The Role of Existing Hydropower in Decarbonizing the U.S. Electric Sector

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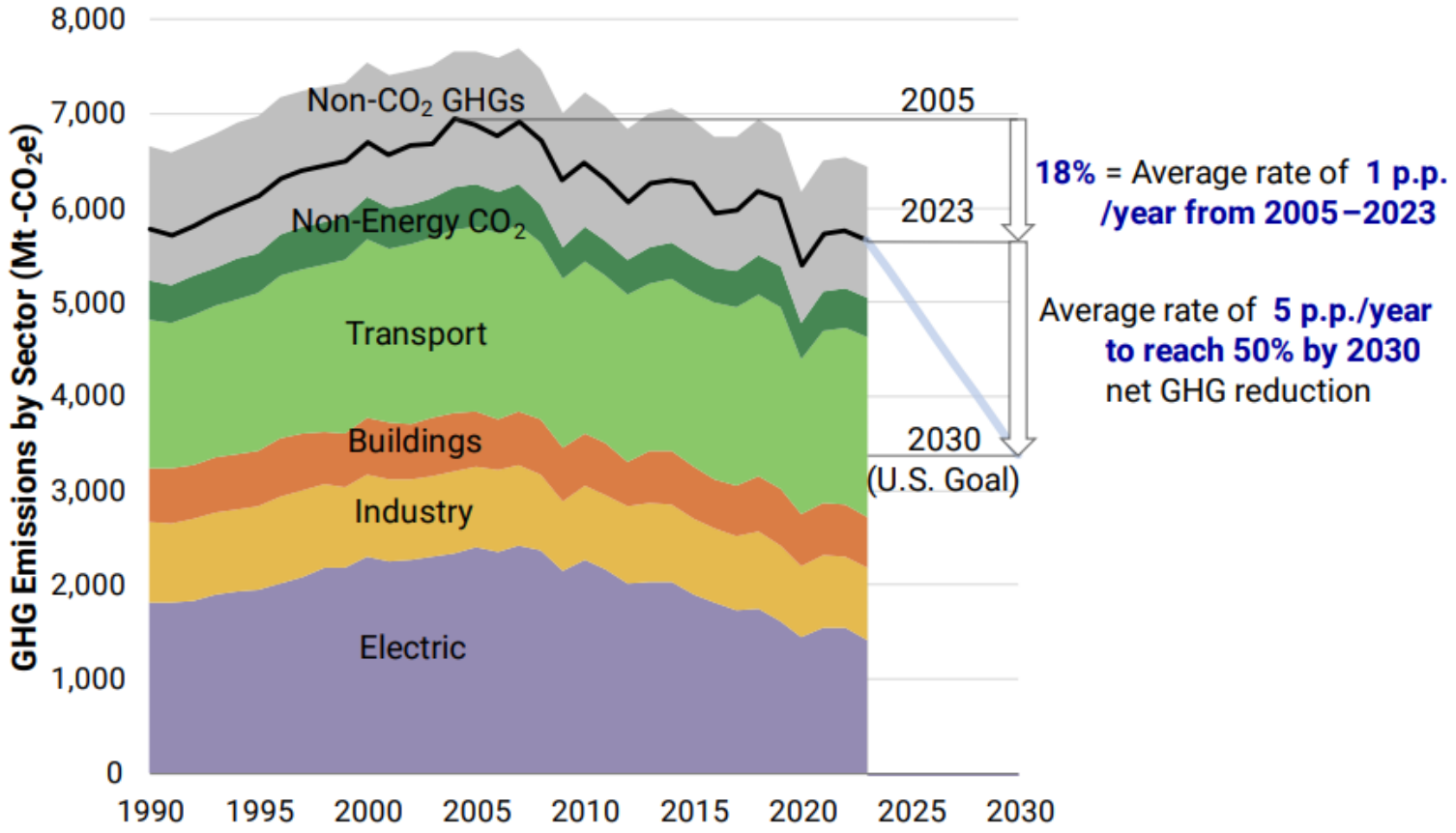
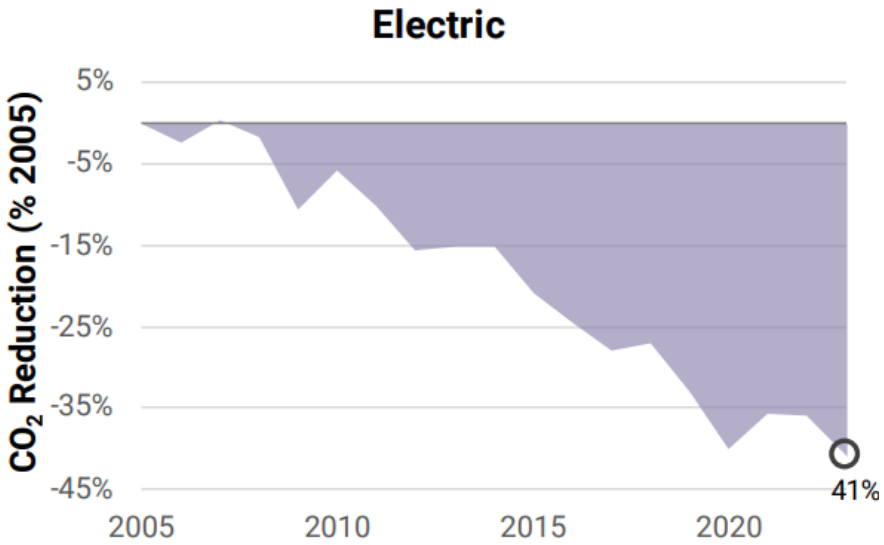
Note: Results are preliminary and for discussion only. No findings should be considered final or communicated widely and may change

Motivation: Progress Toward U.S. GHG Targets Led by Electric Sector



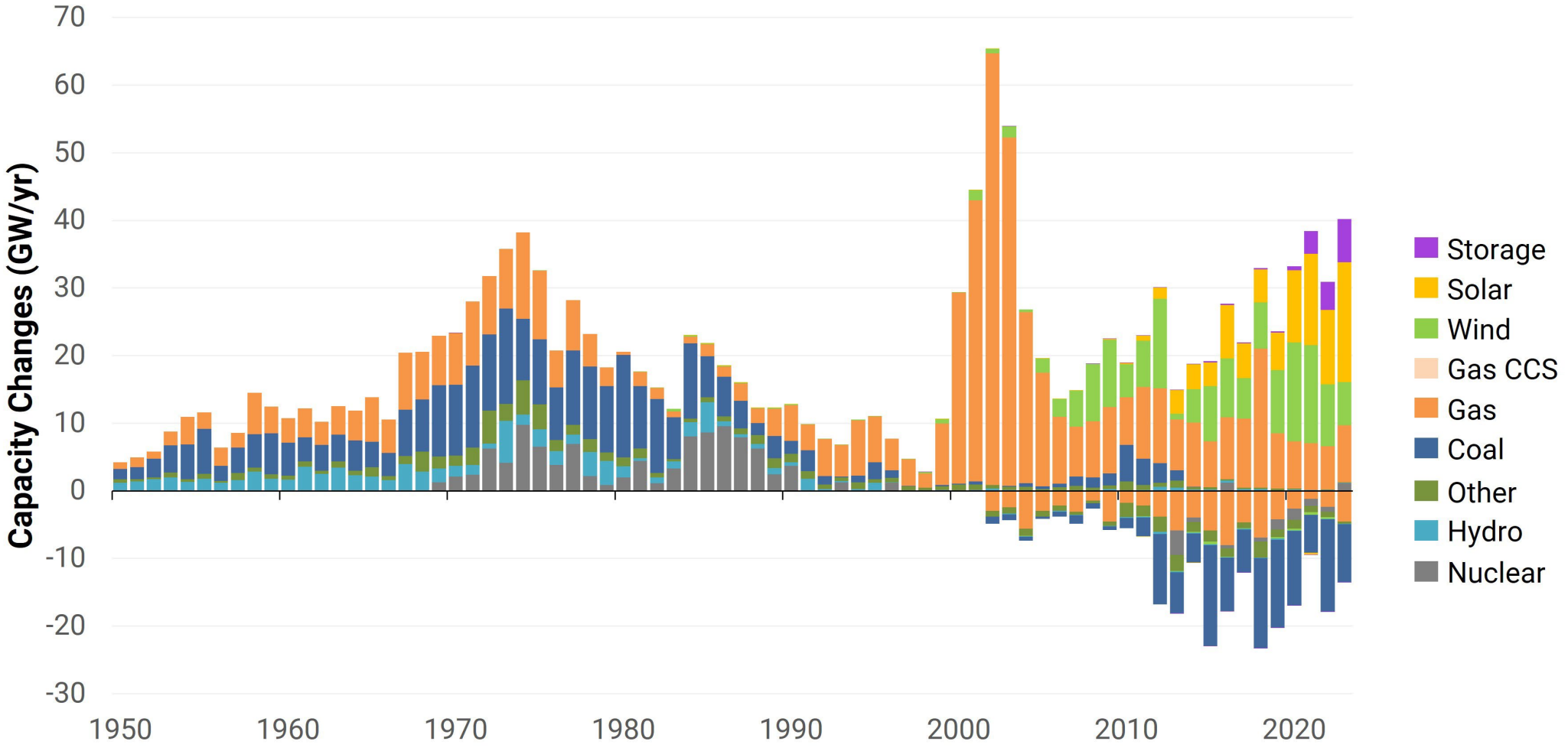


Over 80% of economy-wide GHG reductions came from the power sector since 2005

Figure 1. Historical greenhouse gas emissions trends by sector relative to 2030 U.S. target. Values through 2021 come from U.S. EPA's "Inventory of U.S. Greenhouse Gas Emissions and Sinks," and 2022/2023 values come from Rhodium.

