Retirement of Colorado Coal-fired Power Plants Using the WIS:dom Optimization Model

Prepared By:

Vibrant Clean Energy, LLC

Dr Christopher T M Clack

Prepared For:

Community Energy

January 8th, 2018

VCE

info@vibrantcleanenergy.com

Study Scope

- Determine the change of the electricity system in Colorado between 2020 and 2040. Further, investigate the impact of the entire coal-fired power plant fleet retiring in Colorado by 2040.
- Compute the retail rates for average customers.
- Estimate the electricity generation and installed capacity within Colorado. Preform the modeling at 5-minute, 3-km resolution for the entire period of transition.
- Estimate the total number of FTEs within the Colorado electricity sector.
- Ensure that Colorado does not heavily rely on neighboring states for imported electricity during the transition.
- Calculate the difference between the (early) retirement of assets and the value to the electricity grid due to their retirement.

Approach

- Use the WIS:dom optimization model to transition the Colorado electricity grid from 2020 to 2040.

- Constrain the modeling to WECC and dispatch the system at 5-minute intervals with a 3-km resolution for power plants. Do not allow extensive transmission buildouts (interstate).

- Perform three scenarios:
  1) Keep all current Colorado coal-fired power plants active until 2040;
  2) WIS:dom to determine the most economic pathway for Colorado;
  3) Retire all the current Colorado coal-fired power plants by 2025.

- Compare the three scenarios to determine the effect of the coal-fired power plant fleet being retired or continued.

- The WIS:dom modeling tracks the installed capacities, retirements, generation, transmission build out, costs, emission, resource adequacy, capacity value, and other metrics.

Overall Results

- All three scenarios were stable and feasible for WIS:dom to find solutions from 2020 to 2040 for Colorado. This suggests that Colorado has a diverse potential suite of technologies for electricity generation.

- The pathway that WIS:dom determined was lower cost than the other two scenarios. This implies that retiring all coal plants by 2025 is more expensive than least-cost; likewise, keeping all the coal plants until 2040 is also more expensive.

- The coal-fired generation is ***replaced by a mix of wind, solar, storage and natural gas***; with the majority coming from wind and natural gas. The model is sensitive to capital costs for wind versus solar. With lower solar costs, the majority would come from solar (paired with storage).

- Average retail rates are very stable through all the scenarios. The most expensive was keeping all coal to 2040. The least-cost was the WIS:dom determine scenario, and the early retirement of the coal (by 2025) was very slightly more expensive.

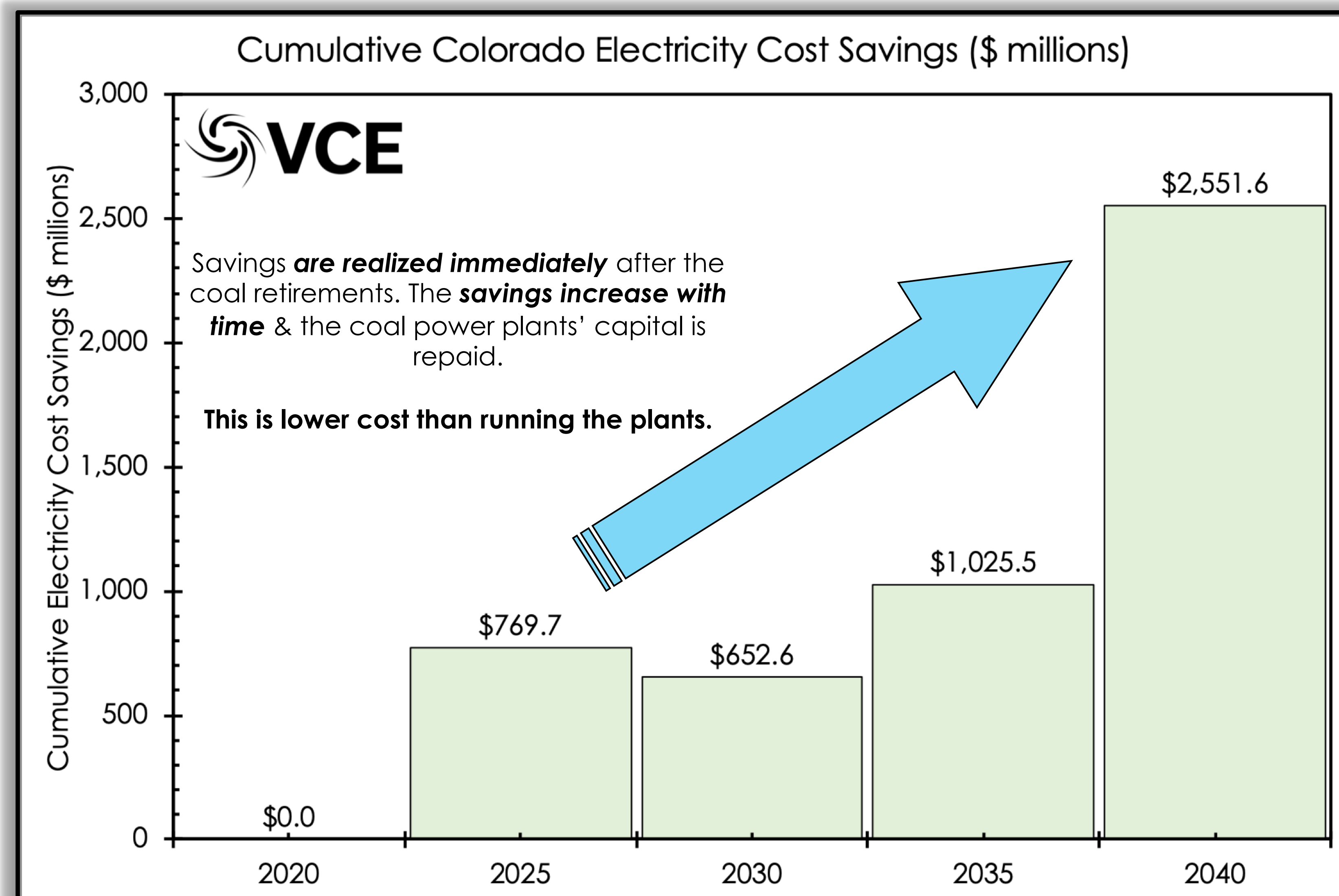
- ***Cumulative emissions are half when coal is retired in 2025 compared with continuing to 2040***.

Overall Results

- It is ***$305 million lower cost per year to retire ALL the coal plants in Colorado by 2025*** than keeping them all running to 2040.
- The cumulative savings from retiring the coal fleet by 2025 compared with it continuing to 2040 is ***$2,551 million*** by 2040. This saving is in addition to repaying all the remaining capital on the coal power plants.
- ***By retiring the coal power plants in 2025, Colorado electricity stops the emission of 510 million metric tons of CO_2 by 2045***. Moreover, it would stop many other health-harming pollution from being emitted.
- Electricity is provided, without fail, for all of Colorado (at 5-minute intervals) when the coal power plants are retired. Natural gas, wind, solar and storage can provide power for Colorado without baseload generation.
- The costs of wind and solar used in the modeling are conservative; they are based on the NREL ATB 2018 (mid). ***Xcel has received bids for wind and solar at prices lower than those projected in the NREL ATB***[1].

