

# The Importance of Energy Sector Coupling

## Learnings from the Annual Decarbonization Perspective

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October 22, 2024



EVOLVED  
ENERGY  
RESEARCH

# Evolved Energy Research

Evolved addresses key policy and strategy questions raised by transformation of our energy system

## NGOs

NRDC, SDSN, GridLab, Sierra Club, CETI, OCT, UCS, EDF, CATF, BPC, Third Way, and others

## State Energy Offices

Washington, California, Massachusetts, Maine, New Jersey, and Oregon

## Utilities/RTOs

SPP, DTE, PGE, Hydro Quebec, PG&E and others

## Others

Princeton University, Breakthrough Energy, Inter-American Development Bank, DOE, NREL, RAP



# Questions:

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- What is the difference between clean electricity and economy-wide net-zero?
  - What are the implications of sectoral coupling on the electricity system?
  - What level of electricity CO2 emissions are consistent with an economy-wide net-zero target?
- How are the U.S. and Europe similar/different?

# Purpose of Evolved's Annual Decarbonization Perspective

- The annual refresh aims to fill a current gap in decarbonization analysis delivering a standardized, regularly updated, technology agnostic and publicly accessible (inputs and outputs) report
  - 6-8 scenarios with continuity between years + additional sensitivities
  - Publication of model inputs/outputs with detailed technology assumptions
- U.S. work is funded by Breakthrough Energy
- European work is funded by Third Way



# Evolved & Breakthrough have released detailed ADP Datasets with state-level outputs

United States Annual Decarbonization Perspective (ADP) 2023

[www.evolved.energy/posts/usadp2003](http://www.evolved.energy/posts/usadp2003)

Contact: [ryan.jones@evolved.energy](mailto:ryan.jones@evolved.energy)

Data	Geography	Data description
1 <a href="#">Mapping zone to county</a>	county	Mapping factors that allow translation between model zones and states/counties based on # households or land area
2 <a href="#">CO2 emissions</a>	state	Annual CO2 emissions
3 <a href="#">sankey data</a>	national	Energy flows used to create sankey diagrams
4 <a href="#">Primary energy</a>	state	Primary energy supply for the U.S.
5 <a href="#">Final energy demand</a>	state	Final energy demand by sector and scenario
6 <a href="#">Electricity gen</a>	state	Annual electricity generation
7 <a href="#">Electricity capacity</a>	state	Installed capacity by generation type
8 <a href="#">Electricity storage</a>	egrid region	Installed storage energy
9 <a href="#">Fuel conversion capacity</a>	state	Capacity for fuel conversion technologies
10 <a href="#">Hydrogen source and use</a>	state	Hydrogen source and use by zone
11 <a href="#">Biomass source and use</a>	state	Biomass source and use by zone
12 <a href="#">Captured carbon source and use</a>	state	Captured carbon by source and use
13 <a href="#">Inter-regional pipe,transmissio</a>	egrid region	Pipeline and transmission capacity between zones by year
14 <a href="#">Gross energy system cost</a>	national	Annual levelized total energy system cost (demand-side costs above reference are shown as a net cost)
15 <a href="#">Investment</a>	state	Annual investment by technology (demand- & supply-side)
16 <a href="#">Health outcomes</a>	state	Health savings relative to baseline
17 <a href="#">Demand-side sales shares</a>	state	Annual % of sales by technology
18 <a href="#">Demand-side stock</a>	state	Annual stock for different demand-side equipment types in each subsector
19 <a href="#">Service demand</a>	national	Demand for energy services allocated to technology



# Long-term energy modeling

“Plans are useless, but planning is indispensable” – Eisenhower

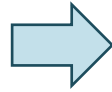
Long-term low emissions pathways illustrate not what will happen, but what could happen, enabling us to discern:

- Critical junctures and pivotal societal choices.
- Universally beneficial strategies that withstand varying scenarios.
- The competitive landscape of technologies, barriers to adoption, and research focal points.
- Crucial compromises, compelling engagement from society, policymakers, and the public with the realities of transitioning to low-carbon energy.

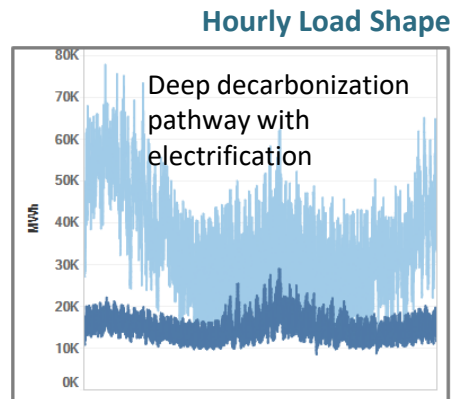
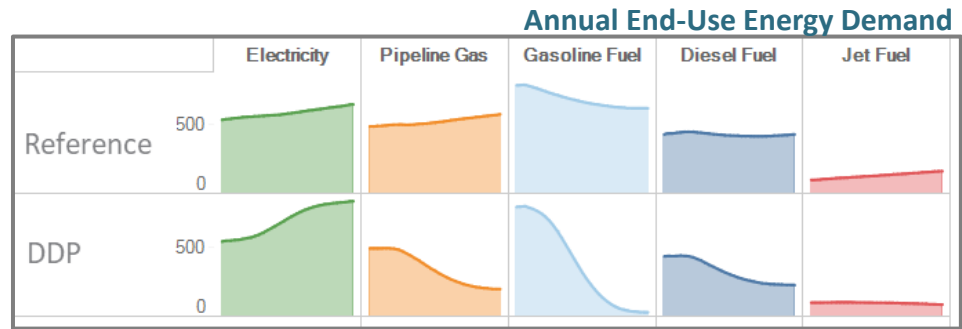
Pathways are a coherent framework for constructing narratives for a transition to a low-carbon energy system

