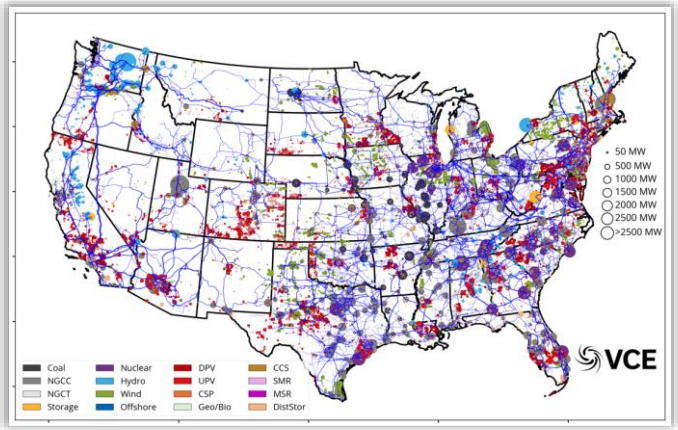
100% Clean By 2050:
What does it look like?

Dr Christopher T M Clack
Vibrant Clean Energy, LLC

Energy Systems Integration Group
Spring Workshop: Virtual Meeting
March 2nd, 2021

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.

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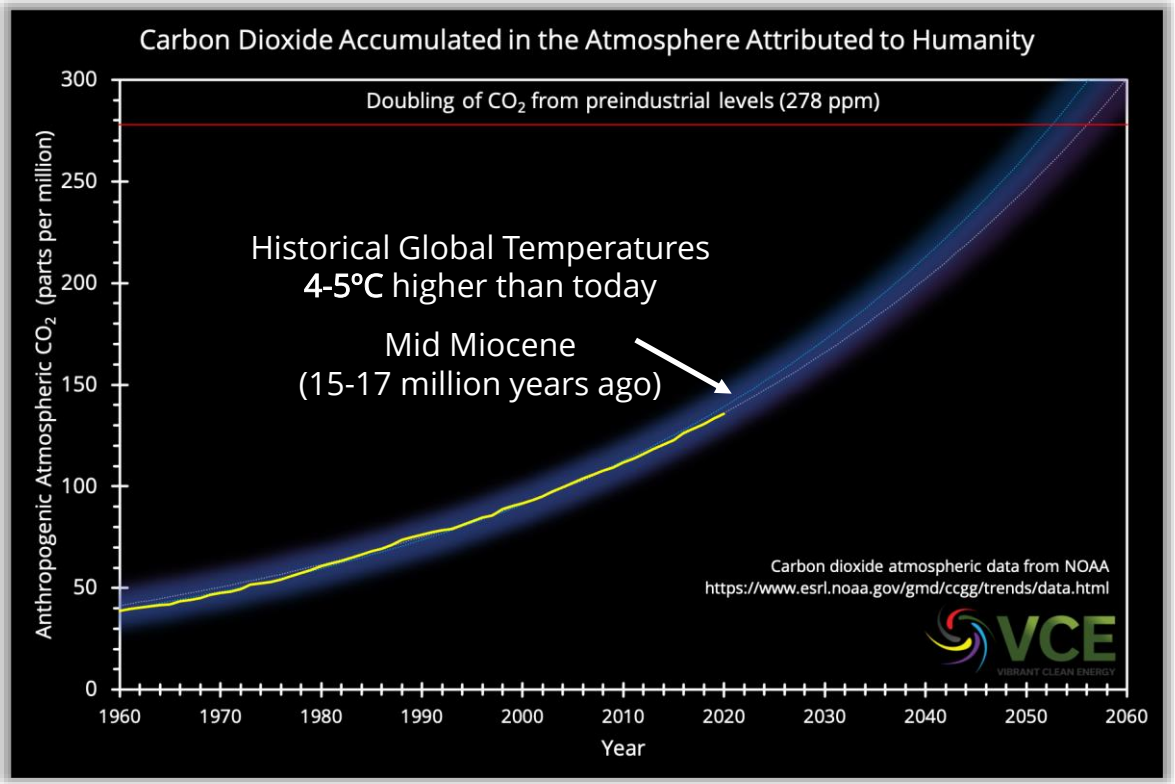
Motivation (Climate Requirements)



Historical Temperature Analysis:
https://www.nature.com/articles/s41598-020-64743-5

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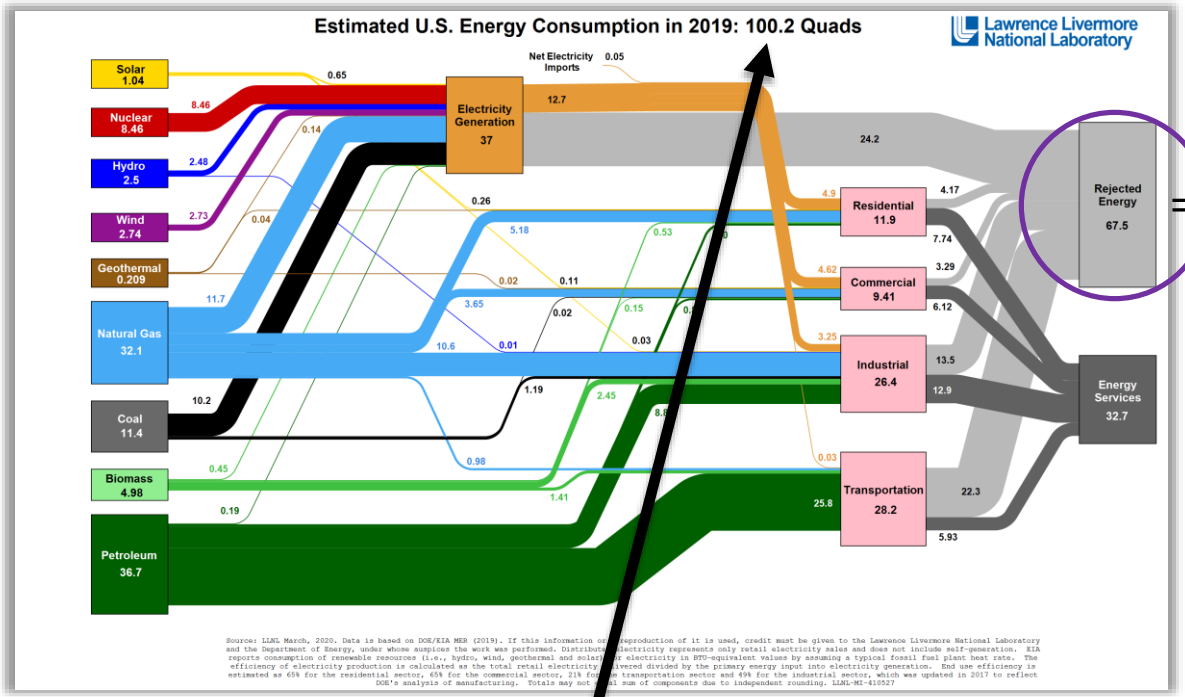
Motivation (Energy Requirements)

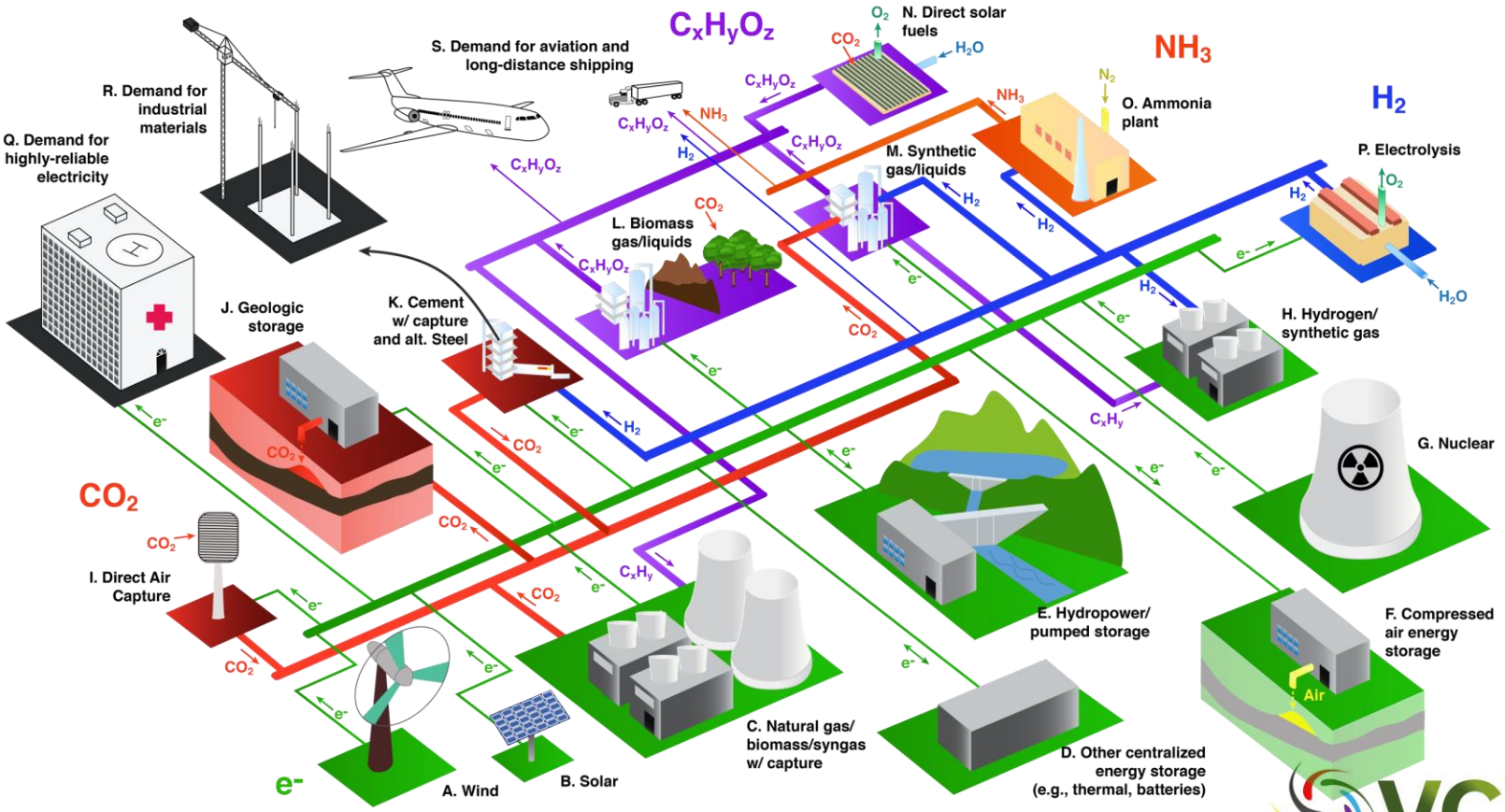


= 19.8 PWh

= 9.6 PWh

This is equivalent to 29.4 PWh (29,400 TWh)

The Whole Economy Needs Clean Energy



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Davis et al. *Science,* 2018

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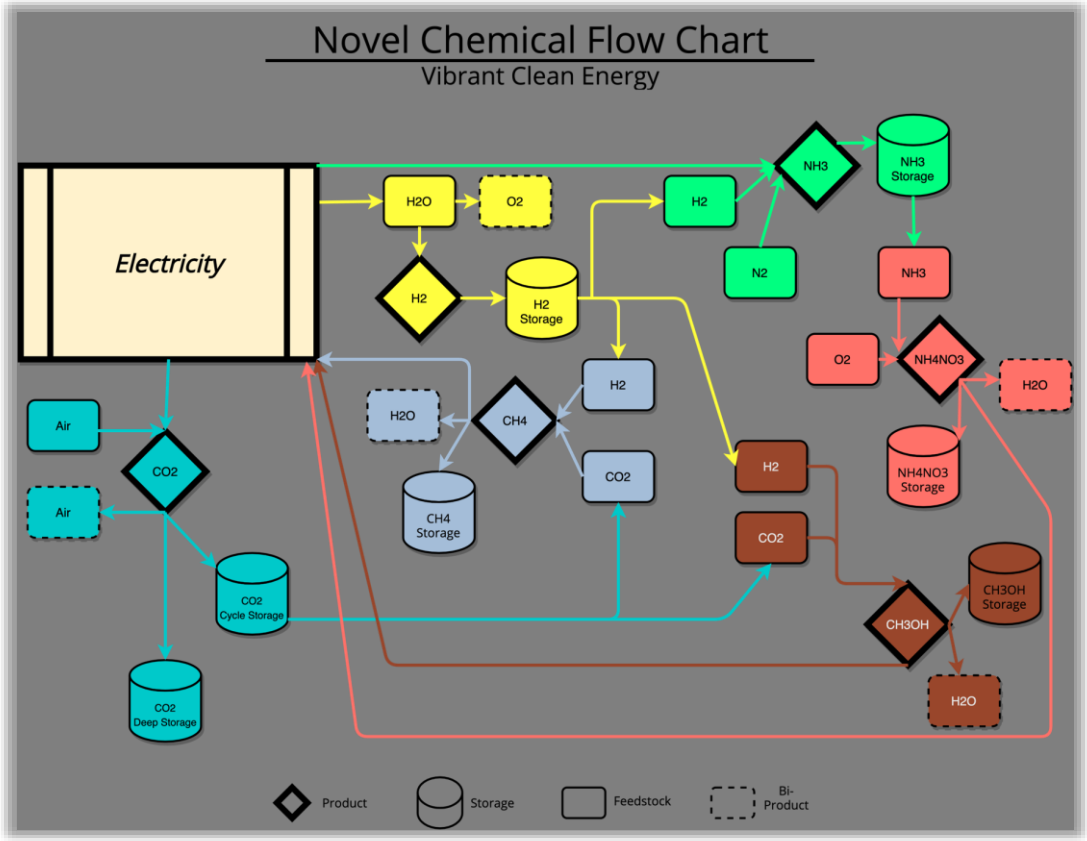
The Whole Economy Needs Critical Products



