

Co-optimization of HVDC Networks and Massive Renewable Generation Expansion

Prepared By:

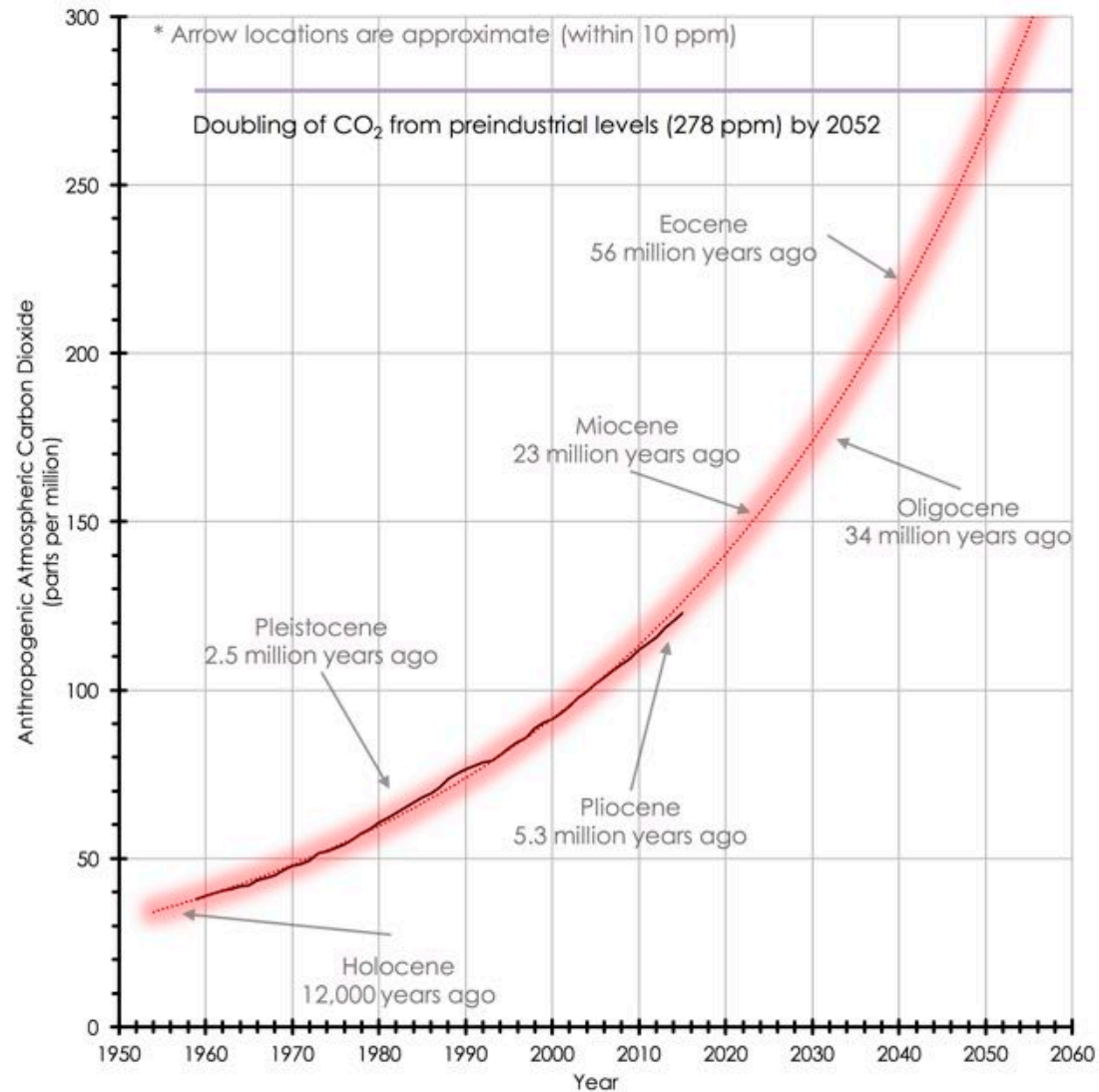
Dr Christopher T M Clack
Founder and CEO, Vibrant Clean Energy, LLC

Prepared For:

The Utility Variable-Generation Integration Group (UVIG)

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The GHGs are rising and nations must transition to low-carbon sources



What is the problem?

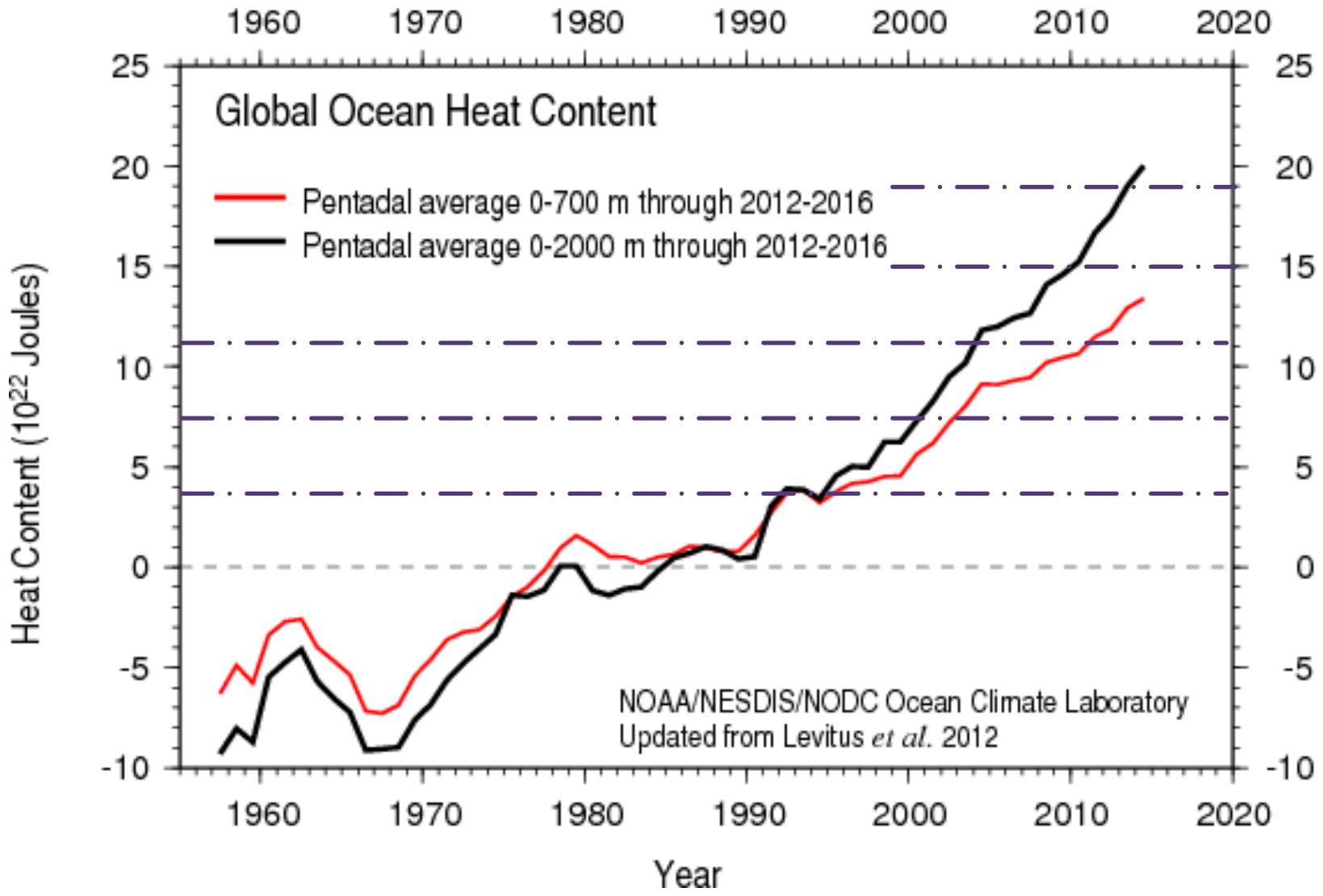
- Carbon dioxide (and other GHGs) are rising at ever increasing rates;
- Global economies must transition to low-carbon sources;
- The longer the delay, the higher the “shadow” cost to remove the carbon or find adaptations;
- Wind and solar technologies are mature and cost-effective; yet they depend on the weather as fuel and are variable;
- As more wind and solar is deployed, each new generator competes with others and can decrease its marginal value;
- Curtailments and transmission congestion can derail the build up of wind and solar. Increasing the cost of electricity and causing economic harm.

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The GHGs are Flooding The Planet With Additional Heat

The vertical distance between the purple dashed lines represent a century (100 years) of global human energy consumption

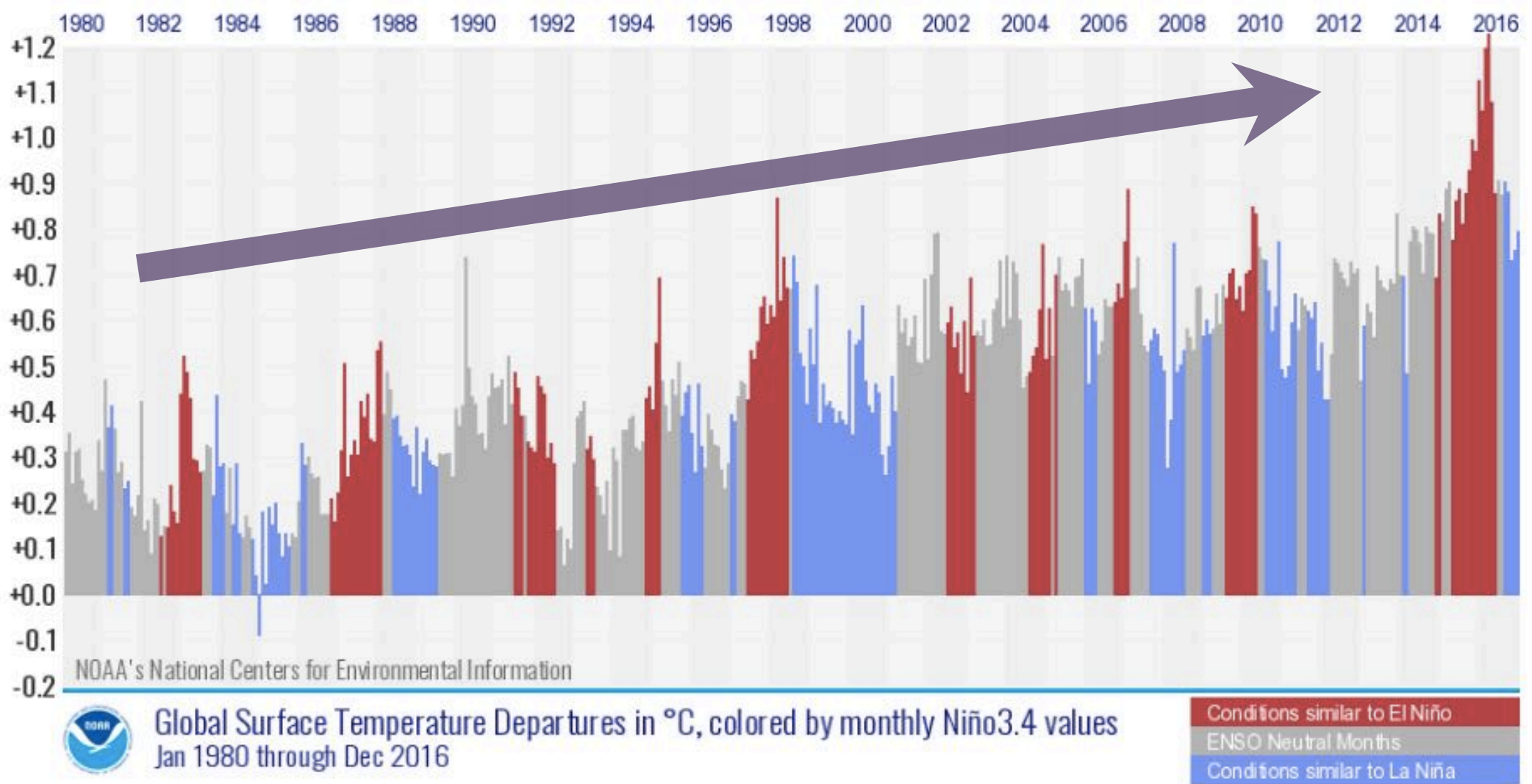
Each year there has been 20 years worth of human energy added to the oceans



500 years of human energy consumption added to ocean as heat in 25 years

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The Heating Effect is Piling Up in the Atmosphere