- Hydropower contributes clean and renewable electricity generation and potential retirements could impact company, state, and federal emissions reductions pathways

Clean Capacity Additions Proceed at Aggressive Pace



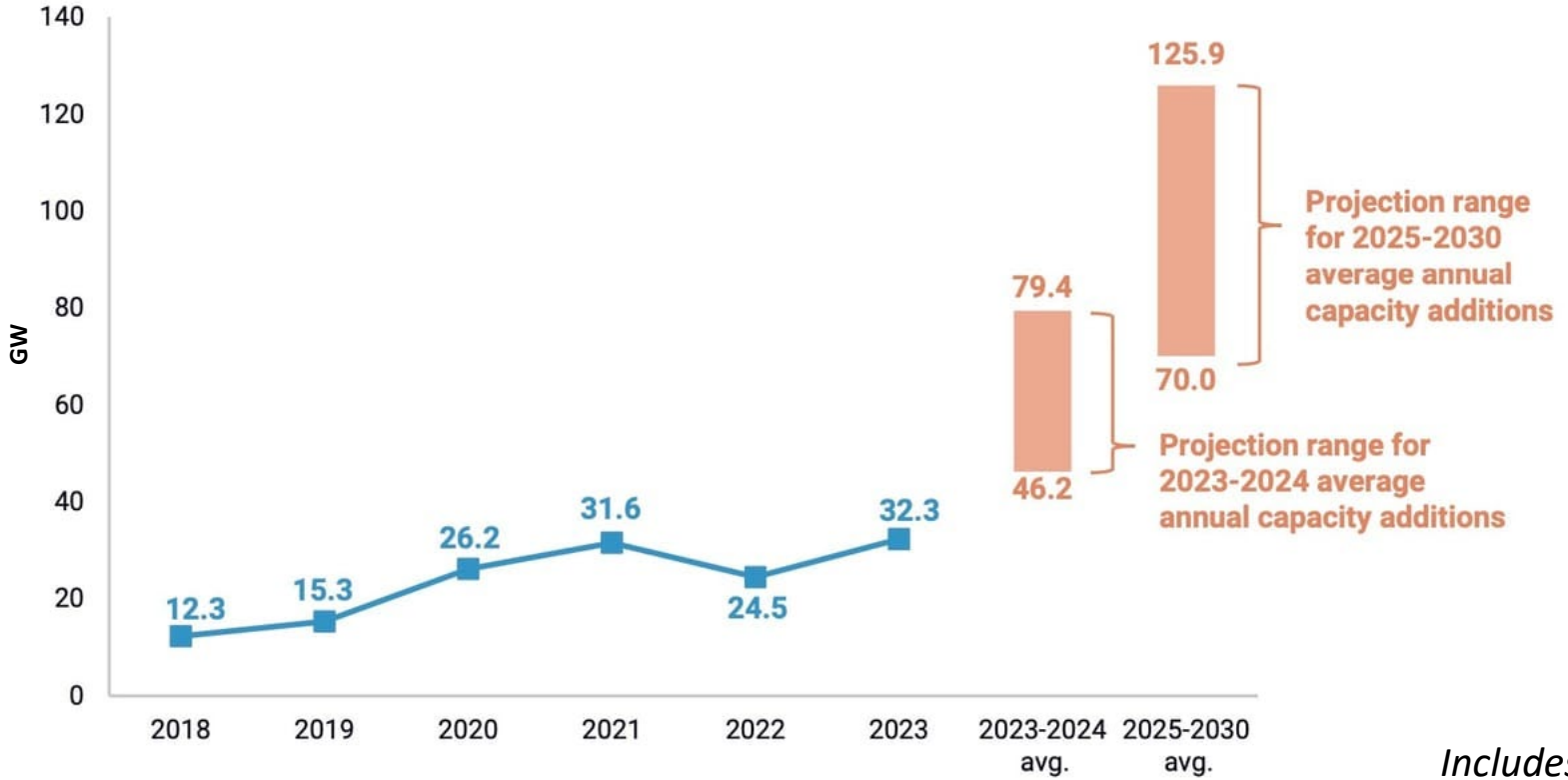
Source: EPRI Analysis of 2023 EIA-860 data

But Current Pace May Be Insufficient to Reach U.S. Targets

FIGURE 4

Annual clean electricity capacity additions vs projections

GW net summer capacity vs. projection range from Energy Innovation, REPEAT Project, and Rhodium Group



Source: Rhodium Group/MIT-CEEPR Clean Investment Monitor, Energy Innovation, REPEAT Project

Includes nuclear, wind, solar, hydro, batteries

Hydropower Relicensing Process Is Extensive

- 17GW of existing hydropower is up for relicensing by 2035
- Relicensing and maintenance costs are increasing
- May involve up to 11 agencies
- Mean license time is 6.6 years, with minimum and maximum time ranging from 1.1 to 19.5 years and a standard deviation of 3.4 years
  - New licensing decisions are on average 2.6 years shorter than relicensing, in part because relicensing decisions generally have greater environmental complexity
- Licensing has a high fixed cost component and imposes a larger cost/kW on smaller projects
- Because generation continues during relicensing, lower risks for existing units

Source: An Examination of the Hydropower Licensing and Federal Authorization Process (nrel.gov)

NREL/ORNL Licensing Analysis Suggests Wide Range of Costs

- Analysis of 82 completed new license and relicensing process costs
- Strong relationship between project size and absolute licensing cost, though economies of scale improve cost per unit
- Total costs at given price point may vary and are uncertain at outset
- Median costs across all studied facilities: $107/kW average cost: $241/kW
  - Excluding new licenses Med: $131/kW, Avg: $281/kW

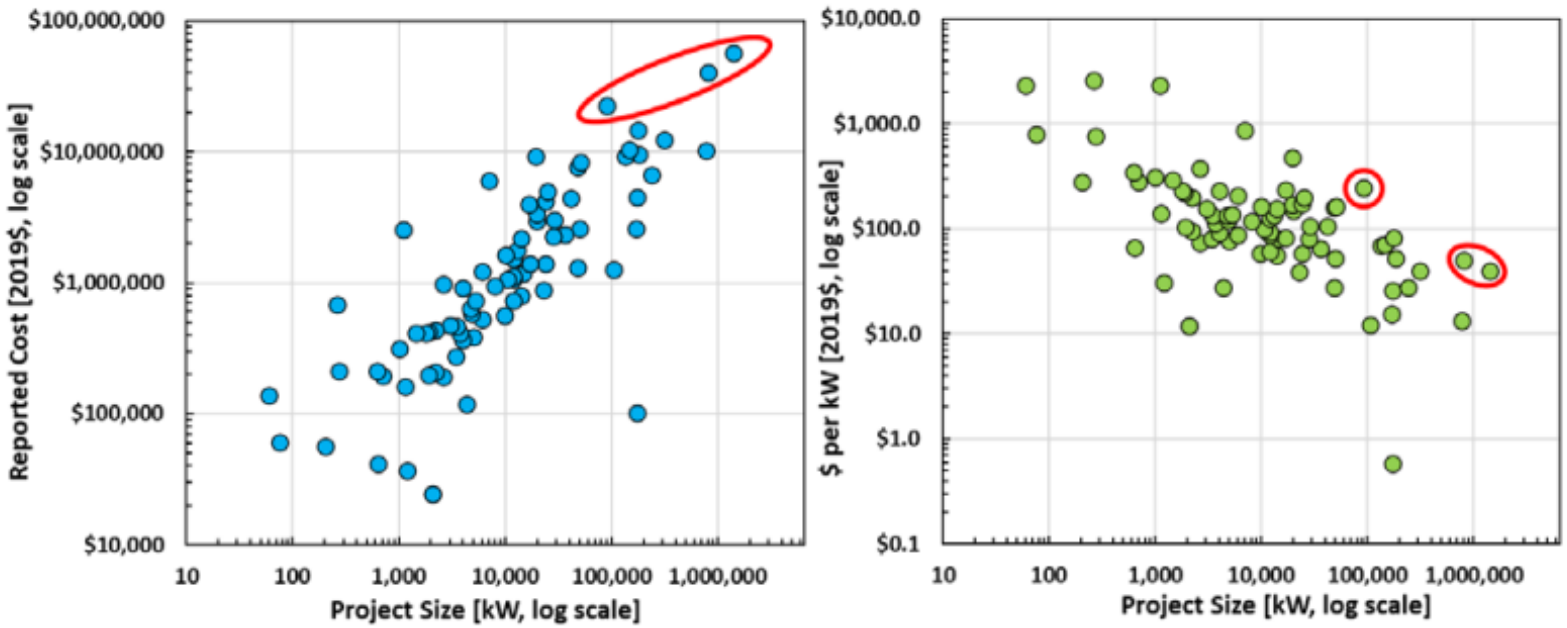


Figure 10. (a; left) Log-log scale scatterplots of reported licensing costs in 2019$ and project generating capacity in kW. (b; right) The size-agnostic $/kW metric and project generating capacity.

Note: The three high-cost outliers are circled in red in both plots; the low-cost/high $/kW outlier is not visible on either plot (i.e., at 0.25 kW | $5,400 | $21,600/kW). Non-generating projects that reported licensing costs are also not shown.

