Minnesota's Smarter Grid:

Pathways Toward a Clean, Reliable and Affordable Transportation and Energy System

Prepared By:

Vibrant Clean Energy, LLC

Dr Christopher T M Clack

Prepared For:

MN PUC Special Planning Meeting

October 30th, 2018

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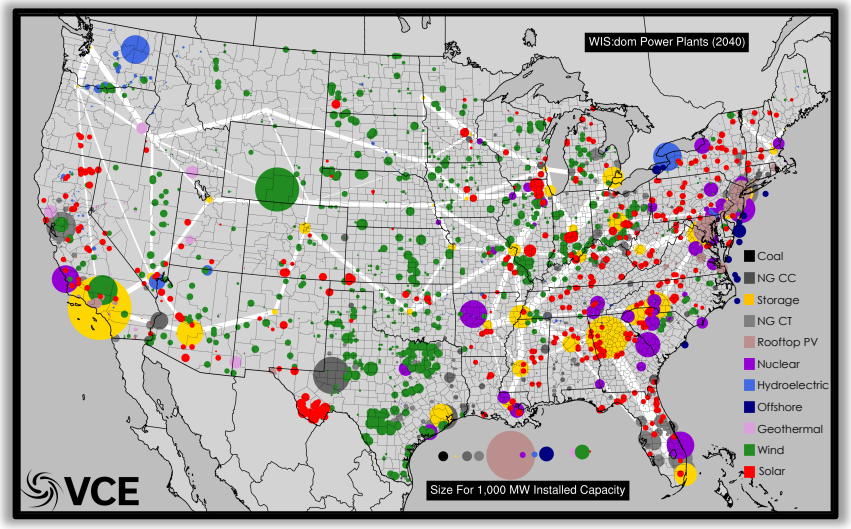

Purpose of Vibrant Clean Energy, LLC:

- 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 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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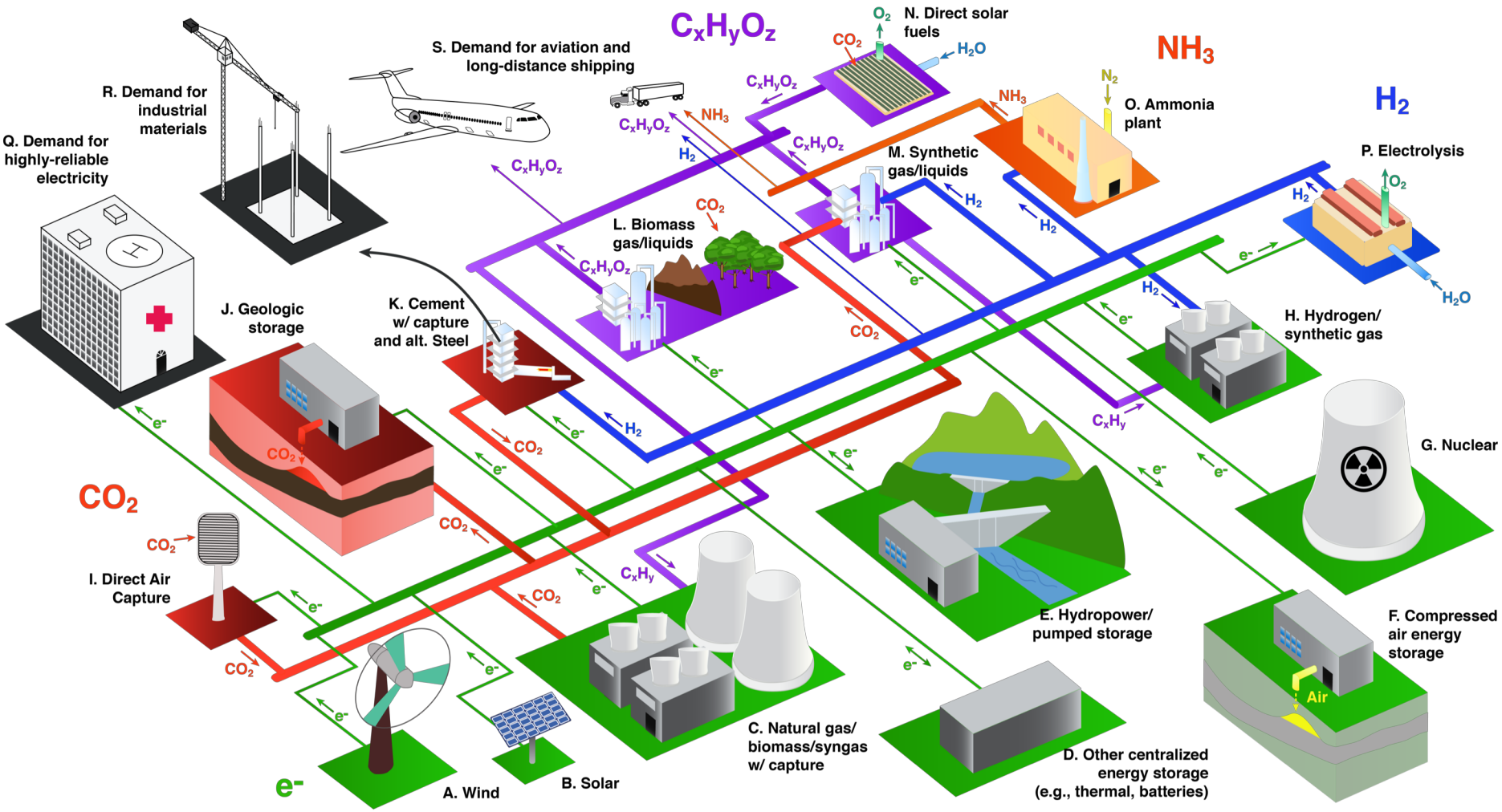
Minnesota's Smarter Grid

- Utilize the WIS:dom optimization model to investigate the pathways available to Minnesota to decarbonize the economy by 80% by 2050;
  - *WIS:dom modeled the **Minnesota electricity grid (along with the MISO and wider Eastern Interconnection)** with electrification of some other sectors taken into account under baseline (BAU) and decarbonized conditions.*
  - *To decarbonize the economy by **80% by 2050**, the electricity sector must decarbonize by a minimum of **91%** (with the consideration of strong EE, electrification of space & water heating and transportation. Note these are all referenced back to **2005**. **Essentially, the MN electricity sector has a maximum of 4.5 mm T of CO_2 emissions allowed to reach goal**.*

- Builds off two previous studies that VCE has performed in the MISO footprint:
  1. *A MISO commissioned study "High penetration renewable energy study for MISO" found here: https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=223249*
  2. *An Energy Foundation funded project in collaboration with UMN and Strategen consulting "Modernizing Minnesota's Grid" found here: http://energytransition.umn.edu/wp-content/uploads/2017/07/Workshop-Report-Final.pdf*

Our Approach With WIS:dom

The Whole Economy Needs Energy



Davis et al. *Science*, 2018

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Electrification That WIS:dom Considers

The WIS:dom optimization model considers

electrification through:

1. Light Duty Vehicles,
2. Heat pump Water Heaters (residential and commercial),
3. Heat pump space heating (residential and commercial),
4. Light Duty Trucks,
5. H2 production for:
    - *Medium / Heavy Duty Trucking,*
    - *Industrial Demands,*
    - *Space heating (residential and commercial),*
    - *Other transportation (Sabitier to Fischer-Tropsch Processes).*

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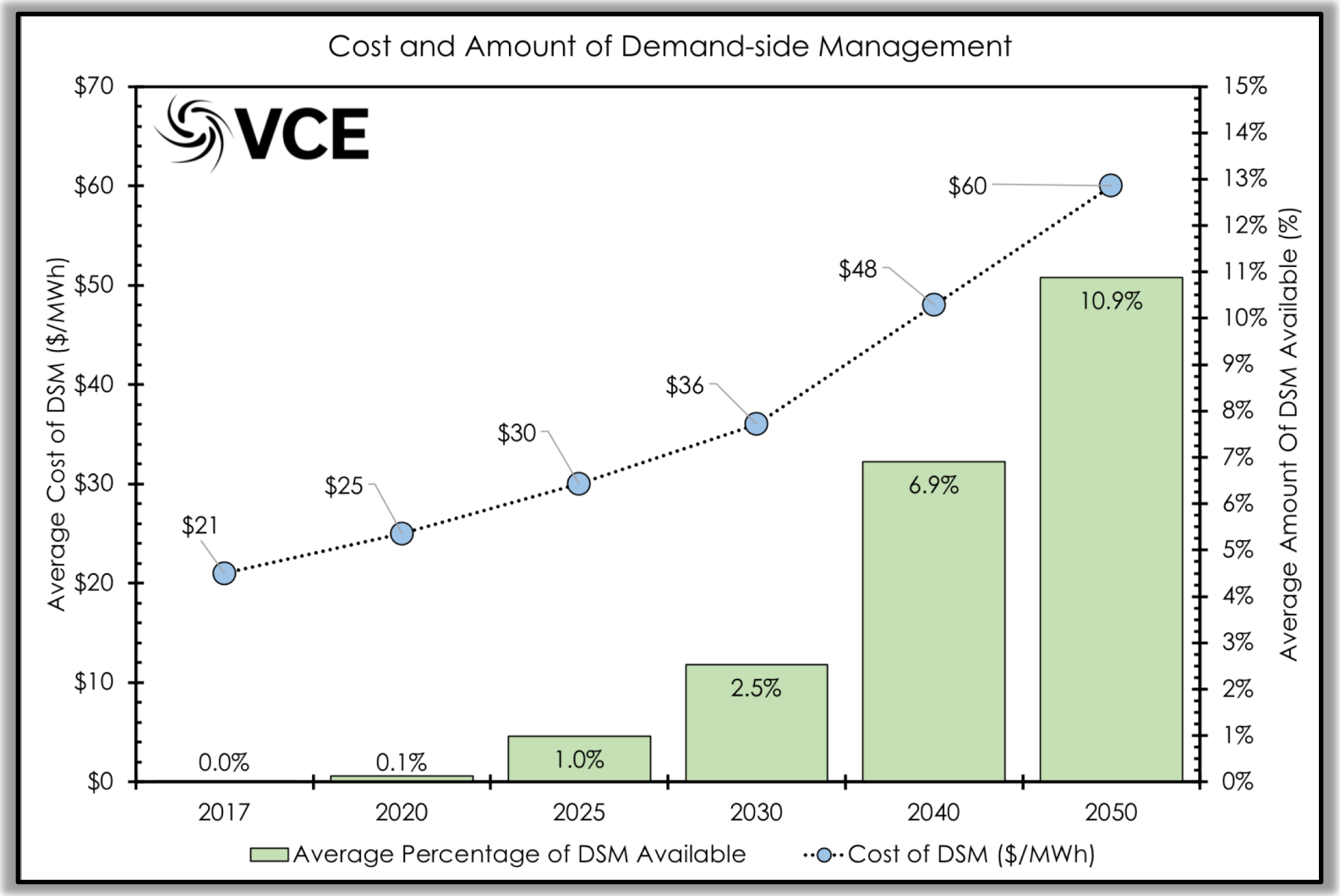
Demand-side Resources Create Flexibility



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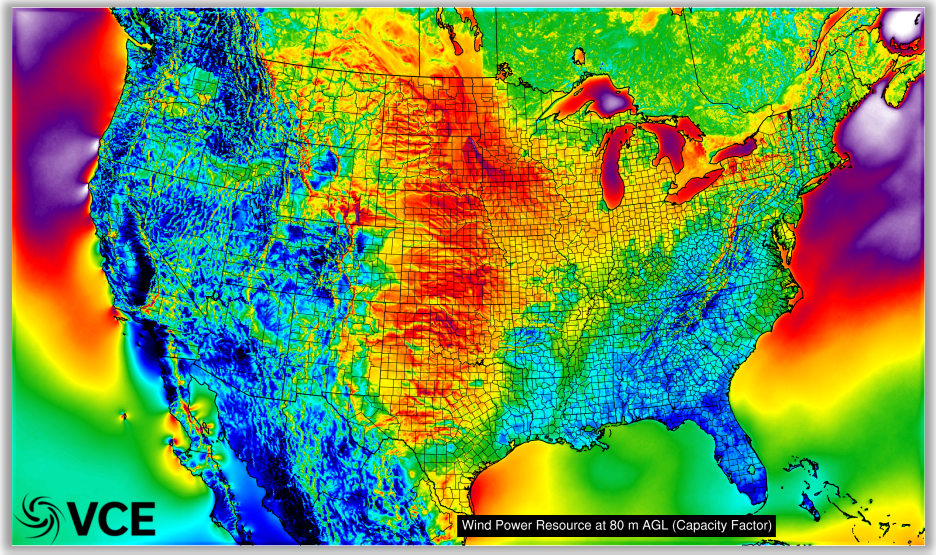
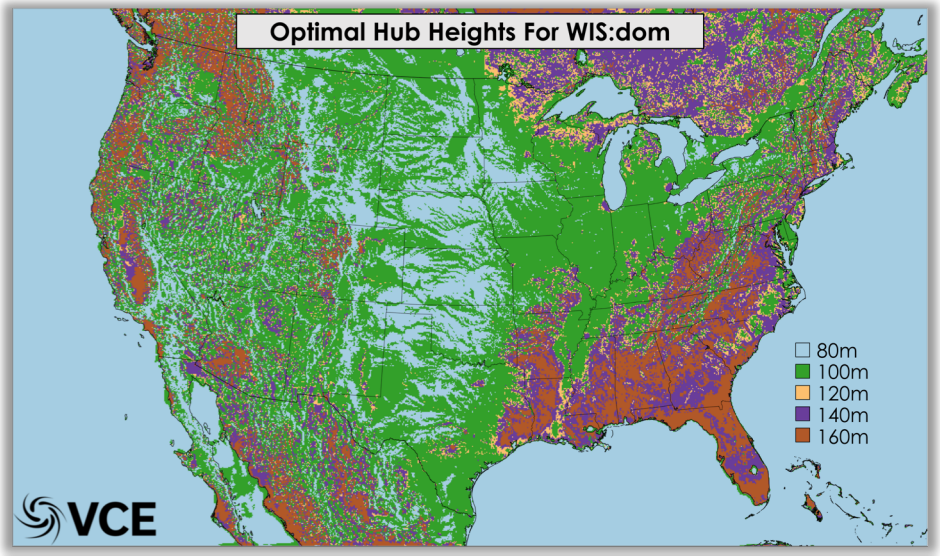
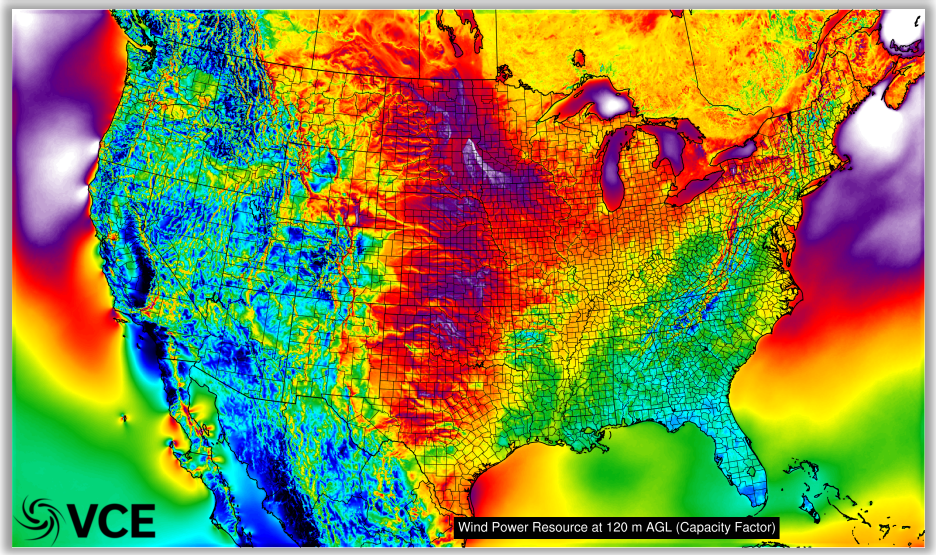
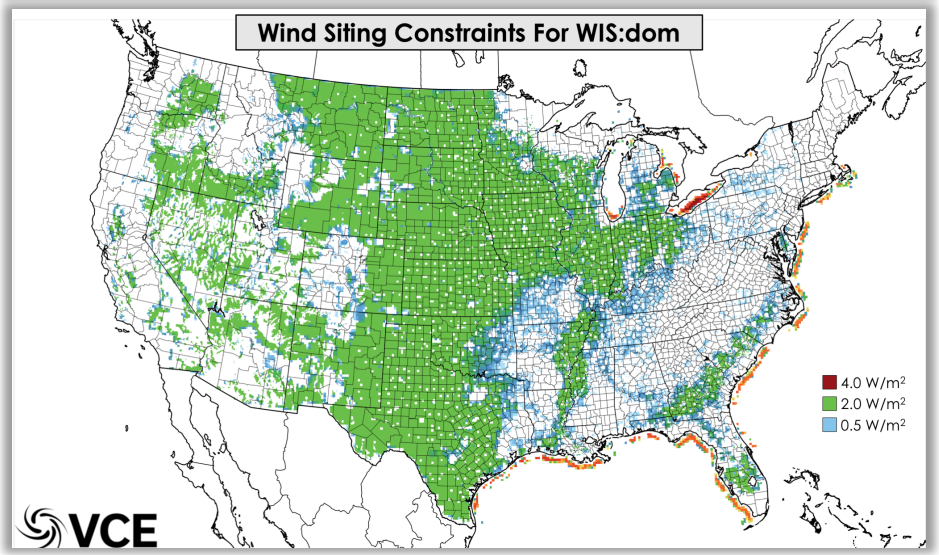
WIS:dom Contains Detailed Weather and Siting Datasets









