Powering Decarbonization

Strategies to Achieve Net-Zero Emissions in the Electric Sector and Beyond

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Preliminary results. Do not cite or quote.

EPRI Analysis: Key Net-Zero Target Insights

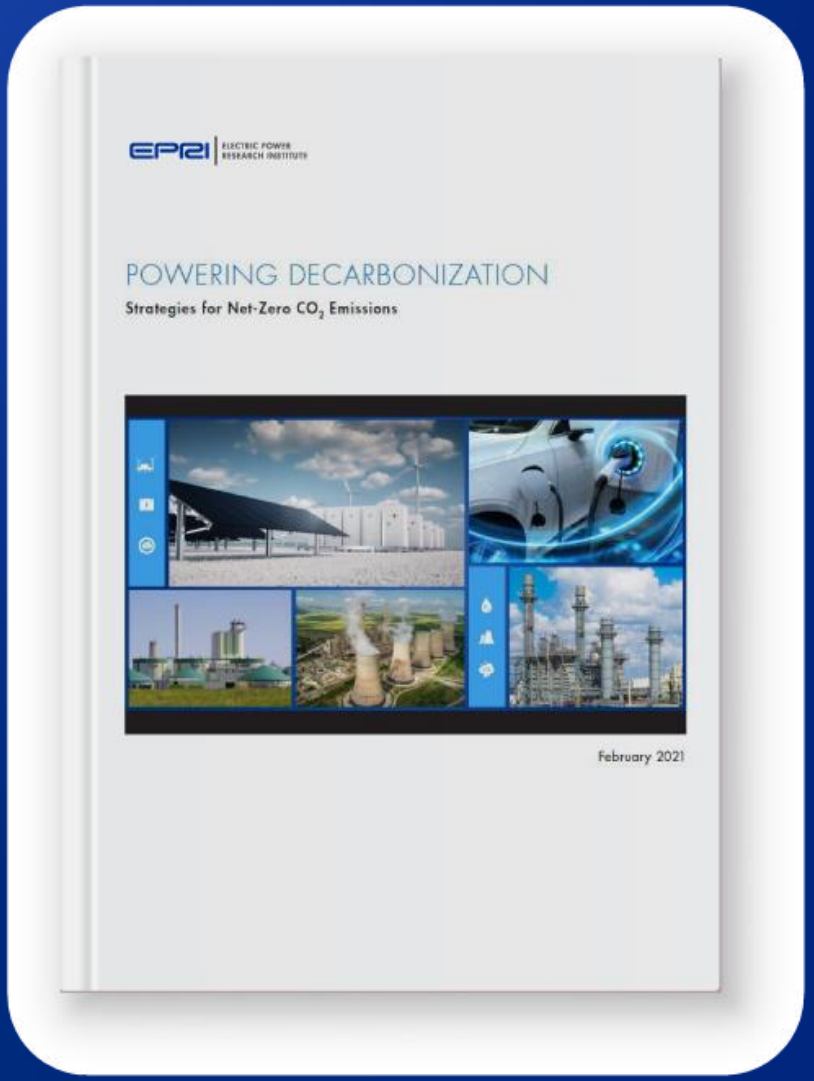
- Zero by 2035 for electric sector involves **rapid transformation**
  - Reducing electric sector emissions up to ~80% below 2005 levels can be cost-effectively achieved with current technologies
  - Negative emissions technologies ("net-zero") are valuable for cost management and flexibility; much higher costs for "absolute-zero"
- **Renewables** projected to play a major role in all scenarios
  - Ensuring reliability: Grid modernization, electricity market redesign, low-carbon firm capacity, new transmission, new resource planning methods
- **Efficiency and electrification** are essential, drive cost reductions and emissions reductions in end-use sectors (many decision-makers)
- Low-carbon fuels (hydrogen, bioenergy) needed to reduce "last 20%" of economy-wide emissions → EPRI's LCRI report in July 2021

Powering Decarbonization

Strategies for Net-Zero CO_2 Emissions

White Paper Published: February 2021

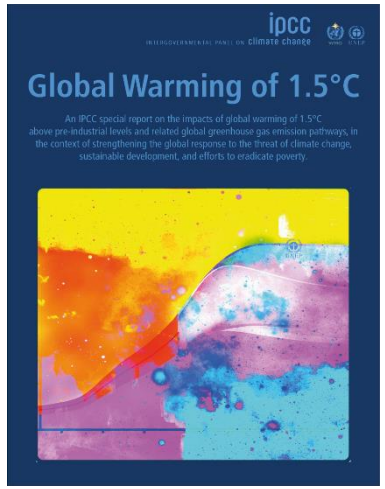
https://www.epri.com/research/products/3002020700
EPRI Report #3002020700



Net-Zero Emissions Targets and Role of the Power Sector

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

- "Net zero" in Article 4.1 of the Paris Agreement: "Parties aim to [...] achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century"



- IPCC Special Report on Global Warming of 1.5 °C (SPM C.1): "In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions [...] reach net zero around 2050"

Clean electricity is the keystone of the energy transition

Questions: Exploring the Economics of Net-Zero Targets

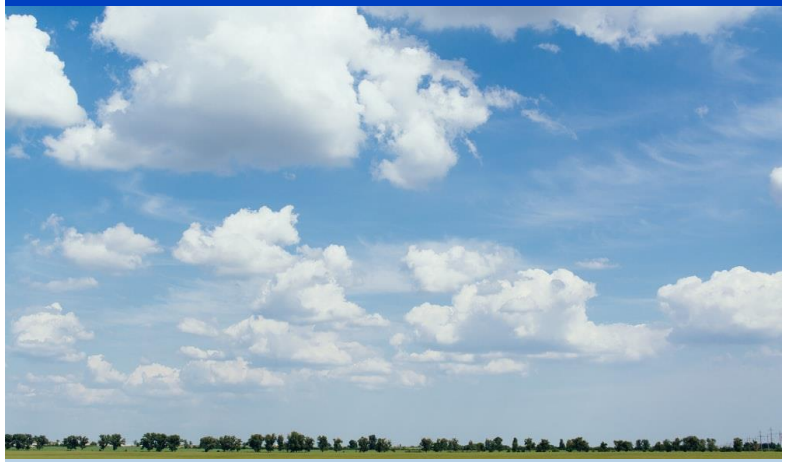
Company CO_2 Pledges and Policy Drivers

- Company pledges and state/federal policies toward (net) zero CO_2 (e.g., Biden plan for 100% clean by 2035)
- Q: How can these net-zero goals be reached?

Defining "Net Zero"

- Many definitions with impacts on the roles and value of different technologies
- Q: What does "net zero" mean, and what are the implications of alternatives?

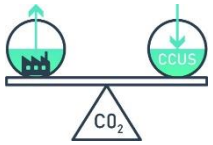
CO_2 Removal Technologies



- Discussions of technologies like bioenergy with carbon capture and direct air capture
- Q: How might the availability of CDR options impact electric sector decarbonization?

Scenarios: What Does a "Zero" Target Mean for Electric Sector?

NET-ZERO



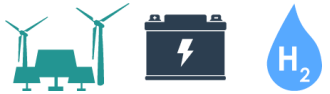
Net carbon emissions equal zero. Any emissions produced from operations are balanced by an equivalent amount of carbon removal or offsets.

CARBON-FREE

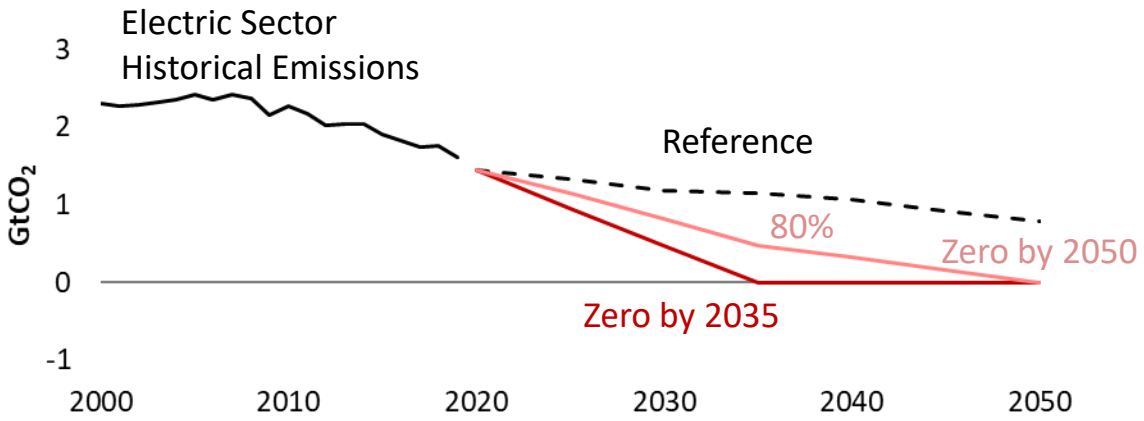
Electricity generation either does not use fossil fuels or does not emit carbon.

100% RENEWABLES

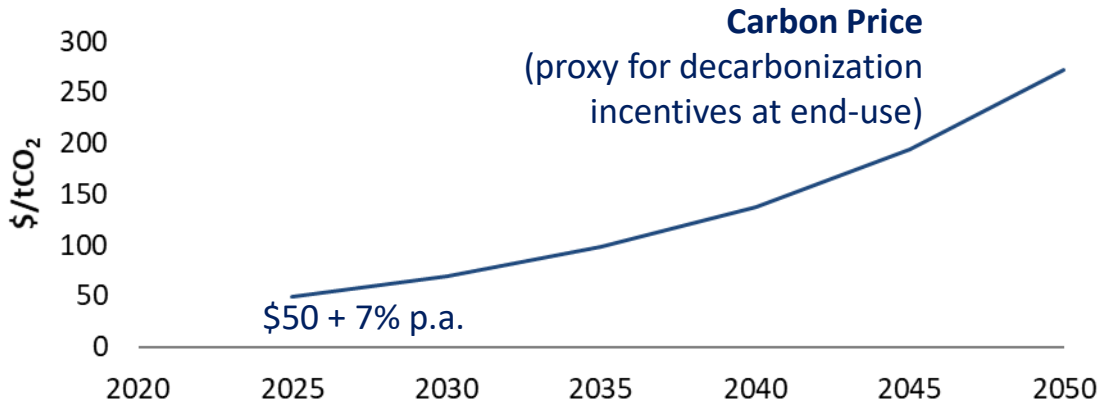
100% of electricity generated from renewable sources such as wind, solar, and hydro.