# Partial equilibrium modeling framework

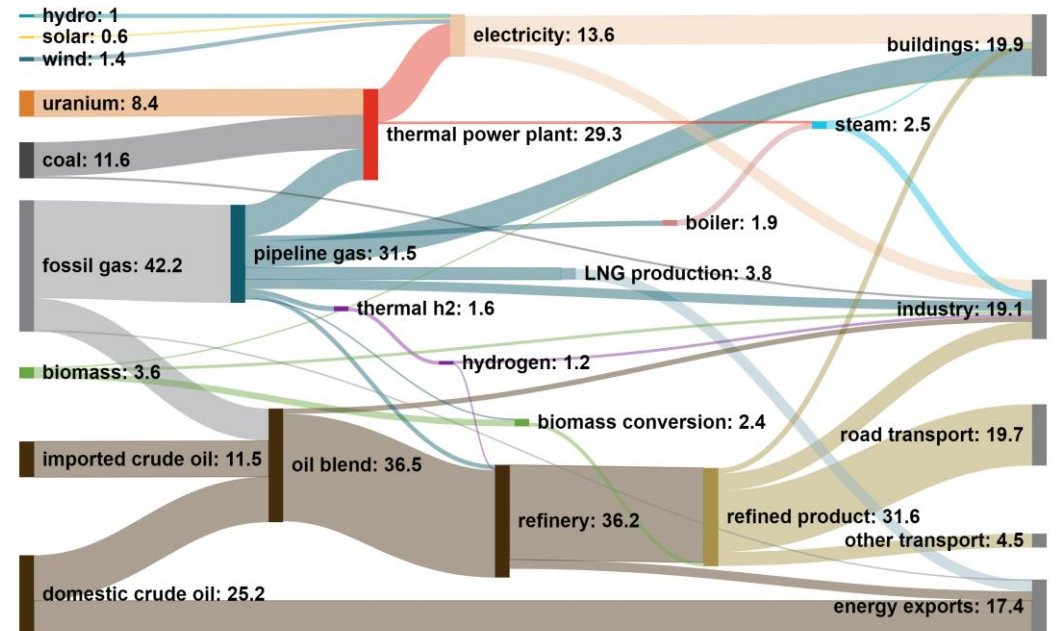
**EnergyPATHWAYS (EP)** is our demand-side stock-rollover accounting model that produces scenarios based on exogenous service-demand and sale shares



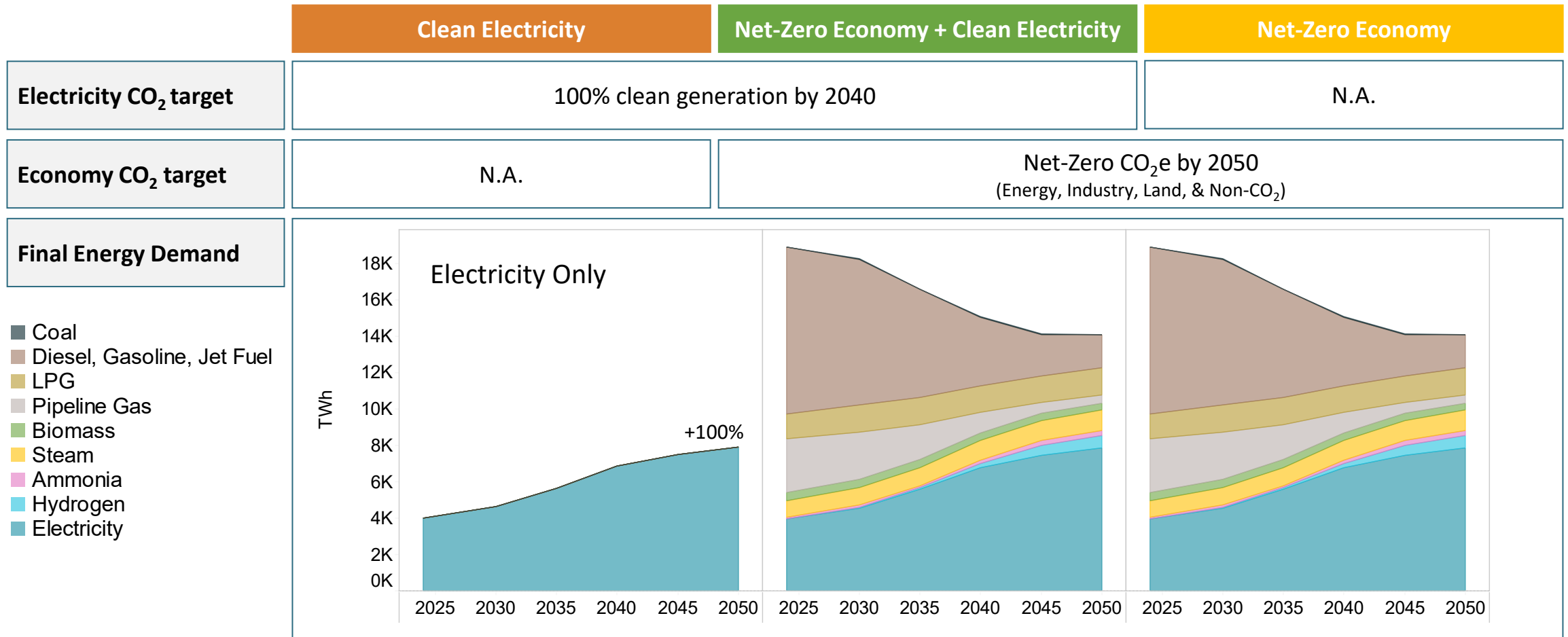
**RIO** is a supply-side macro-energy model that finds the lowest cost investment and operations plan with best-in-class temporal and spatial granularity