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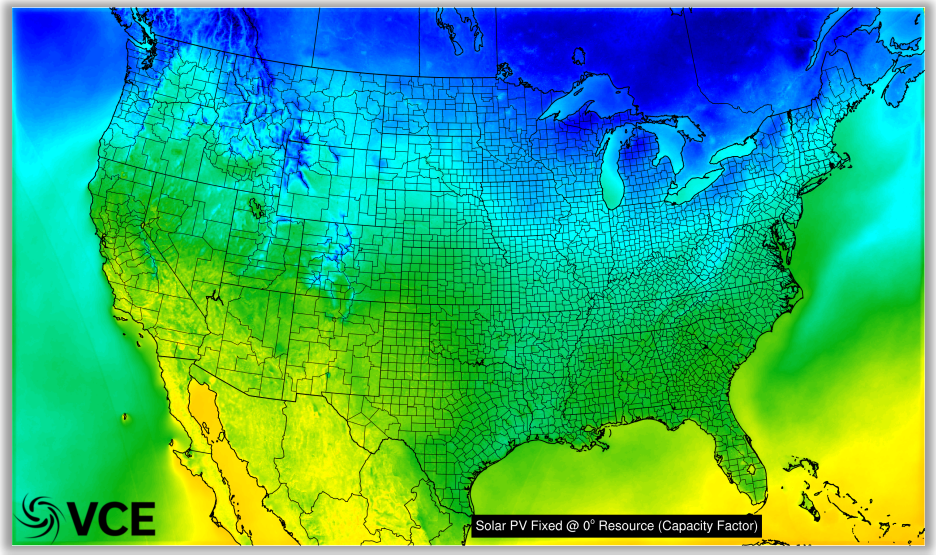

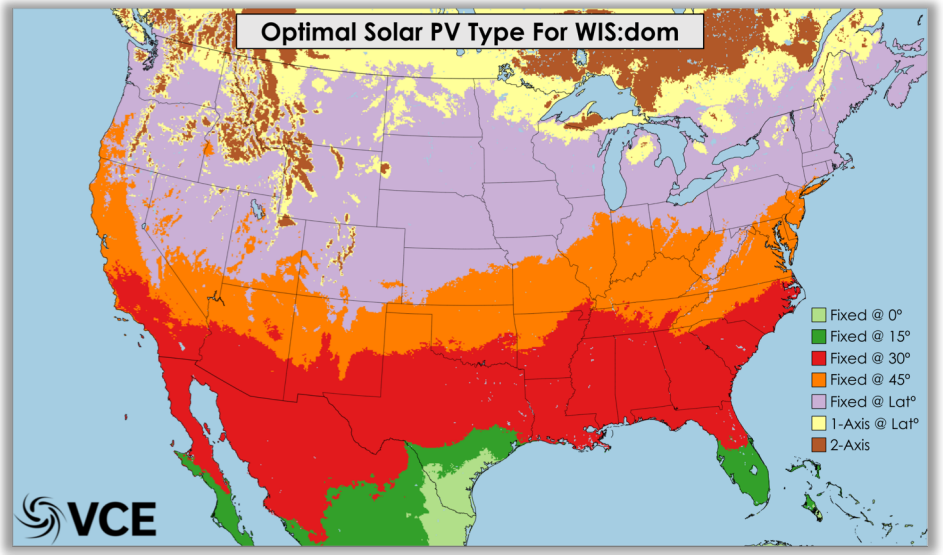

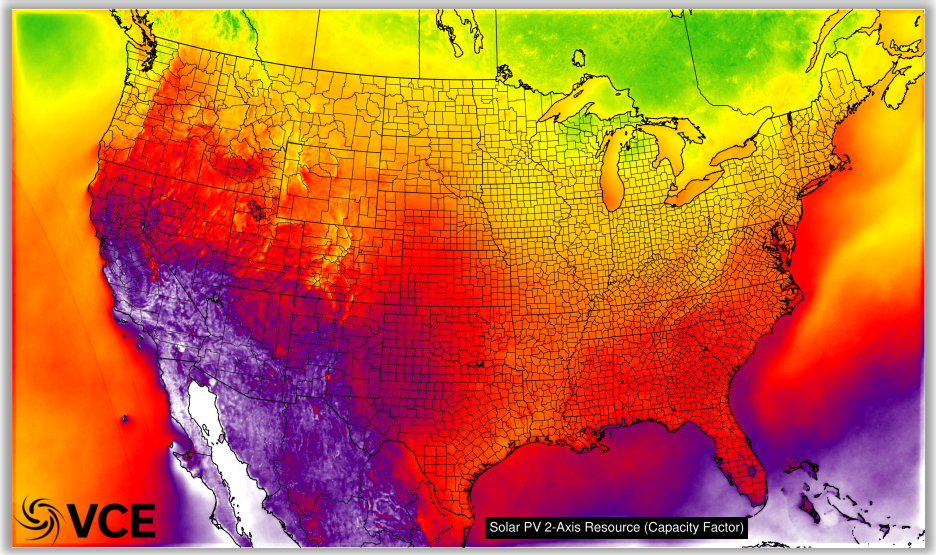

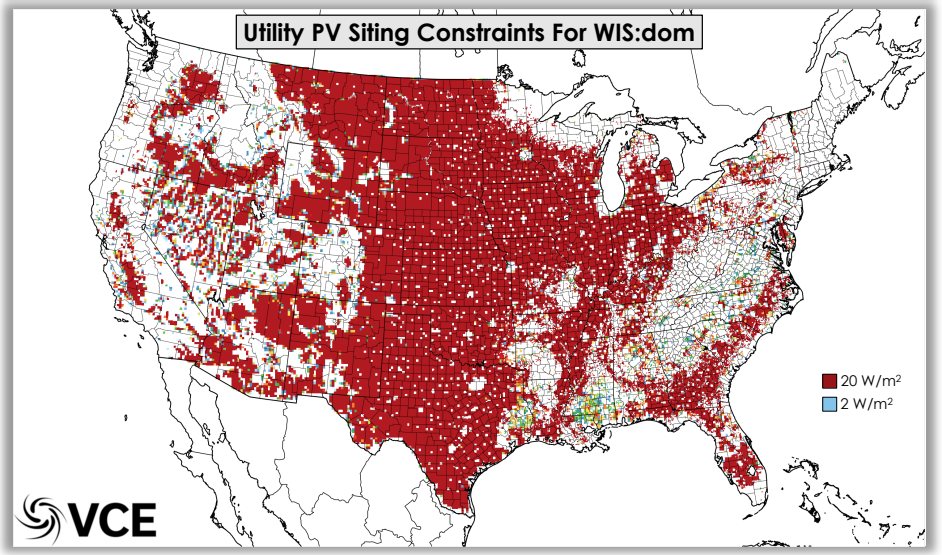

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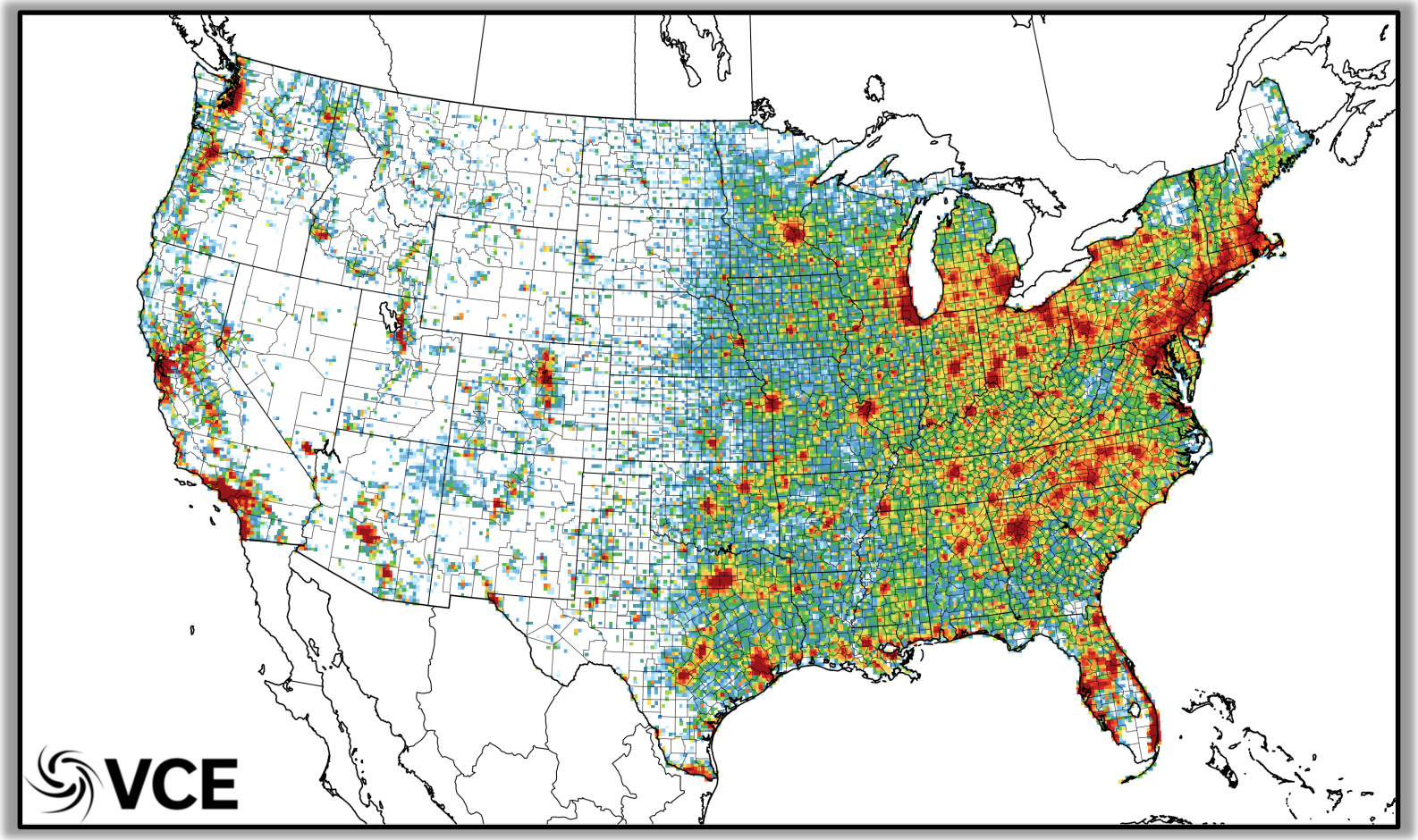
Advanced Screening For Rooftop PV

Note: Logarithmic Color Scale



Maximum
2.5 W/m^2

Minimum
2.5x10^{-5} W/m^2

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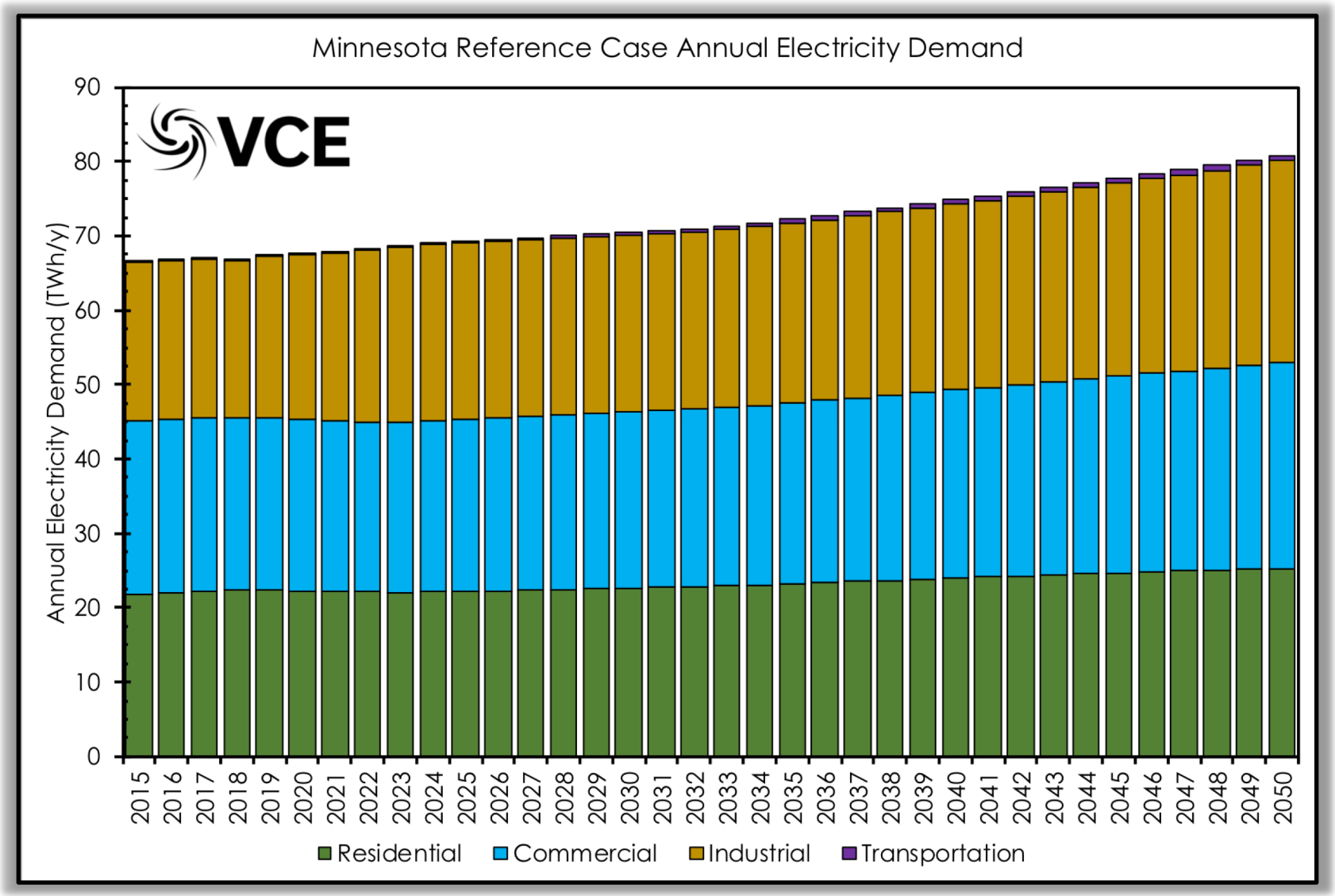
Electricity Demand Changes