[1] https://assets.documentcloud.org/documents/4340162/Xcel-Solicitation-Report.pdf

Cumulative Savings For Colorado

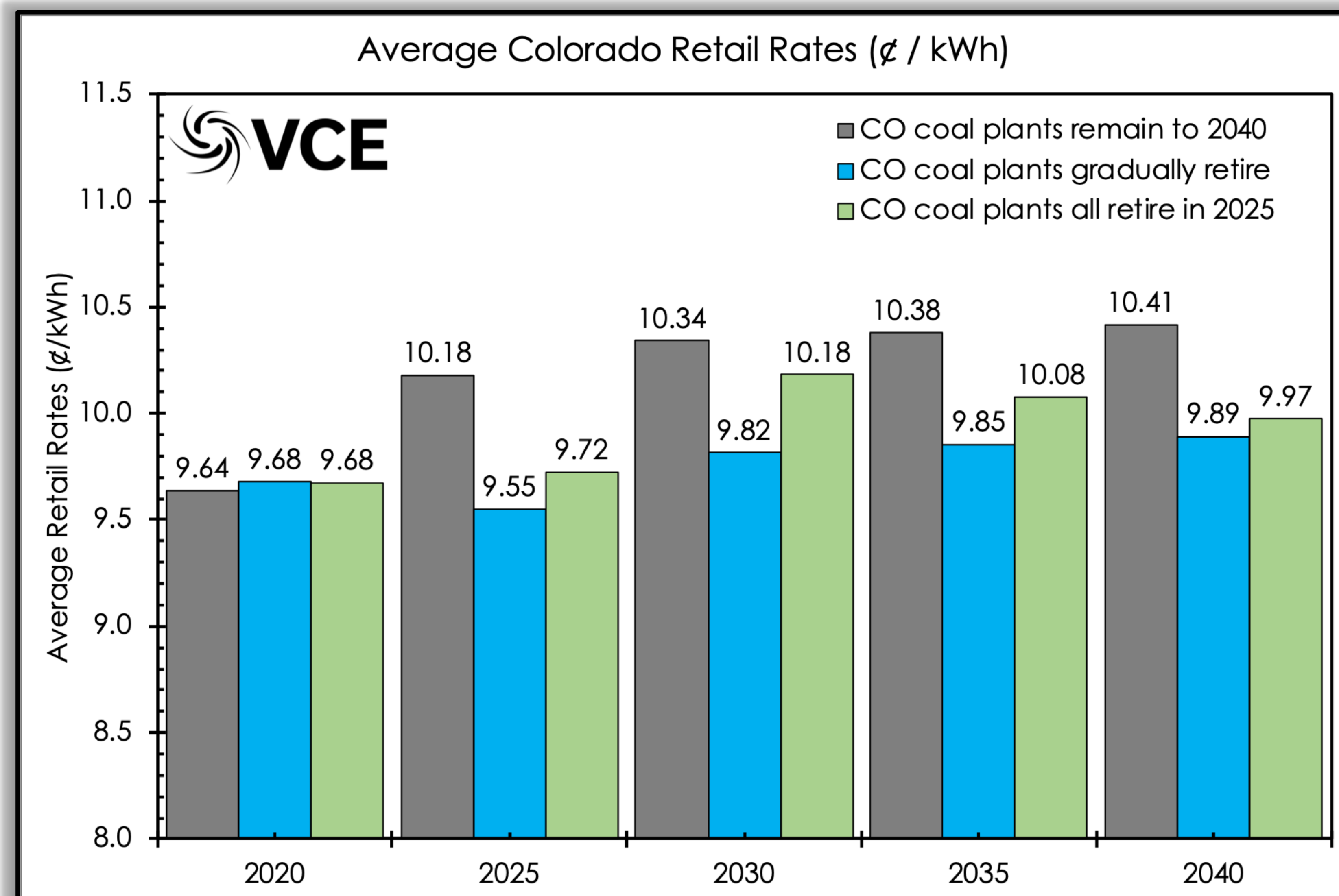


Retiring the coal power plants by 2025 reduces electricity costs for many years to come, and save Colorado a cumulative $2.5 billion while repaying utilities for all their capital outstanding on their coal power plants.

info@vibrantcleanenergy.com

VCE VIBRANT CLEAN ENERGY

Average Retail Rates

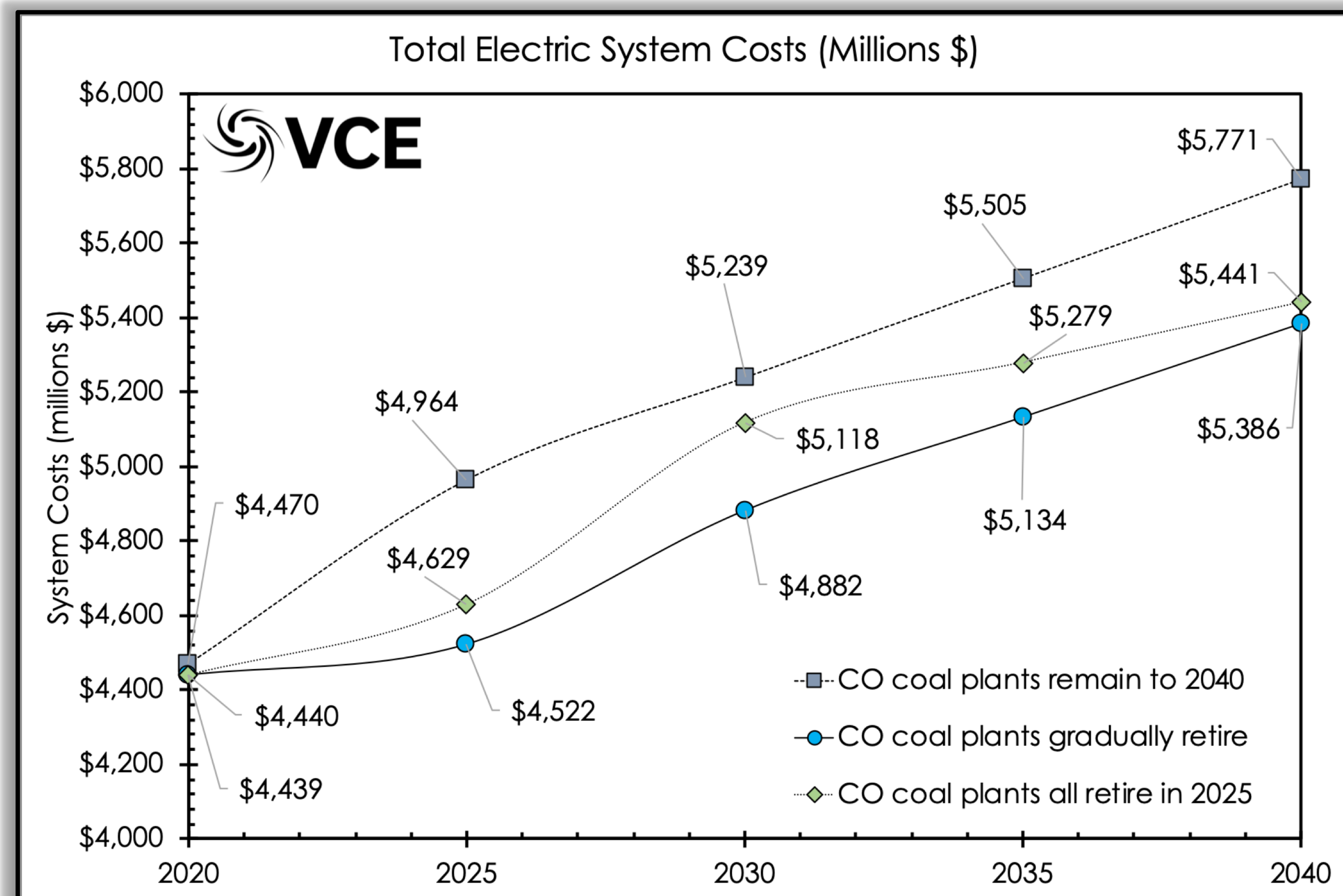


The scenario that retired all coal in 2025 (green) is much cheaper than keeping all the coal running until 2040 (grey). The gradual retirement (blue) is cheapest.

