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Opportunities for Wind Power In Low- and Mid-Quality Resource Regions

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Qualifications and Caveats

This presentation contains data and analysis developed in the context of an ongoing research effort. Results presented are of a preliminary nature and subject to future change without notification. Data and analysis presented are for reference purposes only.

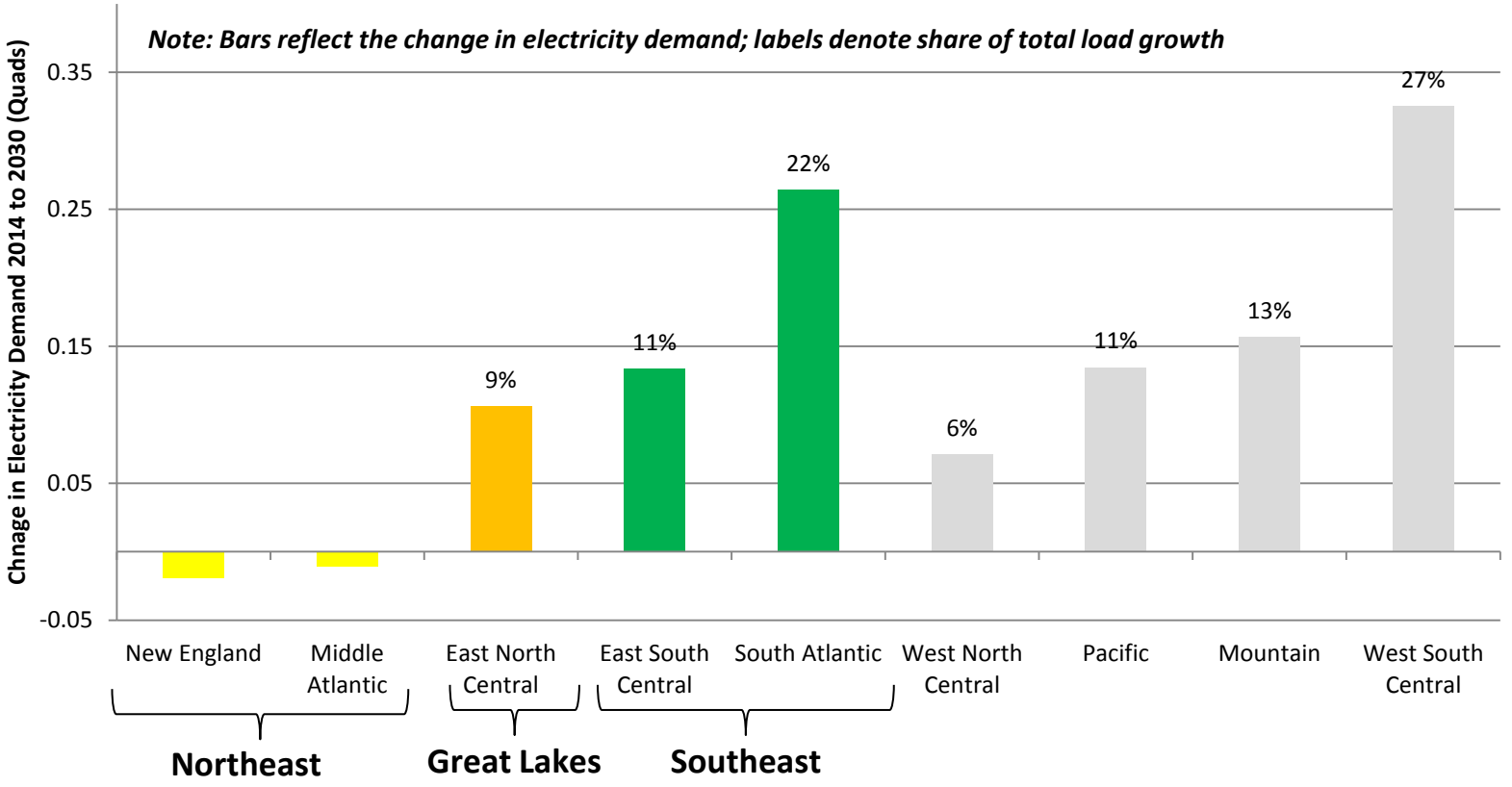
Presentation Overview

1. Wind Power Today in Low- and Mid-Quality Resource Regions
2. Wind Power in the Future Electric Sector
3. Future Market Potential in Low- and Mid-Quality Resource Regions
4. Anticipated Innovations to Capture Future Market Opportunities

Primary Focus Regions

- Lower-quality wind resource regions represent areas where innovation could be first deployed and where their relative value may be largest (moving sites from non-viable to viable)
- These regions are also proximate to existing load and to forecast future load growth

