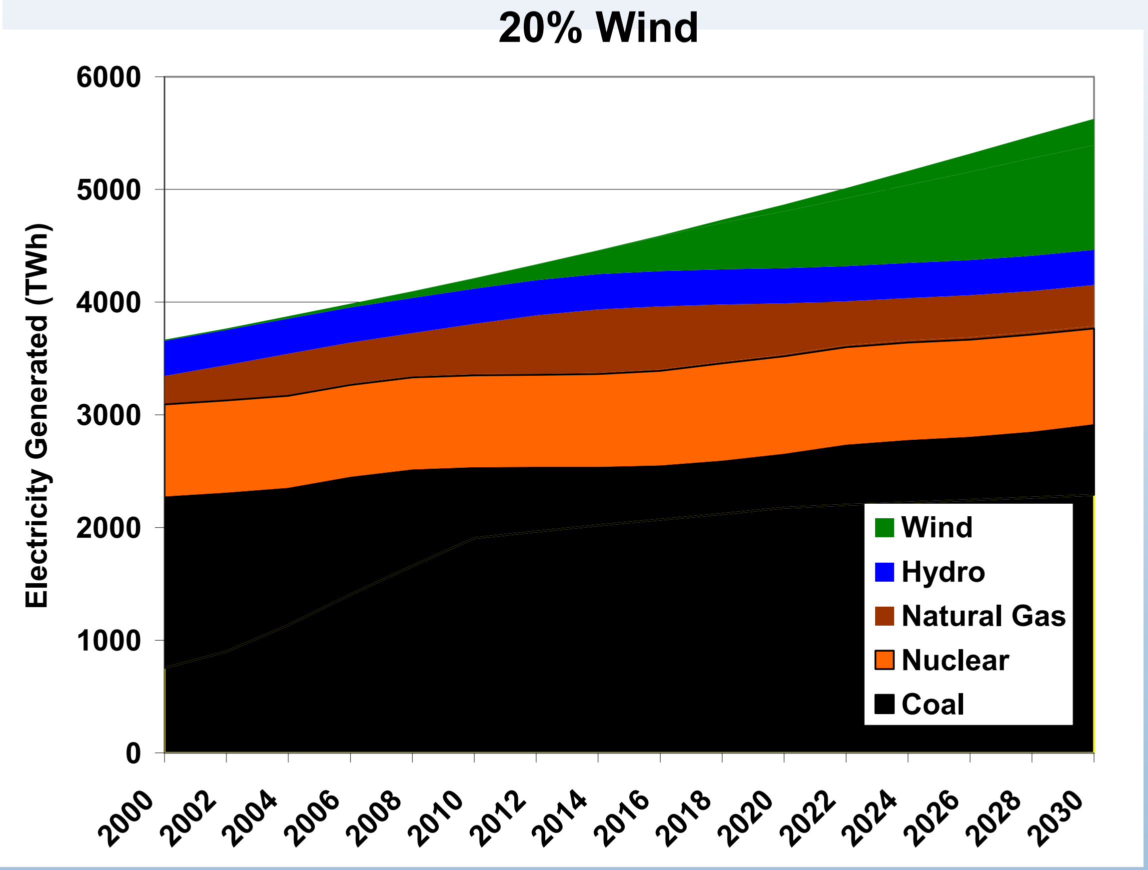
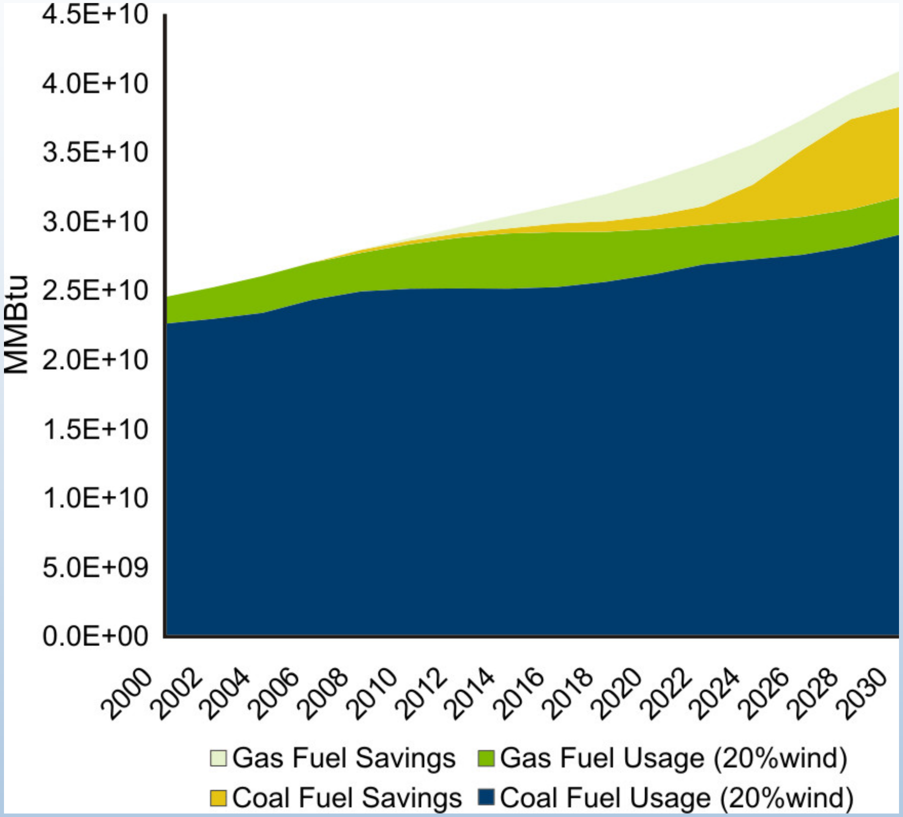
Generation Portfolios