info@vibrantcleanenergy.com

VCE VIBRANT CLEAN ENERGY

System Costs For Colorado Electricity Grid

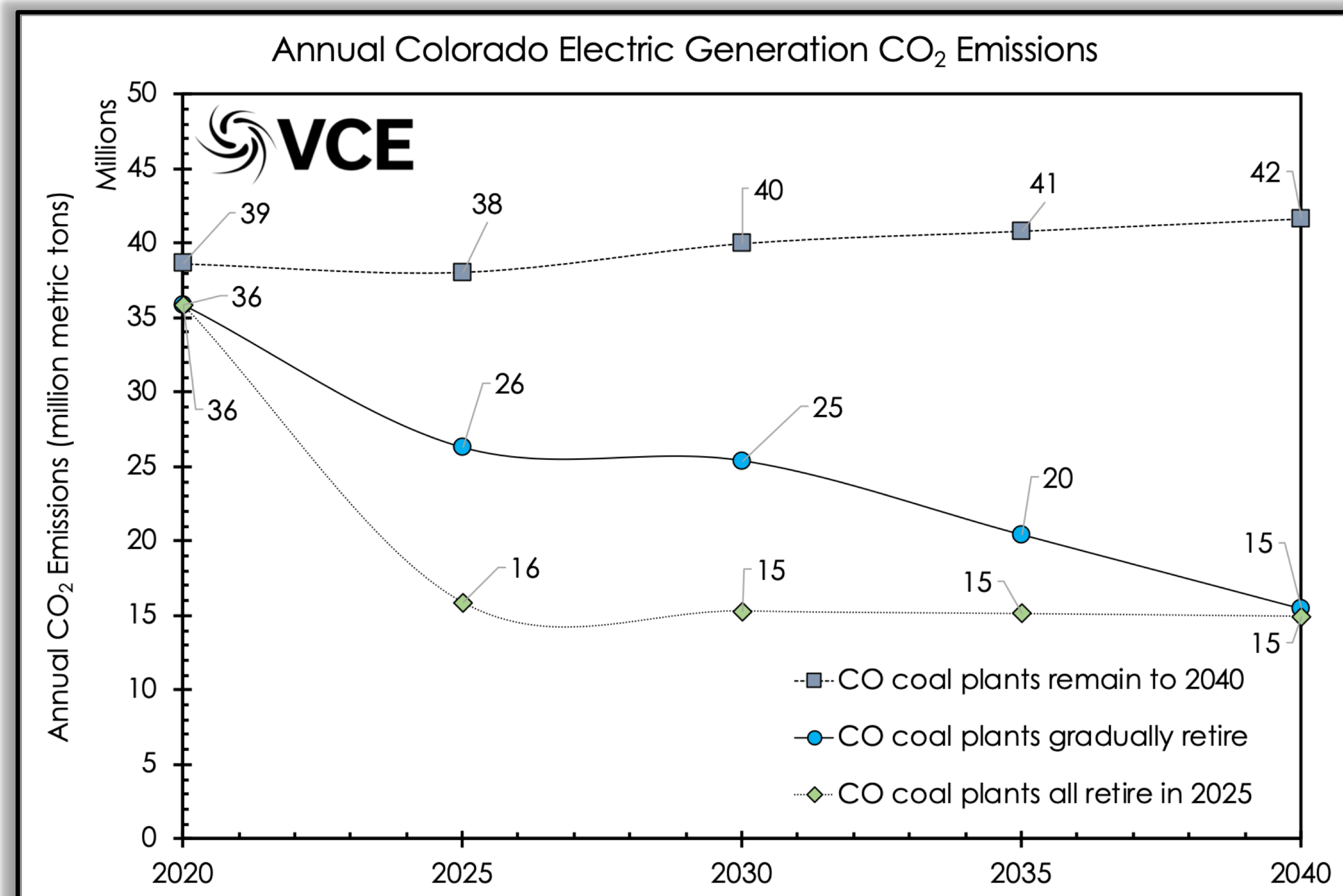


The early retirement of coal is much cheaper than continuing to run them. The savings ($2,551 million) could be used for grid modernization, EE programs, or to procure more renewables.

info@vibrantcleanenergy.com

VCE VIBRANT CLEAN ENERGY

CO_2 Emissions From Colorado Electricity

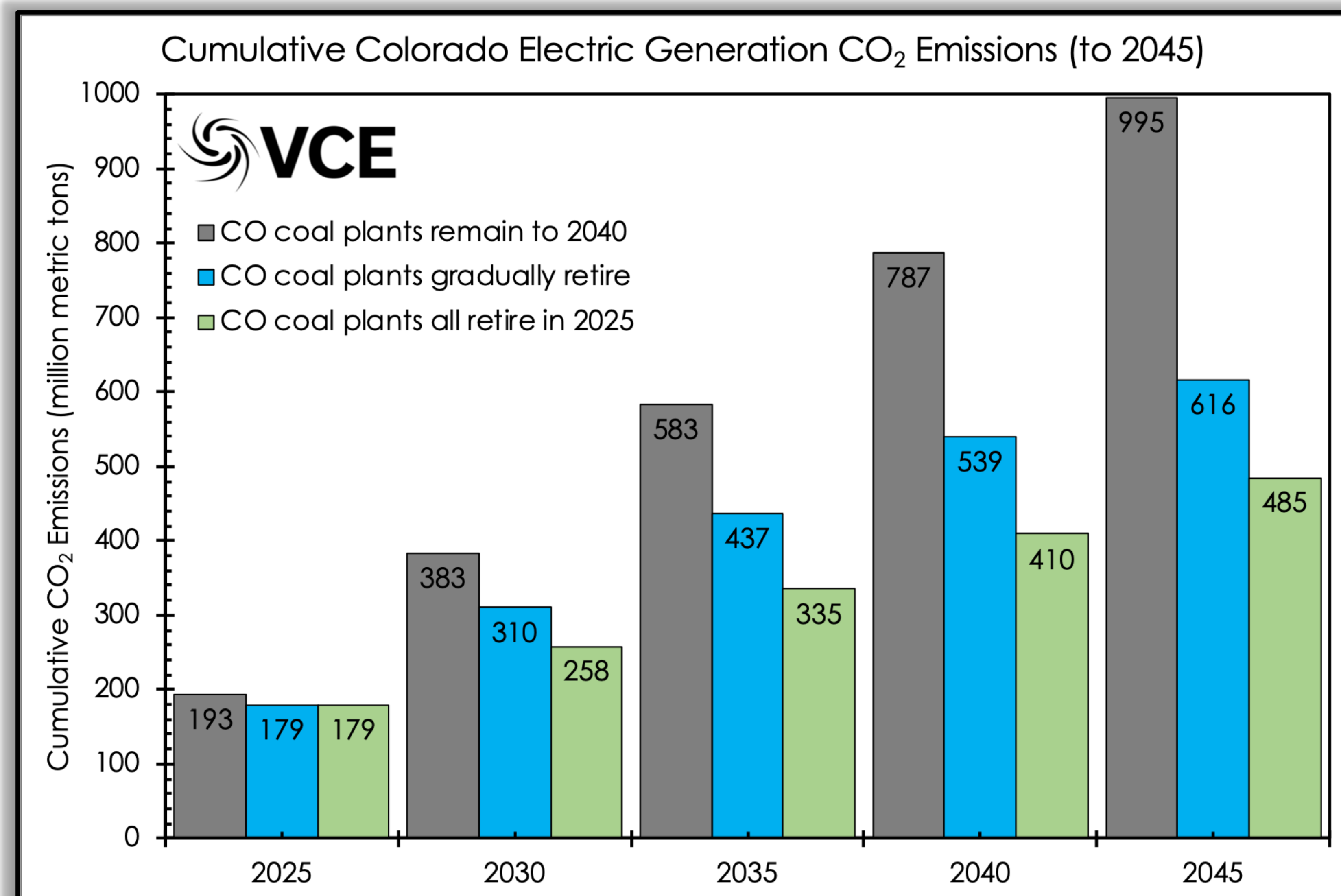


The early retirement of coal emits far less carbon dioxide and other health-harming pollutants. The reduction in these emissions will save residents on health care.

