

The role of transmission in deep decarbonization

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Energy Systems Integration Group
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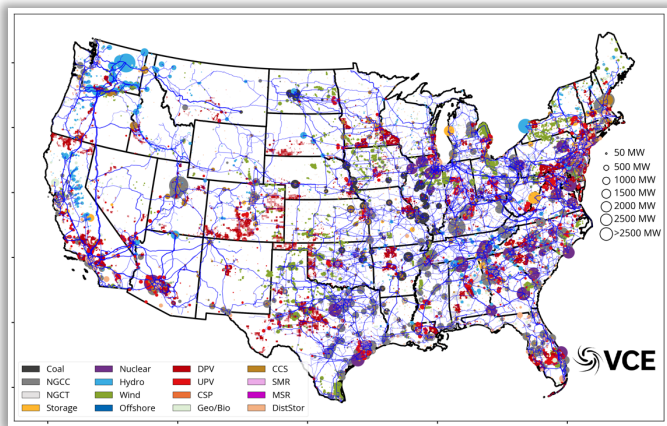
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questions!



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Vibrant Clean Energy

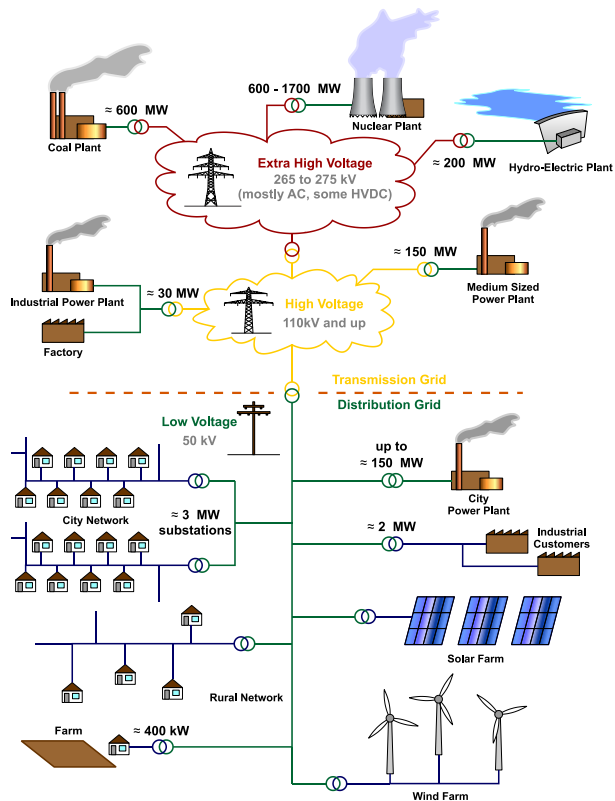


Purpose of Vibrant Clean Energy, LLC:

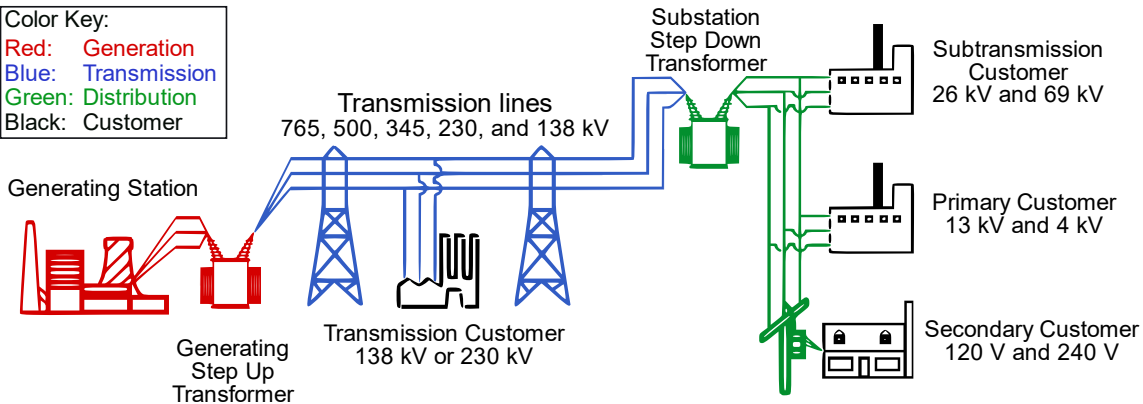
- Reduce the cost of electricity and help evolve economies to near zero emissions;
- Co-optimize transmission, generation, storage, and distributed resources;
- Increase the understanding of how Variable Generation impacts and alters the electricity grid and model it more accurately;
- Agnostically determine the least-cost portfolio of generation that will remove emissions from the economy;
- Determine the optimal mix of VG and other resources for efficient energy sectors;
- Help direct the transition of heating and transportation to electrification;
- **License [WIS:dom](#)® optimization model & [data](#) and/or perform [studies](#) using the model;**
- Ensure profits for energy companies with a modernized grid;
- Assist clients unlock and understand the potential of high VRE scenarios, as well as zero emission pathways.



What is transmission?

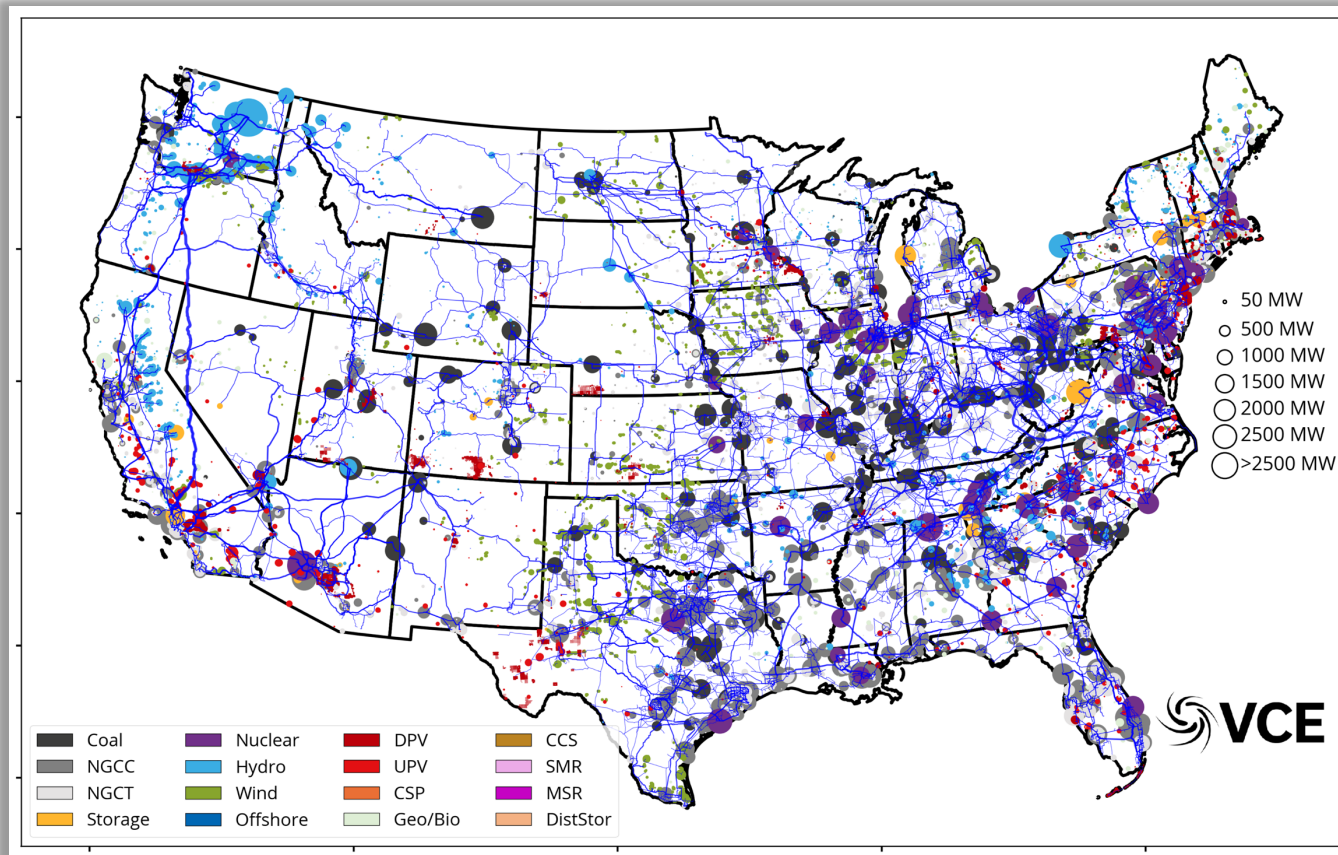


Color Key:
Red: Generation
Blue: Transmission
Green: Distribution
Black: Customer



Transmission is the wires that connect us all together. It moves generation around an electric grid until it is consumed.

The Continental United States Electric Grid (2018)



Available Clean Generation Are Tied To Electricity

Low-marginal Cost Electricity Production Resources (kWh)

- *Wind*
- *Solar*
- *Geothermal*
- *Nuclear*
- *Hydroelectric*

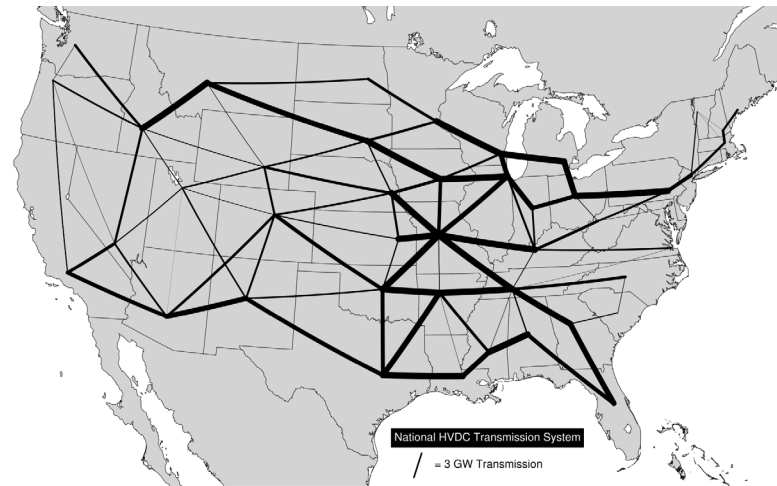
Flexibility Resources (kWh → kW → kWh)

- **Transmission**
- *Hybrid Resources (wind+solar+storage)*
 - *Storage (electricity+heat)*
 - *Electrification*
 - *Direct Air Capture*
 - *Demand-side management*
- *Dispatchable Generation (SMR, EGS, H₂ CC, NGCC+CCS)*
 - *Synthetic Fuel/Chemical Production (H₂, CH₄, NH₃)*
 - *Peaking Generation (H₂ CT)*

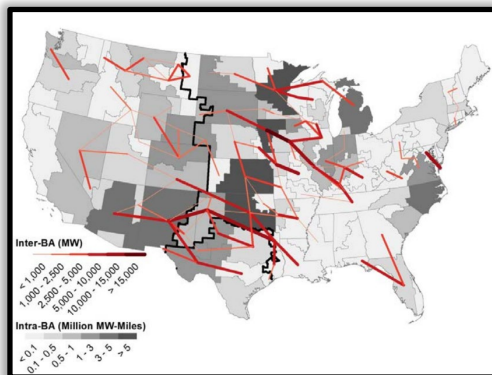
Why is transmission important?

Transmission unlocks:

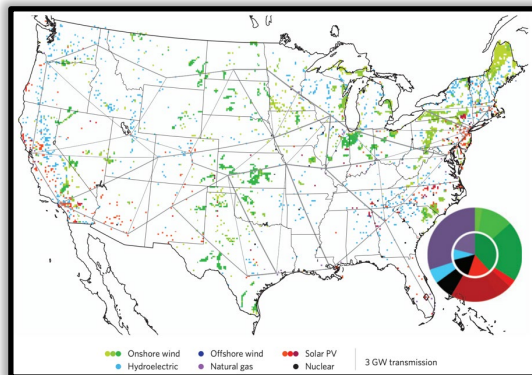
- Easier decarbonization of electricity grid;
- More efficient electrification of other sectors;
- Reduced electricity costs for all customers;
- Enhanced reliability of electricity for users;
- Reduction of curtailment of renewables;
- Increased storage and DER integration;
- Interstate markets for electricity.