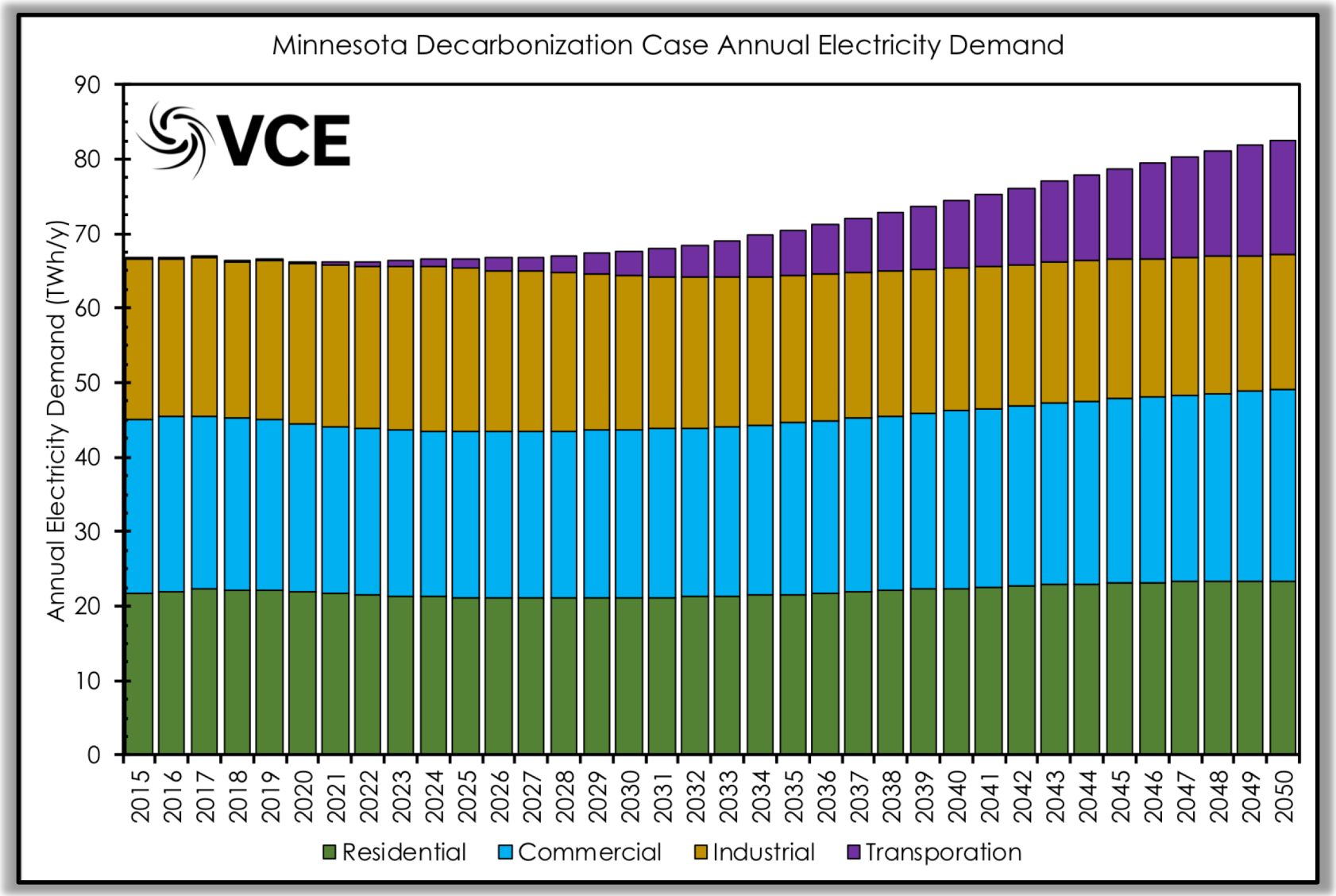
Input Assumption

Baseline Electricity Demand in MN



Data provided by ***Synapse***

Decarbonization Electricity Demand in MN



Data provided by ***Synapse***

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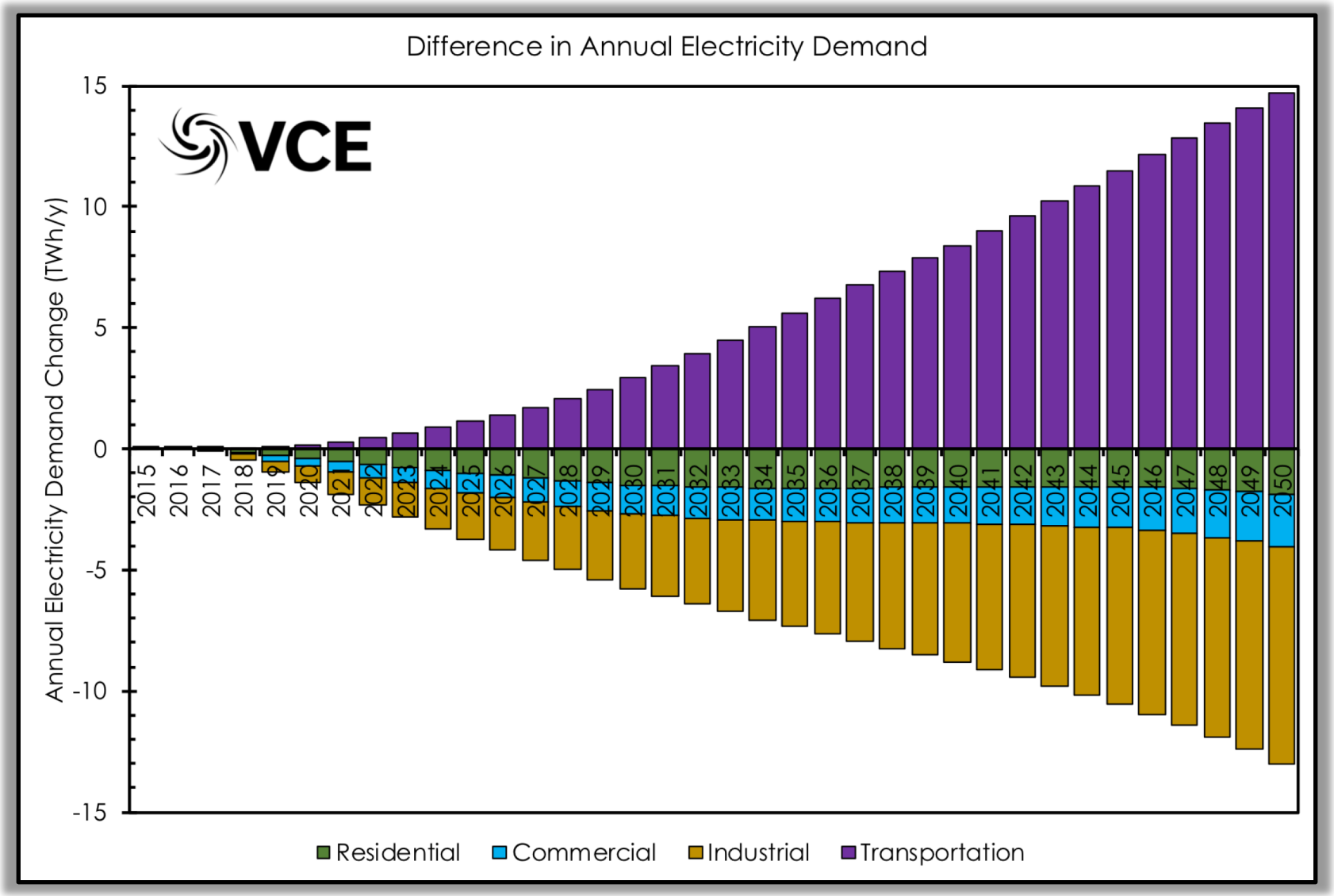
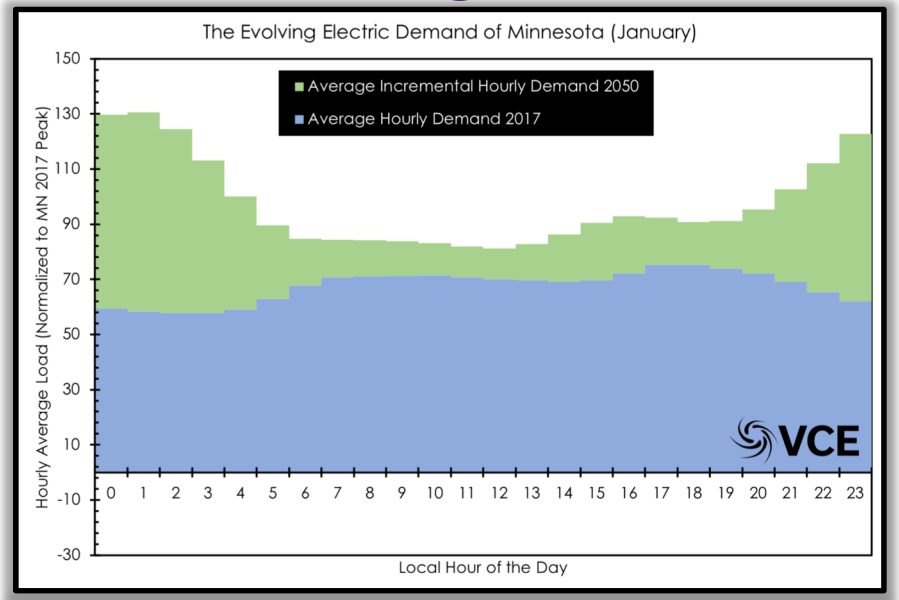
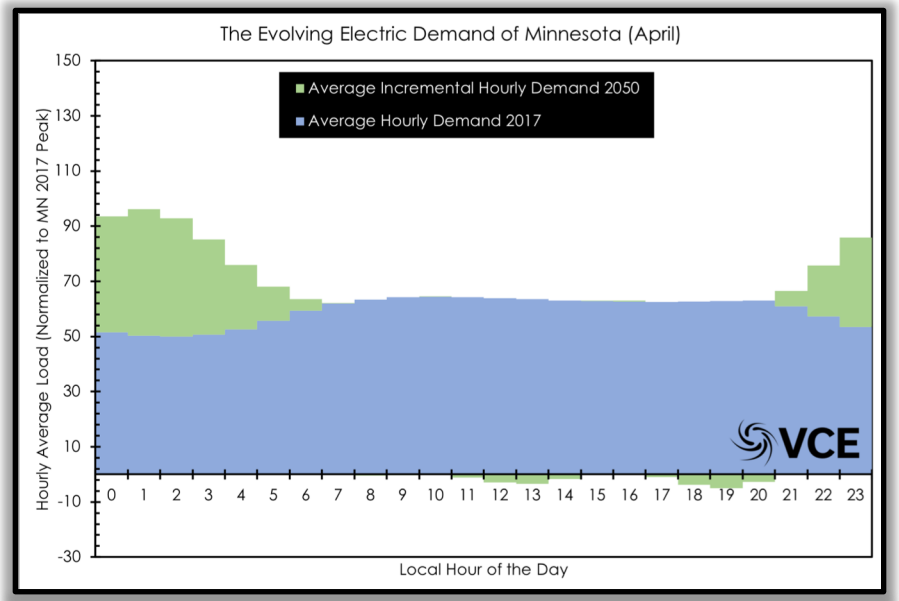
Electricity Demand Change For Decarbonization

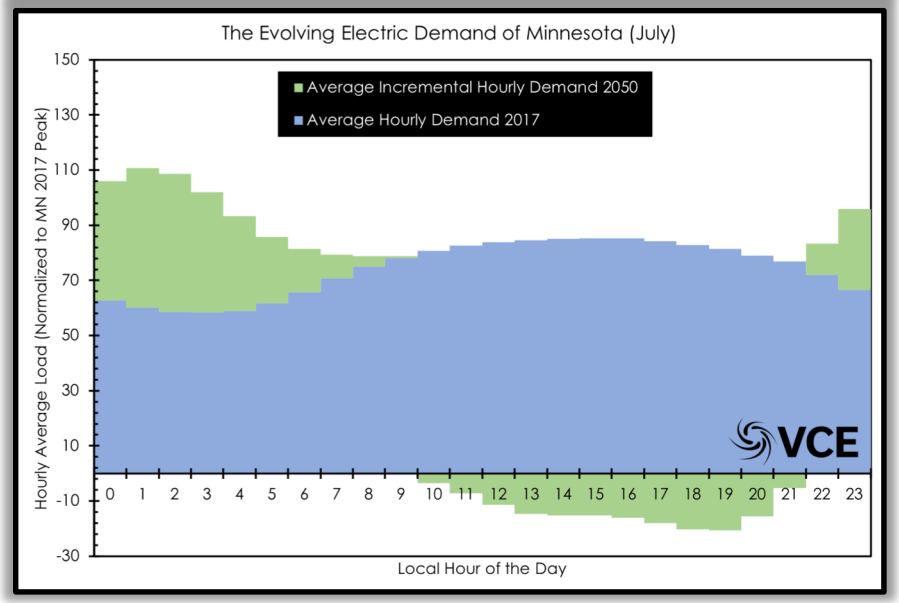


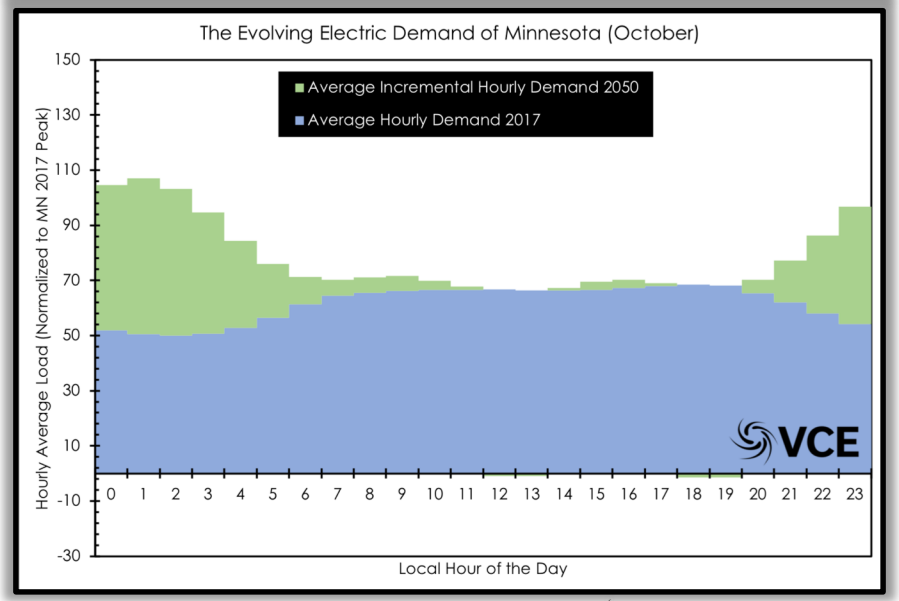
Data provided by ***Synapse***

Change in Hourly MN Demand Profiles









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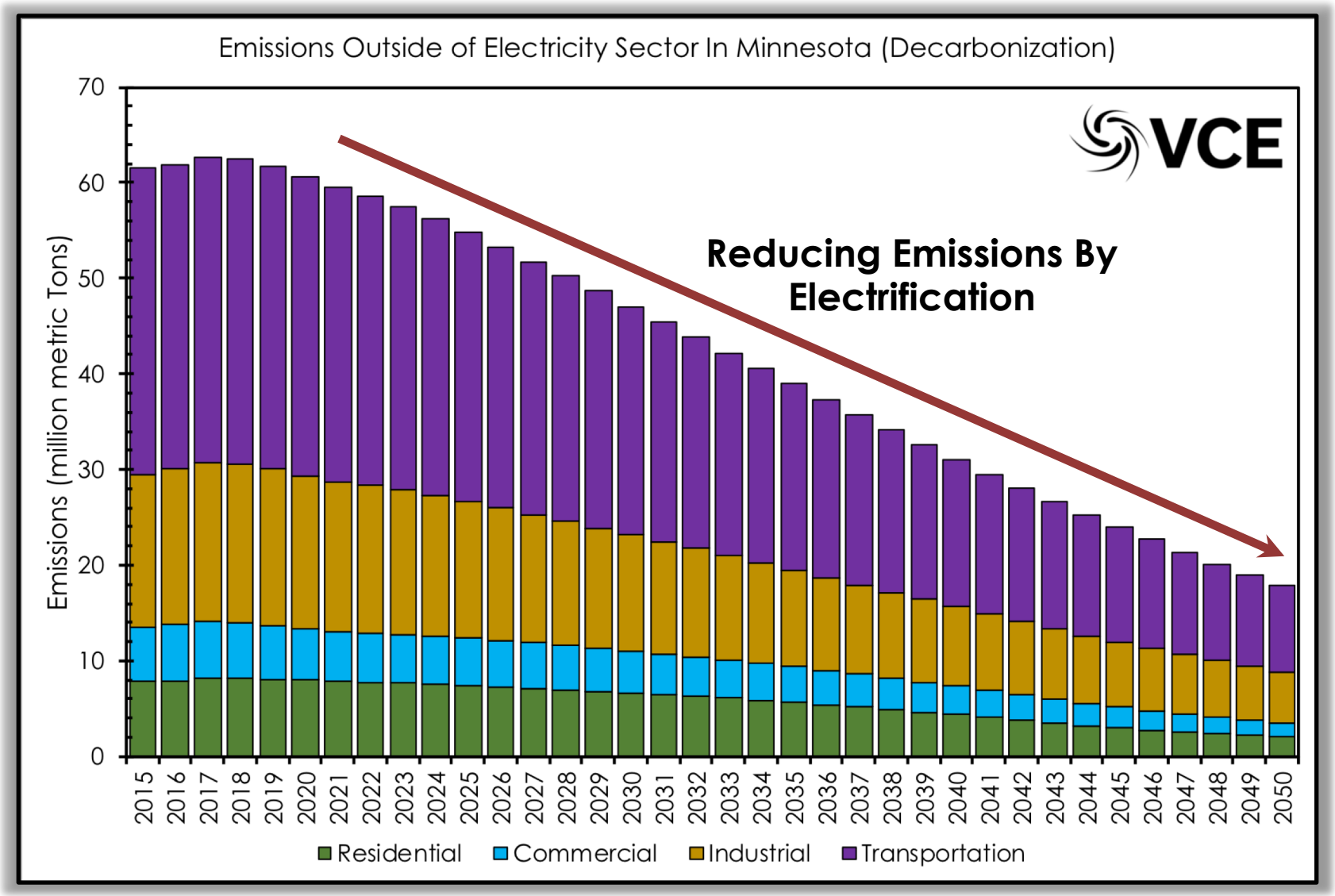
Emissions From Outside Electricity in MN



Data provided by ***Synapse***

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Scenarios Condensed

Scenarios Completed

ID		Scenario	Transmission Expansion	Emission Target	Electrification	MN Flexibility Level	EI Flexibility Level	NG Cost	Nuclear Retirement	DERs
A	1	*Background*	Interstate & Intrastate Allowed	Current Policies	EI Minimal	0% to 2.1% by 2050	0% to 2.1% by 2050	NREL ATB - Low	Follow License Schedule	No Lower Limit
	2		Intrastate Allowed Only							
B	1	*MN Deep Decarbonization*	Interstate & Intrastate Allowed	**MN 80% Economy Reduction**	**MN Extensive**	**0% to 20.8% by 2050**	0% to 2.1% by 2050	NREL ATB - Low	Follow License Schedule	No Lower Limit
	2		Intrastate Allowed Only							
C	1	*High NG Cost*	Interstate & Intrastate Allowed	Current Policies	EI Minimal	0% to 2.1% by 2050	0% to 2.1% by 2050	**AEO 2018 - High**	Follow License Schedule	No Lower Limit
	2			**MN 80% Economy Reduction**	**MN Extensive**	**0% to 20.8% by 2050**				
D	1	*Zero Emission Electricity MN*	Interstate & Intrastate Allowed	**MN 84% Economy Reduction**	**MN Extensive**	**0% to 20.8% by 2050**	0% to 2.1% by 2050	NREL ATB - Low	Follow License Schedule	No Lower Limit
	2		Intrastate Allowed Only							
E	1	*EI Decarbonizes with MN*	Interstate & Intrastate Allowed	**EI 80% Economy Reduction**	**EI Extensive**	**0% to 20.8% by 2050**	**0% to 20.8% by 2050**	NREL ATB - Low	Follow License Schedule	No Lower Limit
F	1	*MN Deep Decarb. with Dominant DERs*	Interstate & Intrastate Allowed	**MN 80% Economy Reduction**	**MN Extensive**	**0% to 32.3% by 2050**	0% to 2.1% by 2050	NREL ATB - Low	Follow License Schedule	**50% from DERs**
G	1	*MN Deep Decarb.with less Flexibility*	Interstate & Intrastate Allowed	**MN 80% Economy Reduction**	**MN Extensive**	**0% to 5.2% by 2050**	0% to 2.1% by 2050	NREL ATB - Low	Follow License Schedule	No Lower Limit
H	1	*MN Deep Decarb. Nuclear Sensitivity*	Interstate & Intrastate Allowed	**MN 80% Economy Reduction**	**MN Extensive**	**0% to 20.8% by 2050**	0% to 2.1% by 2050	NREL ATB - Low	**Allow Early Retirement**	No Lower Limit
	2								**Keep Online Through 2050**	
			External Decision On Transmission Expansion	*Reductions is taken from the 2005 emission record*	*Electrification of Sectors*	*Percentage of Demand*				*Percentage of Demand*

3 Scenarios do not decarbonize or electrify

8 Scenarios achieve 80% emissions reductions by 2050 compared with 2005

2 Scenarios completely decarbonize electricity sector

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Main Conclusions

Based Upon Synthesis Results

Major Conclusions

- ✓ Minnesota has the potential to ***reduce the cost of electricity for customers regardless of decarbonization portfolio***. The cost reduction ***can be up to 2.8 ¢ / kWh*** compared with 2017 average retail costs. If Minnesota chooses to fully decarbonize the electricity sector and perform heavy electrification the cost reduction compared with 2017 would be 1.4 ¢ / kWh. ***The average decarbonization and electrification cost reduction is 2.3 ¢ / kWh***.