TARGET TIMING



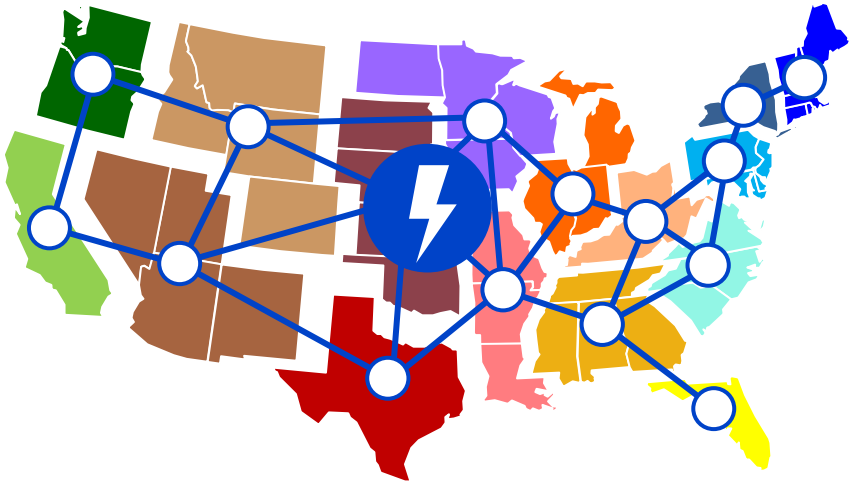
NON-ELECTRIC SECTORS



US-REGEN

Regional Economy, GHG, and Energy

Electric Generation



Detailed representation of:

- Energy and capacity requirements
- Renewable integration, transmission, storage
- State-level policies and constraints

Synchronized

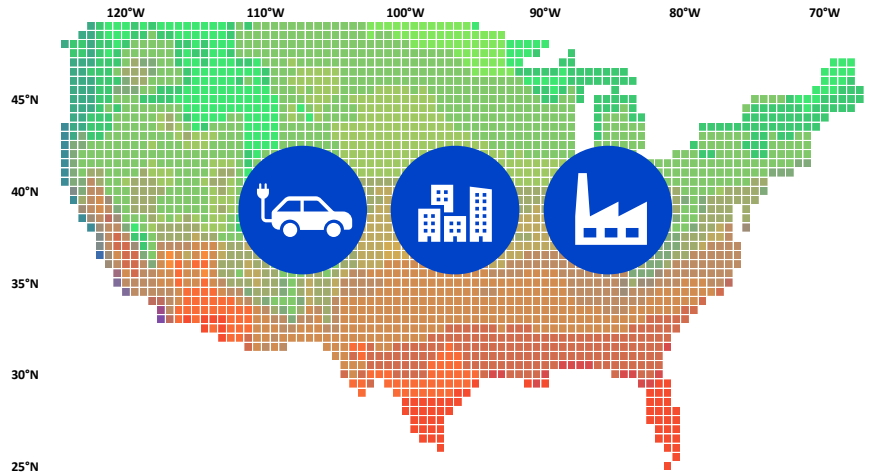
Hourly Load, Renewables, and Prices

Model Outputs:

Economic equilibrium for generation, capacity, and end-use mix

Emissions, air quality, and water

Energy Use



Detailed representation of:

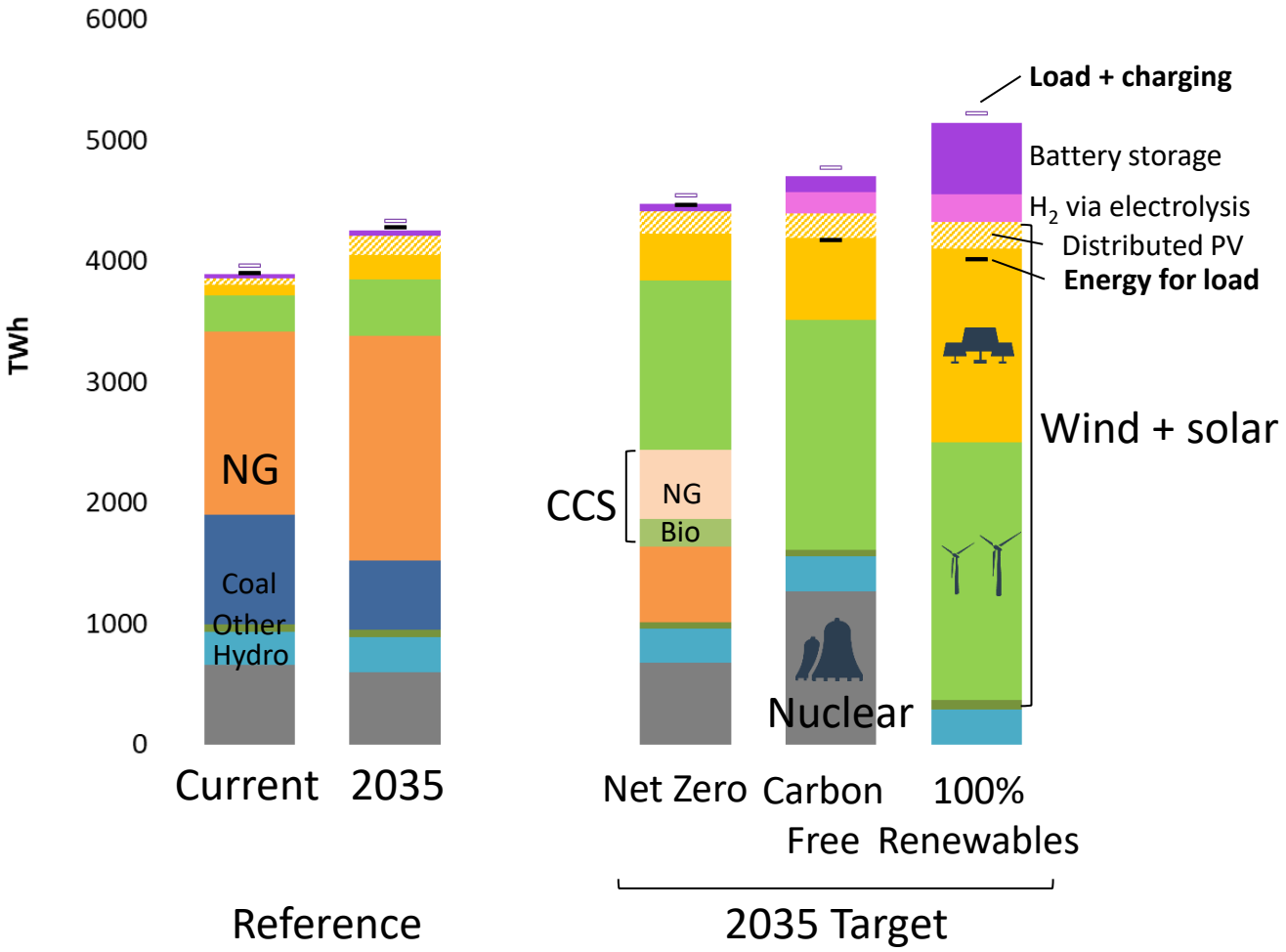
- Customer heterogeneity across end-use sectors
- End-use technology trade-offs
- Electrification and efficiency opportunities

Documentation, articles, and reports available at https://esca.epri.com

Electric Sector Decarbonization

Target Definition Impacts Technology Mix

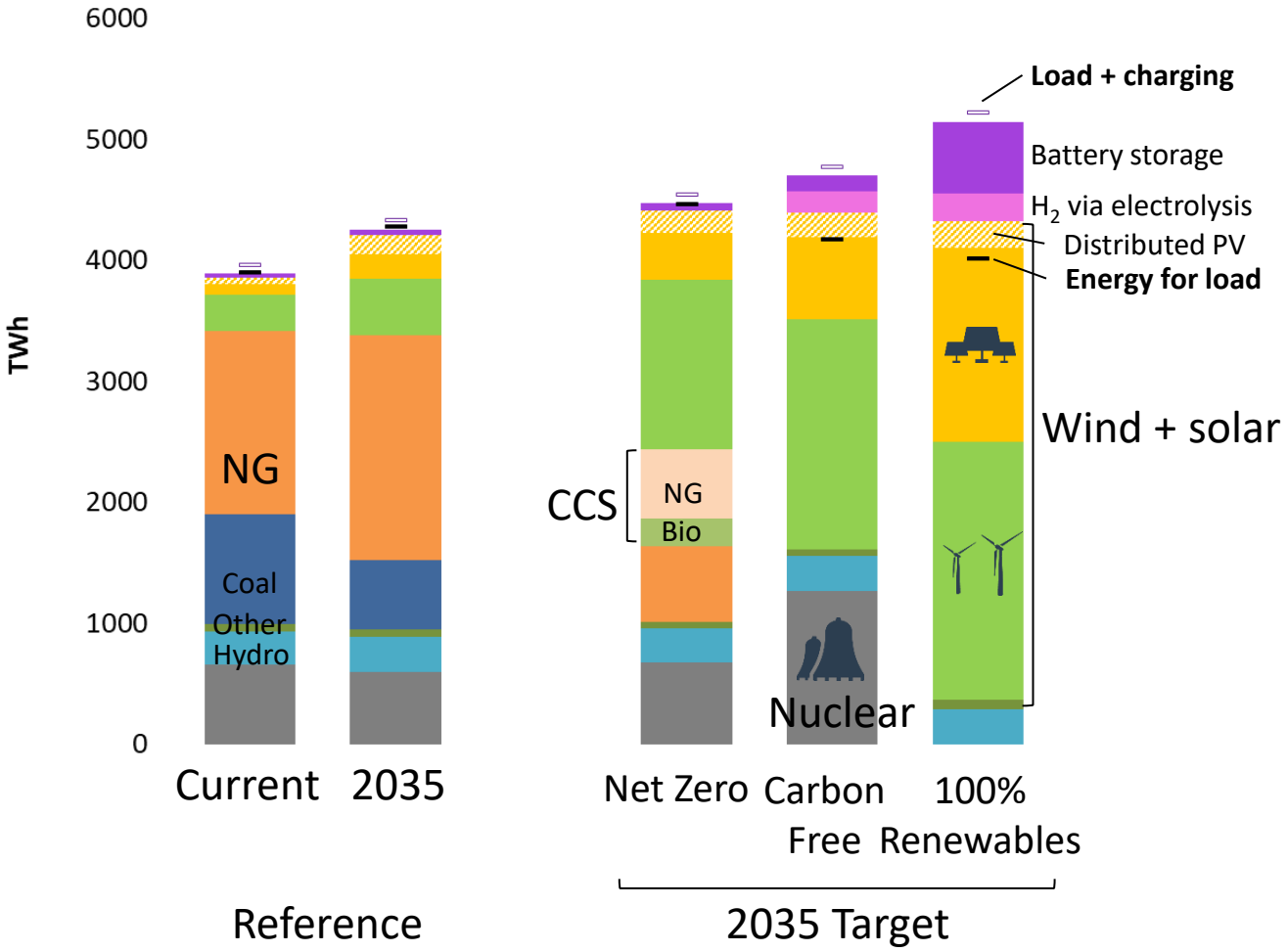
2035 U.S. Generation Mix with Zero Emissions Target