info@vibrantcleanenergy.com

VIBRANT CLEAN ENERGY

CO_2 Emissions From Colorado Electricity

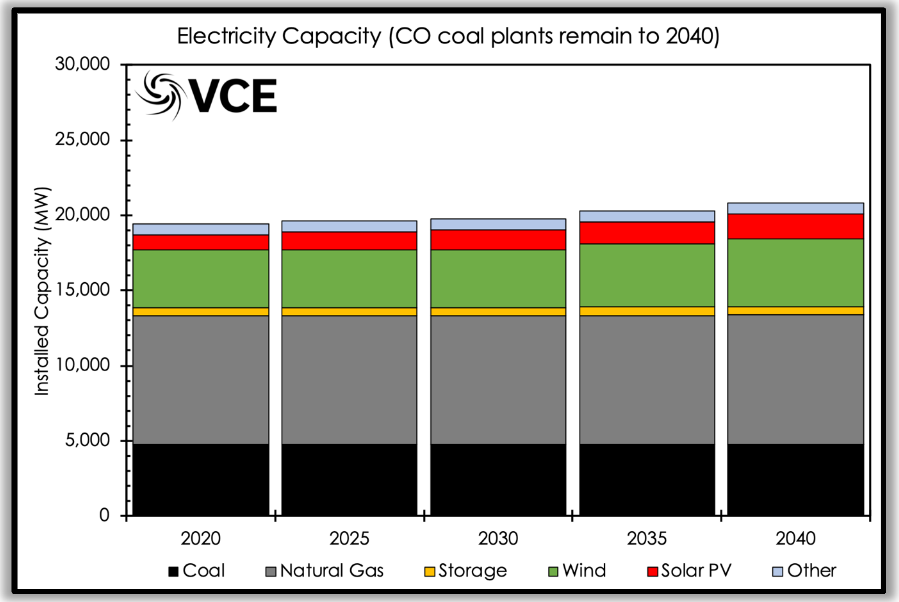


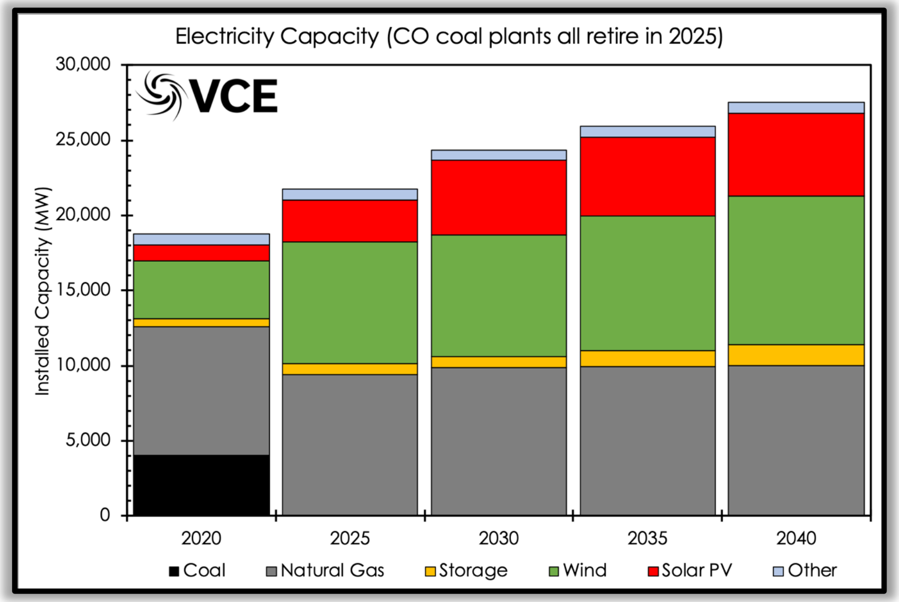
The reduction in carbon dioxide emissions is equivalent to removing all vehicles from Colorado roads for 17 years.

info@vibrantcleanenergy.com

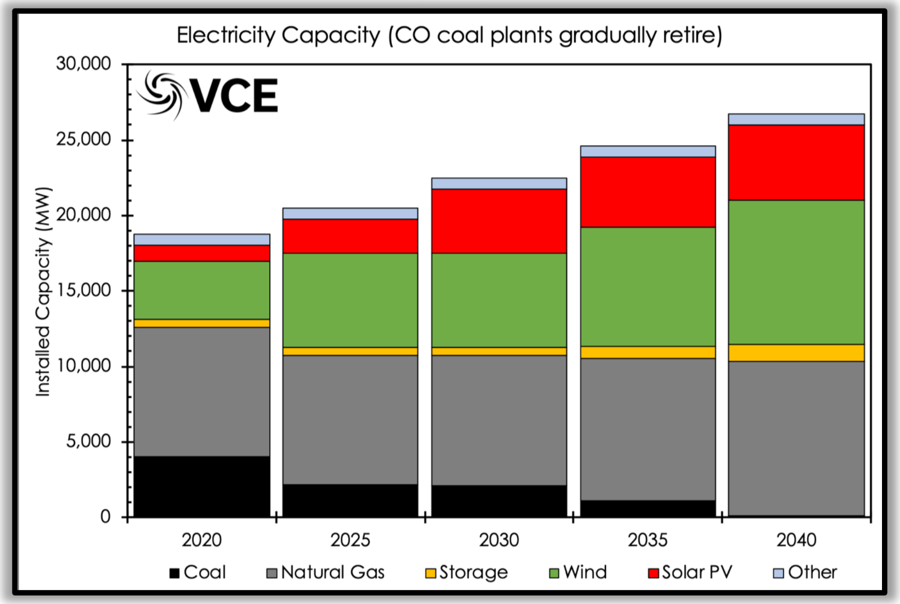
VCE VIBRANT CLEAN ENERGY

Installed Capacity For Each Scenario





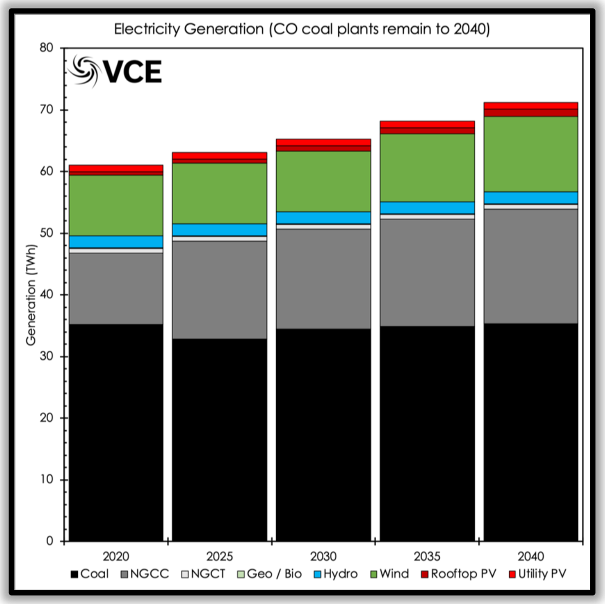
The installed capacity in Colorado grows to replace the coal power plants when they are retired. Wind and solar are dominant in their increase in installed capacities. Natural gas also increases to provide flexible generation.

