Washington Comprehensive Climate Action Plan (CCAP) Emissions Modeling Technical Report

December 2025-Final Technical Report

Prepared for:
Washington Department of Commerce

Prepared by:
Evolved Energy Research and Clean Energy Transition Institute

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Contents

Introduction & Background

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- This Technical Report is the culmination of 15 months of energy pathways modeling to support Washington State's Comprehensive Climate Action Plan (CCAP).
- Throughout the summer of 2024, Evolved Energy Research and the Clean Energy Transition Institute worked with Washington state agency energy experts and external stakeholders to develop the model's assumptions.
- Ultimately the modeling explored eight scenarios. (see page 14)
- Initial modeling results were produced in March of 2025 and vetted by a Modeling Advisory Team, as well as through quarterly public meetings.

Introduction & Background -2-

- The draft Technical Report was released on June 17, 2025 to support state agency staff CCAP drafting through the summer of 2025.
- In recognition of the changed federal policy landscape, the decision was made to add additional scenarios in the fall of 2025 to reflect changes in clean energy incentives.
- These additional scenarios updated the Reference and CCAP scenarios.
- CCAP scenario economic and air quality impacts were also updated.
- This final Technical Report presents the final CCAP and Reference Scenarios and the changes since the draft Technical Report. (see pages 173 to 229)

Evolved provides the analysis to drive decision making for economy-wide decarbonization

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Past partners

NGOs

NRDC, TNC, SDSN, GridLab, Sierra Club, CETI, OCT, UCS, EDF, CATF, BPC, Audubon Society, Breakthrough Energy Foundation, Third Way, RMI, and others

State & Local Energy Offices

Massachusetts, Maine, Washington, California, New Jersey

Utilities

PGE, DTE, Hydro Quebec, and others

Others

Princeton University, University of Queensland, Breakthrough Energy Ventures, Inter-American Development Bank, DOE, NREL, UVA

Clean Energy Transition Institute

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- **What We Are**: Independent, nonpartisan Northwest research and analysis nonprofit organization
- **Our Mission**: Accelerate an equitable clean energy transition in the Northwest
- **Our Role**:
  - Provide unbiased research and analytics
  - Offer an information clearinghouse for policymakers
  - Convene diverse stakeholders

Acronym List

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Acronym	Definition
ACC II	Advanced Clean Cars
ASHP	Air source heat pump
BECCS	Bioenergy with Carbon Capture
BECCS H_2	Hydrogen production from BECCS
BEV	Battery electric vehicle
BTM	Behind-the-meter
CC	Carbon capture
CCGT	Combined-cycle gas turbine
CCS	Carbon capture and storage
CDR	Carbon Dioxide Removal
CFS	Clean Fuel Standard
CT	Combustion turbine
DER	Distributed energy resources
EE	Energy efficiency
EP	Energy Pathways [Evolved model]
EPA	Environmental Protection Agency
EV	Electric vehicle

Acronym	Definition
FCEV	Fuel cell electric vehicle
G2V	Grid-to-vehicle
GHG	Greenhouse Gas
GSHP	Ground source heat pump
GW	Gigawatt
GWh	Gigawatt hour
H_2	Hydrogen
HDV	Heavy-duty vehicle
ICE	Internal combustion engine
IOU	Investor-owned utility
IRA	Inflation Reduction Act
LDV	Light-duty vehicle
LPG	Liquid petroleum gas
MDV	Medium-duty vehicle
MHDV	Medium- and heavy-duty vehicles
MMBtu	One million British thermal units
MMT	Million metric tons

Acronym	Definition
MW	Megawatt
NCS	Natural Climate Solutions
NH_3	Ammonia
NWPCC	Northwest Power and Conservation Council
RE	Renewable energy
RIO	Regional Investment and Operations [Evolved model]
SMR	Small Modular Reactor
TBtu	One trillion British thermal units
TNC	The Nature Conservancy
TWh	Terrawatt hour
Tx	Transmission
V2G	Vehicle-to-grid
VMT	Vehicle miles traveled
ZEV	Zero emissions vehicle

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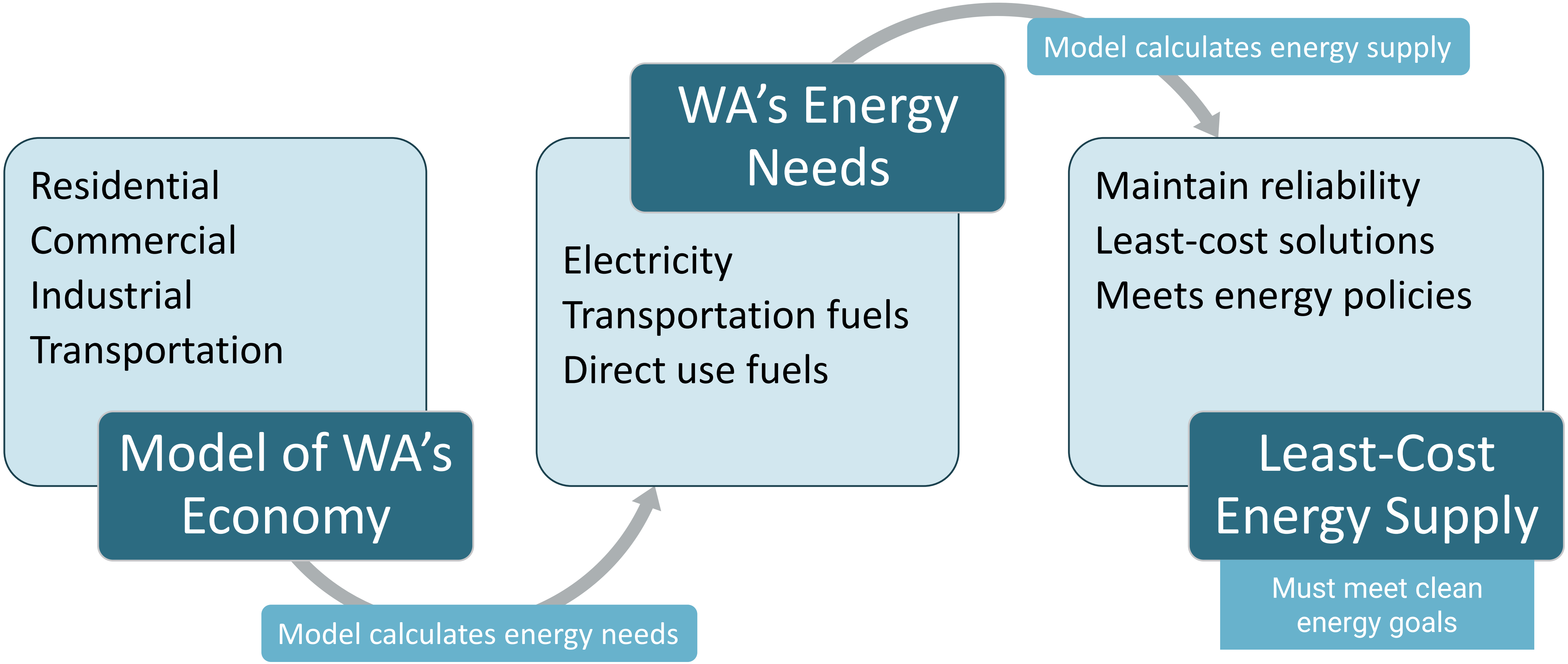
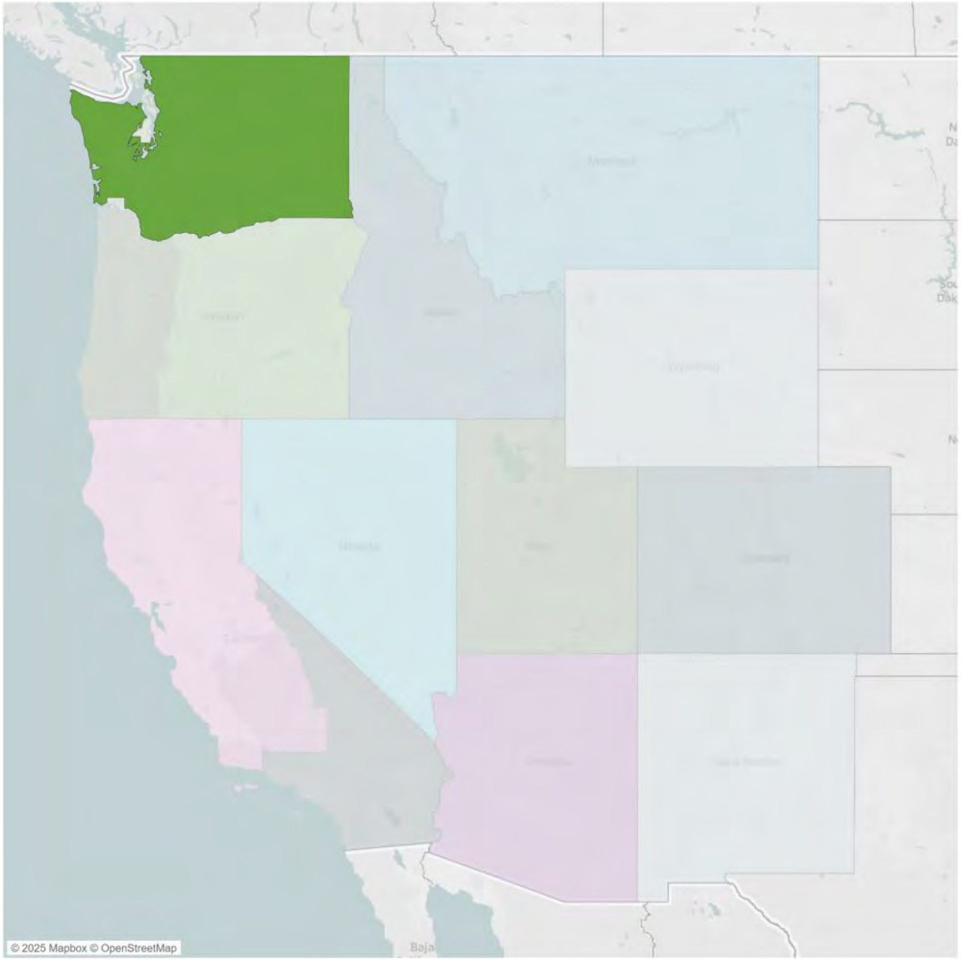
Summary of Energy Pathways Model and Approach

Overview of Modeling Approach



Model Geography: Washington in Western Context

- Washington modeled as part of larger energy system
- All states in the West modeled with their specific energy policies
  - Resource and load diversity
  - Resource competition for Washington
- Transmission between zones modeled with existing transmission capability and the opportunity to expand with an associated cost

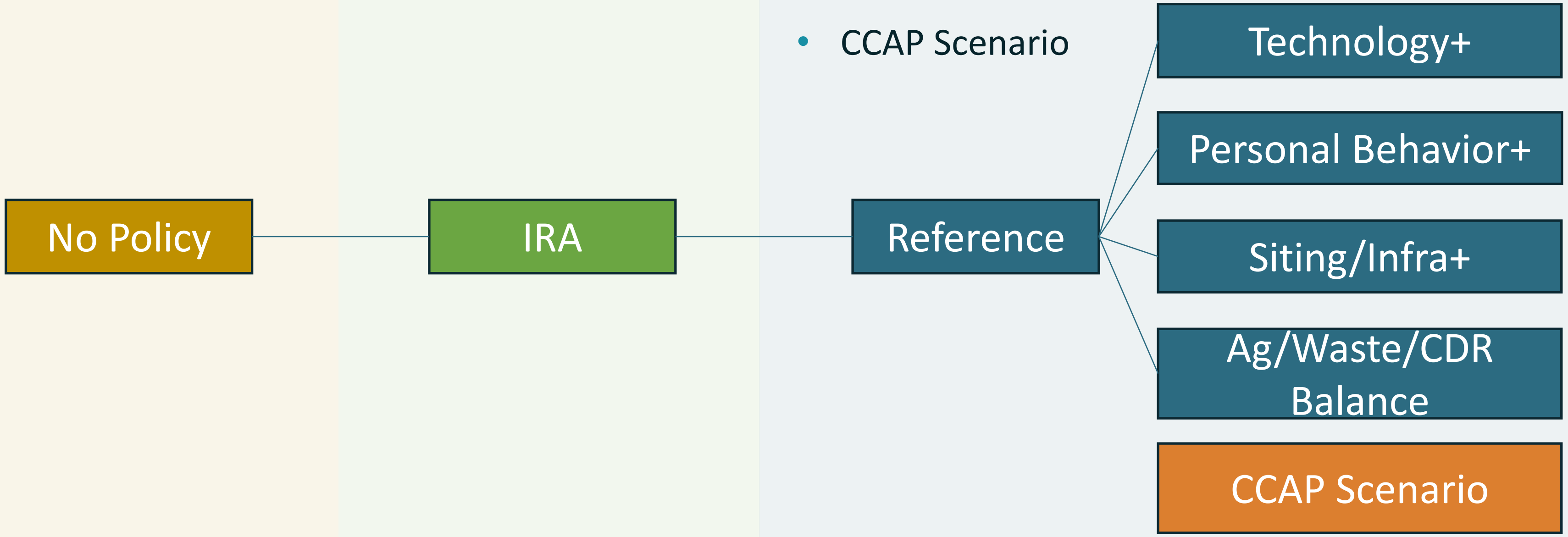


Scenarios

- No federal or state policy/incentives
- Point of comparison to assess all measure impacts

- Federal incentives
- What emissions reductions are driven economically by IRA?

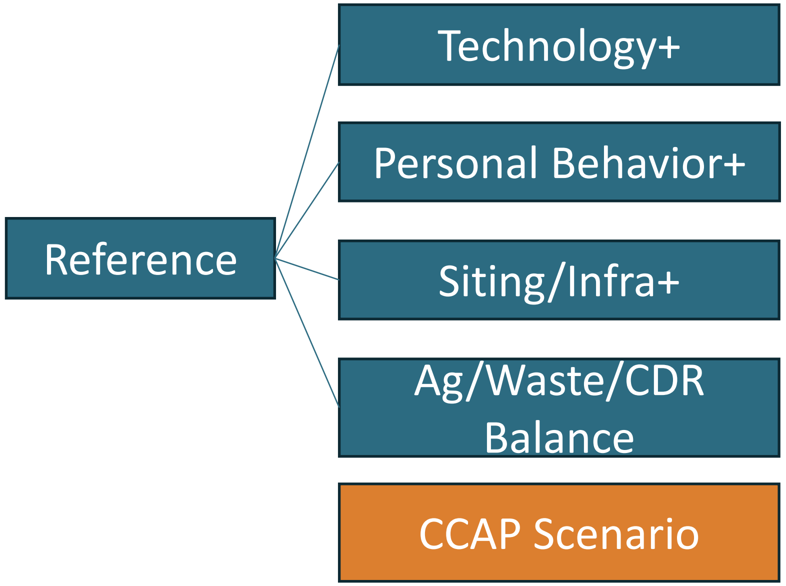
- Meets Washington’s electricity and emissions policy targets
- Reference Scenario – common assumptions
- Explore barriers to achieving targets
- CCAP Scenario



IRA: Inflation Reduction CDR: Carbon Dioxide Removal

Technology & Practice Scenarios

- In the following results we show results for Reference & CCAP scenarios and then Technology & Practice Scenarios
  - Technology & Practice Scenarios refer to the full set of scenarios that achieve Washington's emissions targets
  - These explore different assumptions about technology availability and adoption and customer behavior, as described in the following nine slides



Report Addendum: Update Post-OBBBA

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- The Draft Technical Report was released on June 17, 2025
- In recognition of the changed federal policy landscape, the decision was made to add additional scenarios in the fall of 2025 to reflect changes in clean energy incentives
- These additional scenarios updated the Reference and CCAP scenarios, as shown
- The Reference (final) and CCAP (final) are shown in the final section of this report (pages 173 to 229)

- Updated federal incentives and expiry dates for IRA
- What emissions reductions are driven economically?

- Meets Washington’s electricity and emissions policy targets
- Reference Scenario – common assumptions
- Explore barriers to achieving targets
- CCAP Scenario
- Updated with post-OBBBA assumptions

OBBBA — Reference (final) — CCAP (final)

IRA: Inflation Reduction Act   CDR: Carbon Dioxide Removal

Scenario Assumptions	1. No Policy	2. IRA	3. Reference	4. Technology+	5. Personal Behavior+	6. Siting/Infra+	7. Ag/Waste/CDR Balance	8. CCAP
Clean Electricity Policy	None		CETA; State-by-state clean electricity policy					
Federal Incentives	No IRA incentives	IRA demand and supply side incentives						
Resource Availability	Retain thermal resources if economic and allow new build, TNC TX and RE potential. NREL ATB mid resource prices. Tx and pipeline expansion available in 2035 and onwards. No SMRs. CGS extension option			**Accelerated in state hydrogen adoption to 0.8 GW of electrolyzers by 2030, 4.5 GW by 2035. SMRs (8 modules at CGS, 960 MW) 80 MW by 2030, 960 MW by 2040. 1 GW Offshore wind target by 2040. Enhanced Geo: min 25 MW by 2030, 75 MW by 2040, 175 MW by 2050. 2 MW Tidal**	Same as 1	**Tx and pipeline expansion available in 2030 and onwards**	Same as 1	**Tx expansion from 2033, H2 pipelines from 2032, CO2 pipelines from2033, NH3 pipelines from 2035. Accelerated in state hydrogen adoption to 0.8 GW of electrolyzers by 2030, 4.5 GW by 2035. CGS Extension option. SMRs – Amazon Phase I build out only, 4 SMRs = 320 MW by 2040. No Offshore wind. Enhanced Geo: min 25 MW by 2030, 75 MW by 2040, 175 MW by 2050. 2 MW Tidal**
Clean Fuel Standard	None		Washington, Oregon, California CFS					**New CFS targets**
Economy-Wide GHG Policy	No emissions constraint		WA 45% below 1990 by 2030, 95% below 1990 by 2050; net zero by 2050; Other state targets by 2030; WA 5% gross emissions target					
Non-CO2 emissions	No constraints		WA CH_4 rule, HFC rule, EPA emission reduction supply curves					
CDR and NCS	None		LBNL Roadmap to Removal NCS potential, direct air capture, BECCS, biochar, biomass burial. Opportunities limited by 5% gross emissions cap				**Remove 5% gross emissions cap**	
Buildings: Electrification	AEO 2023 Reference Case	**Princeton REPEAT IRA driven adoption**	Fully electrified appliance sales by 2035, 100% LEDs by 2025	**Heat pump sales: 100% CO2 heat pumps by 2035 (reduced f-gas emissions)**	**Fully electrified appliance sales by 2030**	Same as 3		**Heat pump sales: 50% CO2 heat pumps by 2035 (reduced f-gas emissions)**
Transportation: Light-Duty Vehicles	AEO 2023 Reference Case	**Princeton REPEAT IRA driven adoption**	100% ZEV sales by 2035 (Align with WA Dept of Commerce TES assumptions and ACCII)					
Transportation: Freight Trucks	AEO 2023 Reference Case	**MHDV EPA Phase 3 assumptions**	100% ZEV sales by 2036 (TES assumptions superseded by Advanced Clean Fleets (ACF)					
Transportation: Other	AEO 2023 Reference Case		Maritime, rail: AEO 2023, Air: IATA Roadmap efficiency	**Maritime: 50% domestic, 60% international NH3 by 2050, 20% liquid H2, 10% electric. Rail 40% H2, 20% electricity by 2050. Passenger rail: 80% electric, 20% H2**	**10% reduction in air travel**	Same as 3		**Maritime: 50% domestic, 60% international NH3 by 2050, 20% liquid H2, 10% electric. Rail: 33% H2, 20% electricity by 2050. Passenger rail: 75% electric, 20% H2. 8% reduction in air travel**
Vehicle Miles Traveled	EPA MOVES VMT assumptions		6% decline per capita by 2035 (TES)		**18% decline per capita by 2030, 28% by 2040, 45% by 2050**	Same as 3		**18% 2030, 28% 2040, 32% 2050 per capita decline (L-M-M WSDOT)**
Industry	No process efficiency improvements		1%/yr process efficiency improvements. Fuel switching measures from fuels to electricity from 2030 through 2050	**1.5%/yr process efficiency improvements**	Same as 3			**1.25%/yr process efficiency improvements**
Flexible Load	10% of electric appliance installations by 2050, including space heating, water heating, and air conditioning (linear growth from 0 in 2025) 2/3 of residential electric vehicles in all years and 1/3 commercial vehicles can participate in managed charging No V2G		10% of electric appliance installations by 2050, including space heating, water heating, and air conditioning (linear growth from 0 in 2025) 2/3 of residential electric vehicles in all years and 1/3 commercial vehicles can participate in managed charging No V2G		**50% of electric appliance installations by 2050 Residential electric vehicle managed charging is V2G**	Same as 3		**25% of electric appliance installations by 2050, 2/3 of all electric vehicles in all years can participate in managed charging 50% V2G**