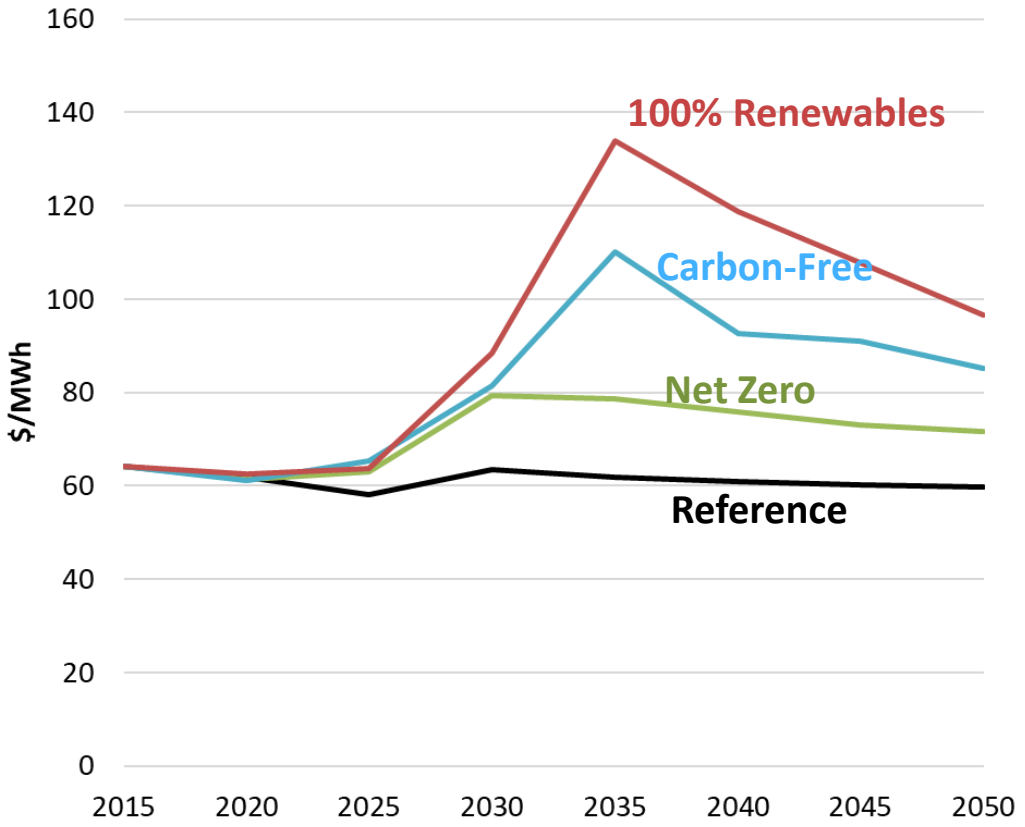
- **Net Zero**: Negative emission technologies and CCUS enable fossil fuels to supplement nuclear and hydro, balancing the variability of solar and wind.
- **Carbon Free**: Rapid build of nuclear and storage (H_2 and battery) to balance larger solar and wind expansion.
- **100% Renewables**: Increased H_2 utilization, much larger battery deployment to replace retiring nuclear and balance dramatic solar and wind expansion.
- Higher prices resulting from more restrictive target definitions discourage **electrification**, drive additional investments in **efficiency,** reducing **load**.

Target Definition Impacts Technology Mix and Costs

2035 U.S. Generation Mix with Zero Emissions Target



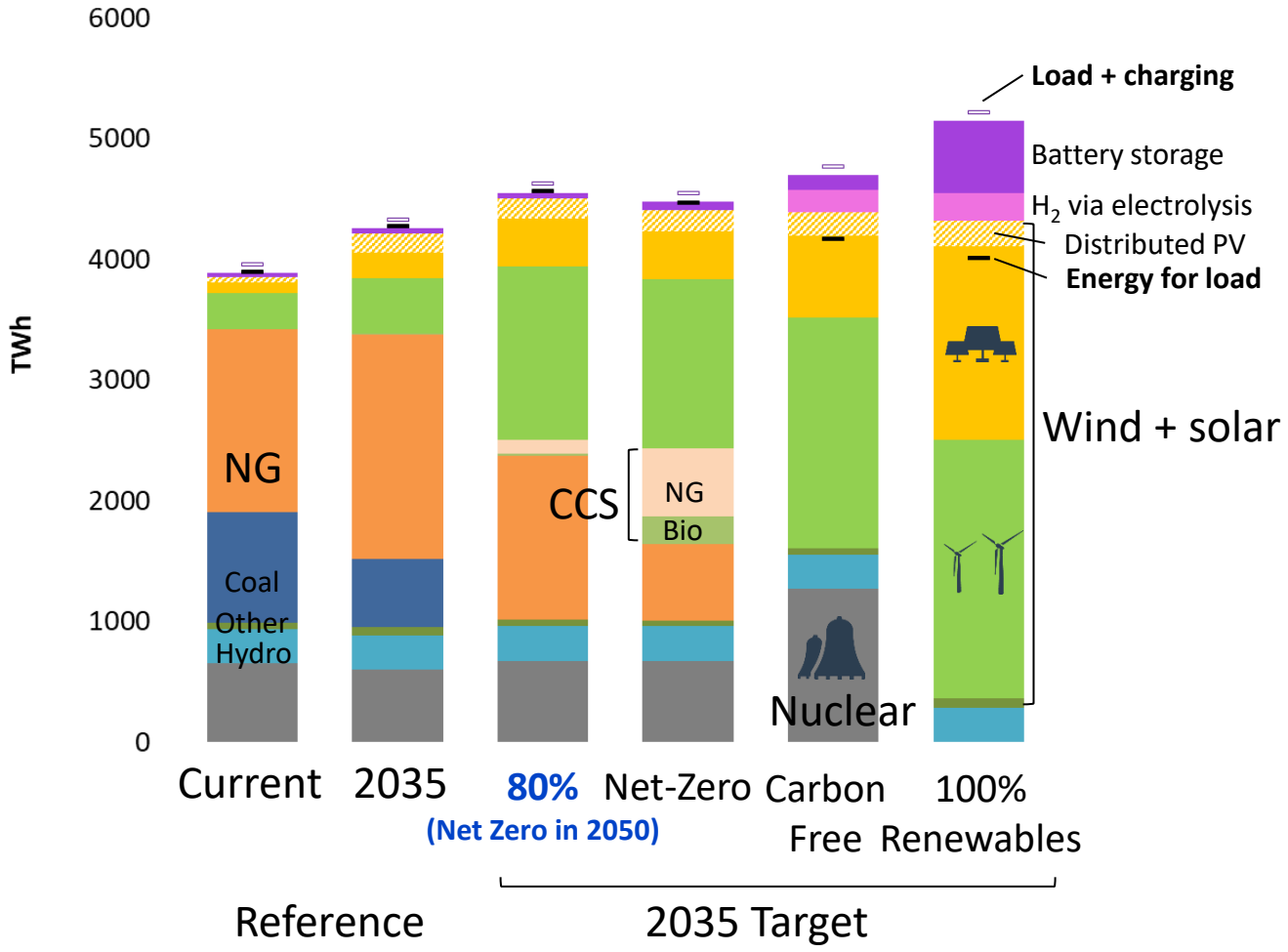
U.S. Average Generation Price



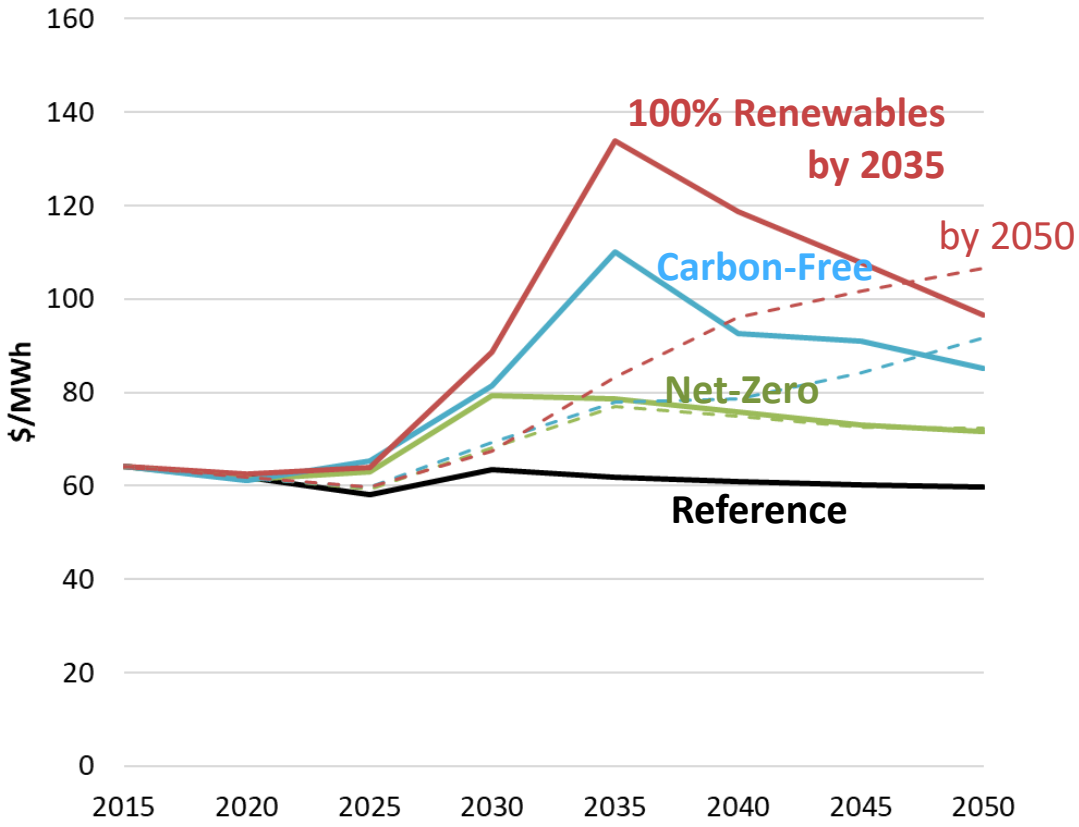
Restricting technology options significantly increases cost of electric sector decarbonization