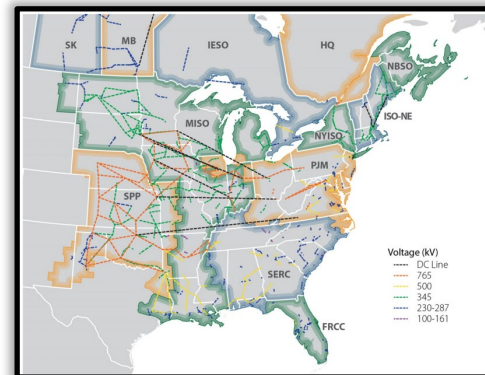
Many studies have shown the benefits of long distance transmission



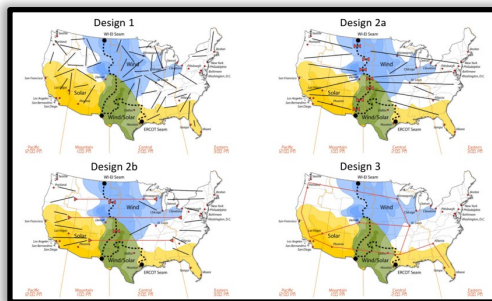
NREL REFs (2012)



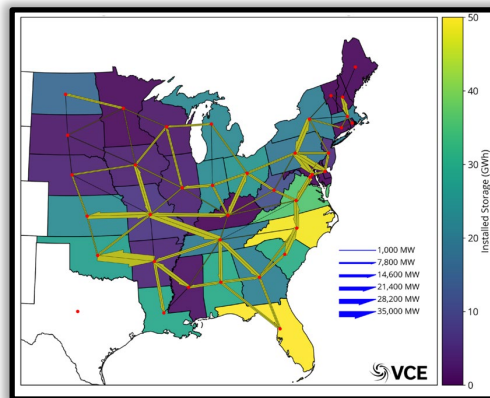
MacDonald, Clack et al. (2016)



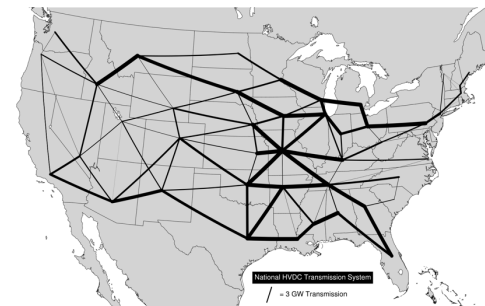
NREL ERGIS (2016)



NREL SEAMS (2018)



ACEG EI Study (2020)



VCE ZBF Study (Mar 2021)



**Note, there are many, many more!*

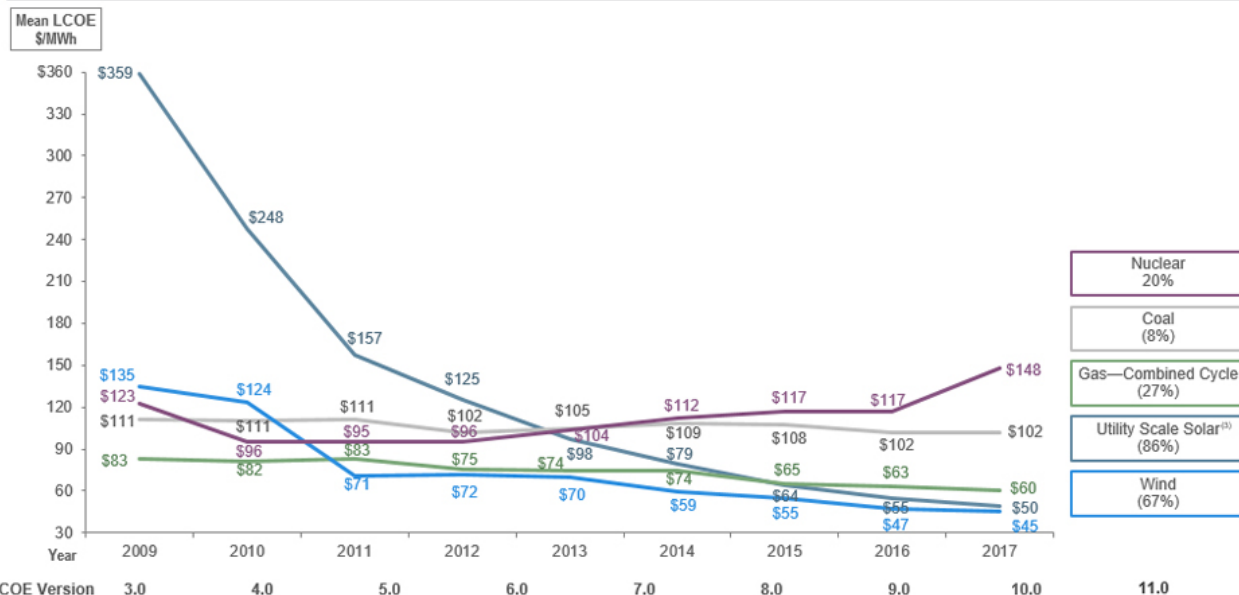
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How does a transmission grid enable deep decarbonization?

Renewables are the cheapest source of electricity

Summary Findings of Lazard's 2017 Levelized Cost of Energy Analysis⁽¹⁾

Selected Historical Mean LCOE Values⁽²⁾



Source: Lazard estimates.

Note: Reflects average of unsubsidized high and low LCOE range for given version of LCOE study.

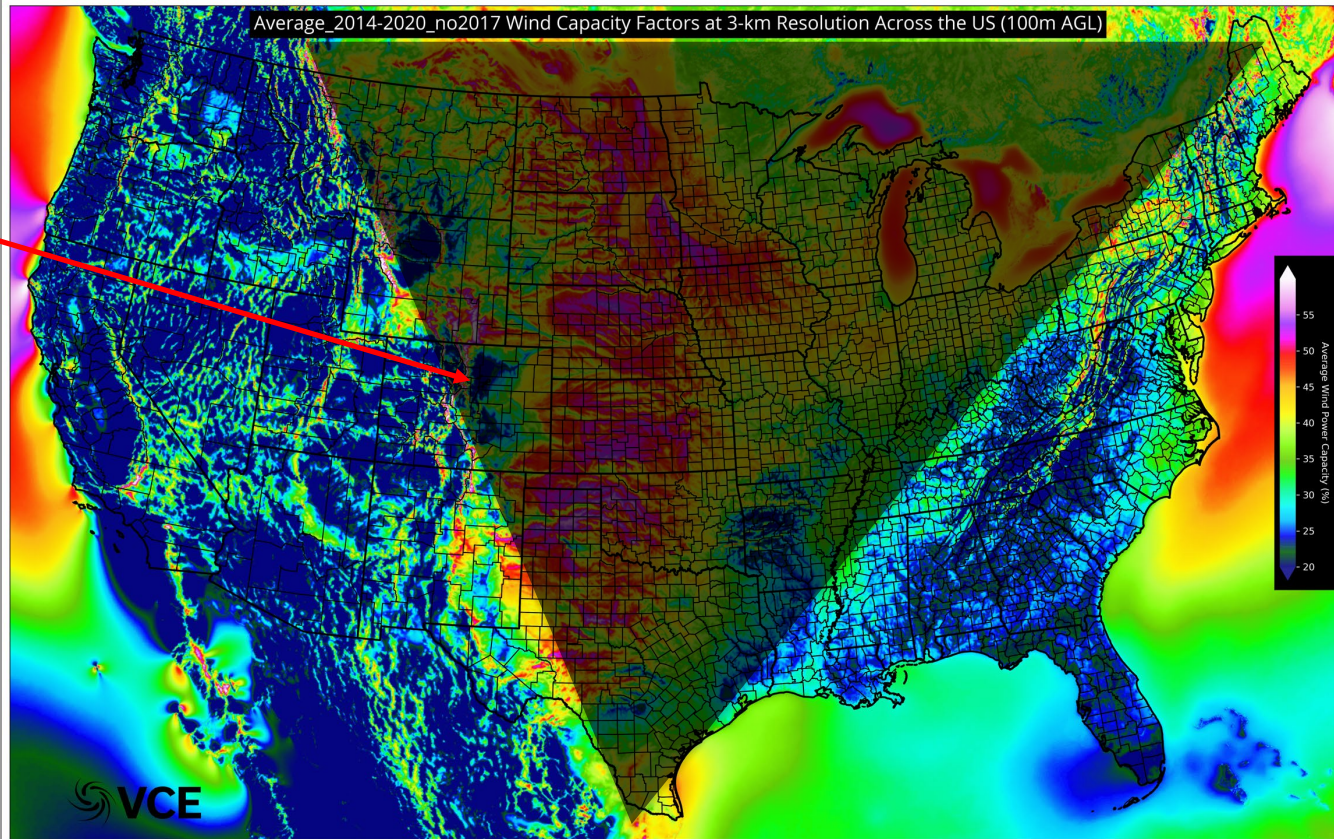
(1) Primarily relates to North American alternative energy landscape, but reflects broader/global cost declines.

(2) Reflects total decrease in mean LCOE since the later of Lazard's LCOE—Version 3.0 or the first year Lazard has tracked the relevant technology.

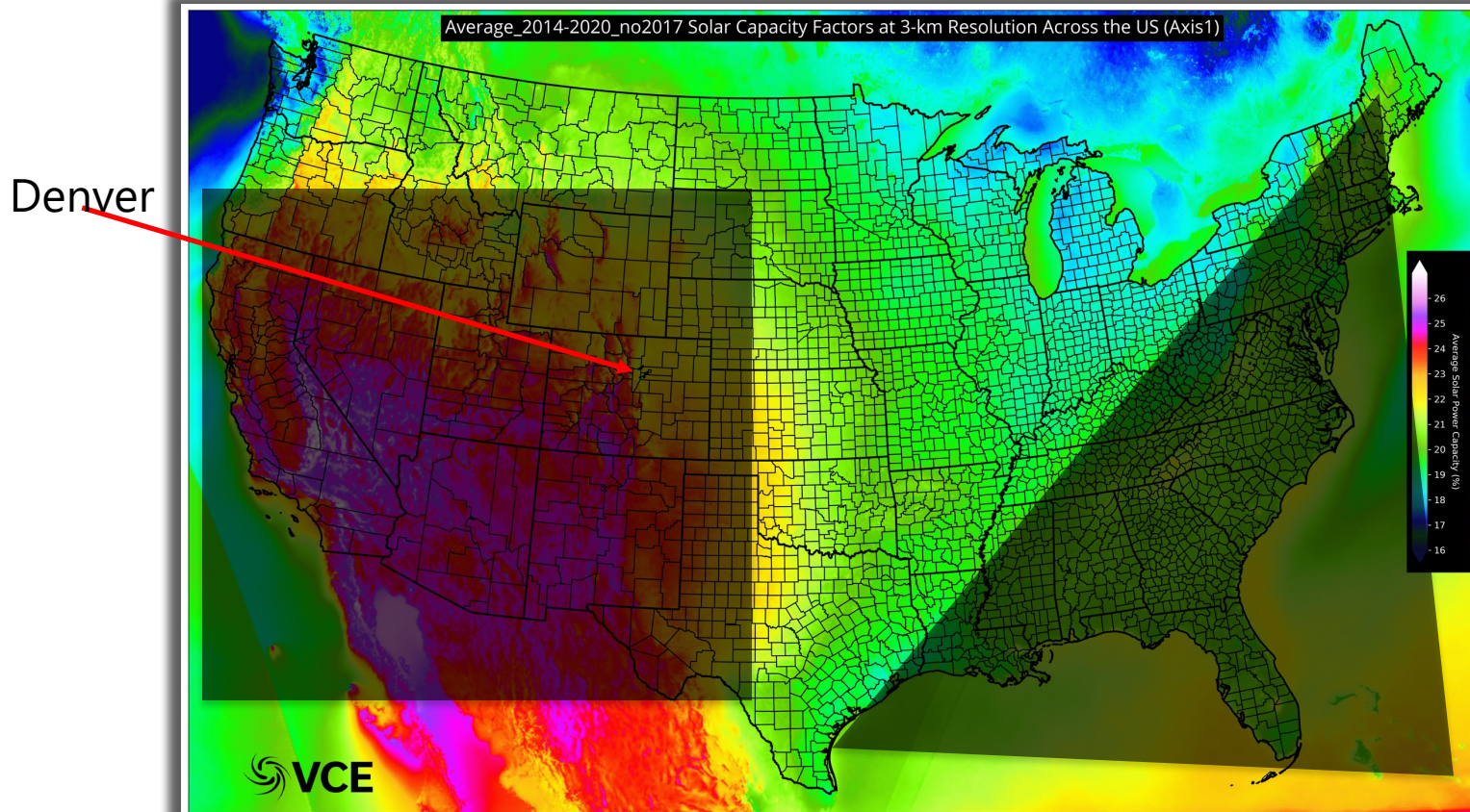
(3) Reflects mean of fixed-tilt (high end) and single-axis tracking (low end) crystalline PV installations.