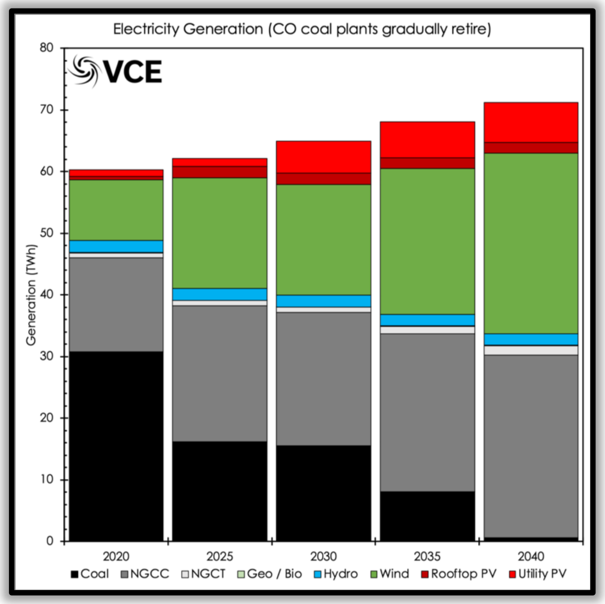


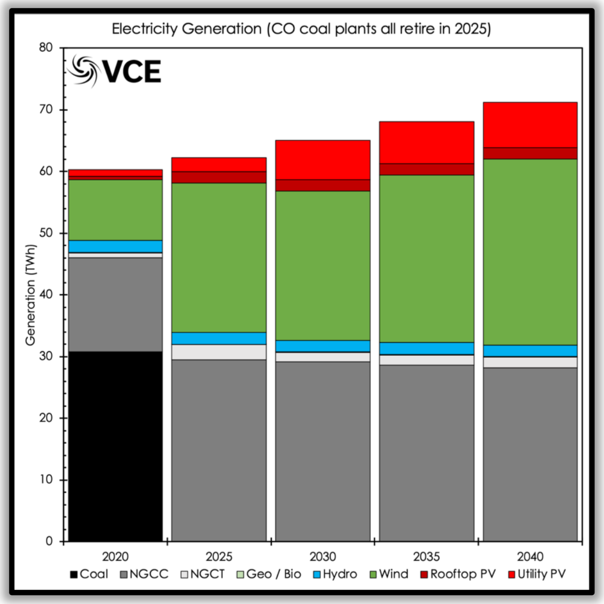
info@vibrantcleanenergy.com

VIBRANT CLEAN ENERGY

Electricity Generation For Each Scenario



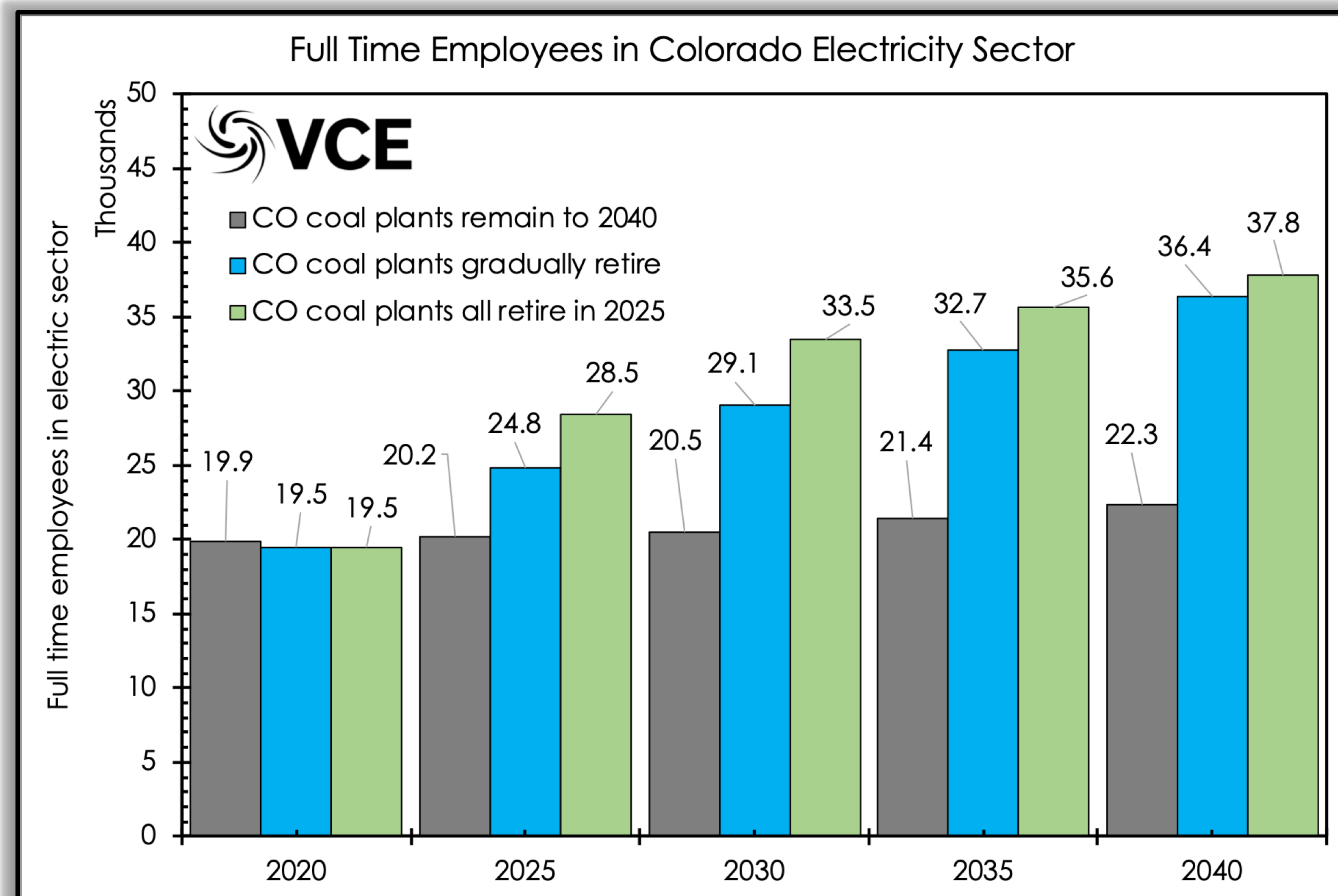




The coal retirement generation is met with a combination of wind, solar and natural gas. Colorado has abundant resources and provides all the new generation from within State sites. Electric storage also increases with the rise of wind and solar across Colorado.

Increased capacity results in higher tax revenues and employment.

Employment For Colorado Electricity Sector



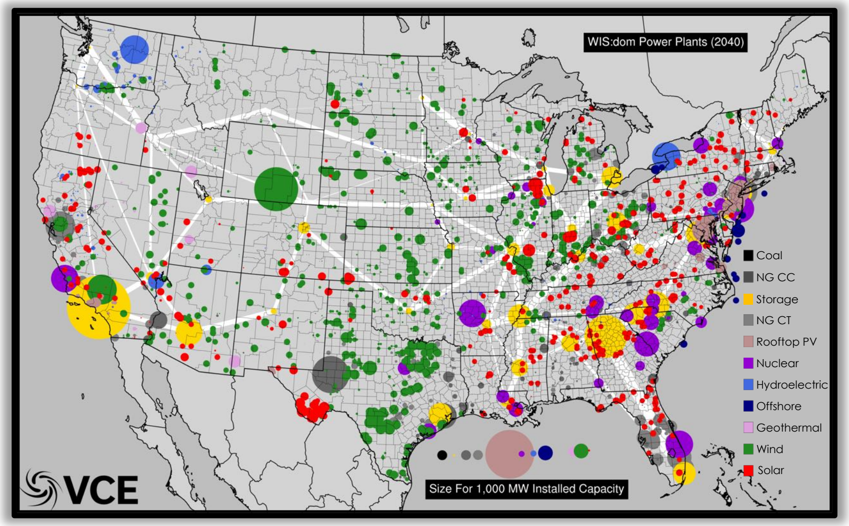
The increase in wind, solar and natural gas comes with a rapid increase in jobs for the electricity sector. The jobs provided are far greater than those lost through the retirement of the coal power plants.

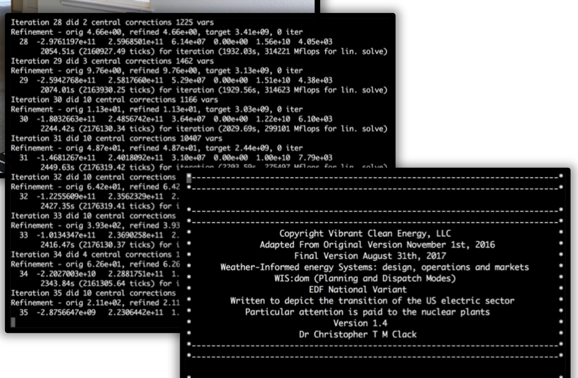
Thank You

Dr Christopher T M Clack
CEO Vibrant Clean Energy, LLC

Telephone: +1-720-668-6873
E-mail: christopher@vibrantcleanenergy.com
Website: VibrantCleanEnergy.com