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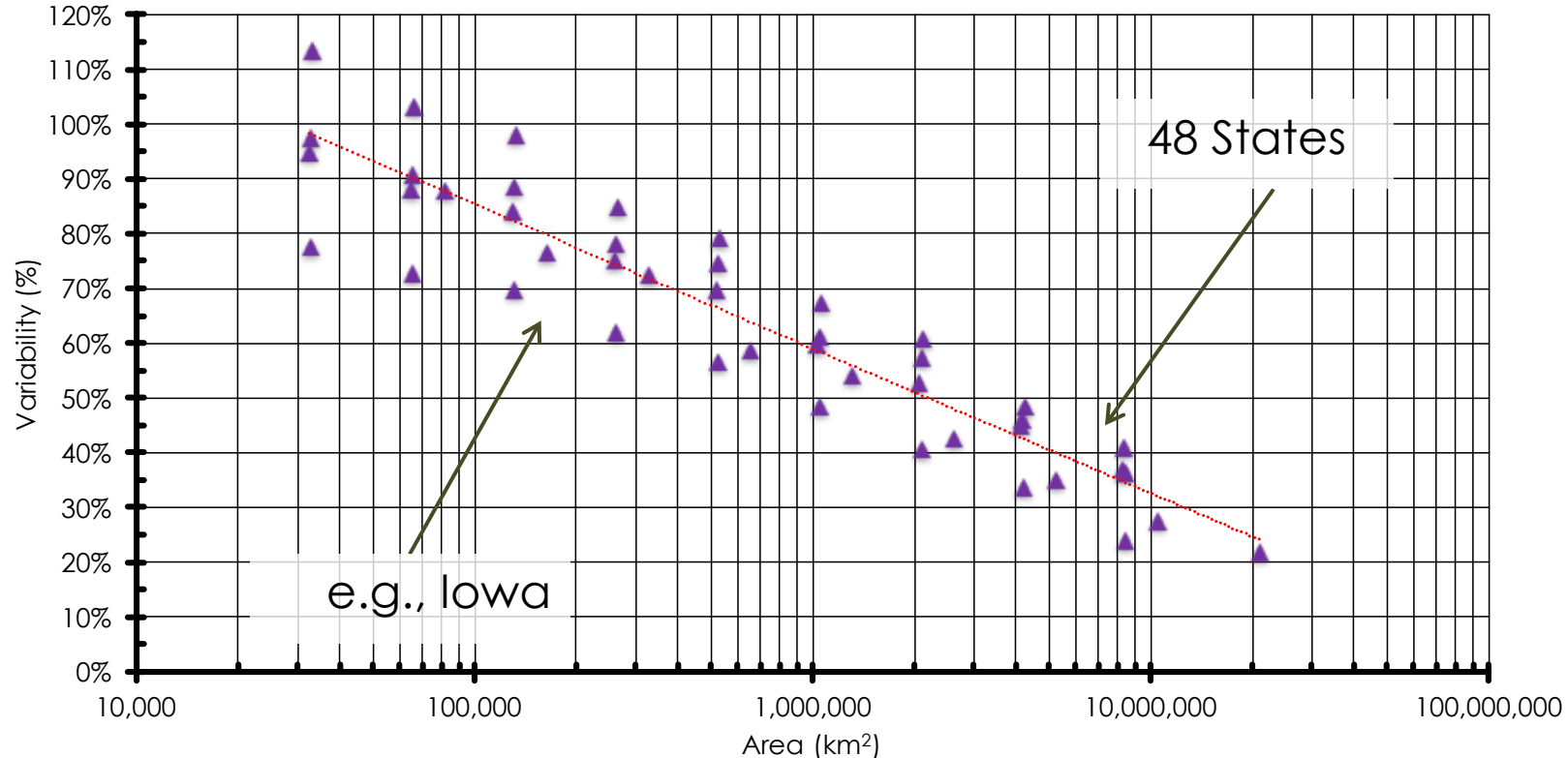
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Solution: Decarbonize the Economy with Renewable Energy

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Geographic Scale Adds Modeling Complexity, But Enhances Benefits of Wind and Solar

The variability of wind power with area

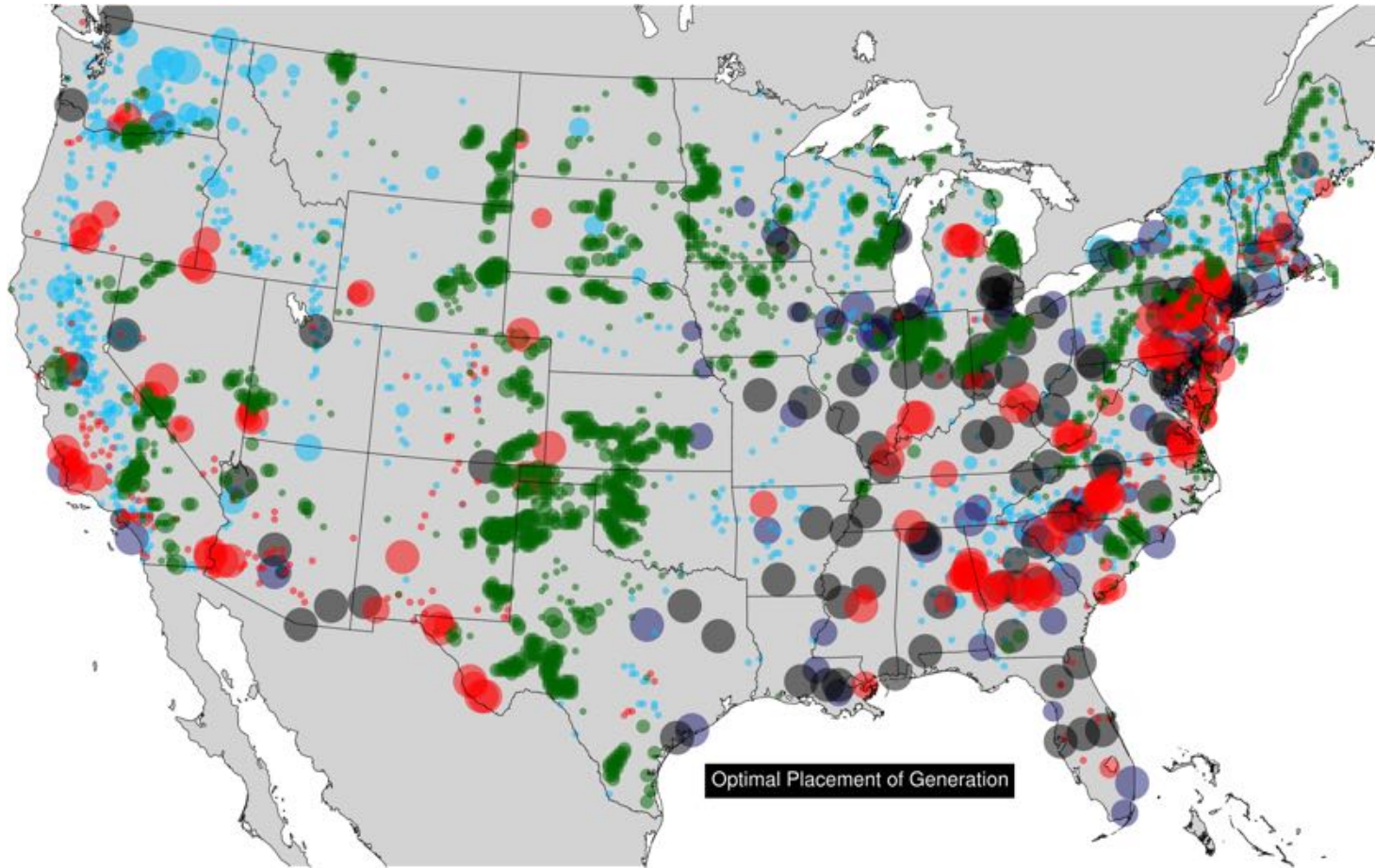


- Larger geographic areas reduce variability, but transmission needs to be considered;
- High resolution data (temporally and spatially) are needed to characterize the resource variability;
- **If scale, resolution, transmission and generation dispatch can be co-optimized, co-benefits emerge.**

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WIS:dom

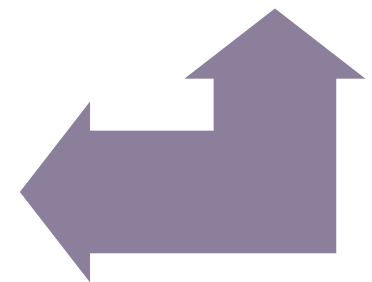
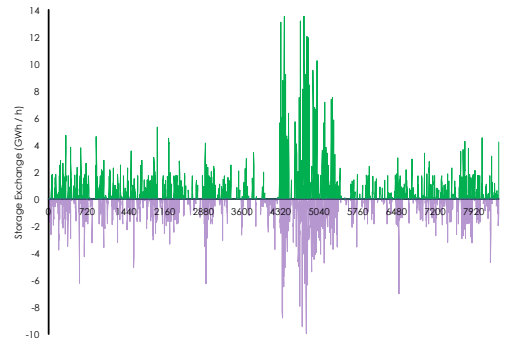
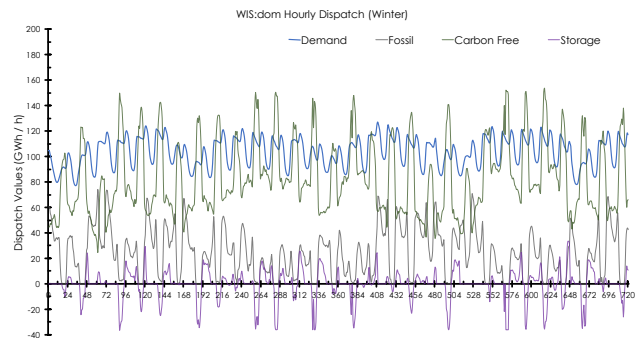
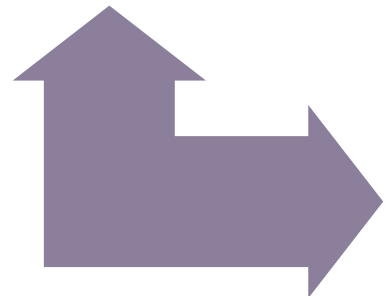
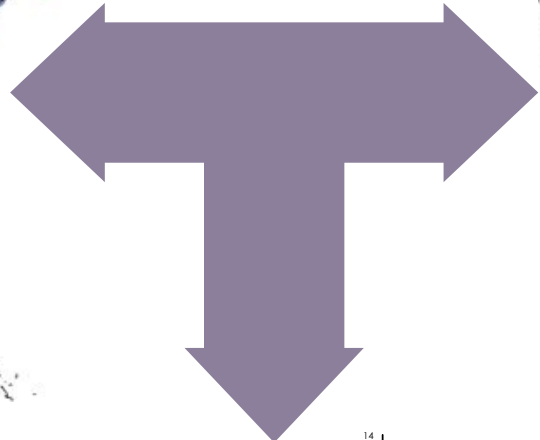
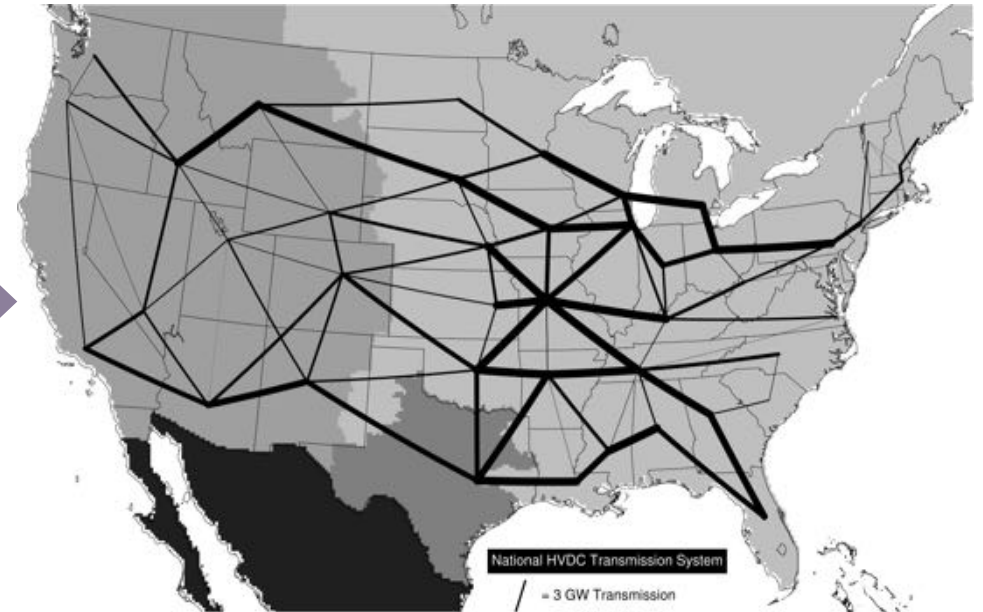
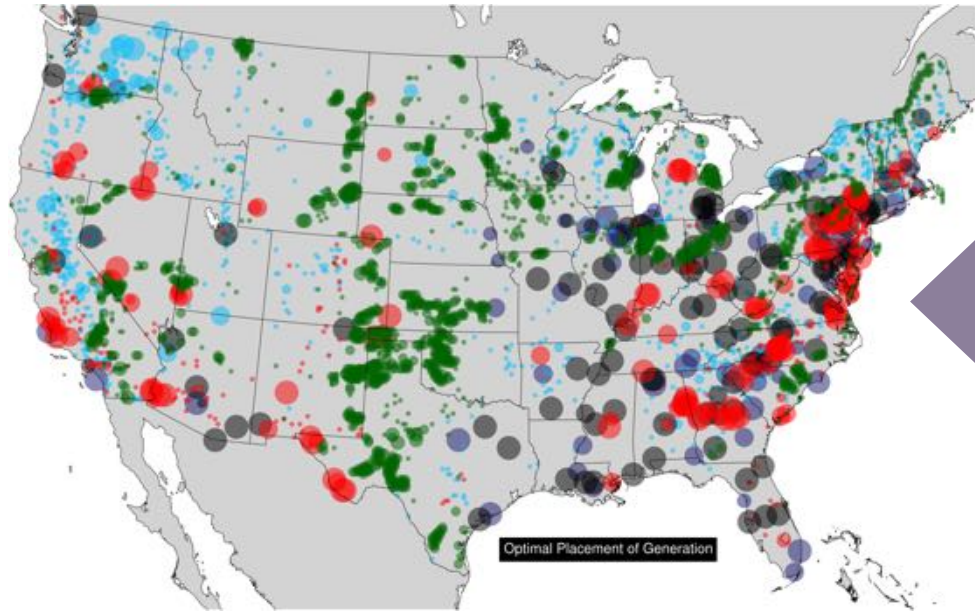
What is WIS:dom?



- The Weather-Informed energy System: for design, operations and markets optimization model.
- In its most mature form, it finds the least-cost energy system that meets the demand every time step, in every market without fail.
- It uses as many technologies as the user wishes and can optimize markets from the size of individual utilities up to the size of continents (such as the US, North America, Europe, China, India, Australia, etc.).
- Derives the profits of each generator and transmission line (each one must be profitable otherwise it is not selected).
- Can march forward in time to signal changing costs, policies, retirements, societal change, and more.
- WIS:dom is agnostic with respect to technology – it finds the cheapest mix to supply all the power needed.