**2021 Energy System**



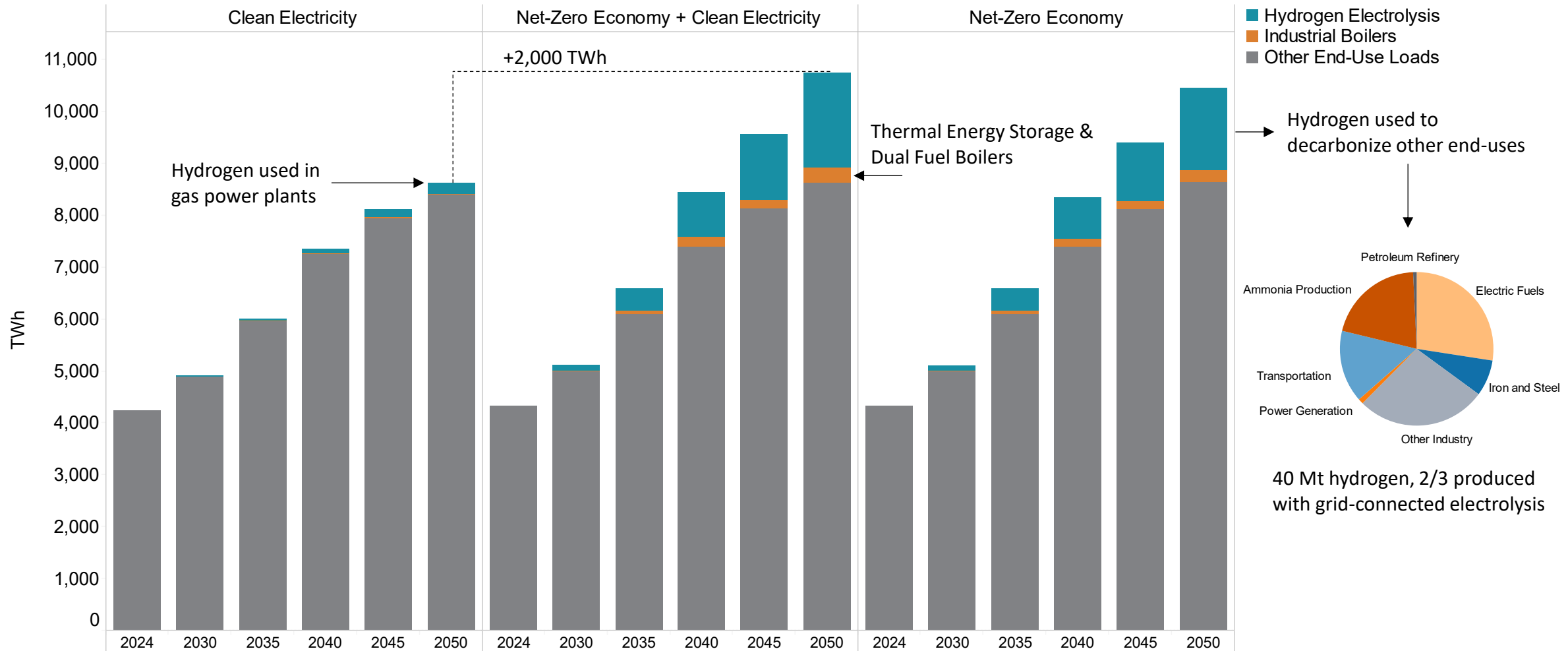
# Scenarios illustrating sector coupling