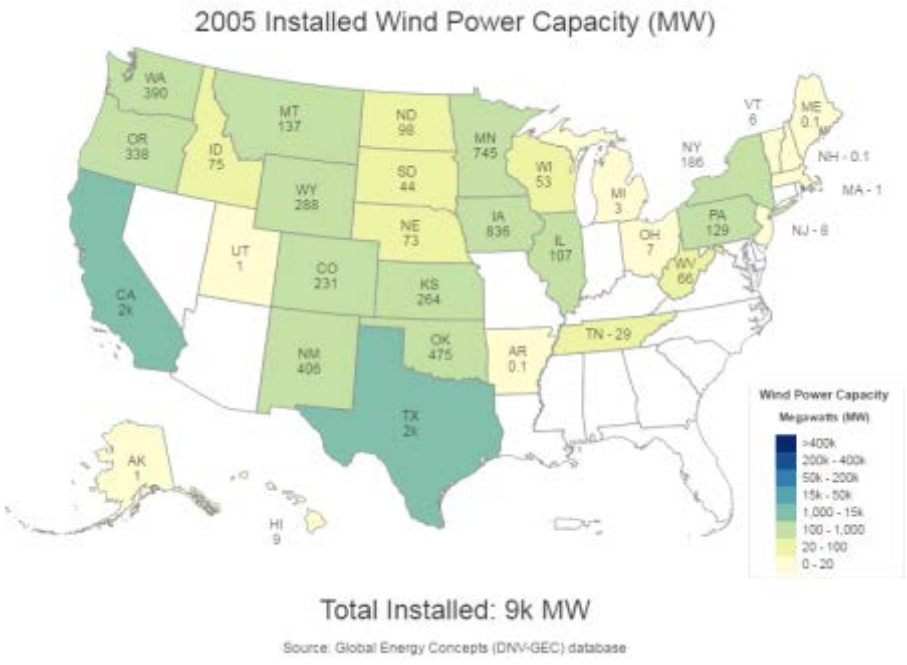
Forecast Demand Growth Among Regions

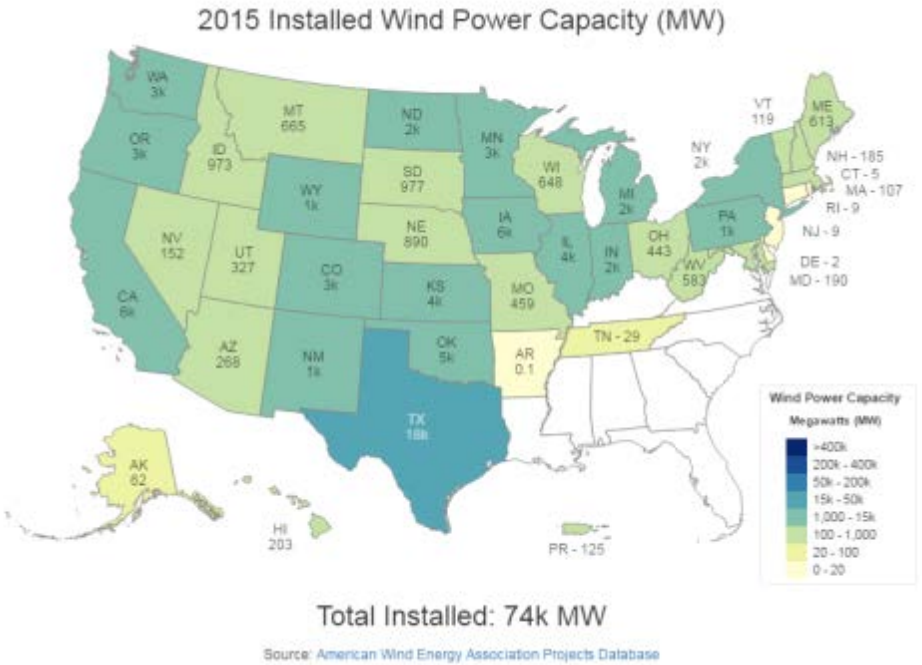


Data Source: U.S. Energy Information Administration Annual Energy Outlook 2016 Early Release (EIA 2016)

- Primary focus regions constitute 58% of current electricity demand and 56% of forecast (2030) electricity demand
- Accessing these markets either via transmission or with locally sited wind projects is likely a key element of continued future wind industry growth