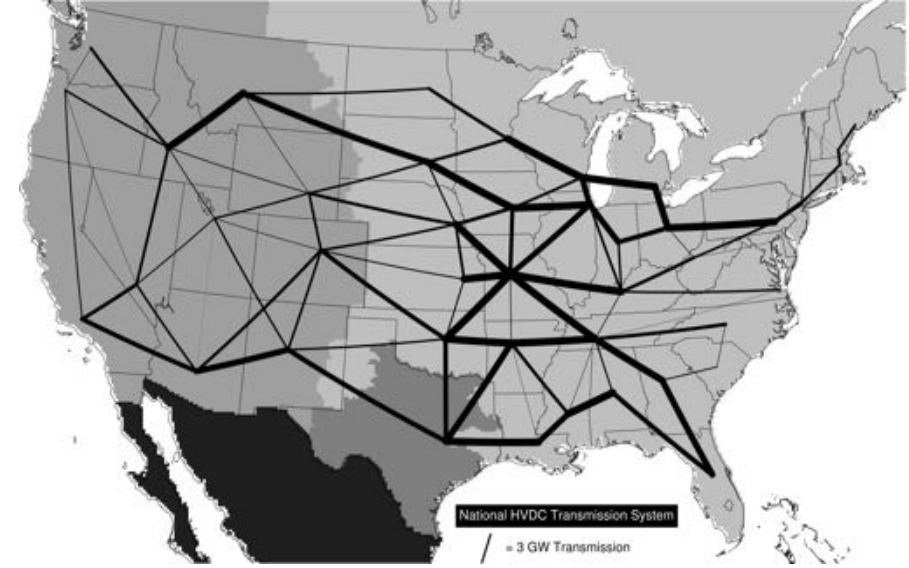
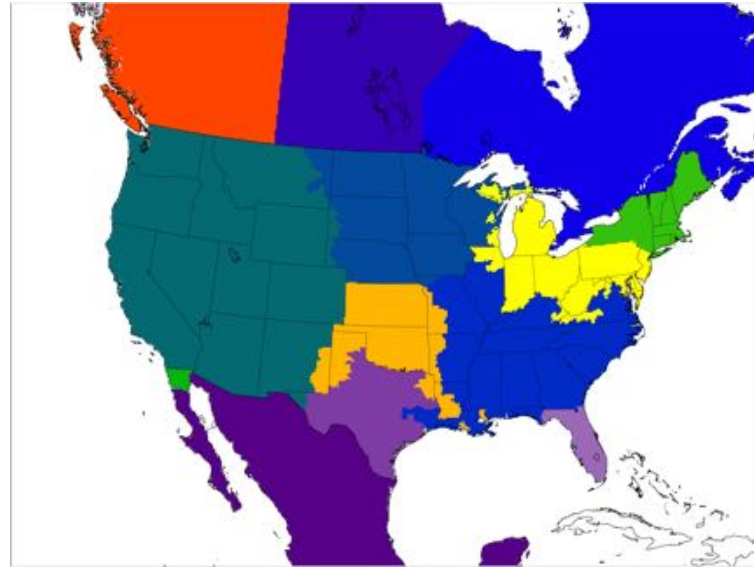
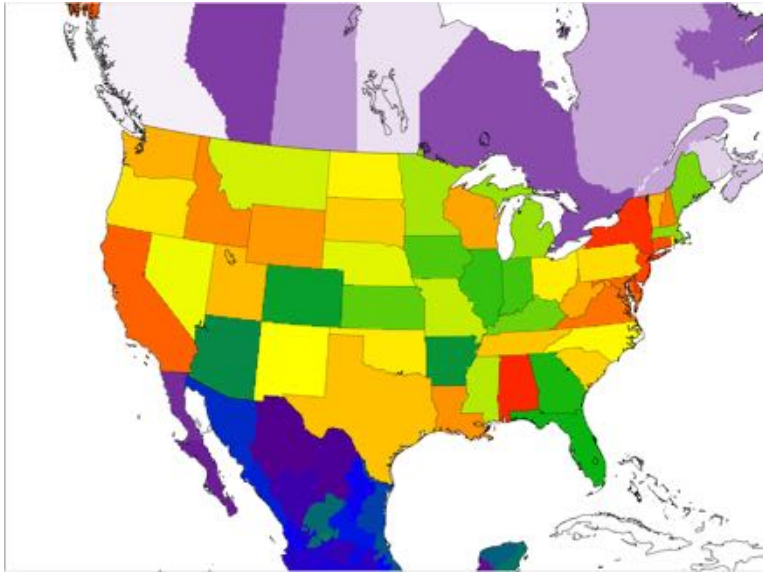
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Simultaneously solve generation, transmission, retirements, reserves, dispatch, loads and storage



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Consider Numerous Scales Simultaneously To Explore Optimal Configurations of the Energy Grid



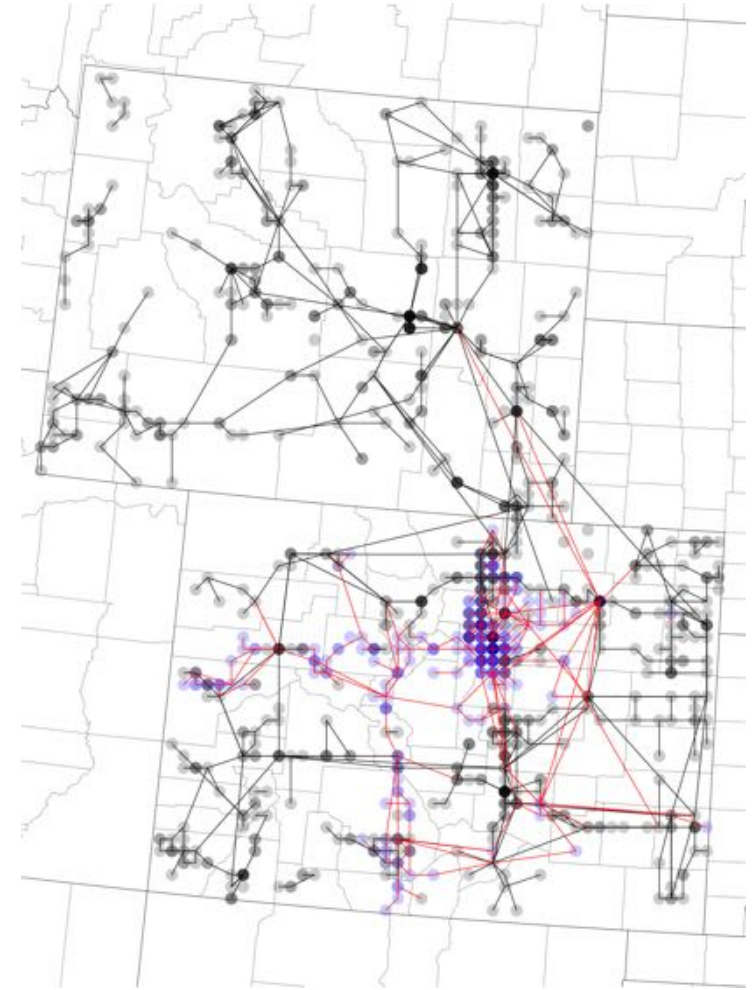
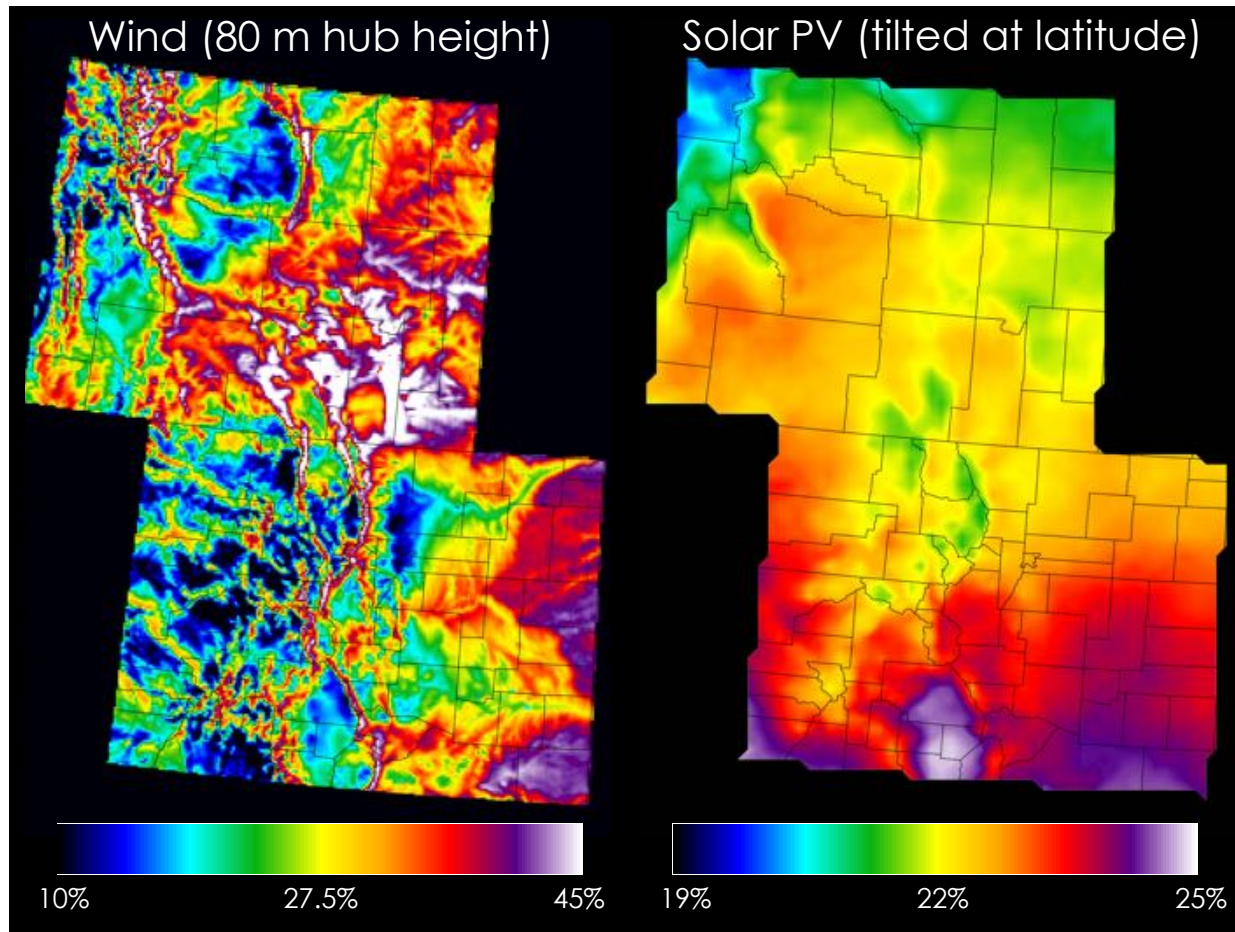
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Detailed localized knowledge to determine the best placement of generators to meet discrete demand profiles



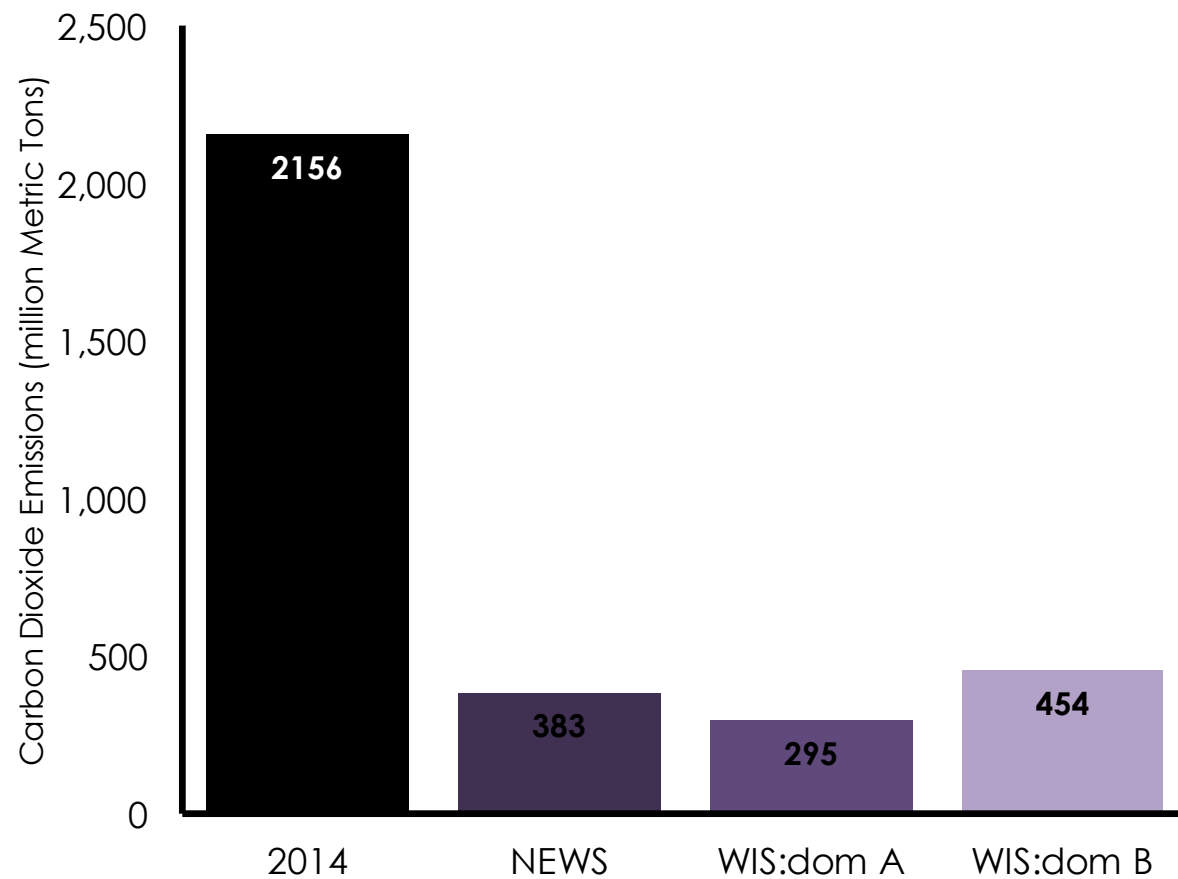
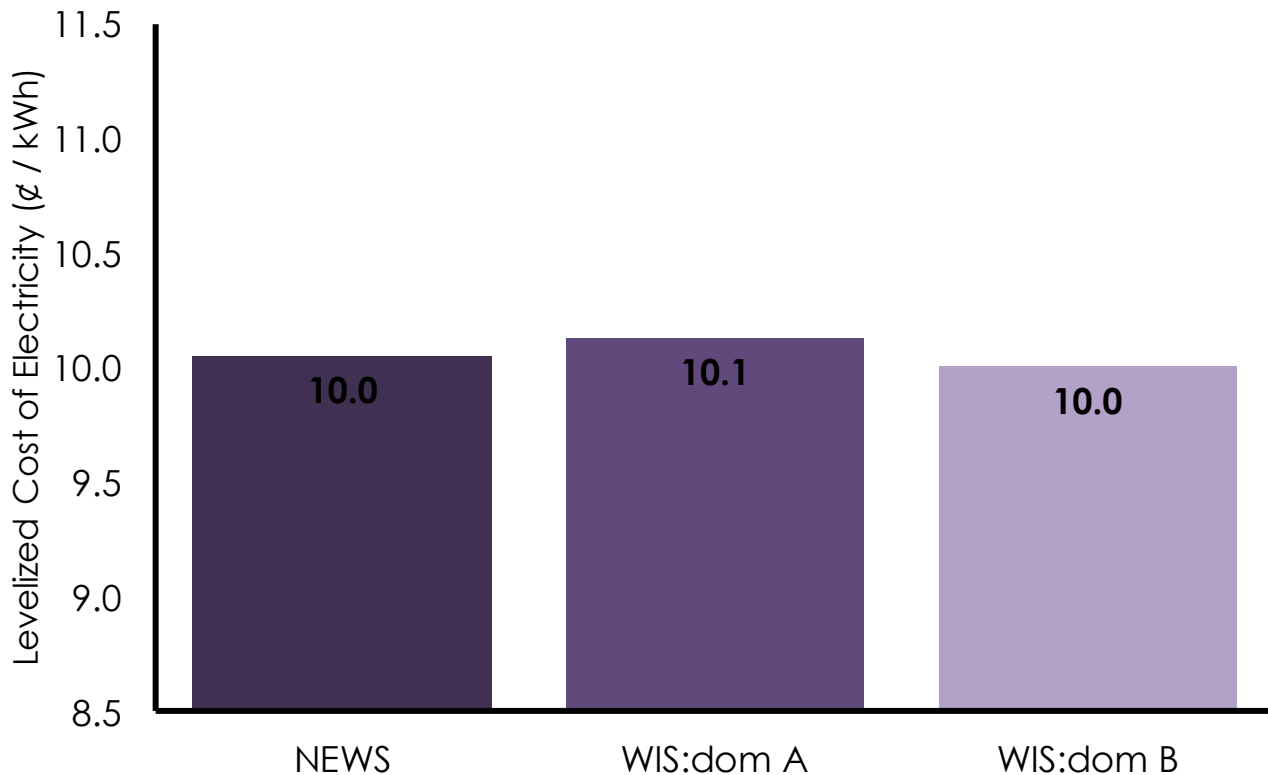
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Some Results and Analyses