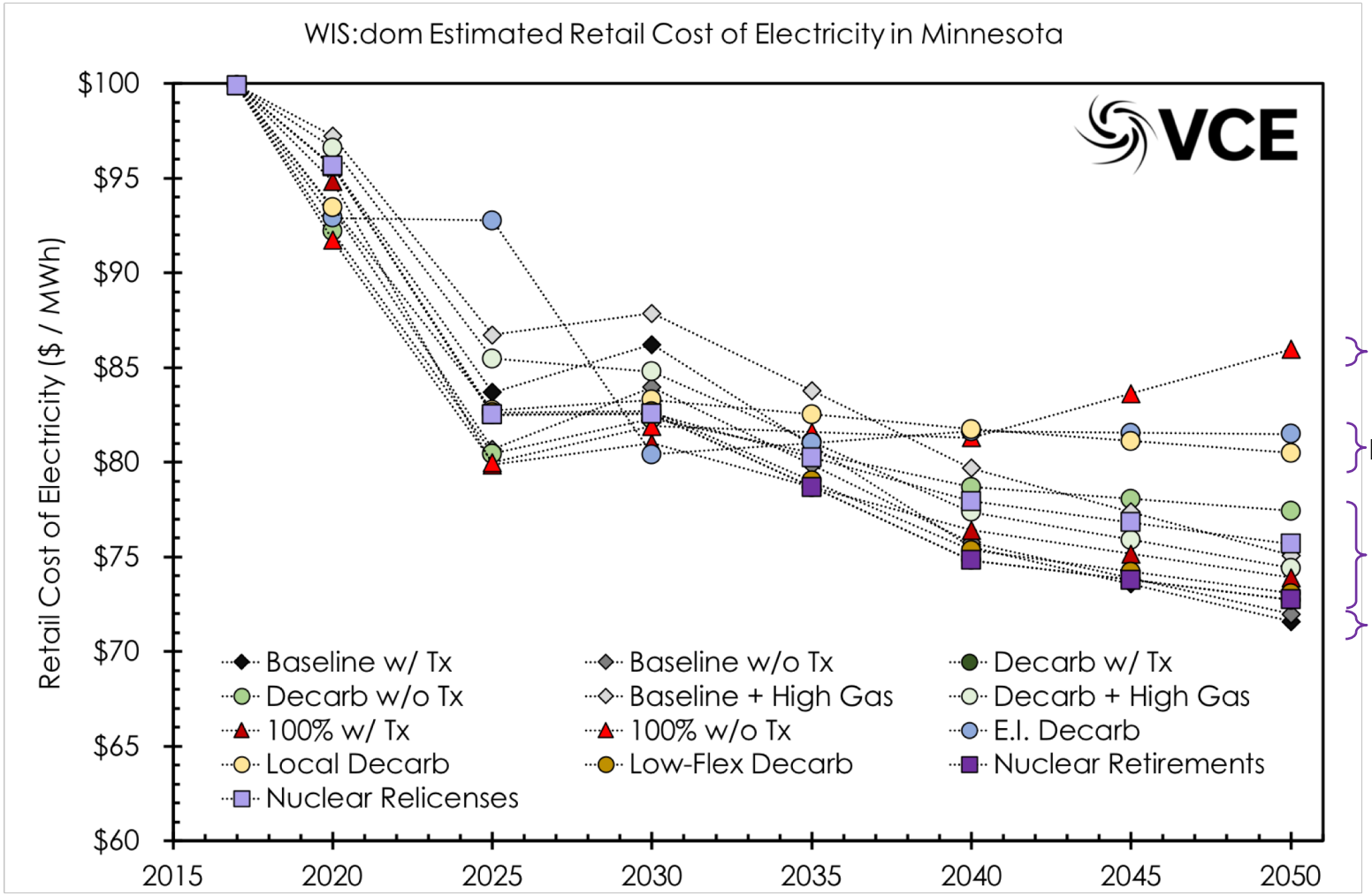
- ✓ Minnesota can completely decarbonize. Doing so along with the rest of the Eastern Interconnection raises the difficulty; however, Minnesota can still achieve its goals.

- ✓ Without action ***emission reductions would cease by 2030***. Further, the asset choices would keep emissions high, or would be stranded if emission targets were enacted at a later date.

- ✓ The jobs within the electricity sector in Minnesota is robust under all scenarios. In particular, ***with decarbonization and electrification jobs in the electricity sector rise dramatically***.

- ✓ If natural gas costs rise, and decarbonization is not chosen Minnesotans could face a cumulative ***additional spend on electricity of approximately $15.6 billion by 2050***. Alternatively, decarbonization and electrification ***could save Minnesotans a cumulative $15.9 to $51.4 billion by 2050***. That equates to an average household saving of $600 - $1,200 per year in energy costs.

Retail Cost of Electricity By Scenario



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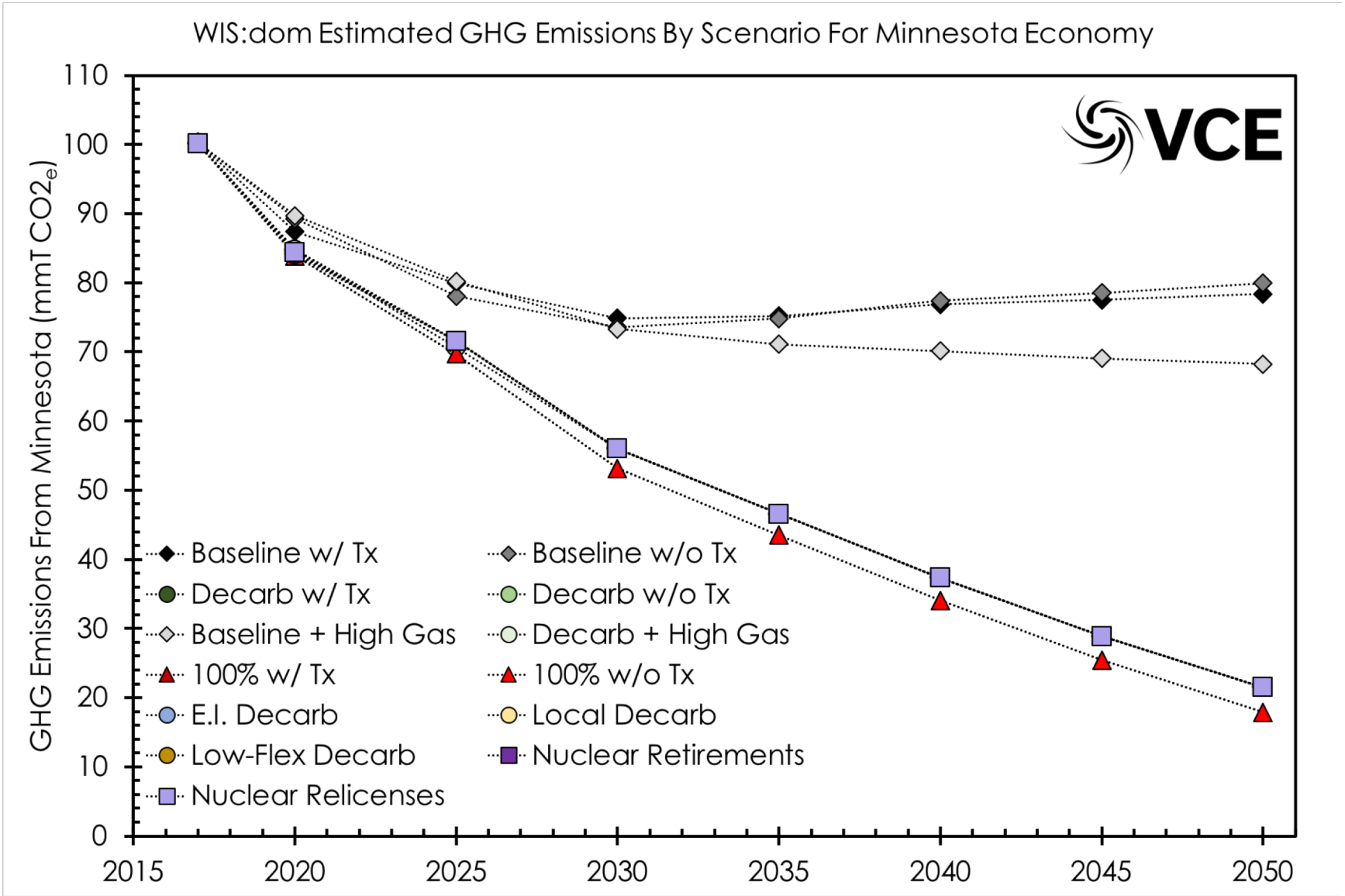
Decarbonization Becomes Clear After 2020



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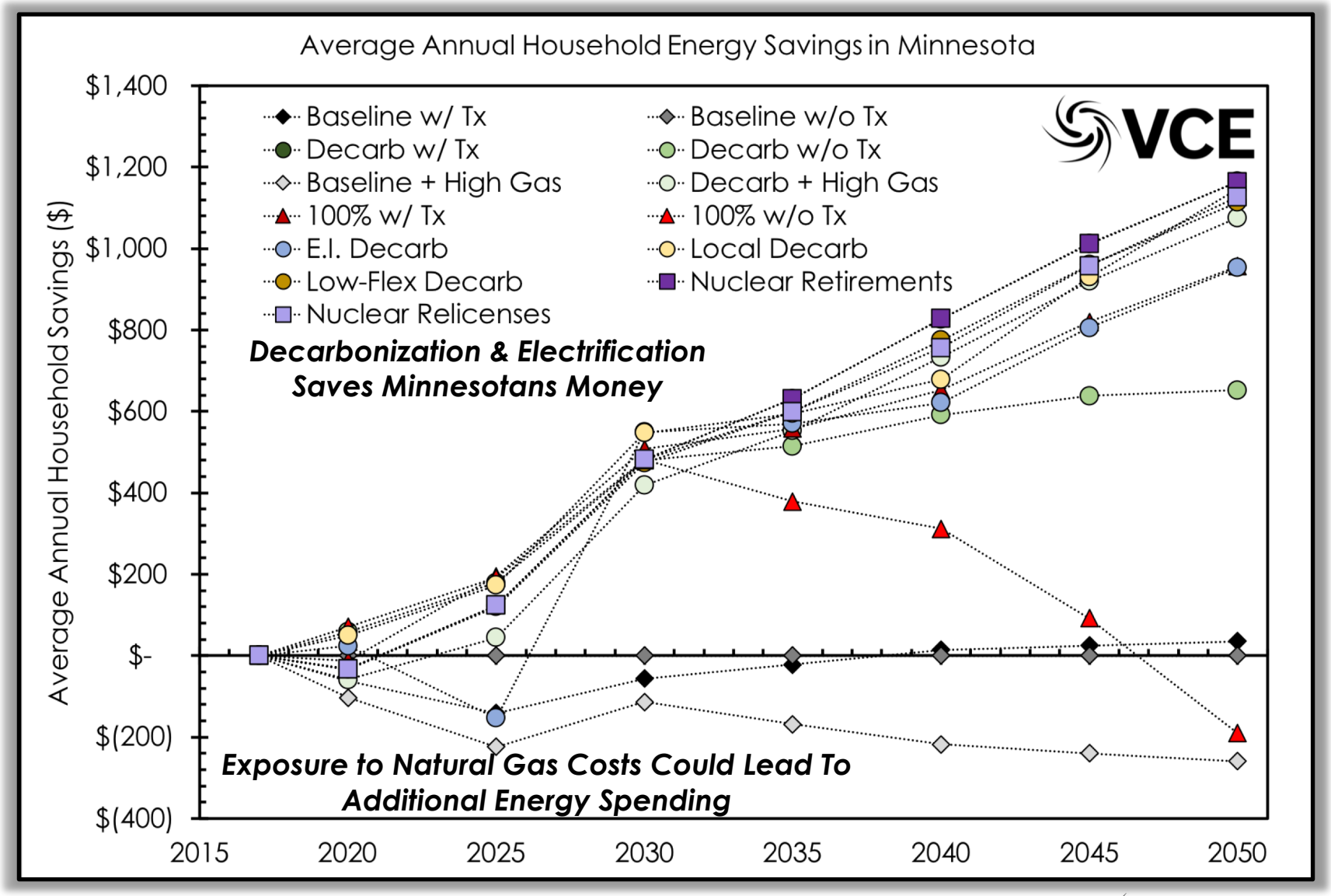
Average Annual Household Savings



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Deeper Dive:
MN Decarbonization

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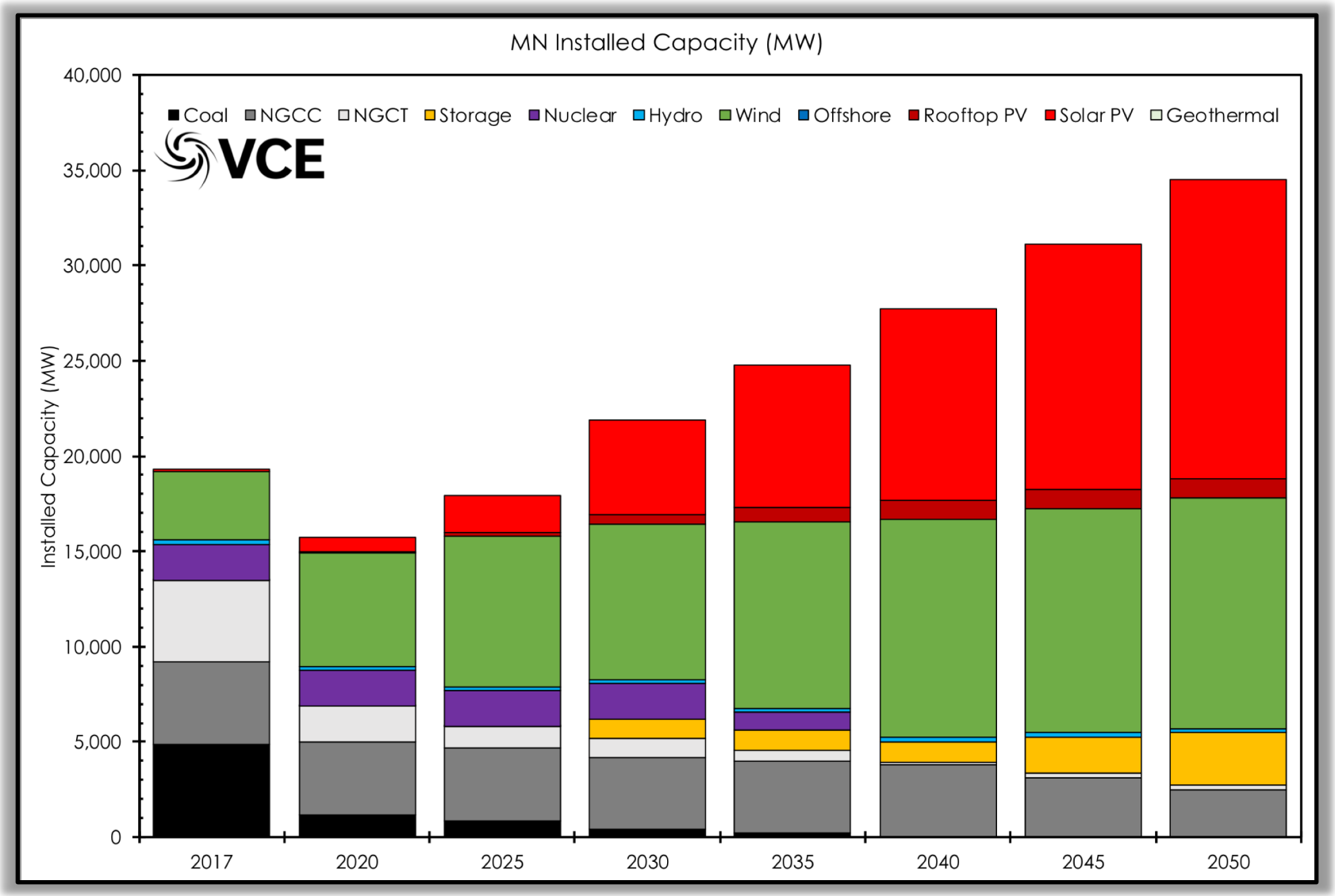
Minnesota Installed Capacity



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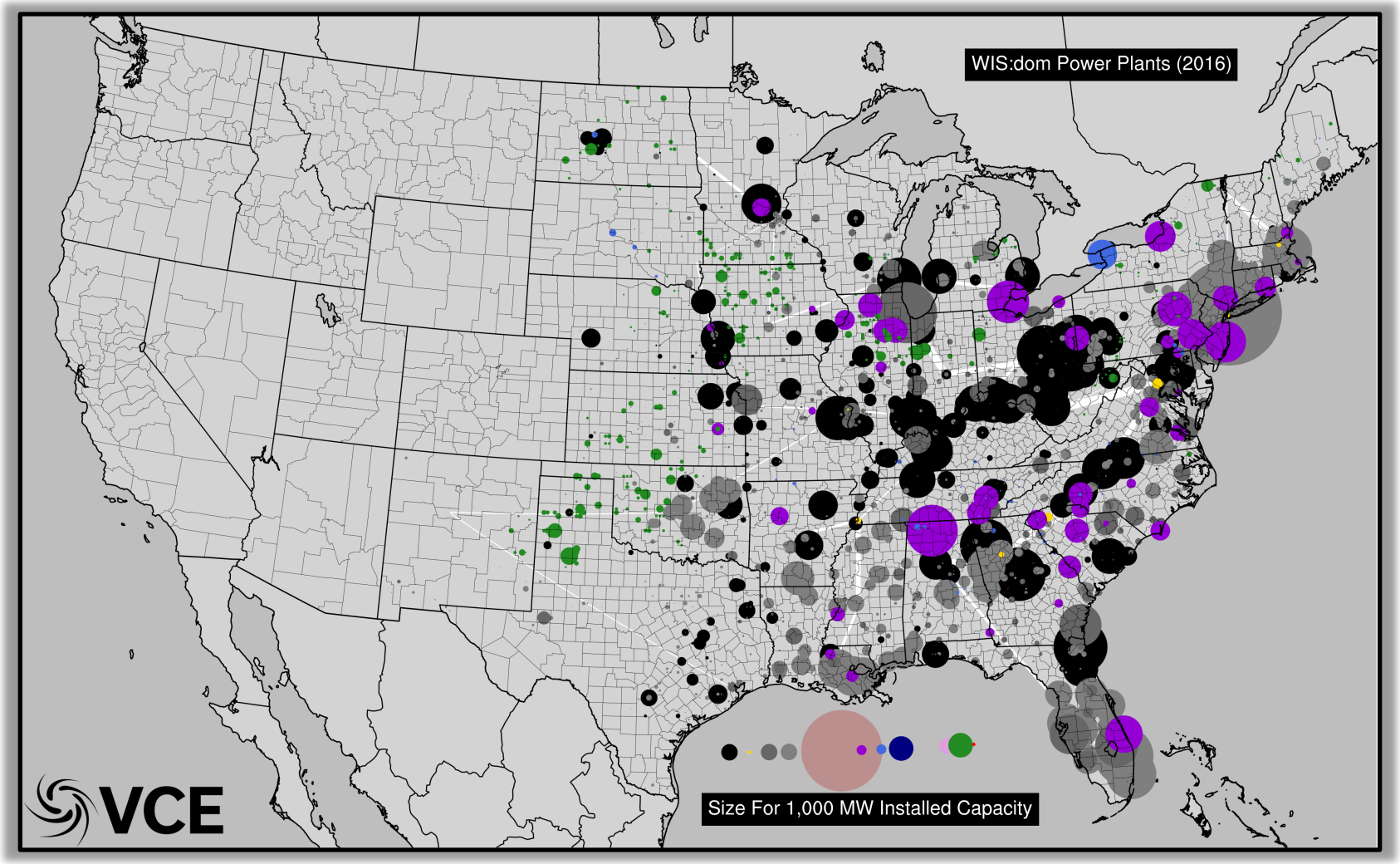
Installed Capacity (Geographic)