Target Definition and Timing Impacts Technology Mix and Cost

2035 U.S. Generation Mix with Zero Emissions Target

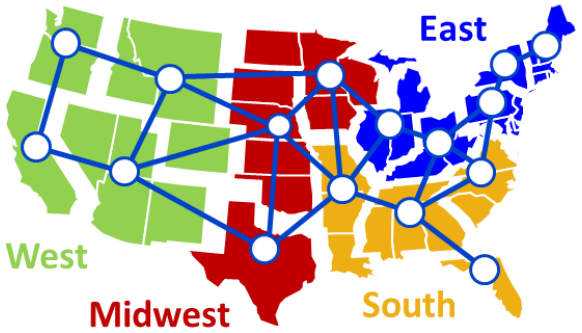


U.S. Average Generation Price

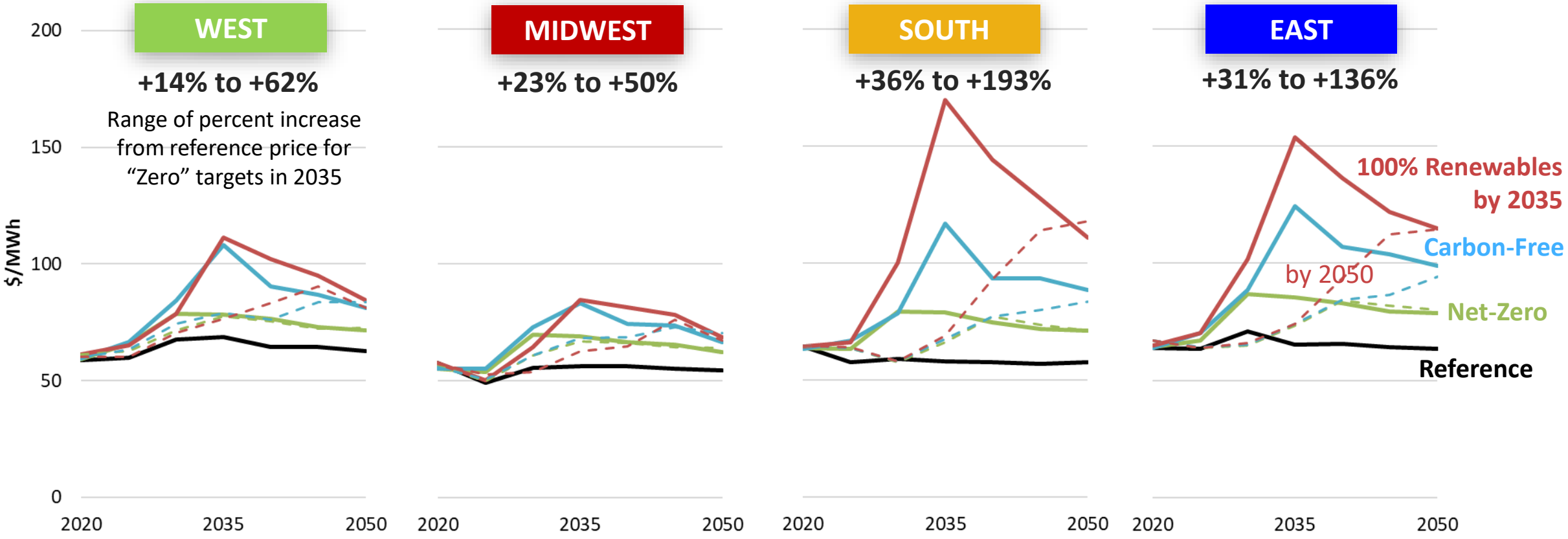


Delaying target allows more gradual introduction of new technology, avoids electricity price spike

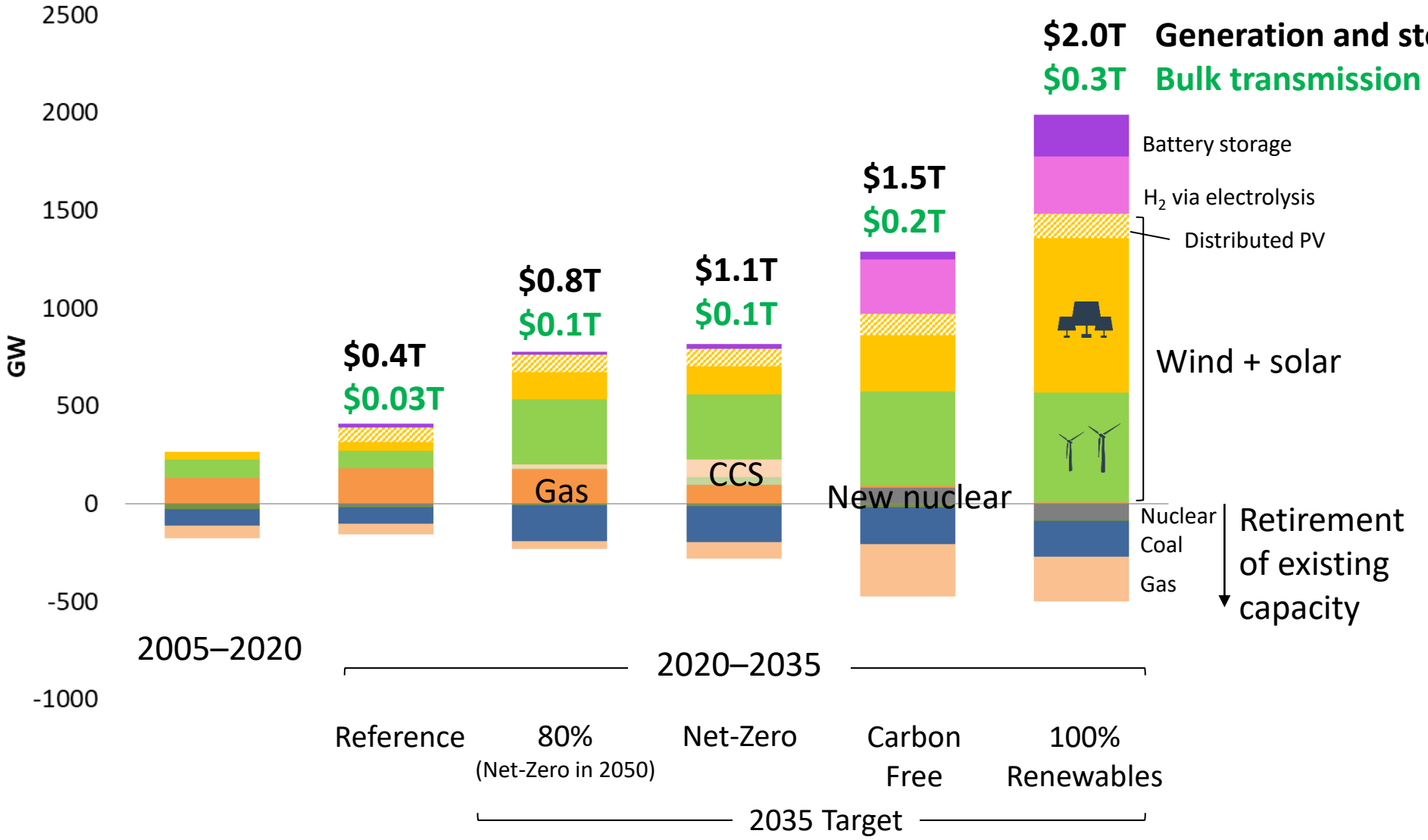
Regional Differences in Achieving "Zero" Targets



- **Net-Zero** less expensive in all regions
- **East** and **South** impacted by limited renewable resource availability (and constraints on transmission expansion)
- **Carbon-Free** similar to **100% Renewables** in **Midwest** and **West**



Cumulative Capacity Investments 2020–2035



Significant acceleration of investments in and dependence on **emerging technologies** in all zero target scenarios

Major Challenges

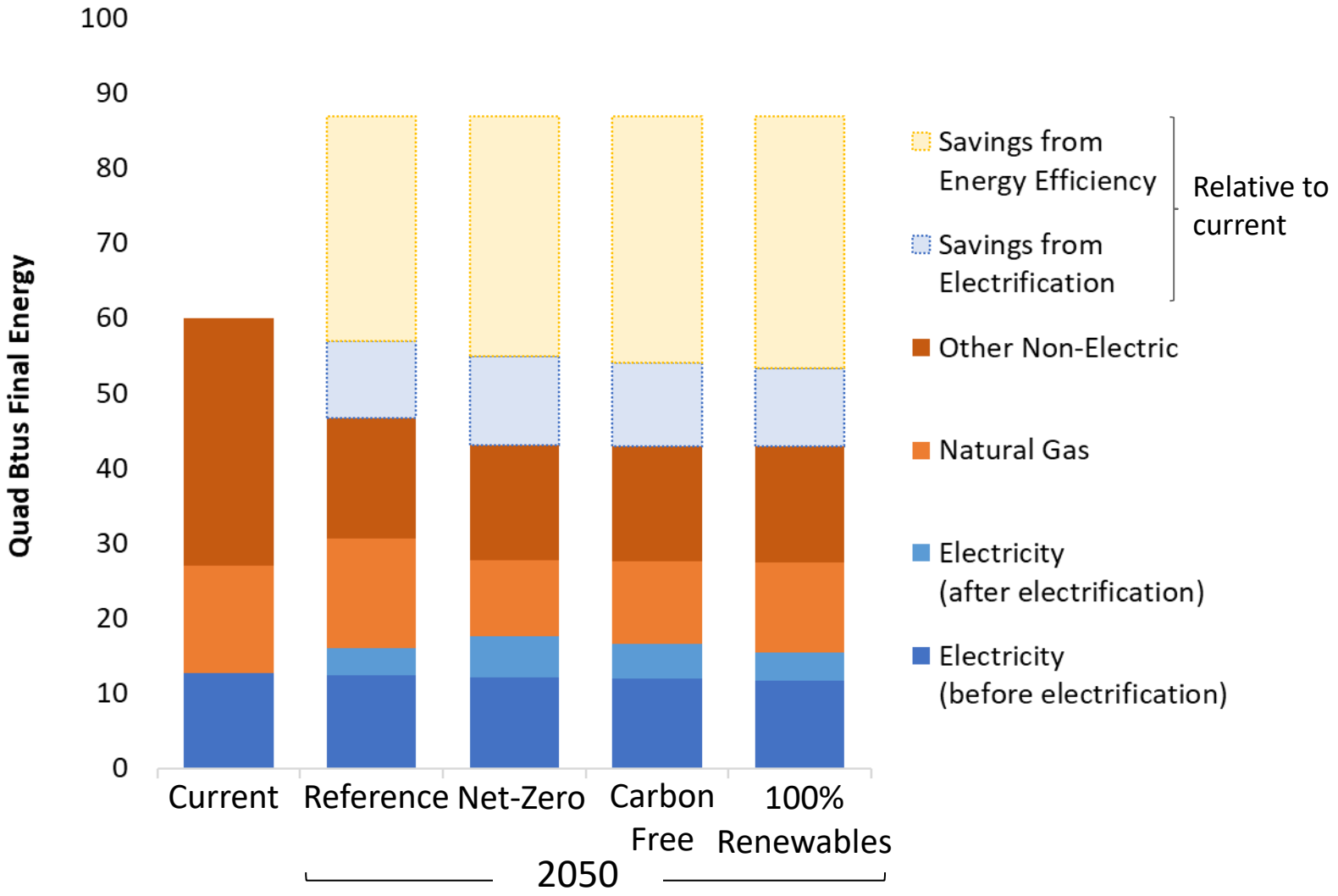
R&D | Siting | Permitting | Market Reform | Grid Modernization