Note: Scenarios based on U.S. ADP 2024 funded by Breakthrough Energy

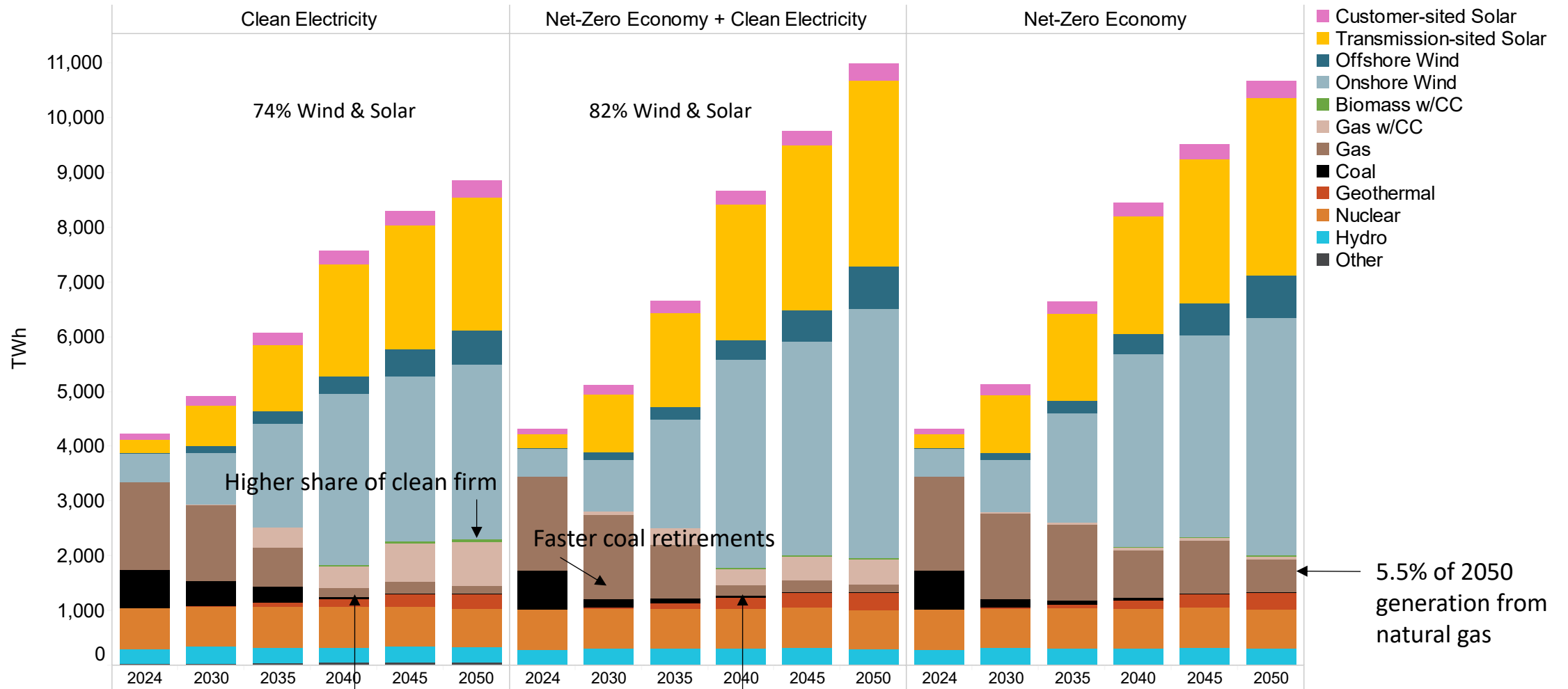
# Electricity load

## Sector coupling scenario results



# Electricity generation

## Sector coupling scenario results

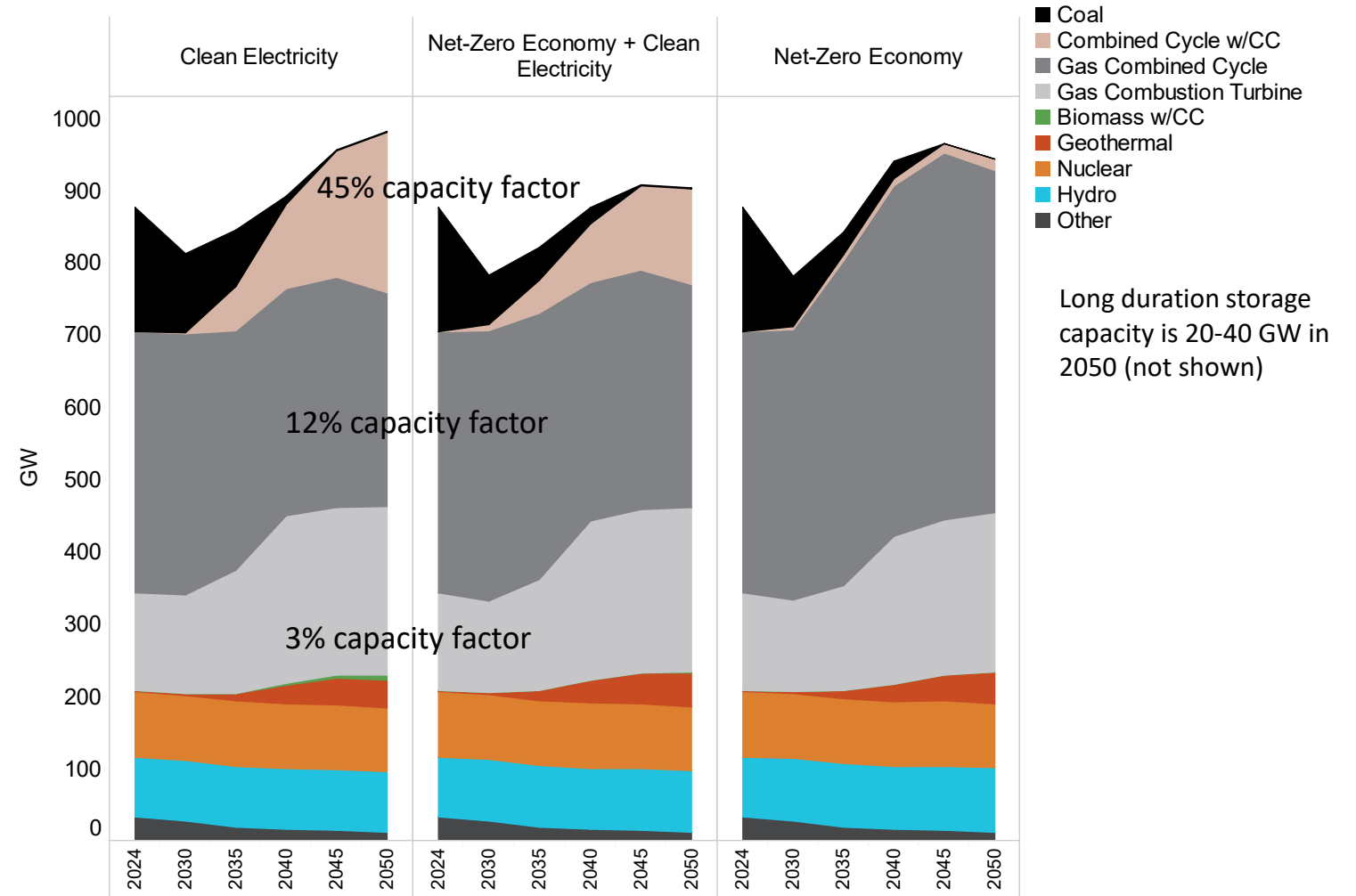


Carbon neutral fuels burned to meet clean electricity targets

# Firm Capacity

## Sector coupling scenario results

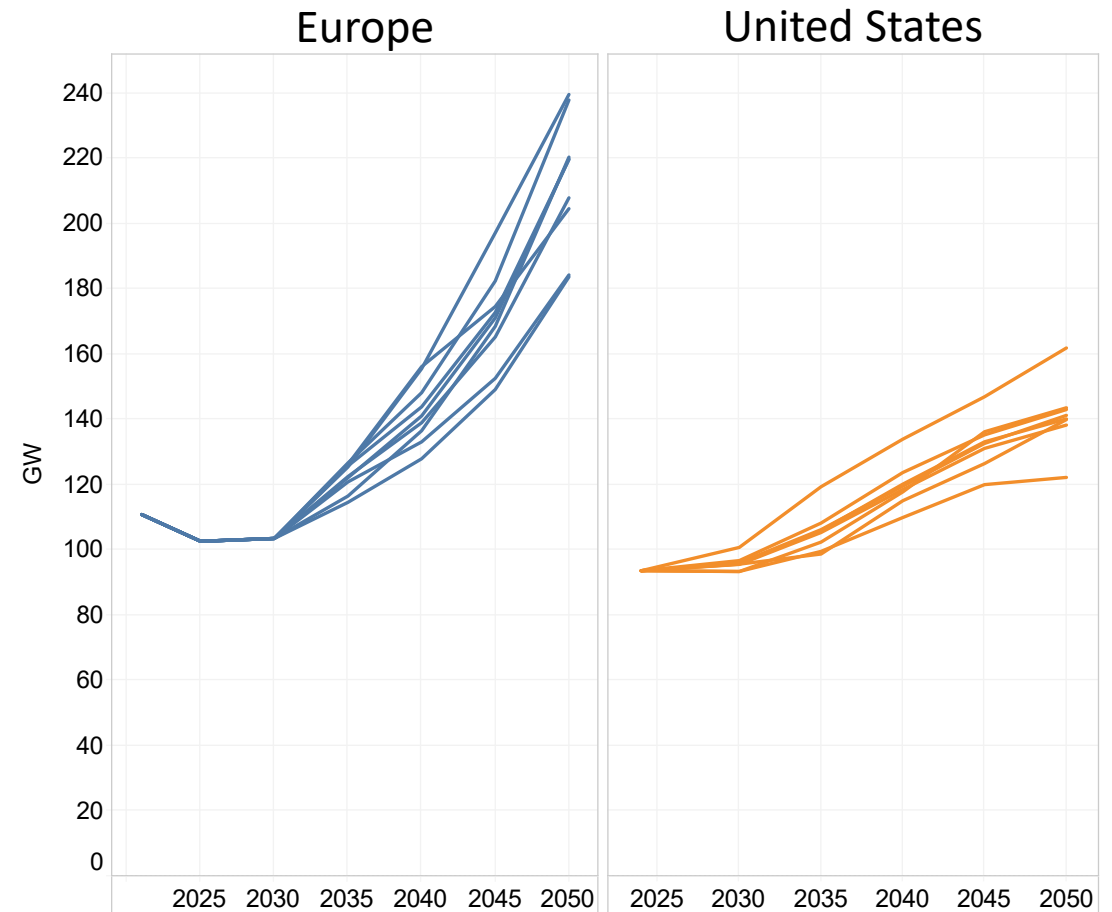
- Firm capacity requirements increase to 2050, but decrease as a % of peak load
- Most capacity is provided by gas operating as peakers
- A mandate to retire all gas without carbon capture increases present value cost by \$300B
- Fuel substitution instead of new infrastructure reduces cost dramatically and increases planning flexibility