Transportation Sales and Stocks

Input	Reference Case inputs and data assumptions	Technology+	CCAP
Light Duty Vehicle Sales Shares	Carb Tailpipe Rule 100% ZEV sales by 2035 (Align with WA Dept of Commerce TES assumptions and ACCII) DMV registration data for current vehicle stocks: https://data.wa.gov/Transportation/Vehicle-Registration-Transactions-by-Department-of/brw6-jymh/data_preview		
Medium Duty Vehicle Sales Shares	100% ZEV sales by 2036 (TES assumptions superseded by ACF, reaching 100% 9 years earlier)		
Heavy Duty Vehicle Sales Shares	100% ZEV sales by 2036 (TES assumptions superseded by ACF, reaching 100% 9 years earlier)		
Maritime Shipping	EIA Annual Energy Outlook 2023	**Maritime: Ammonia 50% domestic, 60% international by 2050, 20% liquid H2, 10% electric**	**Maritime: Ammonia 50% domestic, 60% international by 2050, 20% liquid H2, 10% electric.**
Vehicle Lifetimes	EER standard assumption (15-year average life with normal distribution)		
Transit Buses	EPA MOVES, Washington Transportation Electrification Strategy		
Rail	EIA Annual Energy Outlook 2023	**Rail 40% H2, 20% electricity by 2050. Passenger rail: 80% electric, 20% H2**	**Rail: 33% H2, 20% electricity by 2050. Passenger rail: 75% electric, 20% H2.**
Aviation	EIA Annual Energy Outlook , IATA Roadmap Efficiency		

Transportation Fuel Economy, VMT, CFS

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Technology	Reference Case inputs and data assumptions	Personal Behavior+	CCAP
Light duty cars and trucks	Alignment of vehicle fuel economy assumptions with California		
Medium duty vehicles	Latest federal fuel economy regulations		
Heavy duty vehicles	Latest federal fuel economy regulations		
Buses	Latest federal fuel economy regulations		
VMT Assumption	6% decline per capita by 2035 (TES)	**18% decline per capita by 2030, 28% by 2040, 45% by 2050**	**18% decline per capita by 2030, 28% 2040, 32% 2050**
Clean Fuels Standard	20% carbon intensity reduction by 2034. Carbon credit accounting to assess compliance with program		**Updated 2025 CFS targets**
Air Travel	Annual Energy Outlook 2023	**10% reduction in air travel by 2035**	**8% reduction in air travel by 2035**

Natural Climate Solutions and CDR

Input	Reference Case inputs and data assumptions	Ag/Waste/CDR Balance	CCAP
Natural Climate Solutions (agricultural practices, forestry, land management)	Robertson et al. (2021) "moderate" potential for NCS in Washington Opportunities limited by 5% gross emissions cap	**Remove 5% gross emissions cap**	**Remove 5% gross emissions cap**
CDR (technological)	Direct air capture, BECCS, biochar, biomass burial Opportunities limited by 5% gross emissions cap	**Remove 5% gross emissions cap**	**Remove 5% gross emissions cap**

Electric Supply Resource Eligibility / RPS / CES

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Input	Reference Case inputs and data assumptions	Technology+	Siting/Infra+	CCAP
Clean Electricity Policy	State-by-state clean electricity policy. Washington: Clean Energy Transformation Act (CETA), 100% clean by 2045, coal retirements by 2025			
Economy-Wide GHG Policy	State targets by 2030; net-zero by 2050 Washington: 45% below 1990 levels by 2030, 70% by 2040, 95% by 2050, Net Zero by 2050			
Clean Electricity Resource Eligibility	Renewables and 100% clean fuels, nuclear, fossil gas with carbon capture			
Resource Availability	Retain thermal resources if economic and allow new build, TNC TX and RE potential. NREL ATB mid resource prices. Tx and pipeline expansion available in 2035 and onwards. No SMRs. CGS extension option	**Accelerate in state hydrogen adoption to 4.5GW by 2030 (stretch goal from 2024 Commerce Hydrogen Study).Accelerate CCUS. SMRs (8 modules at CGS, 960 MW). 1 GW offshore wind target. Enhanced Geo: min 25 MW by 2030, 75 MW by 2040, 175 MW by 2050. 2 MW Tidal**	**Tx and pipeline expansion available in 2030 and onwards**	**Tx expansion from 2033, H2 pipelines from 2032, CO2 pipelines from2033, NH3 pipelines from 2035. Accelerated in state hydrogen adoption to 0.8 GW of electrolyzers by 2030, 4.5 GW by 2035. SMRs – Amazon Phase I build out only, 4 SMRs = 320 MW by 2040. No Offshore wind. Enhanced Geo: min 25 MW by 2030, 75 MW by 2040, 175 MW by 2050. 2 MW Tidal**
CES Constraint	CETA: Coal retirements 2025; 100% carbon neutral 2030 (with alternative compliance); 100% RE 2045			
Inflation Reduction Act Incentives	Supply-side incentives included for hydrogen production, renewable electricity generation, battery storage, carbon sequestration, clean fuels, and nuclear			

DER Adoption and Participation

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Input	Reference Case inputs and data assumptions	Personal Behavior+	CCAP
BTM PV	NWPCC 2024 Power Plan rooftop solar forecast		
BTM Storage Adoption	Installed systems but none participate in offering grid services so not tracked by the model		
BTM Storage Parameters	N/A		
Flexible Loads	10% of electric appliance installations by 2050, including space heating, water heating, and air conditioning (linear growth from 0 in 2025) 2/3 of residential electric vehicles in all years and 1/3 commercial vehicles can participate in managed charging No V2G	**50% of electric appliance installations by 2050**	**25% of electric appliance installations by 2050, 2/3 of all electric vehicles in all years can participate in managed charging**
V2G	None (charging only)	**Residential electric vehicle managed charging is V2G**	**50% of residential electric vehicle managed charging is V2G**
Flexible Load Parameters	Space heating loads can be delayed or advanced by 1 hour Water heating loads can be delayed or advanced by up to 2 hours Air conditioning can be delayed or advanced by 1 hour Residential vehicle charging can be delayed by up to 8 hours and commercial vehicle charging up to 3 hours		
Data Centers	NWPCC Forecast on top of existing data center loads		

Building Electrification

Input	Characterizing existing stocks, energy demand, and emissions	Reference Case inputs and data assumptions	Technology+	Personal Behavior+	CCAP
Residential Space Heating	NEEA RBSA, benchmarked with EIA SEDS for Washington	Fully electrified appliance sales by 2035, woodstoves remain by are supplemented with heat pump for hybrid heating shape	**Heat pump sales: 100% CO_2 heat pumps by 2035 (reduced f-gas emissions)**	**Fully electrified appliance sales by 2030**	**Heat pump sales: 50% CO_2 heat pumps by 2035 (reduced f-gas emissions)**
Commercial Space Heating	NEEA CBSA, benchmarked with EIA SEDS	Fully electrified appliance sales by 2035	**Heat pump sales: 100% CO_2 heat pumps by 2035 (reduced f-gas emissions)**		**Heat pump sales: 50% CO_2 heat pumps by 2035 (reduced f-gas emissions)**
Residential Water Heating	NEEA RBSA, benchmarked with EIA SEDS	Fully electrified appliance sales by 2035	**Heat pump sales: 100% CO_2 heat pumps by 2035 (reduced f-gas emissions)**		**Heat pump sales: 50% CO_2 heat pumps by 2035 (reduced f-gas emissions)**
Commercial Water Heating	NEEA CBSA, benchmarked with EIA SEDS	Fully electrified appliance sales by 2035	**Heat pump sales: 100% CO_2 heat pumps by 2035 (reduced f-gas emissions)**		**Heat pump sales: 50% CO_2 heat pumps by 2035 (reduced f-gas emissions)**
Cooking	NEEA RBSA and CBSA	Fully electrified appliance sales by 2035			
Other Appliances	NEEA RBSA and CBSA	Fully electrified appliance sales by 2035			

Industrial Efficiency and Electrification

Input	Reference Case starting point inputs and data assumptions	Technology+	CCAP
Industrial Process Efficiency	1% efficiency improvements per year in all sectors	**1.5%/yr process efficiency improvements**	**1.25%/yr process efficiency improvements**
Electrification	100% of machine drives by 2035 100% of low temperature heat by 2050 50% of integrated steam production, and 80% of integrated steam production in food manufacturing, by 2045 100% of refrigeration by 2040 90% of industrial HVAC loads across industrial subsectors 80% of industrial vehicles including in agriculture by 2050		
Switch to Hydrogen	50% of heat in bulk chemicals 20% of construction energy demand 20% of industrial vehicles by 2050		

Industrial Efficiency and Electrification

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Input	Reference Case inputs and data assumptions
Cement	Cement process is optimized in the model, including retrofits and new build rotary kilns to include direct separation, oxy-combustion, biomass fuel, and CCS, as well as limestone calcined clay cement (LC^3) technology
Thermal Energy Storage	Economic adoption modeled in industrial sector
Hybrid Boilers	Model can invest in dual fuel electric and gas boilers as well as hydrogen boilers

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Demand-side Results

Demand-Side Overview

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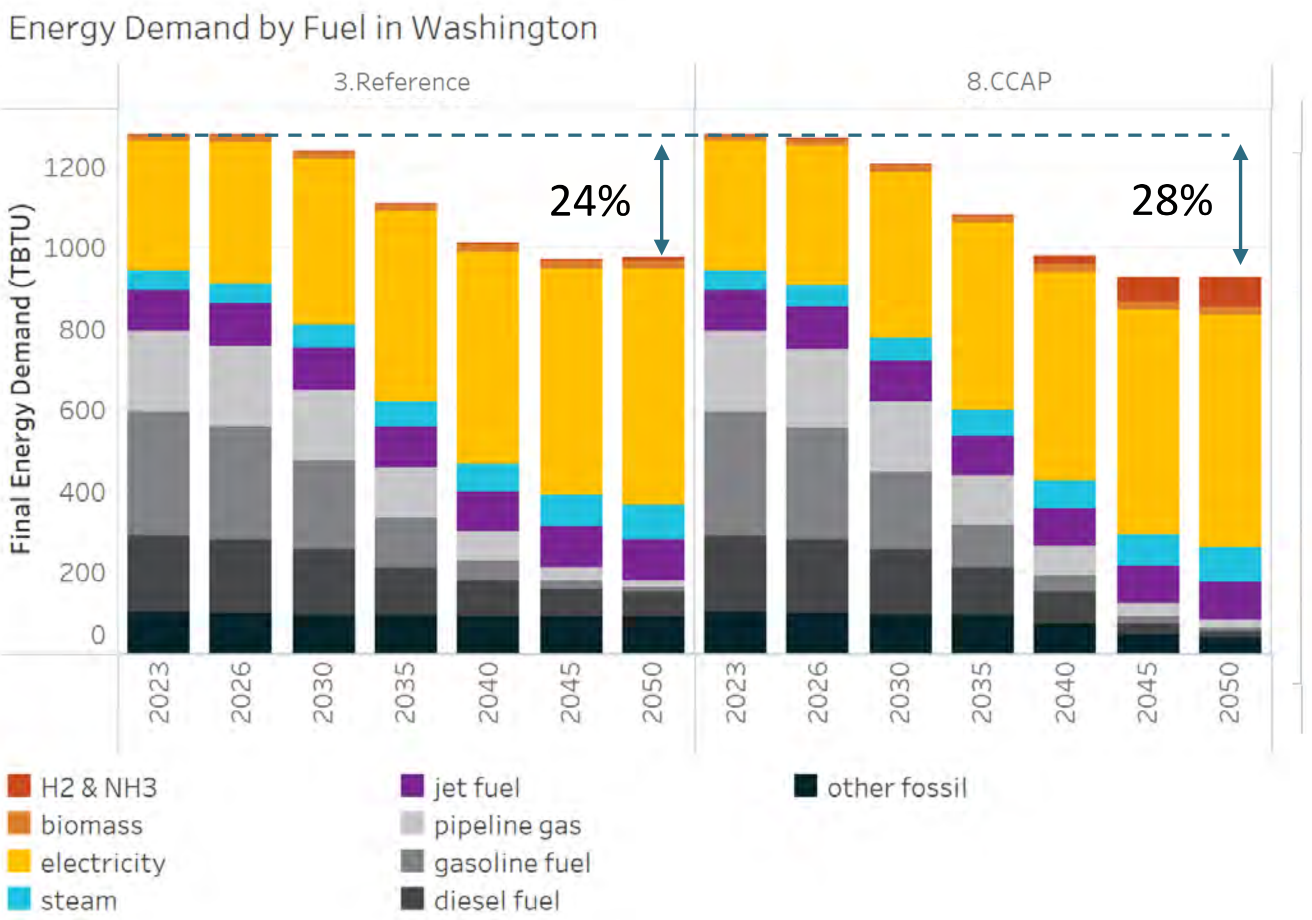
- The demand-side results describe how transformation of energy-consuming technologies progresses through 2050
- Incorporates data sources from Reference Scenario development, projected impact of IRA on technology adoption, and transformation assumptions developed when scoping the scenarios
  - Sales shares specified for the Reference Scenario
  - Efficiency gains
  - Stock forecasts, including the impact of population and productivity growth

IRA: Inflation Reduction Act

Energy Demand by Fuel
Reference & CCAP Scenarios

- Overall energy demand decrease is driven by efficiency gains, mostly from fuel switching to electricity
- Economy-wide energy demand drops by 24% in the Reference Scenario and 28% in the CCAP Scenario



Note: "other fossil" includes fuel oil, LPG, oil, coal, and petroleum coke; H2 = hydrogen; NH3 = ammonia

Energy Demand by Fuel Technology & Practice Scenarios

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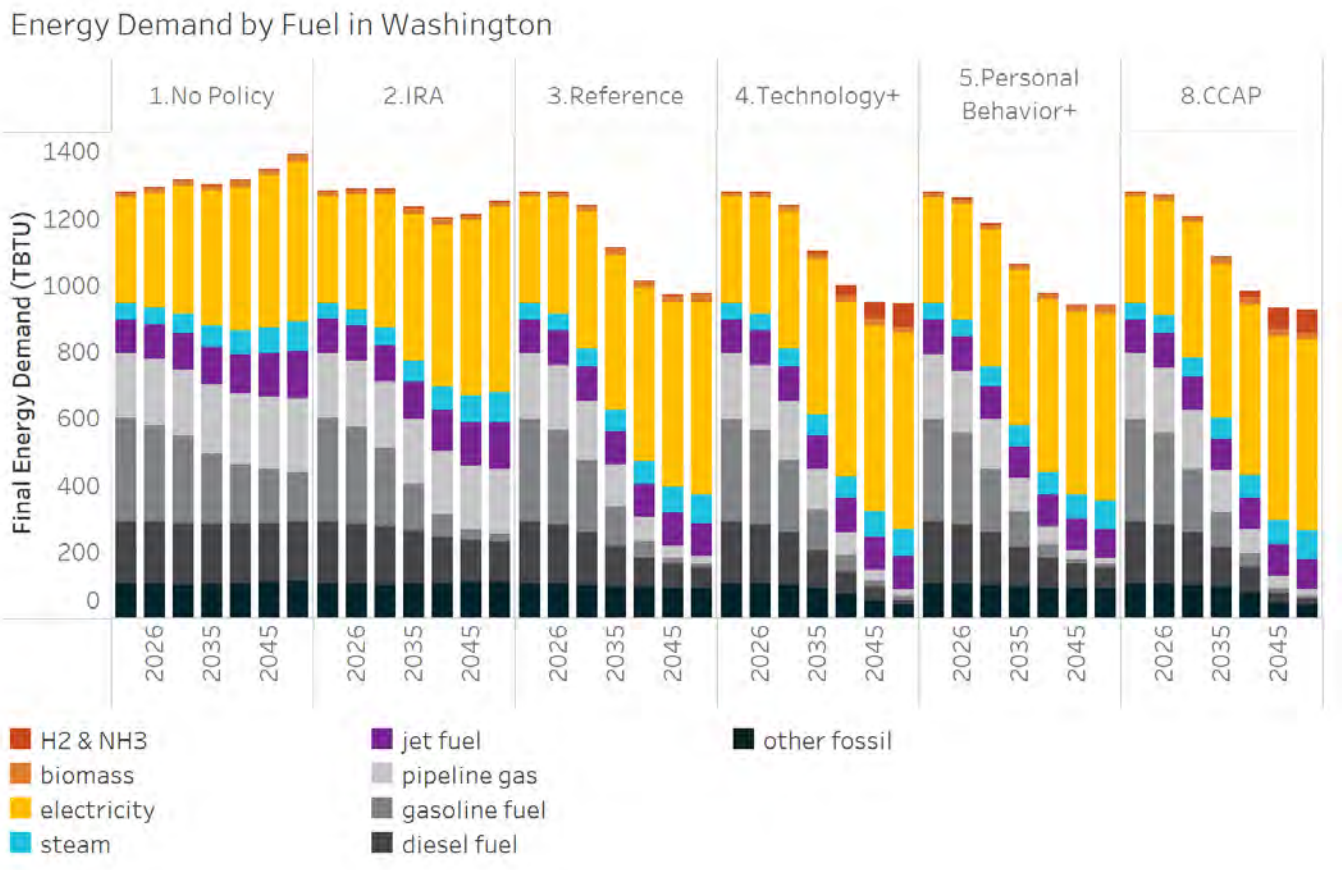
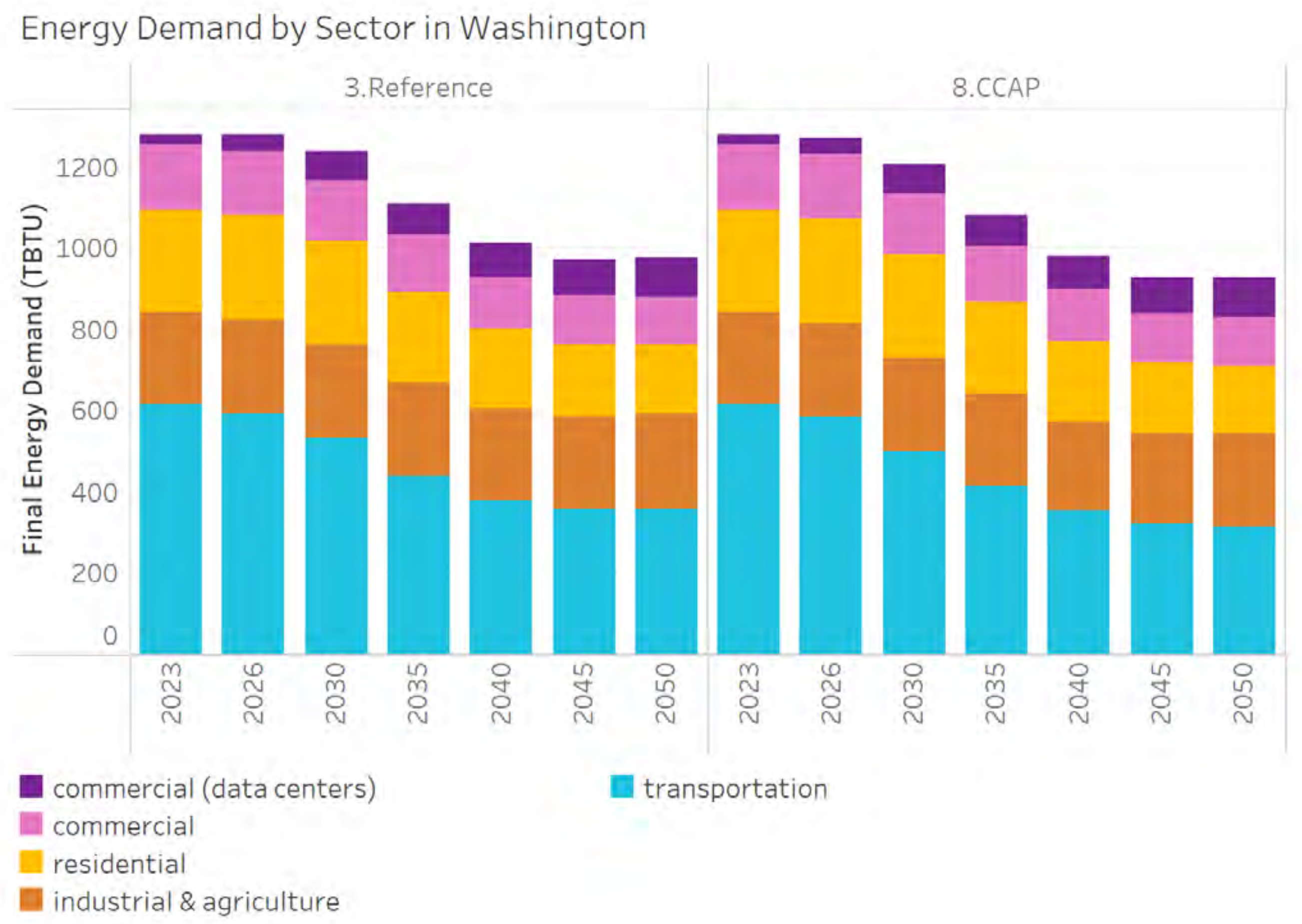
- Energy demand decreases in Technology+ compared the Reference Scenario as non-road transportation is partly electrified and industrial efficiency improvements increase
- Personal Behavior+ also sees reduced energy demand relative to the Reference Scenario as vehicle miles traveled and air travel decrease
- The CCAP scenario takes elements of Technology+ and Personal Behavior+