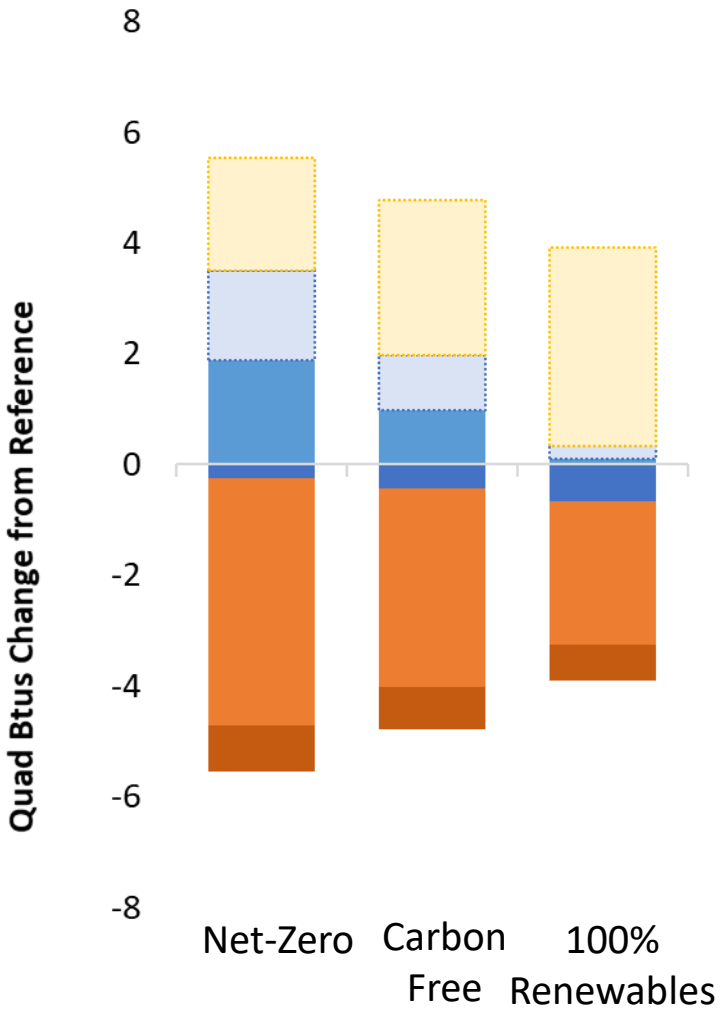
Observations: Electric Sector Decarbonization

- Near-term low regrets options: Retire coal; expand renewable capacity; maintain existing nuclear and gas capacity
- Many low-cost pathways to reach net zero; some are lower-cost than others → Target definitions and timing matter
  - Restricting technology options increases cost of electric sector decarbonization relative to a net-zero formulation, highlighting the value of modest carbon removal deployment
  - Targeting 80% by 2035 allows for more gradual introduction of new technology, avoids electricity price spike but with higher cumulative CO_2
- Wind/solar are likely at the center of least-cost decarbonized electricity systems; policy design and technological cost will impact regional shares but not likely to be 100% everywhere

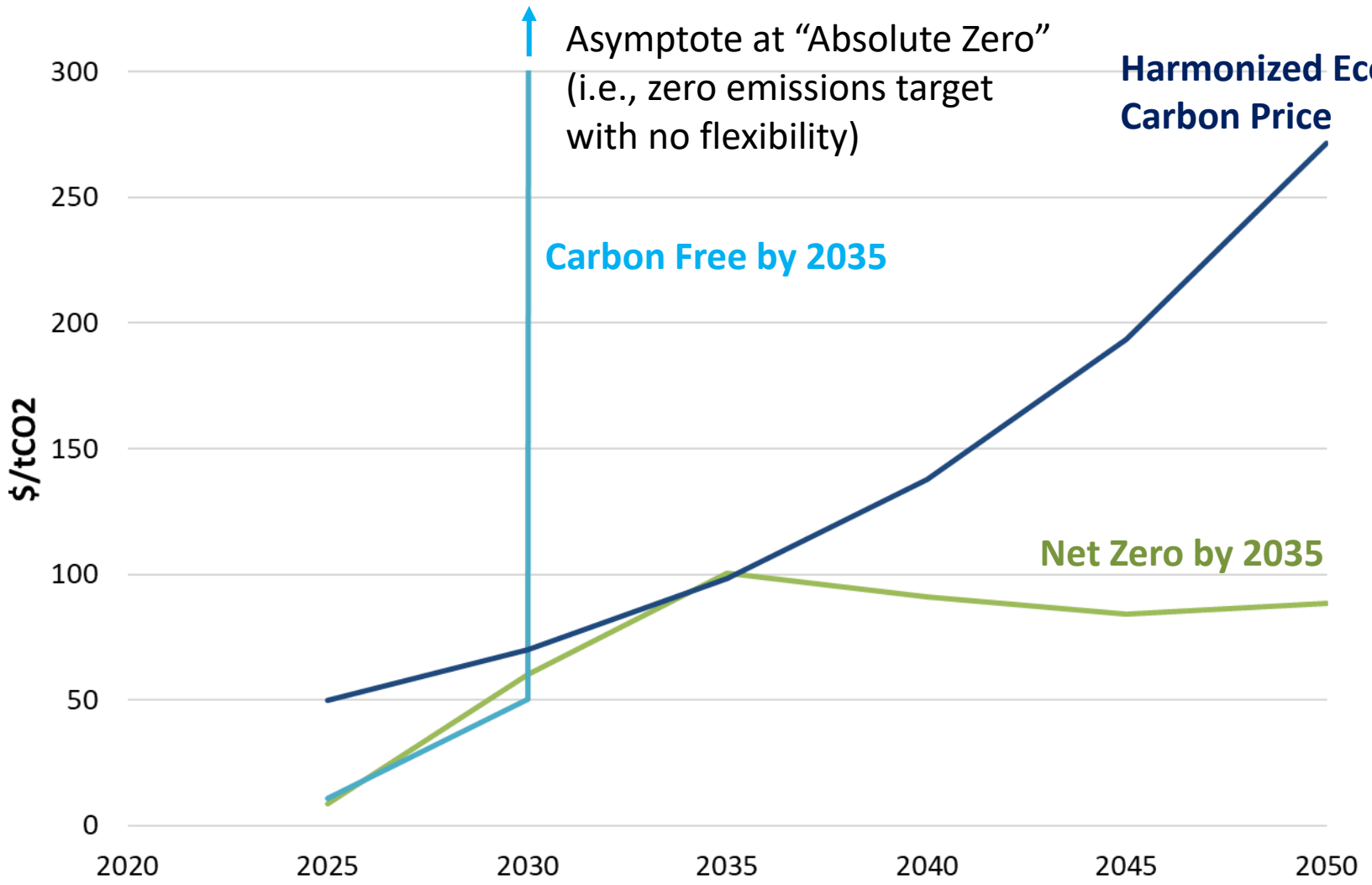
Economy-Wide Decarbonization

Efficiency and Electrification Drive Non-Electric Reductions





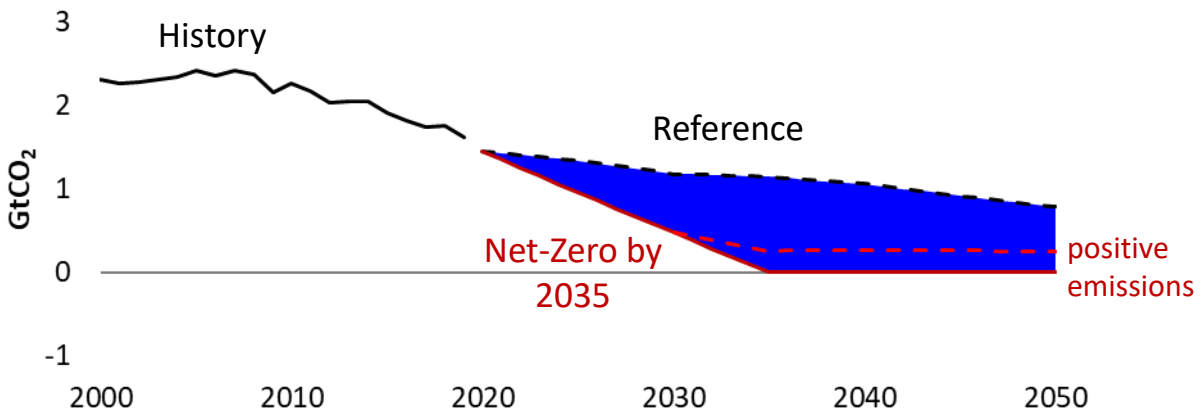
Carbon Price with Electric Sector Zero Targets



- In Carbon Free scenario (similarly in 100% Renewables case), marginal cost of reductions in electric sector is higher than the end-use sectors' price (after 2030)
- In Net Zero scenario, i.e. with negative emissions included, the electric sector's price is lower, hence the opportunity for net-negative emissions with a harmonized economy-wide price

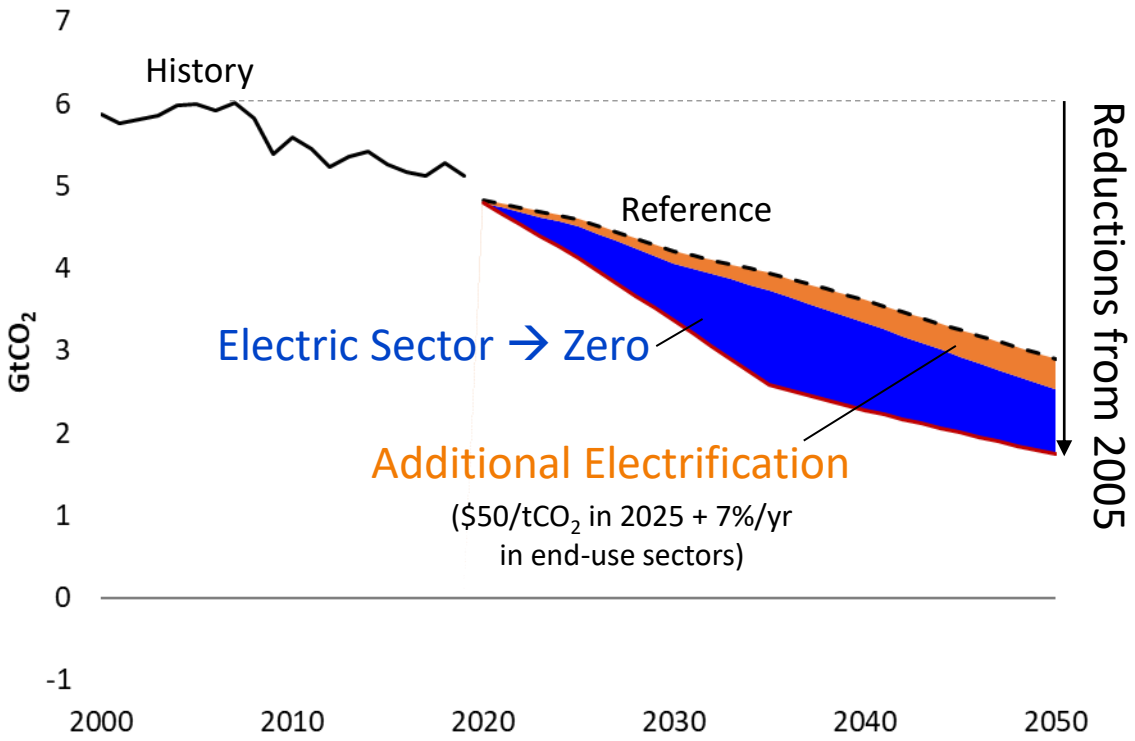
How Does Electric Sector Decarbonization Contribute?