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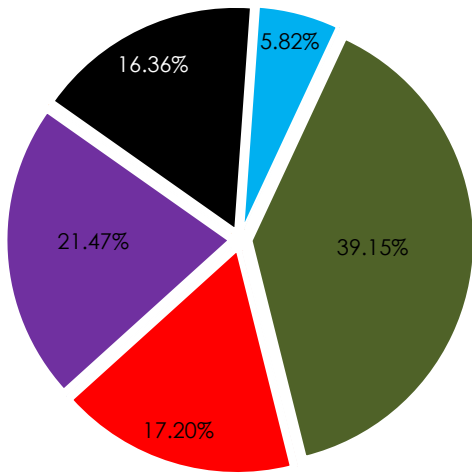
Low-Carbon Electricity Grid Doesn't Need to be Costly



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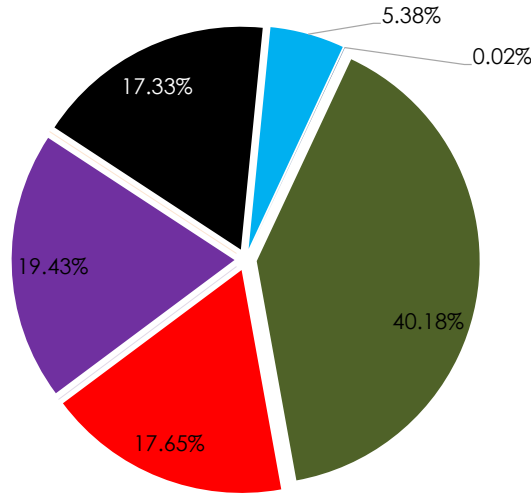
Low-Carbon Electricity Grid Incorporates Diverse Generation

NEWS



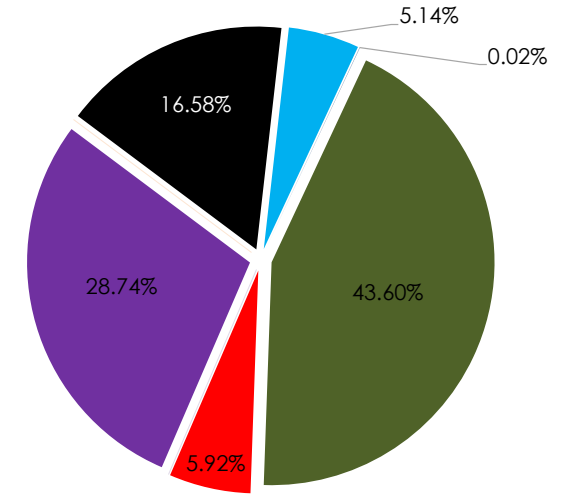
■ Onshore ■ Solar ■ Natural Gas CCGT ■ Nuclear ■ Hydroelectric

WIS:dom A



■ Offshore ■ Onshore ■ Solar ■ Natural Gas CCGT ■ Nuclear ■ Hydroelectric

WIS:dom B



■ Offshore ■ Onshore ■ Solar ■ Natural Gas CCGT ■ Nuclear ■ Hydroelectric

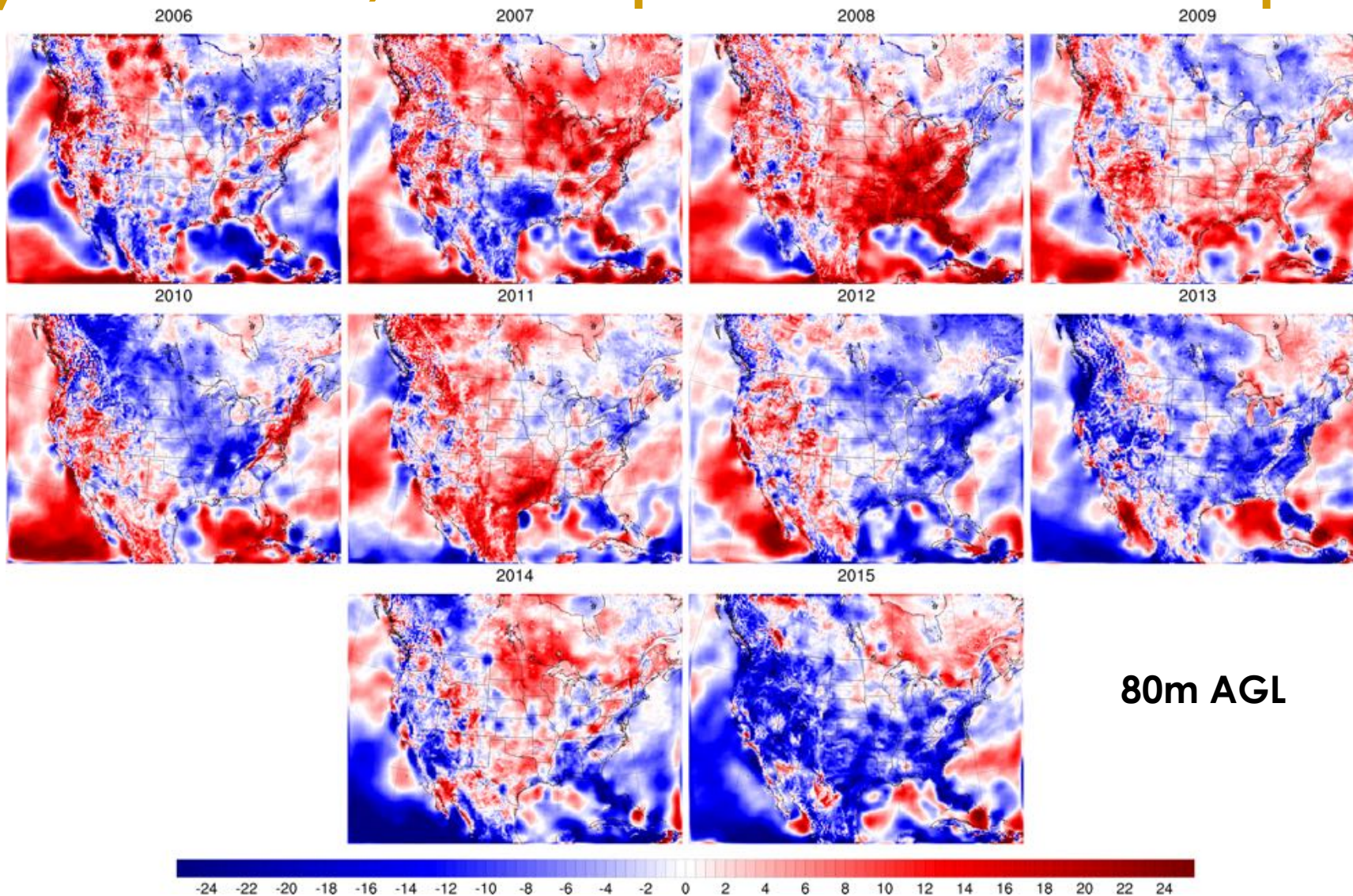
2030 estimated costs results in 79% carbon-free

2030 estimated costs with state-based transmission

2014 costs with ITC still result in lower solar PV energy

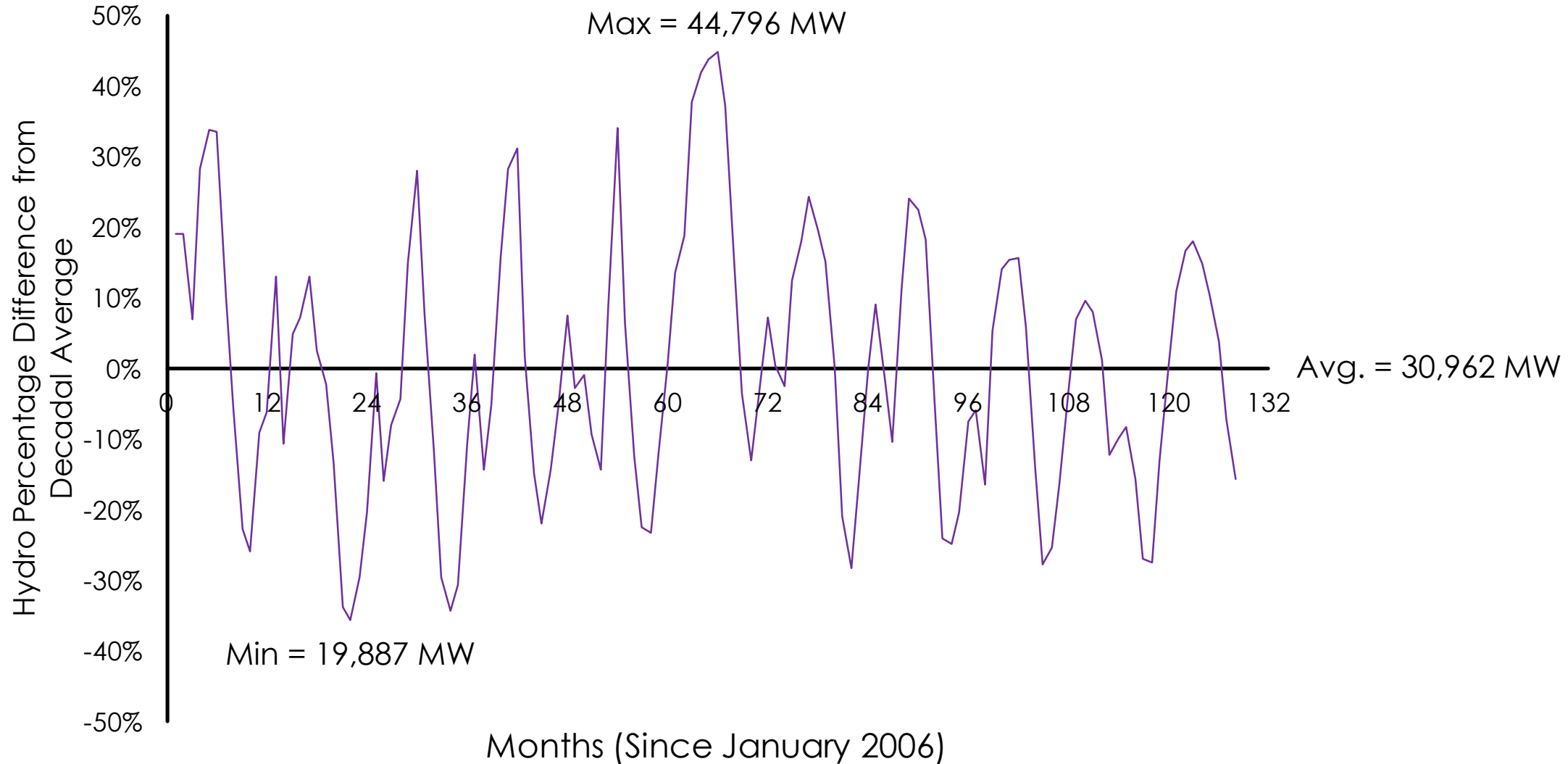
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Why Is there ~20% Back Up Generation In The Optimal?