Historical National Wind Deployment: 2006 - 2015





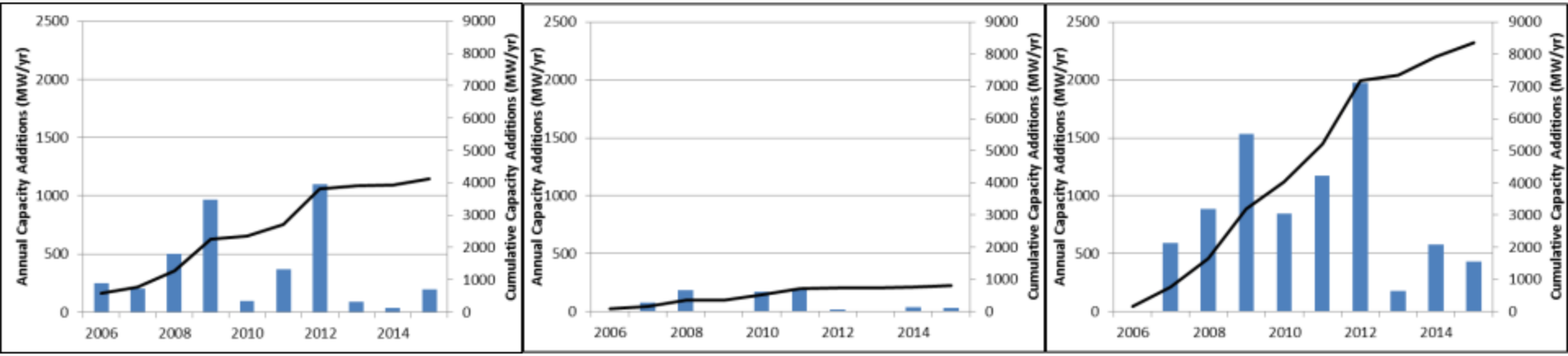
Maps sourced from the DOE WINDExchange: energy.gov/eere/**wind/windexchange**

- Wind deployment through 2005 was concentrated in the Great Plains and in states with favorable policies (e.g., California, Minnesota, Iowa)
- More recently, growth has been regionally dispersed, in part enabled by technological innovations originally targeting “low wind speed” resource regimes
- In high wind penetrations scenarios (e.g., DOE *Wind Vision* [DOE 2015]) wind resources of lower quality that are proximate to electricity demand are increasingly important

Focus Region Trends: 2006 - 2015

Historical Wind Power Deployment by Region

Northeast | **Southeast** | **Great Lakes**



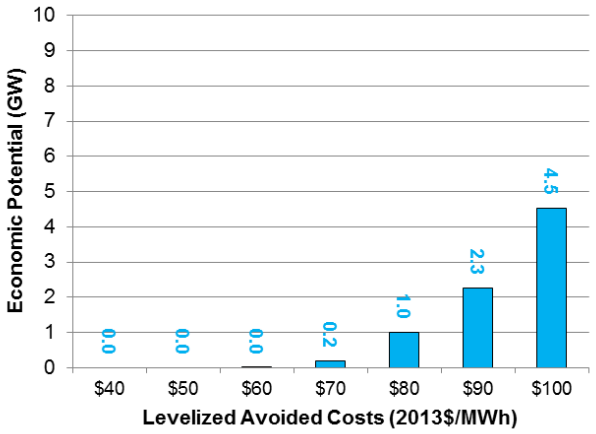
Data acquired from WINDExchange. n.d. Washington, D.C.: U.S. Department of Energy. Accessed May 2016, energy.gov/eere/**wind/windexchange.**

- Of the focus regions, the Great Lakes has observed the largest volumes of recently installed capacity, with peak years of 1-2 GW/yr and the highest cumulative operating capacity at 8.4 GW
- The Northeast has also observed significant growth to 4.1 GW, with an average annual installation rate of nearly 400 MW/yr since 2006
- The Southeast has yet to witness sustained growth, but development interest persists as technology costs continue to fall

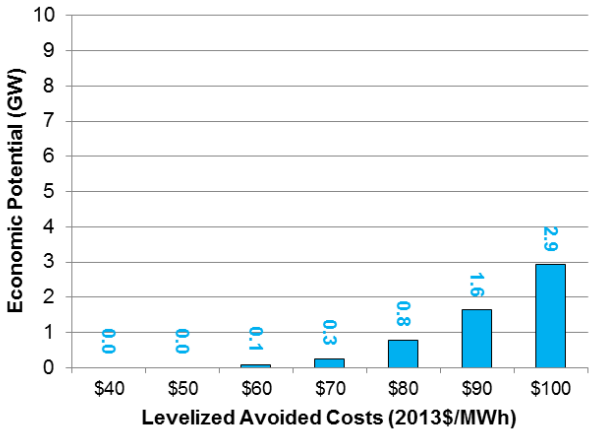
Current Resource Cost Status

Wind Power Quantity at or Below Avoided Cost Thresholds (PTC not Included)