Source: An Examination of the Hydropower Licensing and Federal Authorization Process (nrel.gov)

Small facilities face high costs/kW while large facilities have high absolute costs

Study Design

- Update historical capacity to reflect FERC licensing status
  - Characterize license types and expiration dates
  - Uses ORNL*, database of existing hydro capacity coupled with current (2023) FERC active license data to characterize license status
- Create scenarios to evaluate a range of futures for hydropower units
  - Separately consider federal (age) and non-federal (license status) fleet
- Evaluate the quantitative impacts of early retirement of hydro units on emissions, cost, and generation mix
- Understand value of existing hydropower to electric sector generation and decarbonization and system-level and emissions implications of retirement

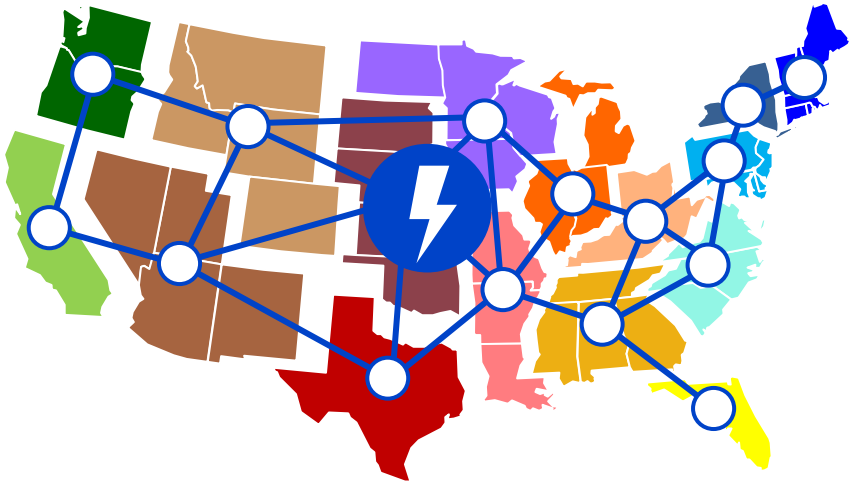
*Source: Megan M. Johnson, Shih-Chieh Kao, and Rocio Uria-Martinez. 2023. Existing Hydropower Assets (EHA) Plant Database, 2023. HydroSource. Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. https://doi.org/10.21951/EHA_FY2023/1972057

Investigate implications of hydropower relicensing and retirement on power system

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

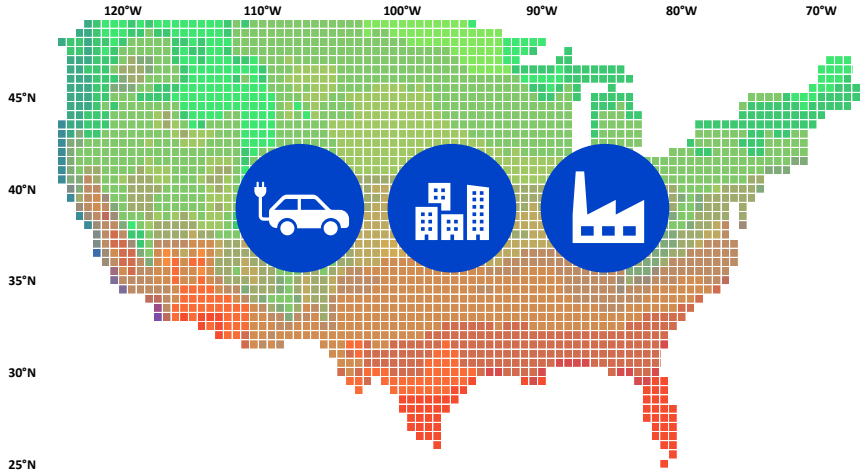
Hourly Load, Renewables, and Prices

Model Outputs:

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

Emissions, air quality, and water

Energy Use

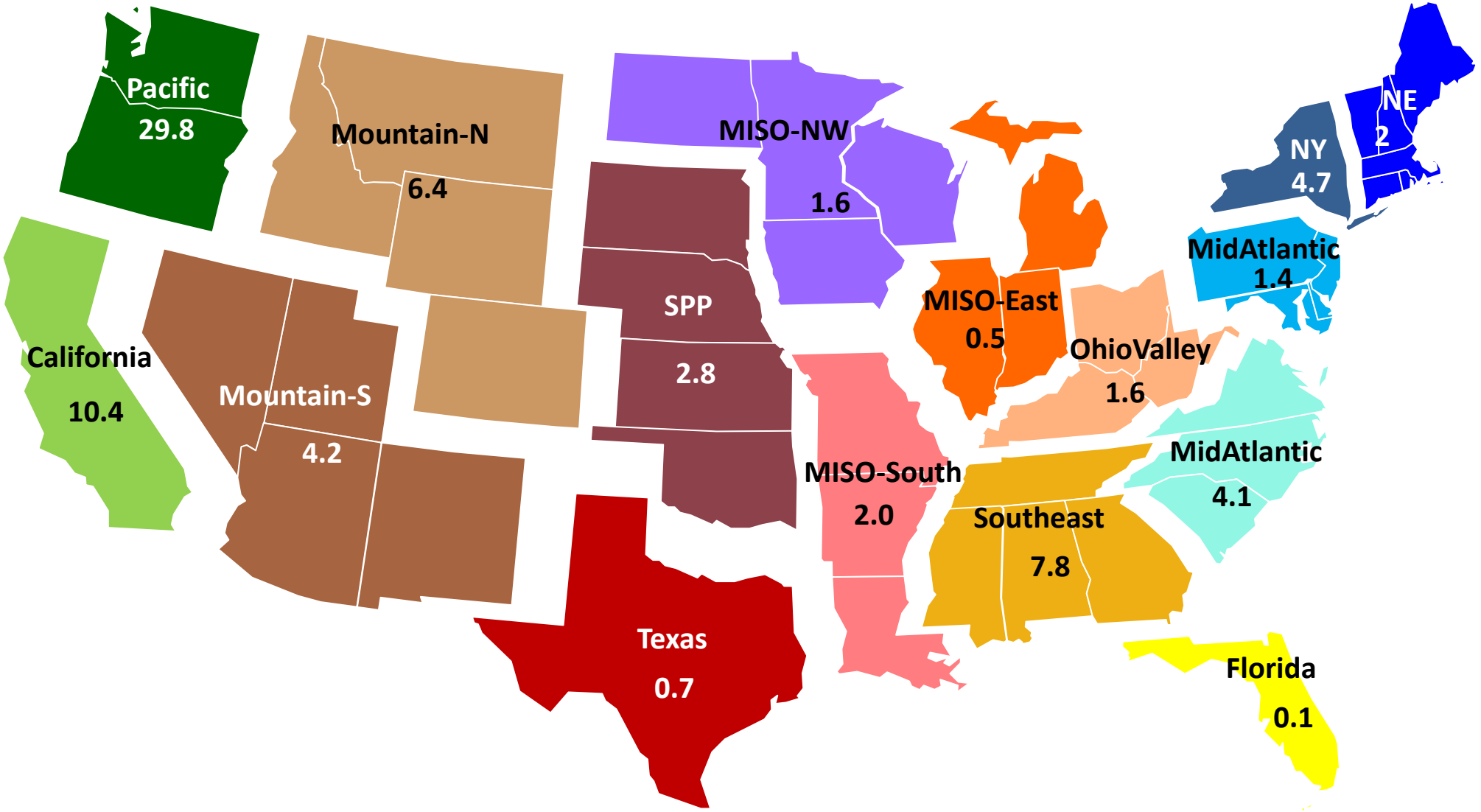


Detailed representation of:

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

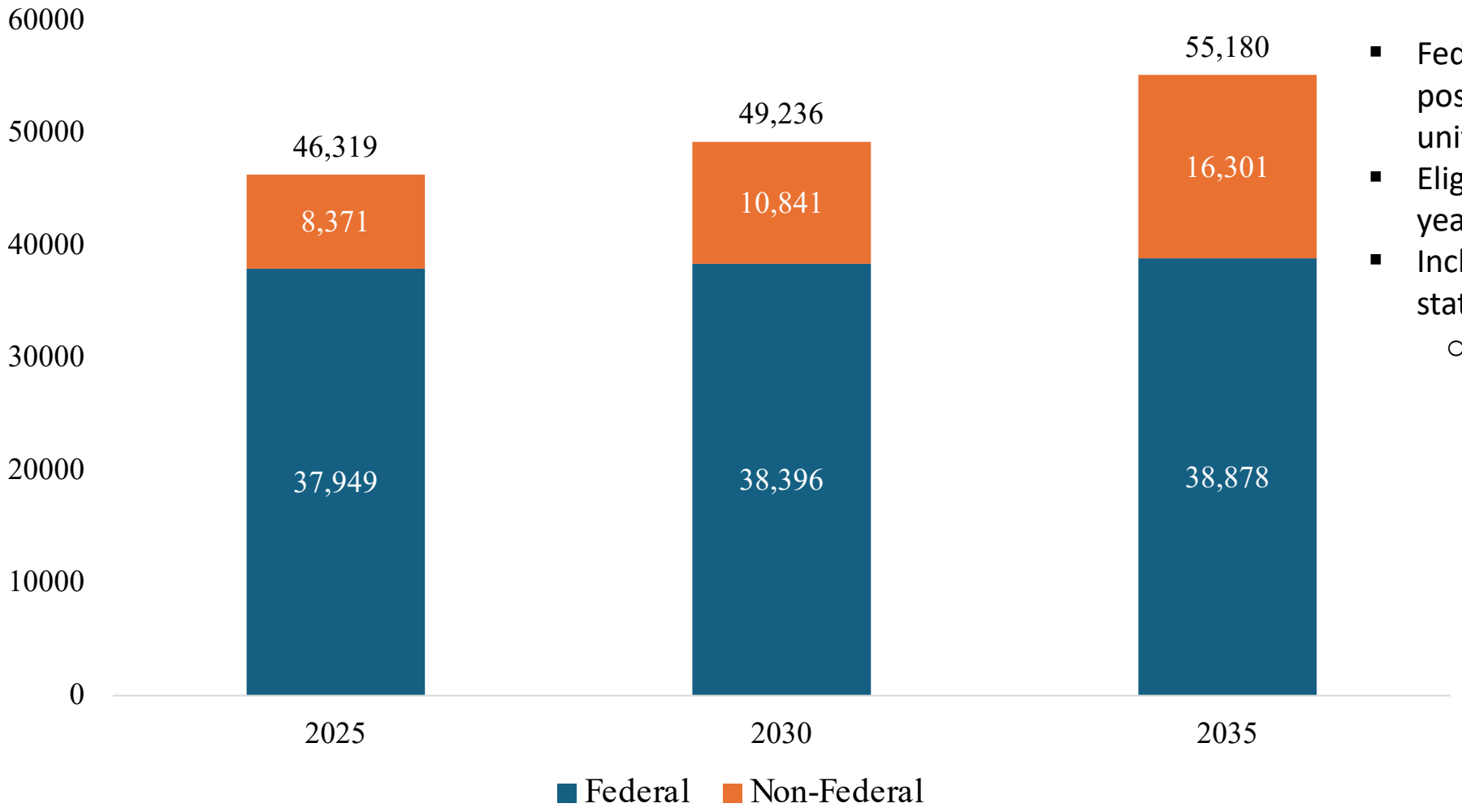
Documentation, articles, and reports available at https://esca.epri.com