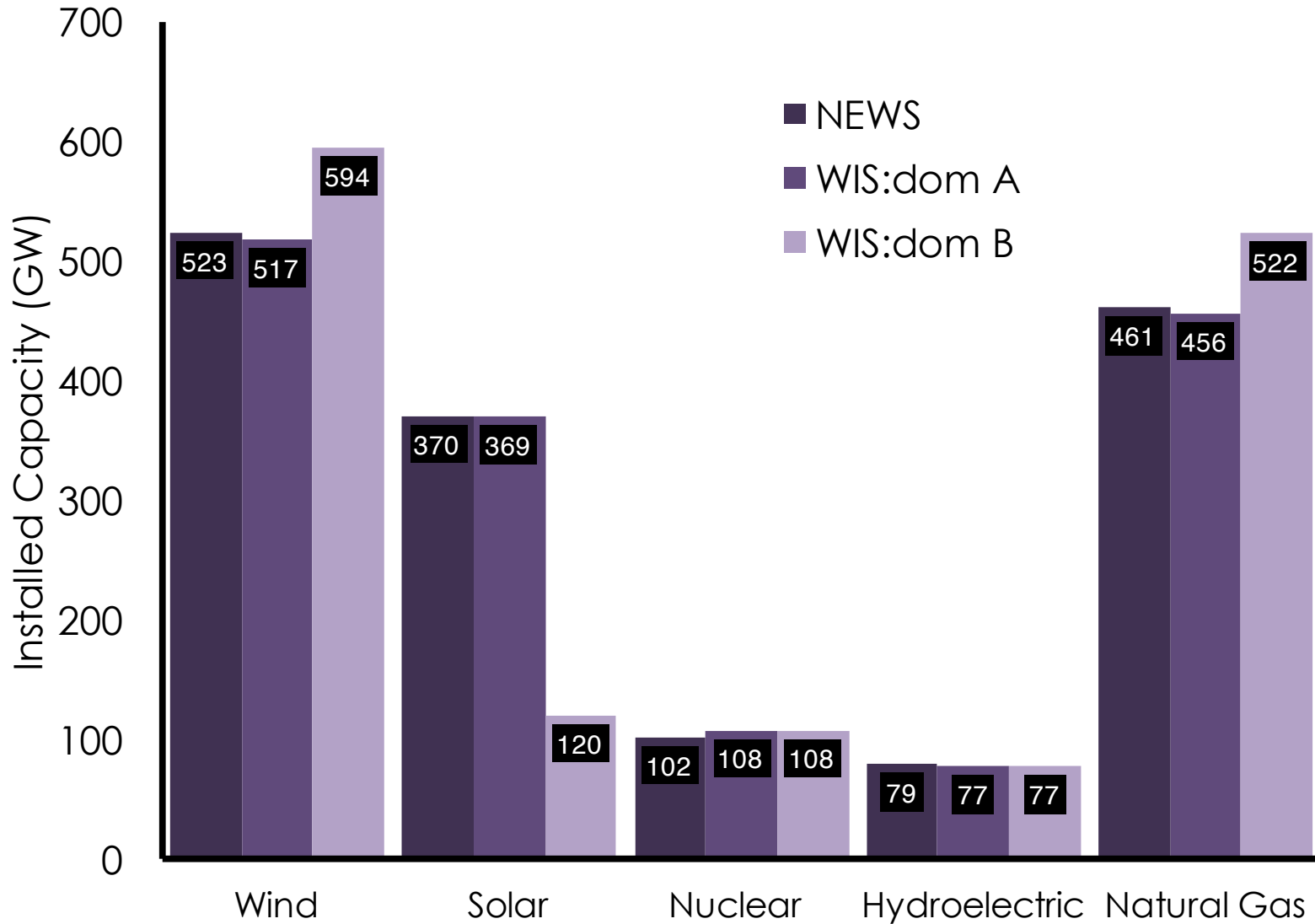
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Why Is there ~20% Back Up Generation In The Optimal?



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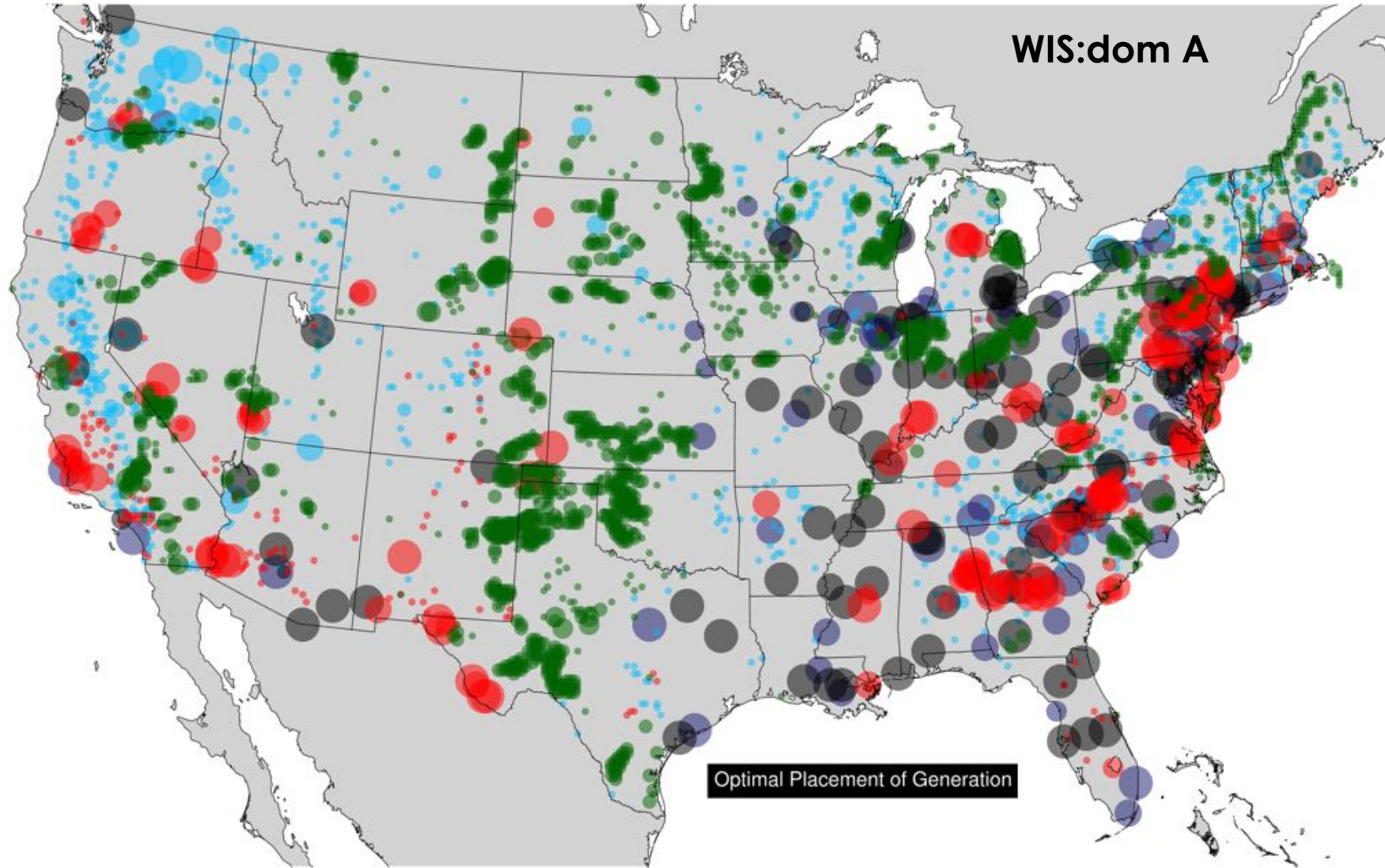
Low-Carbon Electricity Grid Incorporates Diverse Generation



As “cost” parity is approached
the installed capacities tend to:
wind = solar PV = natural gas

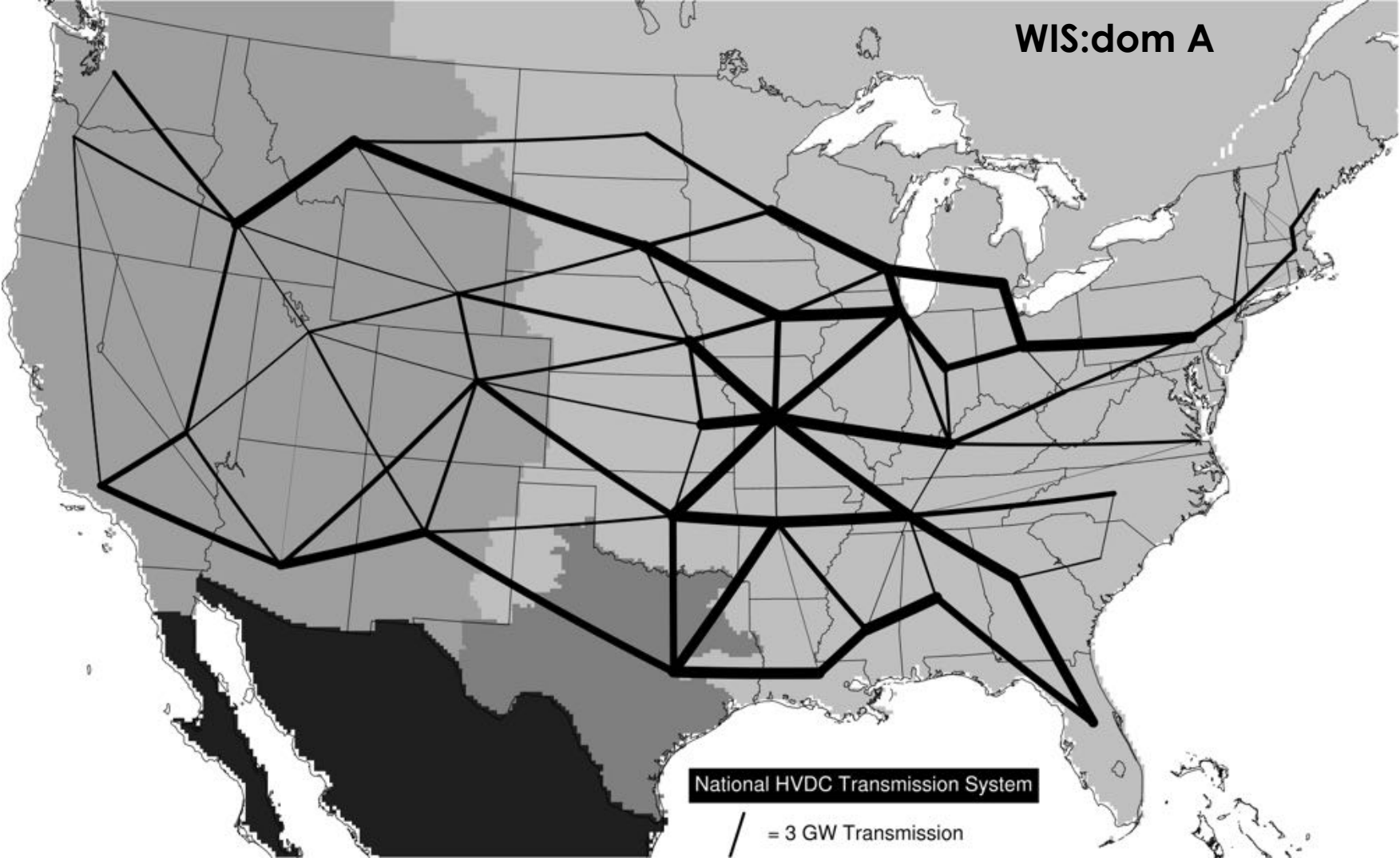
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Low-Carbon Electricity Grid Can Include All States



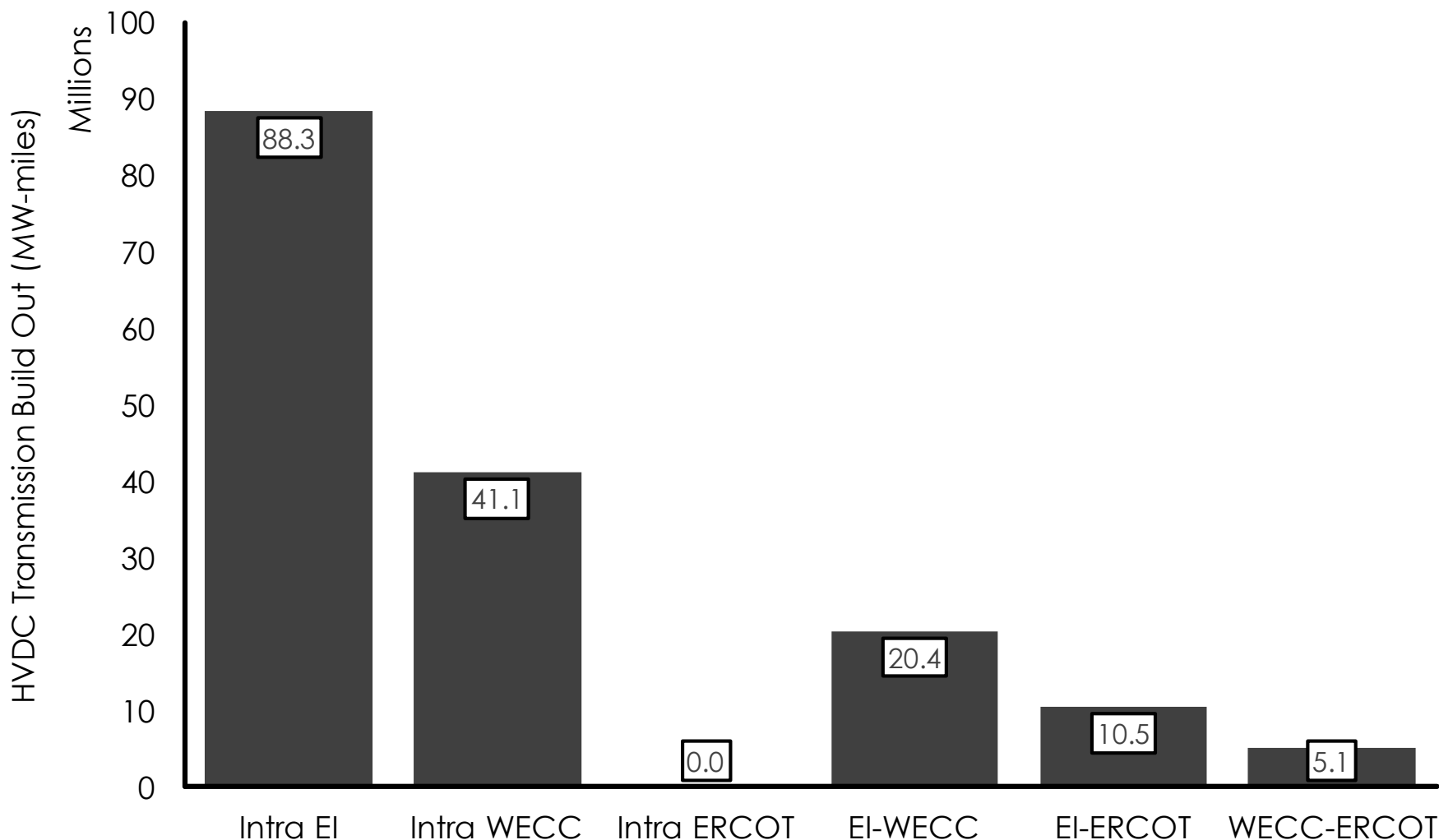
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Low-Carbon Electricity Grid Can Include All States