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Available Clean Generation Are Tied To Electricity

Low-marginal Cost Electricity Production Resources (kWh)

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

Flexibility Resources (kWh → kW → kWh)

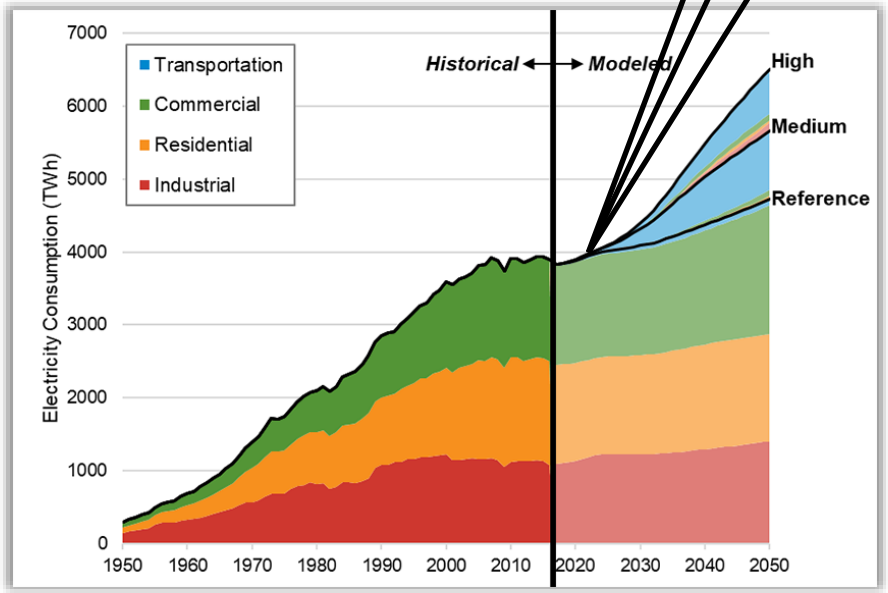
- *Transmission*
- *Hybrid Resources (wind+solar+storage)*
- *Storage (electricity+heat)*
- *Electrification*
- *Direct Air Capture*
- *Demand-side management*
- *Dispatchable Generation (SMR, EGS, H_2 CC, NGCC+CCS)*
- *Synthetic Fuel/Chemical Production (H_2, CH_4, NH_3)*
- *Peaking Generation (H_2 CT)*

Demand For Electricity Will Necessarily Grow

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

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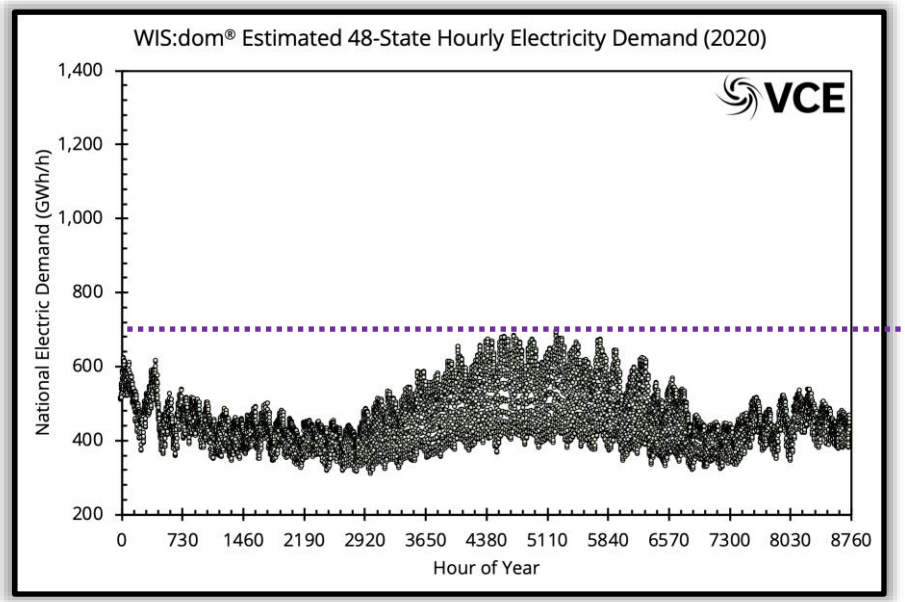
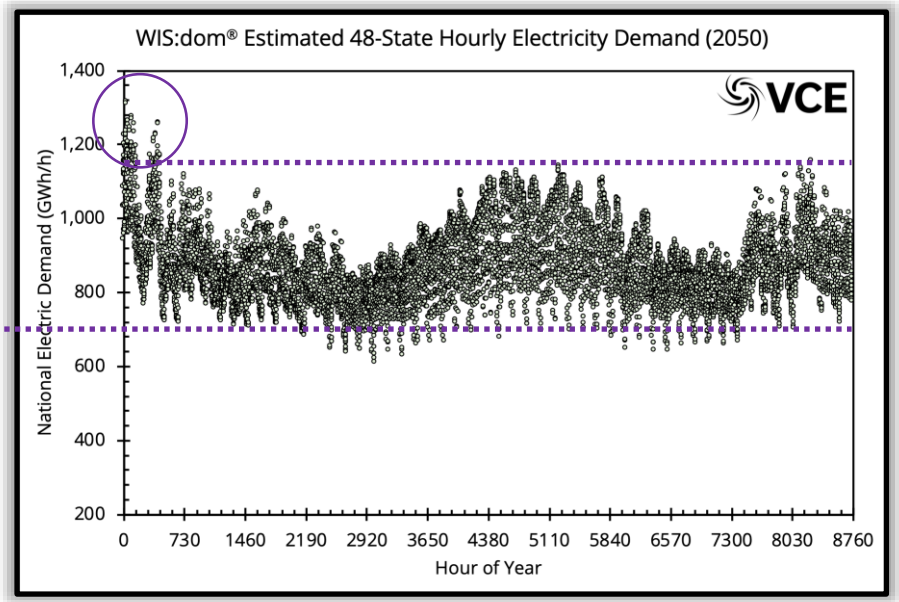
Demand Profiles & Stress Periods Will Change Over Time





* Before synthetic fuel production

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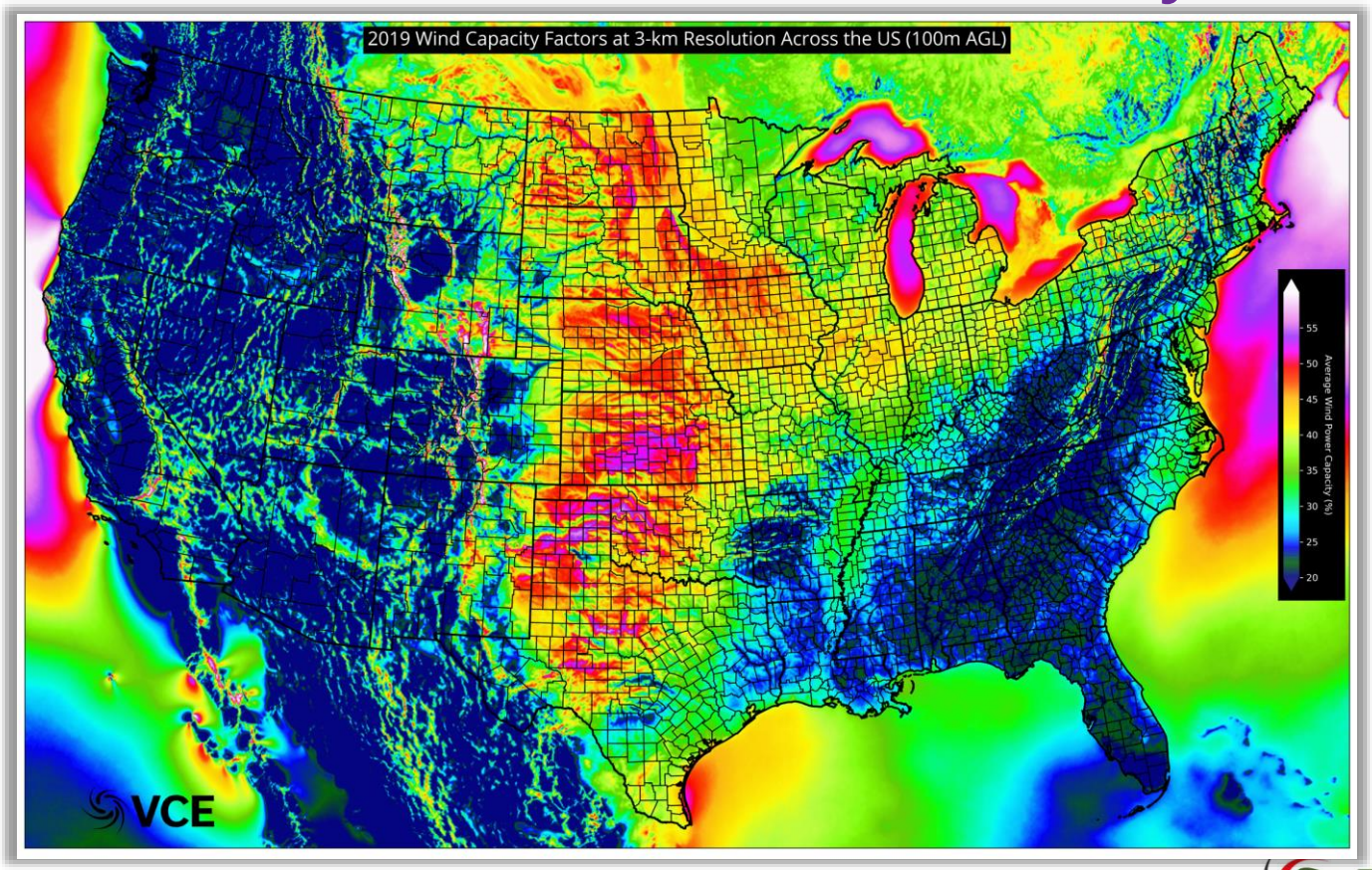
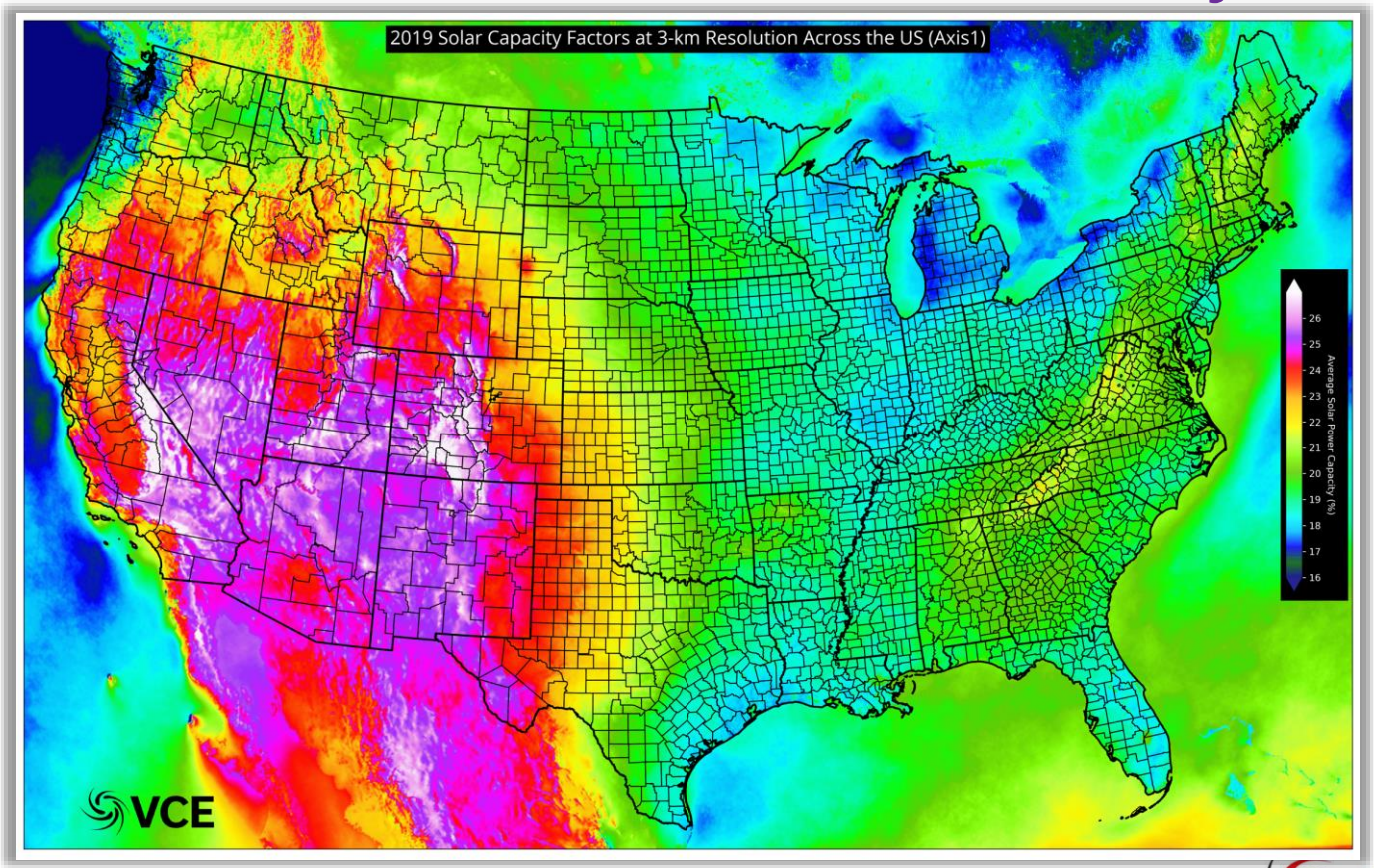
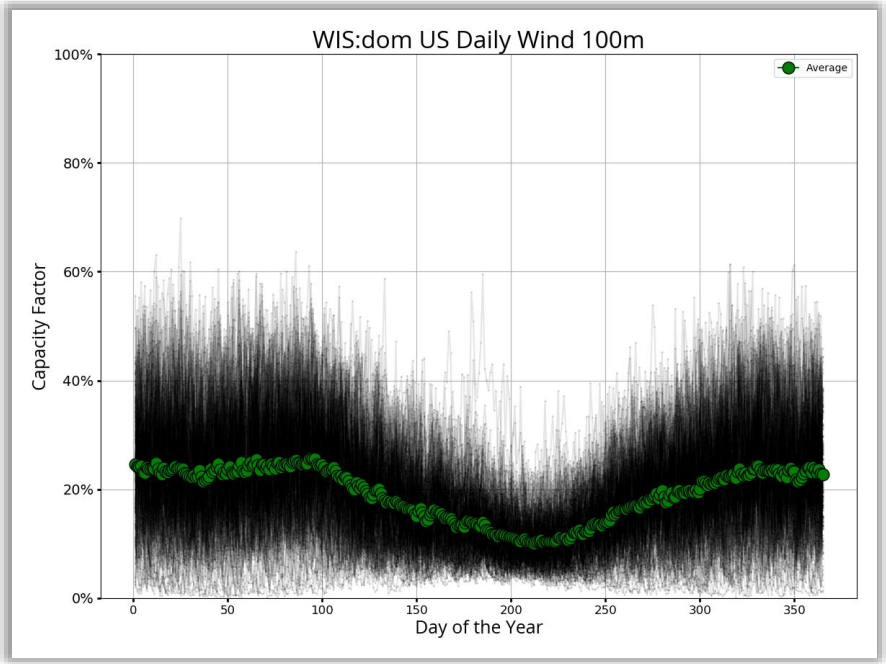
Wind (a fuel of the future economy)