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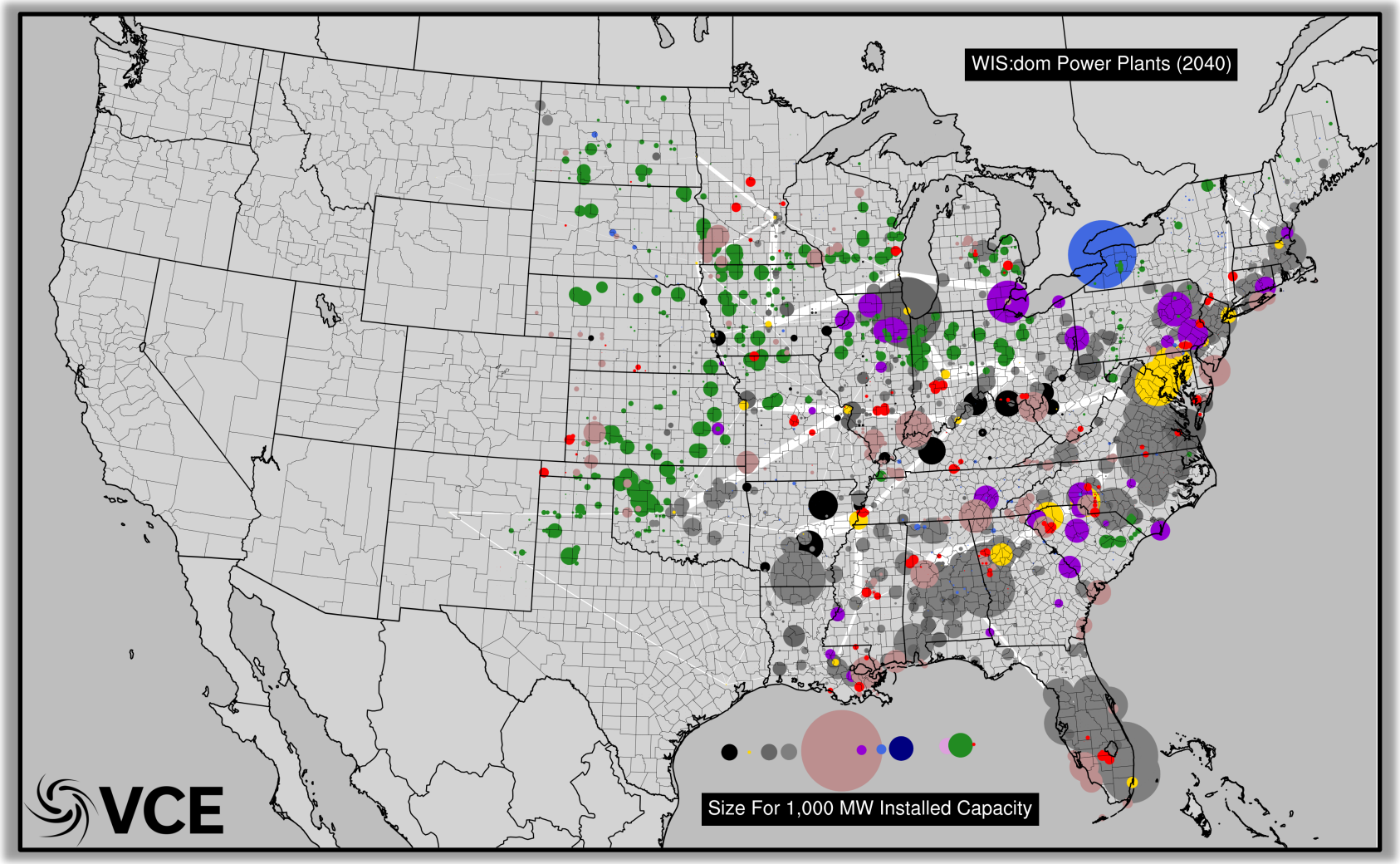

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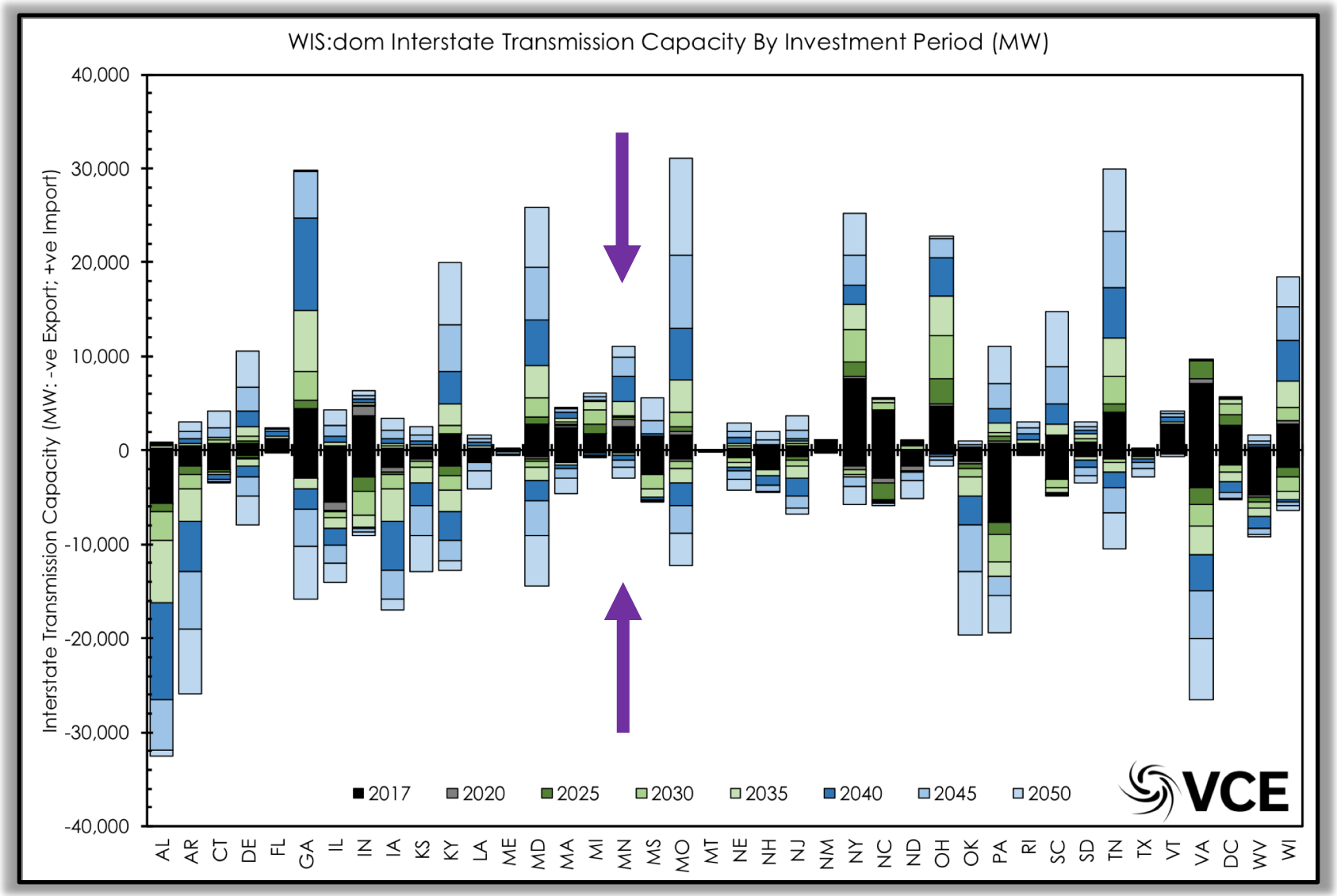
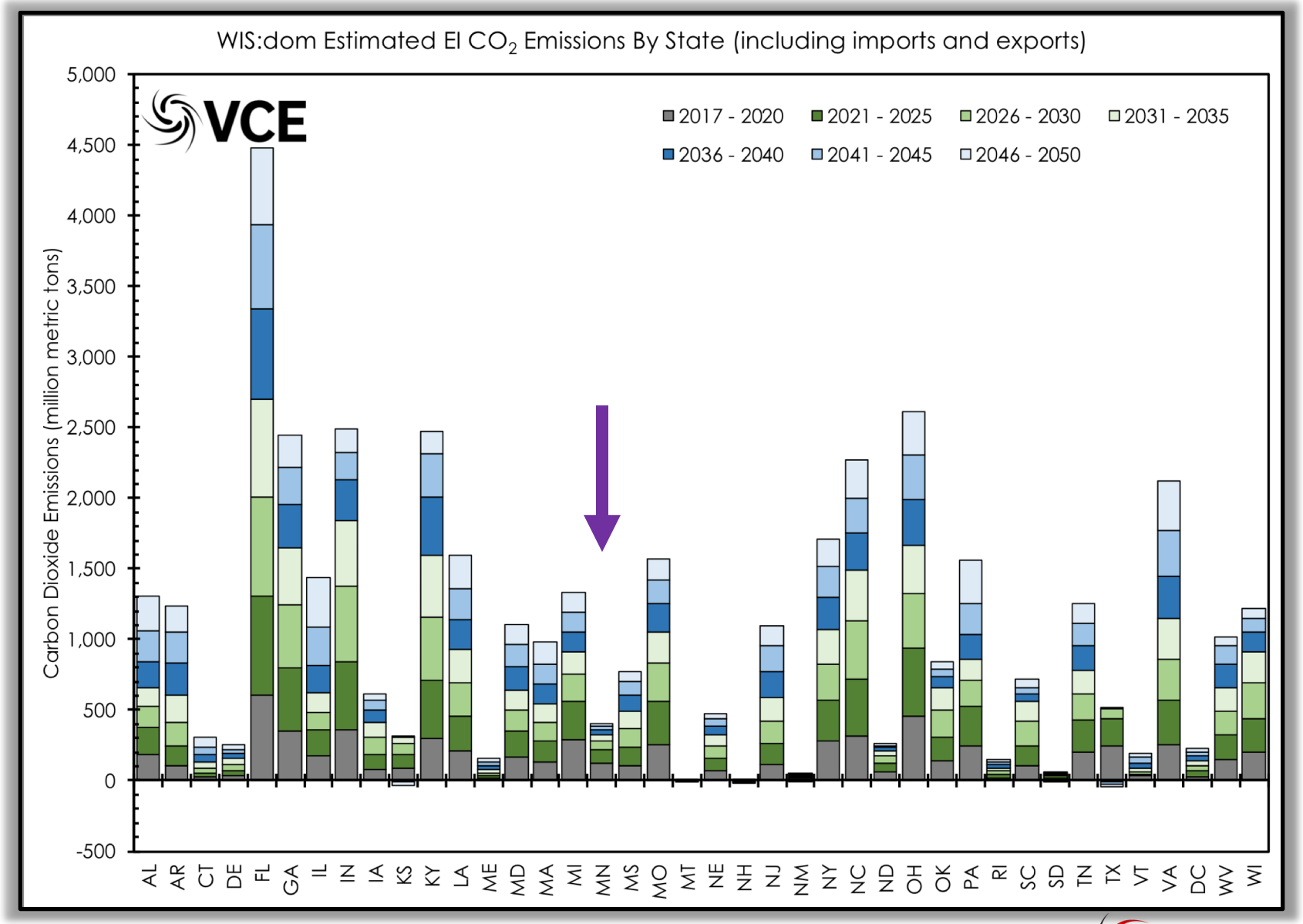
Installed Interstate Transmission Capacity



Cumulative Emissions By State



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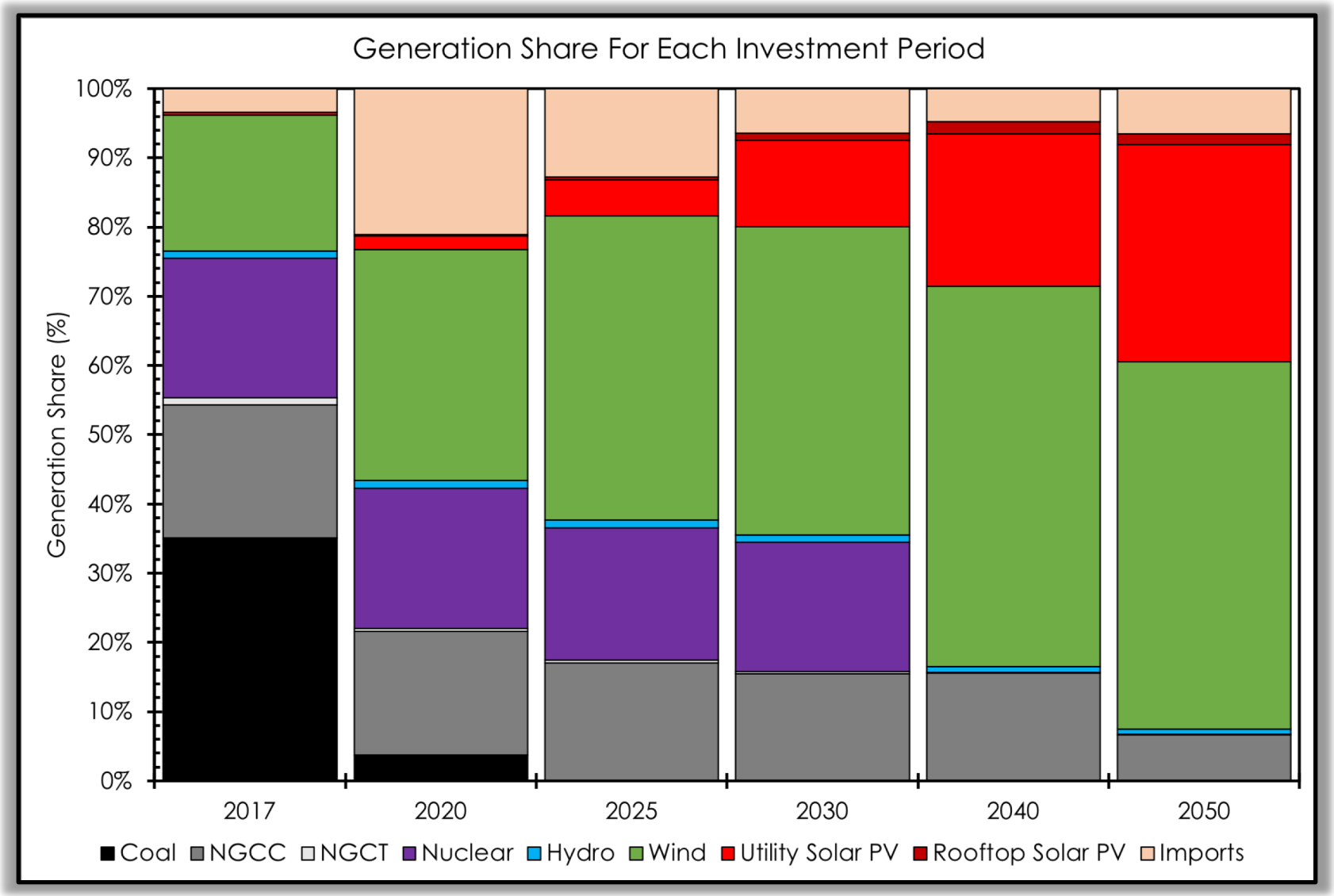
Generation Share For Minnesota (Decarb)