Who Are We: Vibrant Clean Energy

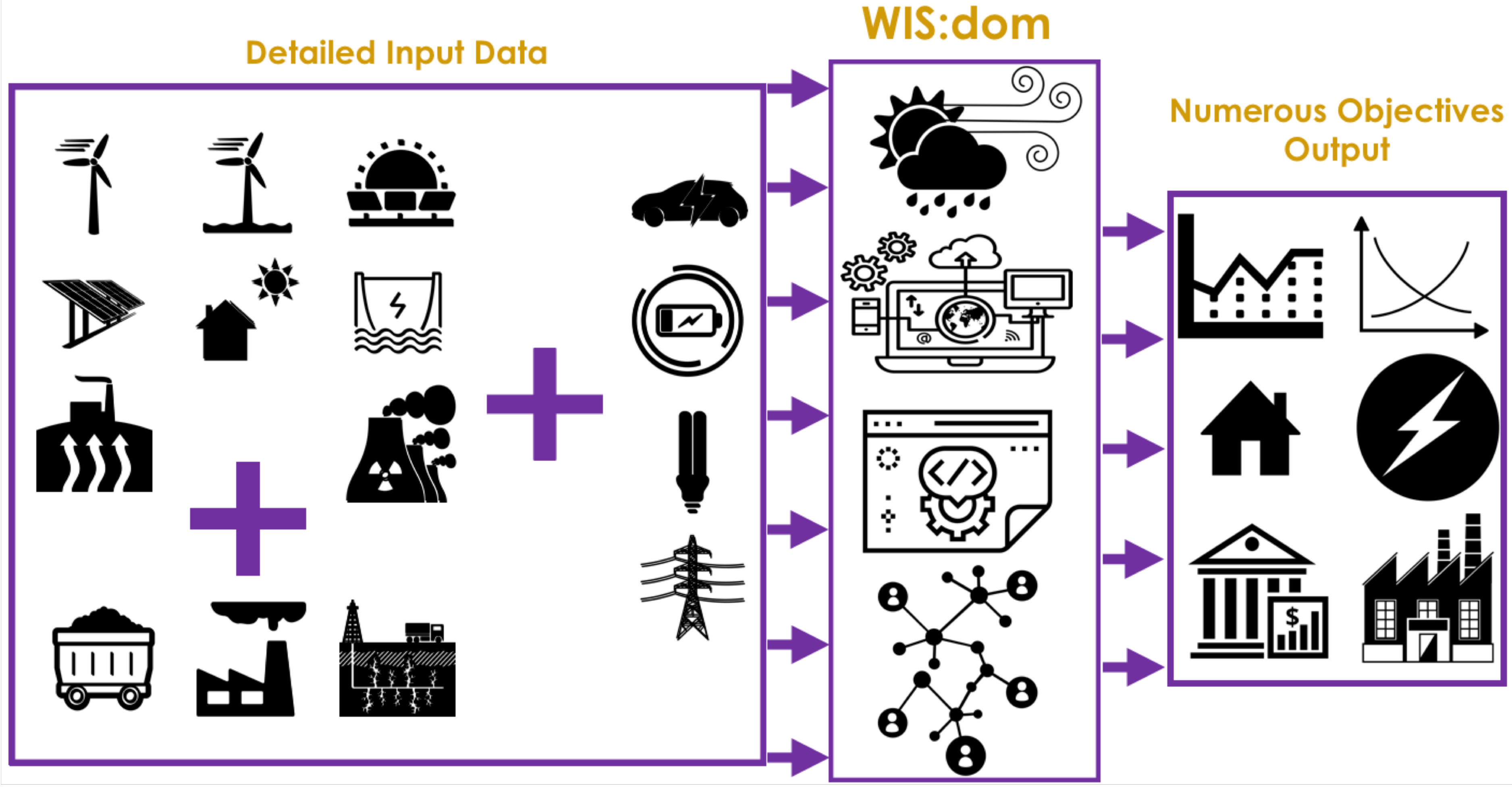




Purpose of Vibrant Clean Energy, LLC:

- 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 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.

Pushing The Envelope: The WIS:dom Model



WIS:dom Optimization Model

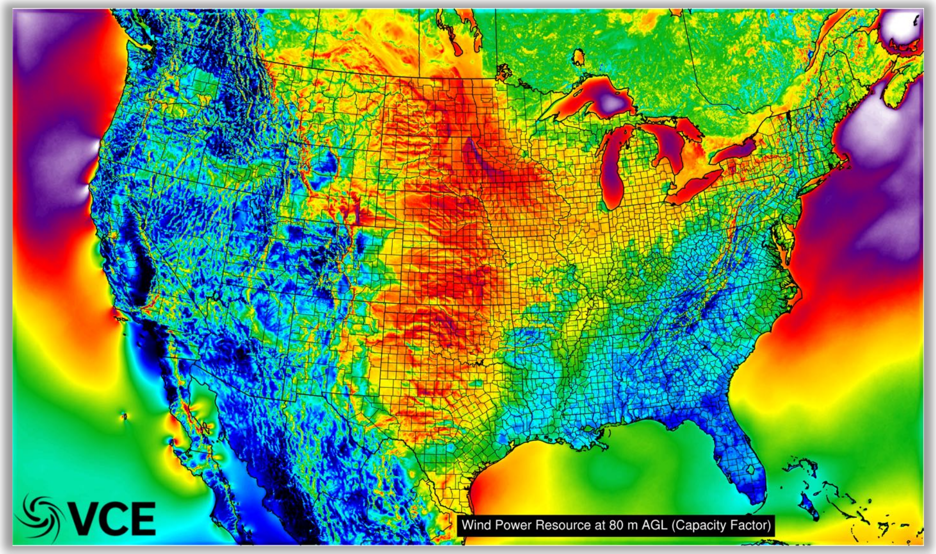
WIS:dom is the ***only*** commercially available combined capacity expansion and production cost model. It combines:

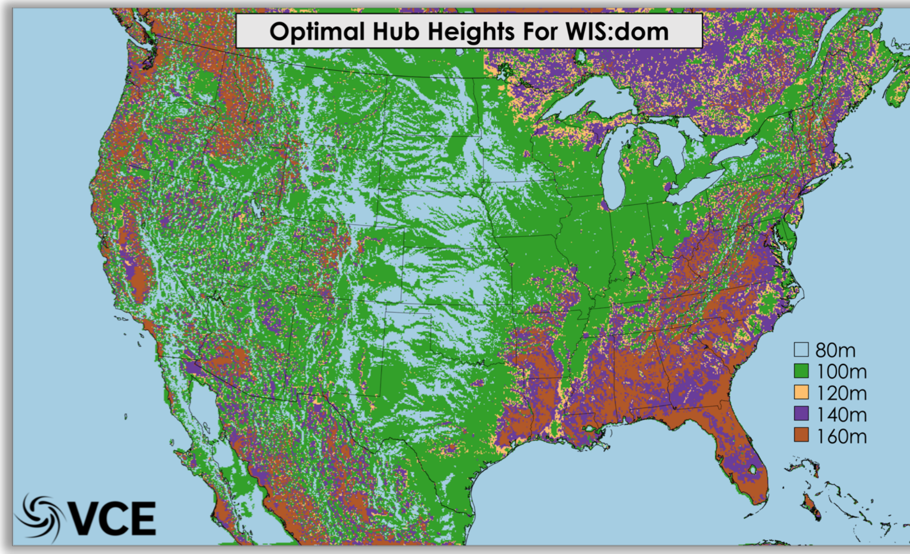
- ✓ Continental-scale (globally capable), spatially-determined co-optimization of transmission, generation, storage, and demand-side resource expansion while simultaneously determining the dispatch of these sub systems at 3-km, 5-minutely resolution;
- ✓ Dispatch includes:
  - ➢ Individual unit commitments, start-up, shutdown profiles, and ramp constraints;
  - ➢ Transmission power flow, planning reserves, and operating reserves;
  - ➢ Weather forecasting and physics of weather engines;
  - ➢ Detailed hydro modeling;
  - ➢ High granularity for weather-dependent generation;
  - ➢ Chronological intervals for at least a full calendar year;
  - ➢ Existing generator and transmission asset attributes such as heat rates, line losses, power factor, variable costs, fixed costs, capital costs, fuel costs, etc.;
- ✓ Large spatial and temporal horizons;
- ✓ Policy and regulatory drivers such as PTC, ITC, RPS, RGGI, etc.;
- ✓ Detailed investment periods;
- ✓ Capable of including electrification of other sectors, hydrogen production, fuel price elasticity, Ammonia production, and carbon mitigation.