Northeast

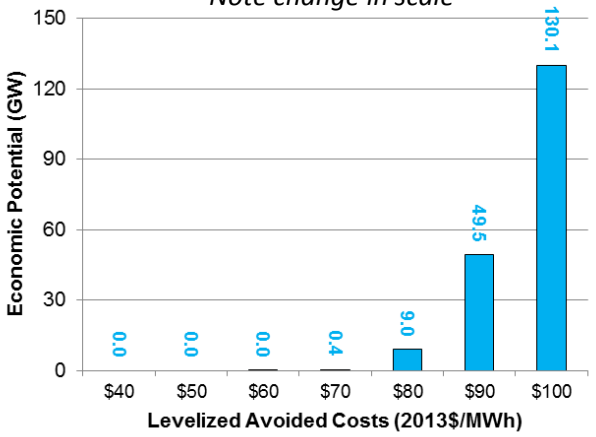


Southeast



Great Lakes

Note change in scale

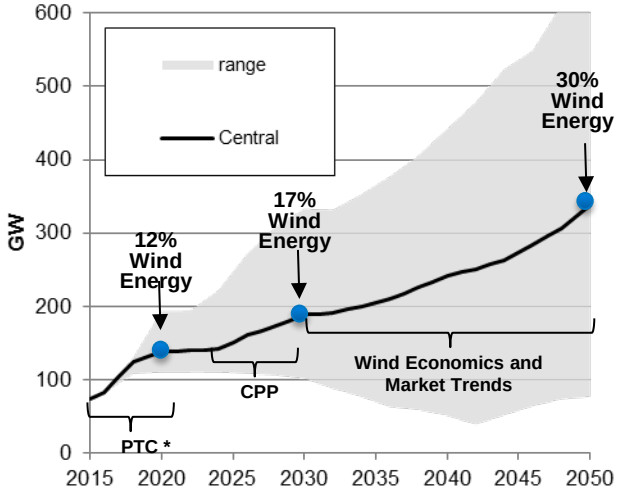


Estimated wind power costs include regional capital cost factors and intra-regional transmission "spur lines".

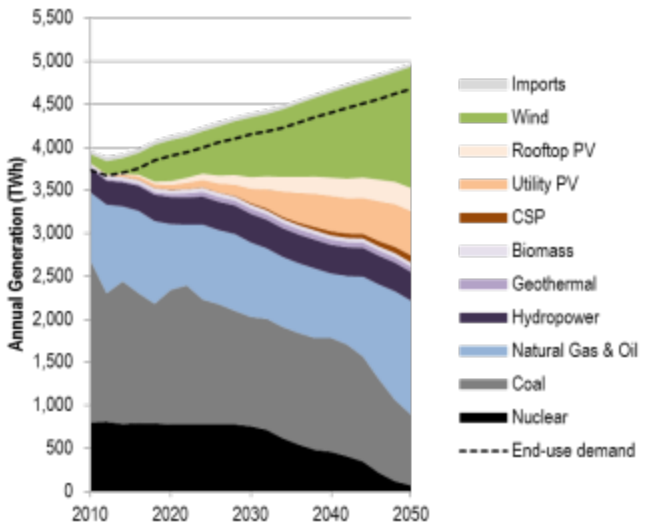
- The Northeast is estimated to have approximately 4.5 GW of unsubsidized wind power that could compete with prices of $100/MWh and 1 GW that could compete with prices below $80/MWh
- The Southeast is estimated to have approximately 2.9 GW that could compete with prices of $100/MWh and 0.8 GW that could compete with prices below $80/MWh
- Easily exceeding the Northeast and Southeast, the Great Lakes region is estimated to have approximately 130.1 GW that could compete with prices of $100/MWh and 9.0 GW that could compete with $80/MWh prices

Future National Wind Deployment: 2015 - 2050

Deployment Range and Central Scenario



Central Scenario Electric Sector Generation Mix



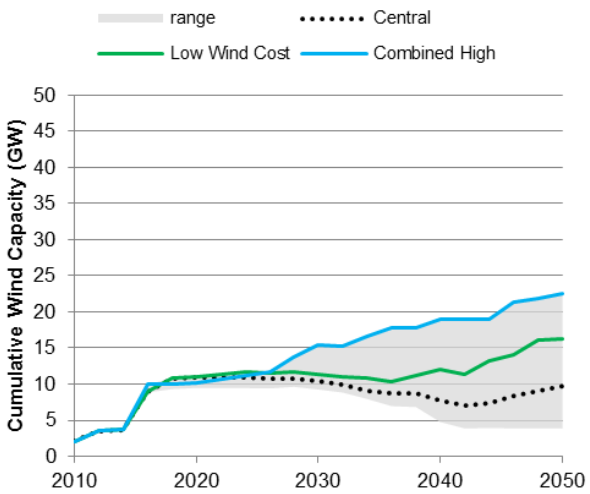
**Modeling of PTC is based on two-year 'under construction' window; transmission additions post-2020 are based on system economics.*