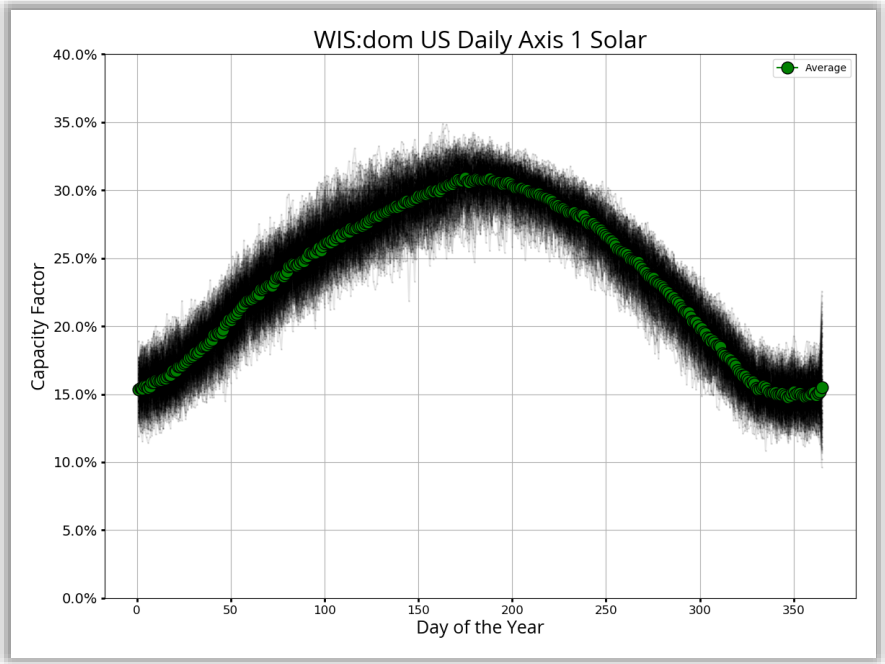


Solar PV (a fuel of the future economy)



We Need to Embrace & Design With Variability in Mind





* Preliminary VCE® 175-year resource dataset

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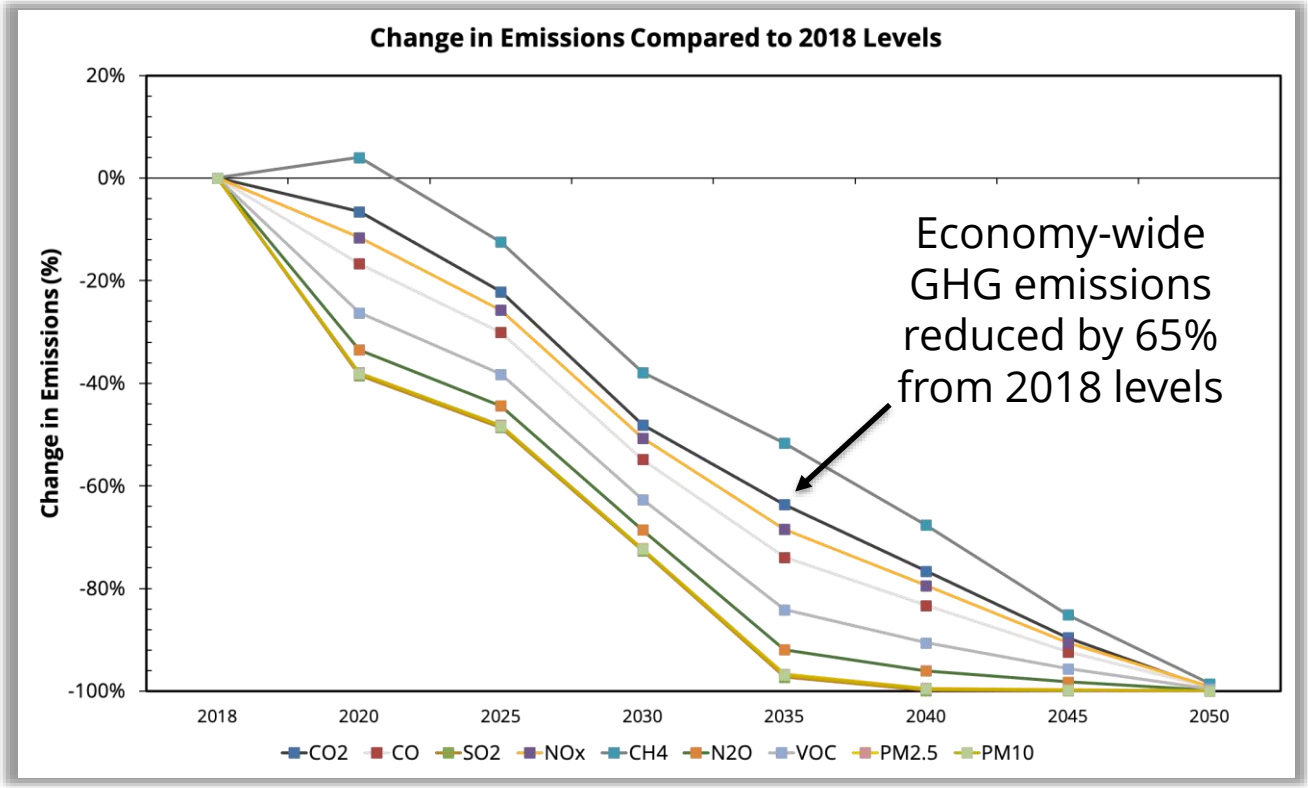
Results from Zero By Fifty (ZBF)

*Note: this is a **possible** pathway, not **the** pathway*

Pollution and GHG Emissions



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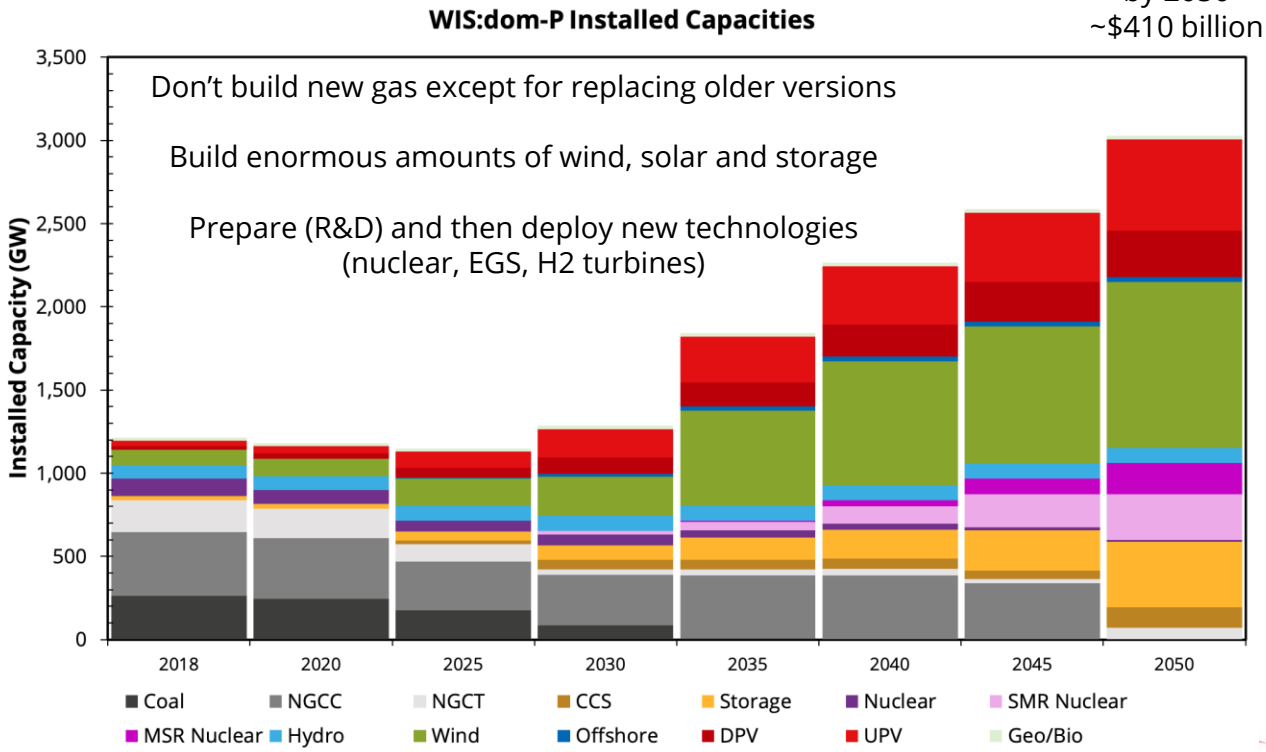
Installed Capacities

Annual Cost
by 2050
~$410 billion



Keep GTs for
reliability &
emergencies

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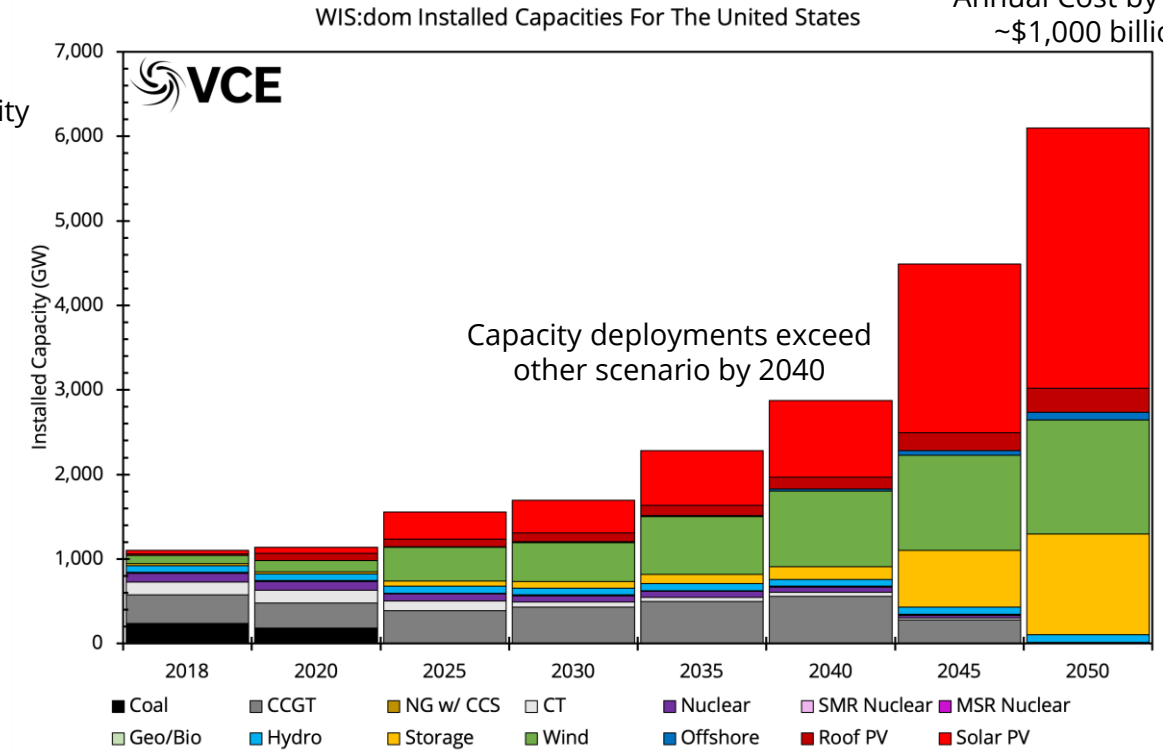
Alternative Installed Capacities (100% VRE+HVDC)