Note: "other fossil" includes fuel oil, LPG, oil, coal, and petroleum coke; H2 = hydrogen; NH3 = ammonia

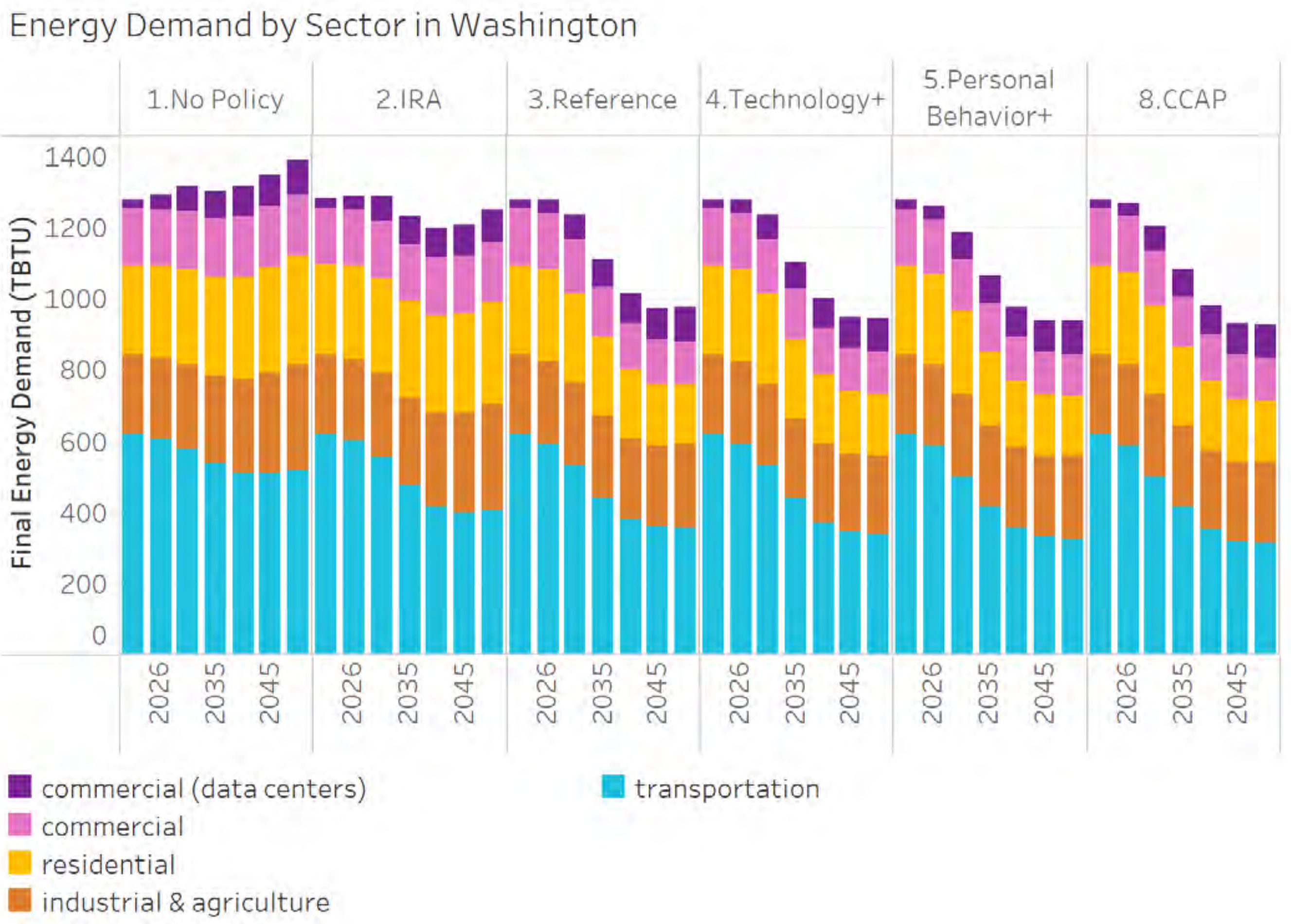
Energy Demand by Sector Reference & CCAP Scenarios

- Transportation efficiency gains are the largest contributor to energy demand reductions
  - Electric drivetrains are highly efficient compared to the internal combustion engines (ICE) they replace
- Residential and commercial appliances gain in efficiency as heat pump systems displace gas boilers, and appliances generally become more efficient



Energy Demand by Sector Technology & Practice Scenarios

- The most pronounced differences across scenarios by sector are in transportation and industry
- Technology+ accelerates industrial efficiency improvements and partially electrifies non-road transportation
- Personal Behavior+ reduces vehicle miles traveled and air travel
- CCAP combines elements of the other scenarios



Electricity Demand
Reference & CCAP Scenarios

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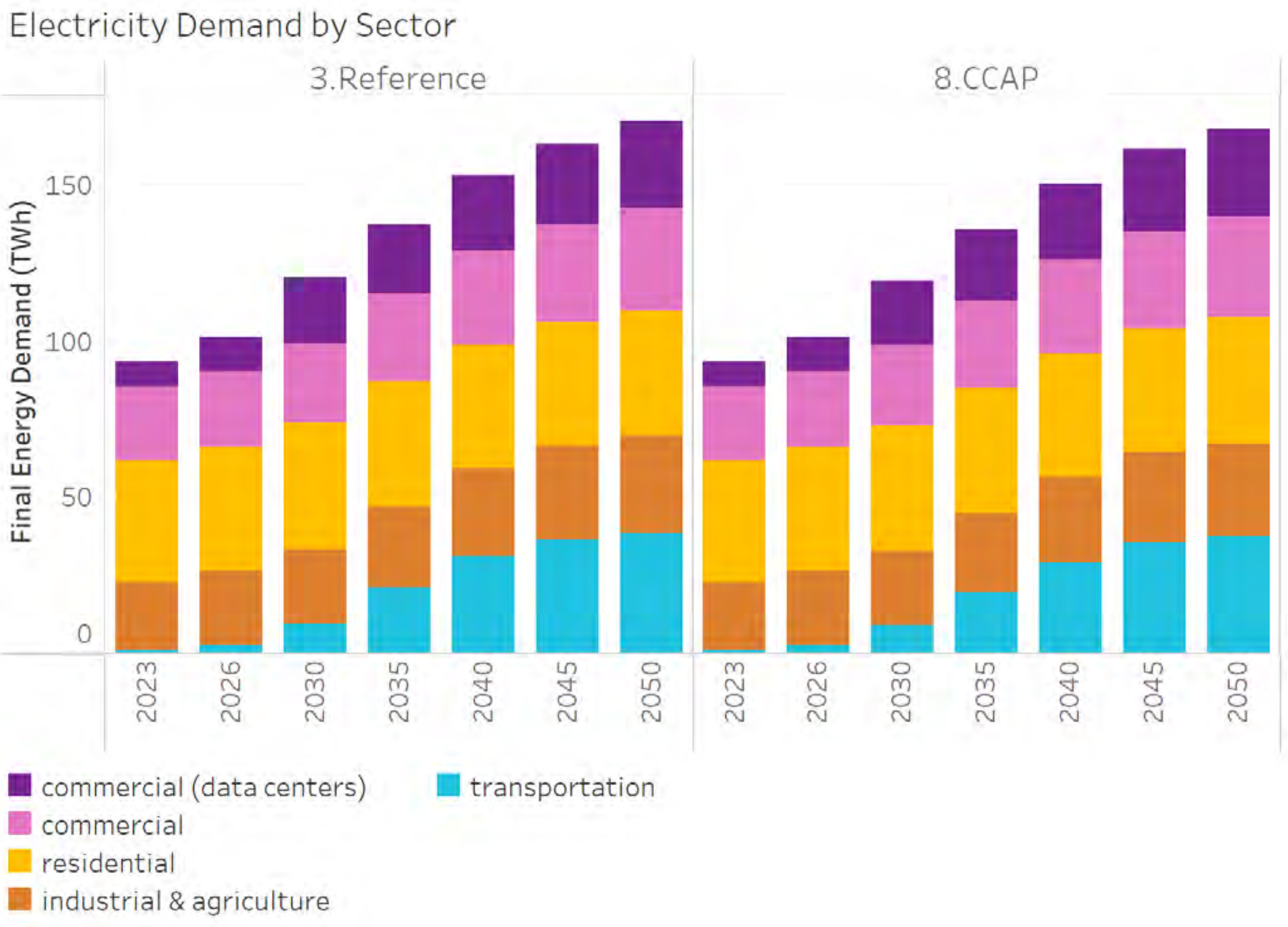
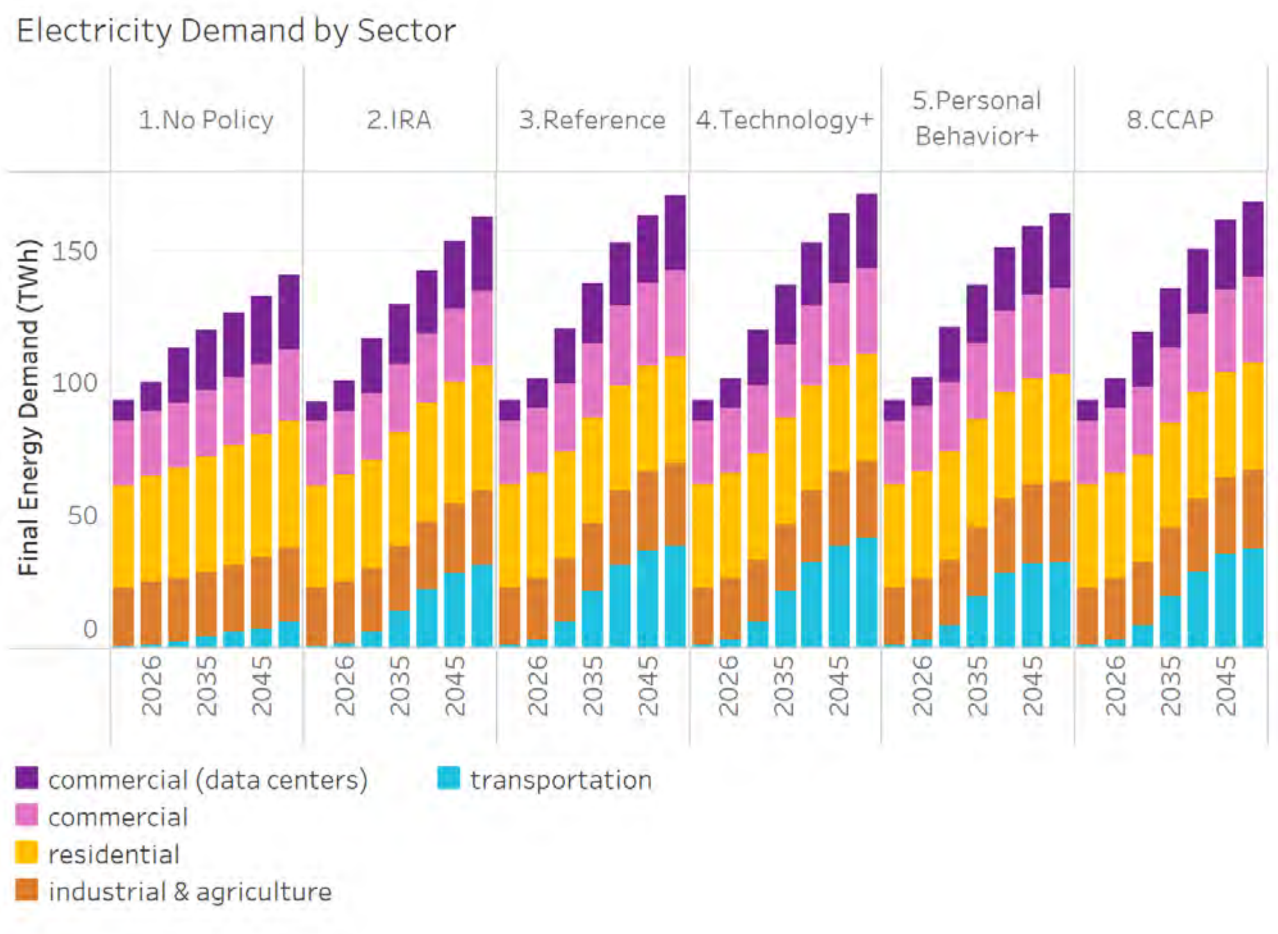
- Electricity final energy demand increases by 83% in the Reference and 80% in the CCAP Scenarios
  - Does not include electricity that is converted to other forms of energy before final demand, such as electricity for electrolysis
- Electricity demand grows in all sectors of the economy. In the Reference Scenario:
  - New transportation loads drive 65% of all growth from 2023 to 2050, not including data centers
  - 260% growth of data centers



Electricity Demand
Reference & CCAP Scenarios

EVOLVED ENERGY RESEARCH

- Electricity final energy demand increases by 83% in the Reference and 80% in the CCAP Scenarios
  - Does not include electricity that is converted to other forms of energy before final demand, such as electricity for electrolysis
- Transportation is the largest differentiator across scenarios



Residential Space Heating

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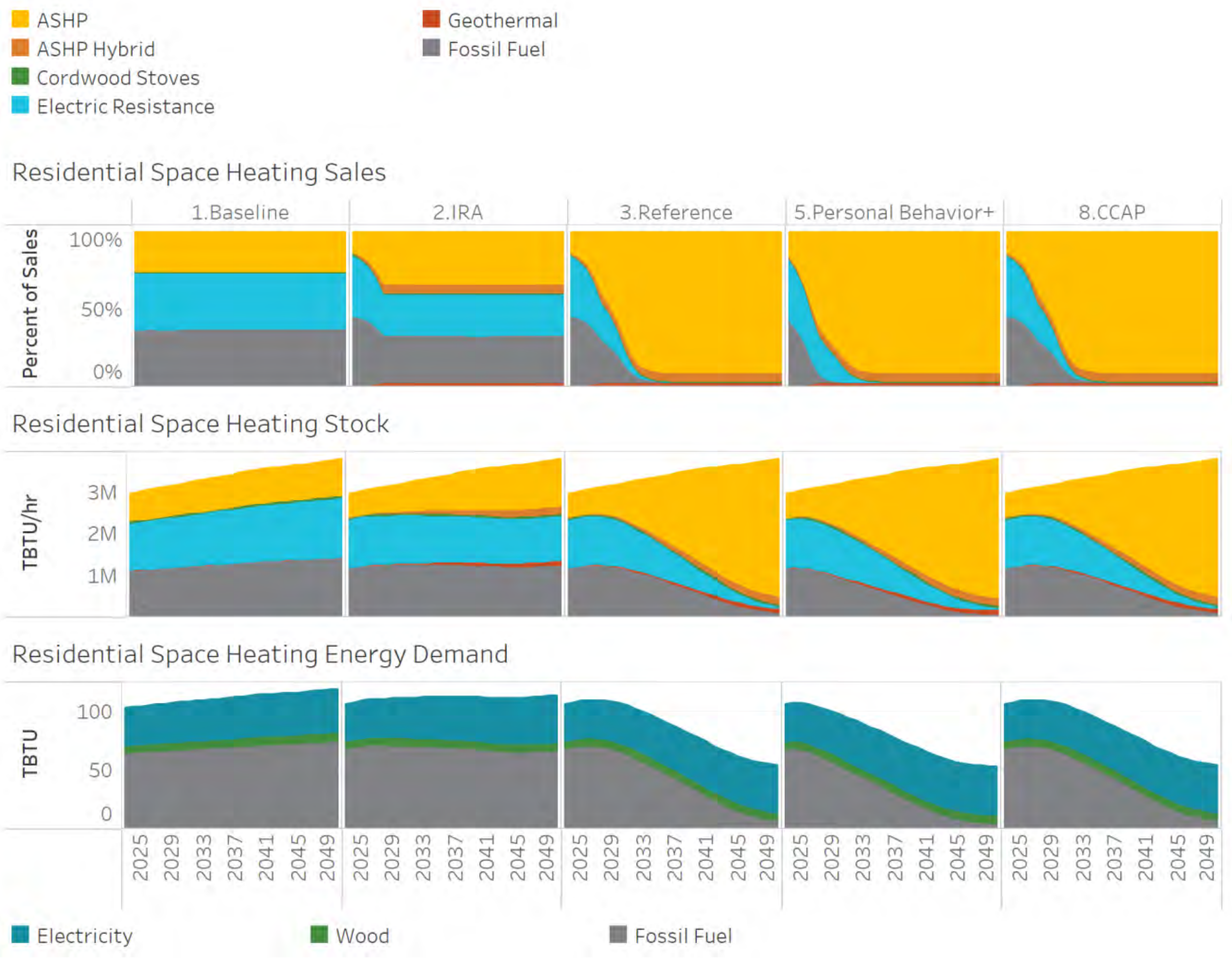
- Fuel switching to electric heat pumps drives down overall energy demand
- Fully electrified appliance sales by 2035
- Wood burning stoves supplemented with hybrid systems