Electric Sector CO_2 Emissions



Electric sector emissions are reduced to zero

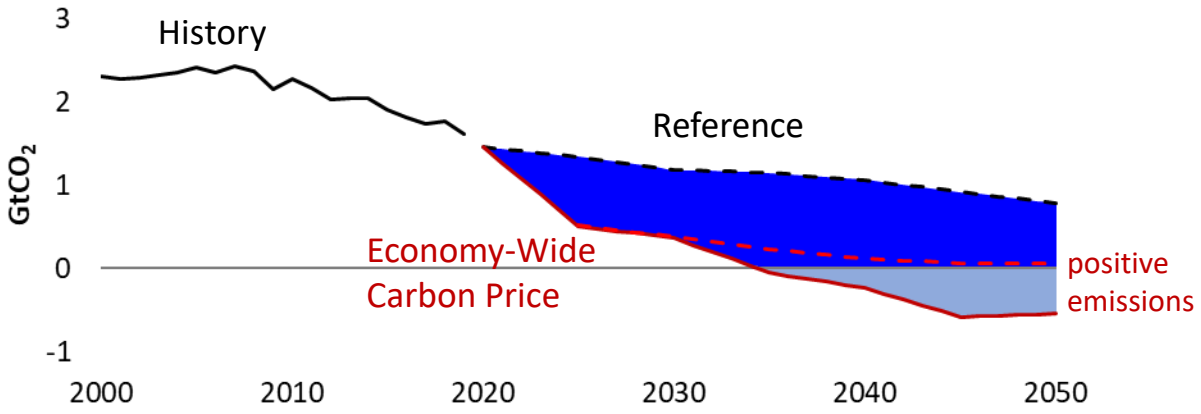
Economy-Wide CO_2 Emissions



Economy-wide emissions fall to ~70% below 2005 with electric sector decarbonization plus additional electrification from CO_2 price in end-use sectors

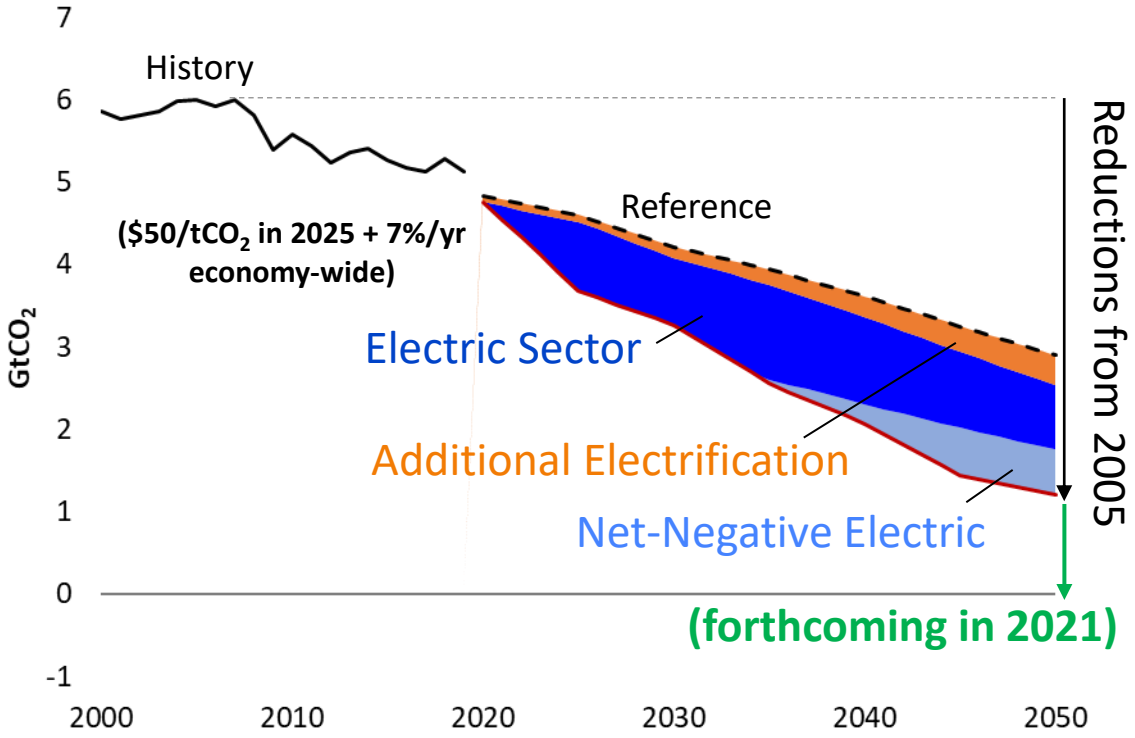
How Does Electric Sector Decarbonization Contribute?

Electric Sector CO_2 Emissions



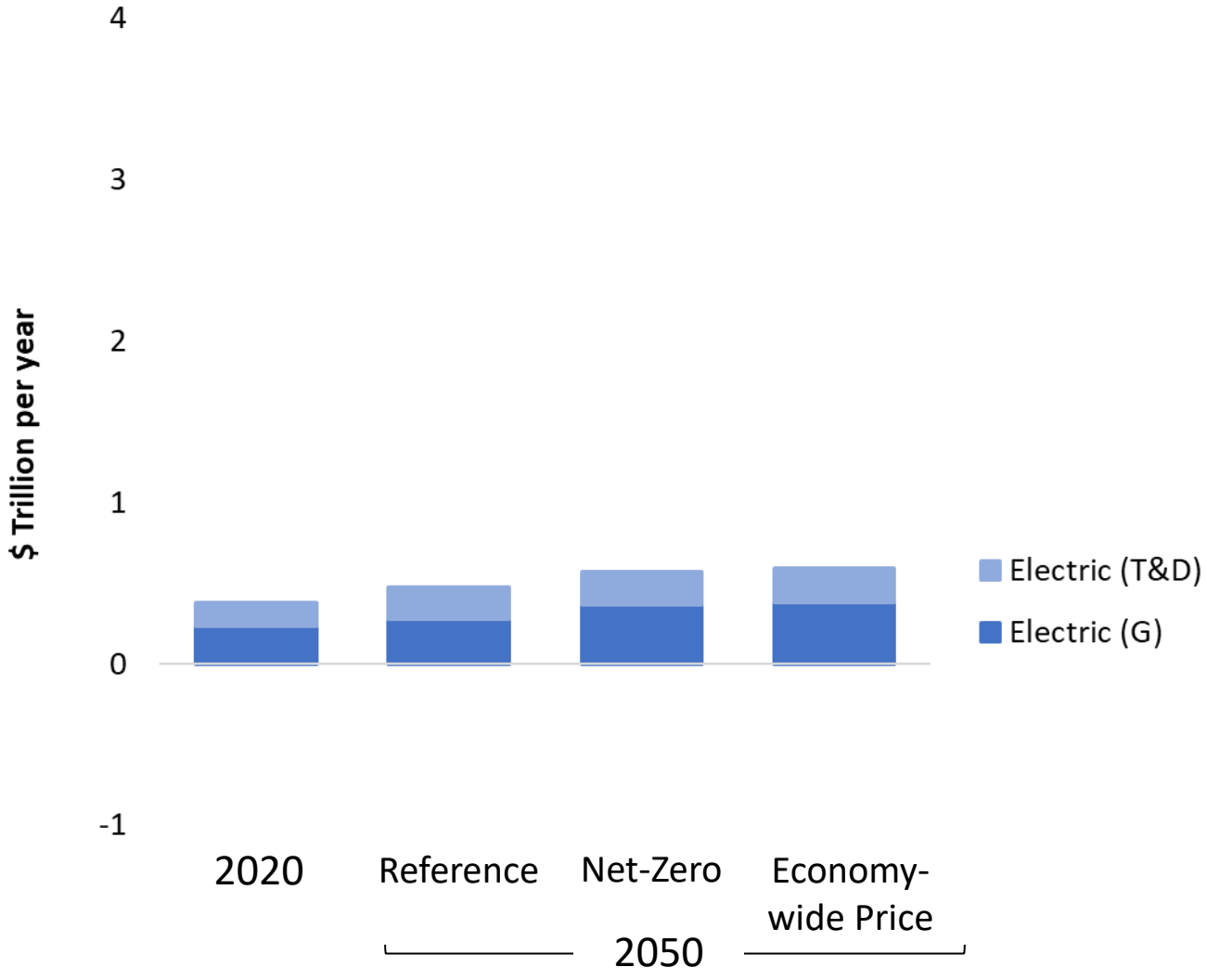
With a harmonized economy-wide carbon price, bio-CCS drives electric sector emissions **net-negative**

Economy-Wide CO_2 Emissions



Economy-wide emissions fall to 80% below 2005 with net-negative electric sector emissions

Total Expenditure on Electricity



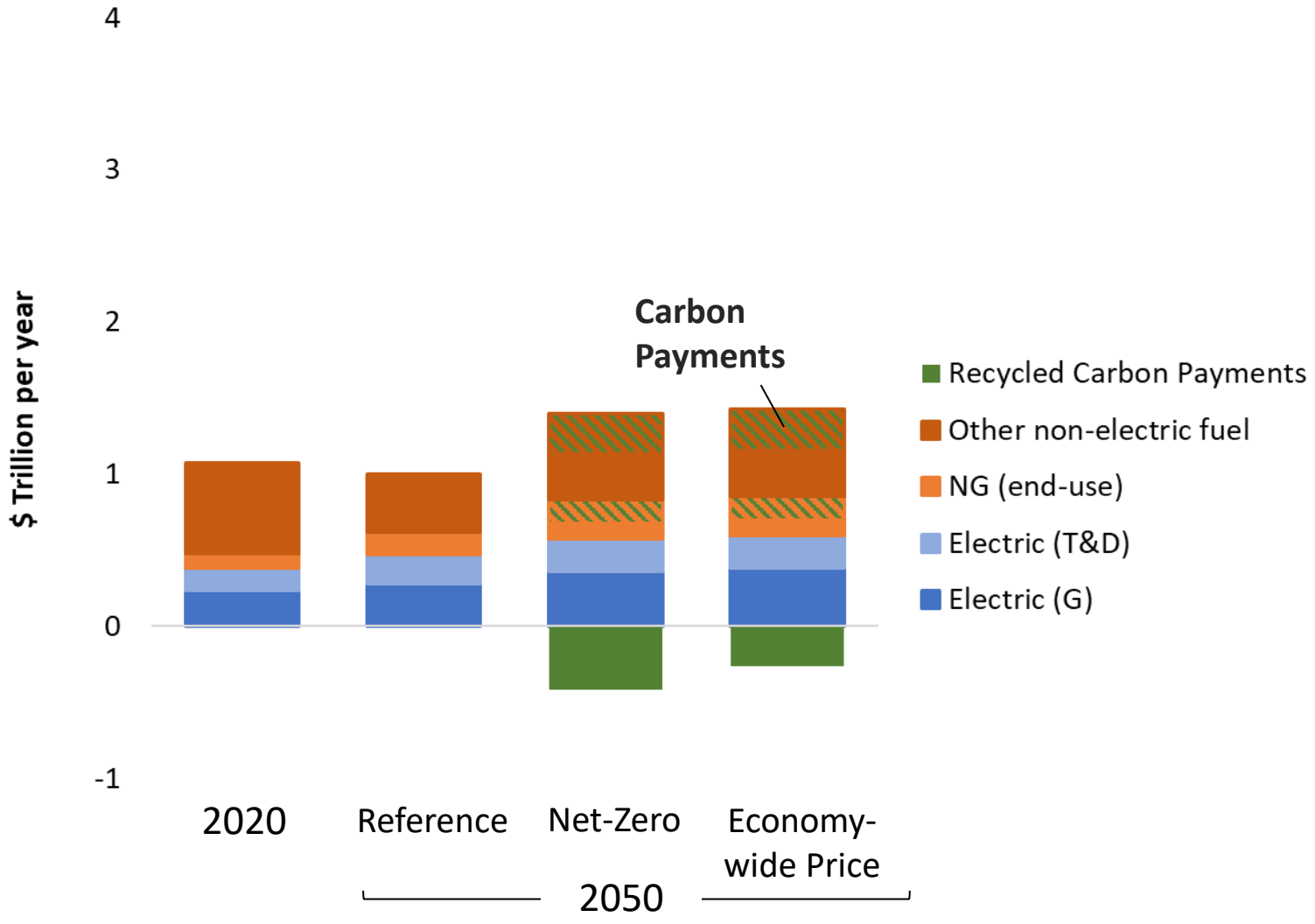
- Total electric system costs rise from ~$400B/year in 2020 to ~$600B/year in 2050 in decarbonization scenarios