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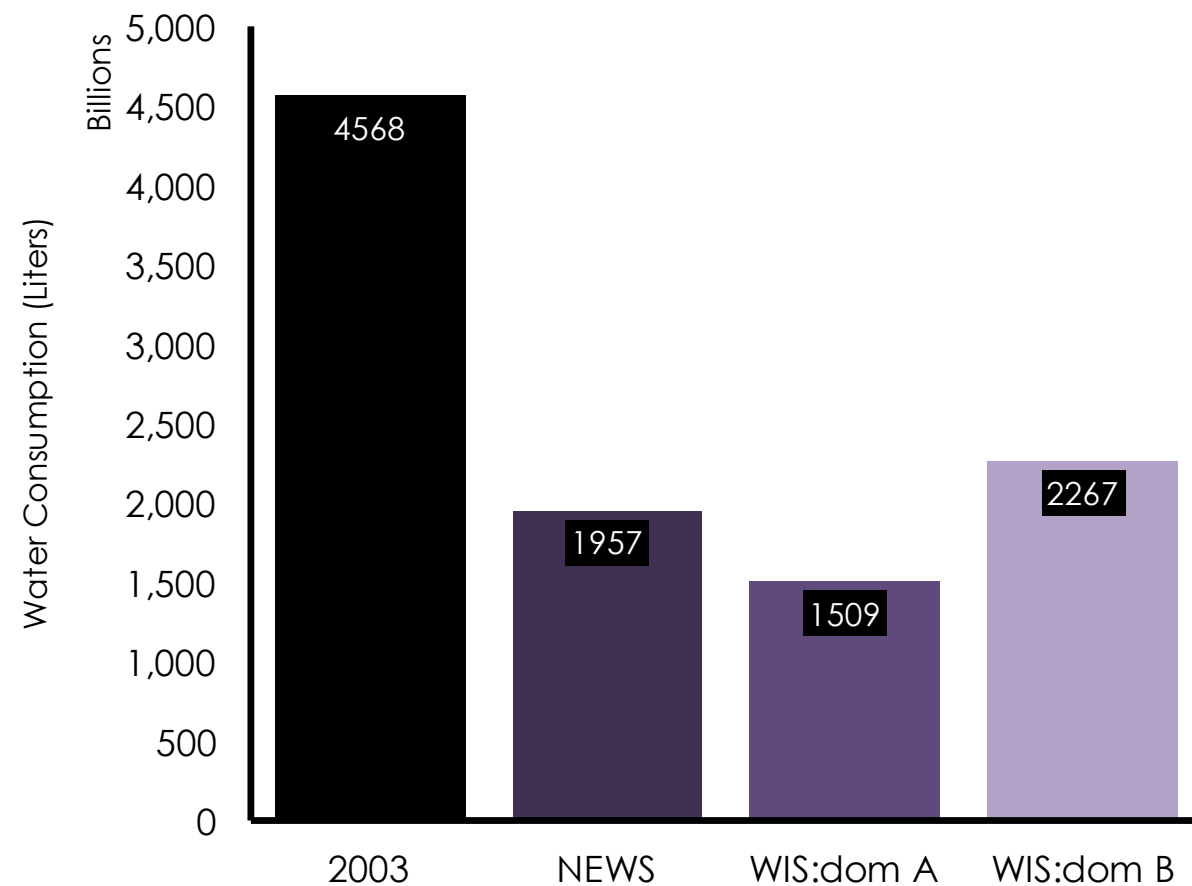
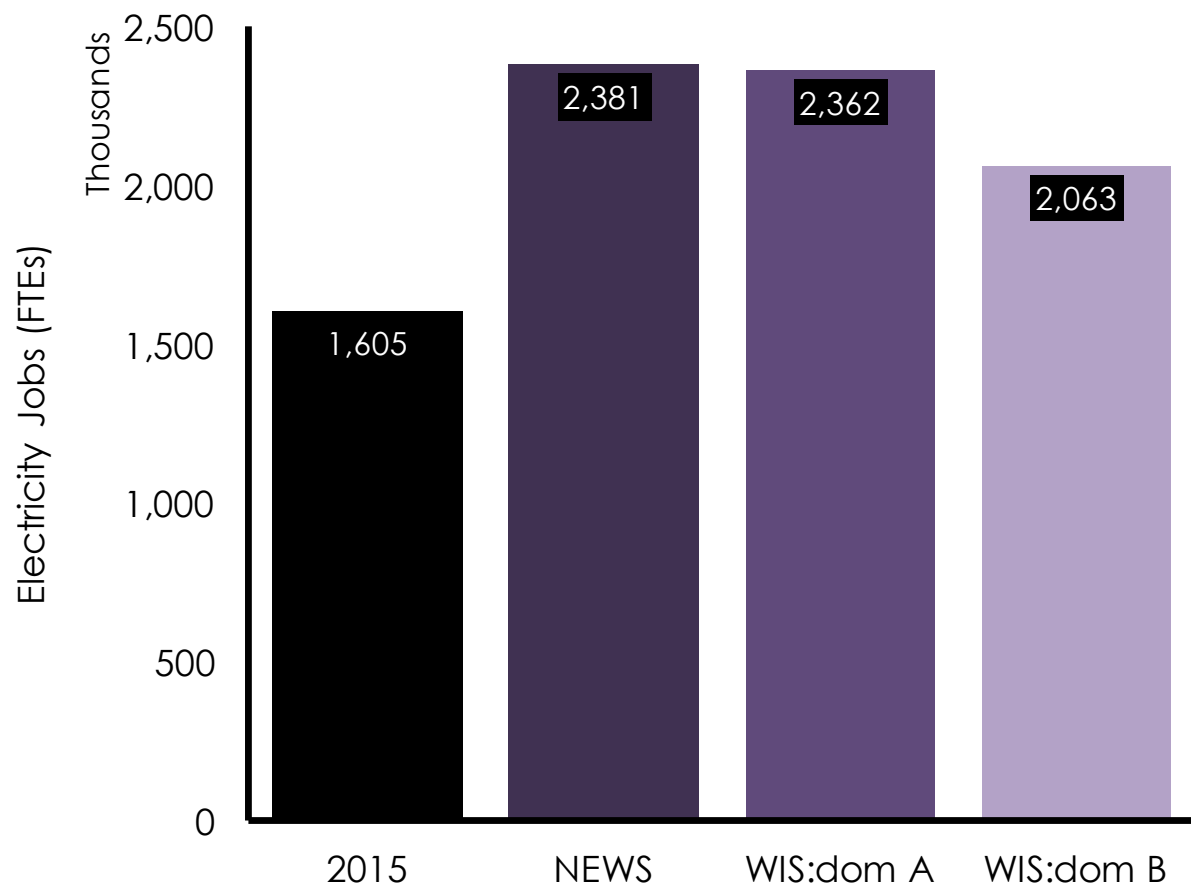
Low-Carbon Electricity Grid Needs a National HVDC superhighway



- The majority of the hypothetical HVDC transmission superhighway would be built within existing interconnects
- The most important connections between interconnects are along the “East-West Seams”
- Cost per MWh of electricity delivered is 0.39¢.
- Can make the system more robust, resilient and reliable.

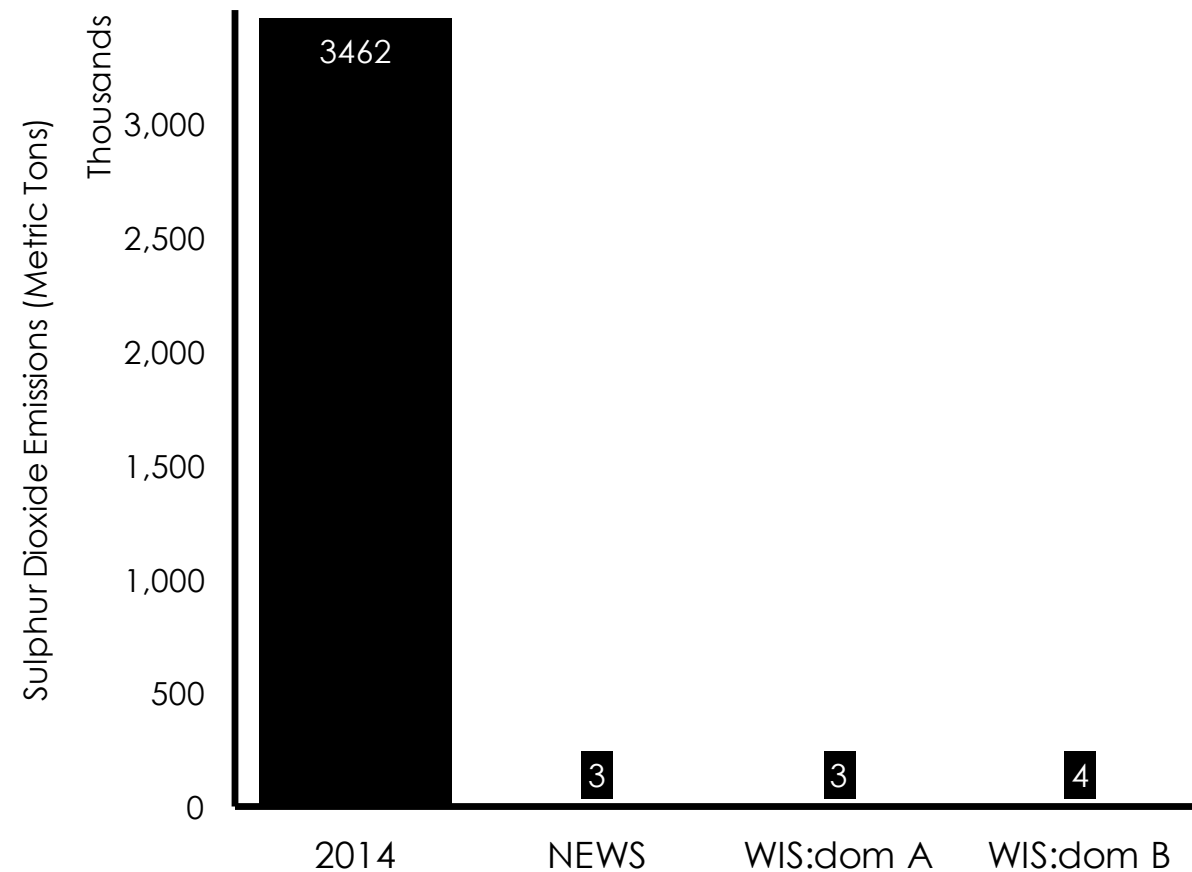
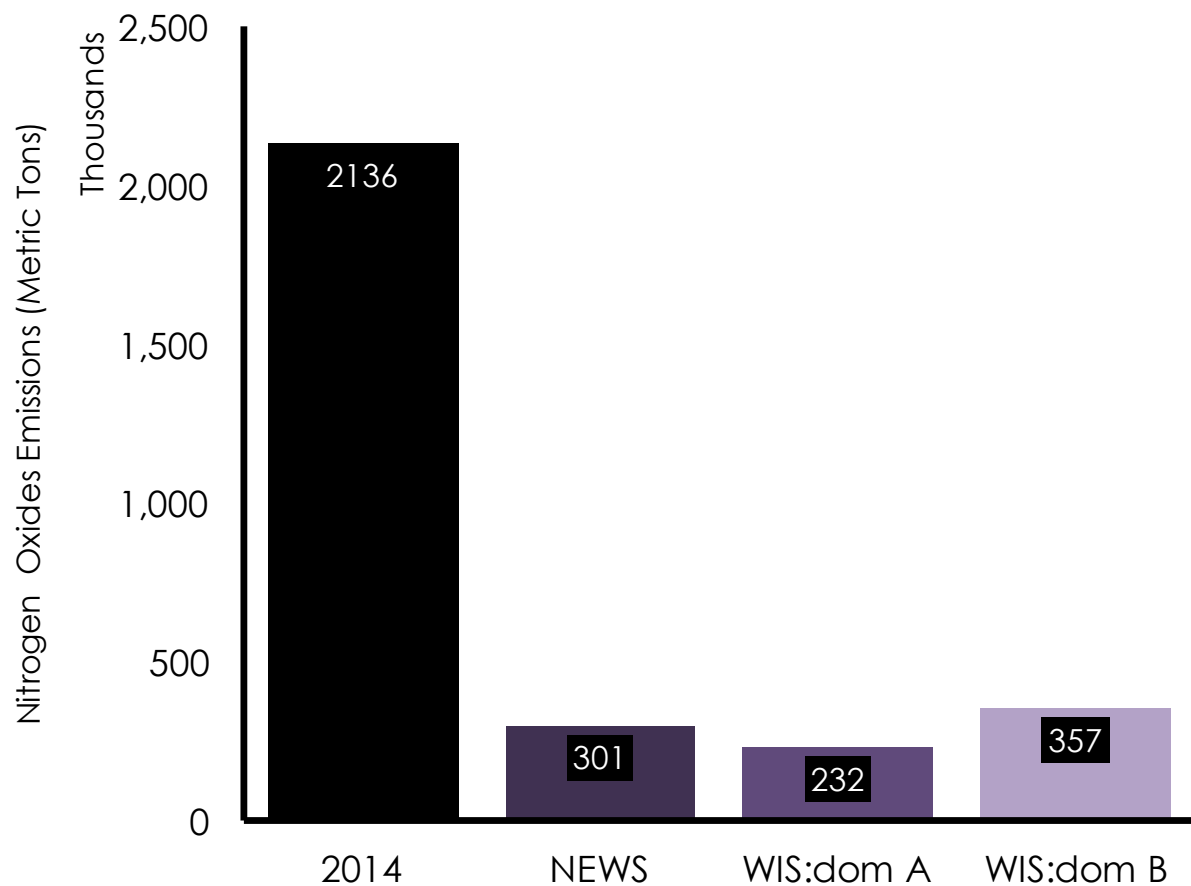
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Low-Carbon Electricity Grid Brings Other Local Benefits