ASHP: Air Source Heat Pump



Commercial Space Heating

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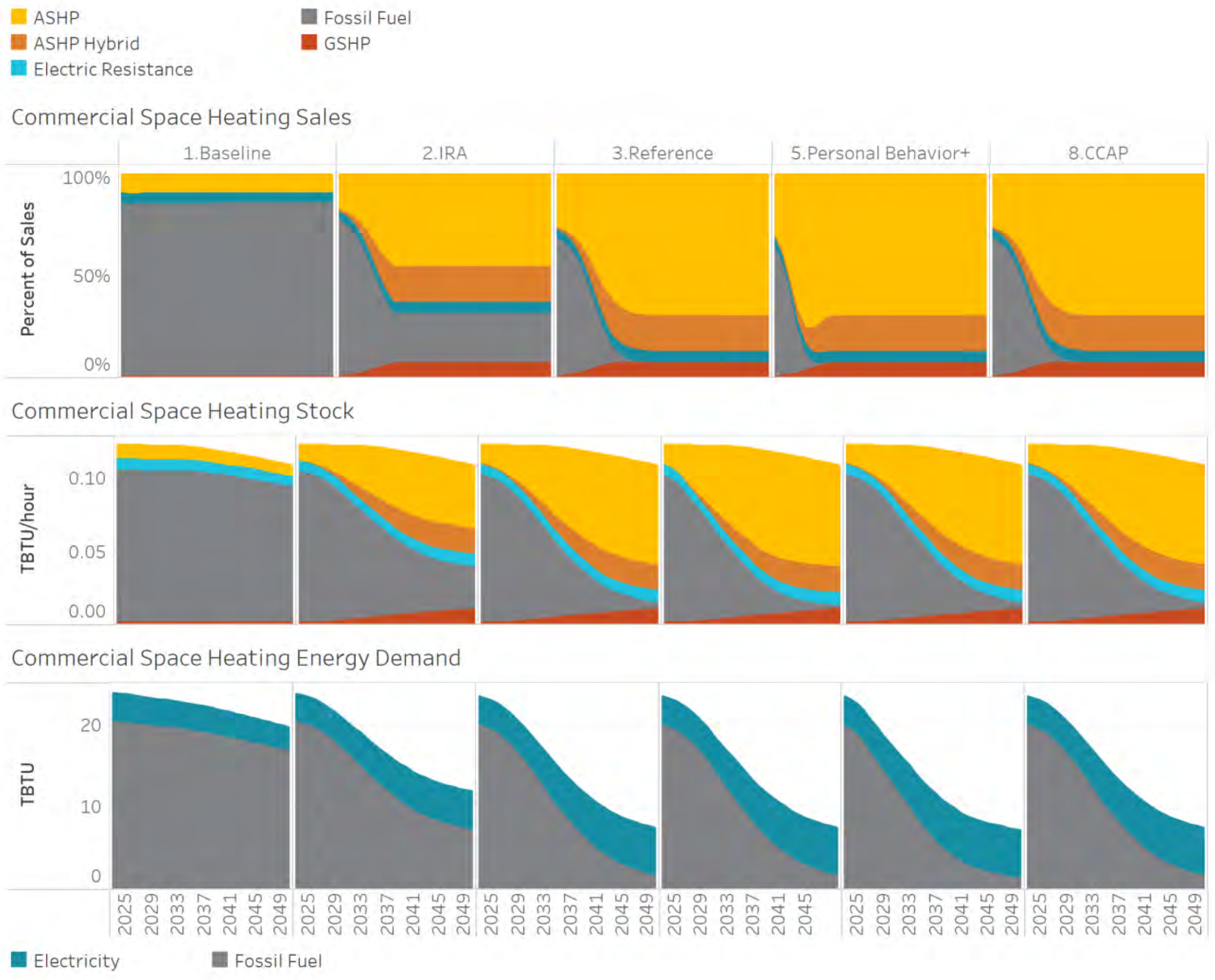
- Personal Behavior+ accelerates electrification to achieve 100% electric appliance sales by 2030 instead of 2035



ASHP: Air Source Heat Pump GSHP: Ground Source Heat Pump

Light Duty Vehicle Sales, Stock, Energy

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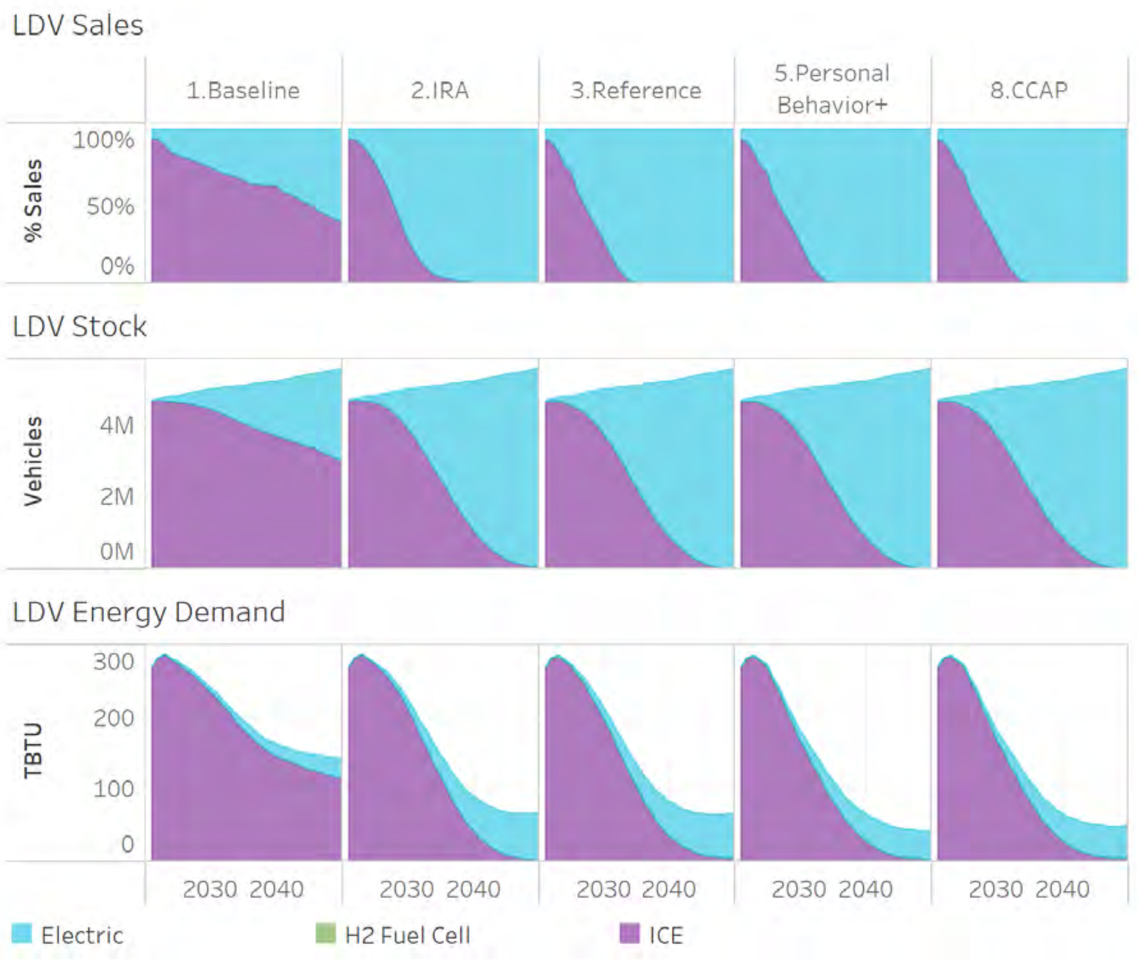
- 100% zero emissions vehicle sales achieved in 2035
  - Aligned with ACC II
- Drop in energy demand from both better drive chain efficiency and 6% reduction in vehicle miles traveled by 2035 in Reference Scenario
- Personal Behavior+ includes 18% decline in VMT per capita by 2030, 28% by 2040, 45% by 2050
- CCAP Scenario includes 18% decline in VMT per capita by 2030, 28% 2040, and 32% 2050, aligned with Washington Department of Transportation's Low, Medium, and Medium projections by year, respectively



Impact of VMT Measures

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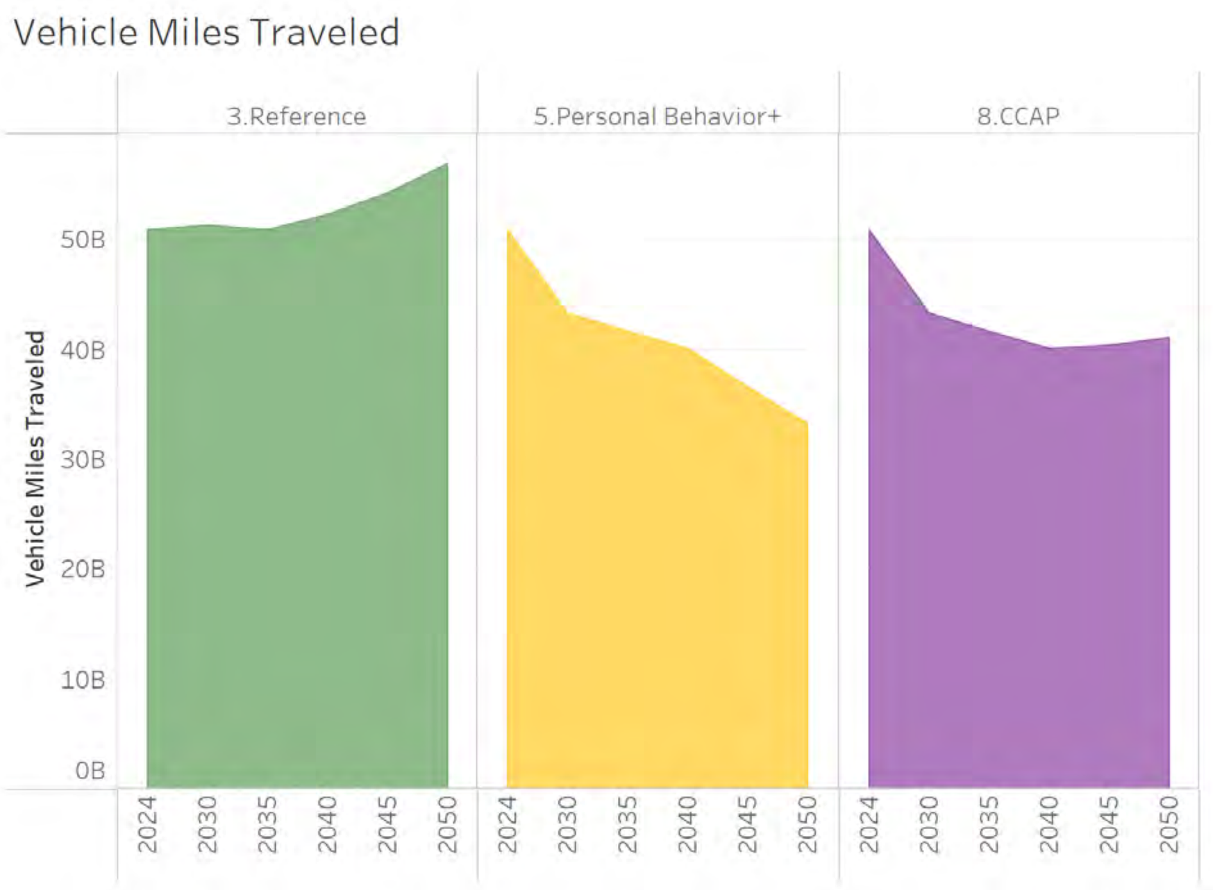
- Personal Behavior+ includes significant reduction in VMT in light-duty vehicles
  - 18% decline per capita by 2030, 28% by 2040, 45% by 2050
- Middle ground taken in CCAP:
  - 18% by 2030, 28% by 2040, 32% by 2050 per capita decline (aligned with Washington Department of Transportation's Low, Medium, and Medium projections by year, respectively)



VMT: Vehicle Miles Traveled

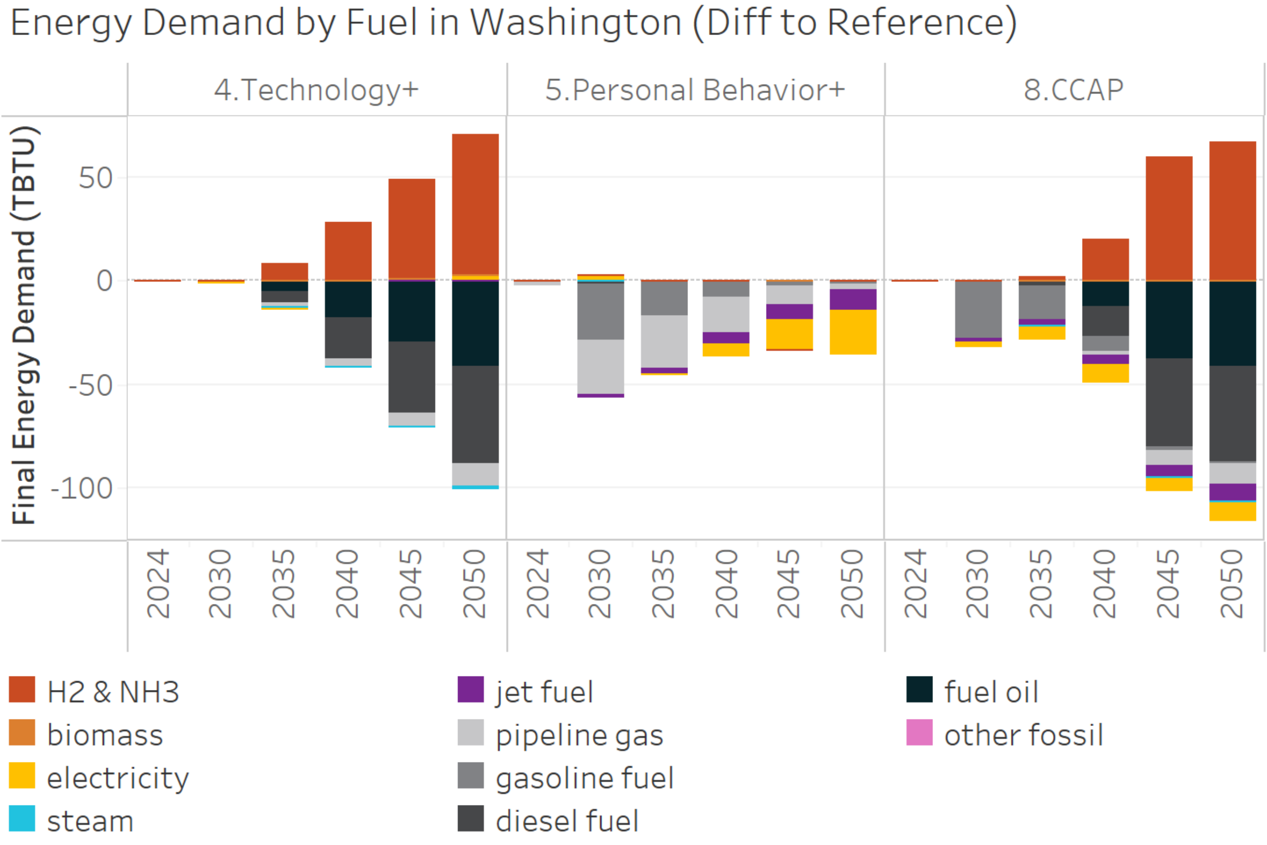
Reference Scenario
Medium and Heavy-Duty Vehicles

- 100% ZEV by 2036
  - Advanced Clean Fleets trajectory
  - Negligible fuel cells, reflecting the Transportation Electrification Study

ZEV: Zero Emission Vehicle

Tech+, Personal Behavior+, & CCAP Scenarios Energy Demand

- Tech+: Measures applied to other forms of transportation drive increased demand for ammonia, hydrogen, and electricity, avoiding liquid fuels
- Personal Behavior+: Decline in pipeline gas use, liquid fuels, and in later years electricity because of VMT reductions and greater buildings electrification
- CCAP: Takes elements of the other scenarios we analyzed



VMT: Vehicle Miles Traveled
CCAP: Comprehensive Climate Action Plan

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Supply-side Results

Supply-side Overview

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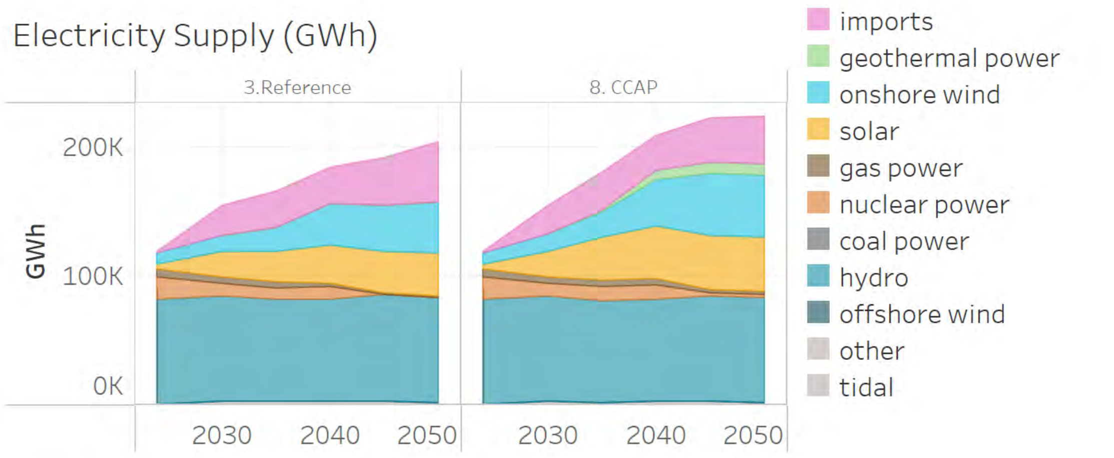
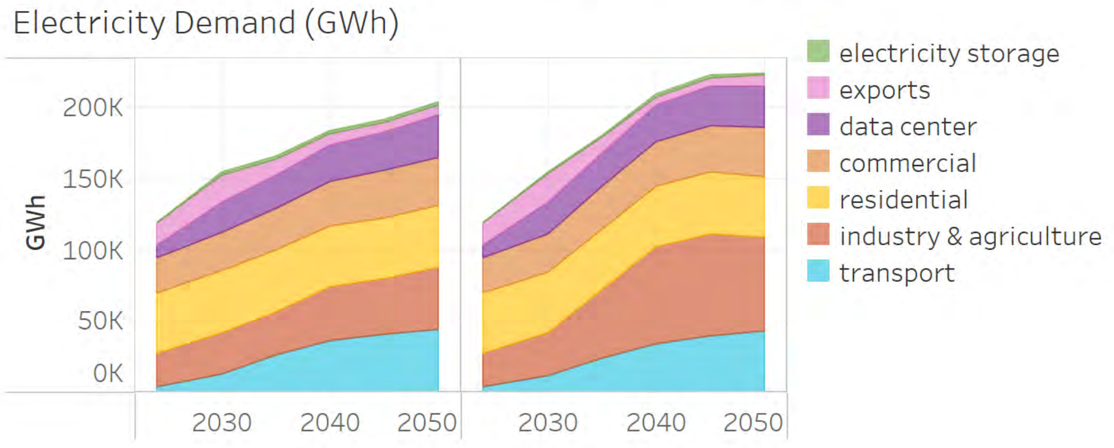
- This section answers the question "**How do we serve the energy demands of the economy at least cost?"**
  - Subject to the constraints defined for the Reference Scenario, such as electricity policy, emissions policy, resource availability, etc.
- Supply-side analysis is concerned with investments in physical infrastructure and system operating costs
  - How many MWs of solar/batteries/transmission/conversion technologies, etc., should we invest in?
  - How much fuel should we purchase?
- Analysis does not answer questions about distributional impacts of investments
  - e.g., What rate do customers pay for electricity for their electric vehicles?
  - However, it does aim to minimize the size of the total cost pie that must be distributed among customers – a strong basis for further work in policy design