US-REGEN Existing Hydro Capacity in 2020 (GW)



*Data taken from: Megan M. Johnson, Shih-Chieh Kao, and Rocio Uria-Martinez. 2023. Existing Hydropower Assets (EHA) Plant Database, 2023. HydroSource. Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. https://doi.org/10.21951/EHA_FY2023/1972057

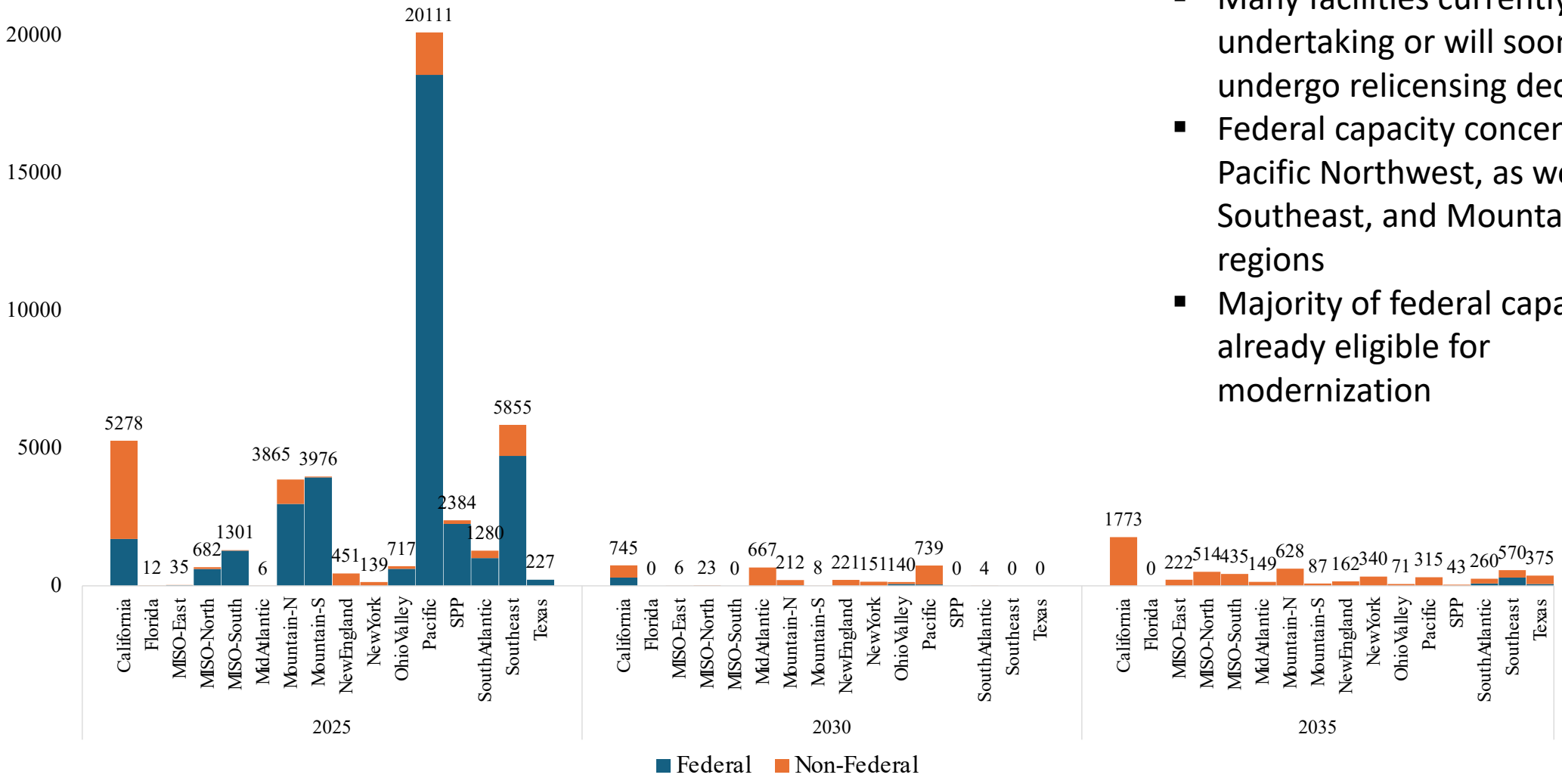
Cumulative Hydro Capacity Up For Retirement/Relicensing (MW)



- Federal capacity included for possible retirement includes all units >50 years old
- Eligible capacity is cumulative by year
- Includes all units in lower 48 states
  - by 2035, there are additional 386.5 MW and 37.3 MW capacity in AK and HI that are up for retirement/relicensing

Note: Non-federal retirement eligibility based on license type and status, while federal retirement eligibility based on age (>50 years). Represents potential modernization efforts

Hydro Capacity Up For Retirement/Relicensing (MW)



- Many facilities currently undertaking or will soon undergo relicensing decisions
- Federal capacity concentrated in Pacific Northwest, as well as Southeast, and Mountain regions
- Majority of federal capacity already eligible for modernization

Scenario Mix

Scenarios	Relicensing/Retiring Decision/Economic Decision	Power Sector CO_2 Target
Retire| Reference	Retire all hydro plants that are up for retirement/relicensing by 2035	No CO_2 target
Relicense| Reference	Relicense all hydro plants that are up for retirement/relicensing by 2035	
Retire Non-Federal| Reference	Retire non-federal fleet up for retirement/relicensing by 2035, leave federal fleet in operation	
Economic Decision | Reference	Economic decision	
Retire| CES35	Retire all hydro plants that are up for retirement/relicensing by 2035	100% clean electricity by 2035
Relicense| CES35	Relicense all hydro plants that are up for retirement/relicensing by 2035	
Retire Non-Federal| CES35	Retire non-federal fleet up for retirement/relicensing by 2035, leave federal fleet in operation	
Economic Decision | CES35	Economic decision	

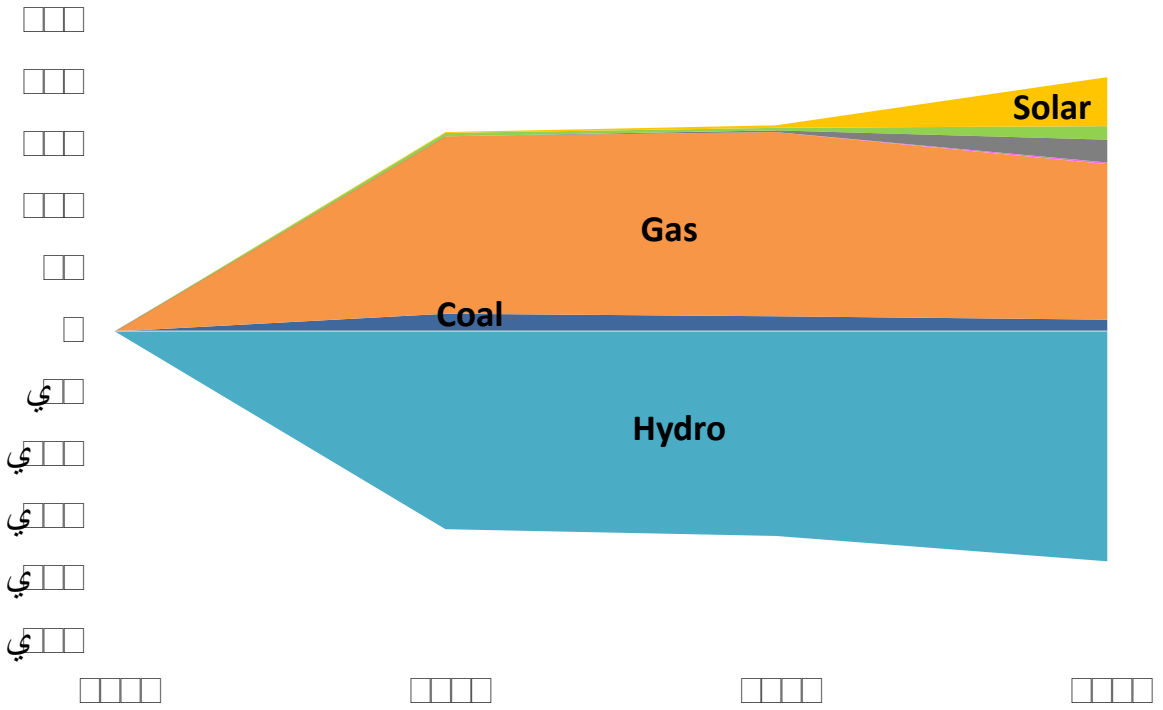
Preliminary Findings (Indicative of Final Results)