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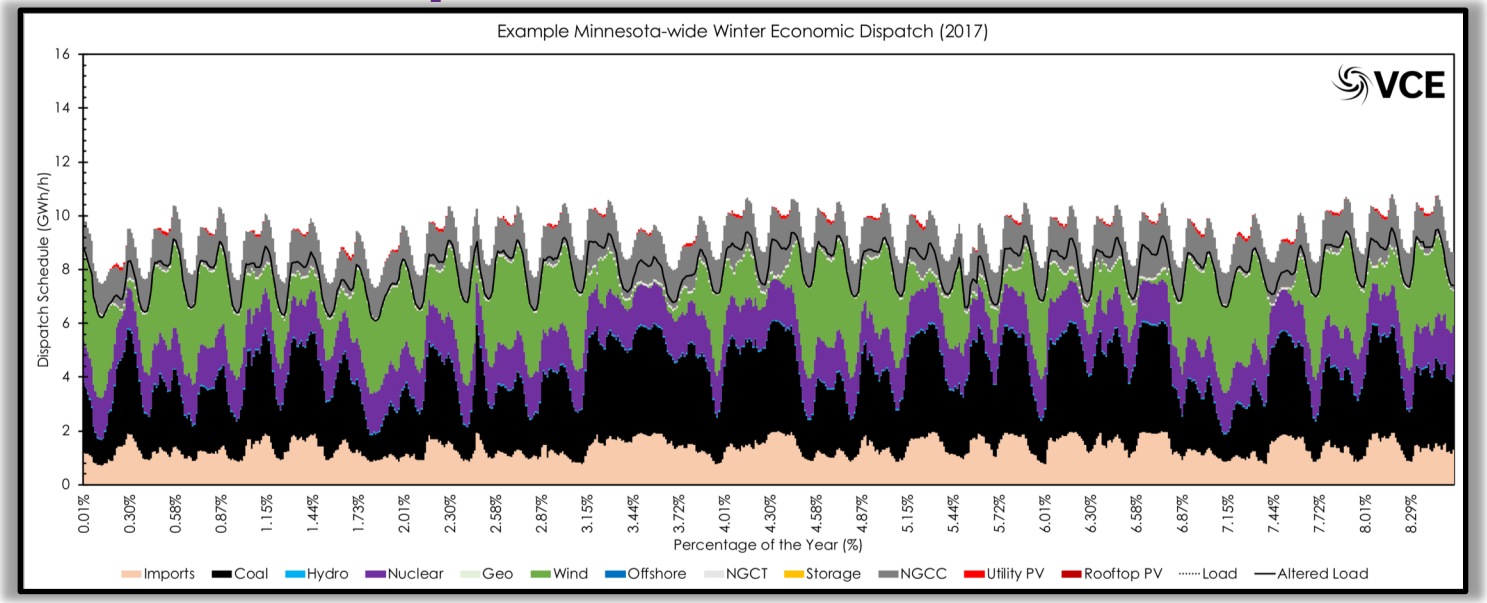
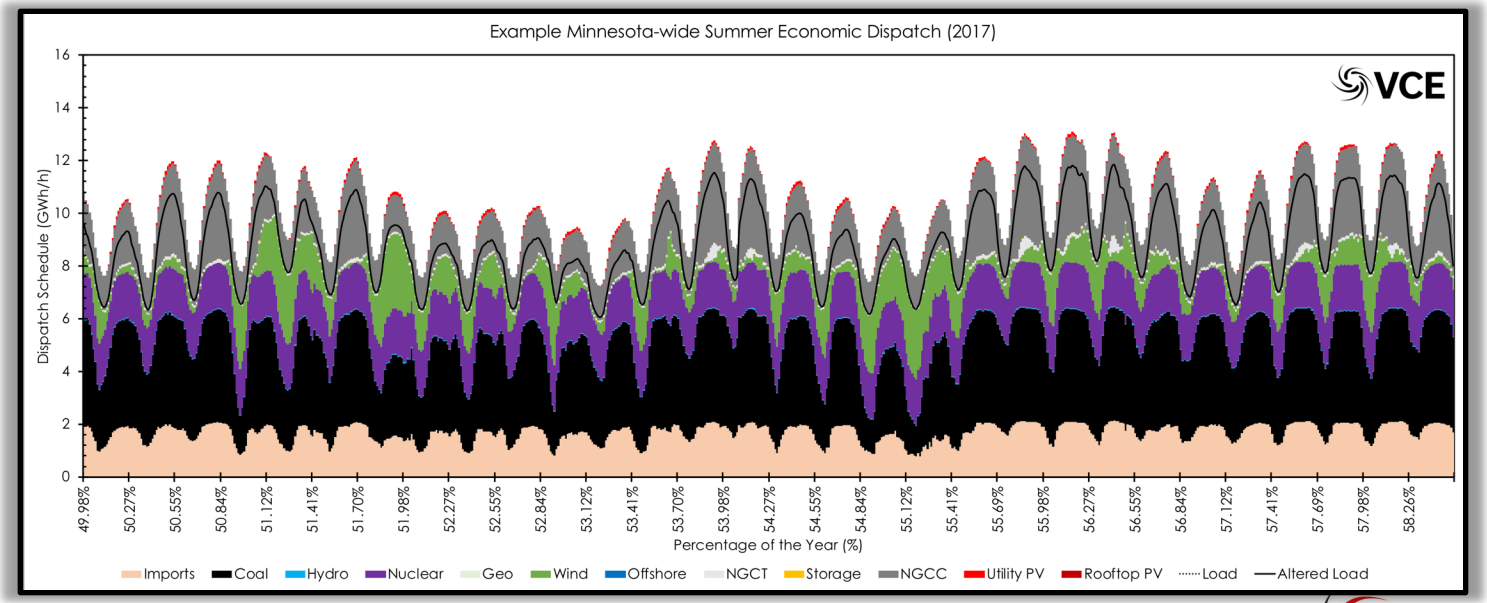
Dispatch For Minnesota





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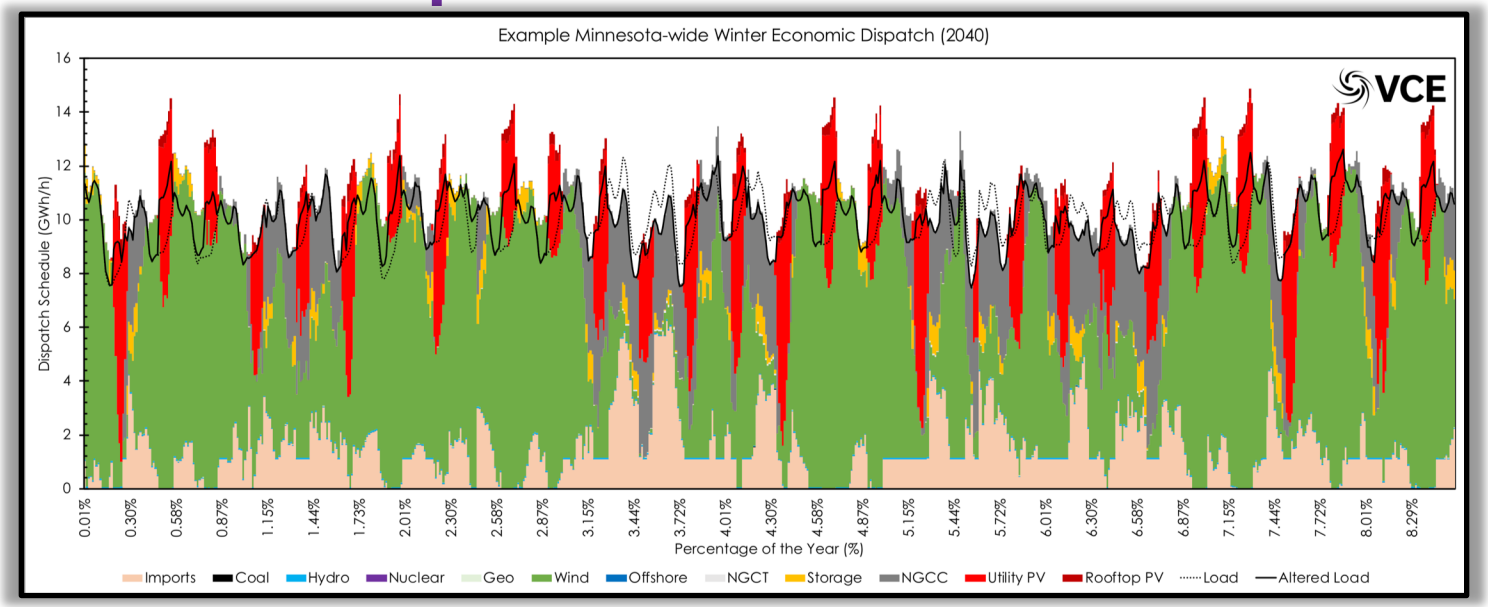
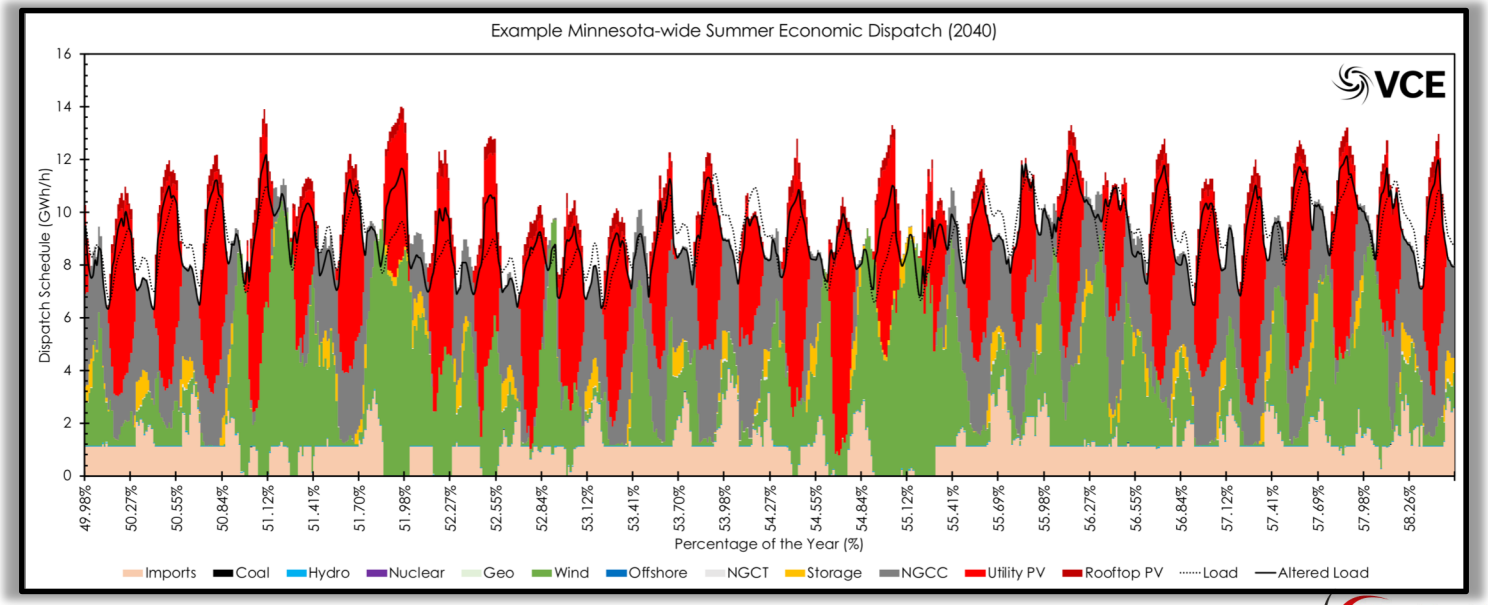
Dispatch For Minnesota





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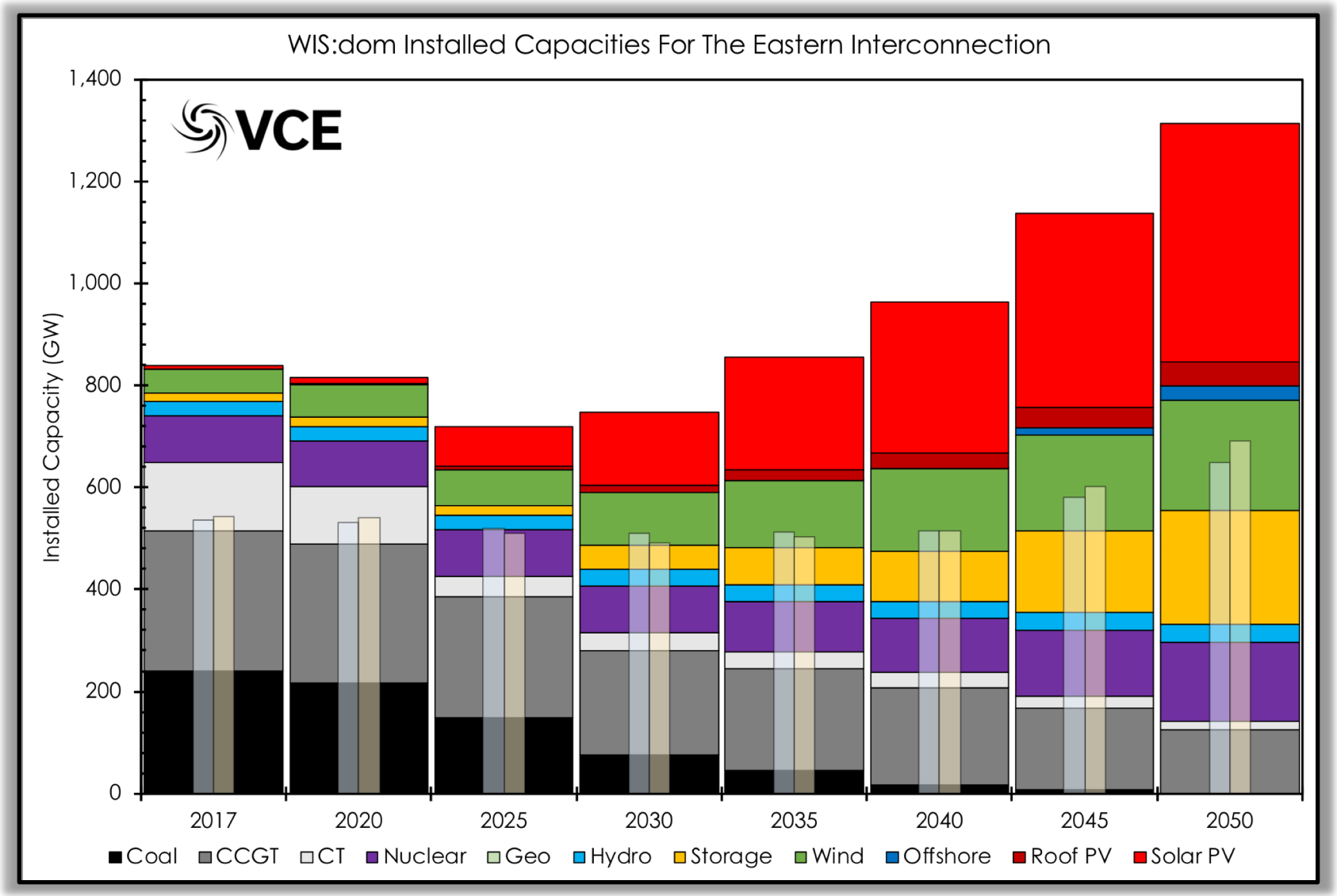
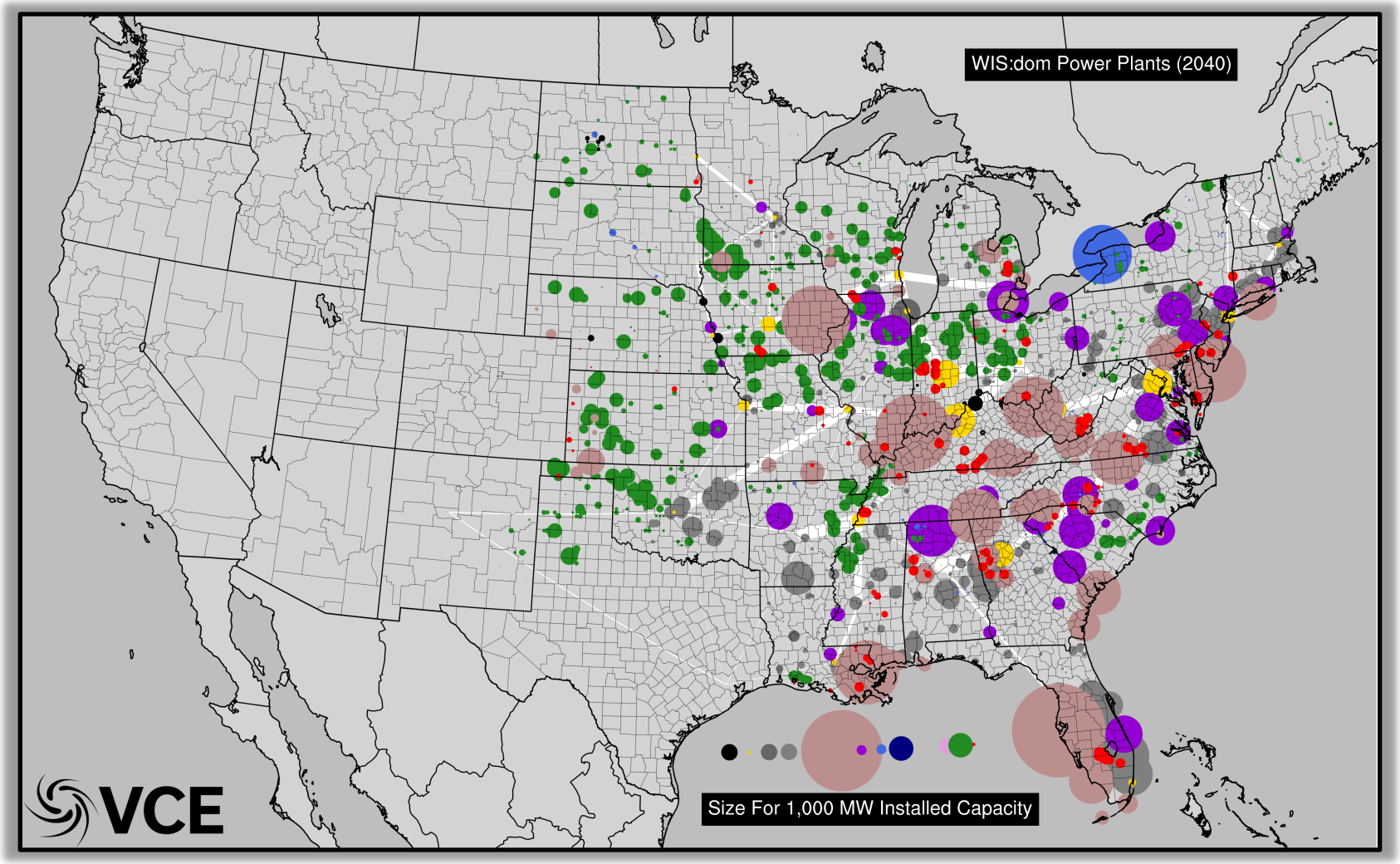
Deeper Dive:
EI Decarbonization