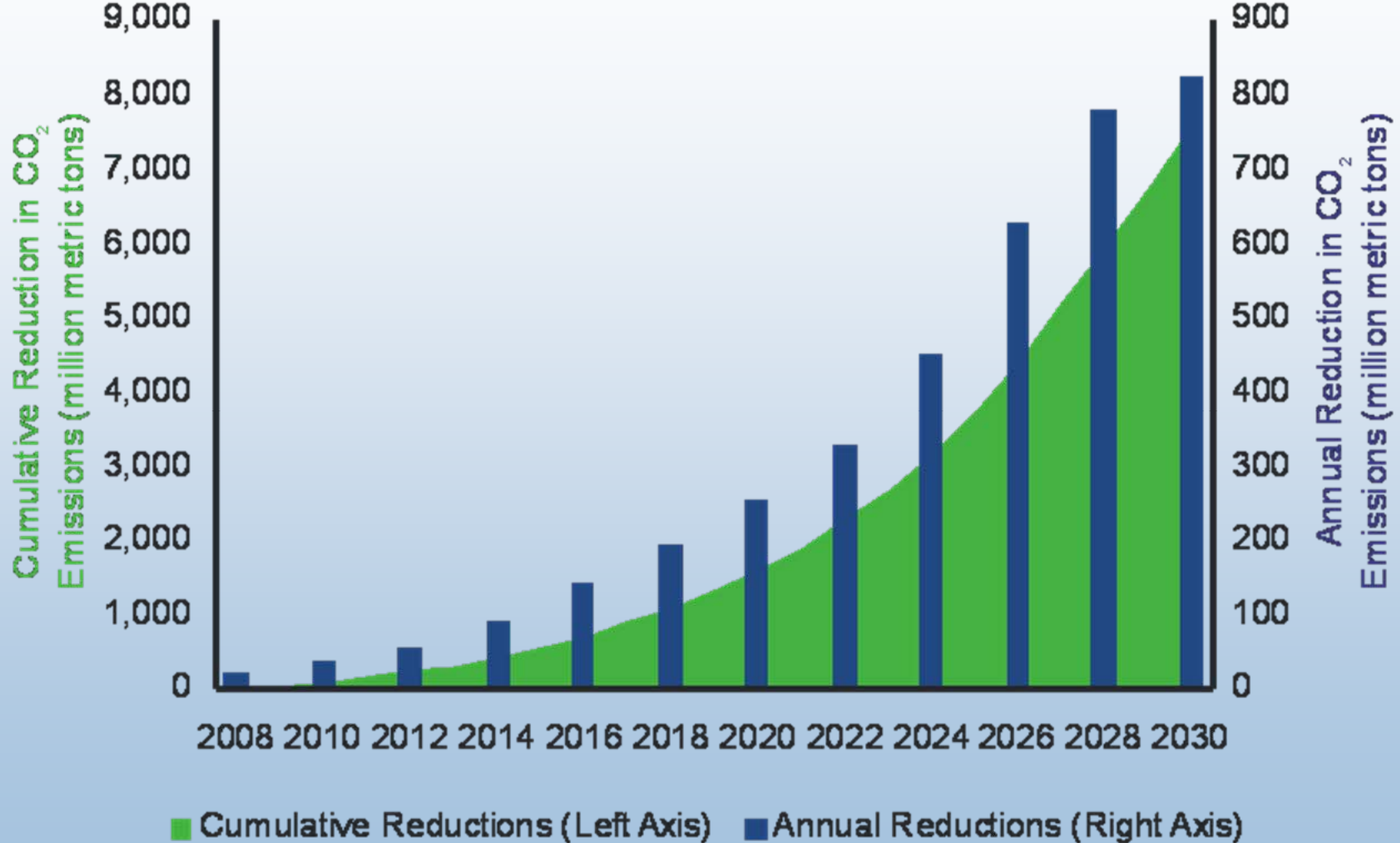
Coal and Natural Gas Fuel Savings



Electricity Sector Fuel Usage

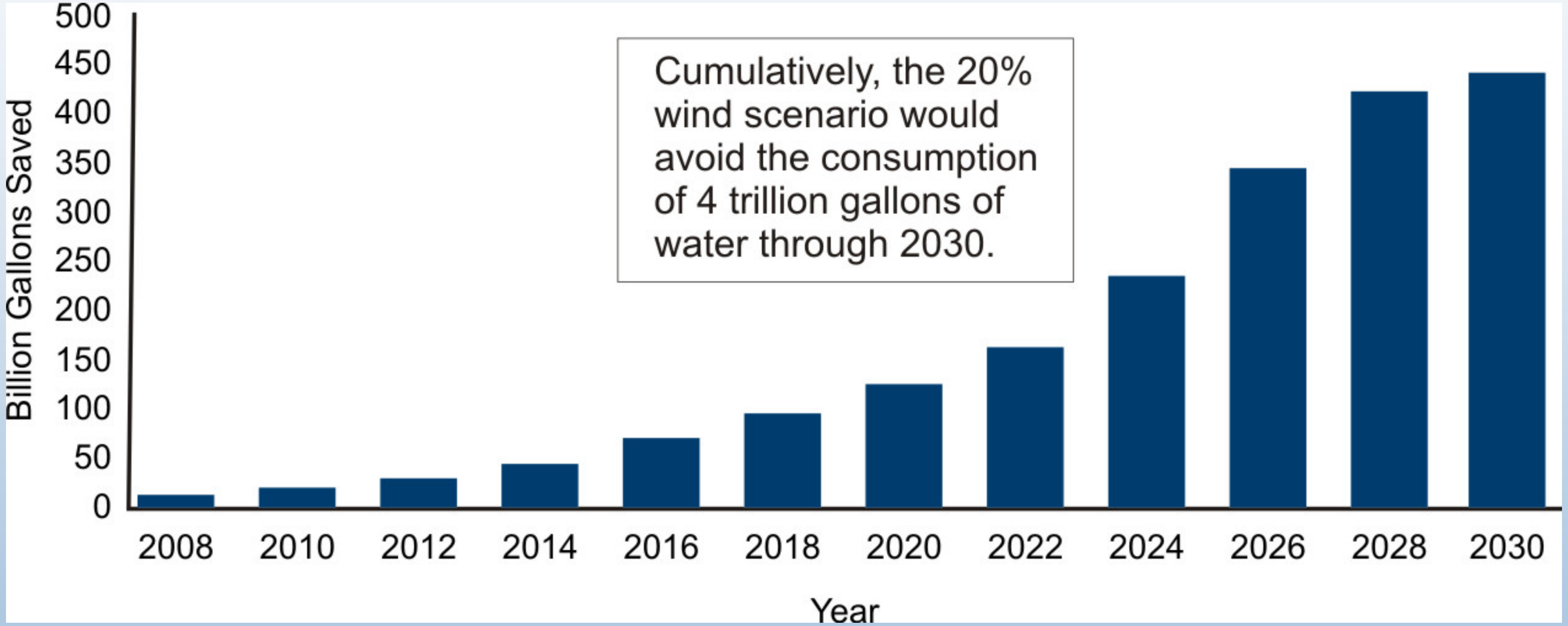
% Reduction in Natural Gas Consumption	Natural Gas Price Reduction in 2030 (2006$/MMBtu)	Present Value Benefits (billion 2006$)	Levelized Benefit of Wind (2006$/MWh)
11%	0.6 - 1.5	86 - 214	16.6 - 41.6