- **17GW of hydropower capacity up for relicensing by 2035**, with additional 39GW of federal plants over 50 years of age
- **Under current policy conditions, hydropower retirements could lead to higher electric sector emissions** compared to retaining existing fleet
  - To meet load requirements, retired hydropower could be replaced by mostly gas generation
- With a **net-zero CO_2 electric sector** target in 2035, **hydropower retirements may increase system costs** relative to retaining the existing hydro generation
  - To meet load requirements, retired units could be replaced by a combination of wind, solar, and nuclear generation

Generation Changes (TWh)

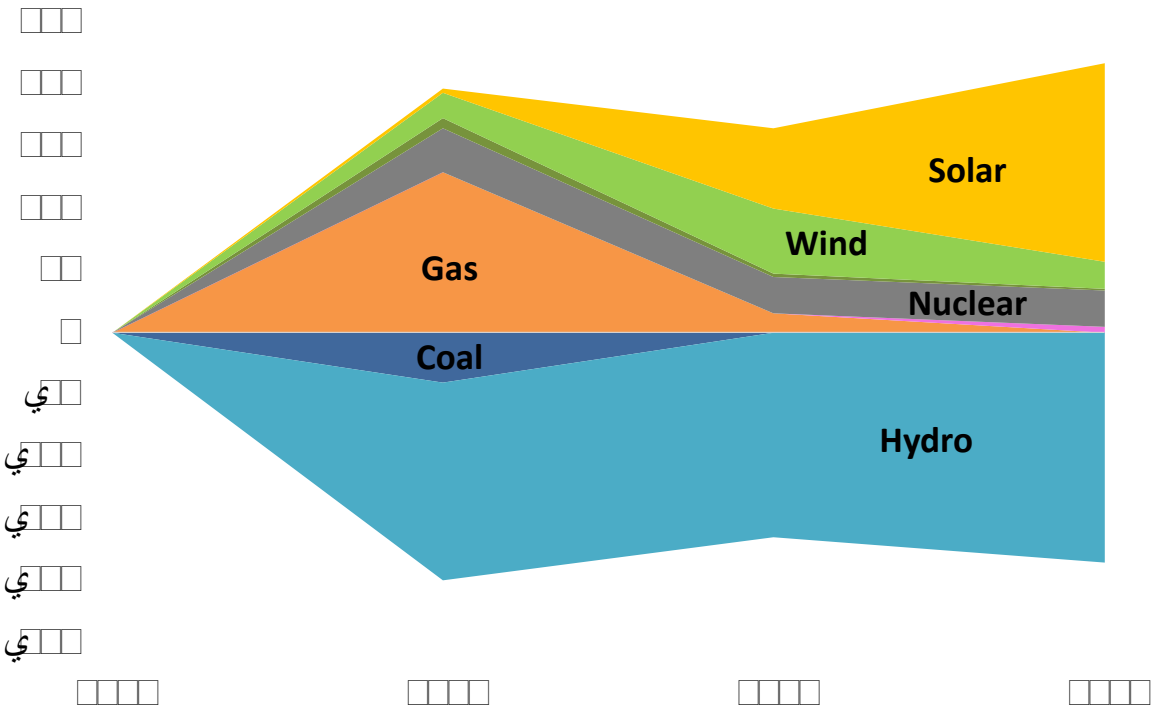
Reference (No Carbon Target)

Retire All Relative to Relicense All Reference



CES35 (Power Sector Net-Zero by 2035)

Retire All Relative to Relicense All Reference

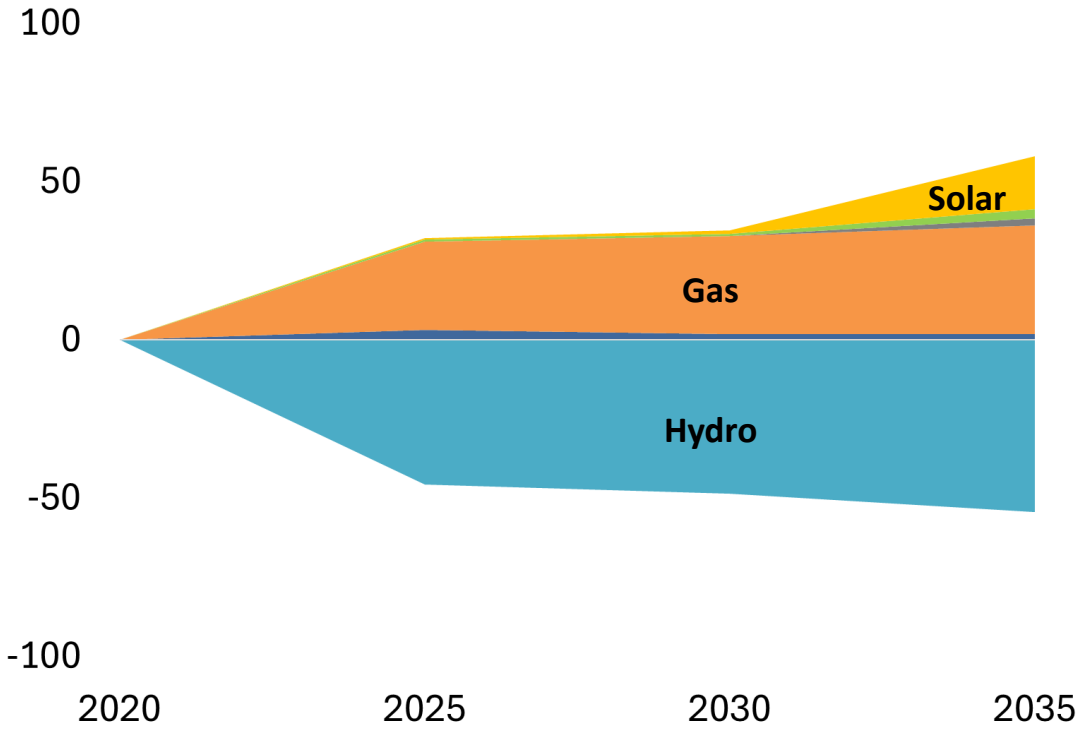


Gas Hydrogen Nuclear Biomass Wind Solar Coal Hydro

Capacity Difference between Relicensing and Retirement (GW)

Reference (No Carbon Target)

Retire All Relative to Relicense All Reference



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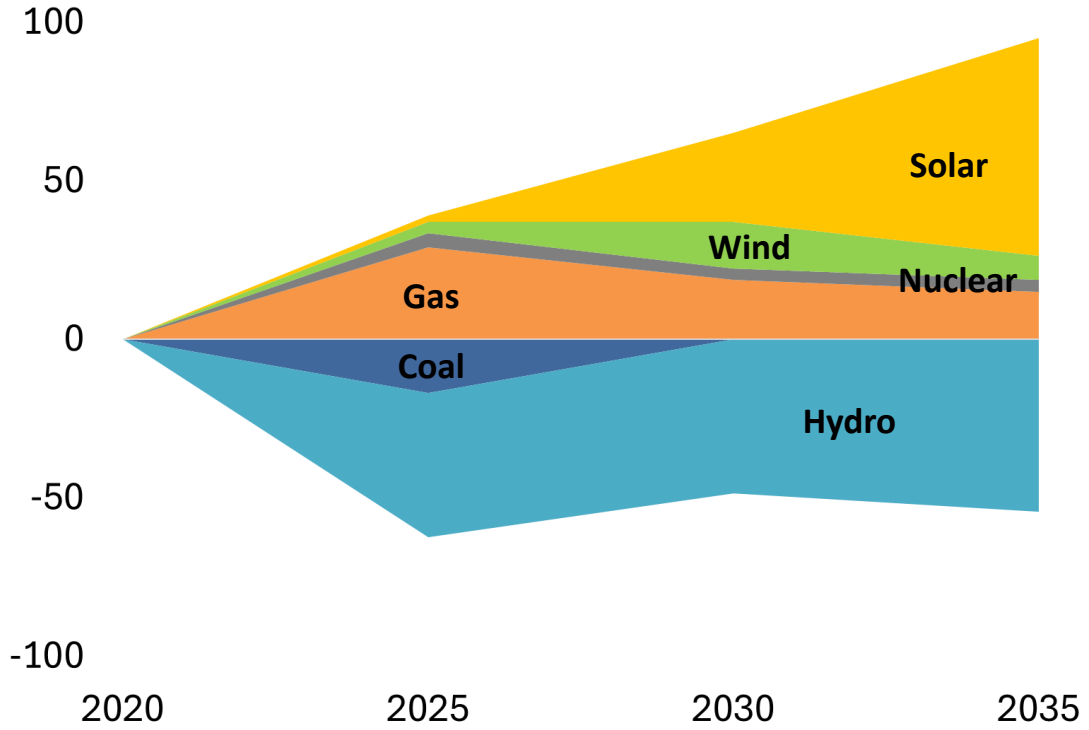
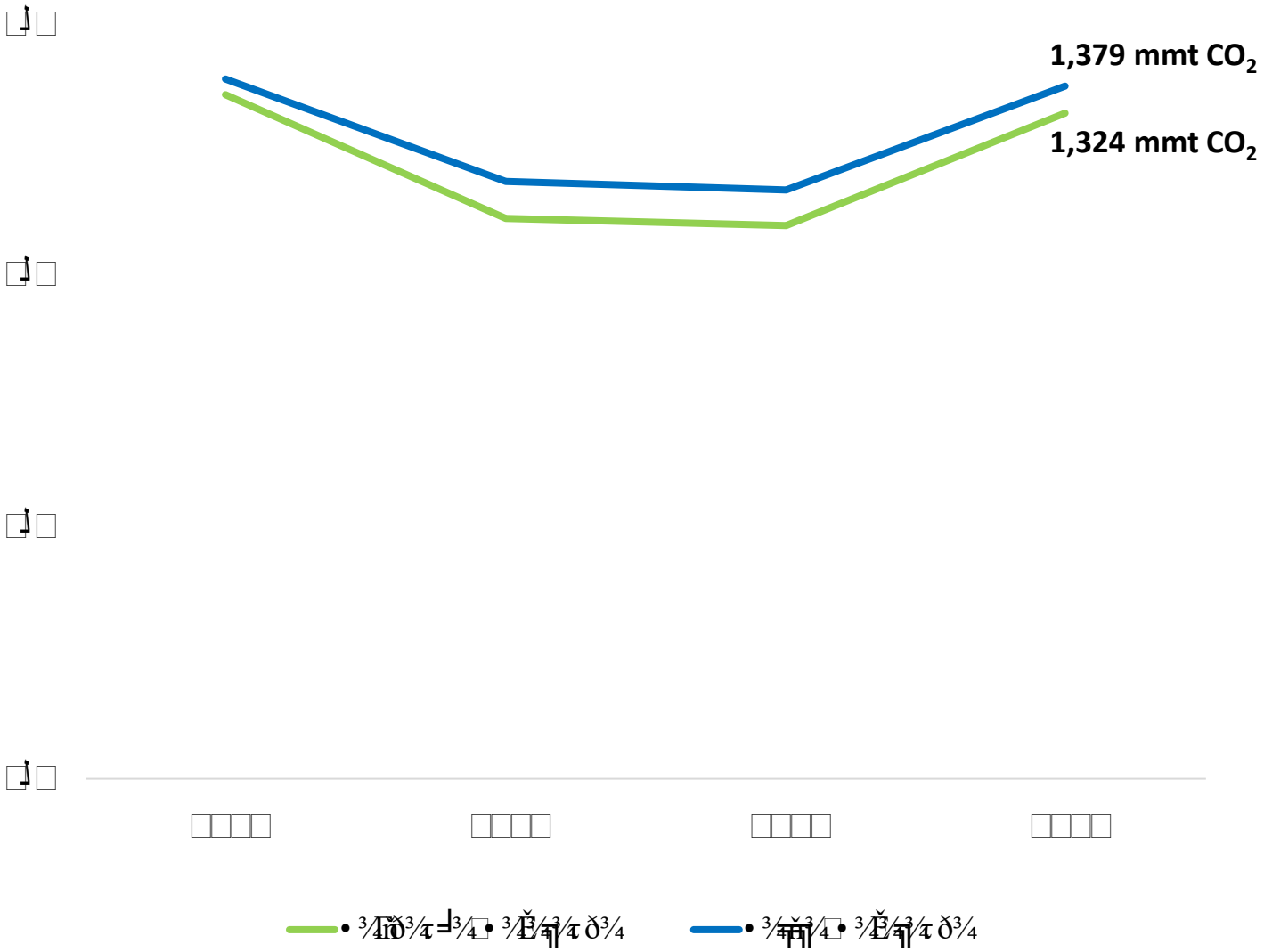