- 12% increase in price
- 39% increase in demand

→ 57% increase in expenditure

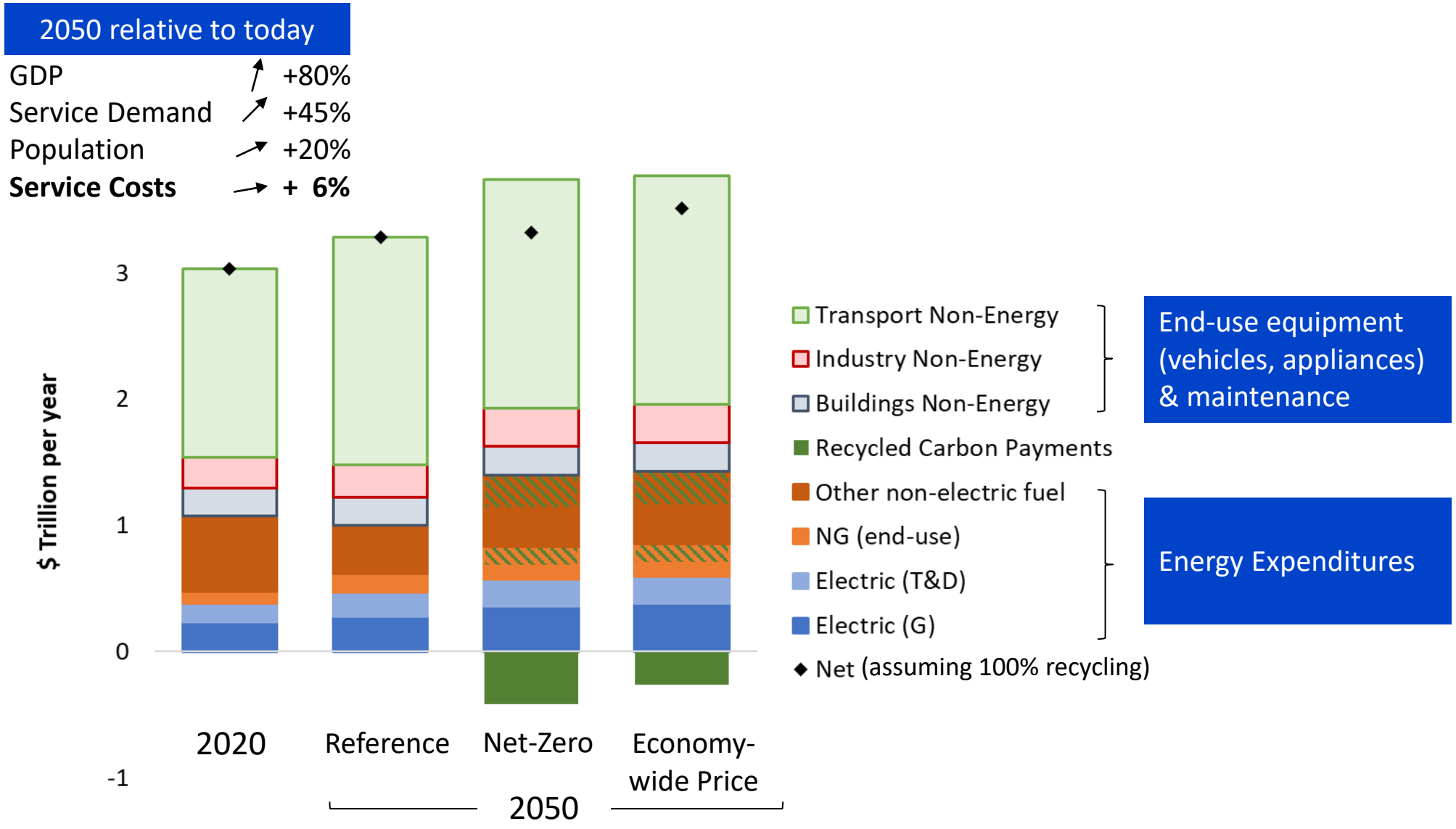
- But electricity is a relatively small component of total energy-service costs

Total Expenditure on Electricity + Non-Electric Fuels

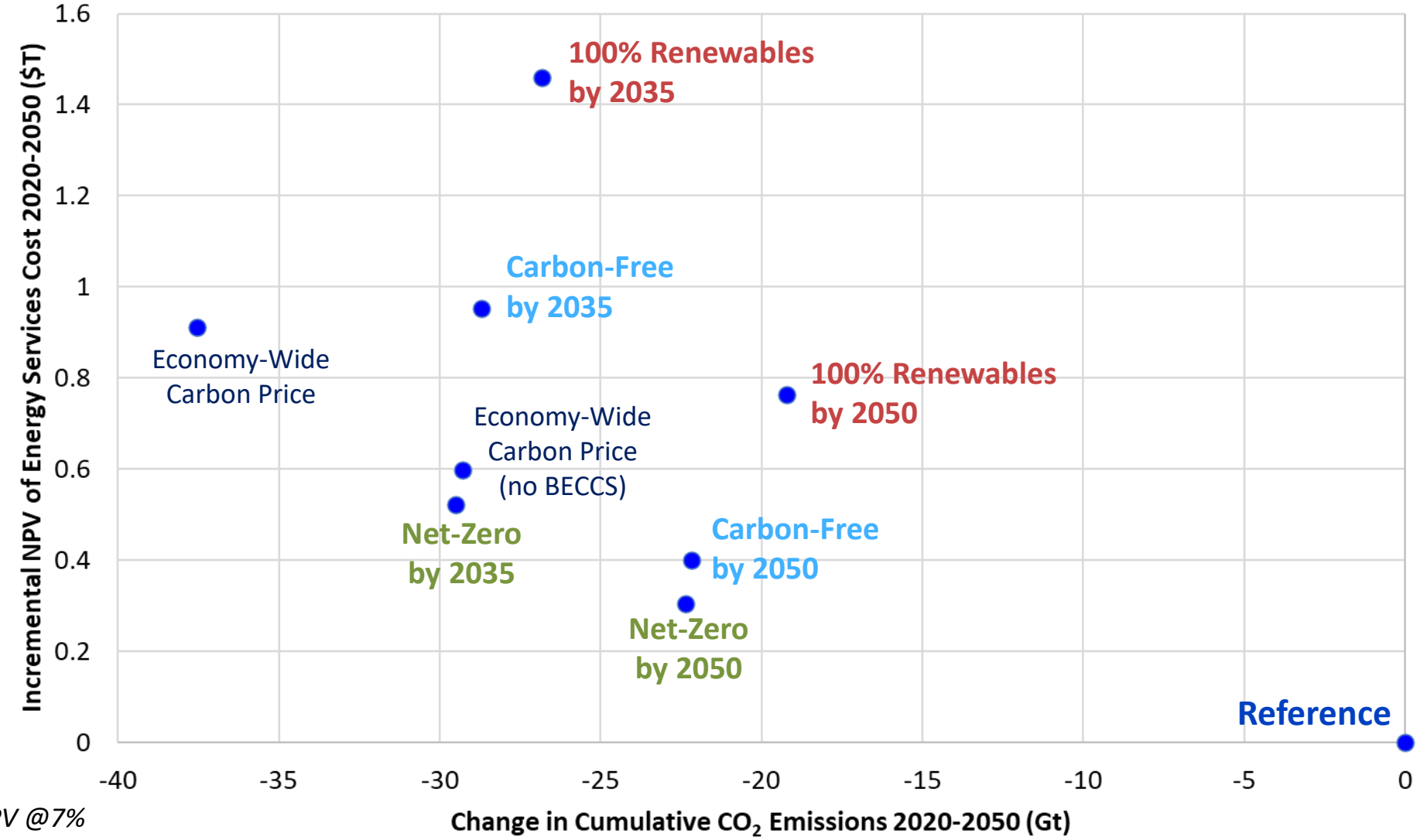


- Electrification in Reference scenario reduces total energy expenditures despite an increase in electricity expenditure
- Zero target scenarios result in increased total energy and electricity expenditures. Higher non-electric expenditures may be partially rebated from carbon funds.

Total Economy-Wide Energy Service Costs



Change in Total Energy Services Cost and Emissions Target Scenarios vs. Reference



NPV @7%

- Net-Zero Targets achieve emissions reductions at lower cost than the more restrictive target definitions
- Carbon-Free and 100% Renewables targets have higher costs and slightly higher emissions because of the higher electricity price discourages electrification
- Shifting the target to 2050 lowers costs while achieving fewer emissions reductions
- Deeper cuts to emissions will require additional efficiency and electrification, CDR, low-carbon fuels, likely higher cost

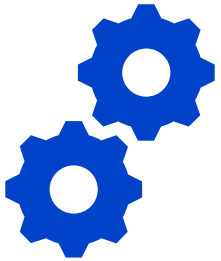
Observations: Economy-Wide Decarbonization

- Electrification/efficiency lower CO_2 and energy service costs and should always complement electric sector targets to reach economy-wide goals
  - Economy-wide CO_2 fall to ~70% below 2005 with electric sector decarbonization plus additional electrification in end-uses
  - CO_2 falls by 80% when negative emissions technologies are available
- Electric sector CO_2 likely to be net negative as economy-wide net-zero is approached → Net-zero economy-wide would require additional technologies and end-use policies

Key Takeaways

Full Portfolio and Optionality

Restricting technology options significantly increases cost of electric sector decarbonization to achieve zero



Timing

Target timing impacts the costs and pace of the transition

Collaboration

Essential to overcome major challenges in reaching zero-emission targets in electric sector, especially by 2035 (R&D, siting, permitting, market reform)

Low-Carbon Resources

Technology advances in low-carbon resources needed to achieve net zero in the electric sector and enable deep reductions in hard-to-electrify end uses

Customer Behavior

Decarbonizing the economy requires redirecting customers' energy equipment choices and changing how they interact with energy providers