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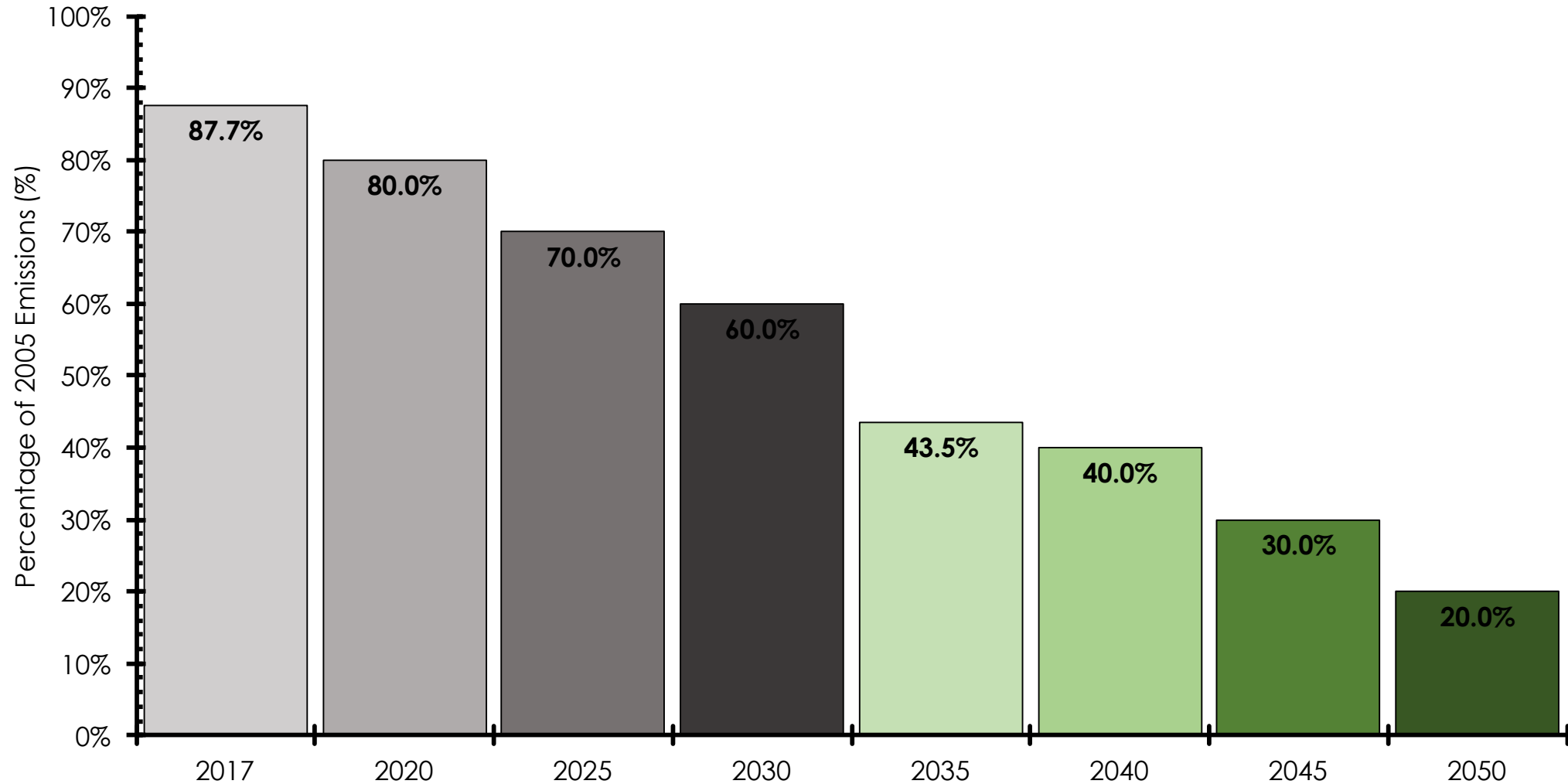
Low-Carbon Electricity Grid Brings Other Local Benefits



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WIS:dom has already been used in MISO footprint for Storage

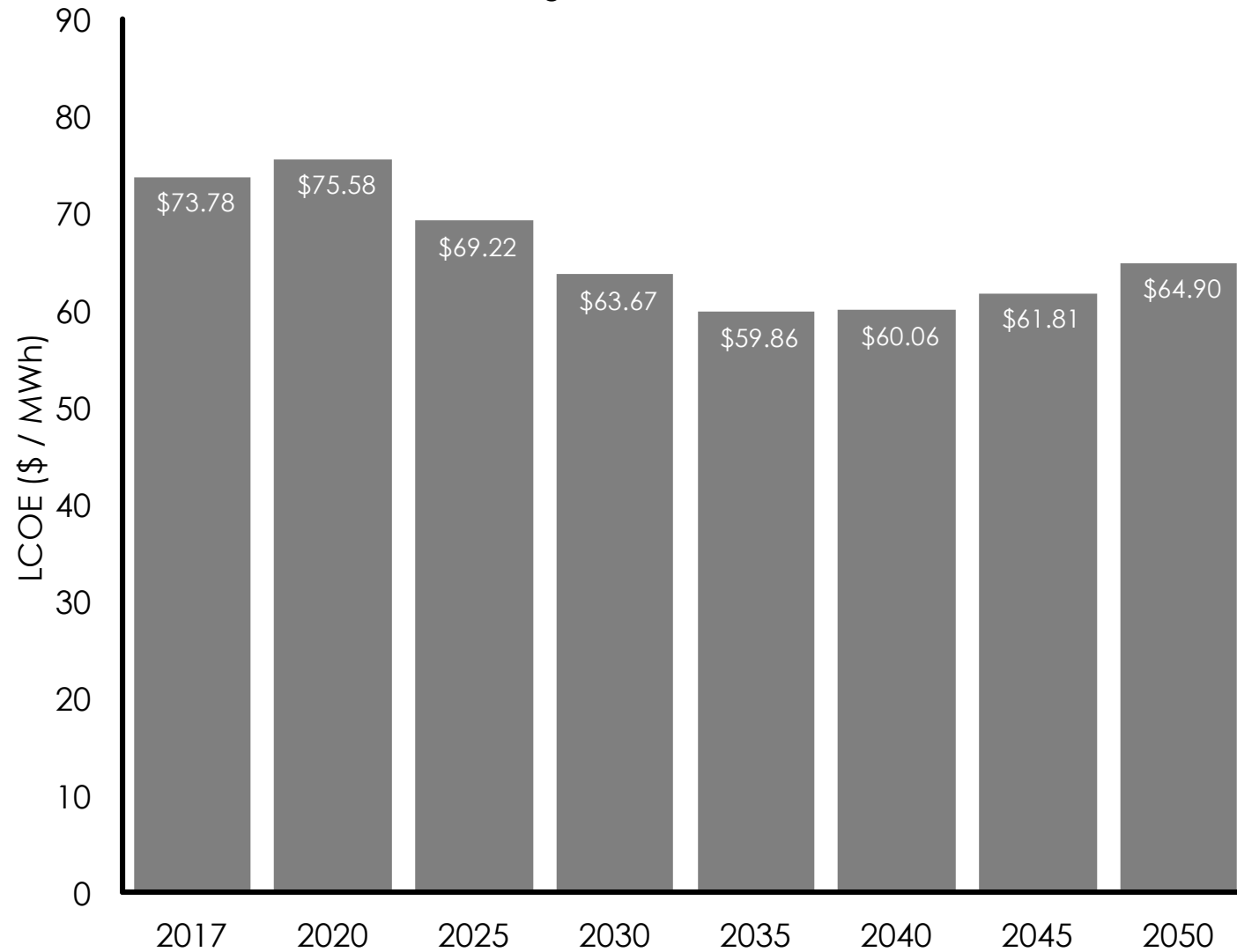
WIS:dom Carbon Dioxide Emissions for MISO Electricity Generation



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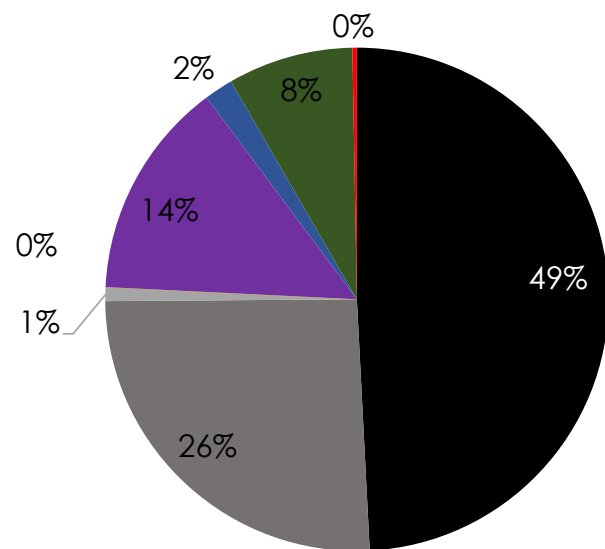
LCOE for Transmission & Storage Allowed, GHG Constraints Scenario



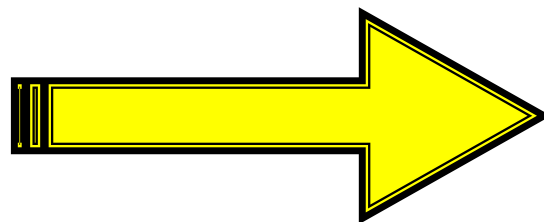
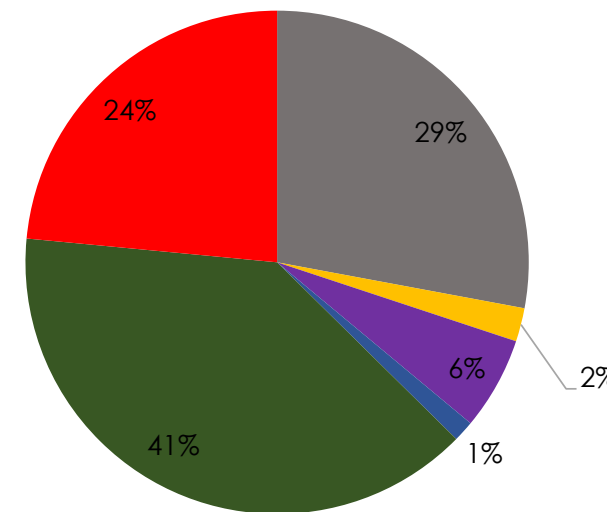
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WIS:dom has already been used in MISO footprint for Storage

WIS:dom Estimated Electricity Generation By Source (2017)



WIS:dom Estimated Electricity Generation By Source (2050)



■ Coal ■ CCGT ■ CT ■ Storage Discharge ■ Nuclear ■ Hydro ■ Wind ■ Solar

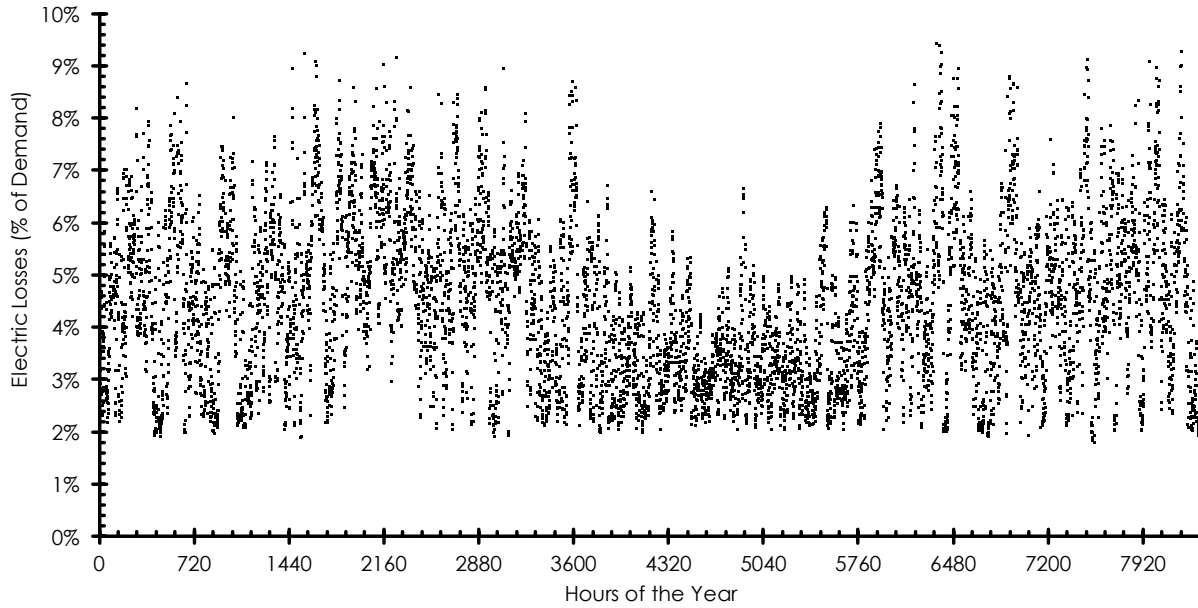
■ Coal ■ CCGT ■ CT ■ Storage Discharge ■ Nuclear ■ Hydro ■ Wind ■ Solar

- Wind and Solar PV become the dominant generation sources by 2050;
- Natural Gas combustion turbines are all retired;
- Only some of the nuclear power plants are retired;
- All coal fired power plants are fully retired;
- Storage discharge accounts for 2% of the dispatched energy.