# A larger increase in clean firm is likely needed in Europe

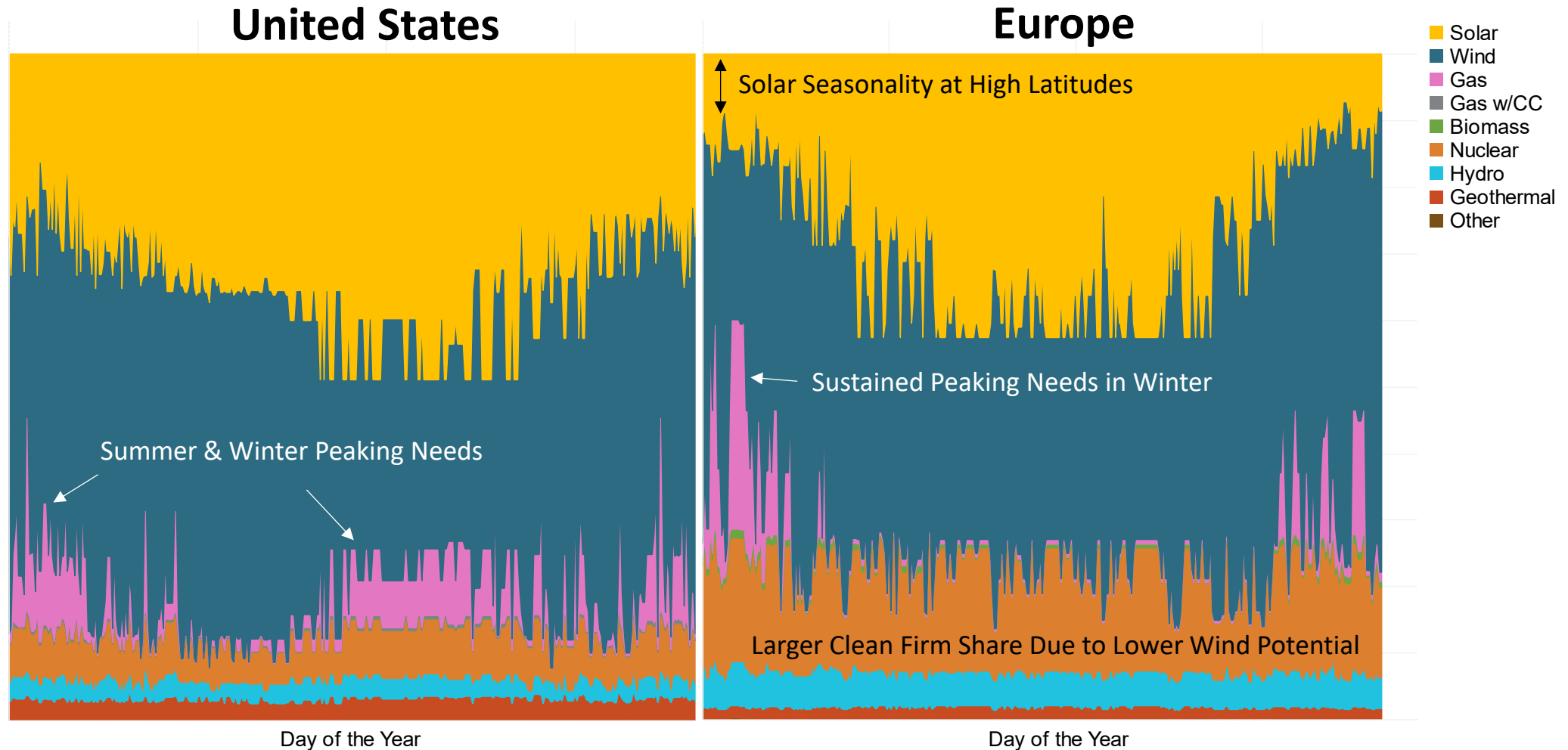
- Lower renewable resource quality in Europe result in a shortage of energy (not just capacity)
  - Typical net-zero scenarios result in half the onshore wind that gets modeled in U.S. scenarios
- Europe exhibits greater seasonality in renewable electricity production with winter Dunkelflauta corresponding to periods of high load (next slide)

Capacity For Nuclear, Gas w/CC, and Geothermal



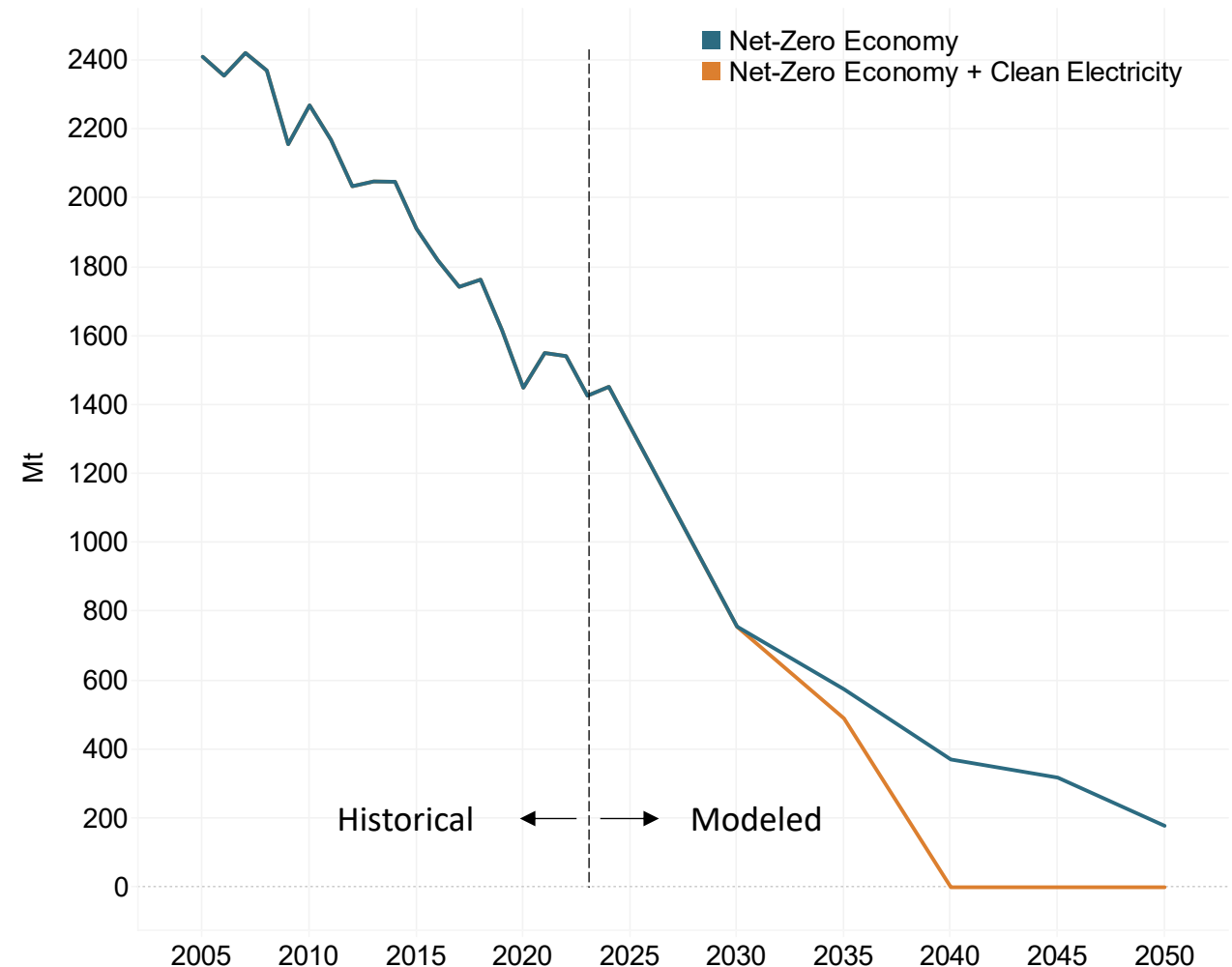
# Seasonality in Renewables - U.S. vs. Europe