Double the Capacity Required

Annual Cost by 2050
~$1,000 billion



Capacity deployments exceed other scenario by 2040

All reliability provided by transmission and storage

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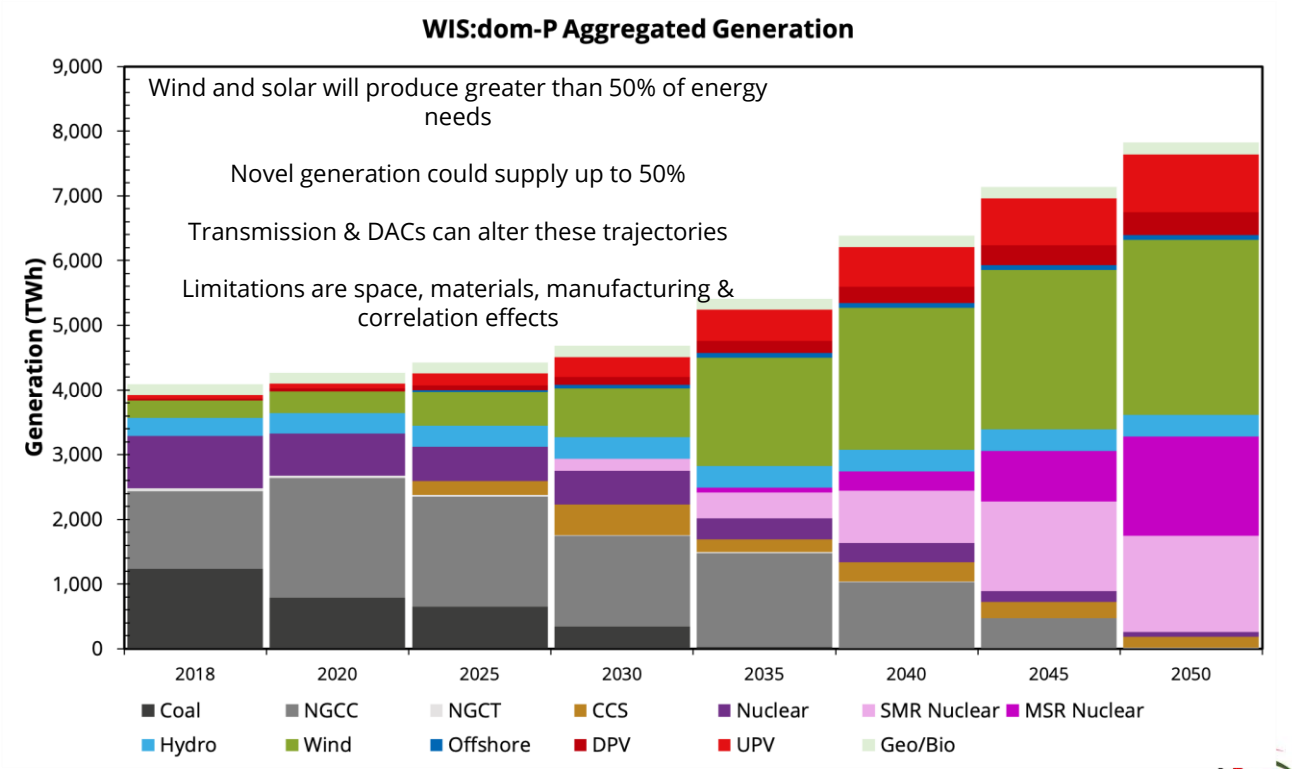
Generation Stack



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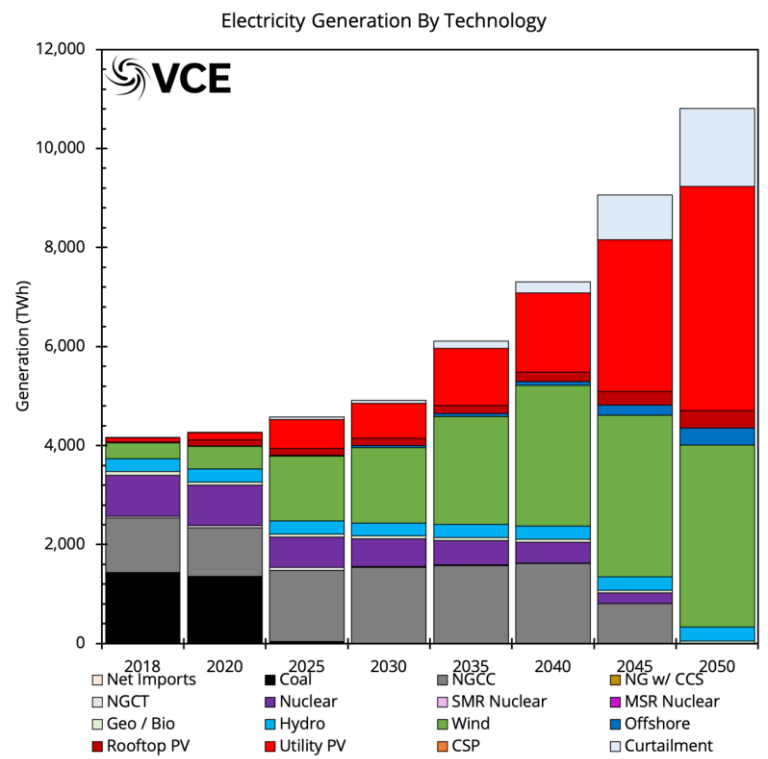
Alternative Generation Stack (100% VRE+HVDC)

Natural gas rises in the near term because of reliability issues



Curtailment reaches 15% of demand

Much more generation to power storage and move around transmission system

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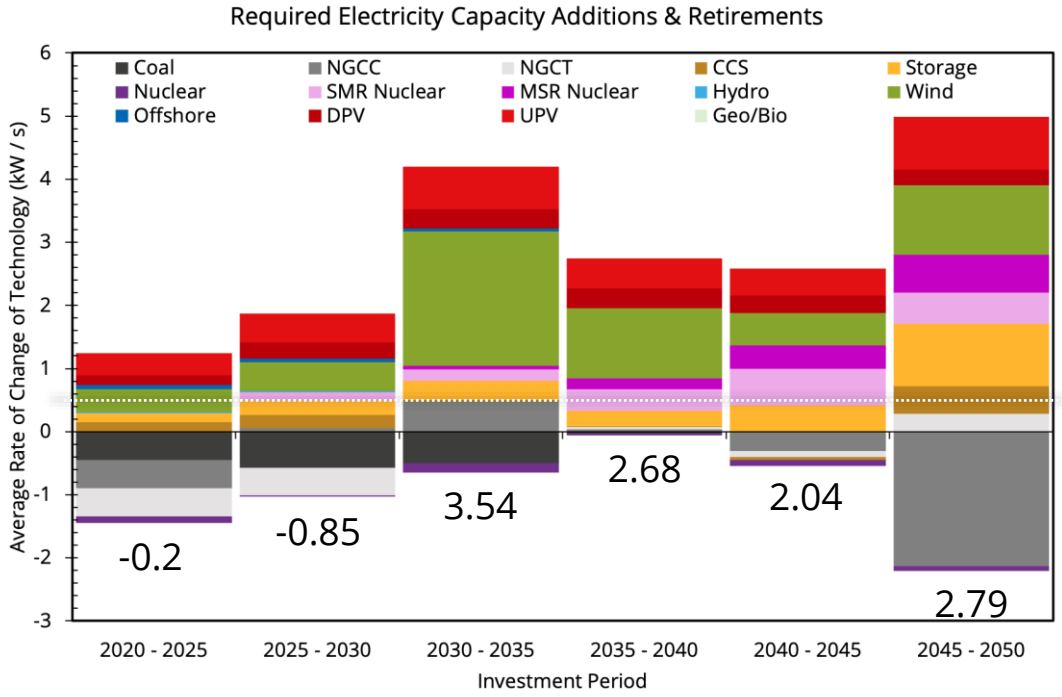
Deployments & Retirements

MW	Coal	Natural Gas	Nuclear	Storage	Hydro	Wind	Solar	Other	Storage MWh	MaxLoad
2020 - 2035	-238,934	-125,885	17,565	105,709	5,783	491,724	345,984	59,498	730,293	125,775
2035 - 2050	-5,351	-343,709	371,772	260,184	1,292	427,727	408,515	65,348	3,548,550	397,096



Historical Average Net Installation Rate is 0.48 kW / s

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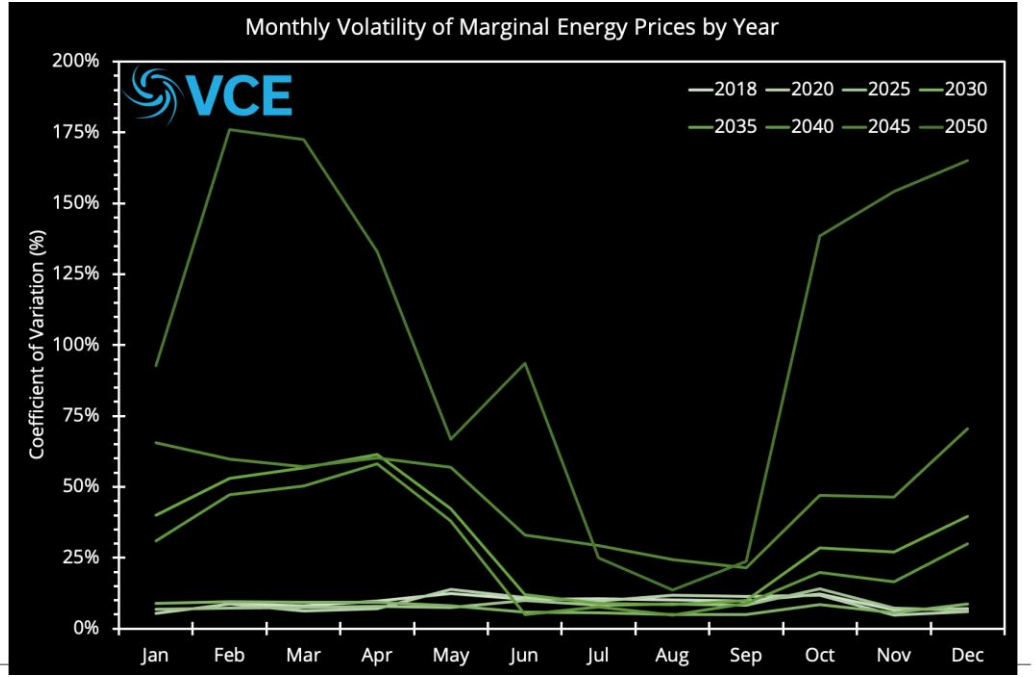
System Cost Components

2018 $	Generation Fixed	Generation Variable	Distribution	Transmission	Hydrogen
2020	$ 161,879,856,147	$ 57,729,389,022	$ 81,199,860,452	$ 3,619,412,641	$ 74,038,326
2035	$ 150,096,807,234	$ 48,890,441,196	$ 93,866,444,801	$ 2,801,320,778	$ 805,489,602
2050	$ 260,746,105,578	$ 16,257,063,493	$126,995,746,572	$ 3,877,240,502	$ 1,523,886,680