- With delivered gas prices at approximately $5 - $6.50/MMBtu between 2020 and 2030, wind capacity steadily marches toward 200 GW by 2030 and becomes a pillar of the future electric sector
- Post-PTC growth is supported by the Clean Power Plan (CPP) in the 2020s and by continued cost reductions for wind combined with increasing fossil fuel prices, growing demand, and retiring coal and nuclear after 2030
- Natural gas and solar PV constitute the primary alternatives to wind power and also represent the resources most likely to be displaced by wind under more optimistic wind scenarios
- Based on recent gas prices and other industry trends (e.g., continued PV cost reductions), there is substantial risk that wind deployment could fall to levels well below those projected under central conditions

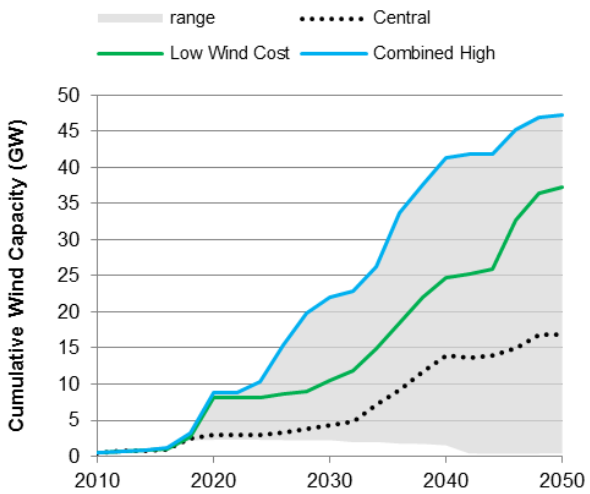
Focus Region Market Potential: 2015 - 2050

Future Wind Power Demand by Region in Specific Scenarios

Northeast



Southeast



Great Lakes

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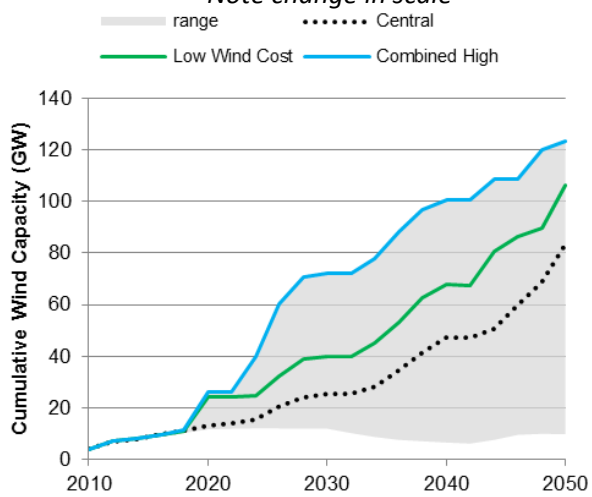


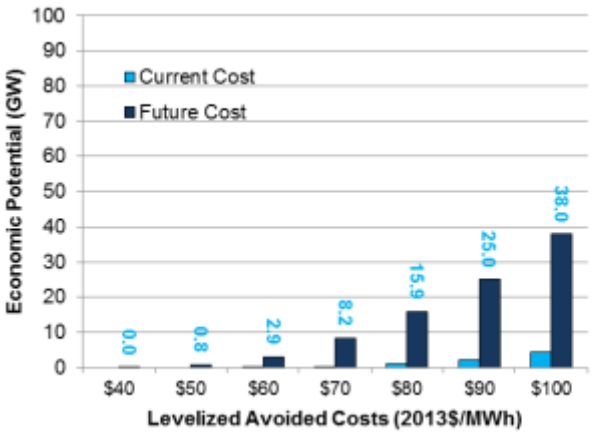
Combined High = Low Wind Cost (NREL 2015 Annual Technology Baseline [NREL 2015]), High Natural Gas Prices (EIA 2015), and High Electricity Demand (EIA 2015)

- Wind technology innovation is an essential component of scenarios that see wind deployment growth in these regions; the relatively higher deployment scenarios require technology innovation and additional favorable conditions such as high gas prices and high load growth
- Across all considered scenarios, the Great Lakes offers the largest demand potential; however, under favorable conditions, even the Southeast could see regional deployment levels approaching 50 GW by 2050
- Scenarios that limit transmission and emissions trading (under the CPP) also tend to increase demand in these regions, particularly in the Southeast and Great Lakes