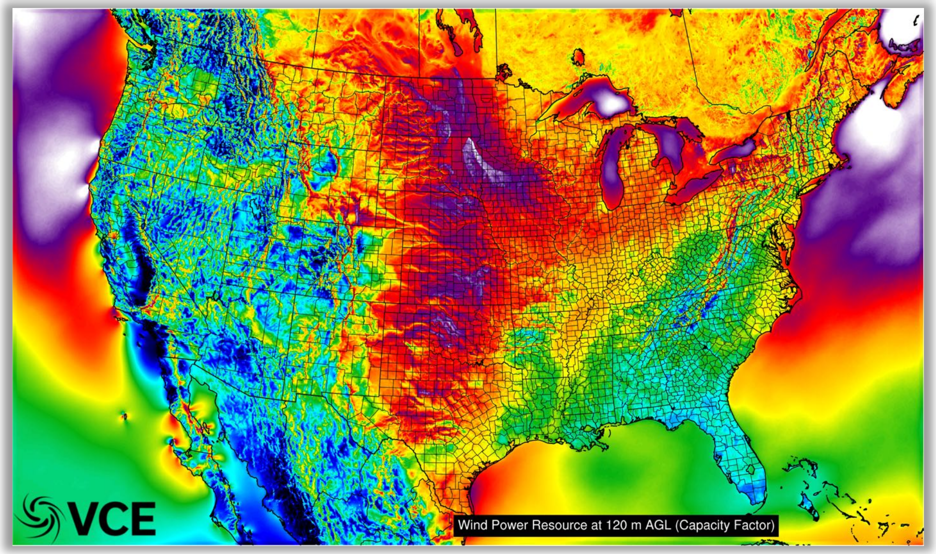
Logical Equations in WIS:dom

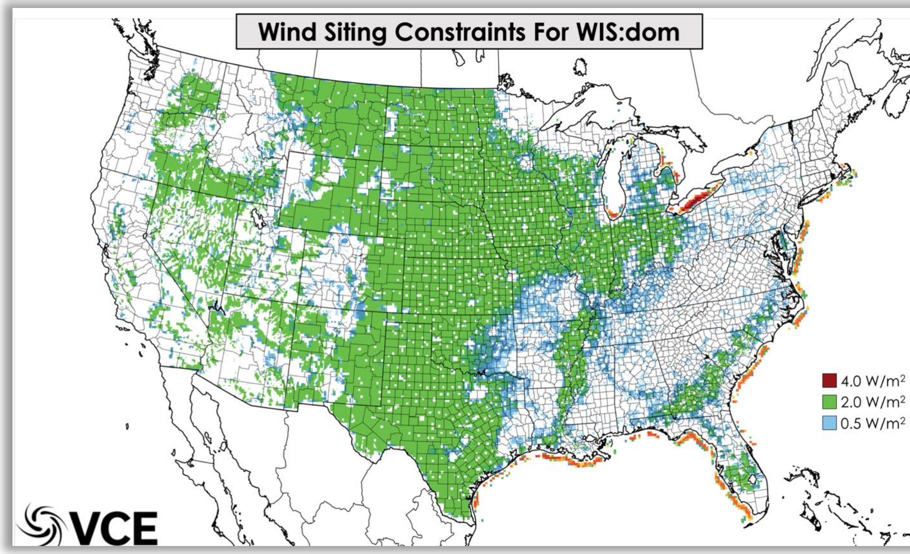
Constraint ID	Equation Name	Equation Purpose	Impact Estimation
1	Total System(s) Cost Objective	To define the objective that is being minimized	**Critical** Other objectives may alter solutions significantly
2	Reliable Dispatch Constraint	Enforce WIS:dom meets demand in each region each hour without fail	**Critical** Strict enforcement of zero loss of load
3	Market Clearing Price Adjustment	Allowing WIS:dom to estimate the dispatch stack & attribute price vs cost	**Critical** Different market structures could impact deployment choices
4	DSM Balancing Constraint	Ensures that DSM providers can balance their demand	**High** Changing the description of DSM and costs could alter solutions
5	Transmission Power Flow Constraint	Produces the optimal power flow matrix and associated losses	**Critical** Transmission power flow significantly impacts dispatch and deployment
6	Transmission Capacity Constraint	Calculates the capacity of each transmission line	**Critical** Without this constraint, power flow could become artifically large
7	Planning Reserve Constraint	Ensure planning reserve margins are maintained	**High** Capacity credit for VREs can alter deployment decisions
8	Coal, NGCC, NGCT, Nuclear, Hydro, Geo Capacity Constraints	Maintain the capacity of generators above their peak production	**High** Without the constraints generations can be incredibly based on marginal costs alone
9	Storage Power & Energy Capacity Constraints	Complex equations & constraints to determine the utilization of storage	**Critical** Storage correctly modeled can change all investment decisions and dispatch
10	Coal, NGCC, NGCT, Nuclear, & Geo P_min Constraints	Constraints that force WIS:dom to adhere to P_min attributes for thermal generators	**Medium** P_min enforcement has lower impacts on decision
11	RPS & Emission Constraints	To enable WIS:dom to understand policy, regulatory and societal limitations	**Critical** When emissions enforced investment decisions are completely changed
12	Generator & Transmission Capacity Expansion Constraints	To require WIS:dom to keep investments in new generation & transmission to specific levels	**Low-Medium** Very tight enforcement could impact decisions, but realistic values do not substantial change solutions
13	Coal, NGCC, NGCT, Nuclear, & Geo Ramping Constraints	Describing the speed at which generators can alter their output for WIS:dom	**Medium** Faster ramping thermal generation is more favorable in lower emission scenarios, so this constraint impacts decisions in those cases
14	DER Deployment & Cost Constraints	Specifies to WIS:dom the amount of DERs to be constructed and/or cost to system of these assets	**Low** Has minimal impact on the overall system costs and investment decisions of utility scale generators
15	CIL & CEL Constraints	Describe the import & export limits between markets, countries, states, and interconnections	**Medium-High** Transmission expanding from existing lines & the addition of market impacts can dramatically alter decisions in some high emission reduction scenarios
16	Spatial Limitation Constraint	Allow WIS:dom to understand the space requirement for generators and competition for land use	**Medium** Without this constraint land use can be over used and over count the amount of generation in a location/site
17	Extraction Limits For VRE	Determines the limits to VRE extraction for nearby sites	**Medium** Impactful for wind siting considerations but much lower for solar PV siting
18	Nuclear & Hydro Dispatch Schedule	Informs WIS:dom that nuclear and hydro must conform to addition constraints regarding the water cycle, water temperature, and refuelling	**Low-Medium** Nuclear suffers a small amount due to offline times & hydro flexibility limited by constraint to assist with other VREs
19	Relicense / Repower Decision	Facilitates WIS:dom opting to relicense or repower an existing nuclear or VRE site	**Medium-High** Repowering can substantially improve existing sites at lower cost, while relicensing enable nuclear to remain within markets for longer
20	Load / Weather Forecast Error Estimator	Enables WIS:dom to detect regions with poor weather and/or load forecasts for consideration during investment decisions	**Low-Medium** Load & weather forecasts are small enough over EI markets that the invesments are not substantially altered. For WECC, the impact is much higher