Lowest cost wind is confined primarily to the central plains

Denver



Lowest cost solar is confined primarily to the west and south east

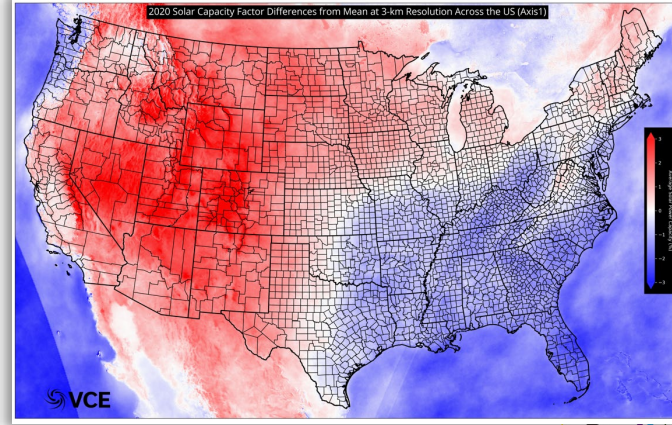
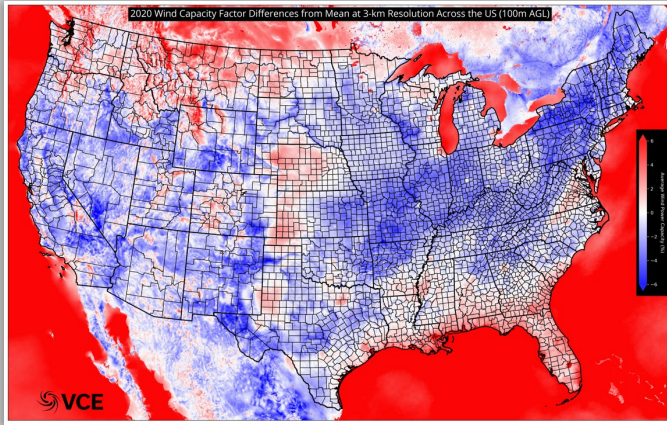
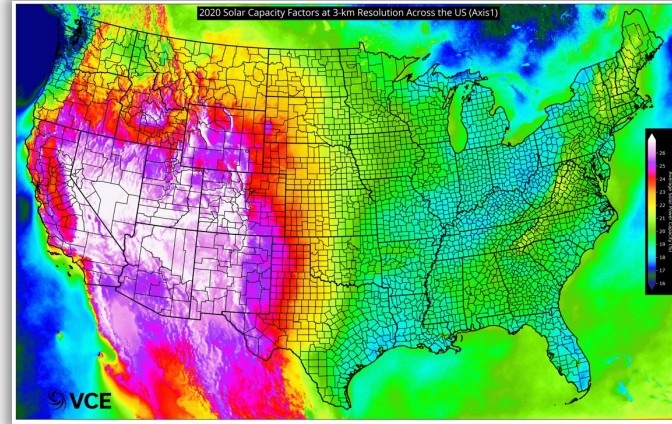
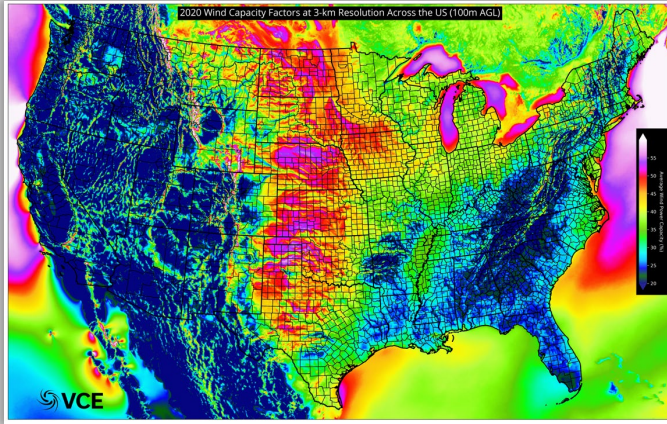


Demands are concentrated & supply will be sparse

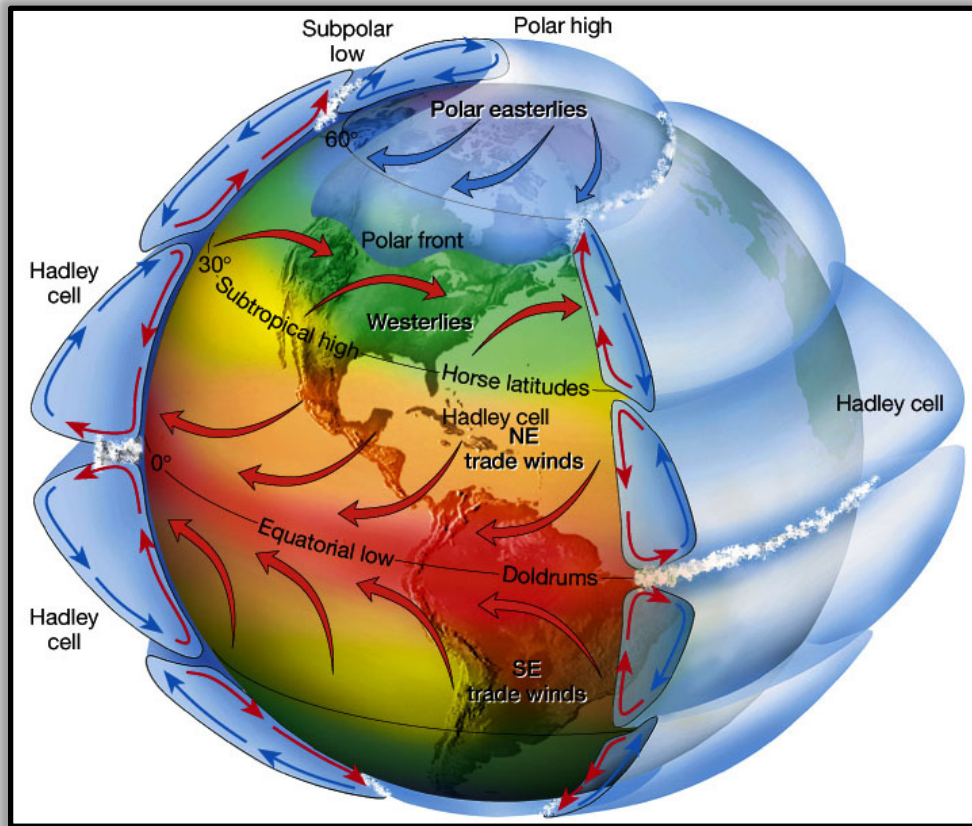
Denver



Interannual variability of VREs can be harnessed



Global Heat Transfer Drives Wind & Solar Constantly



This global heat engine runs **constantly** driving wind and cloud patterns.

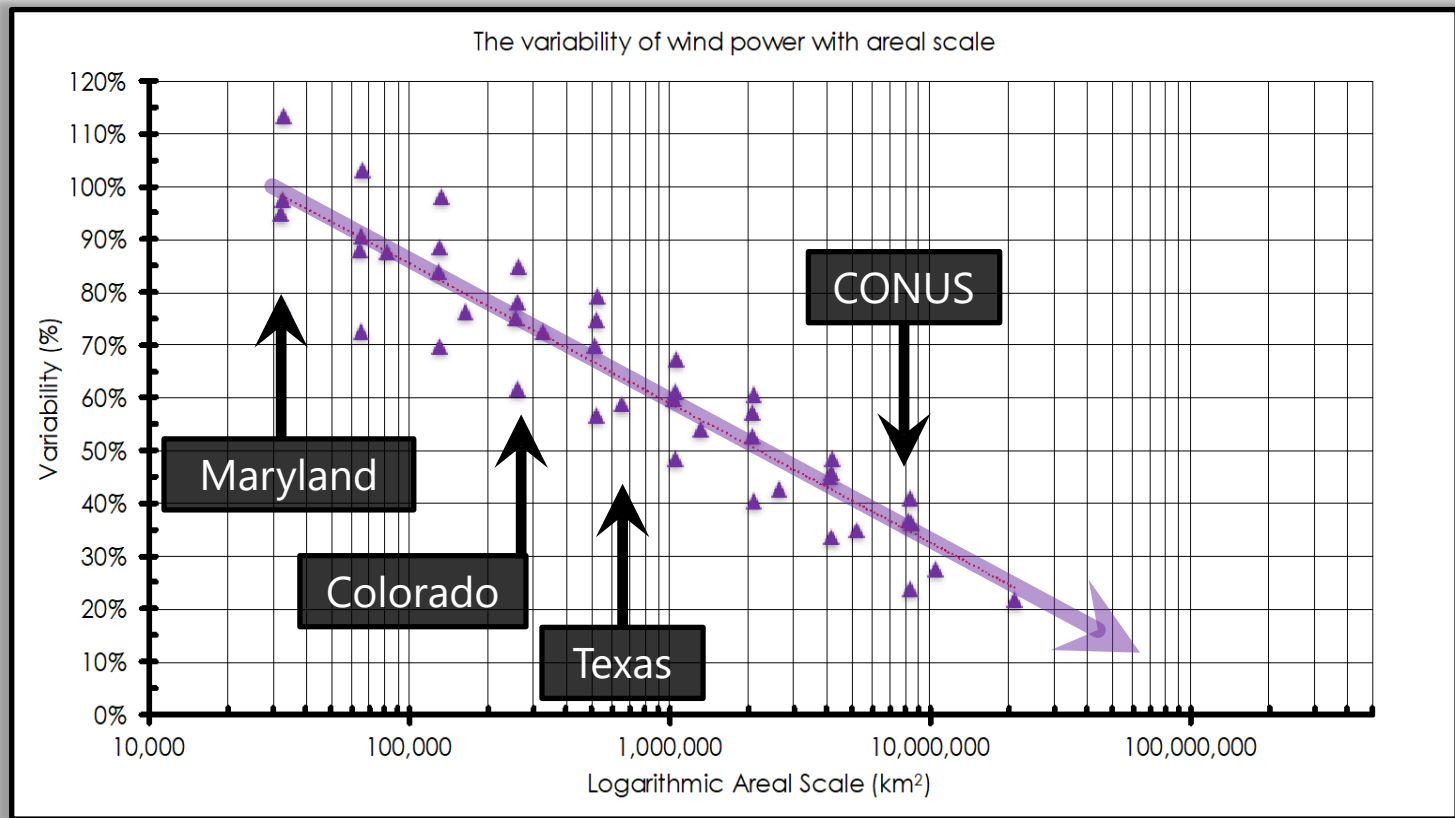
Processes ***are well understood.***

Driven By Solar Irradiance
& Earth-Sun Distance.

Therefore “variability” is a **local effect.**

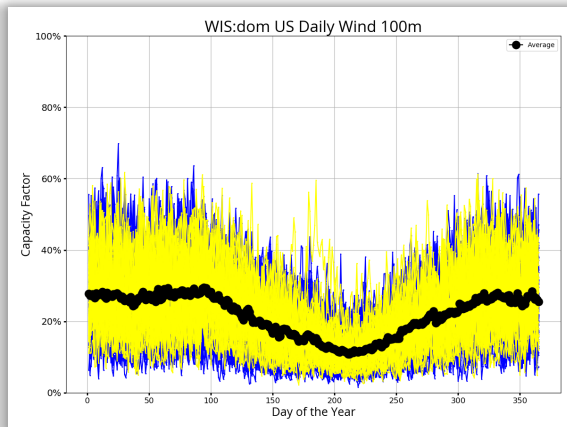
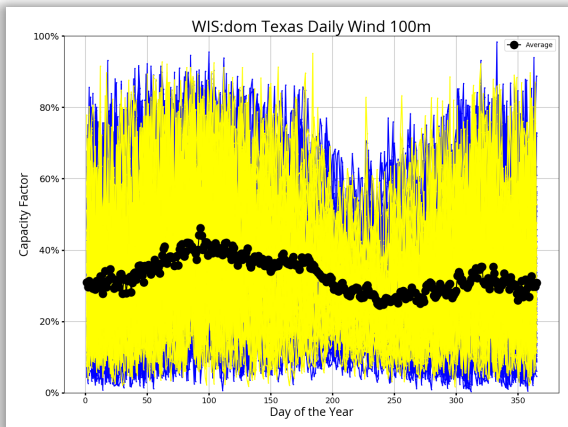
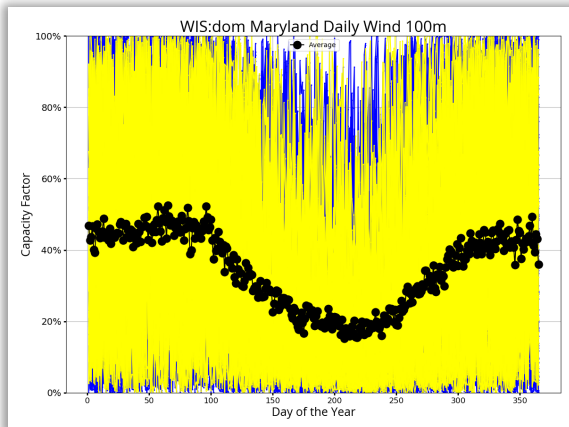
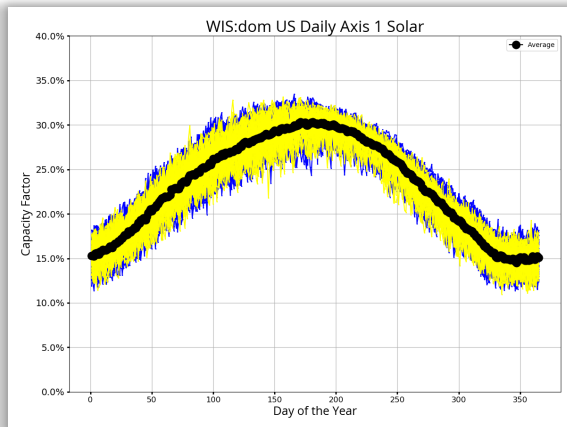
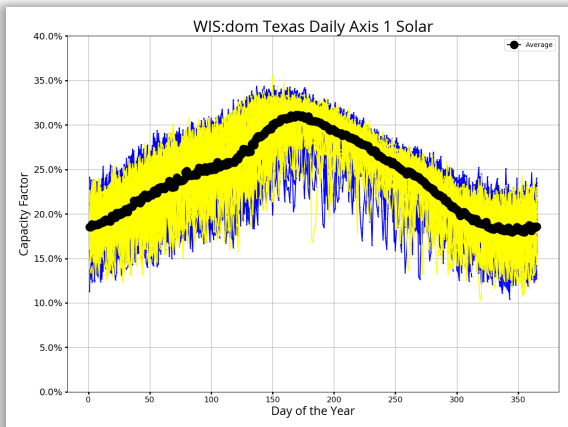
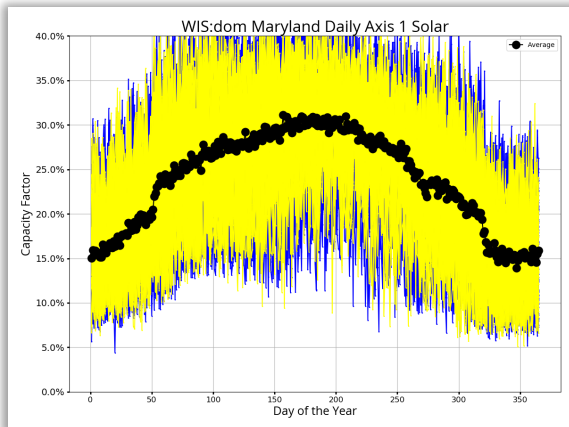
Image Credit: Figure 7.5 in *The Atmosphere*, 8th edition, Lutgens and Tarbuck, 8th edition, 2001