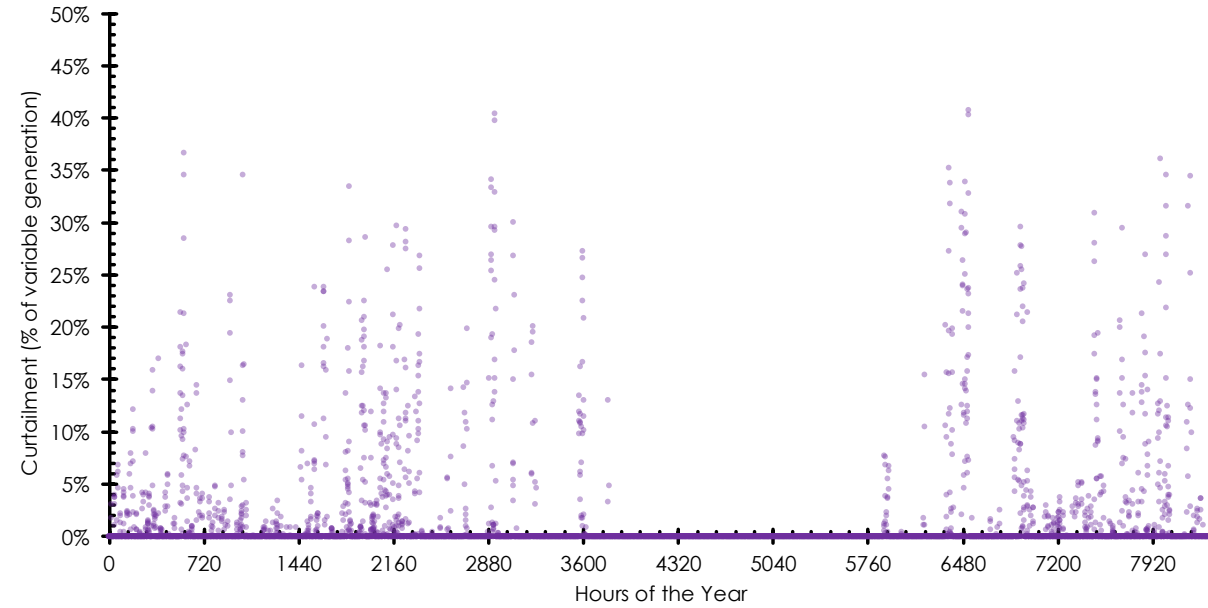
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Low-Carbon Electricity Grid Increases Transmission Use and Curtailment

WIS:dom Hourly Electric Losses



WIS:dom Hourly Curtailment of Wind and Solar PV



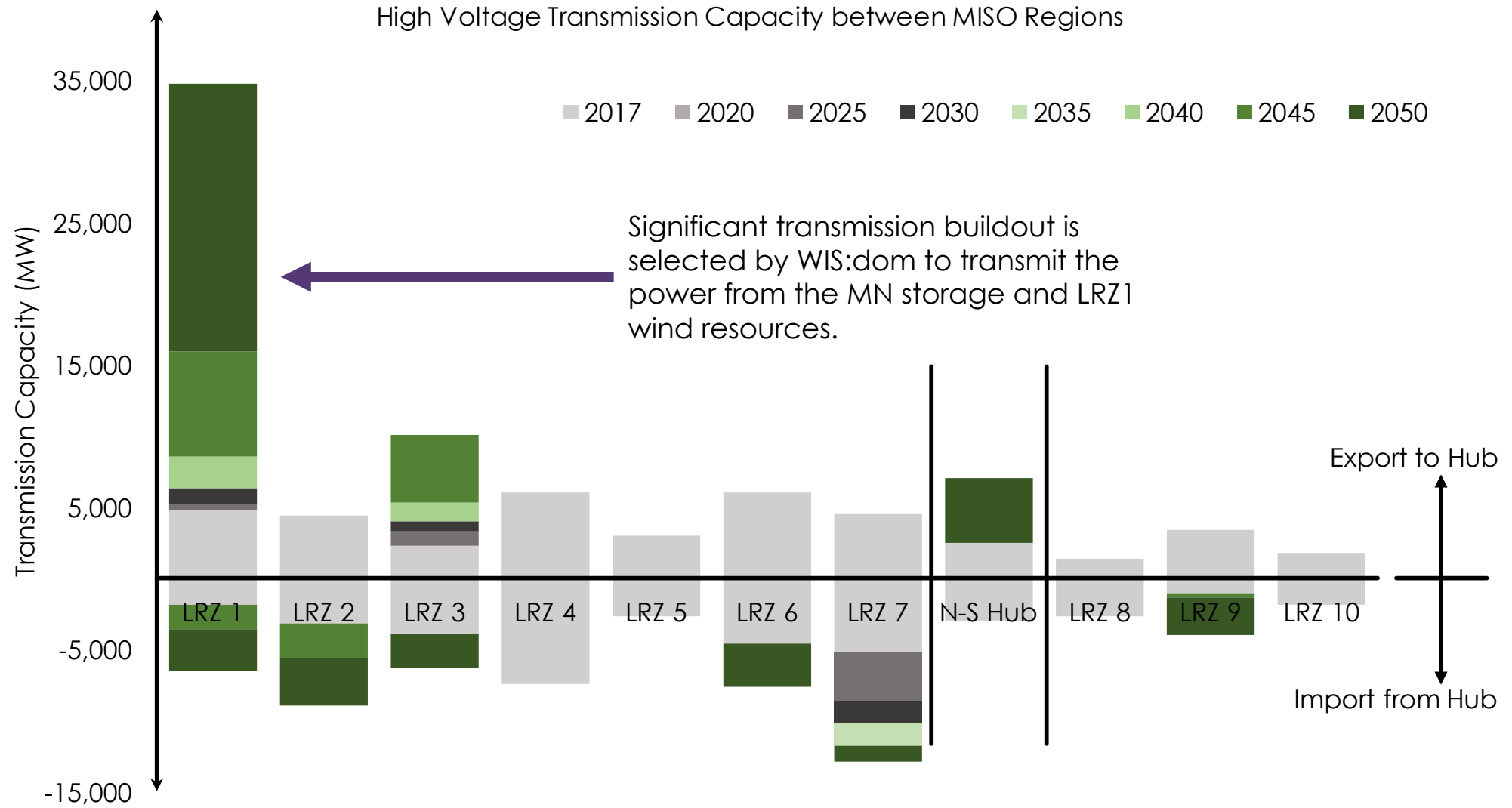
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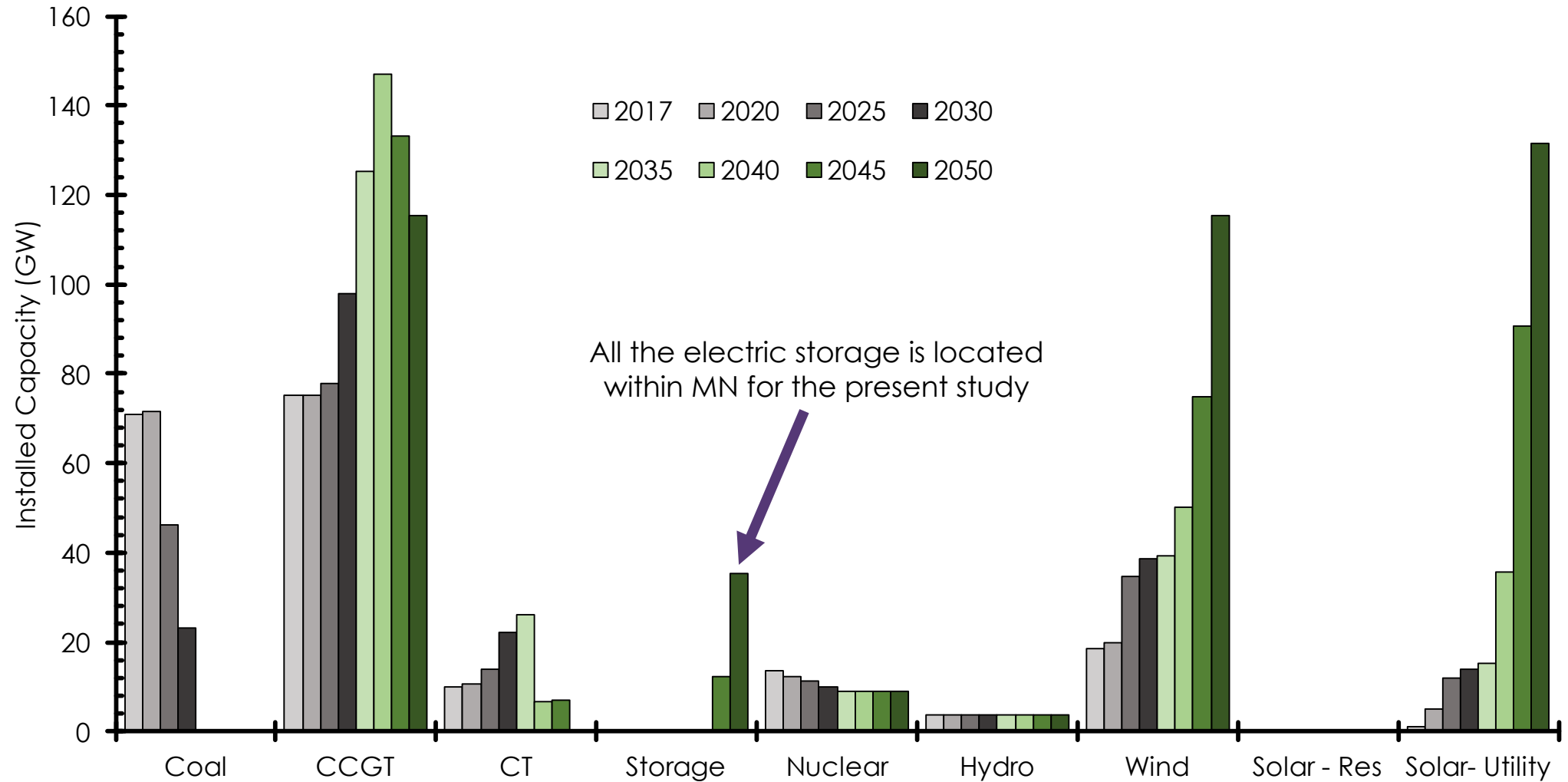
WIS:dom has already been used in MISO footprint for Storage



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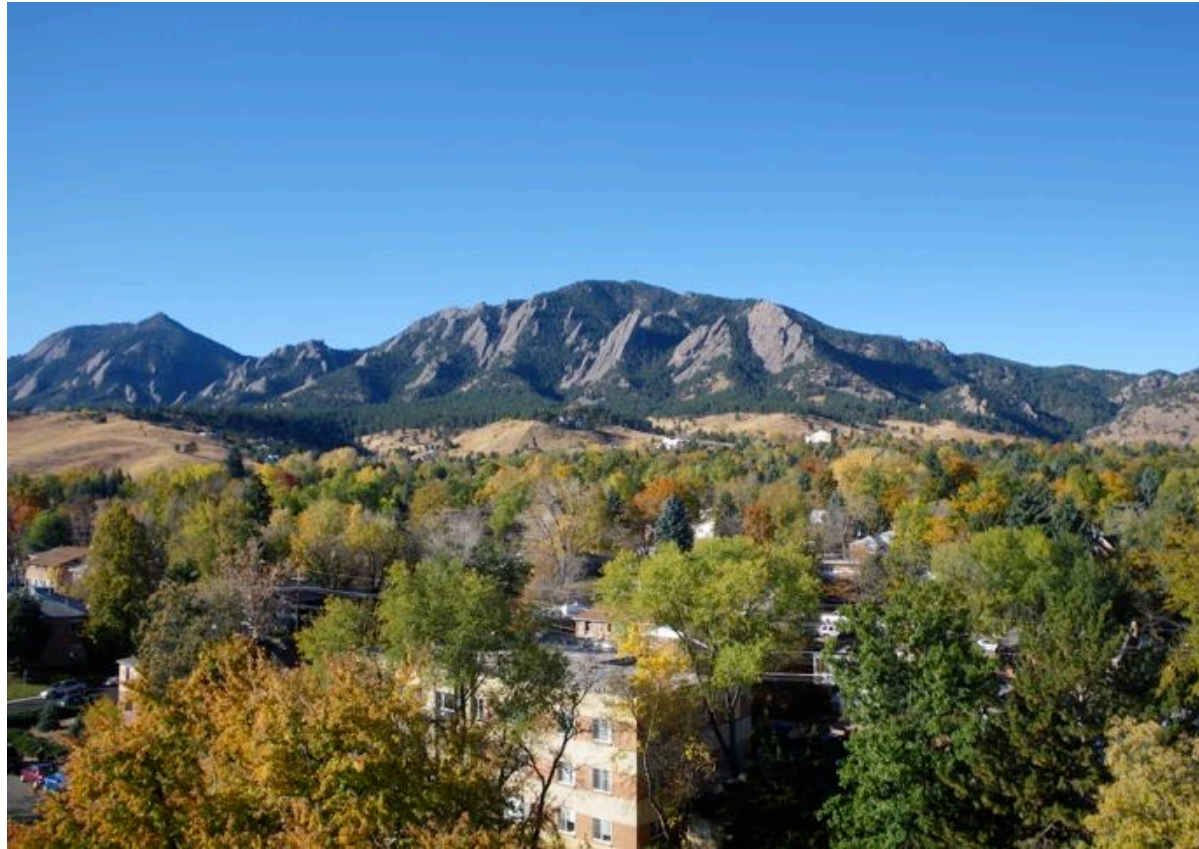
WIS:dom has already been used in MISO footprint for Storage

WIS:dom Installed Capacities for MISO



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We are here to help and answer any questions you have



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