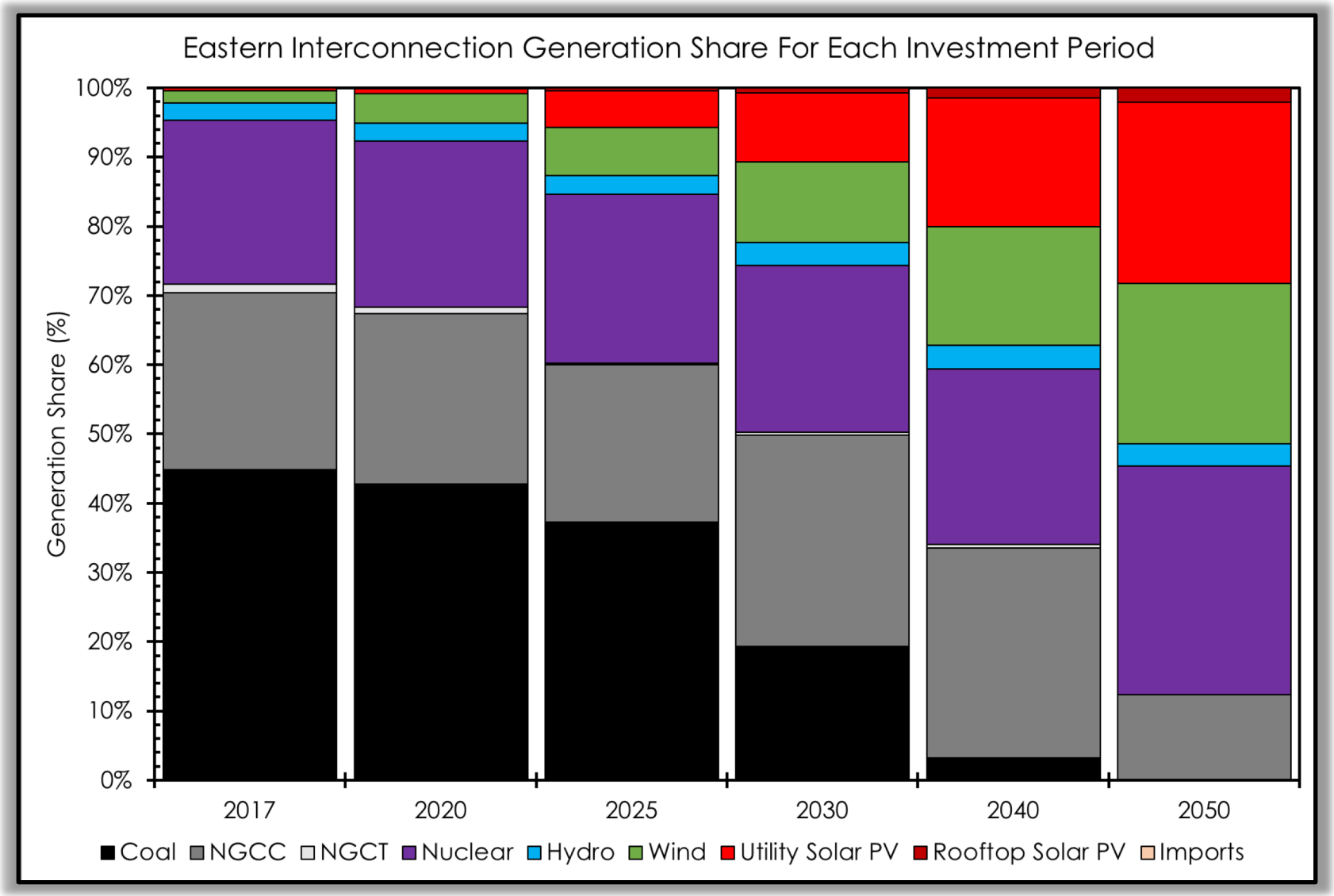
Eastern Interconnection Installed Capacity



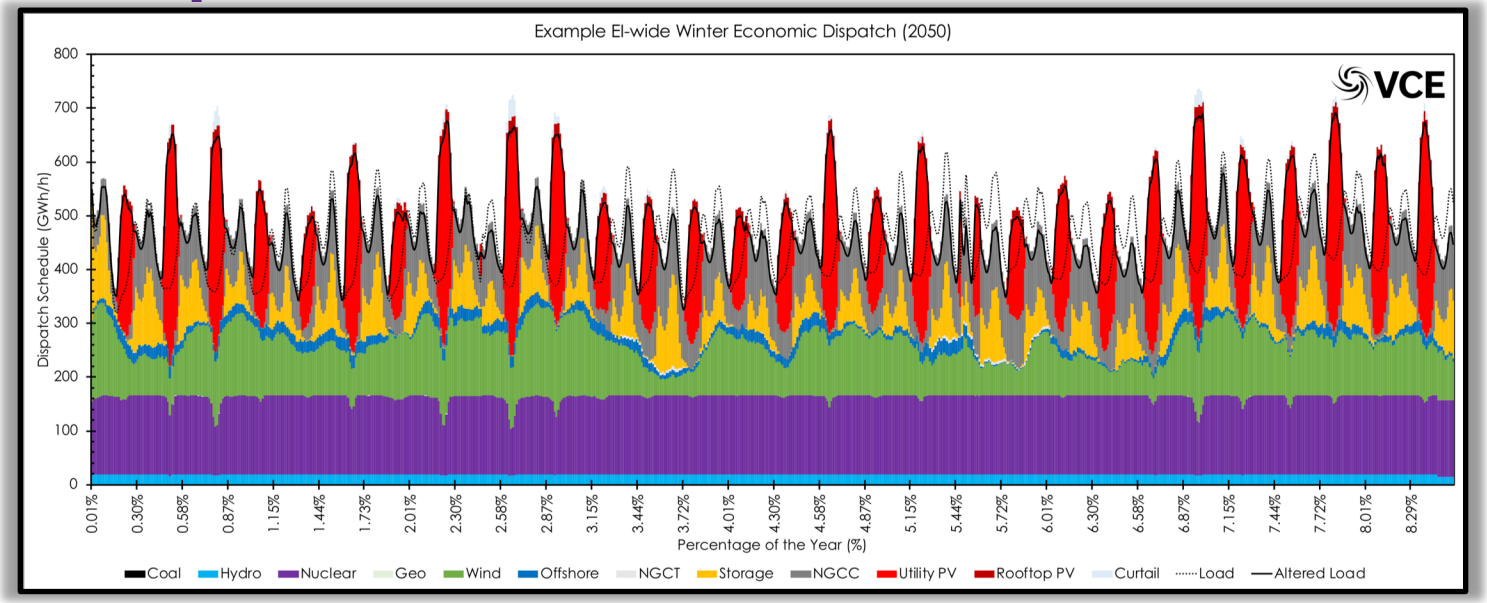
Installed Capacity (Geographic)

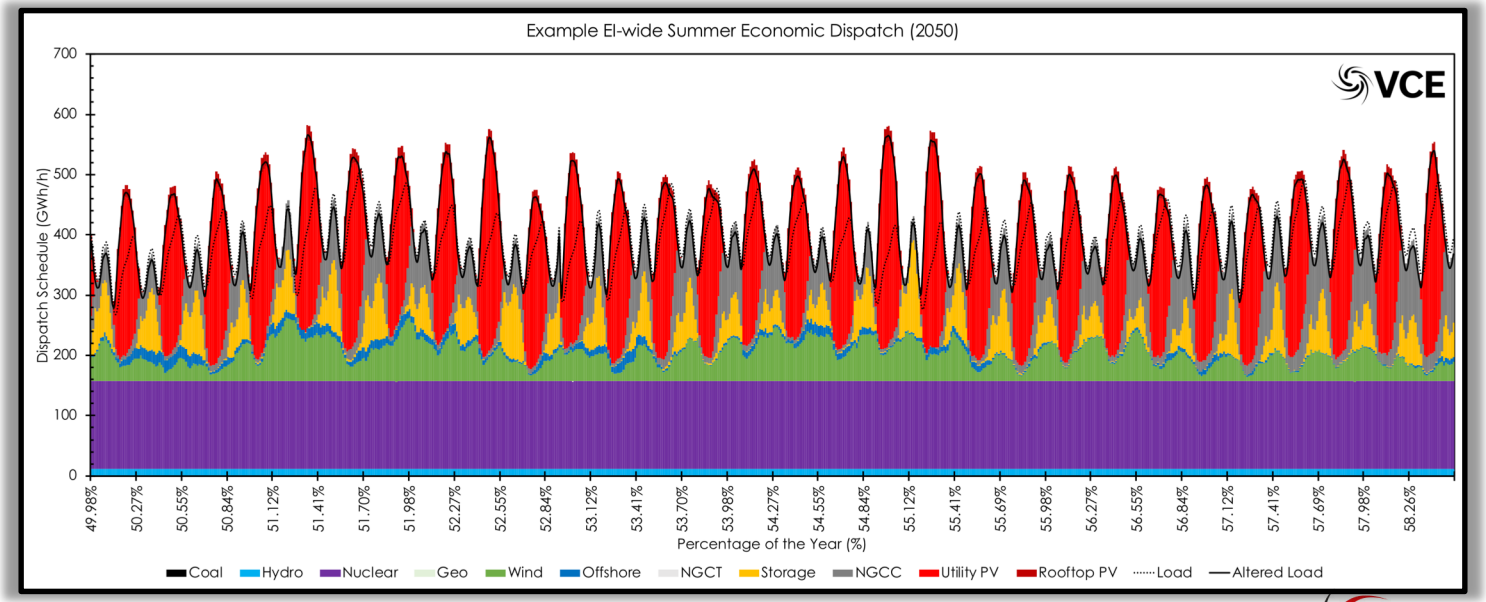


Generation Share For Eastern Interconnection



Dispatch For Eastern Interconnection





Electrification is Key To Low-Cost Decarbonization

- ✓ ***Electrification and decarbonization can be achieved in Minnesota (along with the Eastern Interconnection) to provide a low-cost, low-emissions economy.***
- ✓ The electrification and decarbonization for Minnesota could save each household up to $1,200 per year in direct costs.
- ✓ ***Electrification provides flexibility to the electricity sector that reduces the impact of resource variability (but does not eliminate it completely).***
- ✓ The electrification and decarbonization mitigates over 80% of the GHG emissions from the Minnesotan economy. It also reduces the exposure risk of the economy to volatility of the price of natural gas fuel.
- ✓ ***Without electrification, more transmission is required, and decarbonization becomes much more difficult.***

Thank You

Questions?

Full report found here:
http://www.vibrantcleanenergy.com/media/reports/

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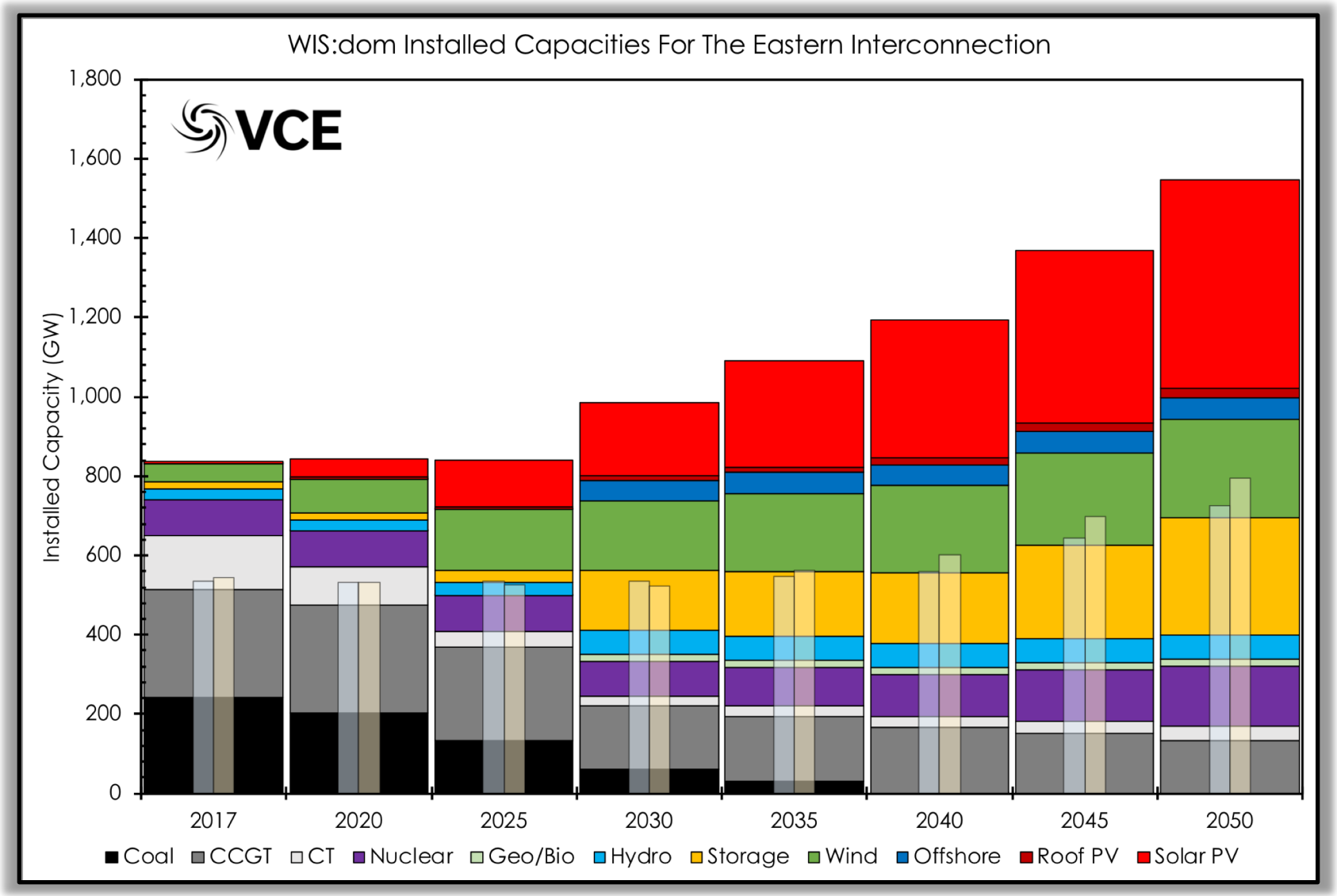
Eastern Interconnect Low-Carbon Grid (much less EE)

Eastern Interconnection Installed Capacity



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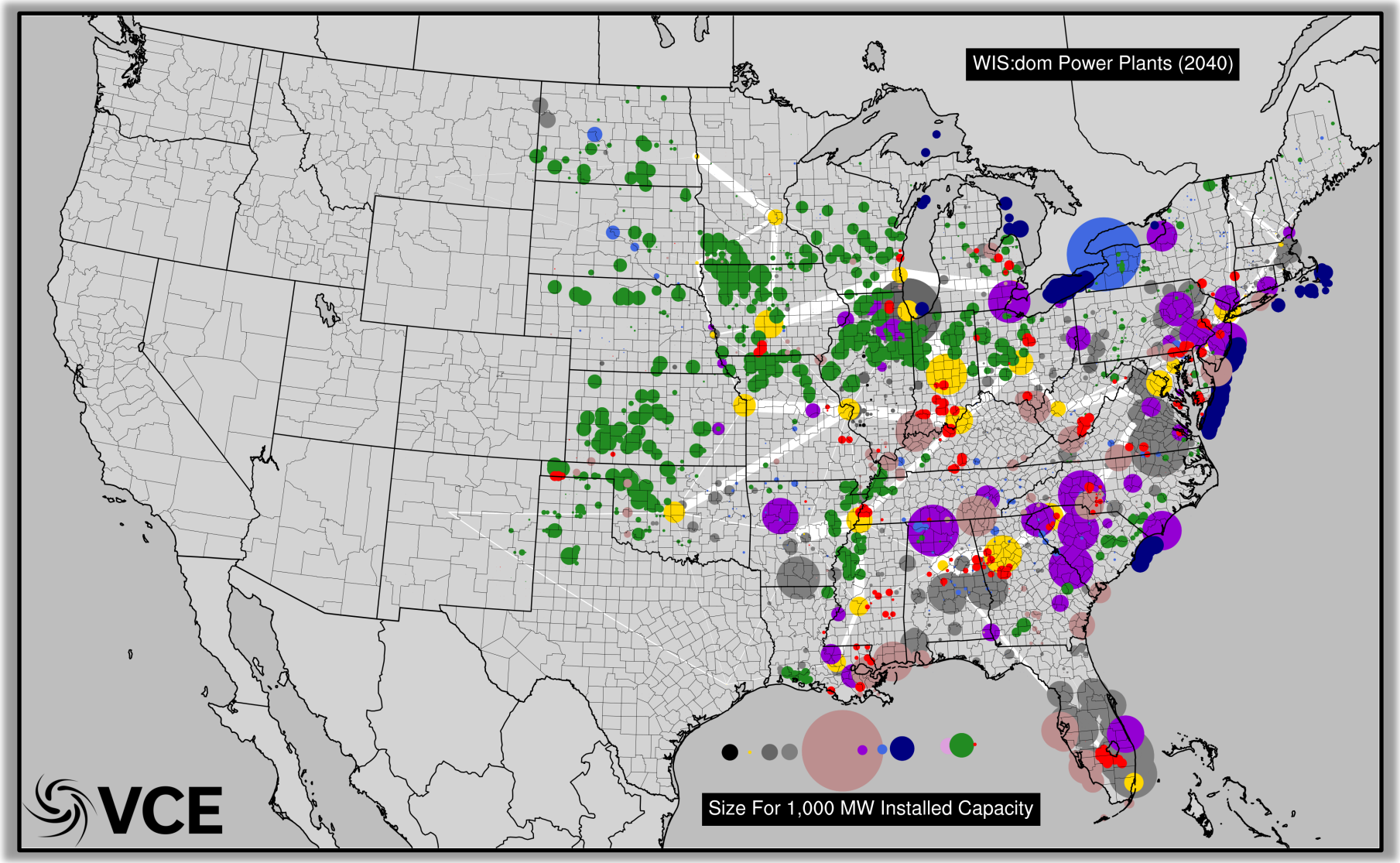
Installed Capacity (Geographic)