Gas Hydrogen Nuclear Biomass Wind Solar Coal Hydro

Electric Sector Emissions ($GtCO_2$)



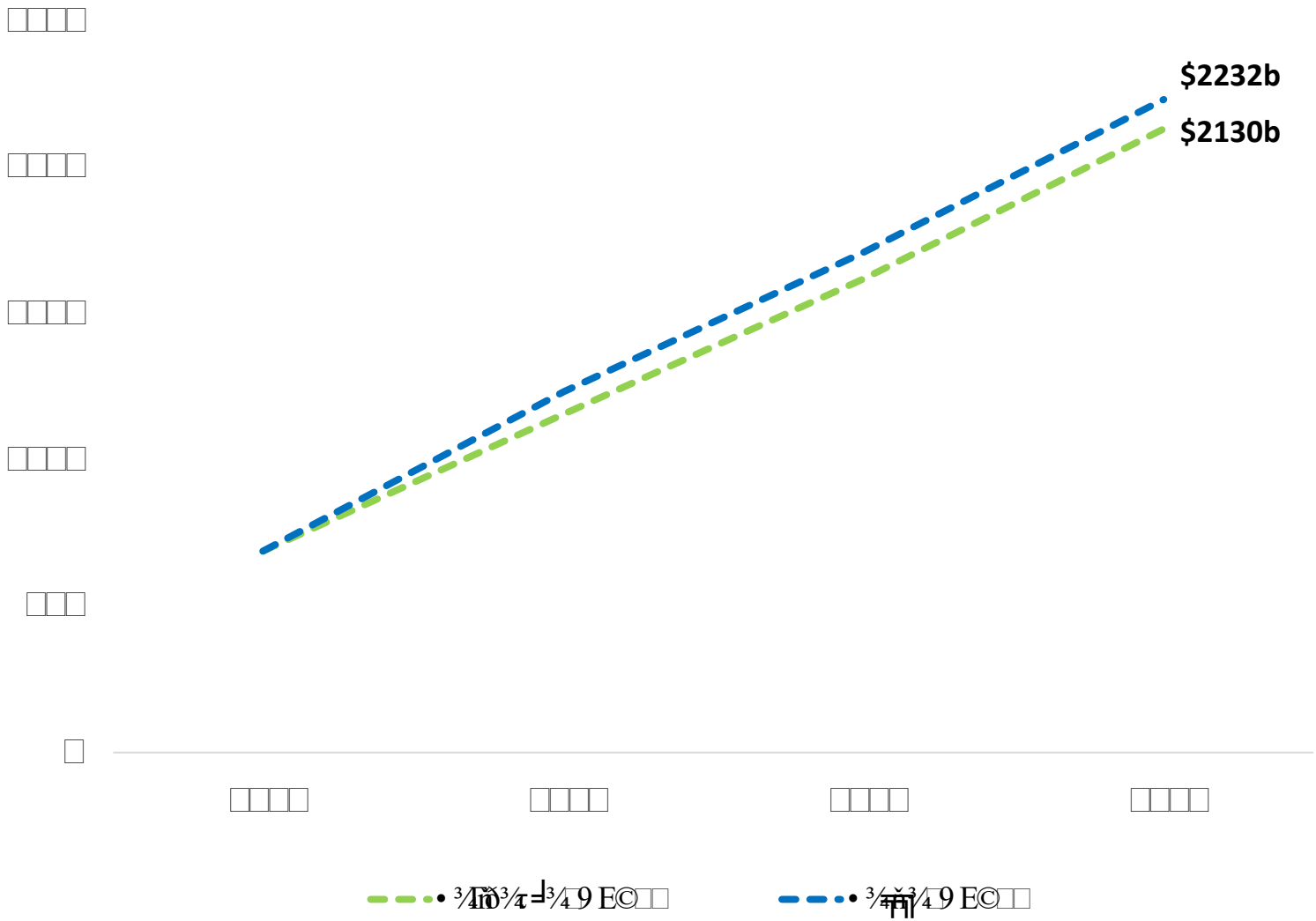
- From year 2025 to year 2035, CO_2 emissions in the Retire|Reference scenario is 4% to 6% higher compared to Relicense|Reference.
- Emissions rebound effect may offset emissions reductions from clean energy deployment

CO_2 Emissions
Relicense|Reference
relative to
Retire|Reference

Year	million ton CO_2	Vehicle Equiv.* Million/yr
2025	72.3	17.2
2030	71.8	17.1
2035	54.95	13.1

*Using EPA GHG equivalence 2023 calculator

System Costs ($Billion)



- System cost is present value to year t.
- Total system costs vary by ~$100b to 2035 from replacing hydropower
- Currently, there is no cost associated with the relicensing decision for hydro plants. Hence more scenarios are to be conducted to investigate the impacts on system costs from the relicensing/retirement decision.

For Discussion

- Relicensing costs range greatly across facility sizes and types
- Retirement and relicensing decisions require assessment of complex trade-offs between operational costs and revenue, direct relicensing costs, and indirect costs and benefits, and many systemic effects aren’t visible on the margin
- Raises questions about feasibility of capacity additions to offset lost capacity while meeting load requirements and climate objectives
- Hydropower is concentrated regionally, and regional effects may be more pronounced than national averages