Variability Of Wind & Solar Shrinks With Larger Areas



Wind & solar ***can back each other up*** using their nature

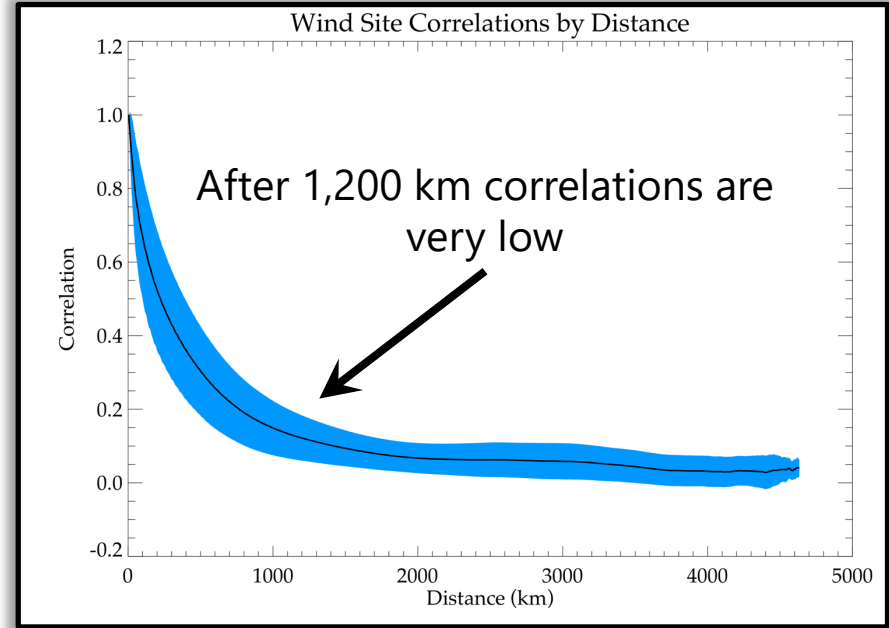
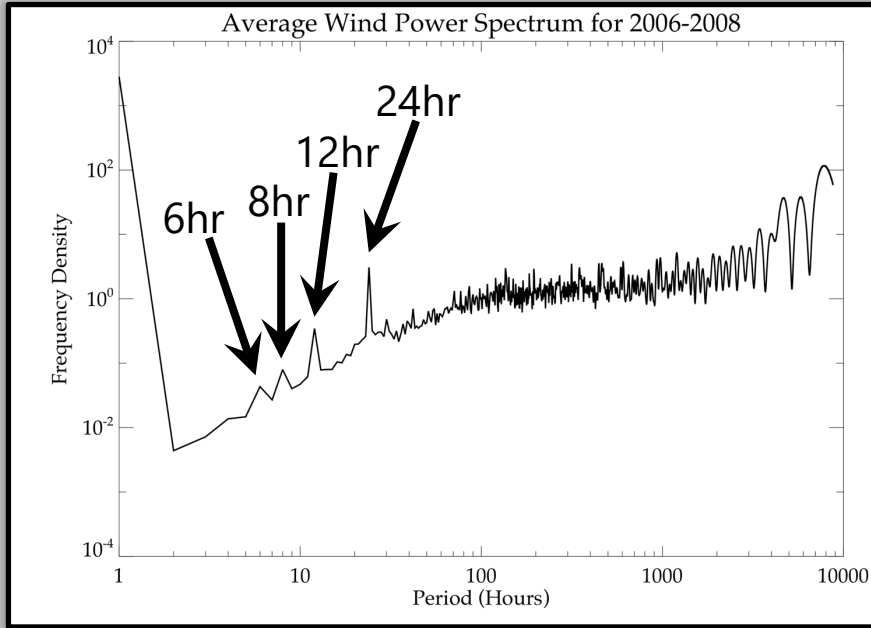
Variability Of Wind & Solar Shrinks With Larger Areas



Daily hypothetical production from the
VCE long-term dataset (1900-2015)

Wind & Solar Are Created By Chaotic Not Random Processes

Therefore, patterns emerge that can be taken advantage of!



Energy Density Accumulates At Predictable Times & Sites Decorrelate Rapidly

Demand For Electricity Will Necessarily Grow

NOTE: In 2019 **29.4 PWh** of primary energy was consumed in the US. Of that **9.6 PWh** was productive for end uses (energy services).

Source: LLNL

63% down

15% up

70% down

7% down

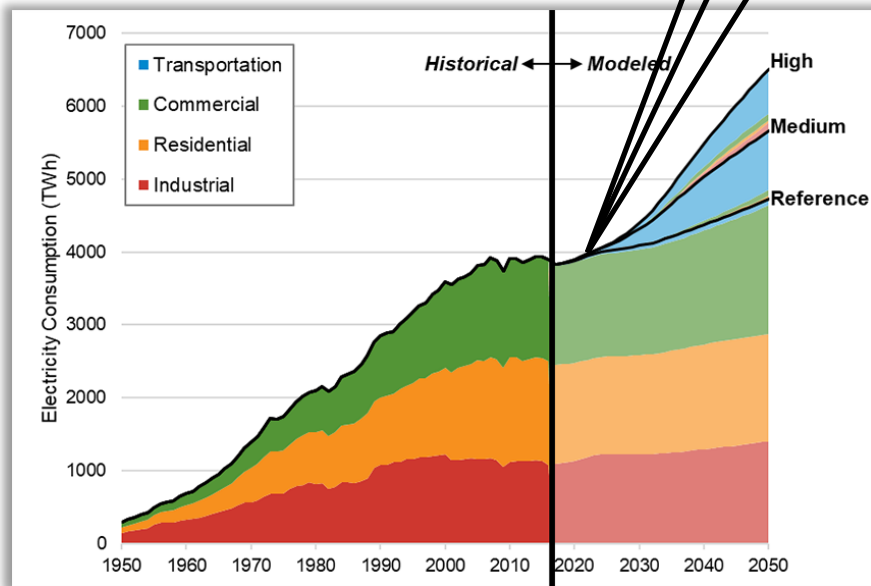
73% down

19% down

ZBF 2050 TWh with synthetic fuels & products (11 PWh)

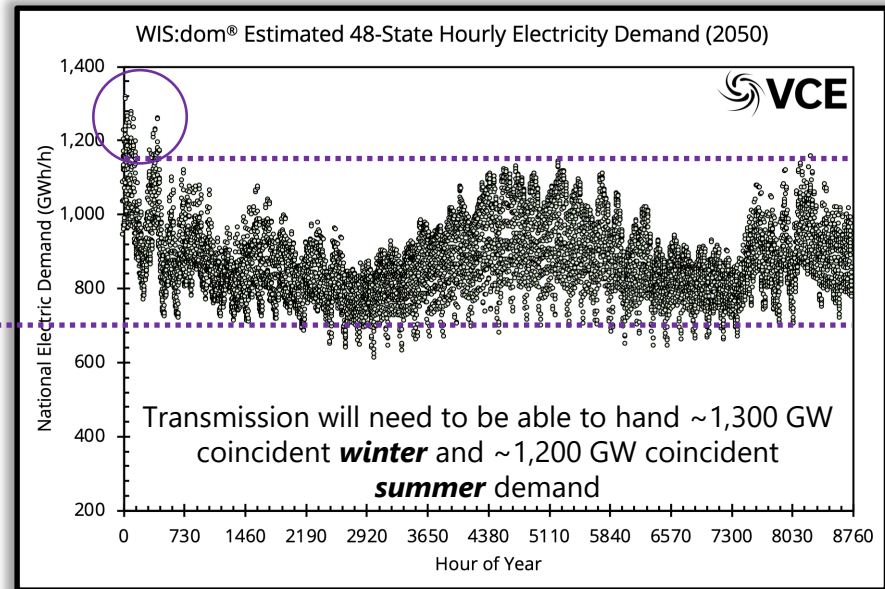
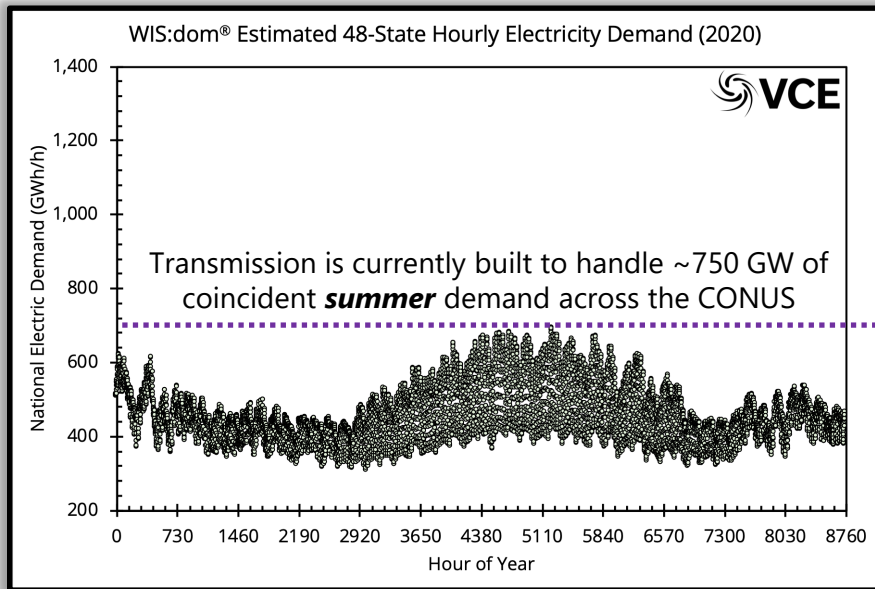
ZBF 2050 TWh with RCP4.5 climate change impacts (8.9 PWh)

ZBF 2050 TWh without climate change impacts (7.8 PWh)



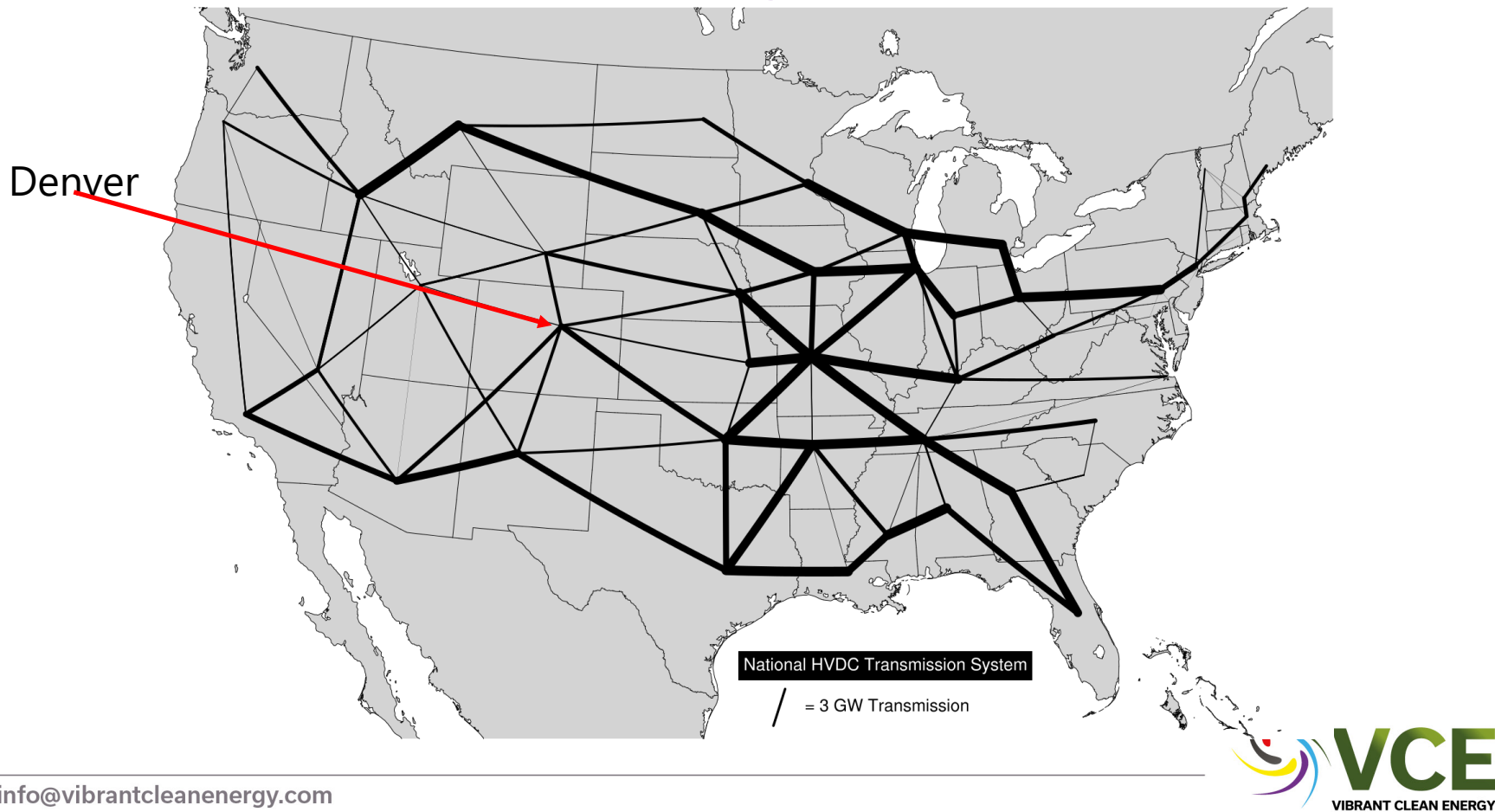
<https://www.nrel.gov/analysis/electrification-futures.html>