## 2050 Net-Zero Daily Electricity Generation Comparison



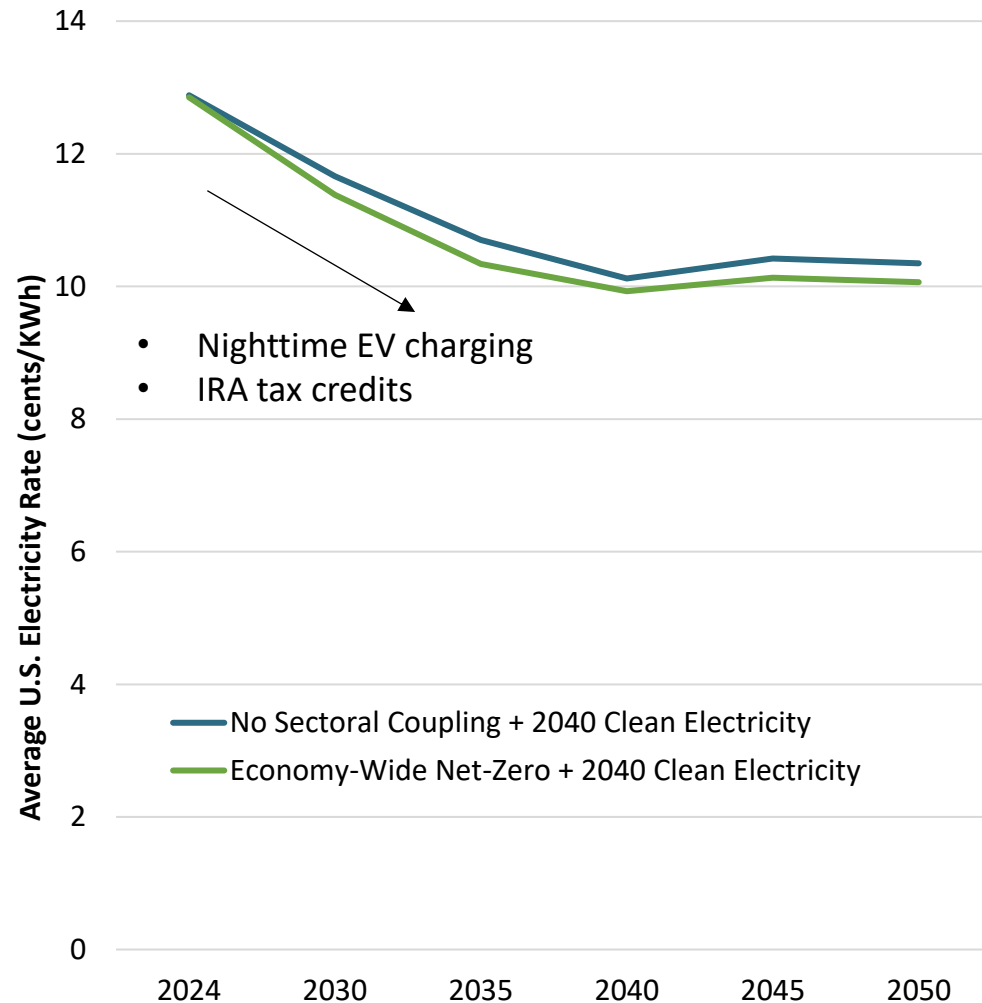
# Electricity CO<sub>2</sub> Emissions Sector coupling scenario results

- U.S. electricity emissions reductions of 90%+ is consistent with economy-wide net-zero
- The last 5-10% is the most expensive to eliminate and increased scenario present value cost by \$130B in the modeled example
- Economy-wide emissions balance changes very little when enforcing 100% clean electricity
- More sequestration is used in power instead of other places; More clean fuels are allocated to power instead of transportation