Avoided Carbon Dioxide Emissions

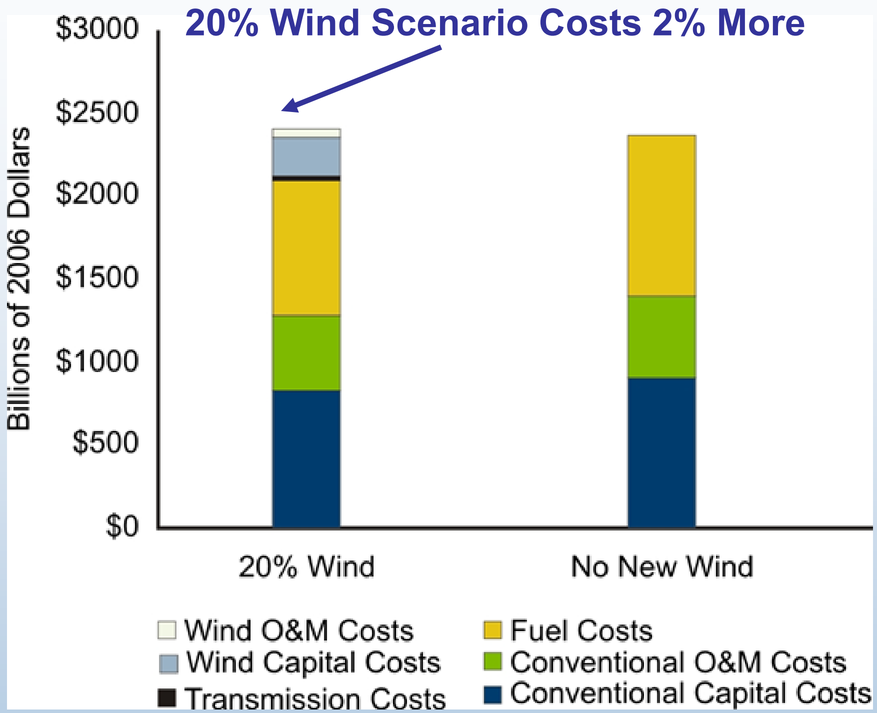


Valued from $50 - $145 billion in Net Present Value

Water Savings



Direct Electric System Cost



Present Value Direct Costs (billion $2006)	Average Incremental Levelized Cost of Wind (2006$/MWh-Wind)	Average Incremental Levelized Rate Impact (2006$/MWh-Total)	Impact on Average Household Customer (2006$/month)
$43 billion	$8.6/MWh	$0.6/MWh	$0.5/month

Conclusions

- Providing 20% of U.S. electricity from wind by 2030 is technically feasible
  - Wind capacity in 46 states
  - Transmission expansion required
- Benefits include (but not limited to) reduced
  - Carbon emission and risk of financial consequences of future carbon regulation
  - Natural gas prices
  - Water consumption
- Incremental cost of wind technology modest compared to planned electric sector investment

Website (documentation and results) at: http://www.nrel.gov/analysis/winds

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Wind Deployment Systems (WinDS) Model

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Background of Model

Qualitative model description

WinDS minimizes systemwide costs of meeting electric loads, reserve requirements, and emission constraints by building and operating new generators and transmission in 26 two-year periods from 2000 to 2050. The primary outputs of WinDS are the amount of capacity and generation of each type of prime mover—coal, gas combined cycle, gas combustion turbine, nuclear, wind, etc.—in each year of each 2-year period. **Figure 1** shows an example of WinDS capacity estimates for the United States for different generation technologies over the next 50 years.

This section also includes information on the linear program formulation, qualitative details on transmission, and qualitative details on wind intermittency.

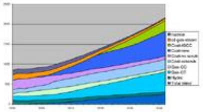

Figure 1. Base Case WinDS Capacity Estimates

While WinDS includes all major generator types, it was designed primarily to address the market issues of greatest significance to wind—transmission and intermittency. The WinDS model examines these issues primarily by using a much higher level of geographic disaggregation than other models. As **Figure 2** represents, WinDS uses 358 different regions in the continental United States. These 358 wind supply regions are then grouped into three levels of large regional groupings—the power control areas (PCAs), North American Electric Reliability Council (NERC) regions, and national interconnect regions. The WinDS regions were selected using the following rules and criteria:

- Build up from counties (so that electric load can be determined for each wind supply/demand region based on county population).
- Do not cross state boundaries (so that state-level policies can be modeled).
- Conform to PCAs as much as possible (to better capture the competition between wind and other generators).
- Separate major windy areas from load centers (so that the distance from a wind resource to a load center can be well approximated).
- Conform to NERC region/subregion boundaries (so that the results are appropriate for use by integrating models that use the NERC regions/subregions).
- Conform to the three major interconnects within the U.S. grid system (to limit capacity and energy transmission exchanges between the interconnects).

Figure 2. Regions Within WinDS

Much of the data inputs to WinDS are tied to these regions and derived from a detailed GIS model/database of the wind resource, transmission grid, and existing plant data. The geographic disaggregation of wind resources allows WinDS to calculate transmission distances, as well as the benefits of dispersed wind farms supplying power to a demand region.

As shown in **Figure 3**, WinDS disaggregates the wind resource into five classes ranging from Class 3 (5.4 meters/second at 10 meters above ground) to Class 7 (>7.0 m/s). WinDS also includes offshore wind resources and distinguishes between shallow and deep offshore wind turbines. Shallow-water turbines are