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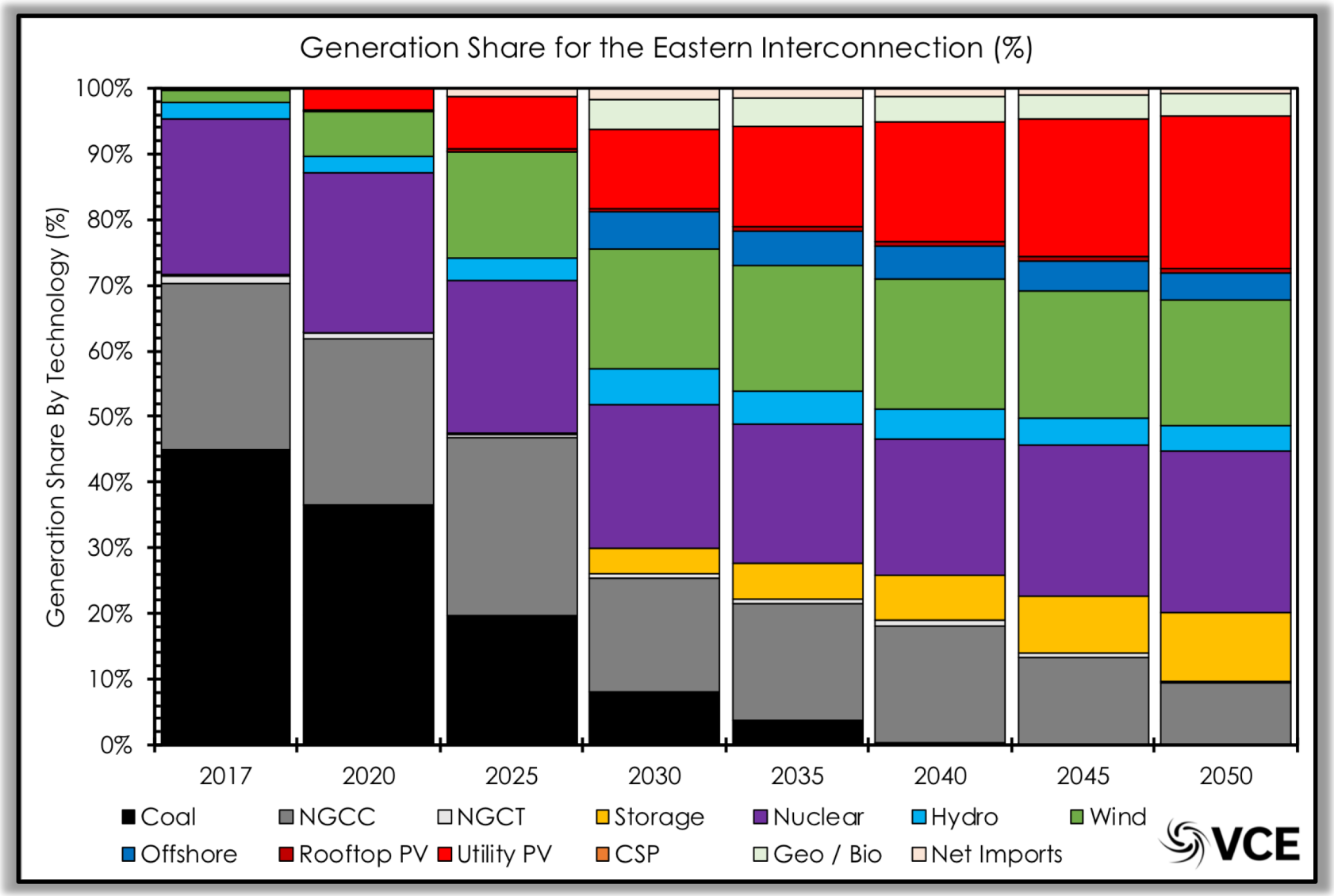
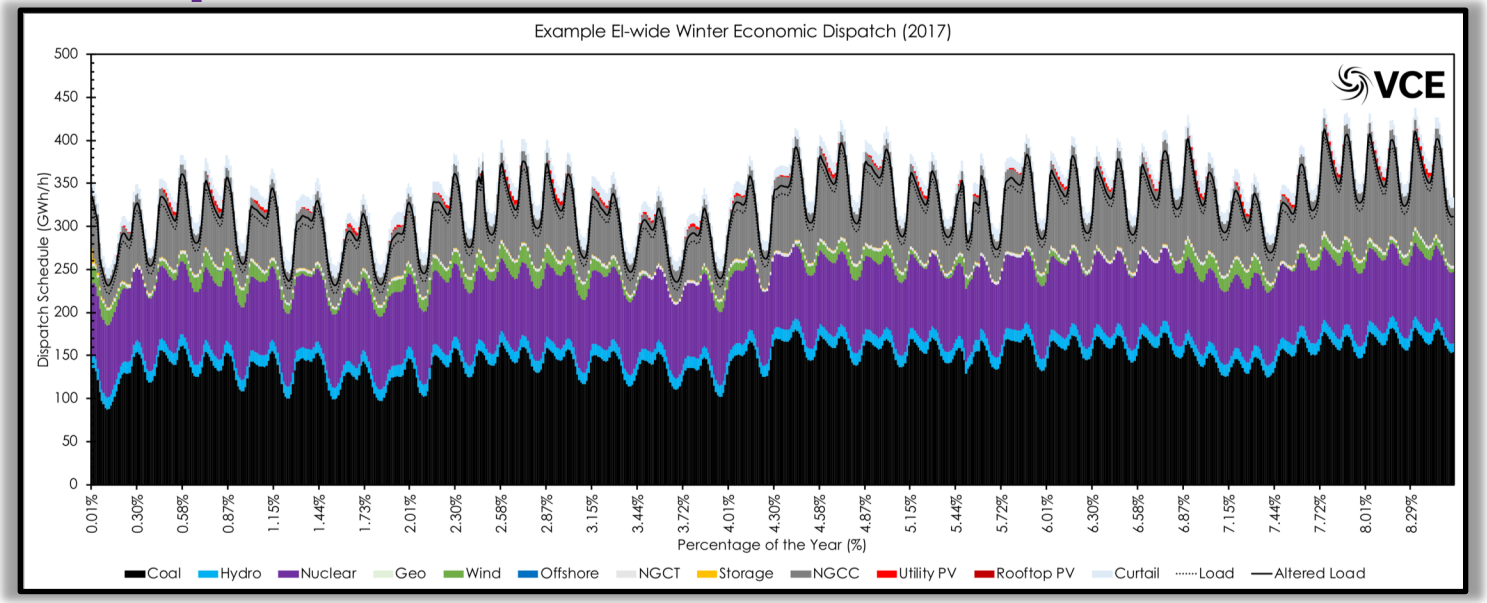
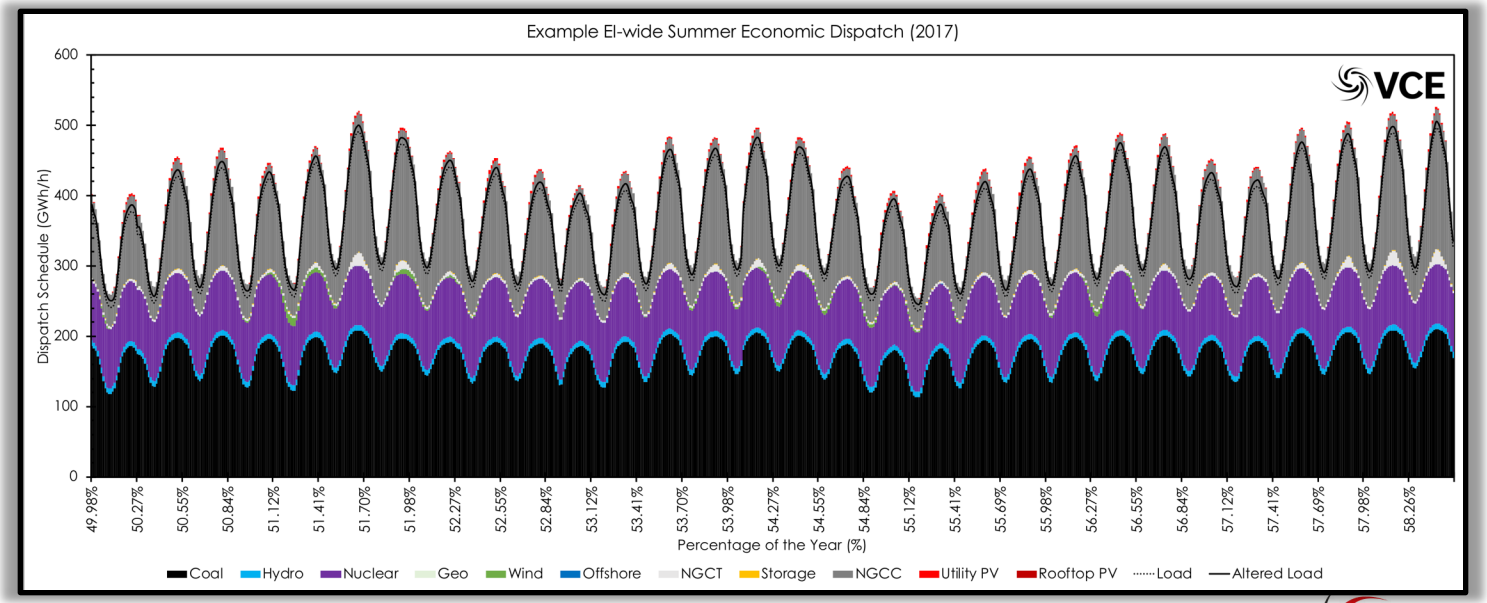
Generation Share For Eastern Interconnection

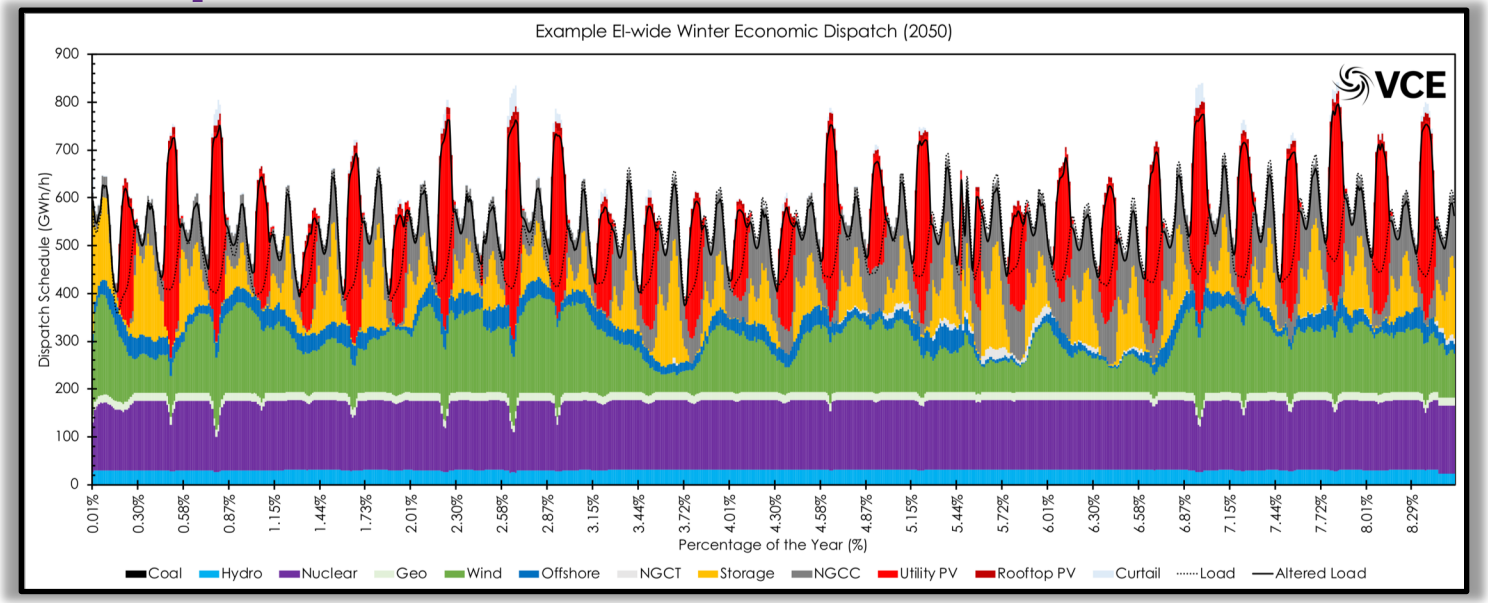


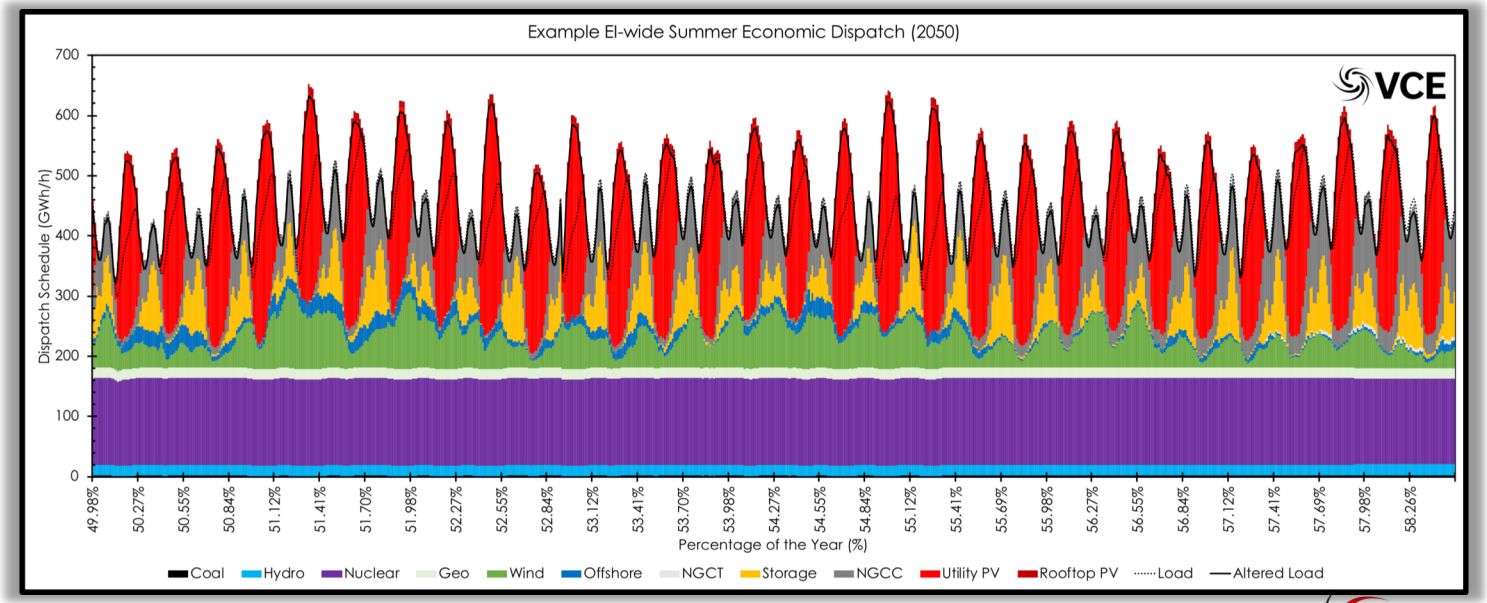
Dispatch For Eastern Interconnection



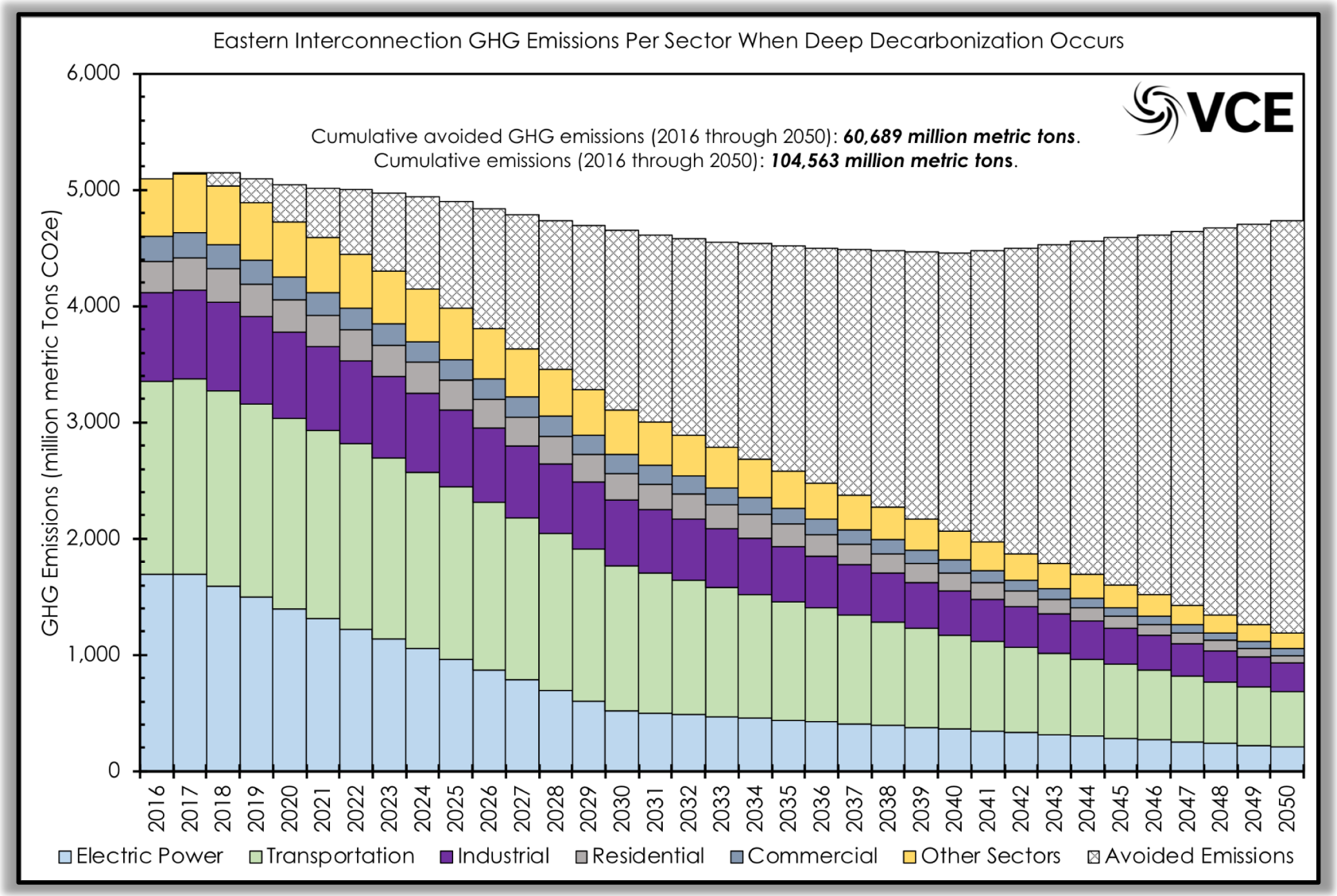


Dispatch For Eastern Interconnection





Avoided Emissions For Eastern Interconnection



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