Retail Rates

2020 – 10.7¢/kWh
2035 – 7.6¢/kWh
2050 – 7.1¢/kWh



Electricity GHG

2020 – 409.4 g/kWh
2035 – 118.2 g/kWh
2050 – 1.1 g/kWh

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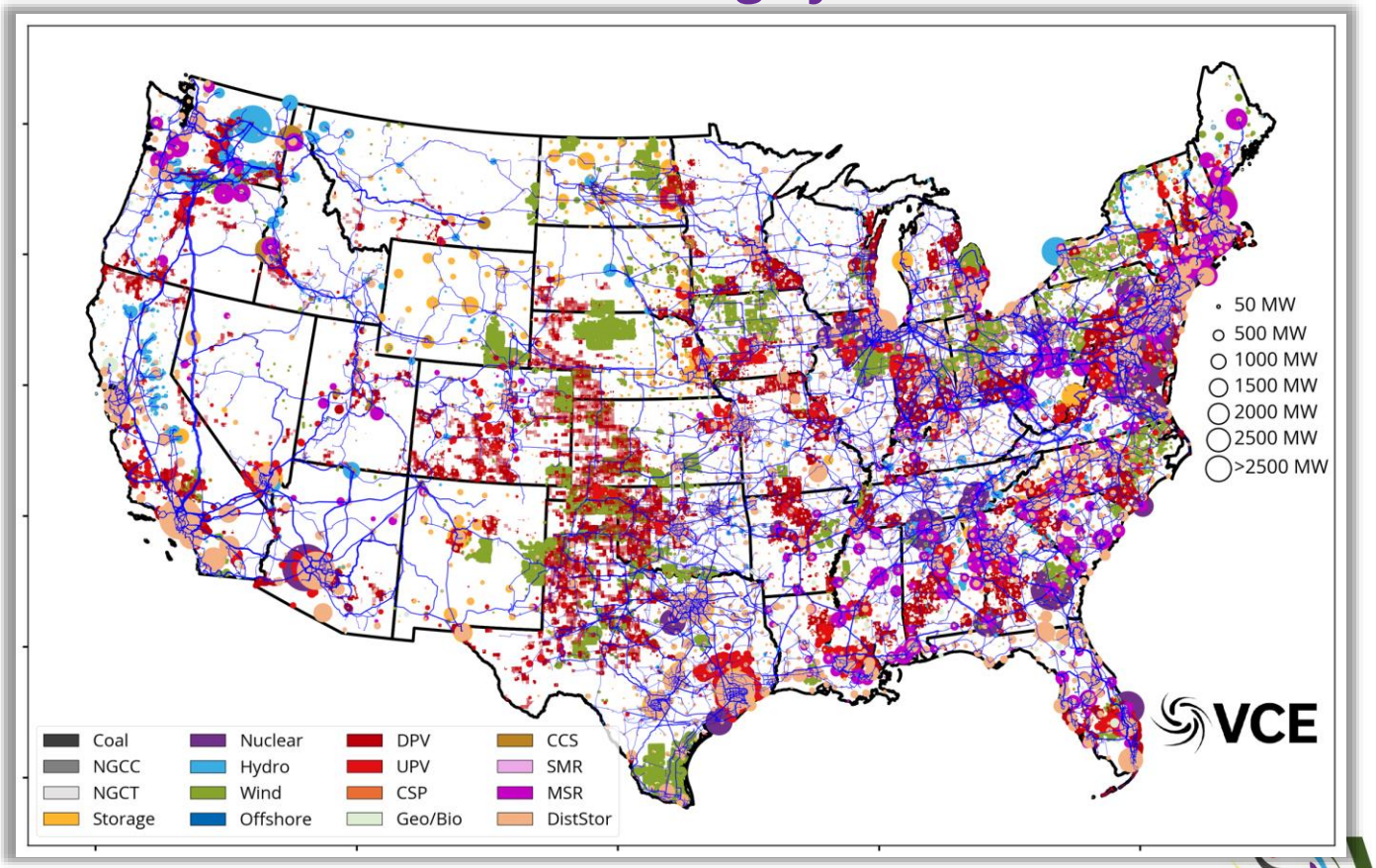
Resource Siting by 2050



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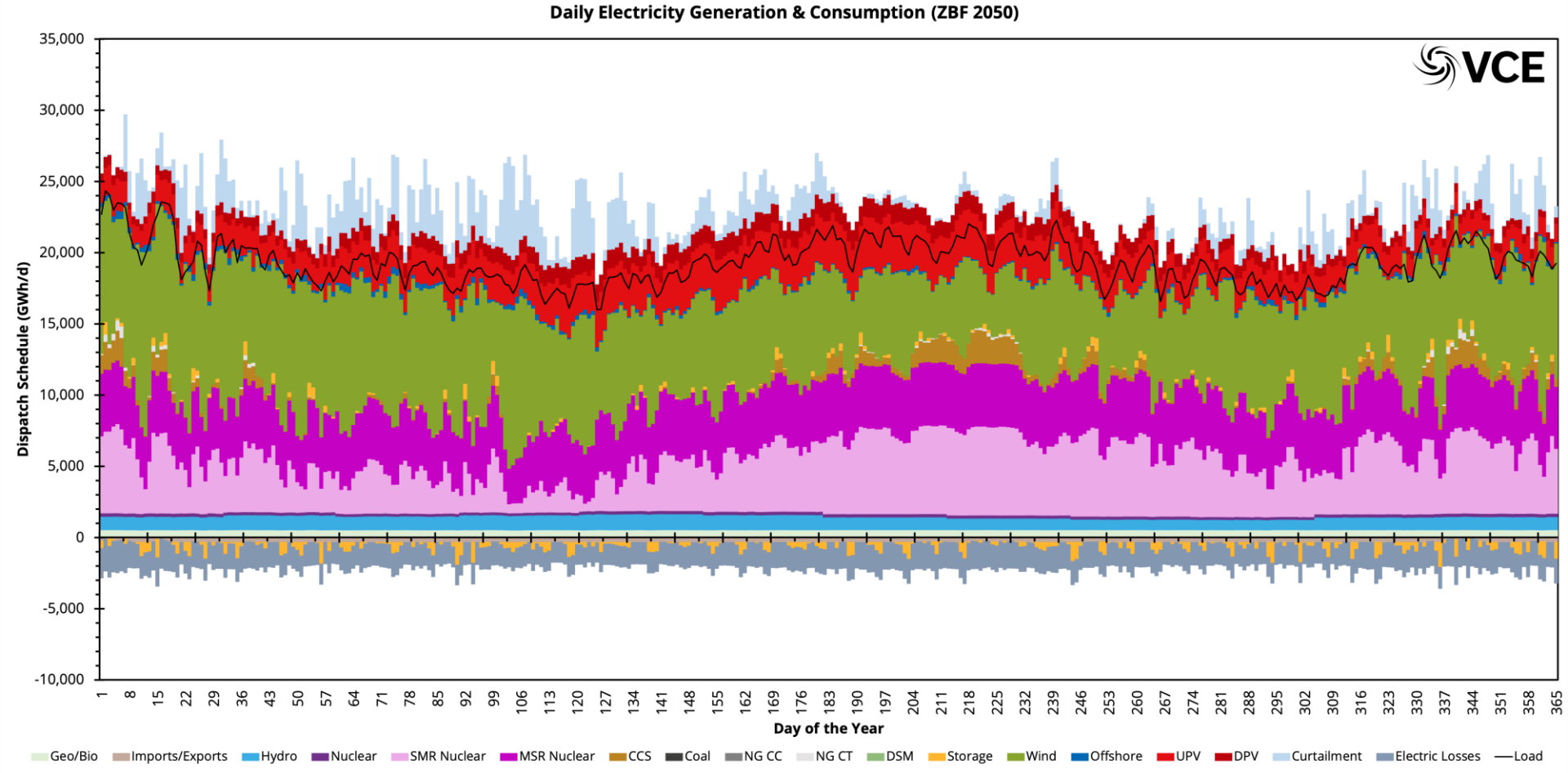
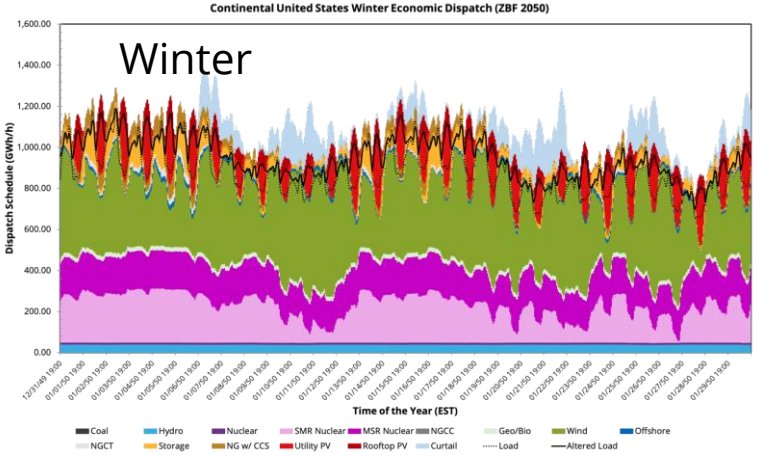
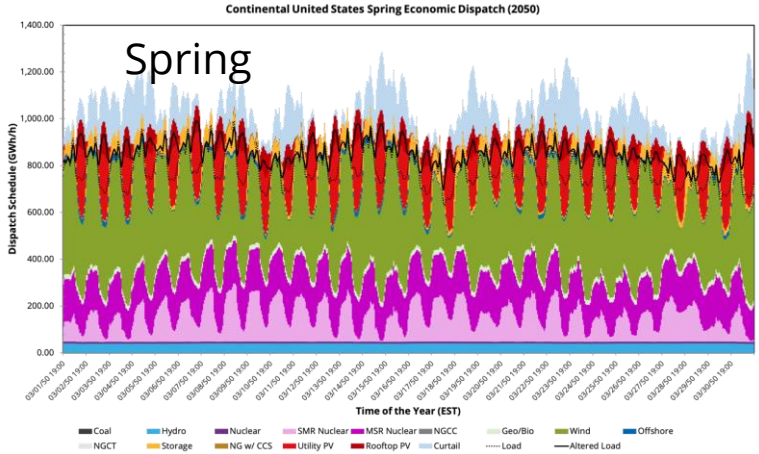
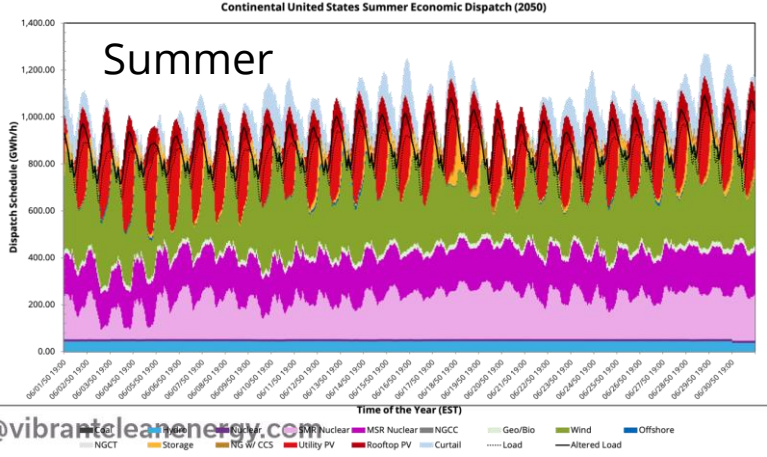
Dispatch of the System