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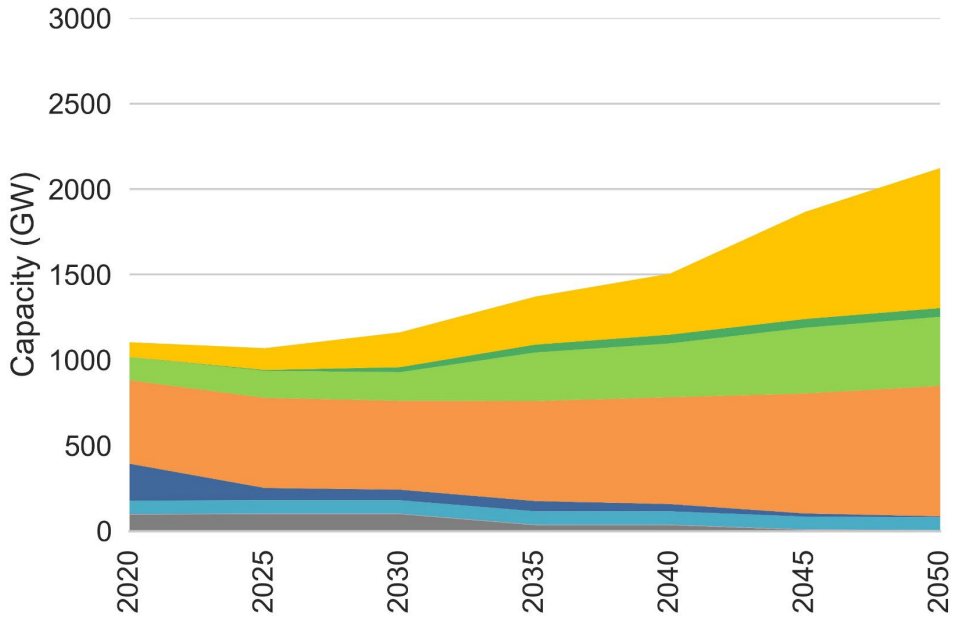
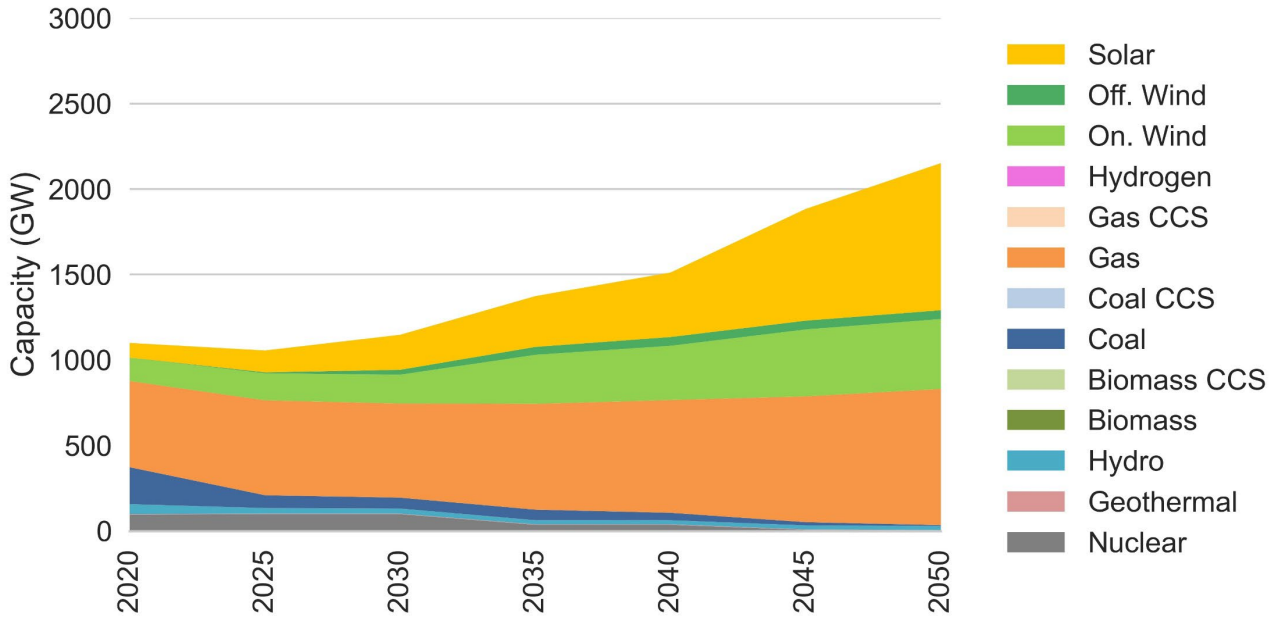
Backup Slides

Capacity (GW) in Reference Scenarios (No Carbon Target)

Relicense| Reference

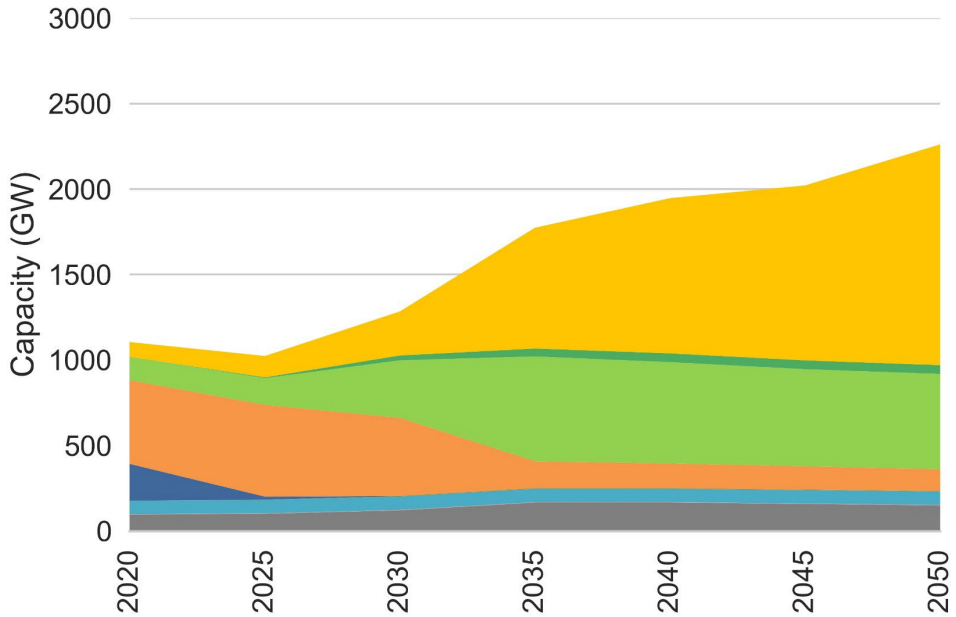


Retire| Reference

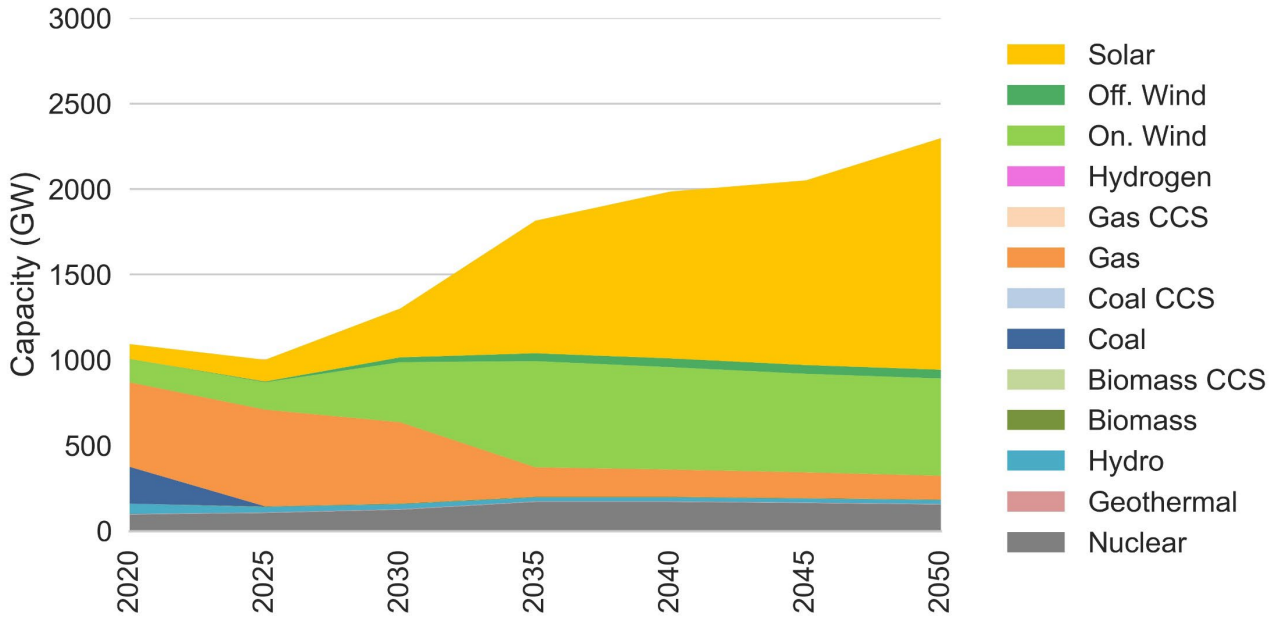


Capacity (GW) in CES35 Scenarios (Power Sector Net-Zero by 2035)