Washington Electricity Generation & Consumption Reference and CCAP Scenarios

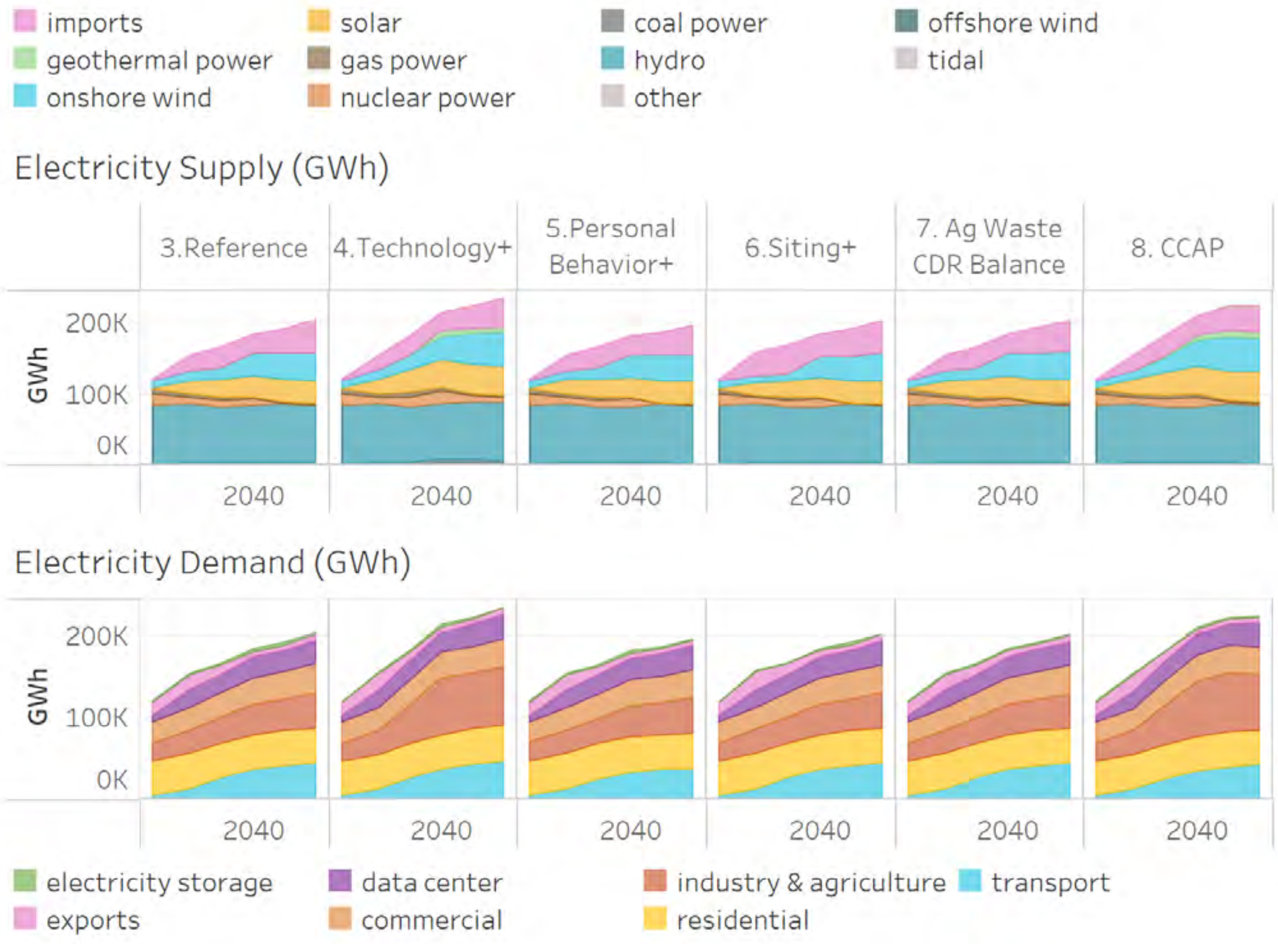
- System changes by 2030
  - Renewable growth
  - Data centers and transport electrification are largest drivers of load growth
  - Increasing imports
- System changes by 2050
  - Data center growth at a slower rate from 2030
  - Additional load growth from electrification
  - Imports play an increasingly important role in meeting Washington's energy needs
  - Gas plays a role in reliable system operations





Electricity Generation & Consumption by Scenario Technology & Practice Scenarios

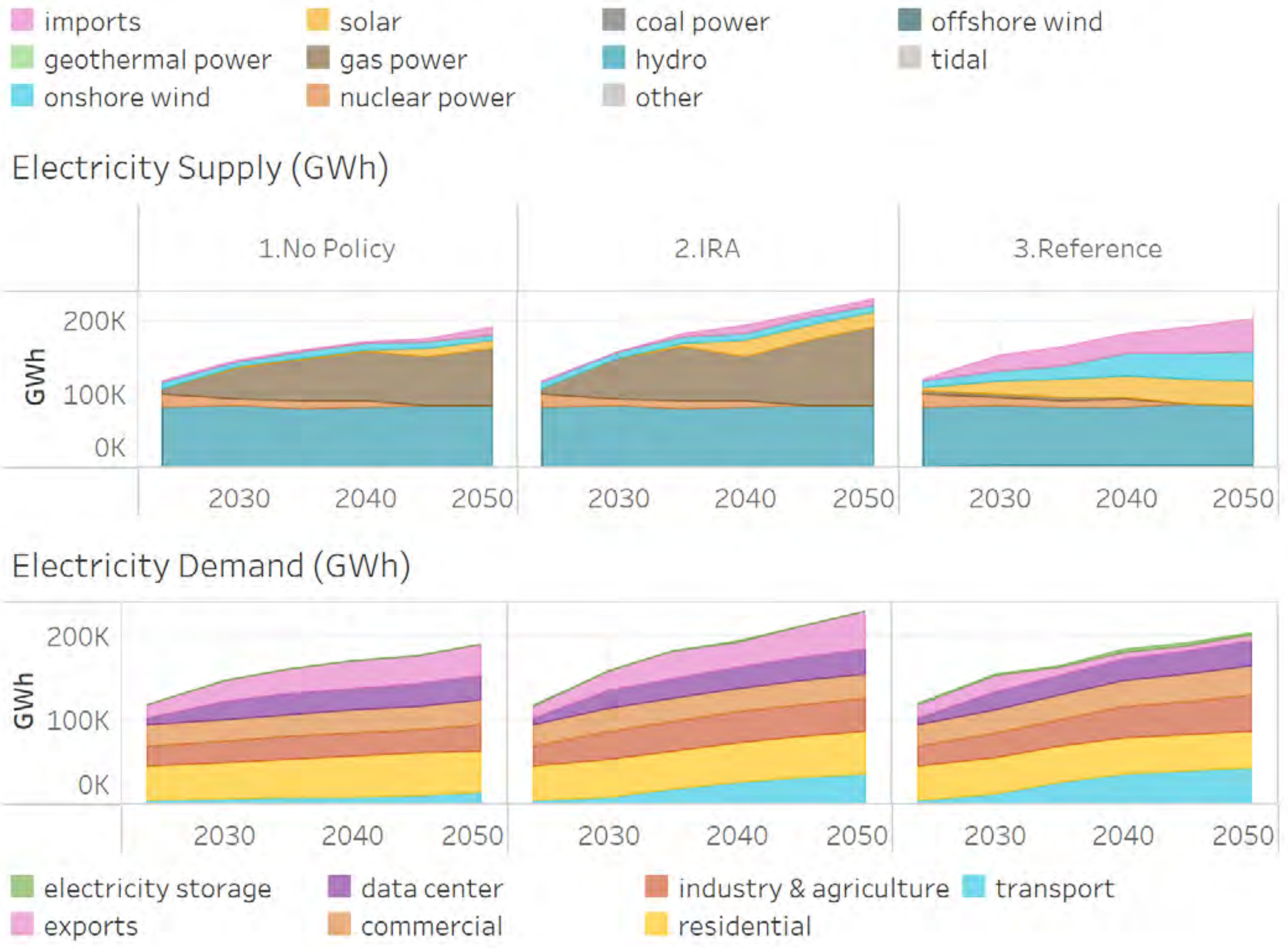
- Technology+ includes significant new load from electrolysis additions in Washington
  - Increased loads accompanied by fewer imports as geothermal power generation ramps up as well as nuclear from SMRs
- Smaller power sector in Personal Behavior+ due to reductions in transportation sector demand
  - Passenger cars and trucks make up only a fraction of the total transportation sector
- Siting+ relies more heavily on imports in early years, decreasing in-state onshore wind generation



SMR: Small Modular Reactor

Washington Electricity Generation & Consumption Comparison to No Policy

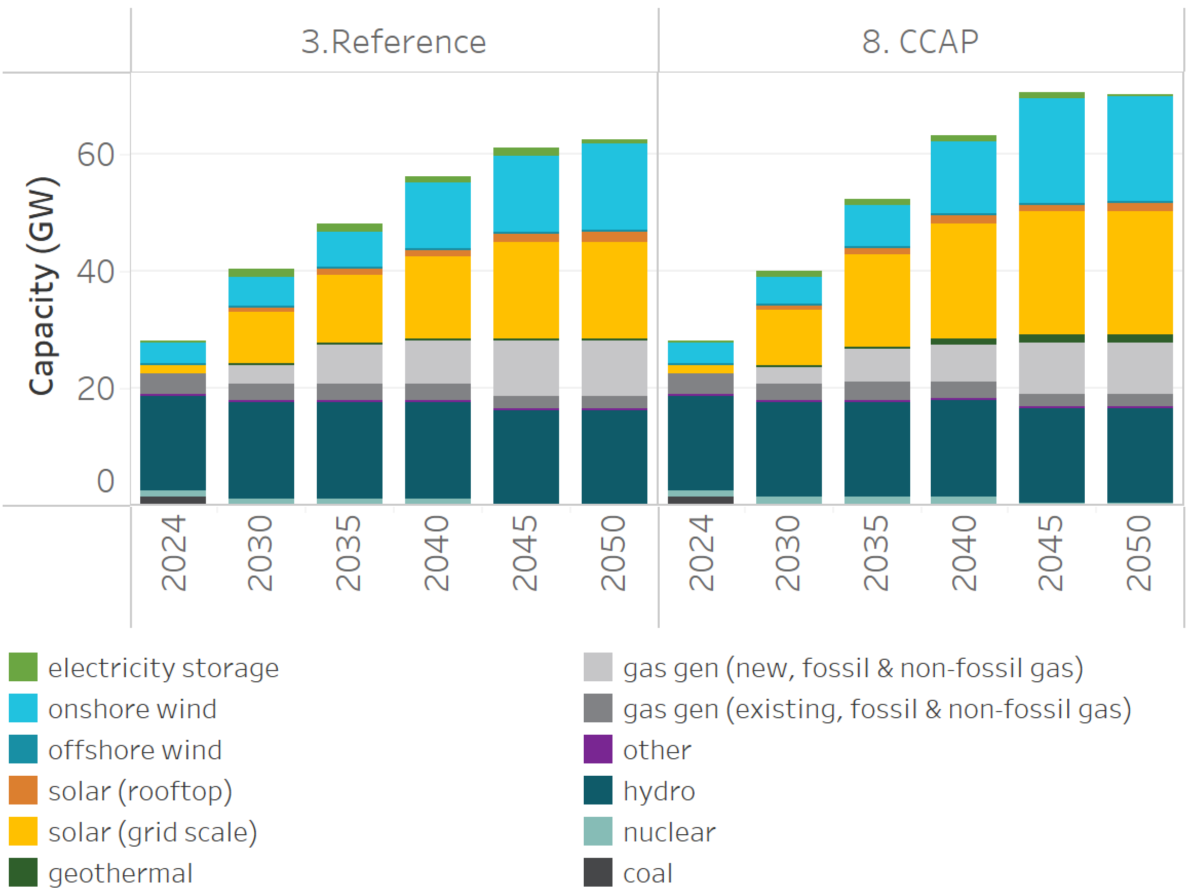
- Growth in gas power production under No Policy and IRA Scenarios
  - Unrealistic, but useful point of comparison for Washington energy and emissions policy
- High rate of load growth by 2030 in all scenarios in the study
  - Data centers are largest near-term source of new load
  - Met with gas power in No Policy and IRA Scenarios and a mix of clean imports and renewables in the Reference
- Washington remains a net exporter in No Policy and IRA Scenarios and becomes a net importer in the Reference Scenario



Washington Installed Capacity Reference and CCAP Scenarios

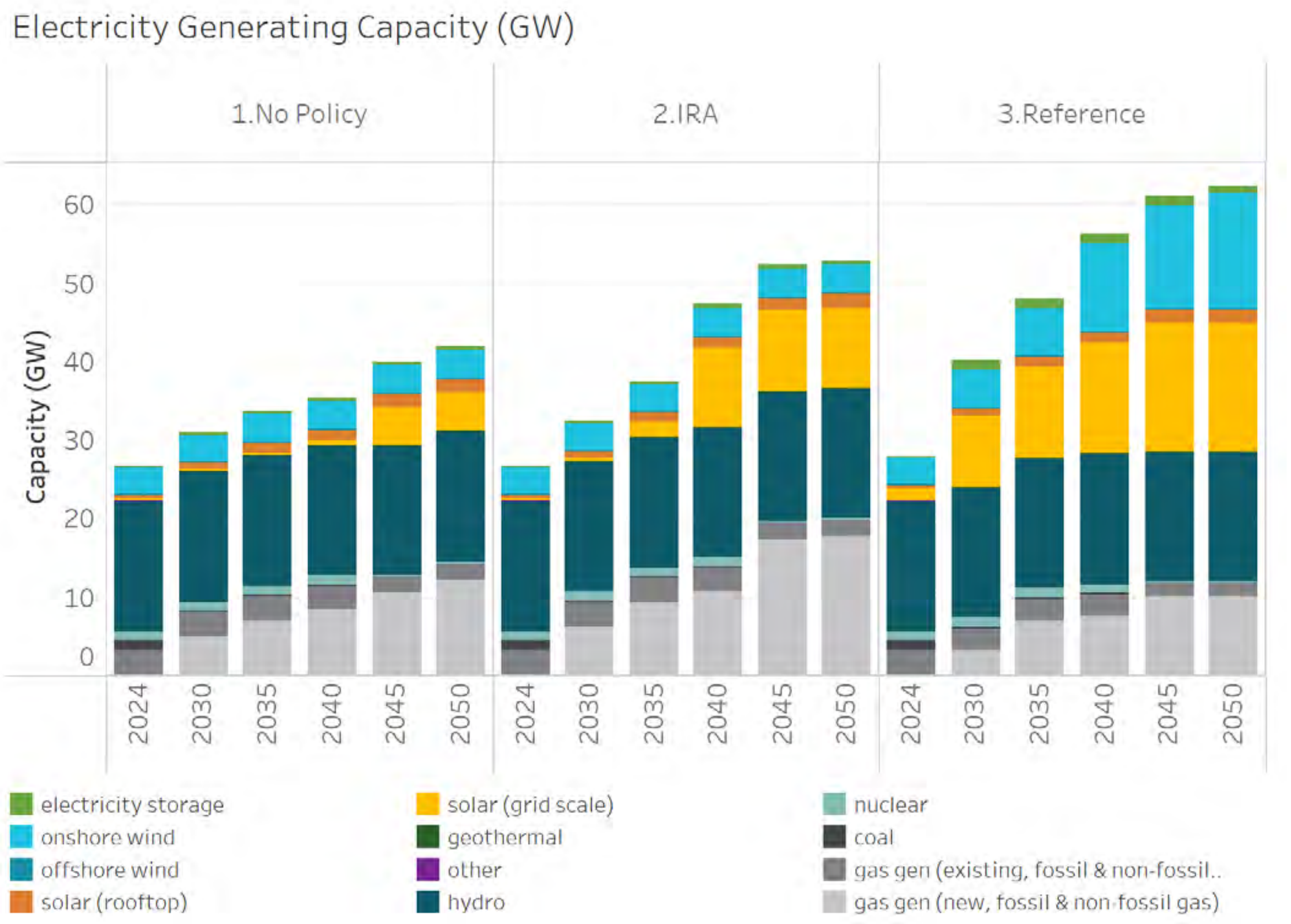
- Capacity growth in Washington
  - Solar and wind growth
  - Gas capacity growth offering reliability with clean fuels in future years
- Columbia Generating Station retired in 2043
- Model sees the addition of more gas power capacity than in previous pathways studies
  - Data center load is much higher driving additional capacity needs

Electricity Generating Capacity (GW)



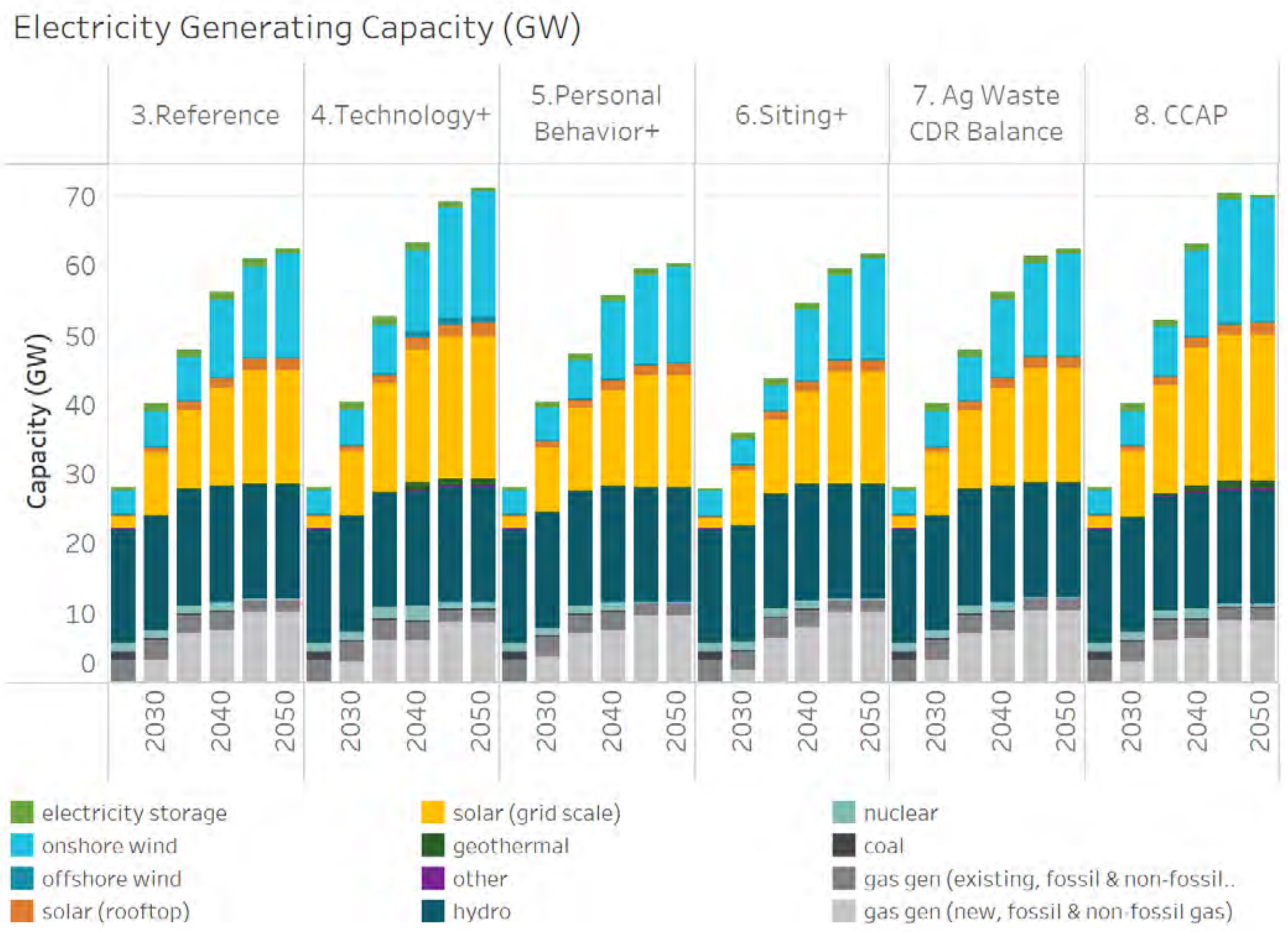
Washington Installed Capacity by Zone Comparison to No Policy Scenario