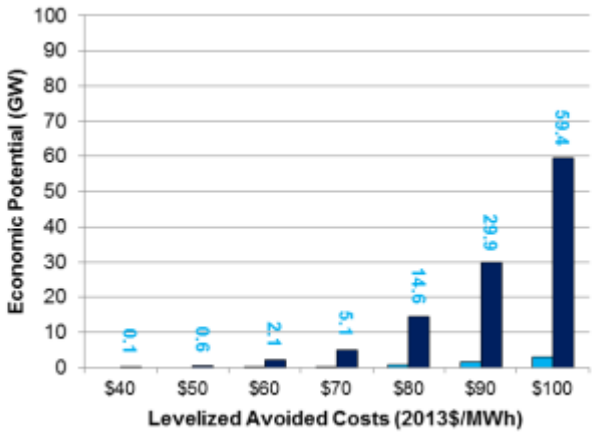
Future Resource Cost Status

Wind Power Quantity At or Below Avoided Cost Thresholds (PTC not Included)

Northeast



Southeast



Great Lakes

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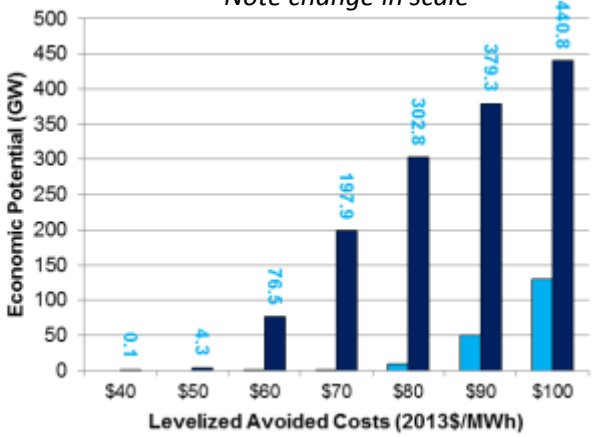
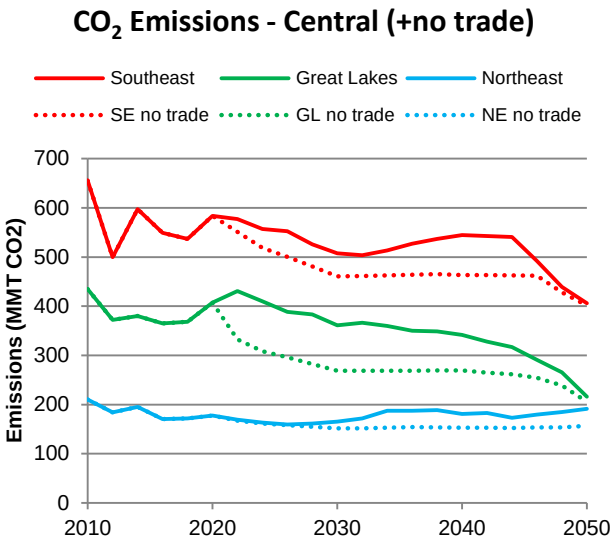
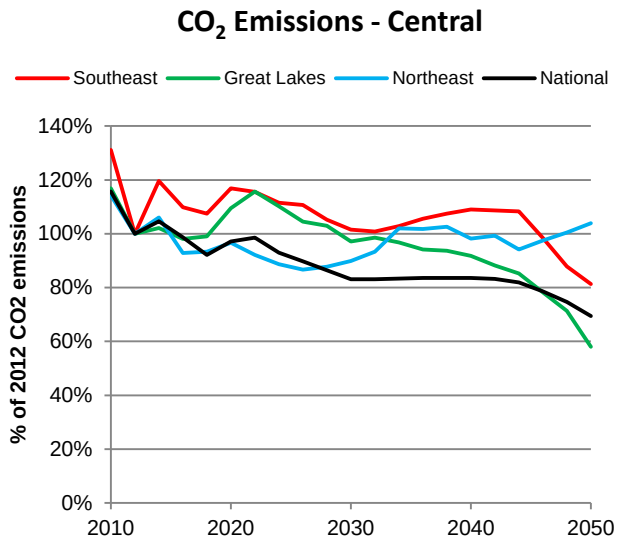


Estimated wind power costs include regional capital cost factors and intra-regional transmission "spur lines".