Together...Shaping the Future of Electricity

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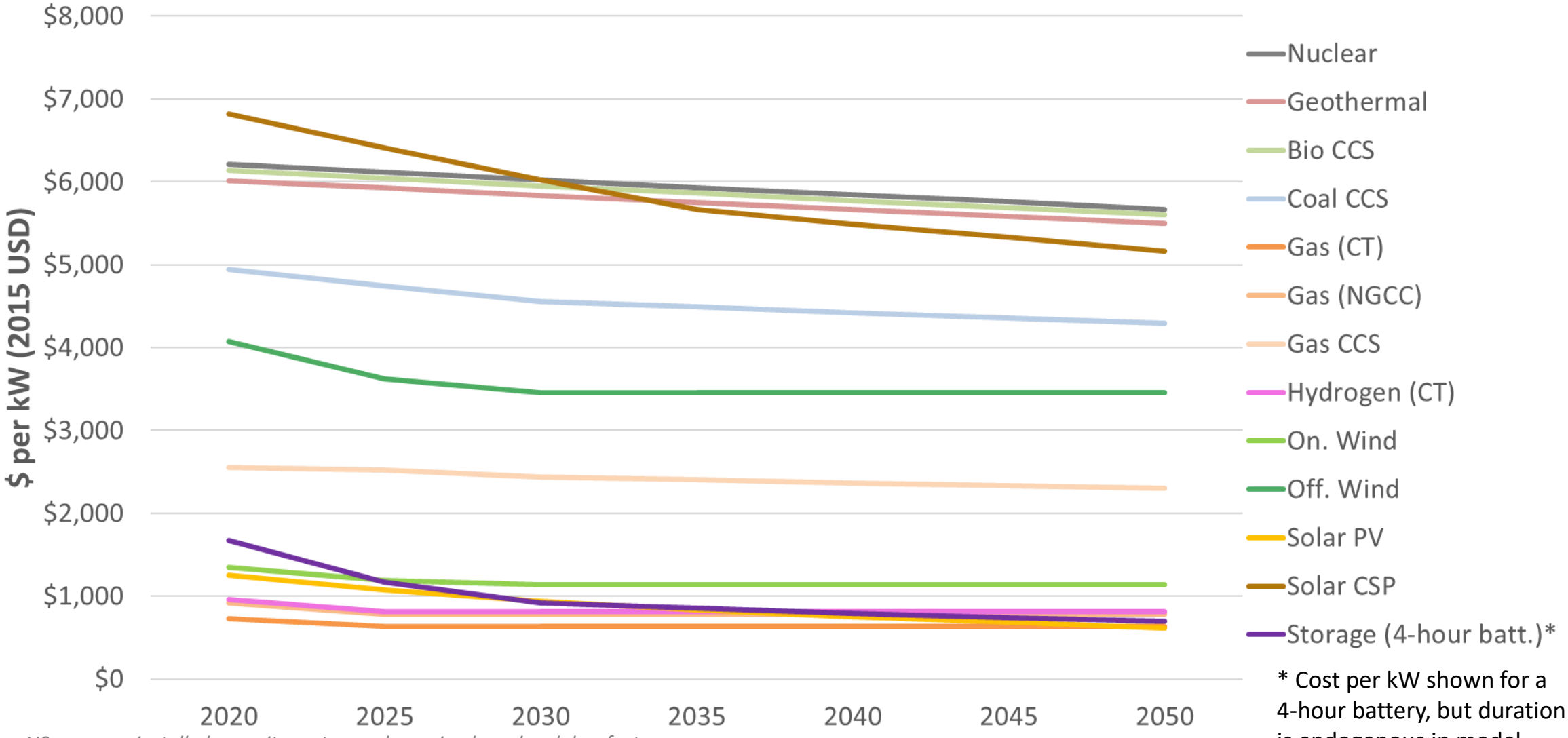
For more information, see our website at https://esca.epri.com

US-REGEN Capital Costs for Electric Technologies

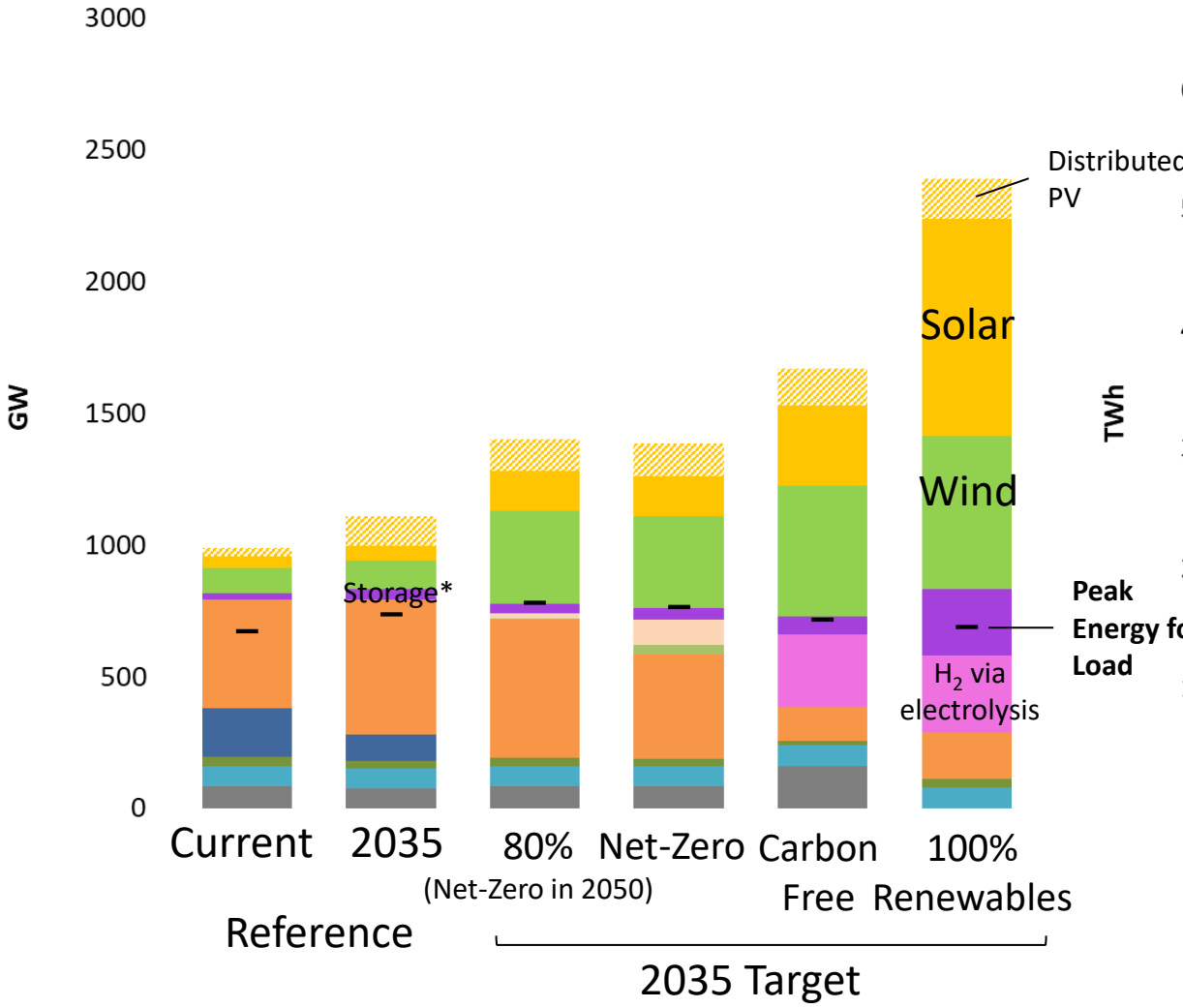


US average, installed capacity costs vary by region based on labor factors

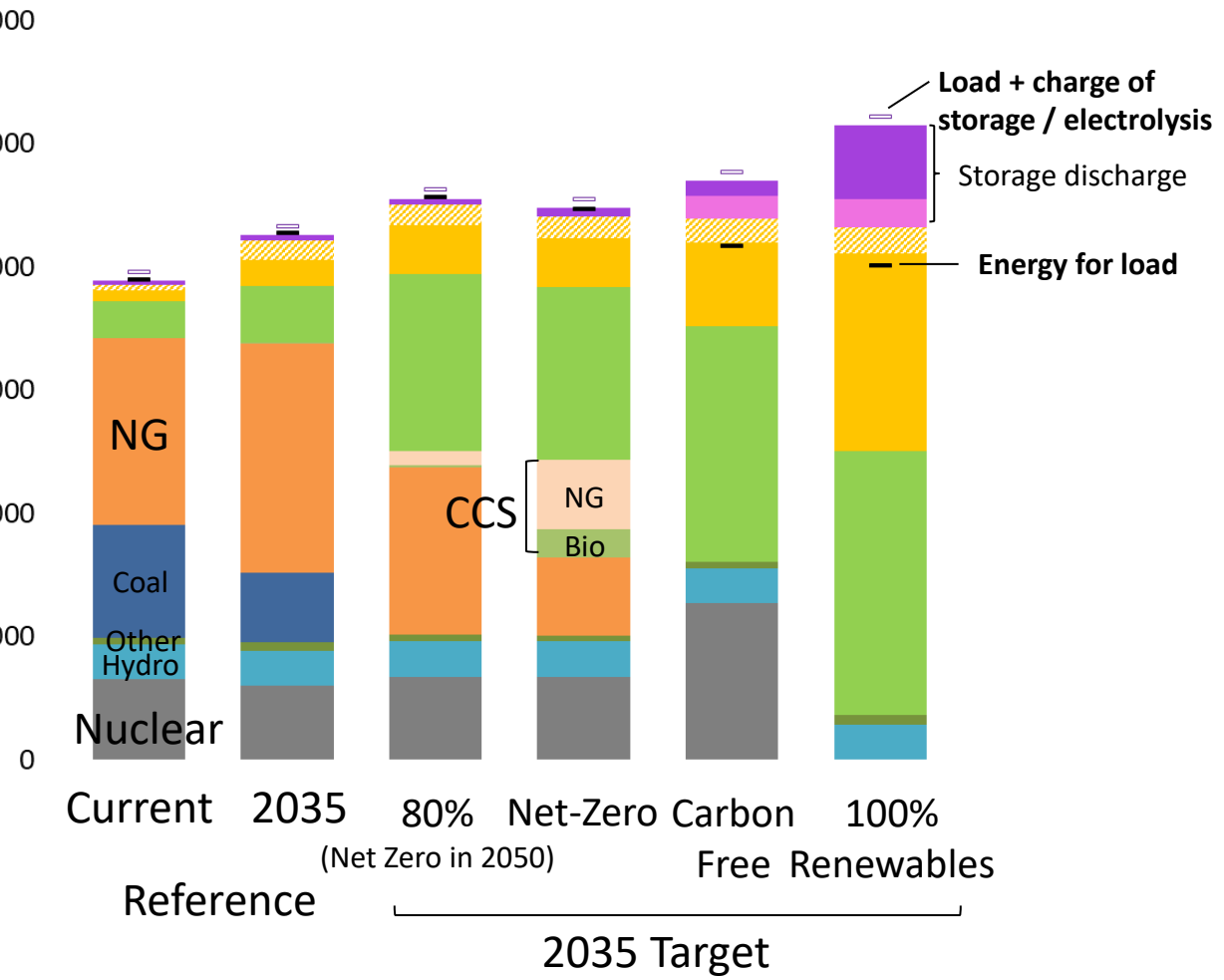
* Cost per kW shown for a 4-hour battery, but duration is endogenous in model

Technology Mix Depends on "Zero" Target Definition

U.S. Capacity



U.S. Generation



* Storage includes existing pumped hydro and new battery storage