- Gas capacity in No Policy and IRA Scenarios utilized for energy and operated at high-capacity factors fueled by fossil
- Gas capacity for reliability in the Reference and used infrequently fueled by clean gas
- IRA incentives and economics drive similar levels of solar investment in the IRA Scenario compared to Reference Scenario
- In-state wind investment dependent on Washington clean electricity and emissions policy



Installed Capacity by Scenario
Technology & Practice Scenarios

- Large capacity additions of wind and solar in all scenarios
- Technology+ Scenario includes significant investment in geothermal, 1 GW of offshore wind, and nuclear SMRs
  - Increased growth in capacity meets larger loads and displaces imports
- Siting+ Scenario reduces the need for capacity growth in the near-term
  - Trading investment in renewables for investment in transmission



CCAP Scenario
Generation Capacity Map

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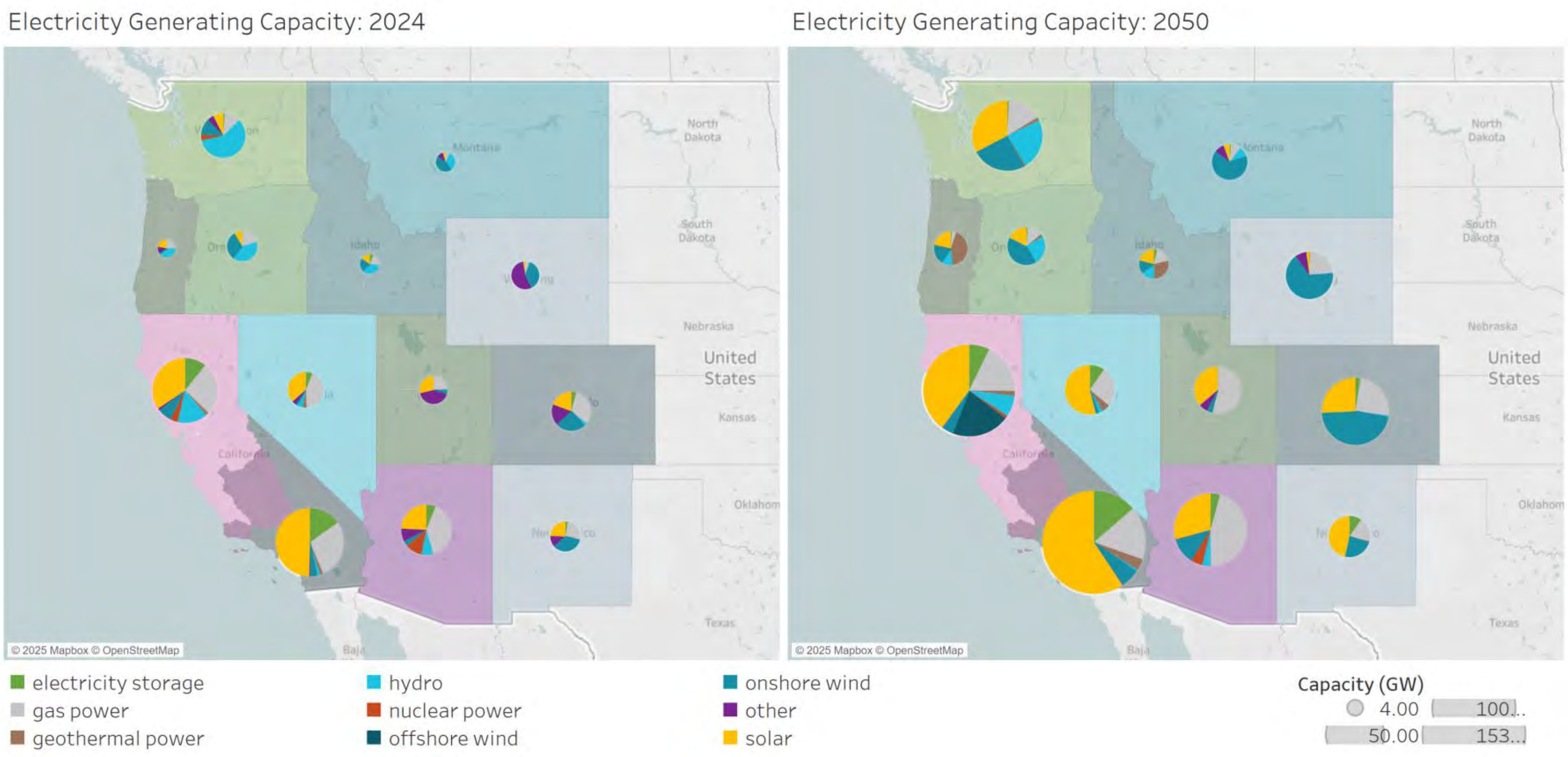
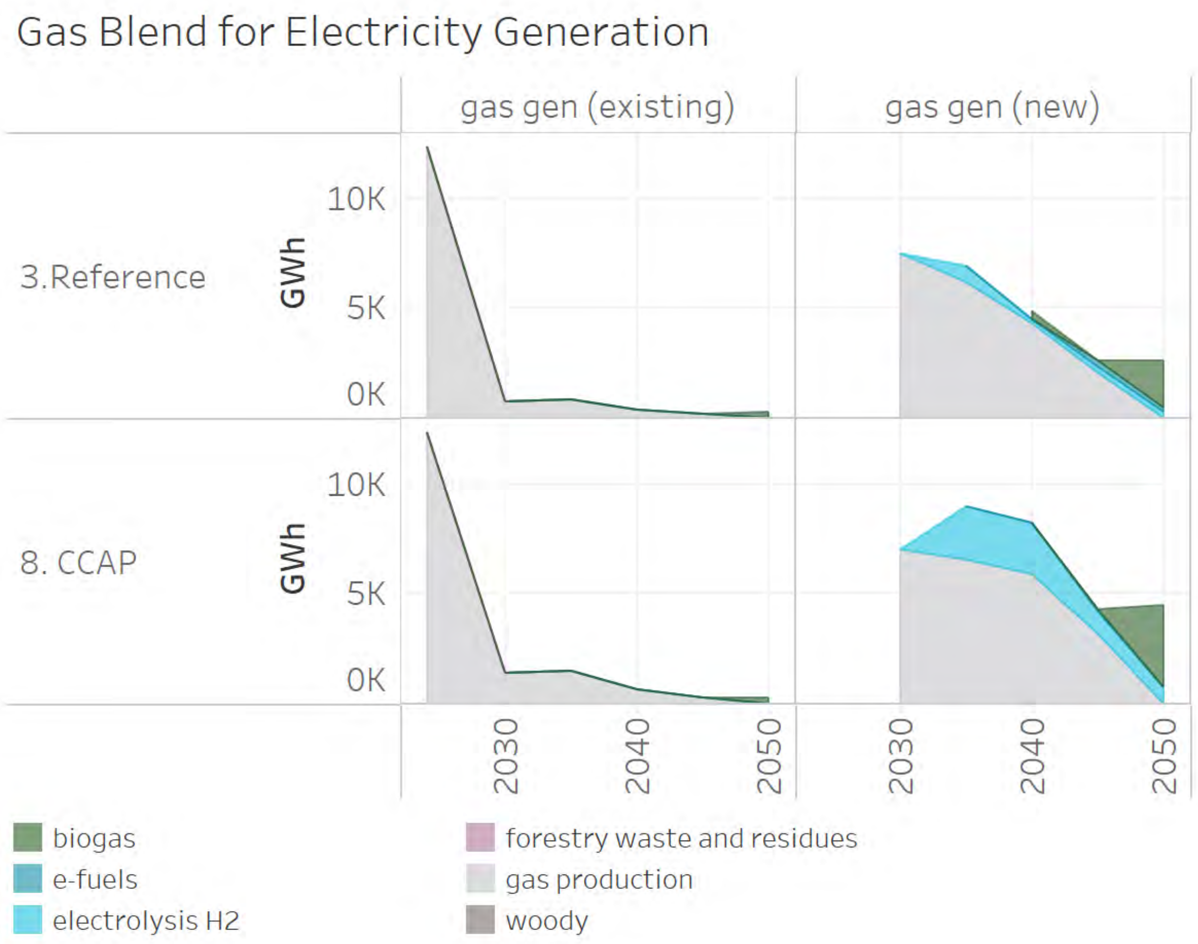
- From 2024 to 2050, total generation capacity grows dramatically in the West and renewables dominate



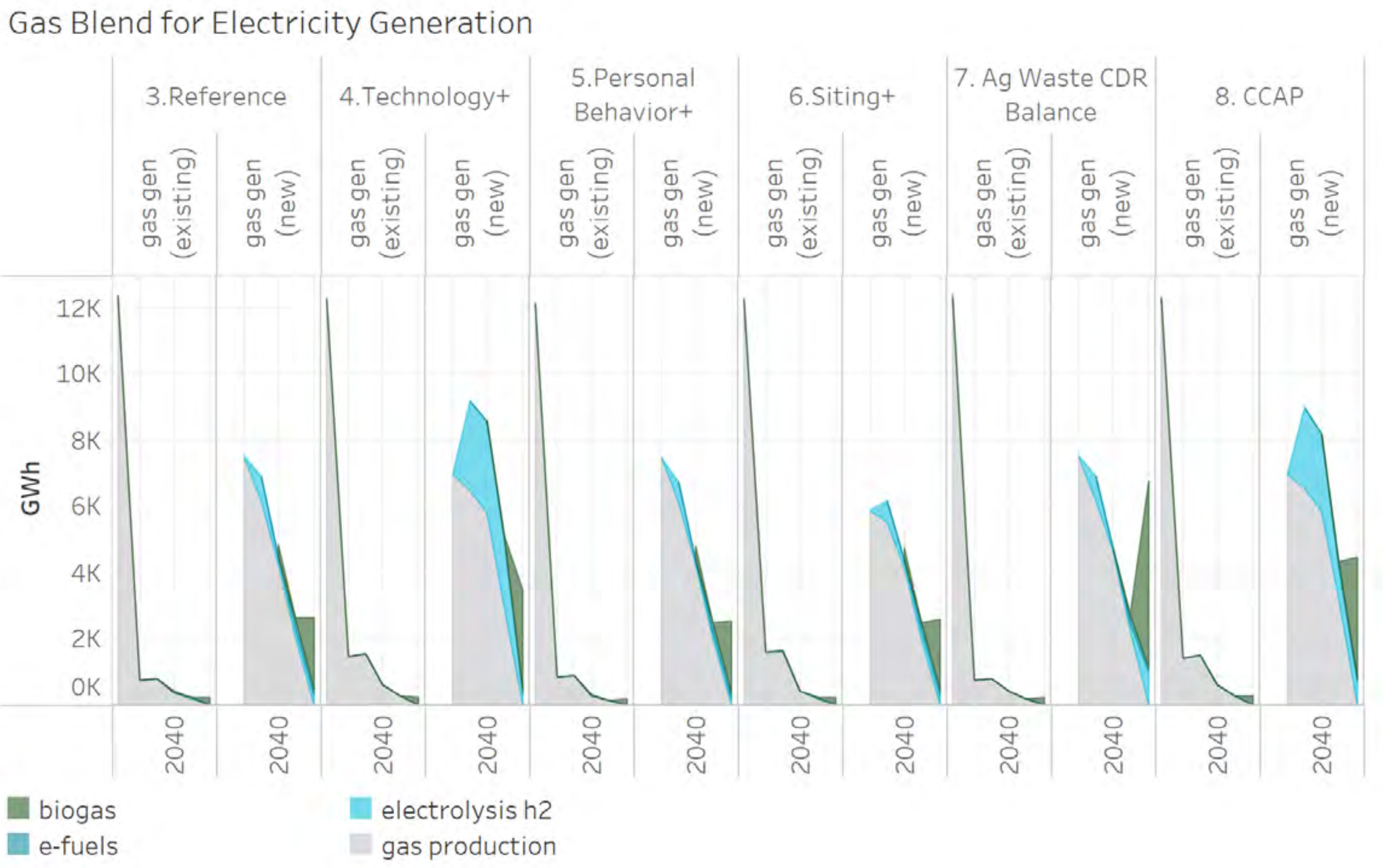
Washington Gas Blend for Electricity Generation Reference and CCAP Scenarios

- Existing gas generation transitions from an energy to reliability role
- Fully decarbonized gas blend by 2050
- Electrolysis hydrogen looking for a market in CCAP scenario



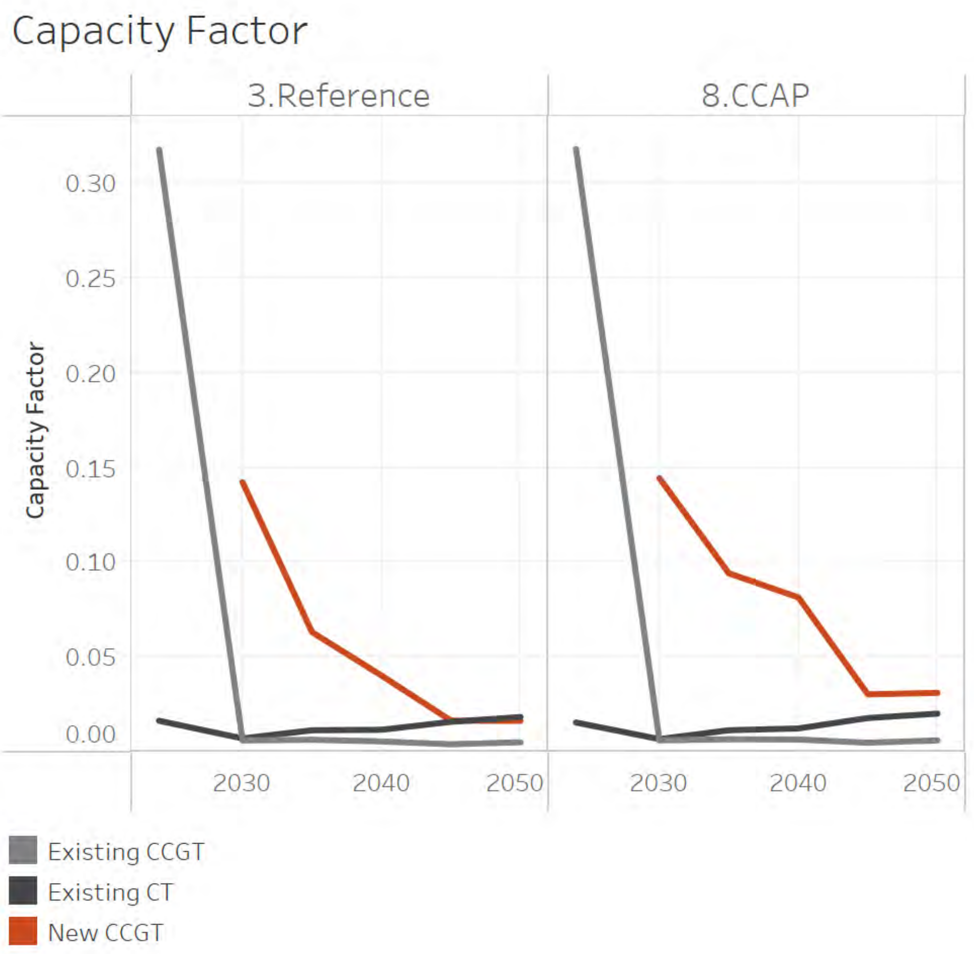
Washington Gas Blend for Electricity Generation Technology & Practice Scenarios

- Increased hydrogen combustion in Technology+ Scenario utilizing in-state electrolysis production
- Similar trend to Reference Scenario as in other scenarios



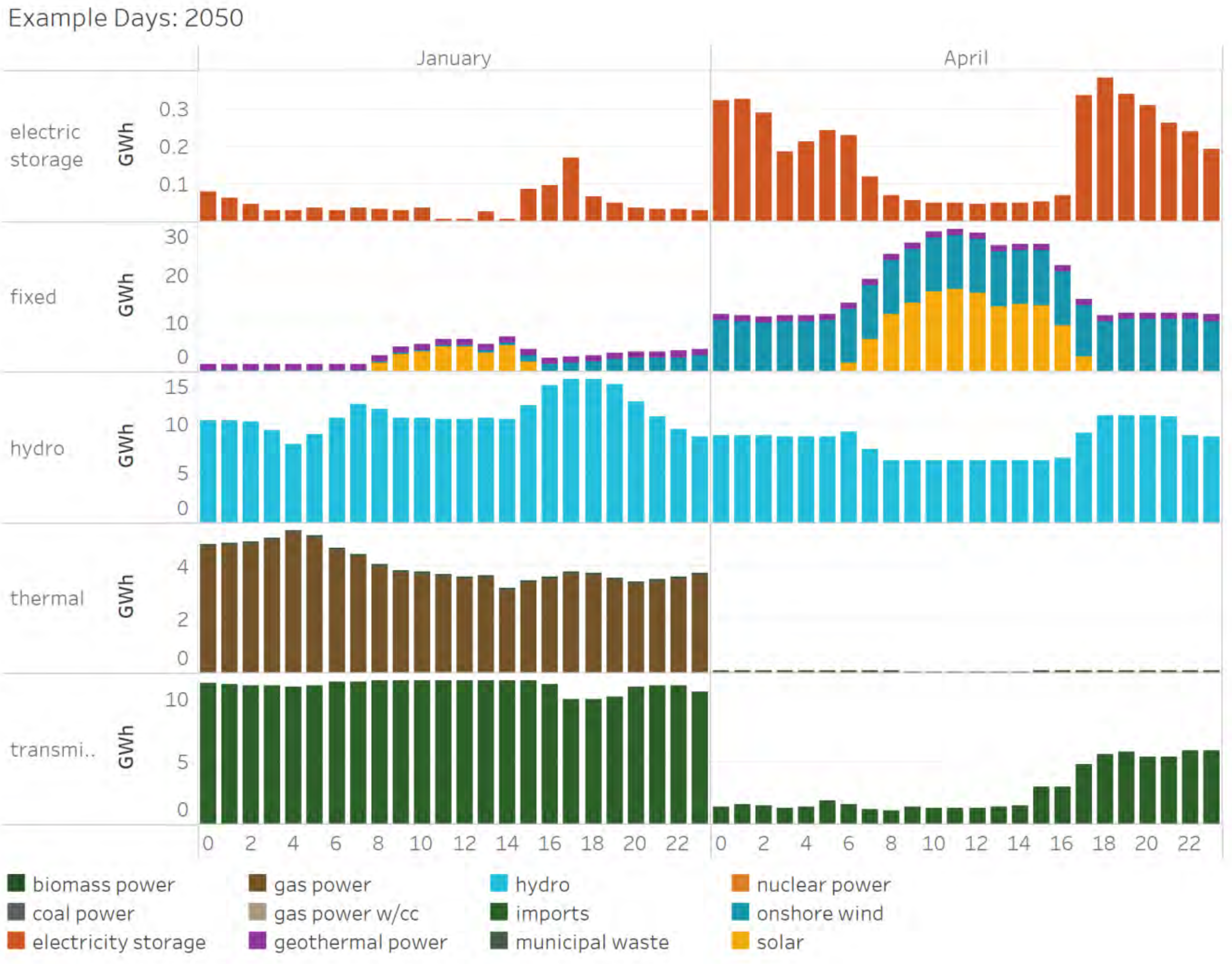
Washington Gas System Operations

- Existing gas generation capacity factor drops to close to zero by 2030
- New highly efficient turbines that burn increasingly clean blended gas are added
- Low-capacity factors: usage during renewable energy deficits