Relicense| CES35

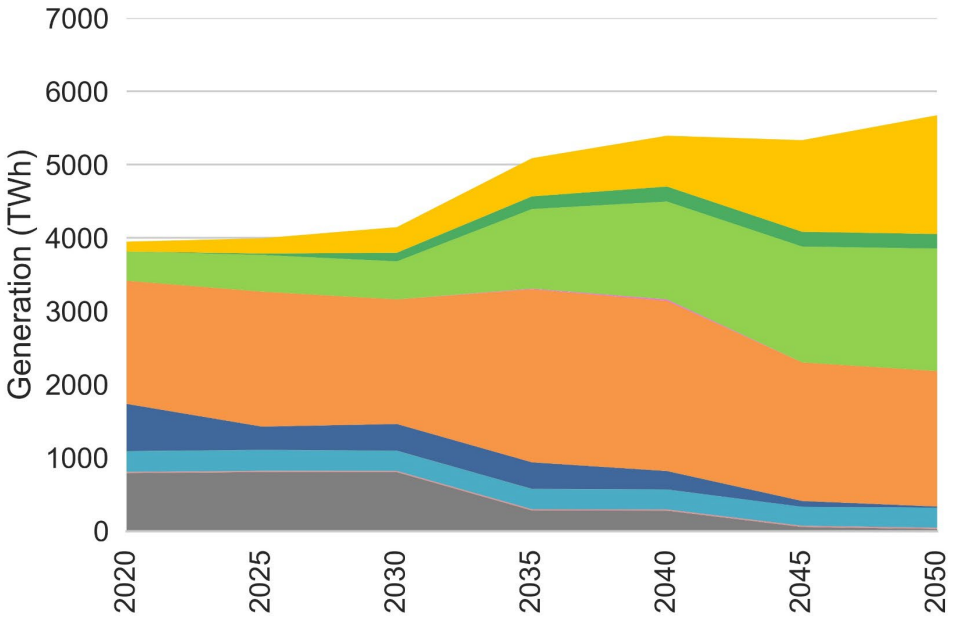


Retire| CES35

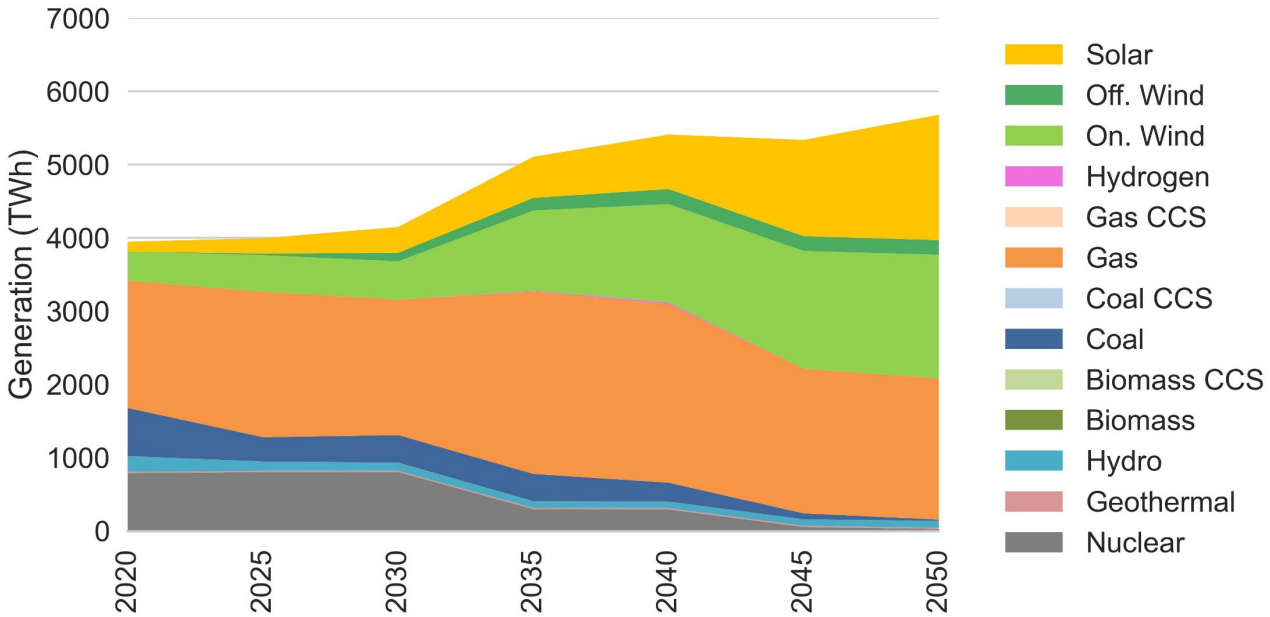


Generation (TWh) in Reference Scenarios (No Carbon Target)

Relicense| Reference

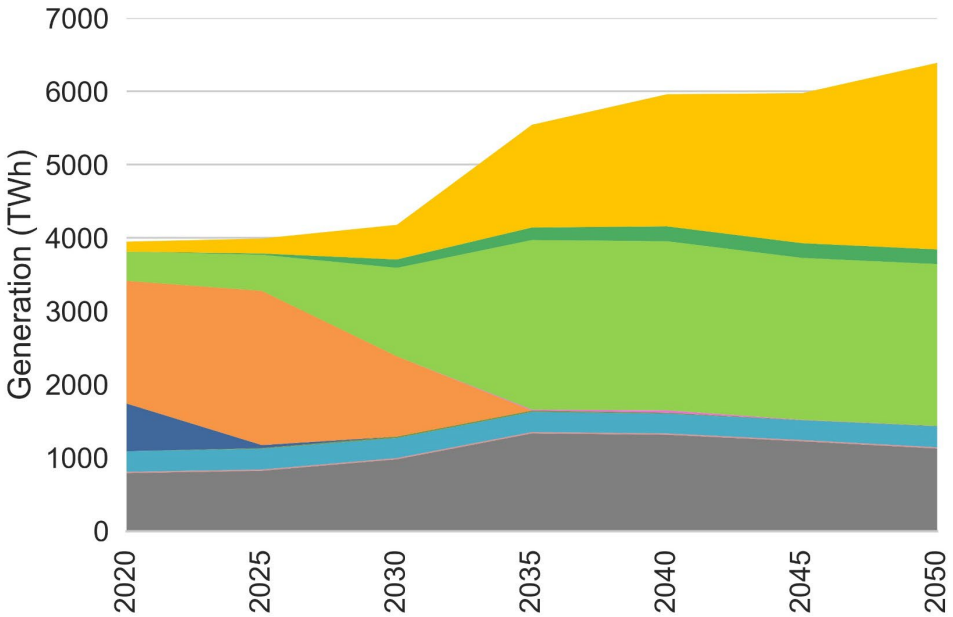


Retire| Reference

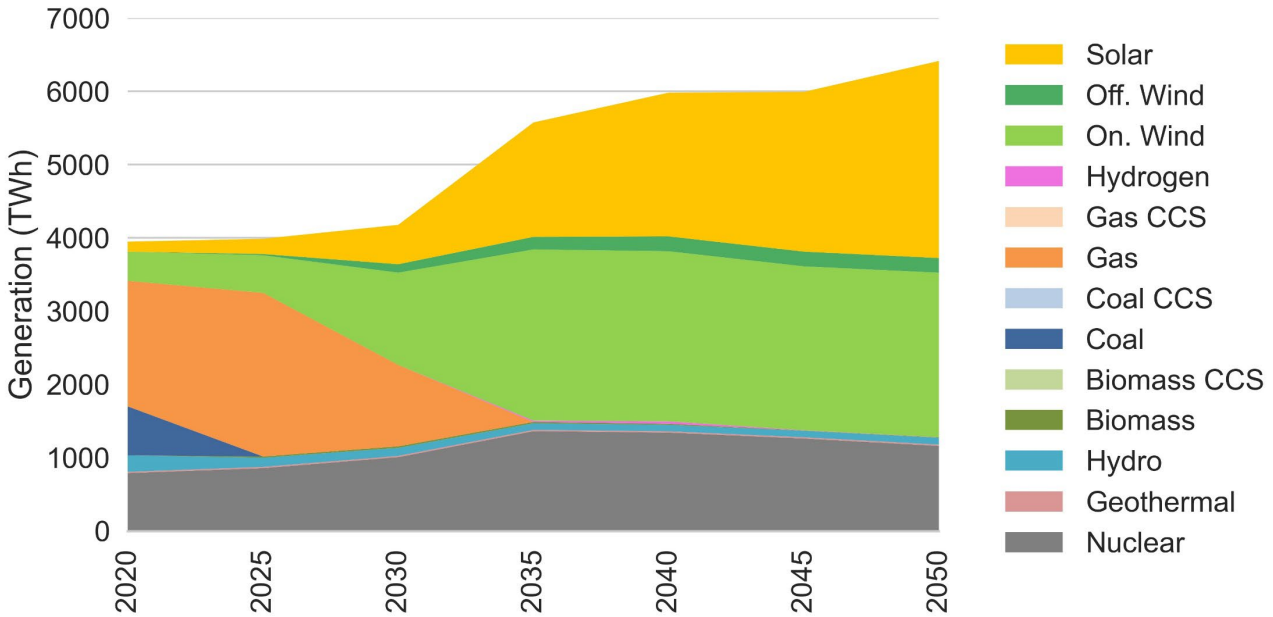


Generation (TWh) in CES35 Scenarios (Power Sector Net-Zero by 2035)

Relicense| CES35



Retire| CES35



REGEN End-Use Model Level of Detail by Sector

Cars and Light Trucks

- ICEV
- PHEV
- EV
- FCV
- Autonomous Vehicles

Bus and Passenger Rail
Aviation (domestic)
Aviation (international)

Light Commercial Trucks
Heavy Trucks
Freight Rail (non-energy)
Shipping (domestic)
Shipping (international)
Military

Fuel Transport (rail)
Pipeline

Residential and Commercial

Space Cooling
Space Heating
Water Heating
Clothes Dryers
Cooking
Lighting
Other Appliances
Electronics
Ventilation
Other Building

- Central A/C
- Window A/C
- Air-Source Heat Pump
- Ground-Source Heat Pump
- Electric Furnace/Resistance
- Gas Furnace
- Oil/LPG Furnace
- Wood Furnace/Stove

Agriculture
Construction
Mining (non-energy)
Non-Building Commercial
Water Services

Bulk Chemicals
Iron and Steel
Paper/Pulp/Wood
Food
Cement
Other Manufacturing

- Boilers
- Co-gen Boilers
- Process Heat
- Machine Drive
- Feedstocks
- Facilities

Refining
Upstream Energy Extraction

SECTORS / ACTIVITIES → **END-USES** → **TECHNOLOGIES**

Licensing Process Integrates Many Individual Factors

- Larger projects are more likely to have more complicated licensing processes but still correlate with lower costs per unit
  - Notable exception: Relicensing costs are higher, and correlate with larger units (fewer large facilities are new builds)
- Factors correlating with higher license costs
  - Inclusion of settlement agreement
  - Presence of endangered species
  - Require an Environmental Impact Statement
  - Fish passage guidelines
  - Associated with investor-owned utility (joint correlation with facility size)