# Average Electricity Rates

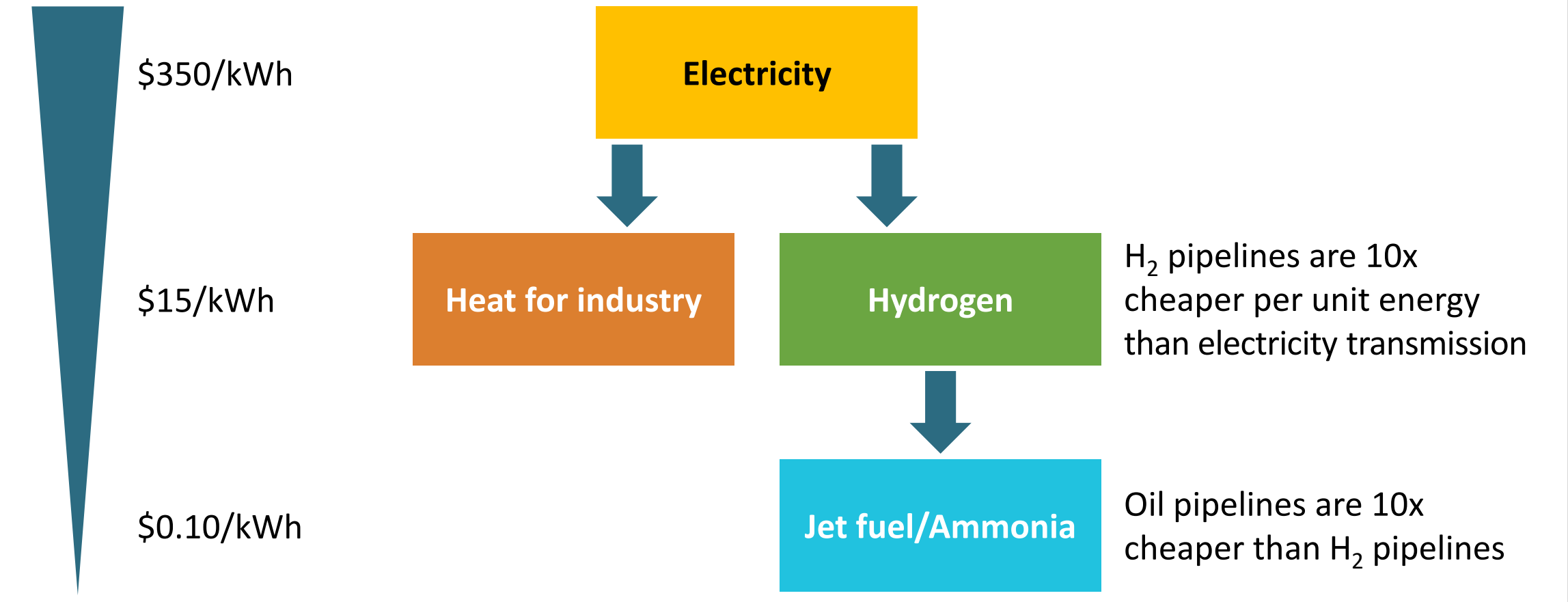
## Sector coupling scenario results



- Sectoral coupling reduces rates for electricity customers
  - Higher percent of delivered renewables and better load factors due to responsive load
- Sectoral coupling also makes clean fuels cheaper and reduces overall land-use
  - Reduces demand for biomass and results in less geologic sequestration