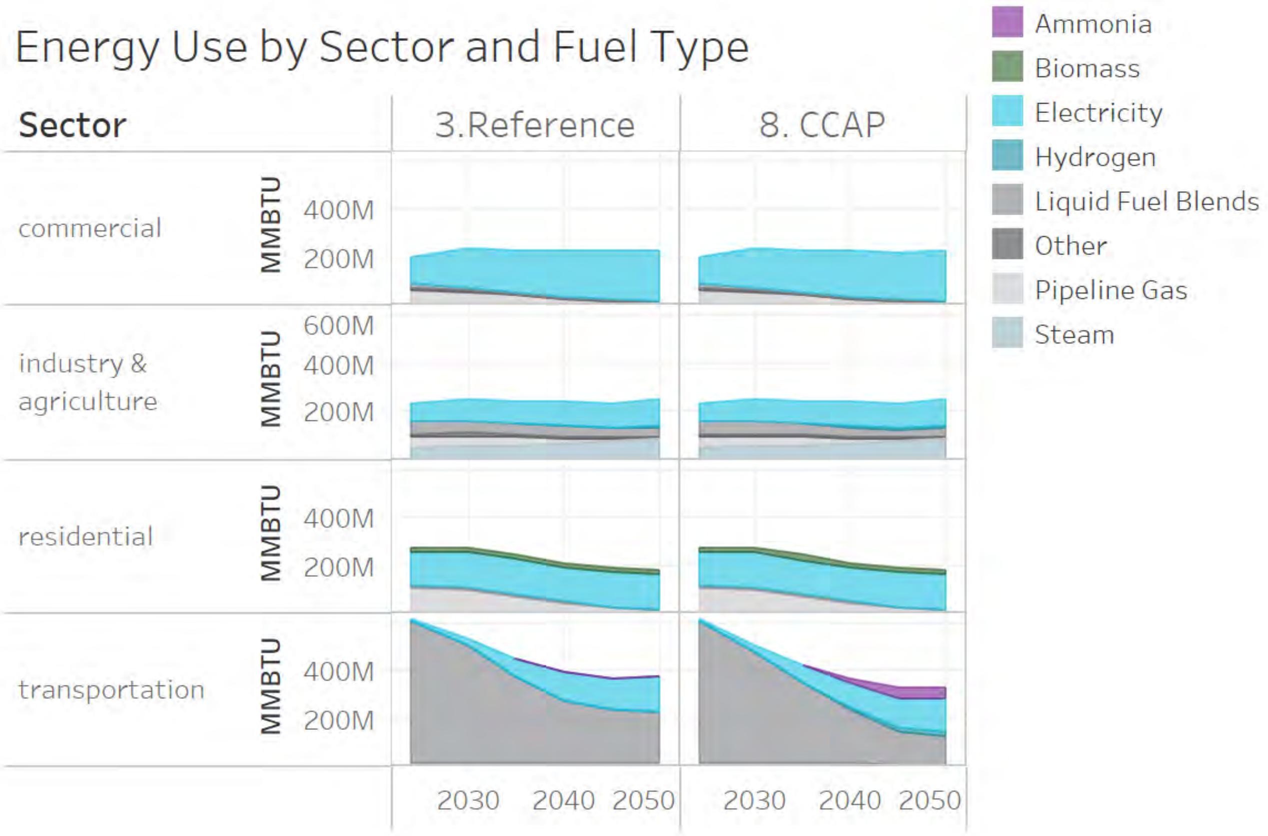
Washington Example Days: 2050

- The January day shows limited renewable availability, and the April day shows renewable energy abundance
- Low solar and wind generation in the state
  - Thermal generation and imports of renewable energy used to meet load
  - Thermal generation uses clean fuels to maintain reliability during difficult conditions
- The April day has abundance of renewable energy
  - Thermal generation not needed
  - Limited imports
  - Active storage to shift generation from the middle of the day



Washington Energy Use by Sector and Fuel Type

- Growth in energy demand in commercial sector from data centers offset by demand reduction in transportation
  - Transition to electricity and efficiency gains of electric motors
- General trend towards greater electricity use as the demand side electrifies
- Hydrogen and ammonia use limited in Reference Scenario as no transition to hydrogen fuel cells or ammonia combustion in shipping as is the case in the CCAP Scenario



Energy Use by Sector and Fuel Type Technology & Practice Scenarios

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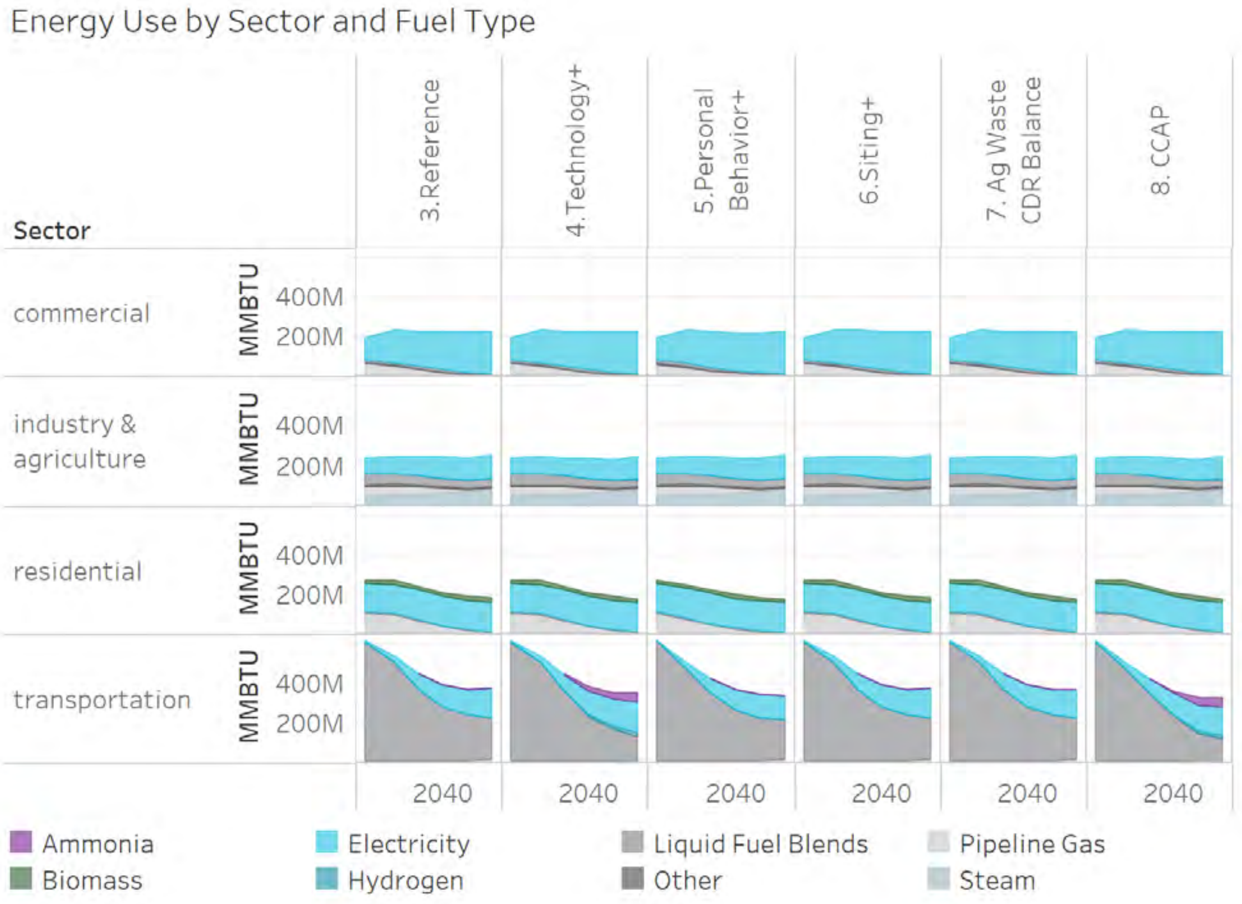
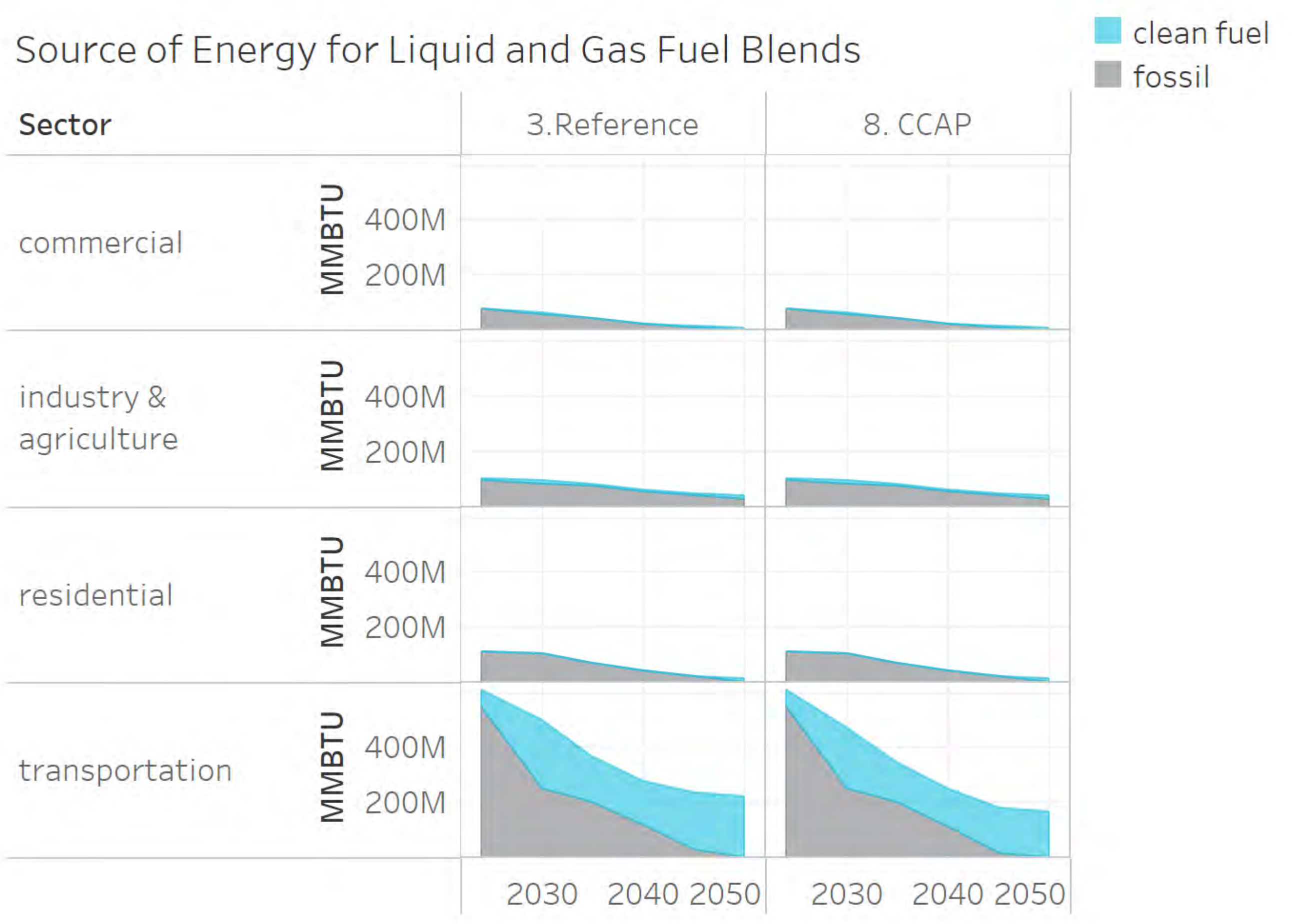
- Technology+ Scenario drives greater electricity, ammonia, and hydrogen use in transportation as other forms of transport are transitioned to clean technology



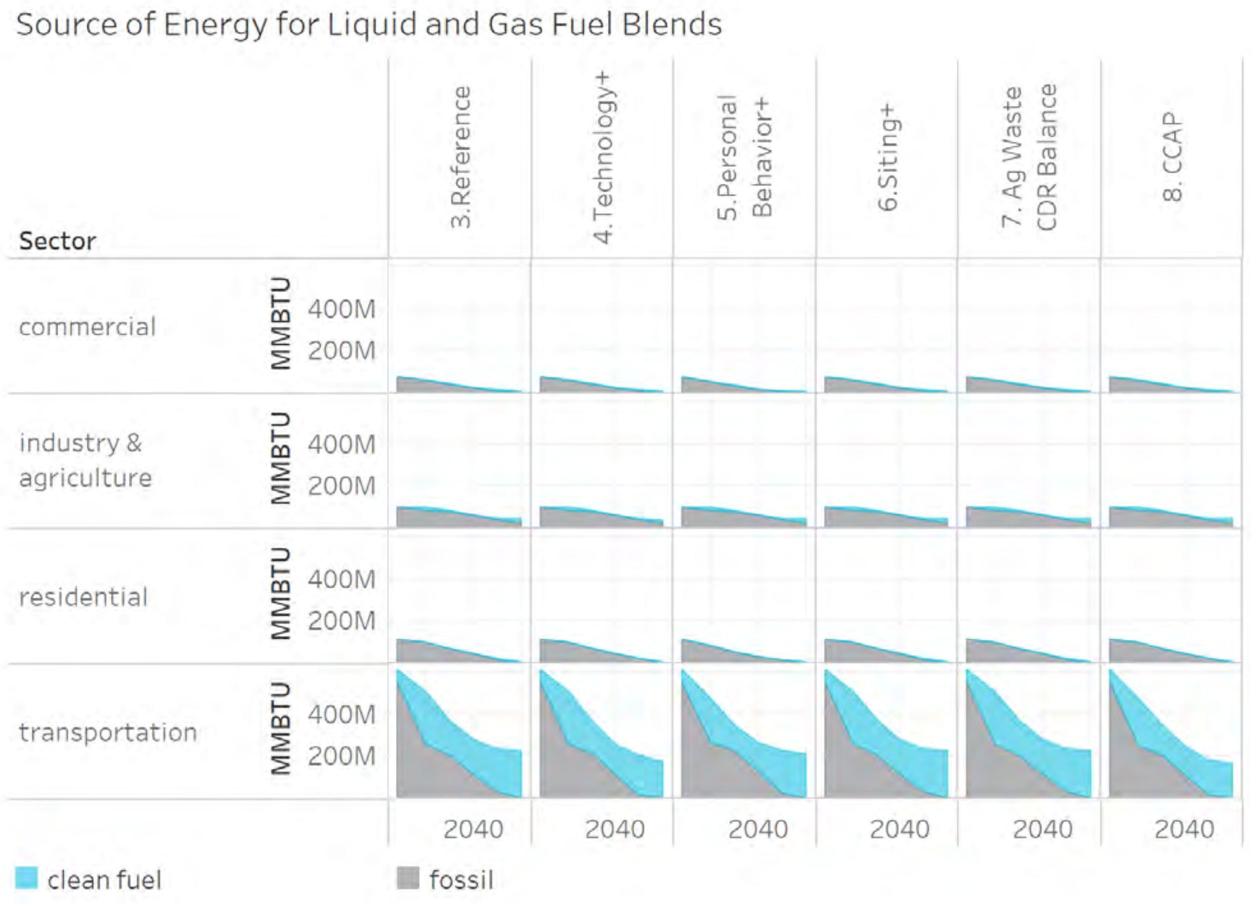
Washington Source of Liquid and Gas Fuel Blends

- Clean fuel required by 2030 to meet emissions target
- By 2050:
  - Liquid fuels in transportation fully decarbonized
  - Remaining natural gas blend majority decarbonized



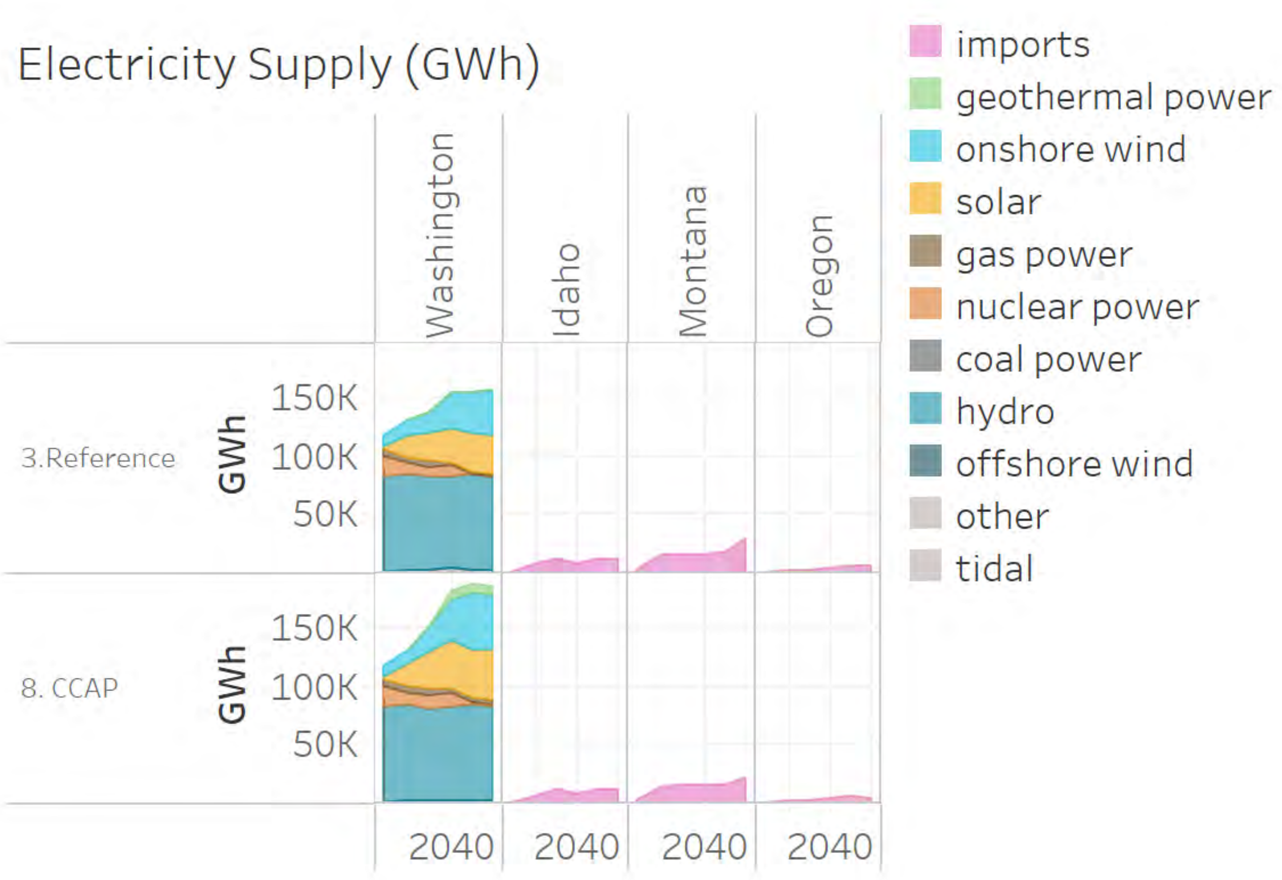
Source of Liquid and Gas Fuel Blends Technology & Practice Scenarios

- Lower demands for liquid fuels and therefore clean liquids in Technology+ Scenario by 2050
- Lower demands for clean liquids in 2030 and onwards in Personal Behavior+ Scenario



Where does Washington's Electricity Come From?