Weather-Informed Modeling

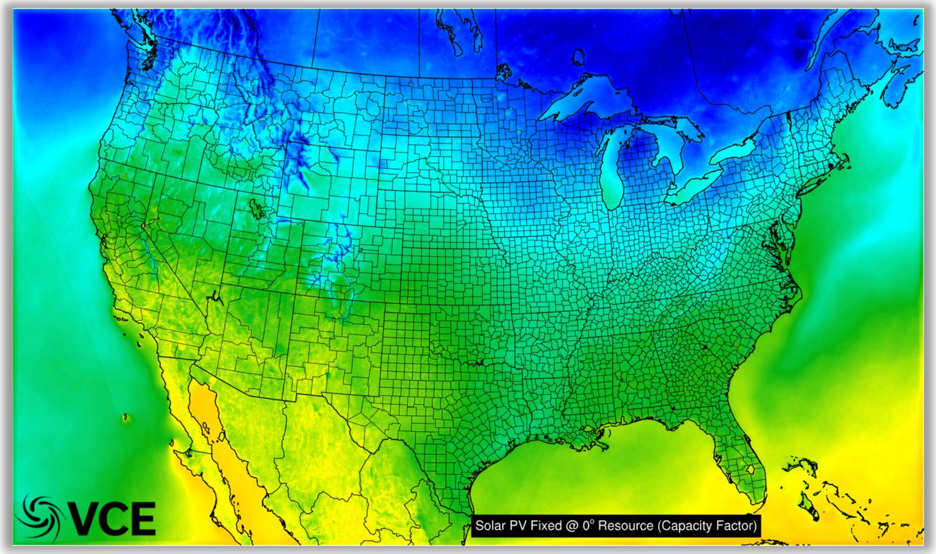


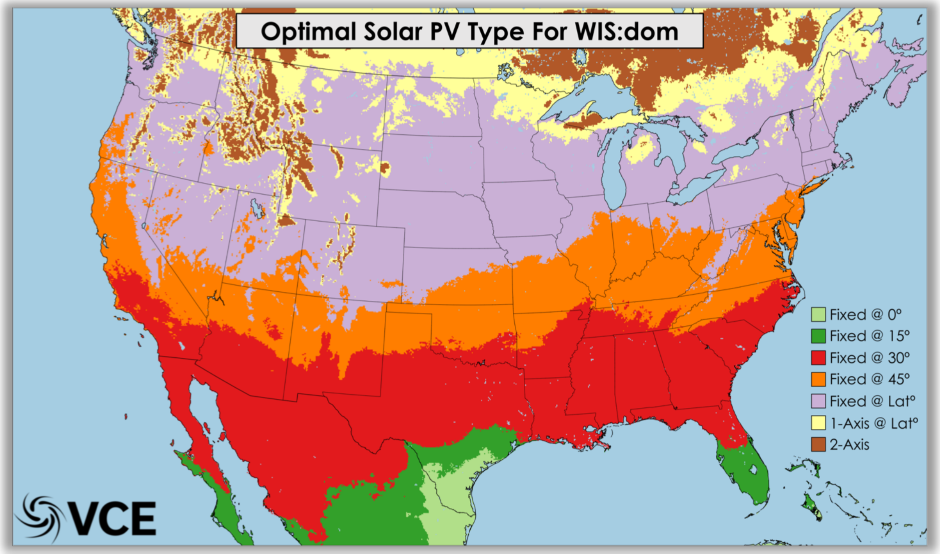


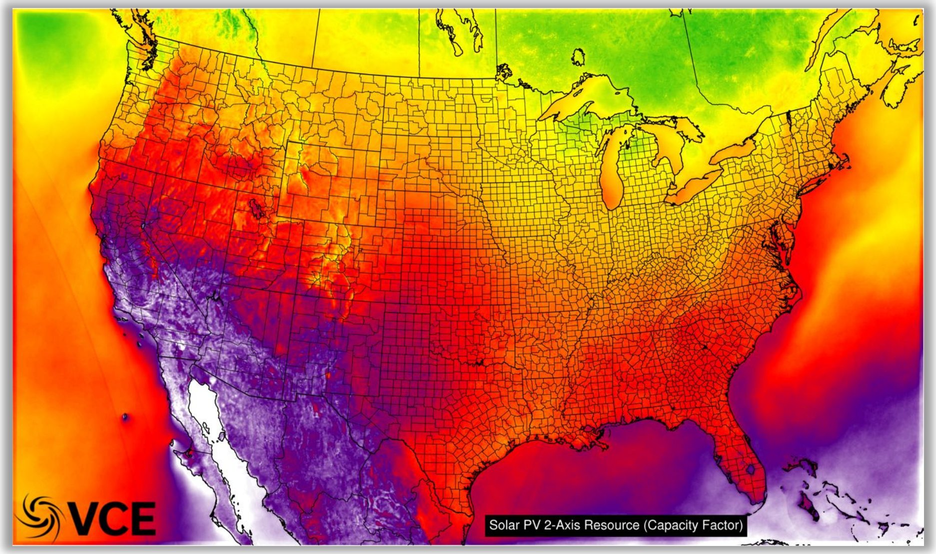


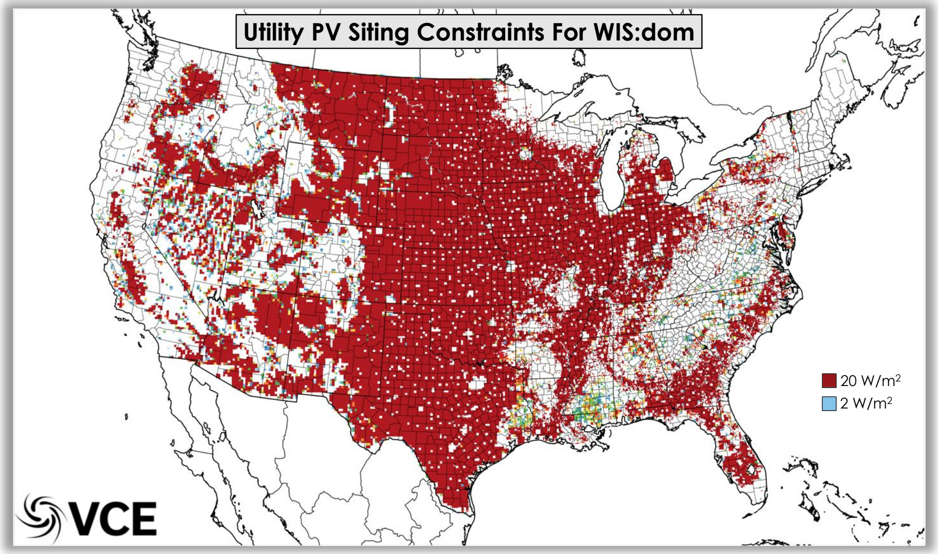


Weather-Informed Modeling





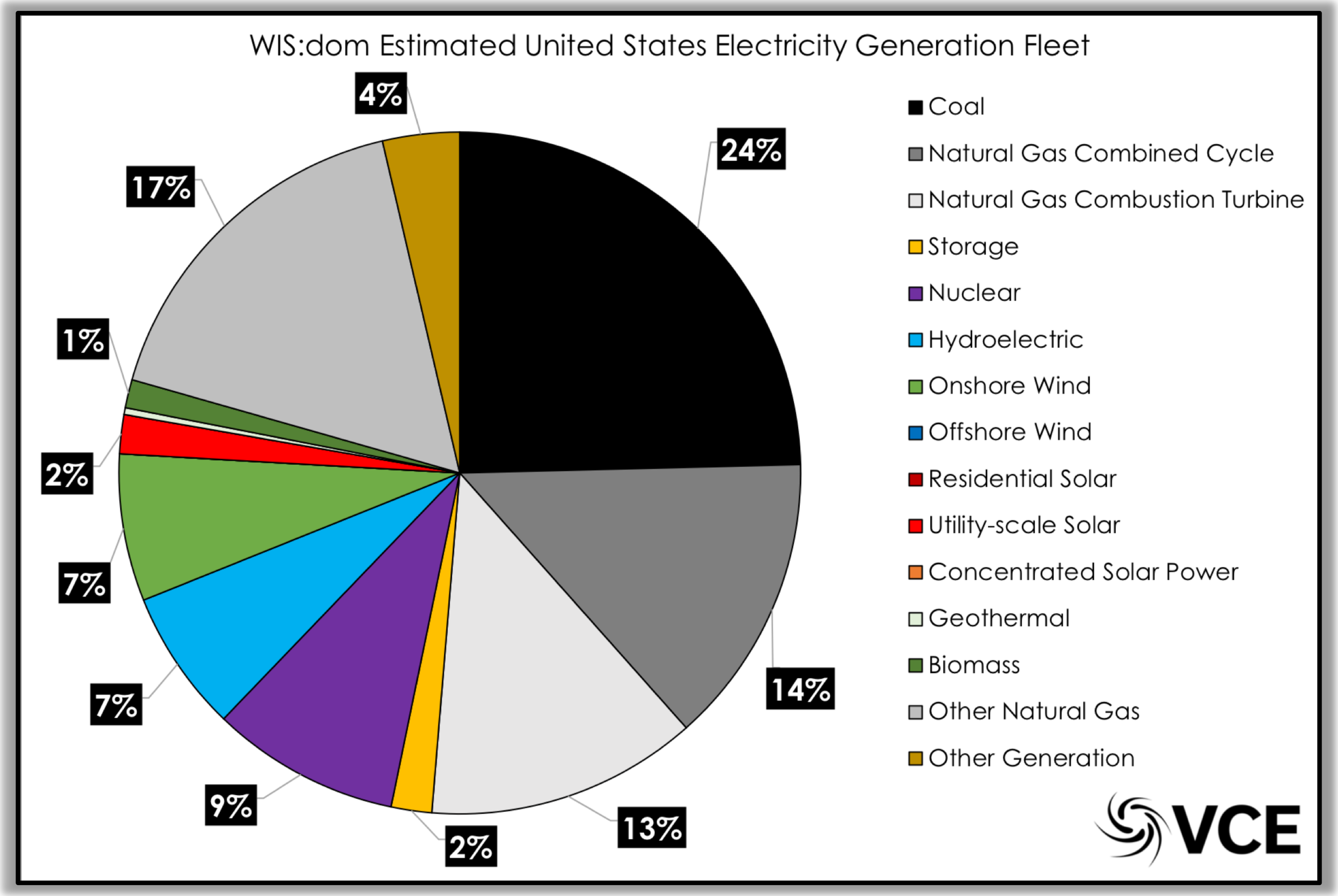




info@vibrantcleanenergy.com

VIBRANT CLEAN ENERGY

Start from Today: Generators



info@vibrantcleanenergy.com

VCE
VIBRANT CLEAN ENERGY

Start from Today: Electricity Transmission