# Sectoral coupling and energy storage cost

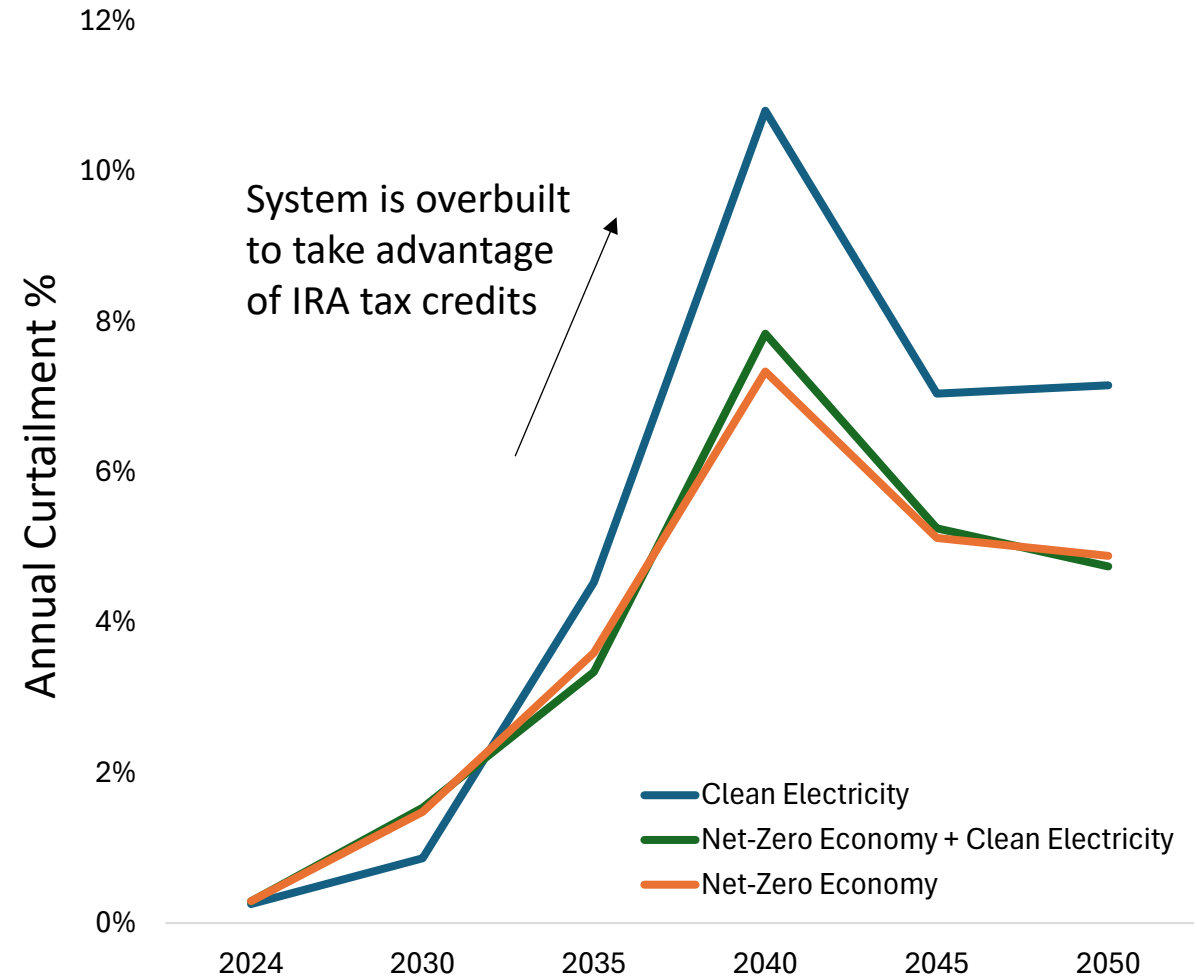
## Storage Capital Cost



# Renewable Curtailment

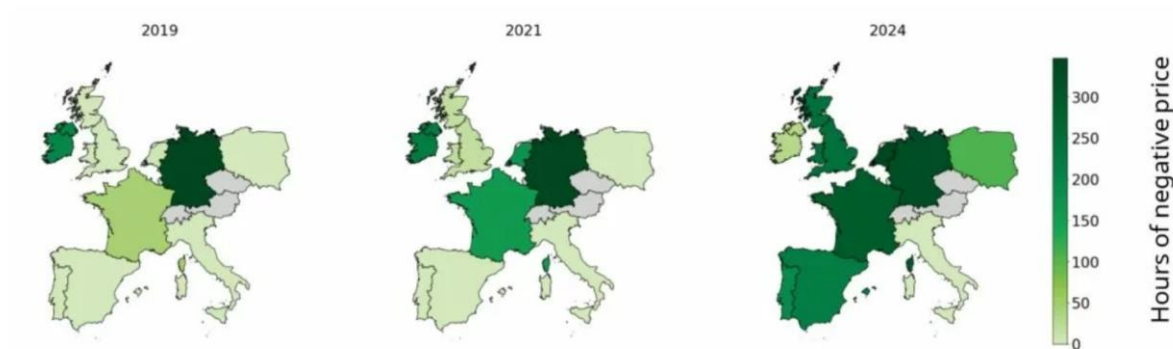
## Sector coupling scenario results

- 2050 curtailment of 5% with sectoral coupling vs. 8% without sectoral coupling
- Curtailment shown here is an underestimate because local transmission constraints are ignored



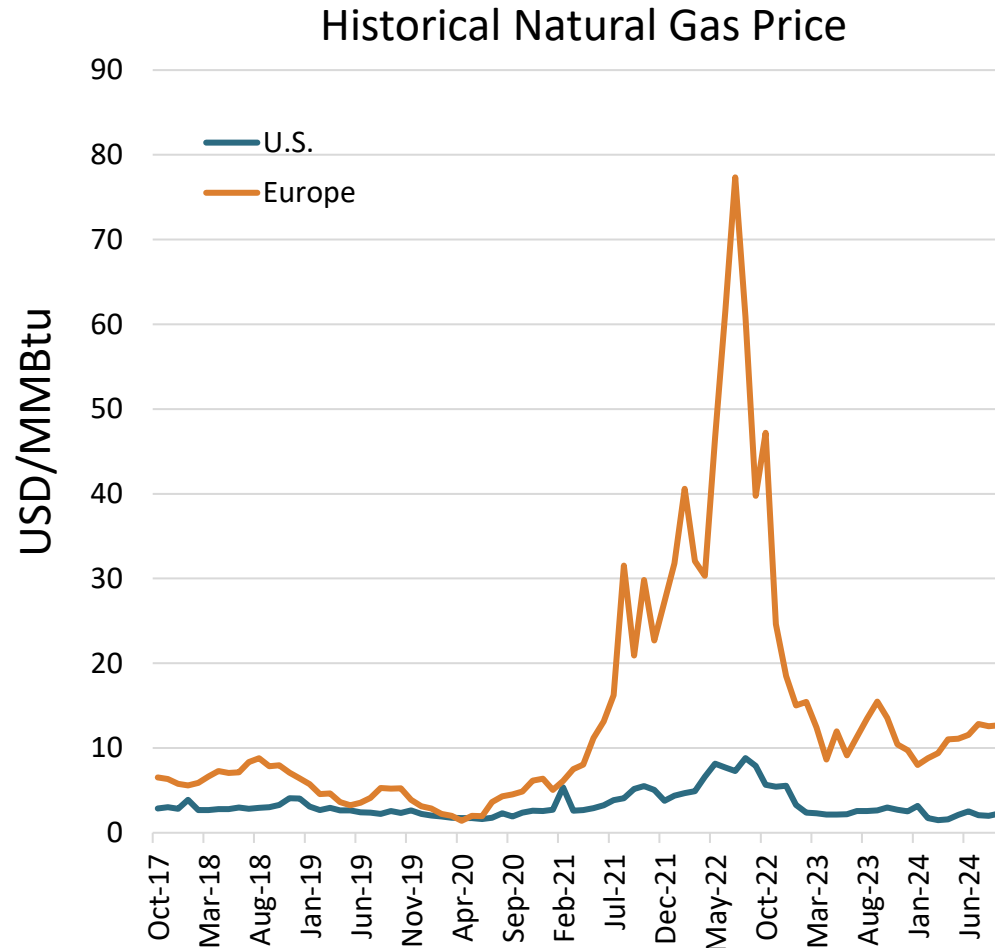
# Recent increases in negative market prices in Europe presage the same for the U.S.

- Like the U.S., Europe is having difficulty building wind quickly, but solar is being built at a record pace
  - Solar capacity in Europe has doubled since 2020
- Negative prices have increased dramatically in 2024 across Europe
  - IRA tax credits will drive negative prices in the U.S. just like feed-in-tariffs have done in Europe
- Near-term needs for balancing solutions on both continents highlights **opportunities for sectoral coupling**



Source: Nordpool, EPEX, SEMOpx

# Higher European gas prices motivate sectoral coupling



- Electrification of heat and the use of thermal storage is incentivized in Europe by higher gas prices
  - Large district heating systems add increased sectoral coupling opportunities
  - Power to gas and direct use of hydrogen are both more competitive
- High gas prices mean that gas with carbon capture is uncompetitive in Europe
- High gas prices have encouraged a boom in solar capacity

# Key technologies when modeling 100% clean

1

Low capital cost (\$/kW) hydrogen and heat technologies with deep markets and (High willingness to pay in economy-wide scenarios)

2

The use of clean fuels in **existing** thermal powerplants with minimal new capital investment

3

Pairing thermal storage with clean-firm technologies to improve the economics of high capital cost assets (Nuclear, geothermal, CCS)

500 MW Nuclear  
Reactor  
95% Capacity Factor



20 GWh Thermal  
Storage



1000 MW Steam  
Turbine  
40% Capacity Factor

**Expensive! Must have  
high utilization**

**Low capital cost and can  
operate when needed**

# Summary: What does electricity only miss?

## Electricity Only Overestimates:

- The importance of getting to 100% clean
- The cost of getting to 100% clean
- Electricity energy storage (The best storage is the storage you don't need to build)
- The annual capacity factor for thermal assets
- Renewable curtailment

## Electricity Only Underestimates:

- The % of electricity that can be supplied with wind and solar
- New MWs of renewables & MW-miles of transmission
- Competition for biomass & sequestration storage capacity
- The importance of market reforms for load-participation

# THANK YOU

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