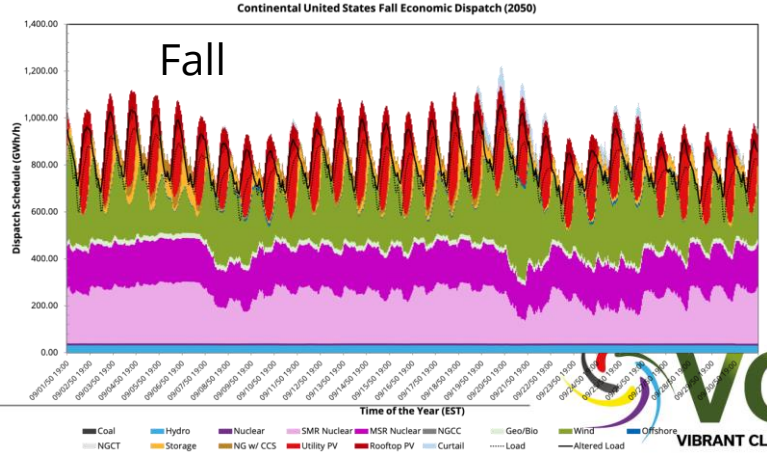


Dispatch of the System

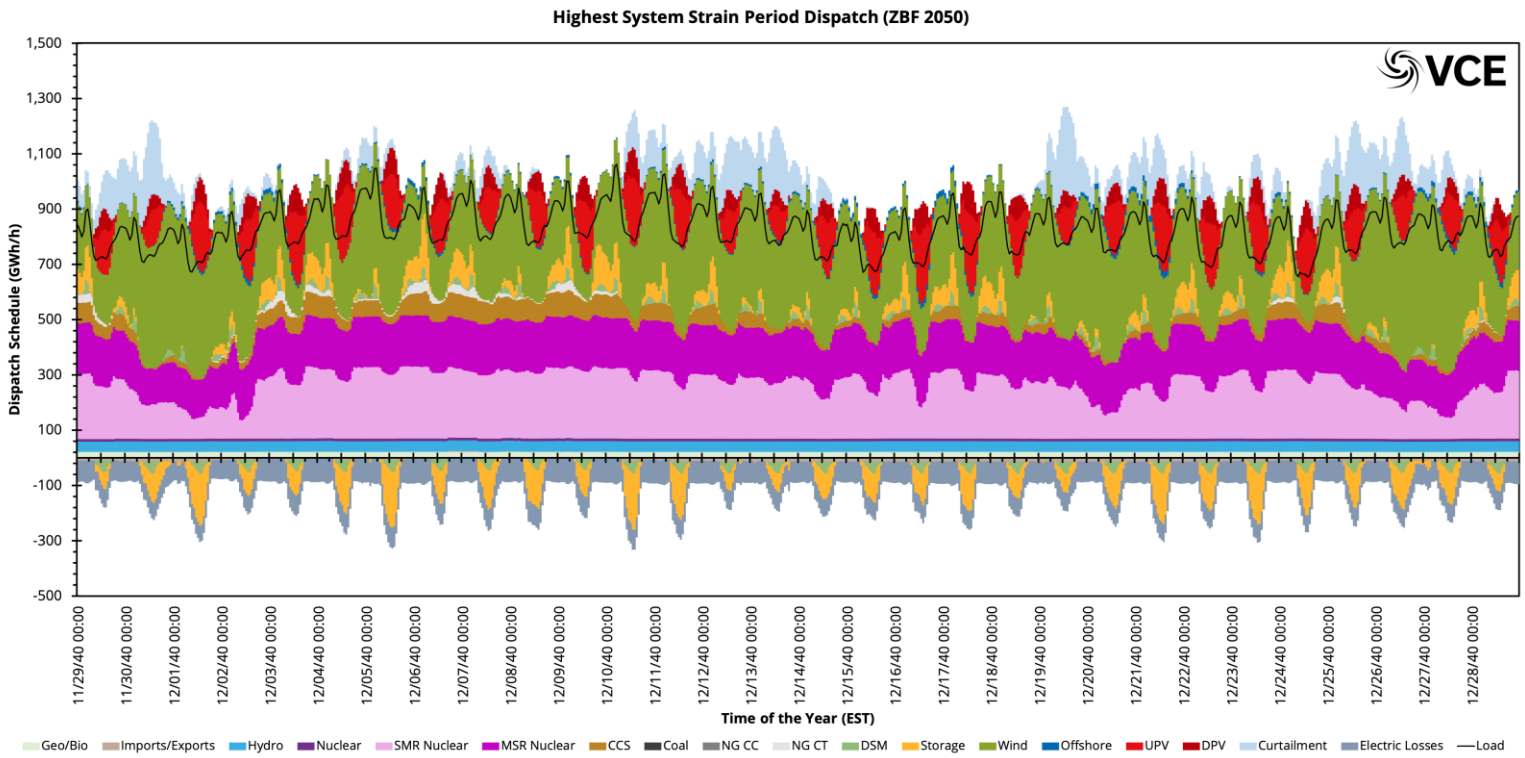








Dealing with the worst weather and demand combinations



Minimum VRE contribution to meeting demand is 18% with a maximum is 93%

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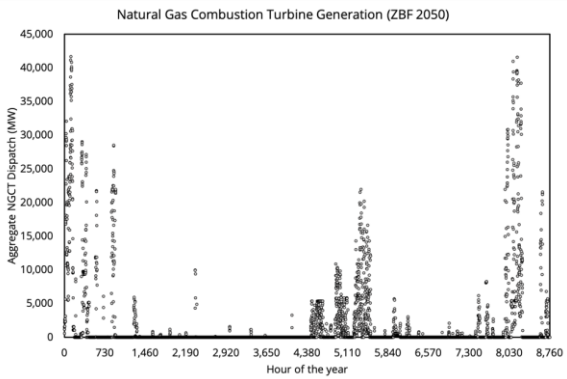
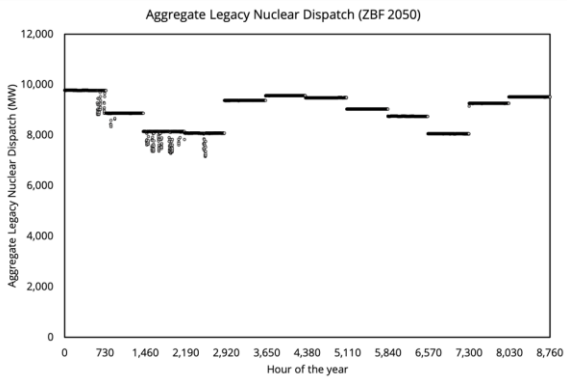
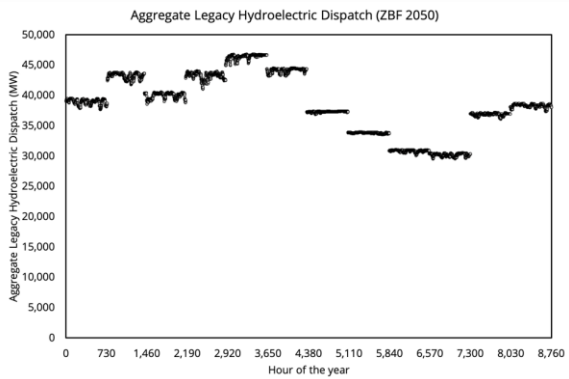
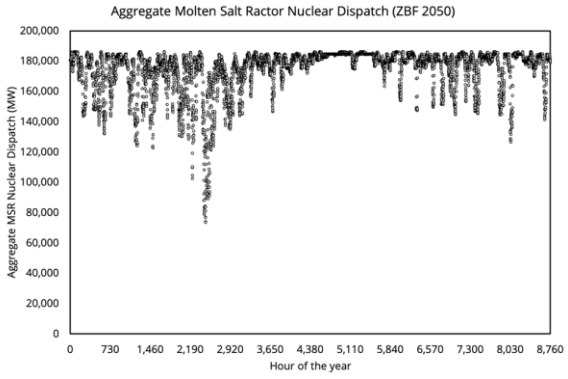
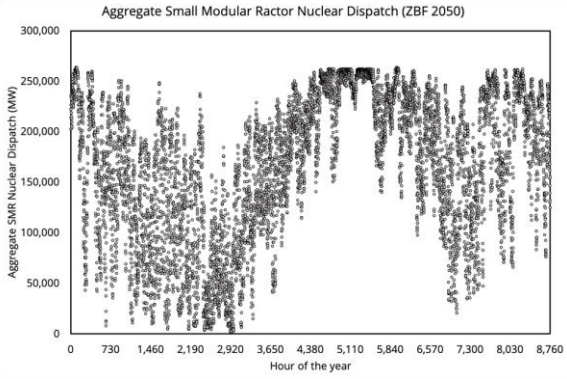
Dispatch of Generation (2050)

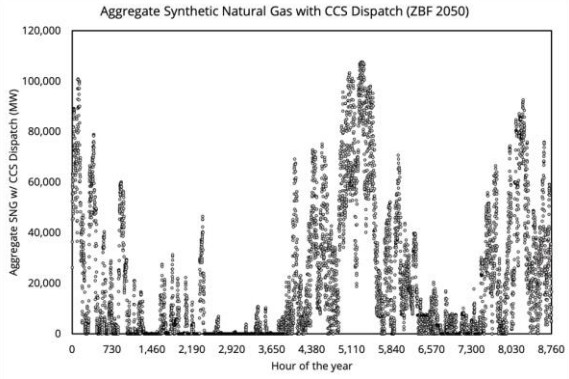












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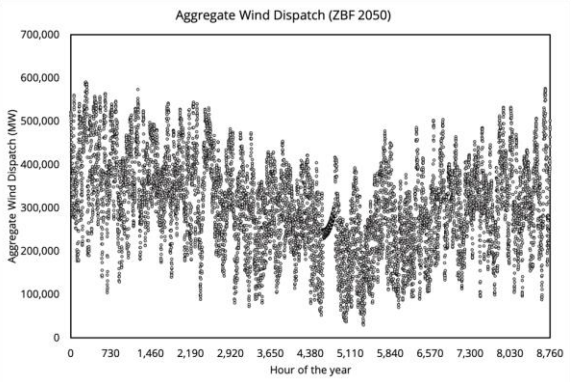
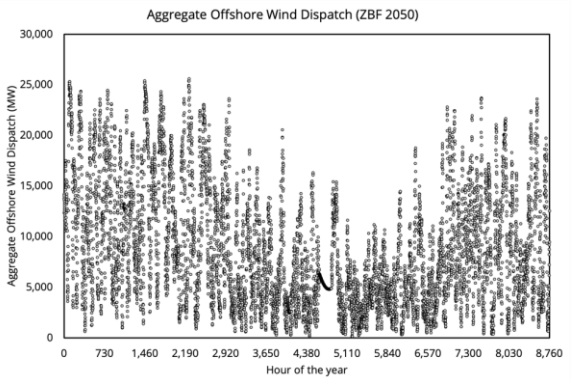
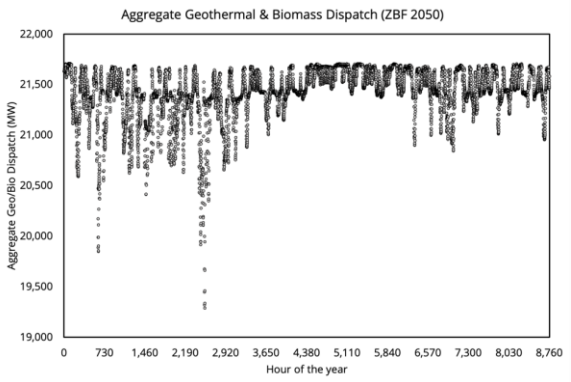
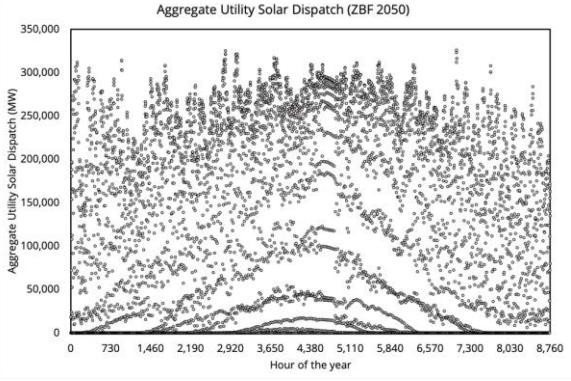
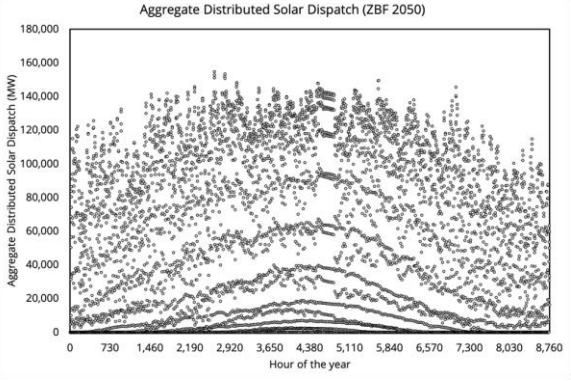
Dispatch of Generation (2050)

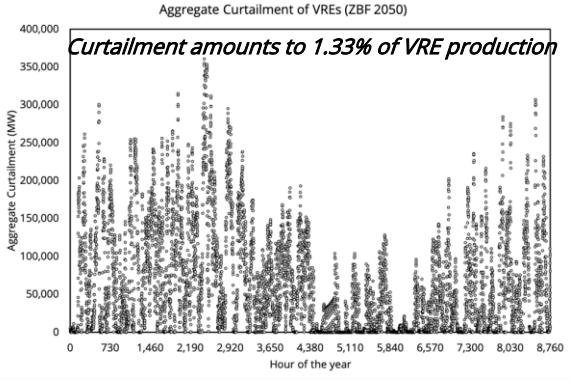












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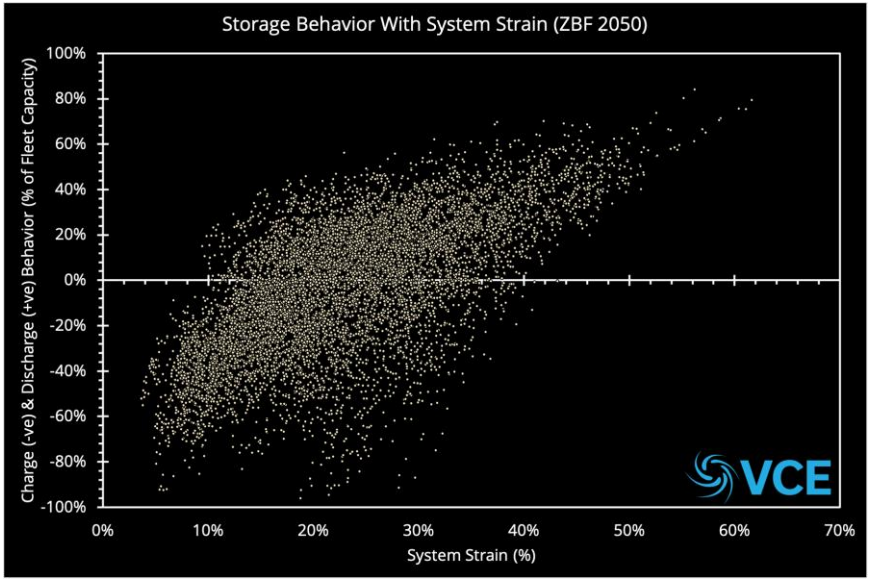
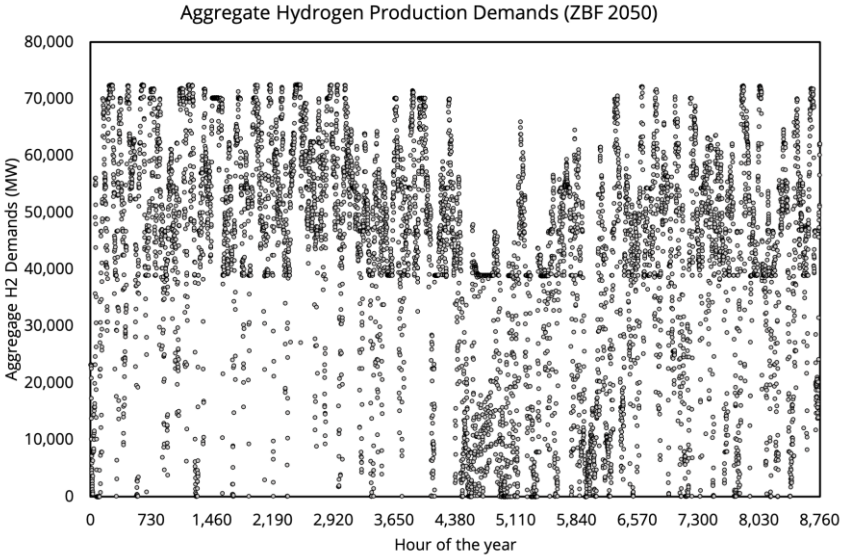
Behavior of Storage (Diurnal & Seasonal)