- Quantities at or below specific thresholds are increased by an order of magnitude in many cases
- In the future, all regions are anticipated to have GWs of unsubsidized wind that can compete with $60/MWh prices and tens of GWs that can compete with $80/MWh prices
- The Great Lakes region, in particular, looks to offer vast potential even at prices as low as $60/MWh

Regional CO_2 Emissions to 2050

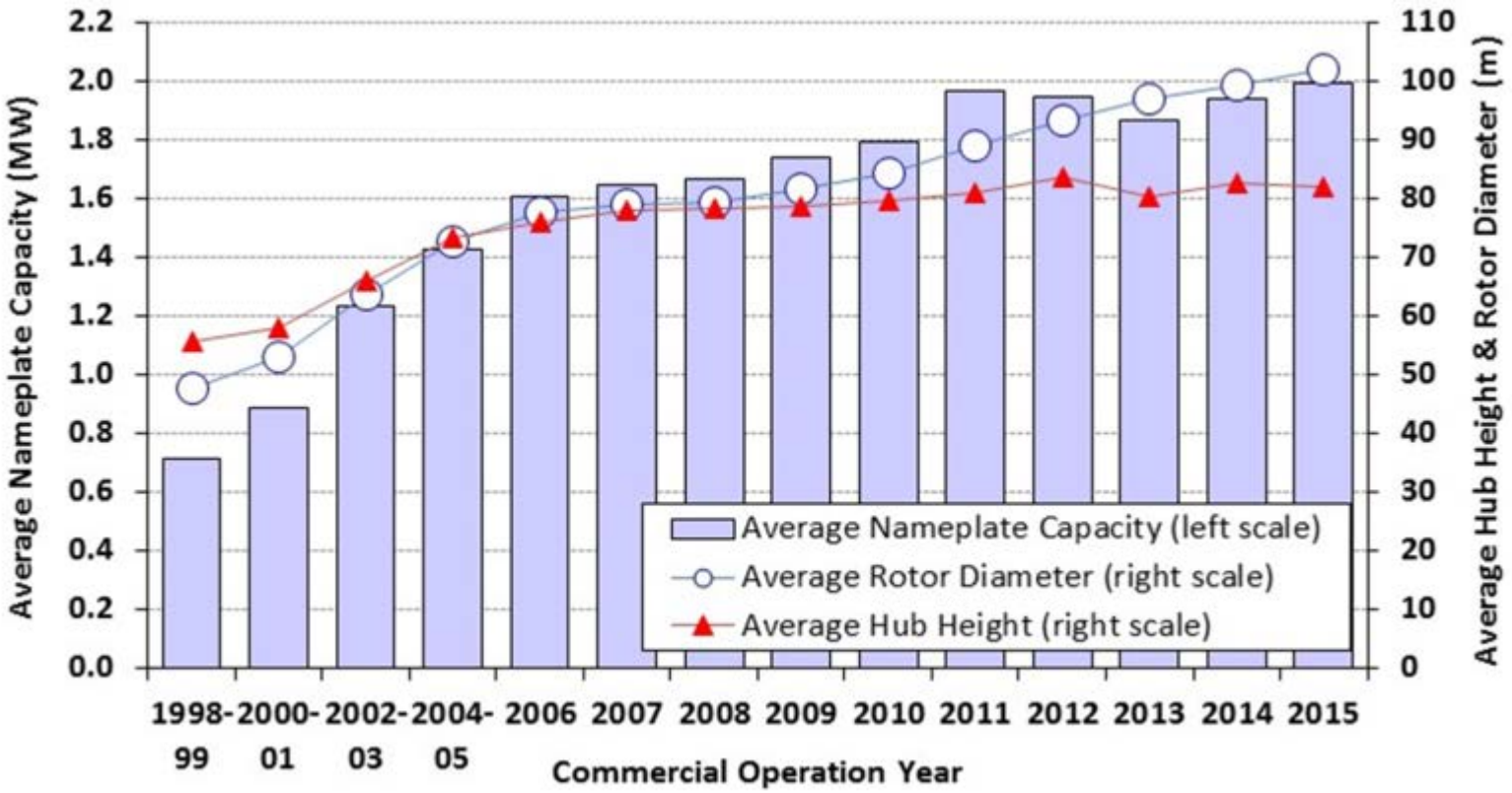




2012 emissions are estimated based on ReEDS; emissions from "direct use" facilities are excluded.