Demand Profiles & Stress Periods Will Change Over Time



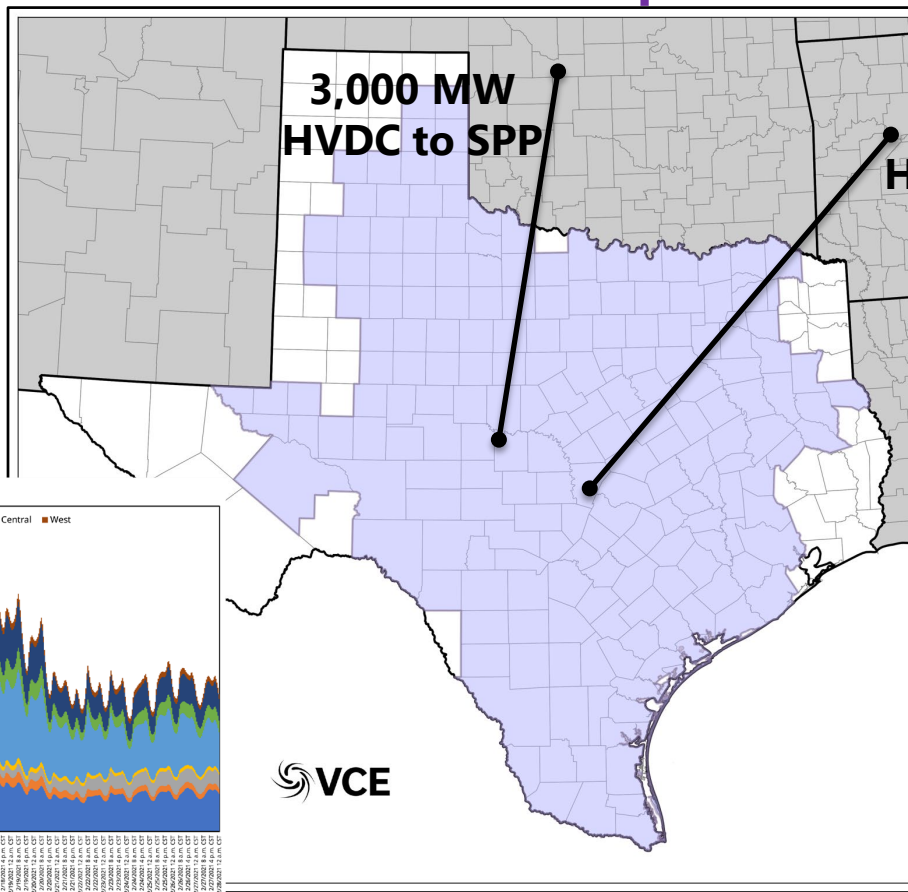
* Before synthetic fuel production

Could a continental transmission grid help deep decarbonization?



How could a transmission grid handle extreme events?

Could have transmission for ERCOT helped for Storm Uri? [YES!]

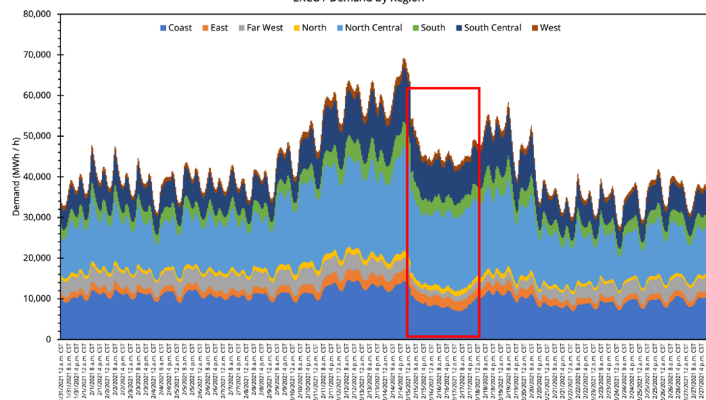


3,000 MW
HVDC to MISO

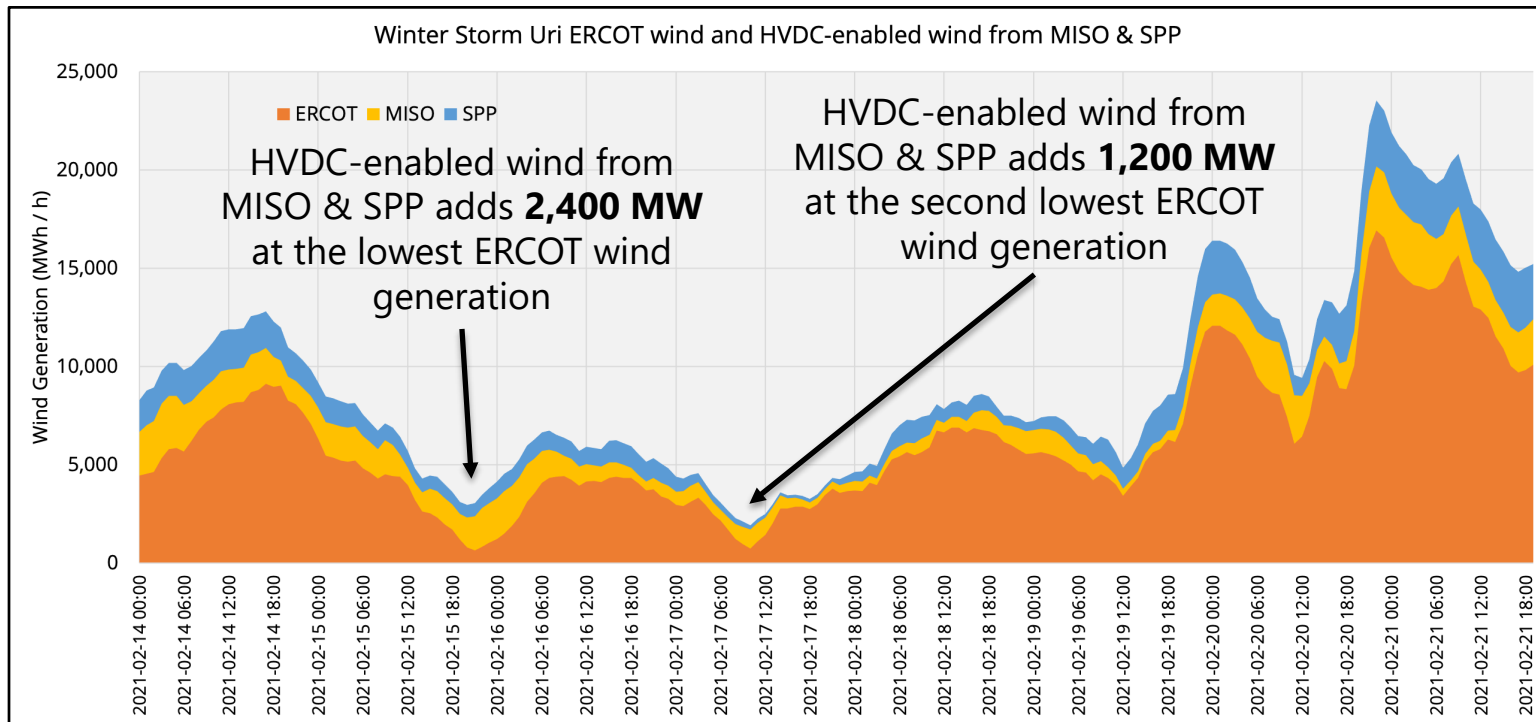
3,000 MW
HVDC to SPP

*NB: Each HVDC
transmission line
would cost
~\$1.2 billion*

ERCOT Demand by Region



Could have transmission for ERCOT helped for Storm Uri? [YES!]



Over the blackout period HVDC-enabled wind from MISO & SPP could have provided **515 GWh** of clean generation

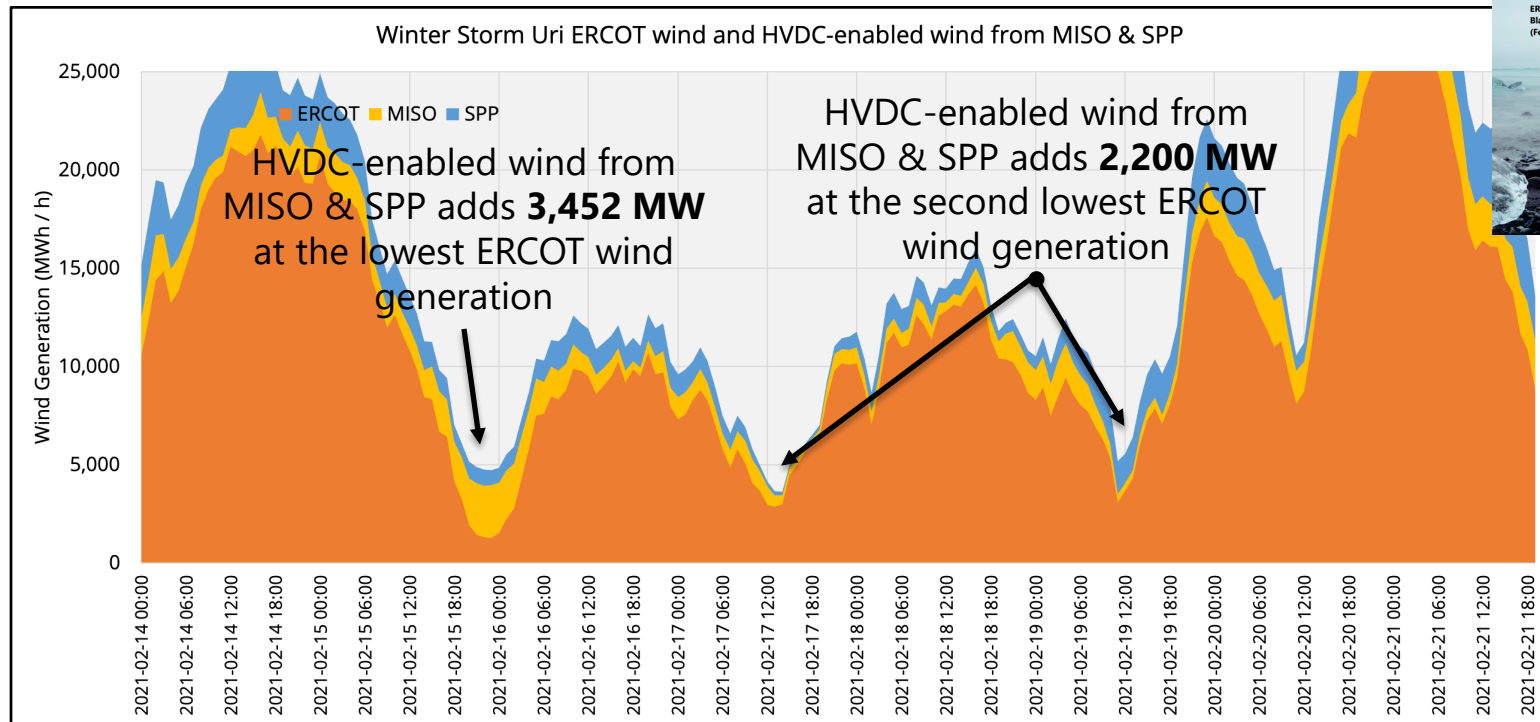
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NB: We assume additional wind is built for these transmission lines, which will provide generation all year; but our focus is this extreme event.



Could have transmission for ERCOT helped for Storm Uri? [YES!]

* VCE white paper on ERCOT coming by tomorrow morning



Strong winterization would increase HVDC-enabled wind to **643 GWh** & ERCOT could have removed second lowest generation substantially

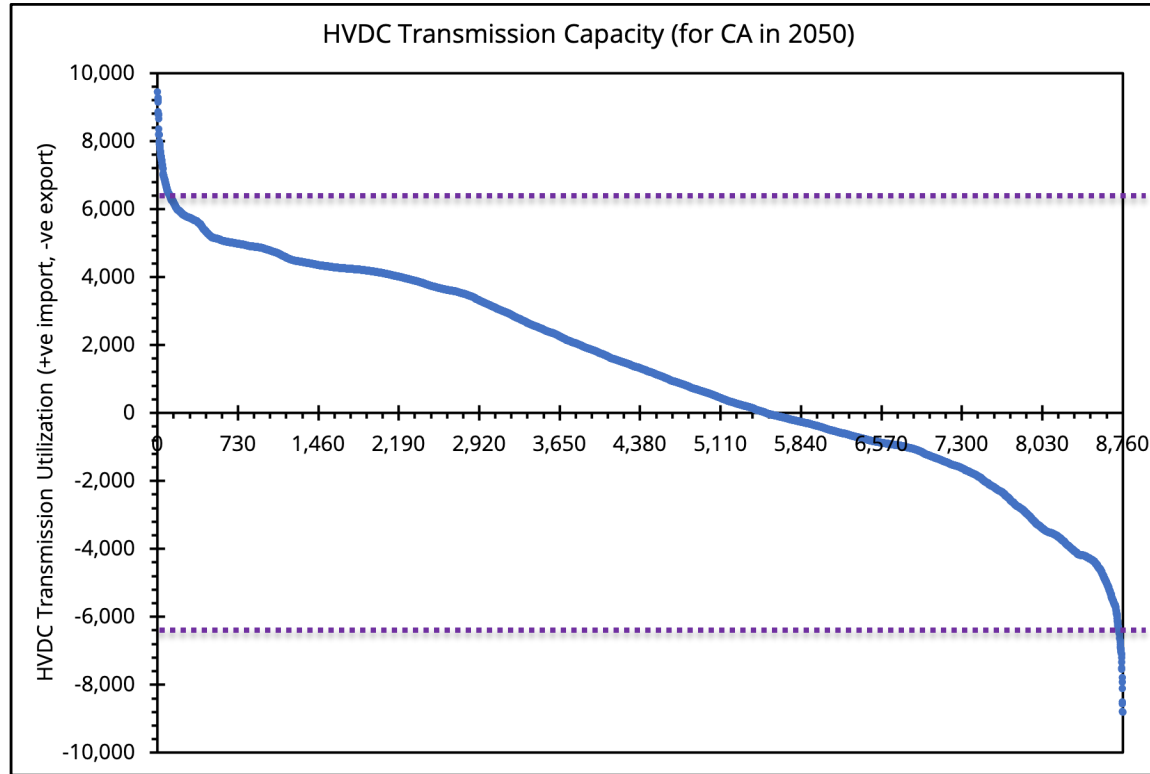
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NB: We assume additional wind is built for these transmission lines, which will provide generation all year; but our focus is this extreme event.