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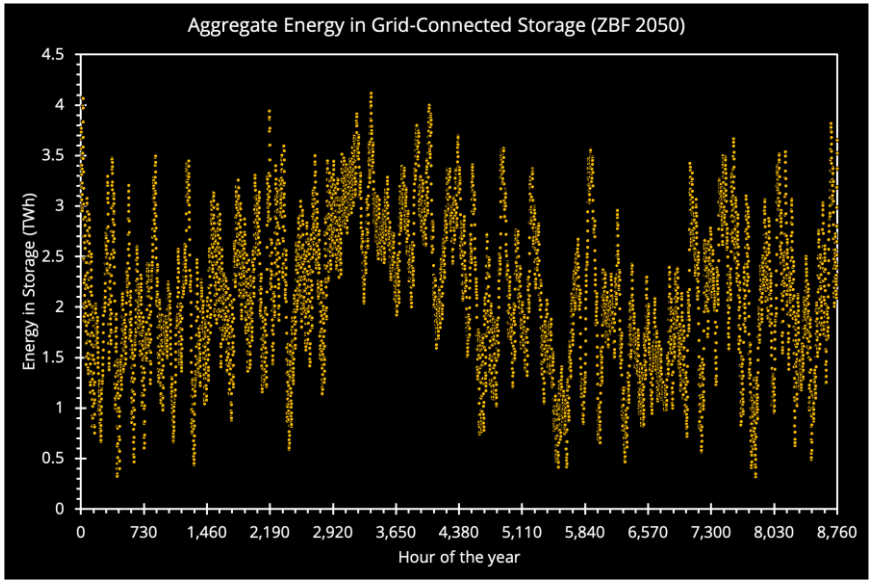
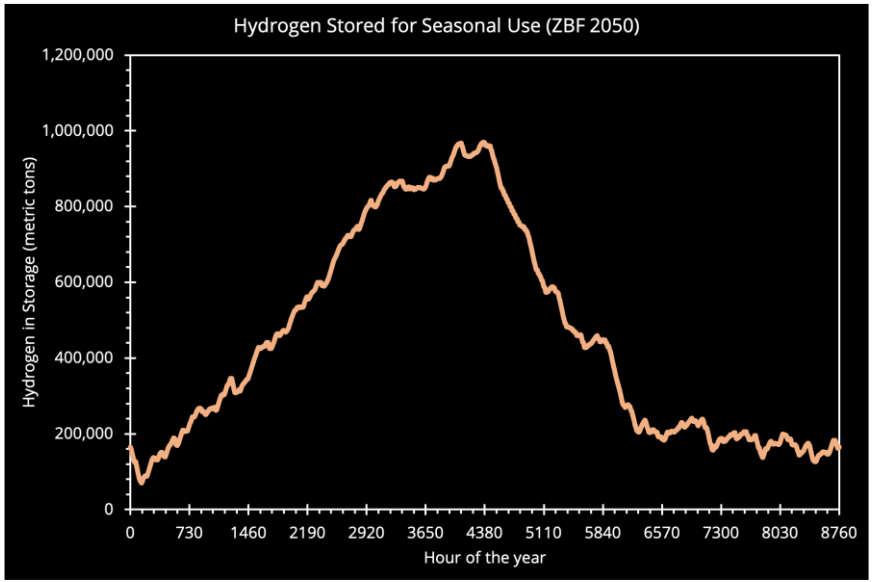
Behavior of Storage (Diurnal & Seasonal)





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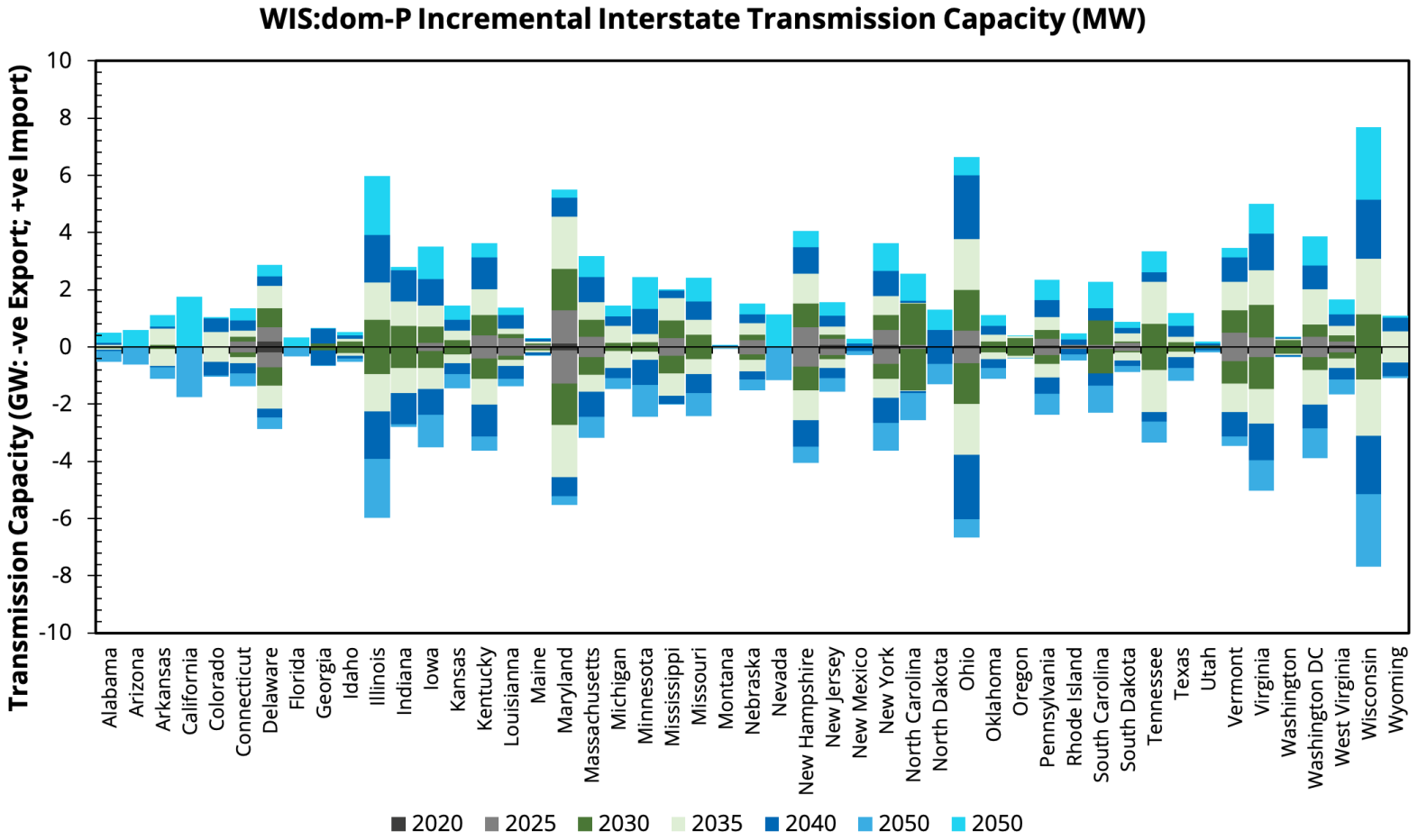
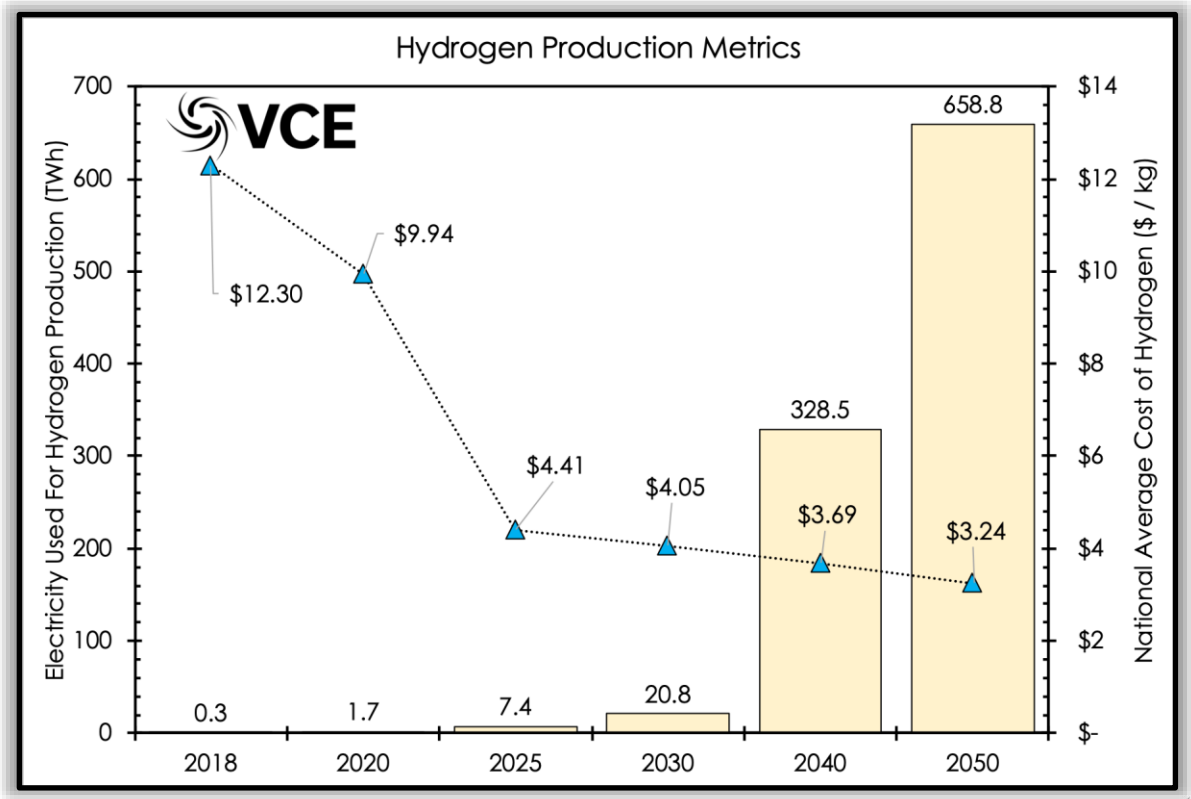
Transmission Construction



Hydrogen Economy



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Basic Checklist For Reaching Climate Goals

- *Build additional **500 factories** for the production of wind turbines, blades and towers by 2025*
- *Build out the supply chain for solar PV **by five-fold***
- *Build **13 Gigafactory scale battery plants** by 2035, with eight by 2030 and three by 2025*
- ***Rebuild the nuclear industry** for SMR and MSR production by 2030 and 2035, respectively*
- *Manufacturing facilities for **2000s level production of Natural Gas** (now with CCS)*
- *Facilitate manufacturing of transmission infrastructure at a level to **double that of China***
- ***Modernize the distribution grids** to enable smart grids by 2030*
- ***Reinvent electricity markets** to enable DERs and fuel production across the continent by 2030*
- ***Create a hydrogen economy** and associated basic infrastructure by 2035*
- *Convert **all vehicle production to EVs by 2030** at the latest, preferably 2025*
- *Demand all **new buildings have ASHP and HPWH** for space and water heating by 2025*
- ***Convert** all water heaters and space heating to heat pumps by 2040*
- *All industry **must have CCS** or electricity alternatives by 2040*
- *Produce all ammonia for fertilizer through electricity and hydrogen by 2040*
- *Aviation and shipping must be **enabled by synthetic liquid fuels** by 2045*
- ***Retrain dislocated workers** with some of the millions of new jobs created*