- Under central conditions, CO_2 emissions in the Eastern focus regions are estimated to be flat or slowly declining
- Emissions can be sensitive to CPP compliance scenario
  - With full credit trading, regional emissions reductions in the focus regions are less than the national average
  - More restrictive CPP trading could lead to more significant reductions in these (and nationwide)
- Greatest emissions reductions are found in the Great Lakes region, where wind deployment was estimated to be greatest; wind's potential to reduce emissions could be significant in the Southeast region, which comprise a significant share of total U.S. emissions

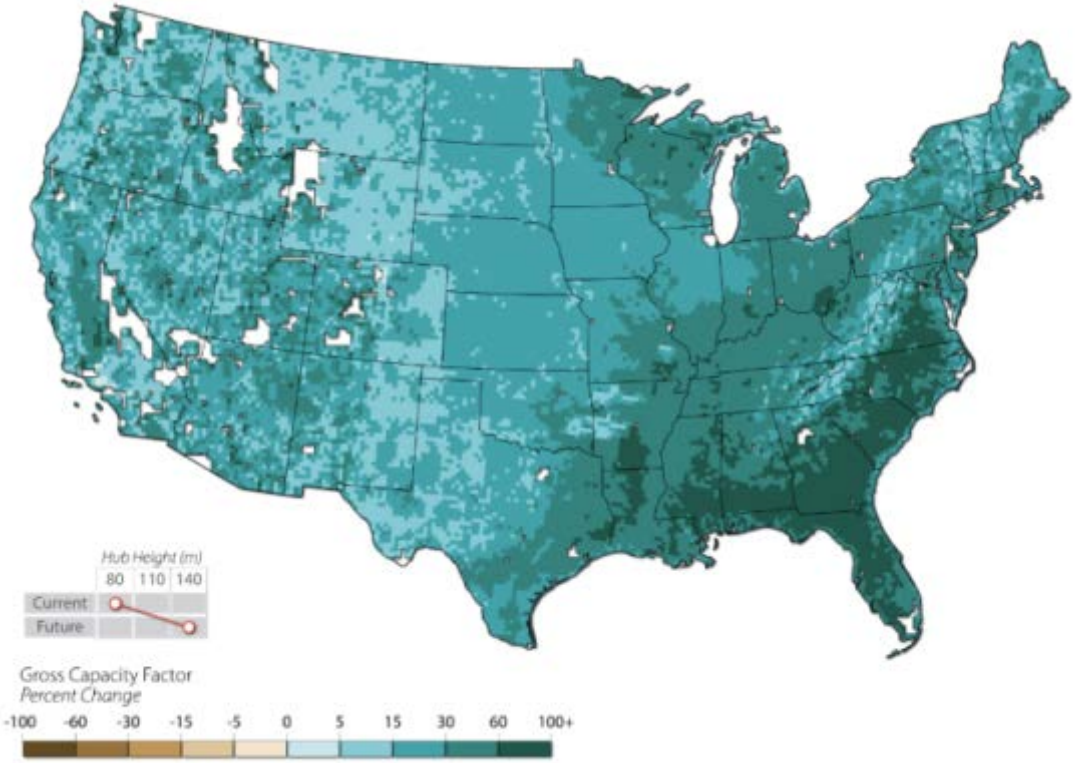
Innovation Opportunities: "Tall Wind"



Source: Wiser and Bolinger 2014 (2015 data are preliminary)

- Future sources of innovation are anticipated to be similar to historical trends and enable continued turbine scaling or "tall wind"
- More specifically continued rotor diameter growth, increased hub heights, and increased nameplate capacity are all anticipated to be key elements of continued cost reduction
- Manufacturing, logistics and balance of plant, and whole plant optimization improvements will also be important

Potential Impacts on Capacity Factors from Innovation



Underlying resource data are from AWS Truepower Mesoscale modeling. Data reflect the change in gross capacity factor when going from 80m to 140m with continued growth in rotor diameters (e.g., 122m, for IEC Class III Turbines).

- Portions of the Southeast and Great Lakes could see capacity factor improvements approaching 100% (i.e., near doubling of capacity factors) as a function of higher hub heights and larger rotors alone
- Although somewhat smaller on a percentage basis, improvements in the wind belt are also non-trivial

Summary and Conclusions

- Future wind deployment estimates span a large range due to significant uncertainties in future market conditions
- Wind can help support regional reductions in CO_2 emissions, particularly in regions that have constituted a substantial proportion of historical U.S. electric sector emissions
- Tall wind innovations including increased hub heights, larger rotors, and larger nameplate capacities are anticipated to remain important drivers of future cost reductions and are particularly important for low- and mid-quality regions
- Focusing on aggressive technology innovation:
  - The Great Lakes could see demand for 30 GW of new capacity by 2030
  - The Southeast could see demand for 9 GW of new capacity by 2030
  - The Northeast could see demand for 3 GW of new capacity by 2030
- Lower gas prices of $4 - $5/MMBtu (delivered prices in the 2020s), among other factors, could substantially erode these demand opportunities; coupled with limited innovation, these conditions could result in little to no growth
- Higher gas prices of $6 - $8/MMBtu (delivered prices in the 2020s) and a preference for local renewable resources could support substantially greater levels of demand

Thank You

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