How could a transmission grid be deferred or avoided? What are the alternatives?

An Example for California



Reduce
HVDC by
3,000 MW
(a large
single line)

This is a simplified example!

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An Example for California (today's alternatives)

<i>California example</i>			Assume 500 miles
<i>2025 (current trends)</i>	Natural Gas	Storage	Transmission (HVDC)
Capital (\$/kW)	\$ 887.00	\$ 139.00	\$ 401.60
Capital (\$/kWh)	\$ -	\$ 160.00	\$ -
Fixed (\$/kW-yr)	\$ 11.40	\$ 8.10	\$ 0.53
Variable (\$/MWh)	\$ 4.50	\$ 26.30	\$ 25.00
Fuel (\$/MMBTU)	\$ 2.90	\$ -	\$ -
Capacity Factor (%)	0.348%	0.348%	0.448%
Size (MW)	3,000	3,000	3,000
WACC	5.87%	5.87%	5.87%
Term	30	10	40
LCOE (\$/MWh)	\$21,564,585	\$156,929,204	\$5,981,038

This is a simplified example!

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An Example for California (must reach alternatives)

<i>California example</i>			Assume 500 miles
<i>Cost to match HVDC</i>	Natural Gas	Storage	Transmission (HVDC)
Capital (\$/kW)	\$ 135.00	\$ 85.00	\$ 401.60
Capital (\$/kWh)	\$ -	\$ 1.00	\$ -
Fixed (\$/kW-yr)	\$ 11.40	\$ 6.50	\$ 0.53
Variable (\$/MWh)	\$ 4.50	\$ 1.30	\$ 25.00
Fuel (\$/MMBTU)	\$ -	\$ -	\$ -
Capacity Factor (%)	0.348%	0.348%	0.448%
Size (MW)	3,000	3,000	3,000
WACC	5.87%	5.87%	5.87%
Term	30	10	40
LCOE (\$/MWh)	\$6,063,043	\$6,105,326	\$5,981,038

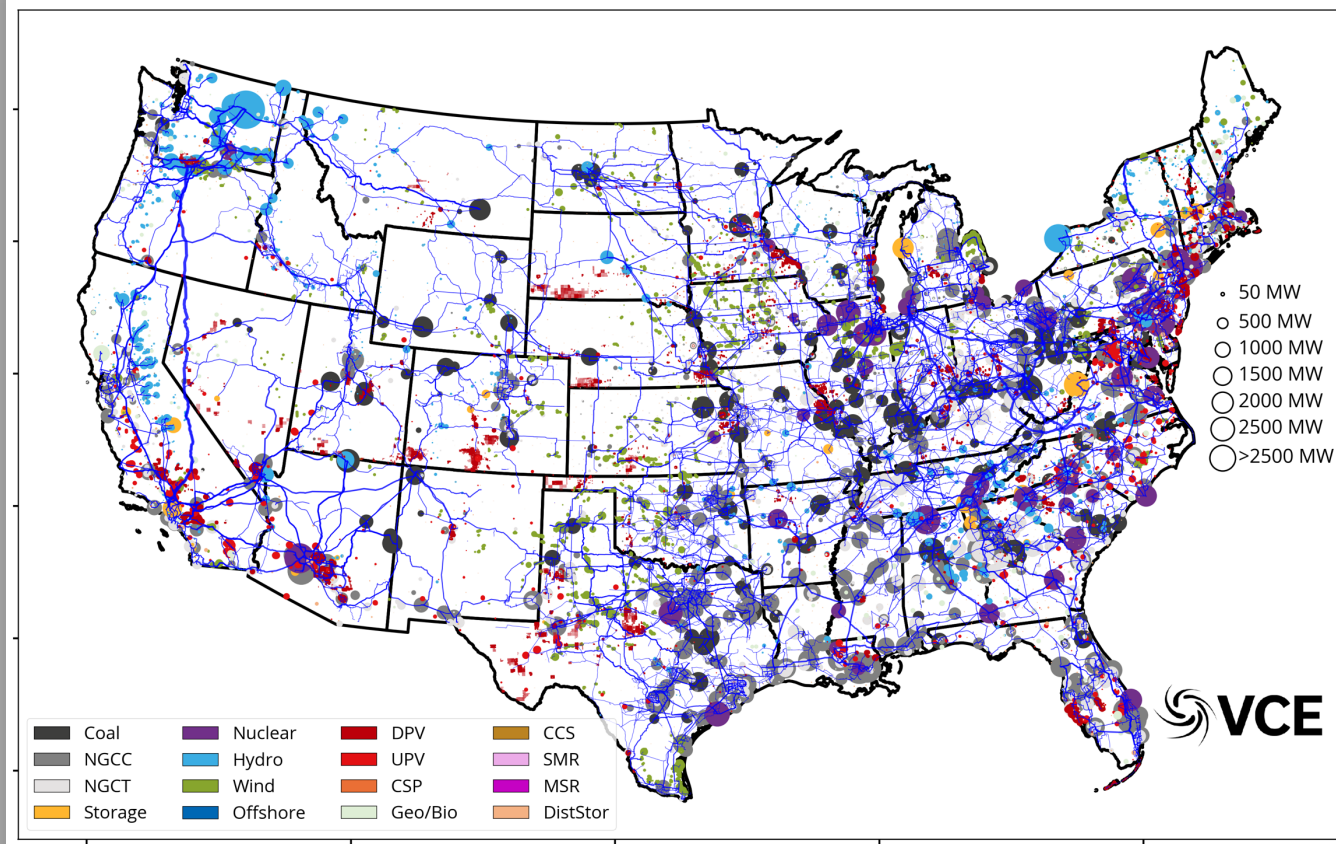
This is a simplified example!

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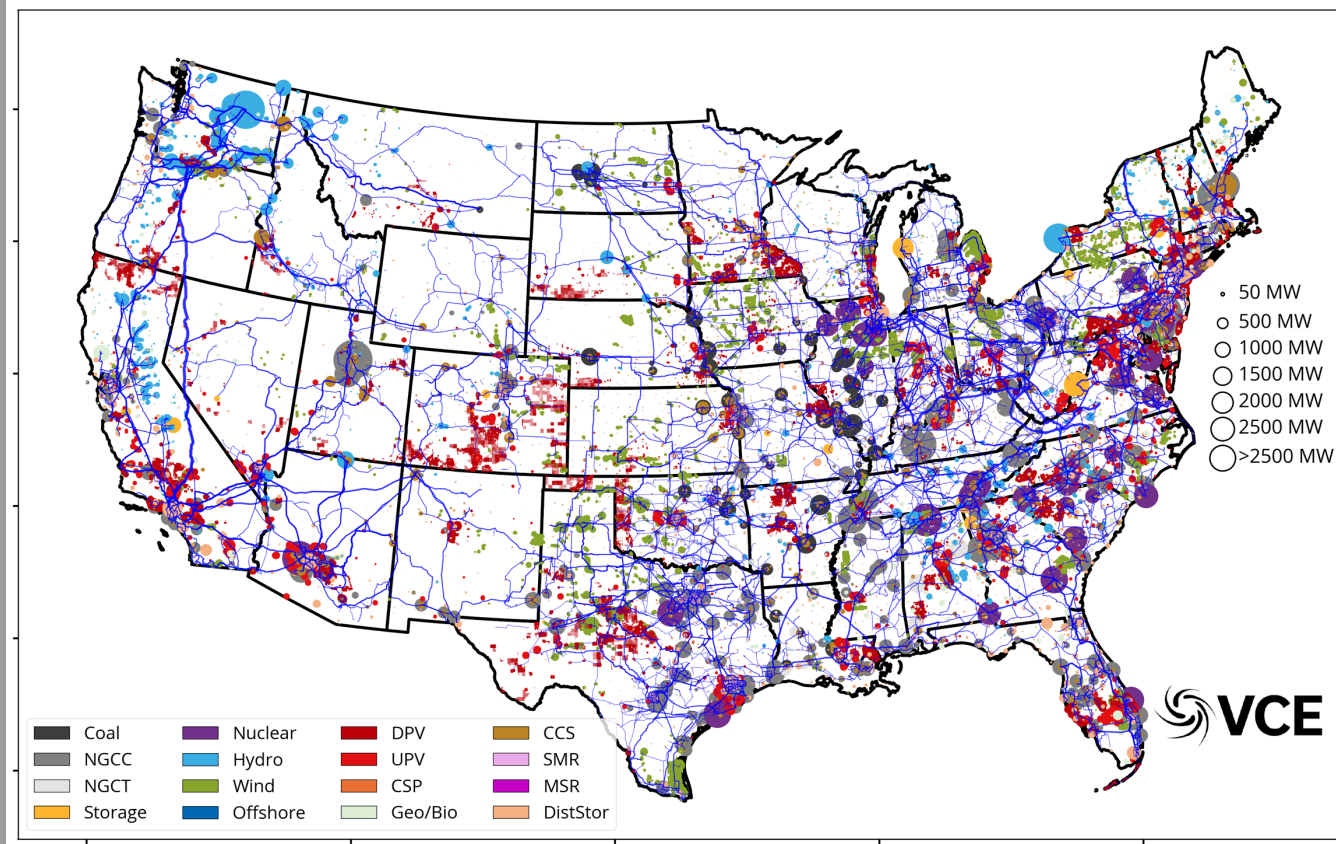


Results from Zero By Fifty (ZBF)