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Thank You

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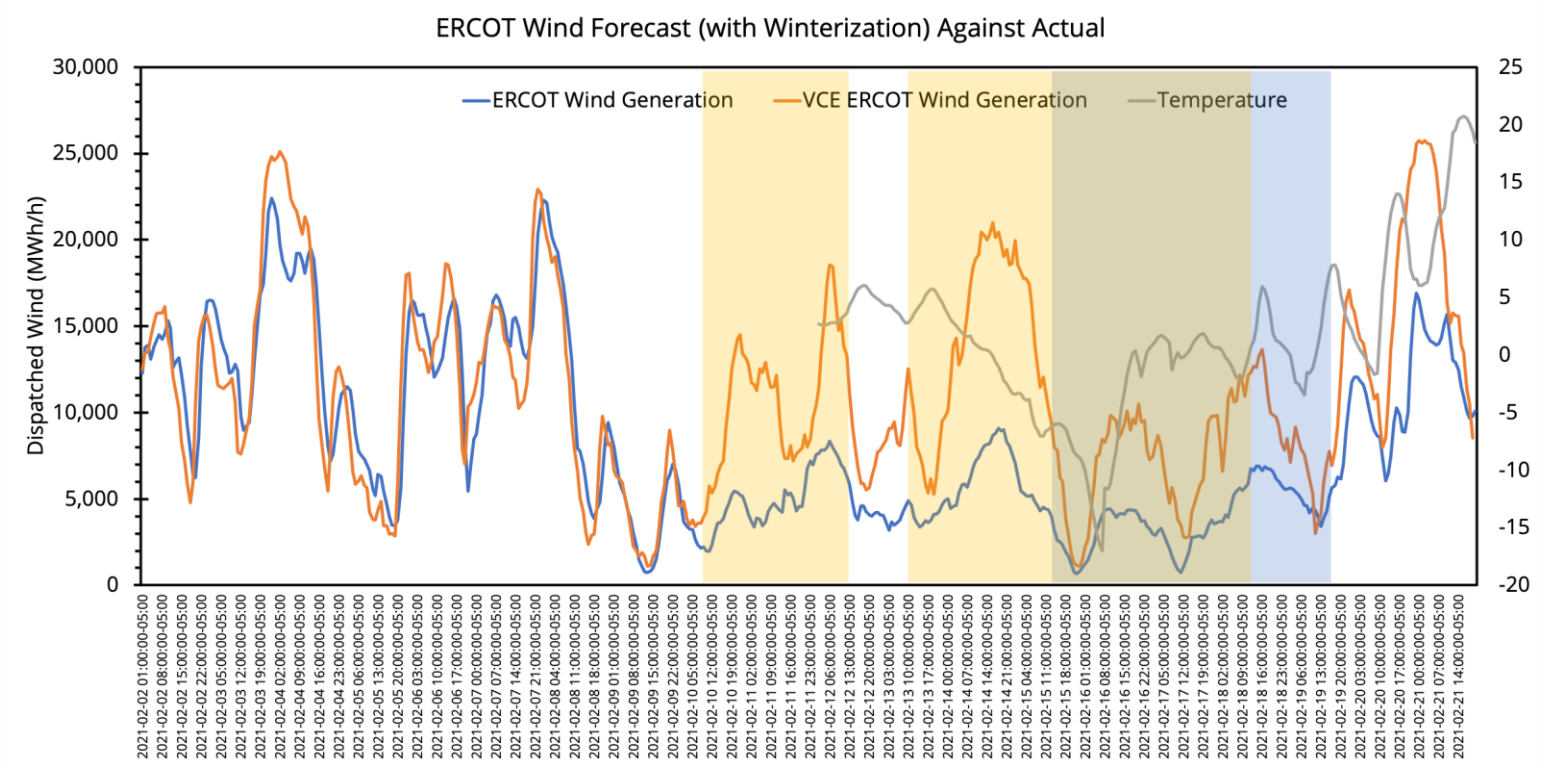
Texas Energy Crisis (wind left on the table ~$4.8 billion in revenue)



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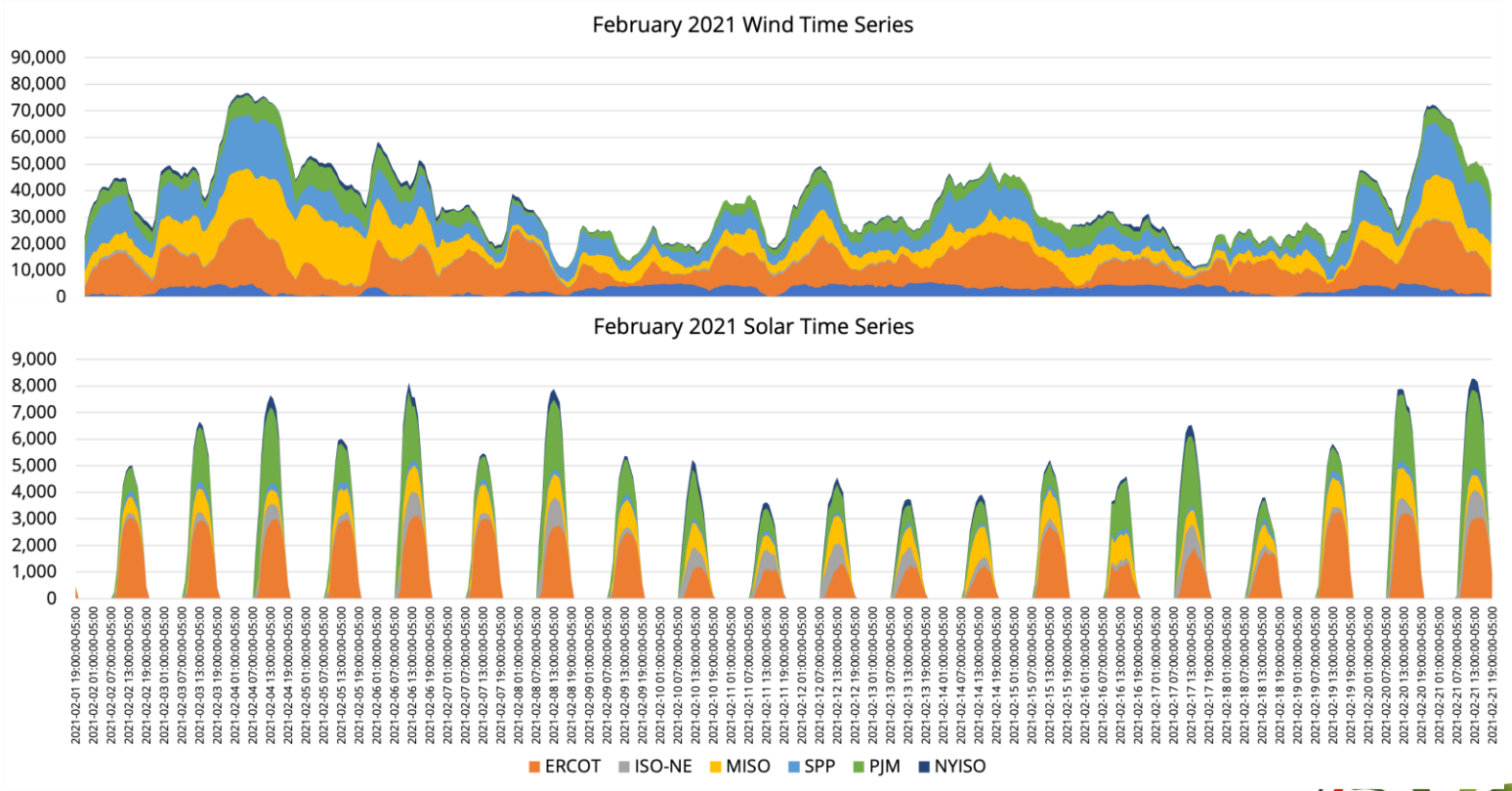
Texas Energy Crisis (other regions could have helped)



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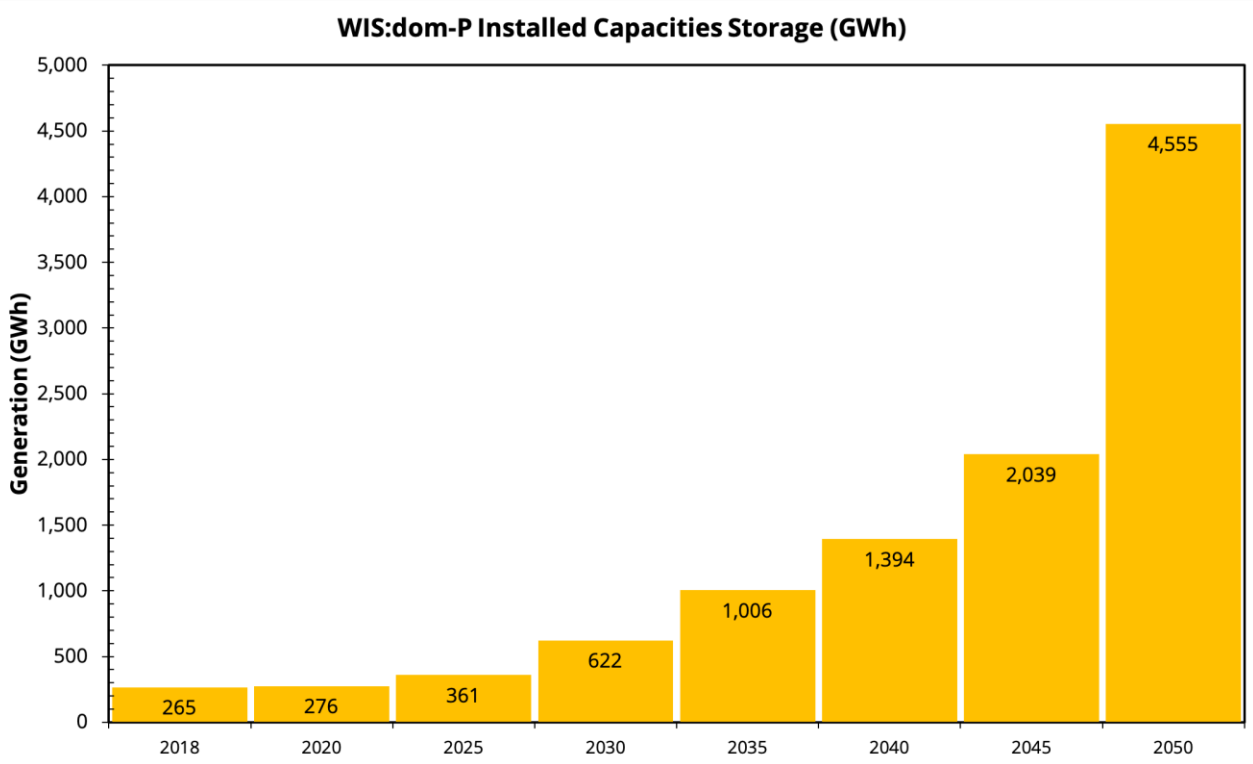
Installed Capacities (Storage Energy)



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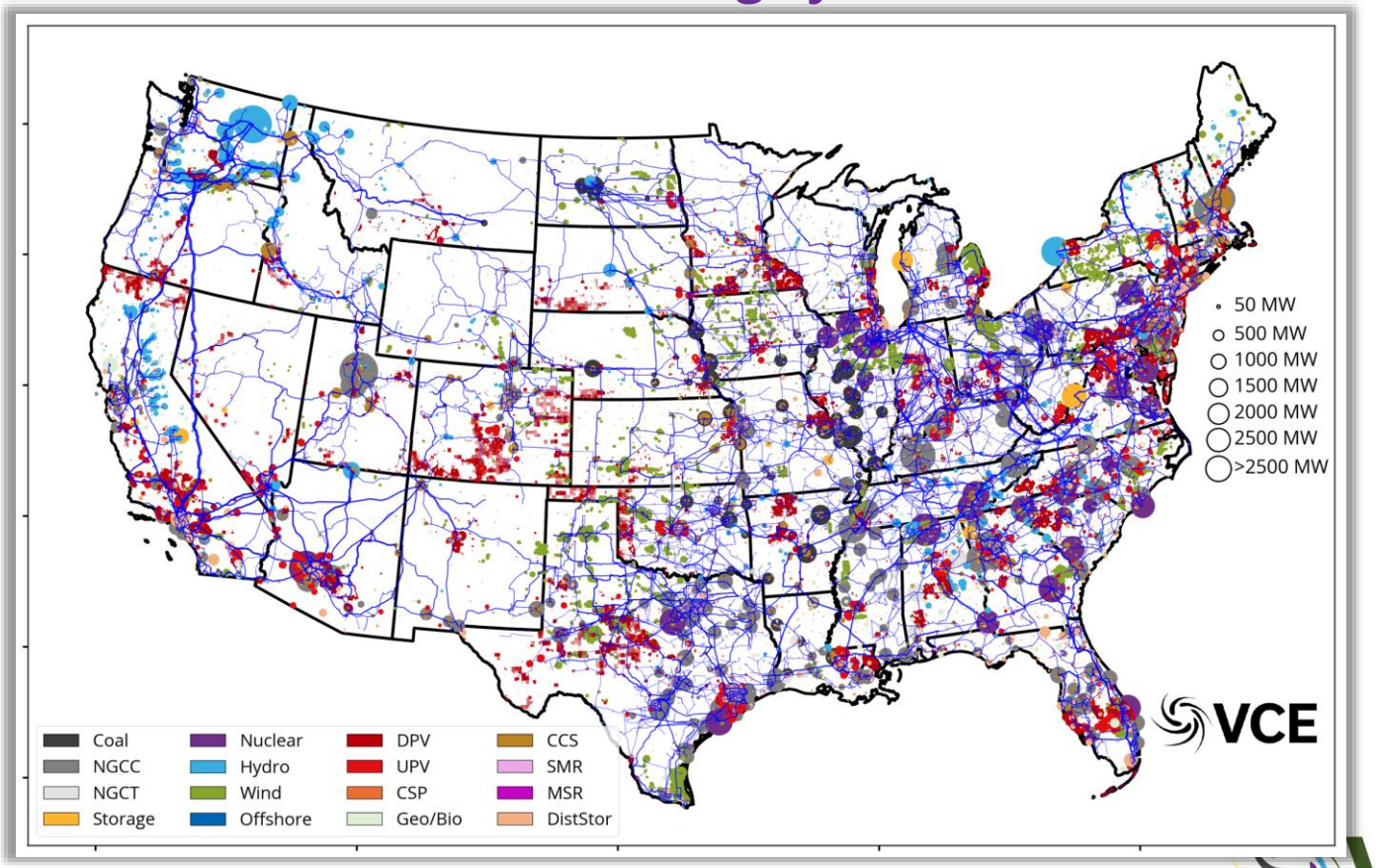
Resource Siting by 2035



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