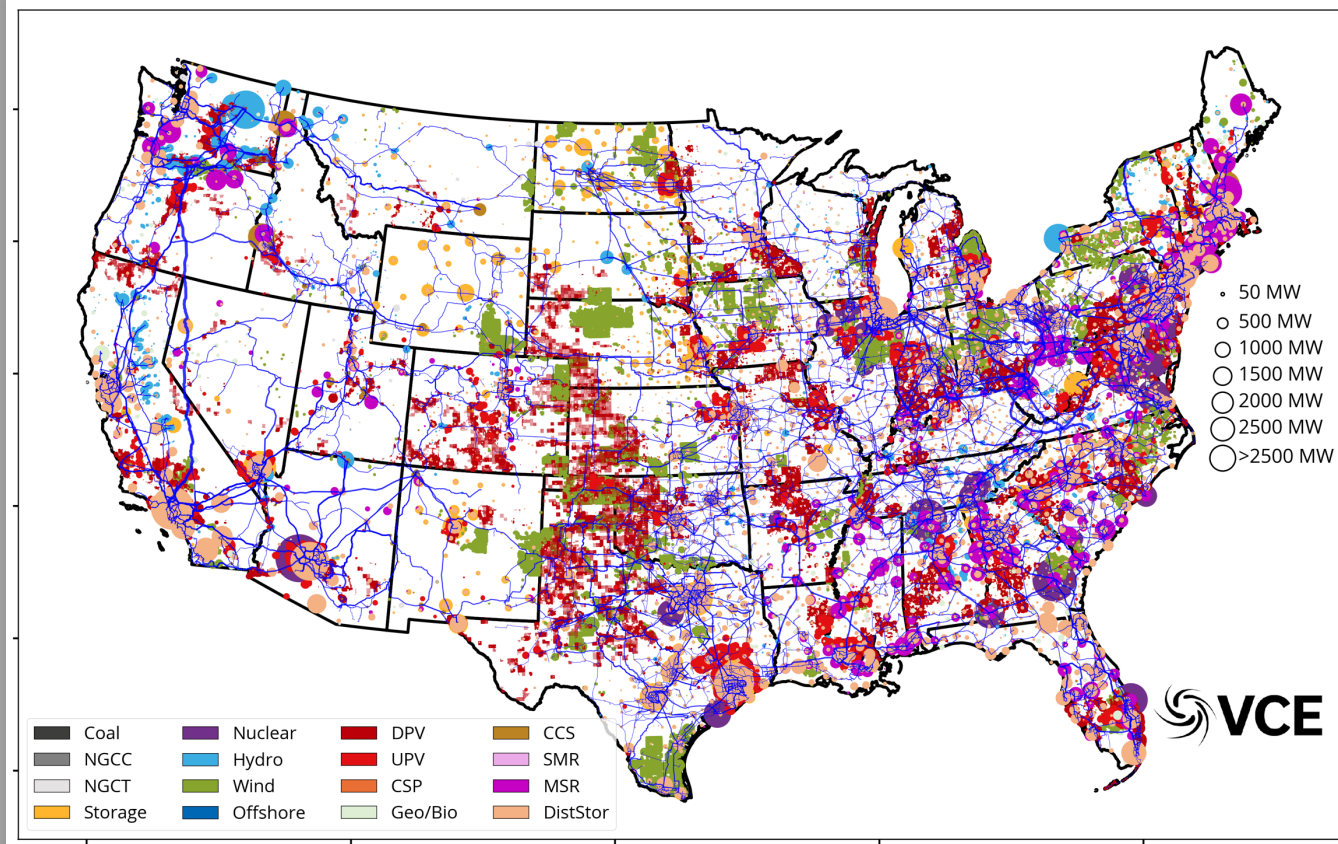
Resource Siting by 2020



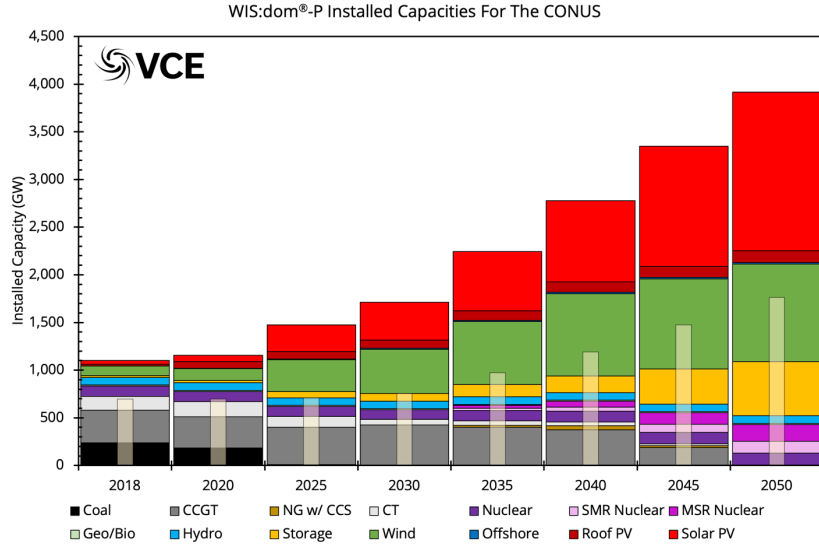
Resource Siting by 2035



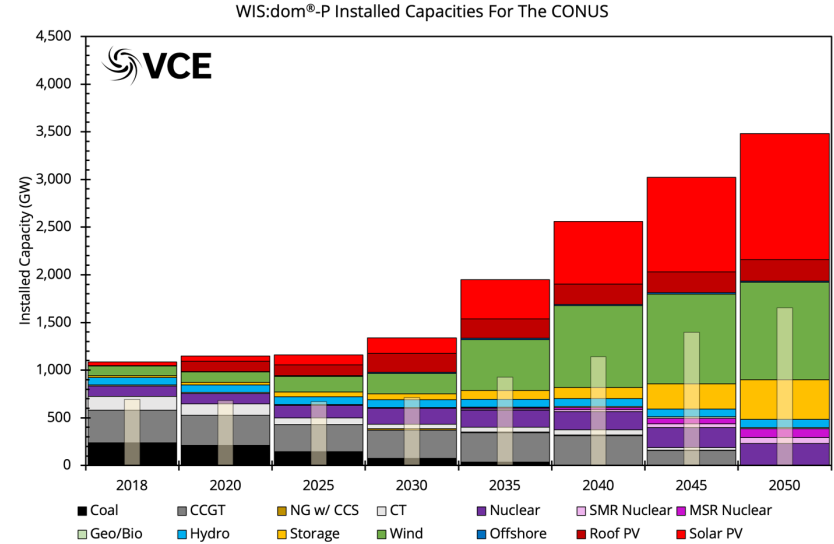
Resource Siting by 2050



Installed Capacities

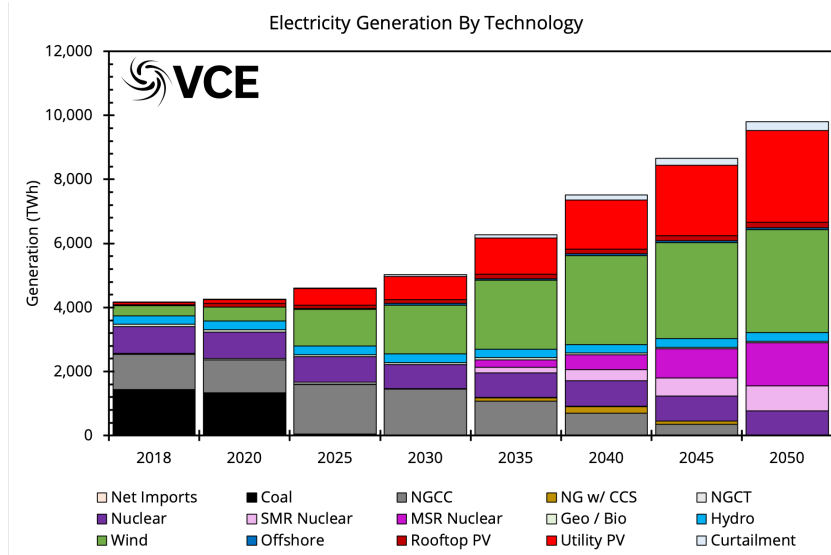


Without HVDC

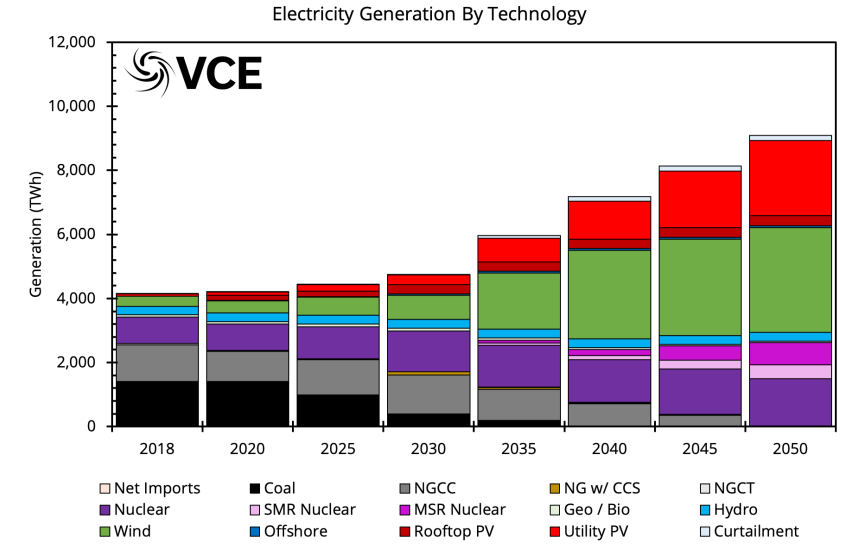


With HVDC

Generation Stack

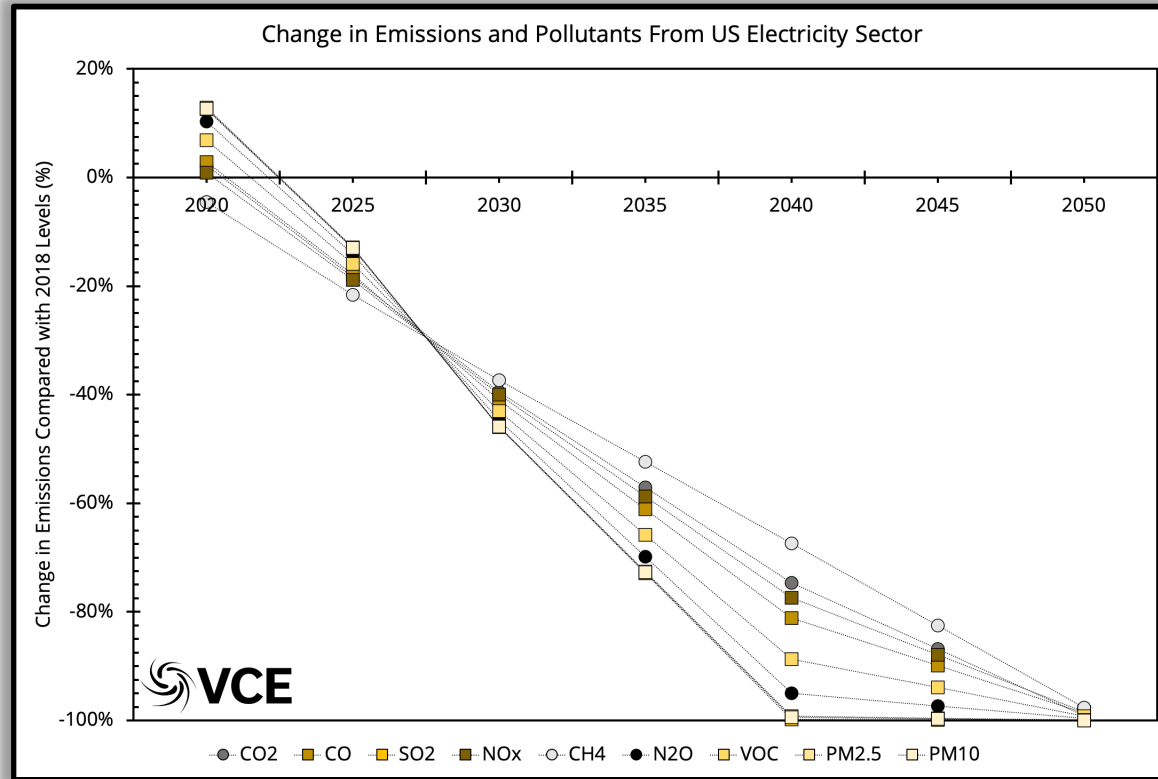


Without HVDC

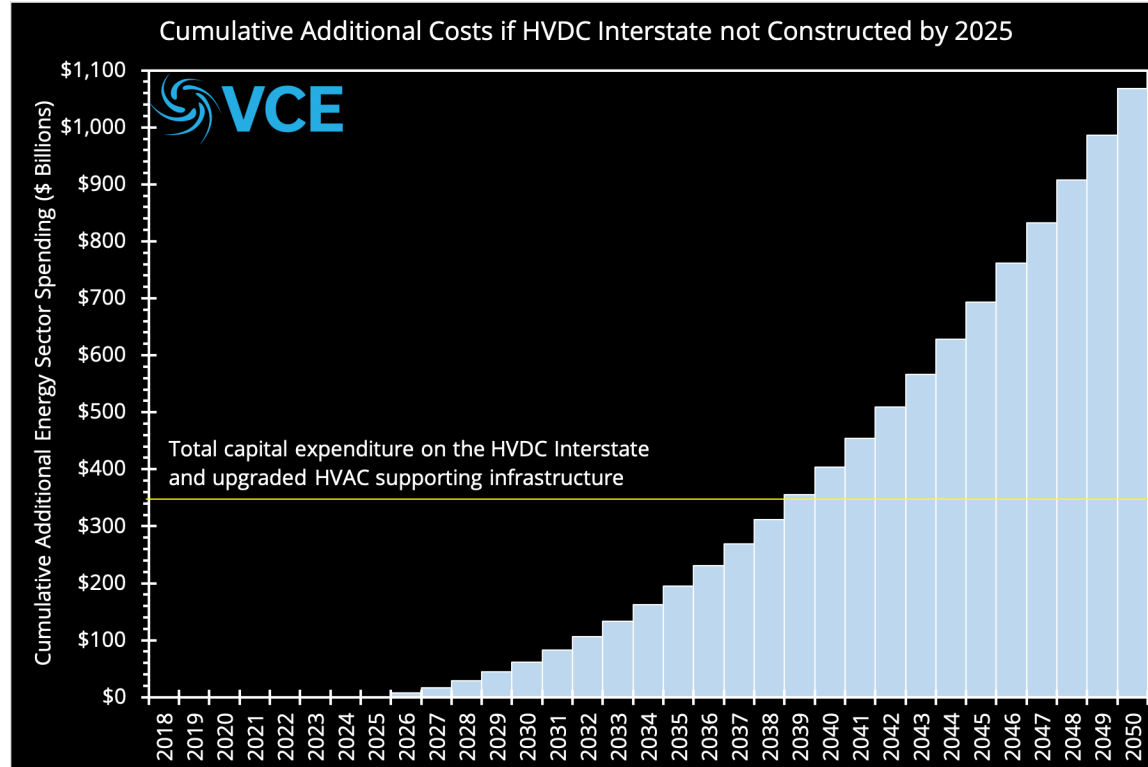


With HVDC

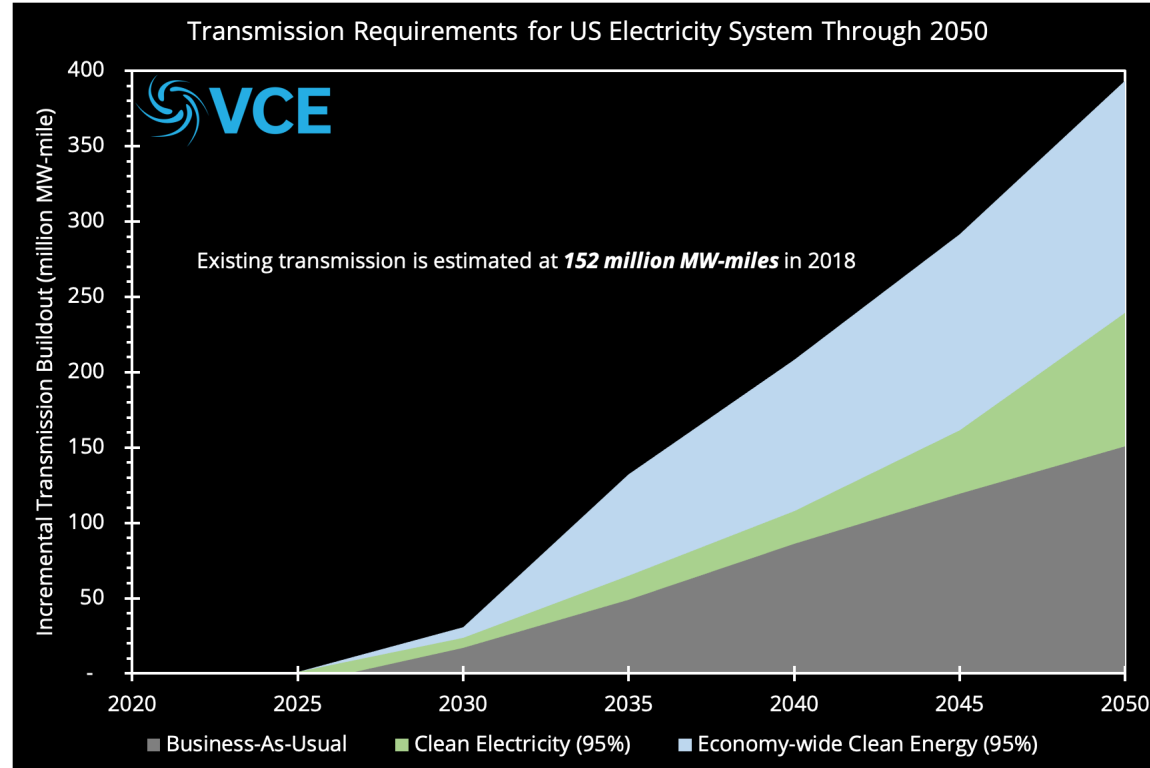
Pollution and GHG Emissions



Not building an HVDC grid adds \$1 trillion in energy costs by 2050

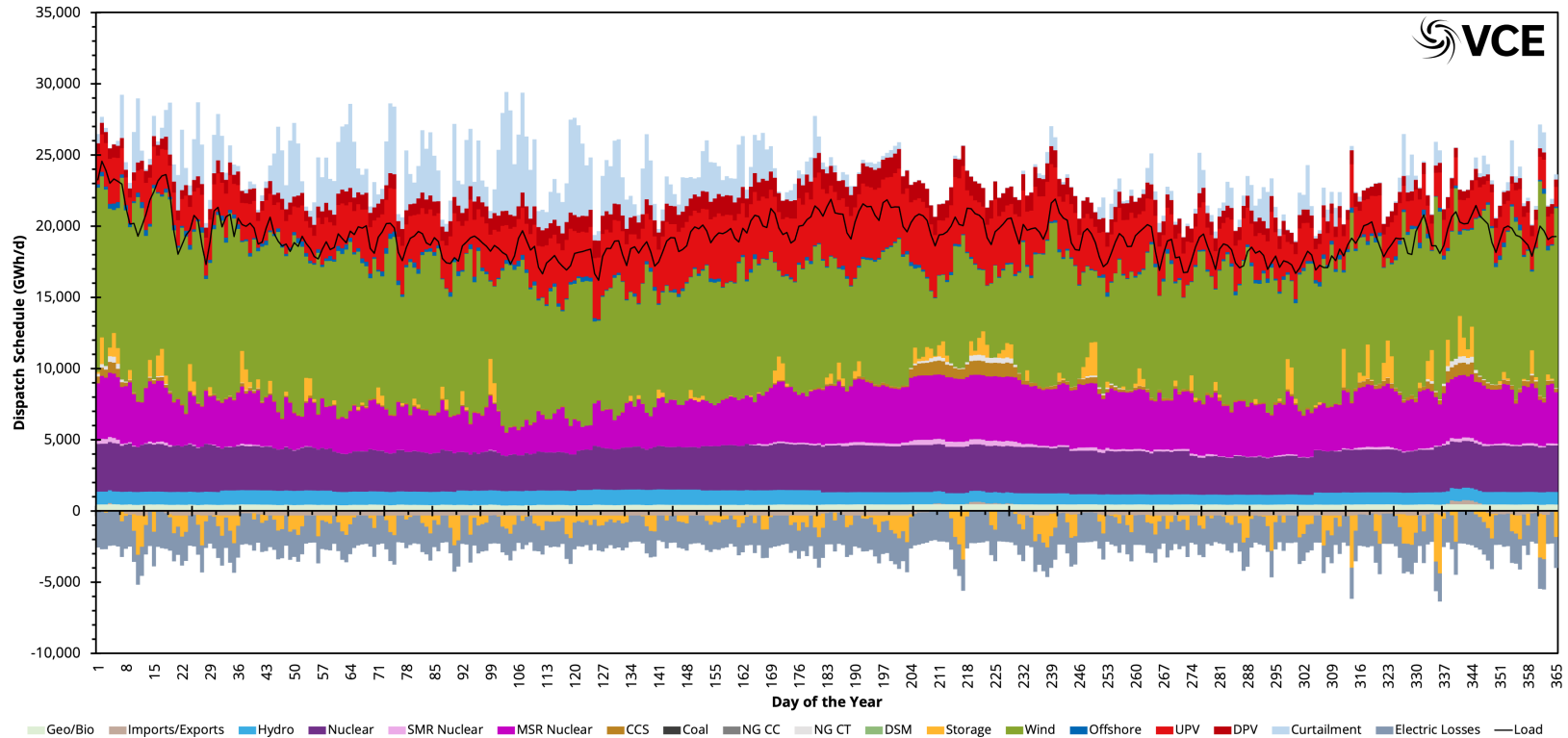


The United States needs a lot of new transmission to meet its goals



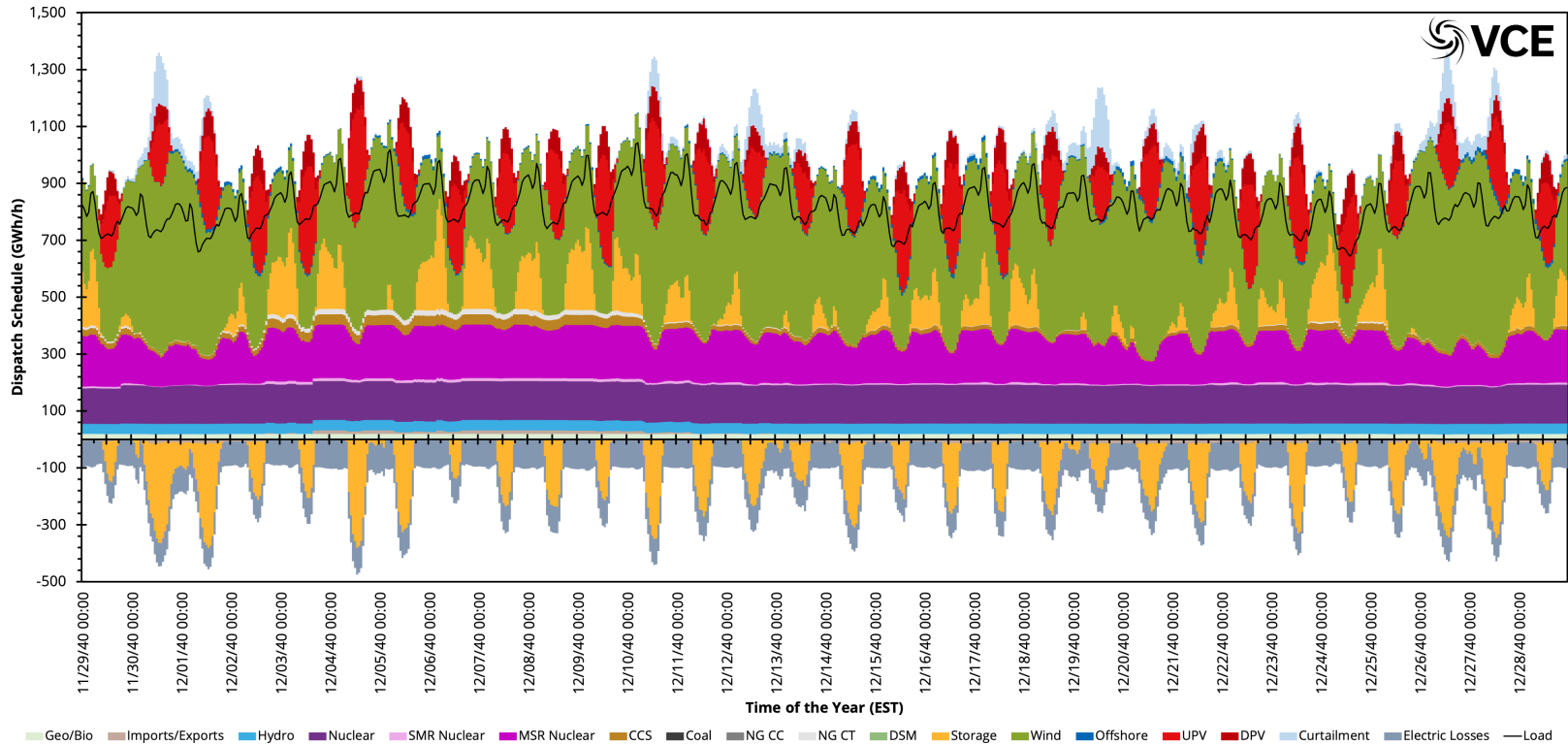
Operations of a CONUS-wide system

Daily Electricity Generation & Consumption (ZERO EMISSION ECONOMY 2050)

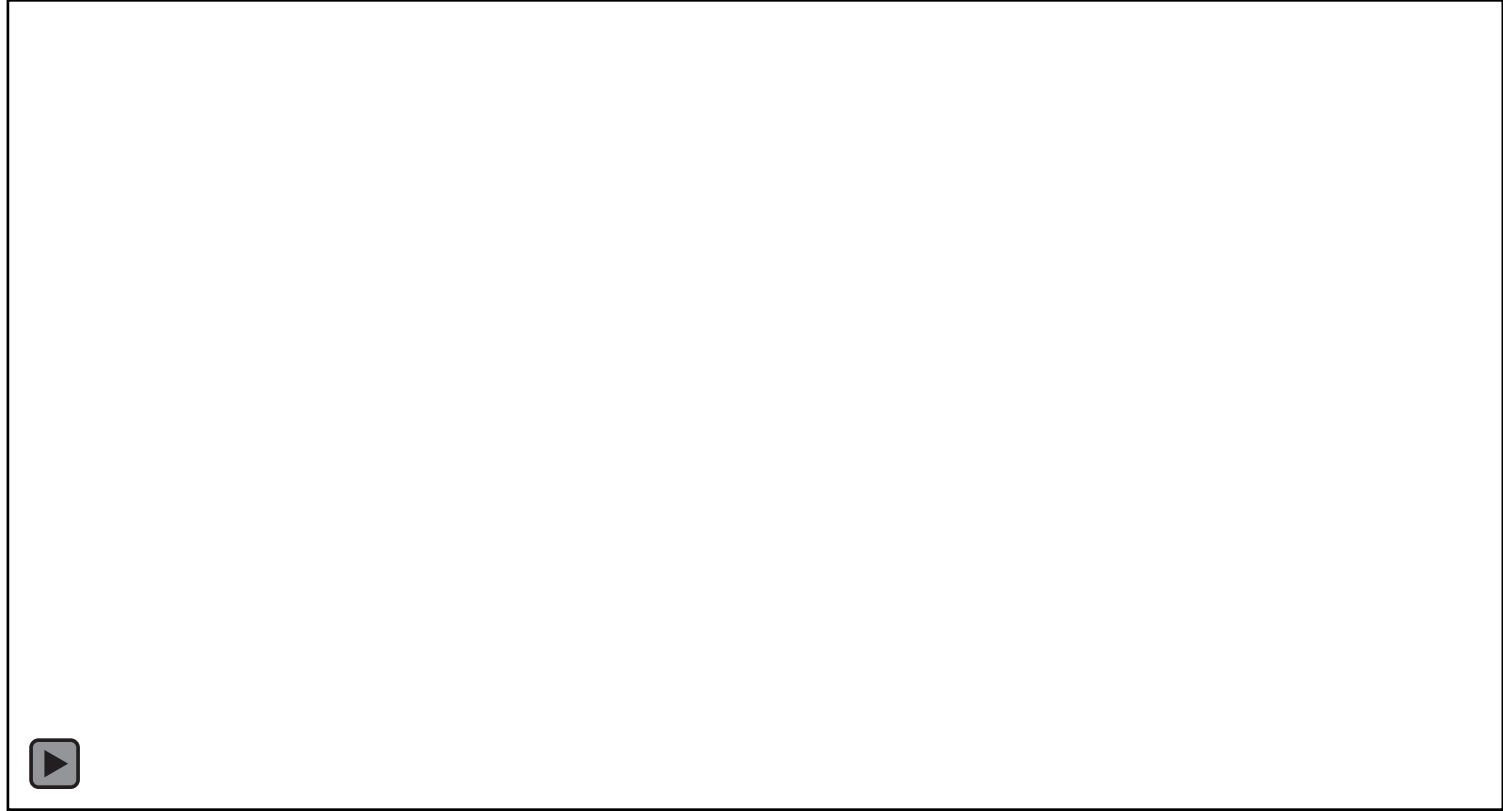


Operations of a CONUS-wide system

Highest System Strain Period Dispatch (ZERO EMISSION ECONOMY 2050)



Example system running across CONUS



Thank You

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