- Growth in imports over time facilitated by expanded transmission
- Majority of imported energy comes from onshore wind build in Montana and Wyoming
- Transmission and resource diversity across the West also plays a balancing role for Washington



Hydrogen Use in Washington

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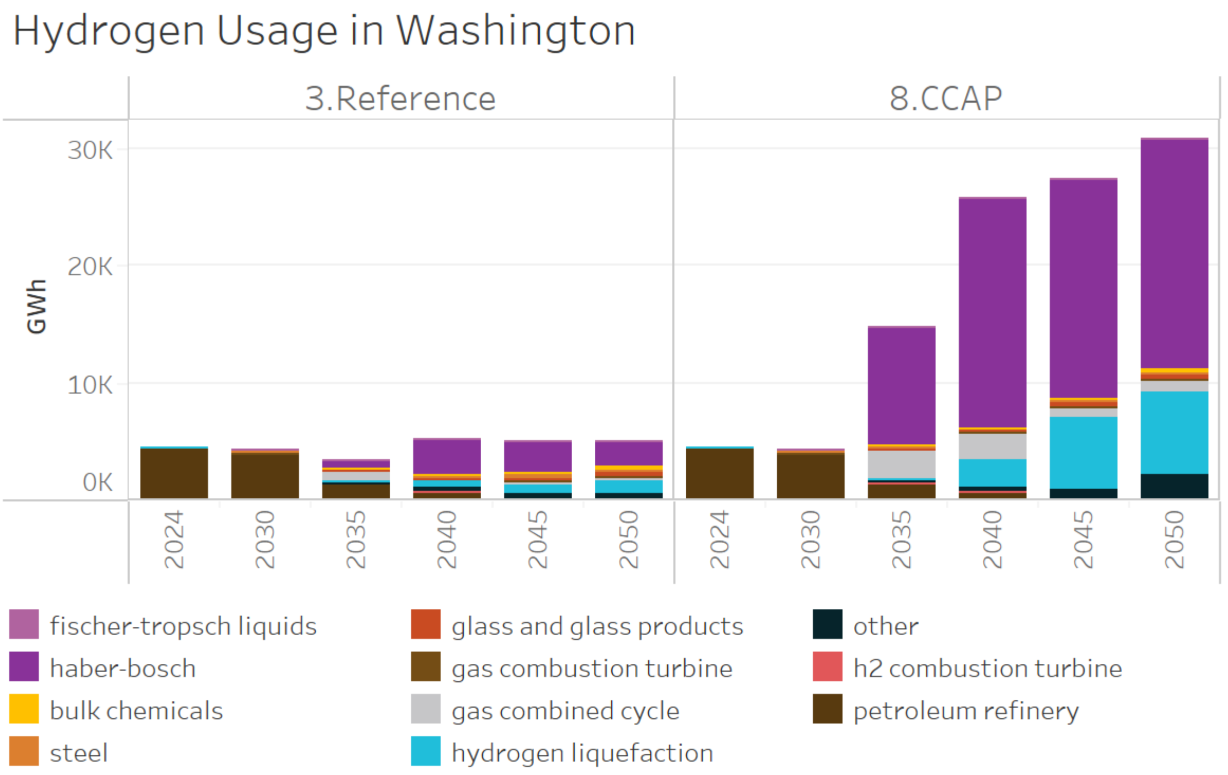
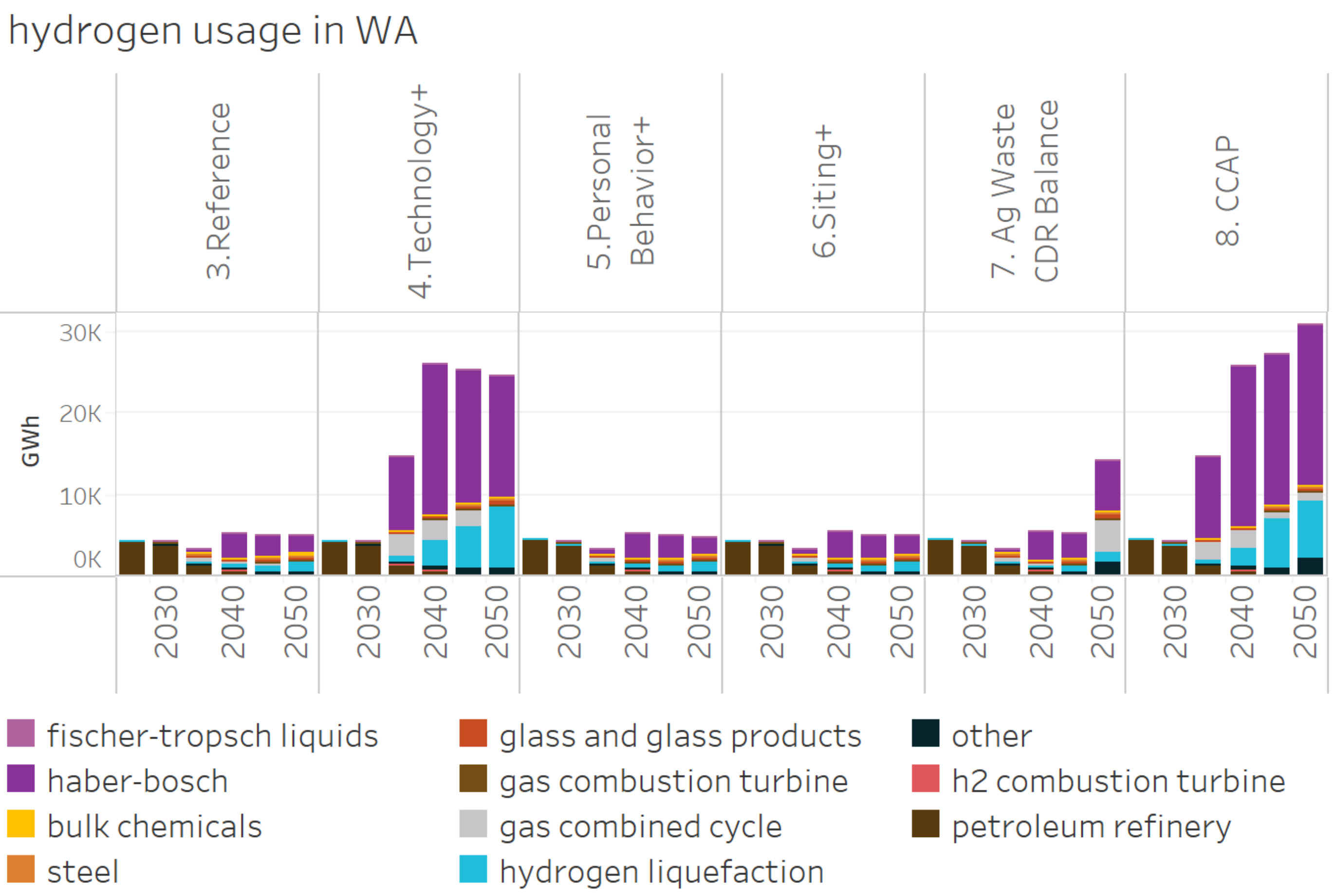
- Early hydrogen use in refining, dropping off with fossil fuel demand
- Majority of hydrogen products imported from elsewhere
  - Fischer Tropsch liquids almost entirely imported
- Washington's Green Electrolytic Hydrogen Report[1] found more Fisher Tropsch in Washington because of carbon supply from cement
  - This study assumes a transition to low-carbon limestone calcined clay cement (LC³), reducing captured CO2 from cement production
- Hydrogen to gas power early in Washington, transitioning to ammonia production in CCAP



[1]https://www.cleanenergytransition.org/programs/deep-decarbonization-pathways/green-electrolytic-hydrogen-report

Hydrogen Use in Washington Technology & Practice Scenarios

- Electrolyzer growth in Washington going primarily to ammonia production and hydrogen for fuel cells
- Hydrogen going to electric power production early on because of a lack of a carbon source to produce clean fuels and other markets for hydrogen products



Source of Hydrogen

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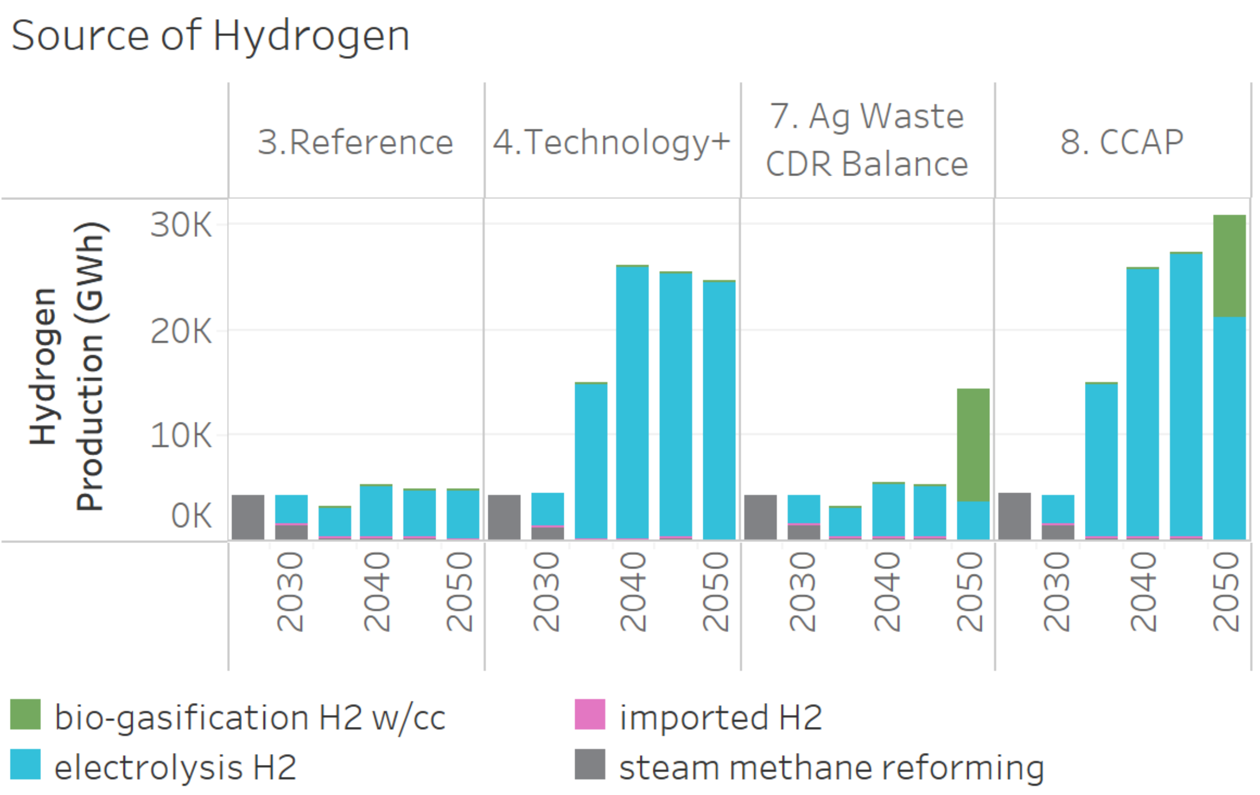
- Electrolysis in all scenarios by 2030 represents Northwest hydrogen hub activity
- Further growth in Technology+ Scenario in line with Washington's Green Electrolytic Hydrogen Report[1]
- Market for hydrogen products restricted in Ag/Waste/CDR balance scenario
  - Marine fuel opportunity for ammonia only in fuel oil blending
- CCAP supply in 2050 supplemented with BECCS H2 that also contributes to carbon sequestration
  - BECCS/BECCS H2 refers to a group of Bioenergy with Carbon Capture and Sequestration technologies. Bio-gasification hydrogen production with carbon capture is the selected technology in 2050. See slide 223 for more information



[1]https://www.cleanenergytransition.org/programs/deep-decarbonization-pathways/green-electrolytic-hydrogen-report

Transmission Between Zones Reference and CCAP Scenarios

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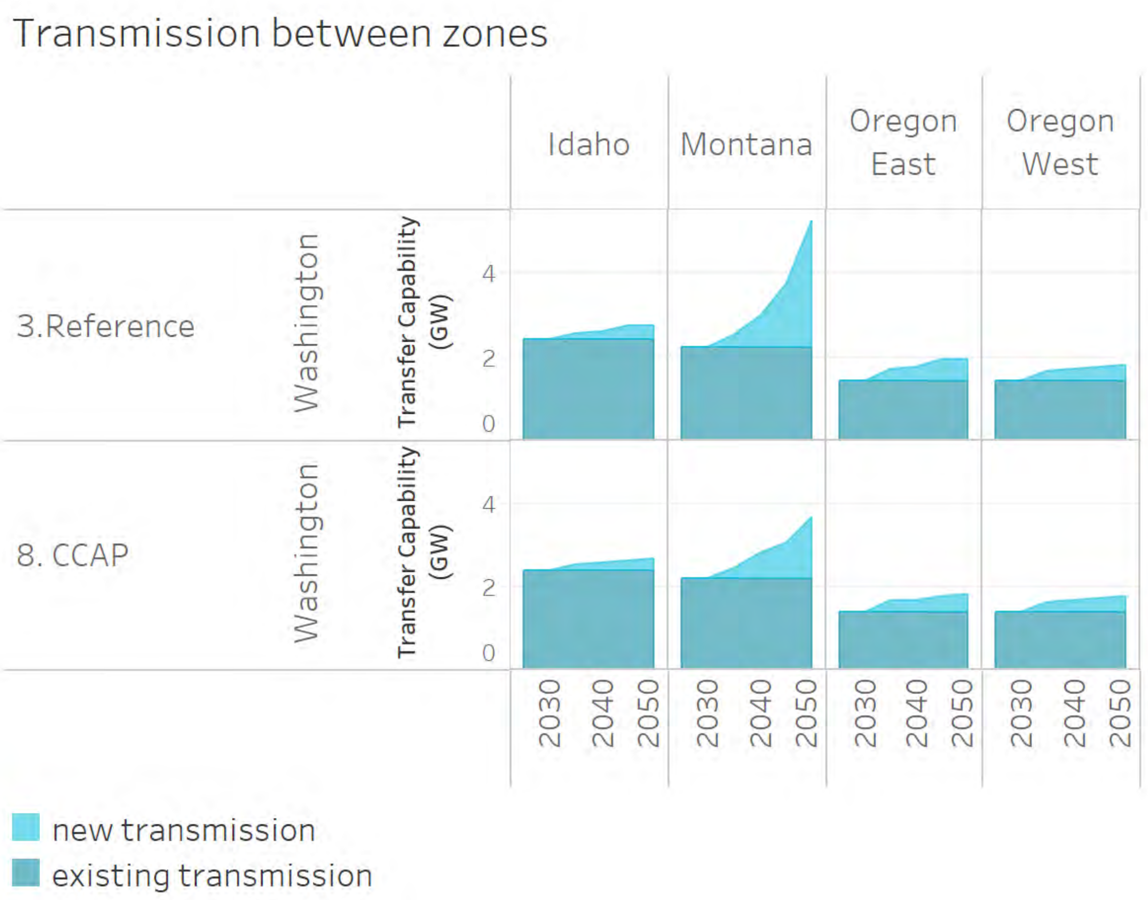
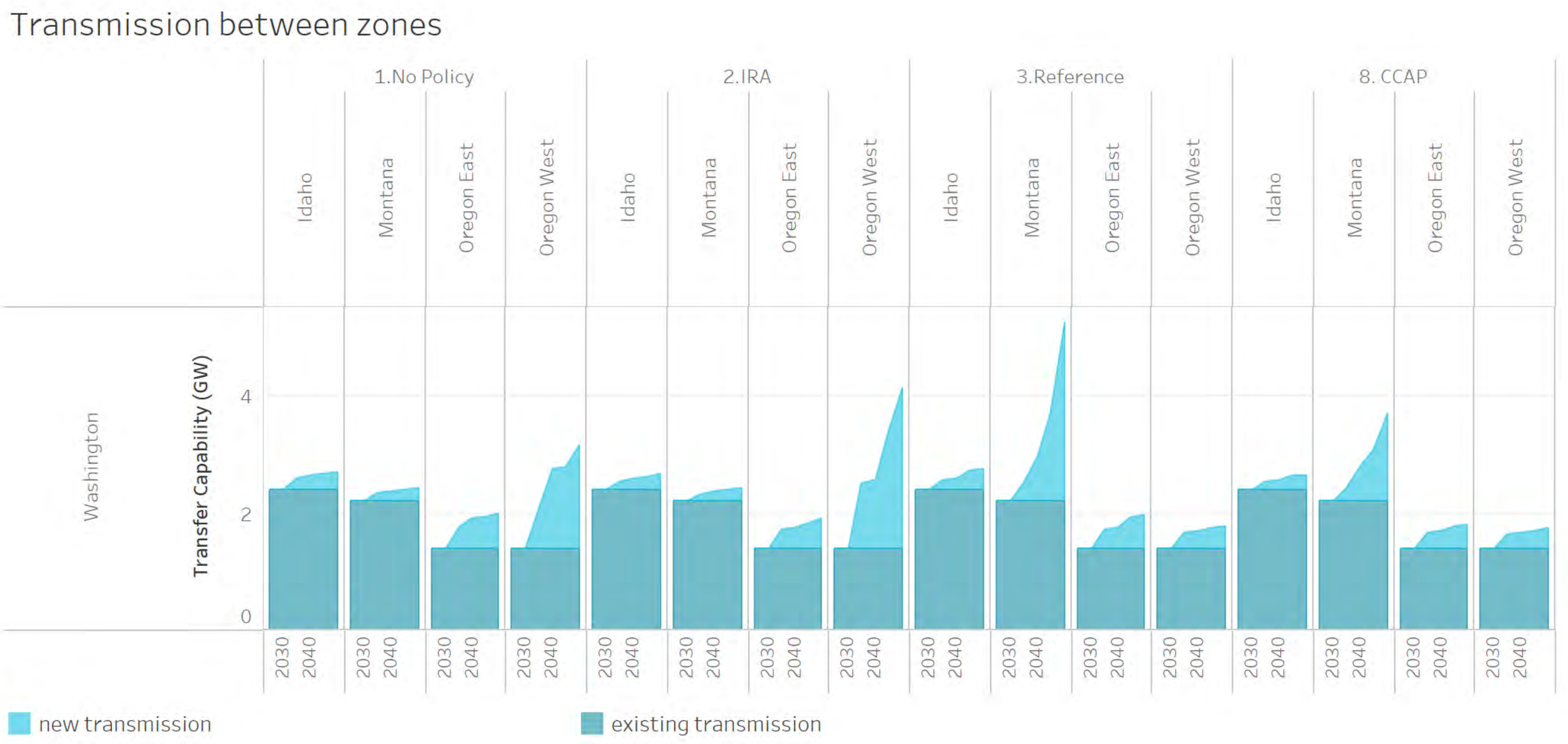
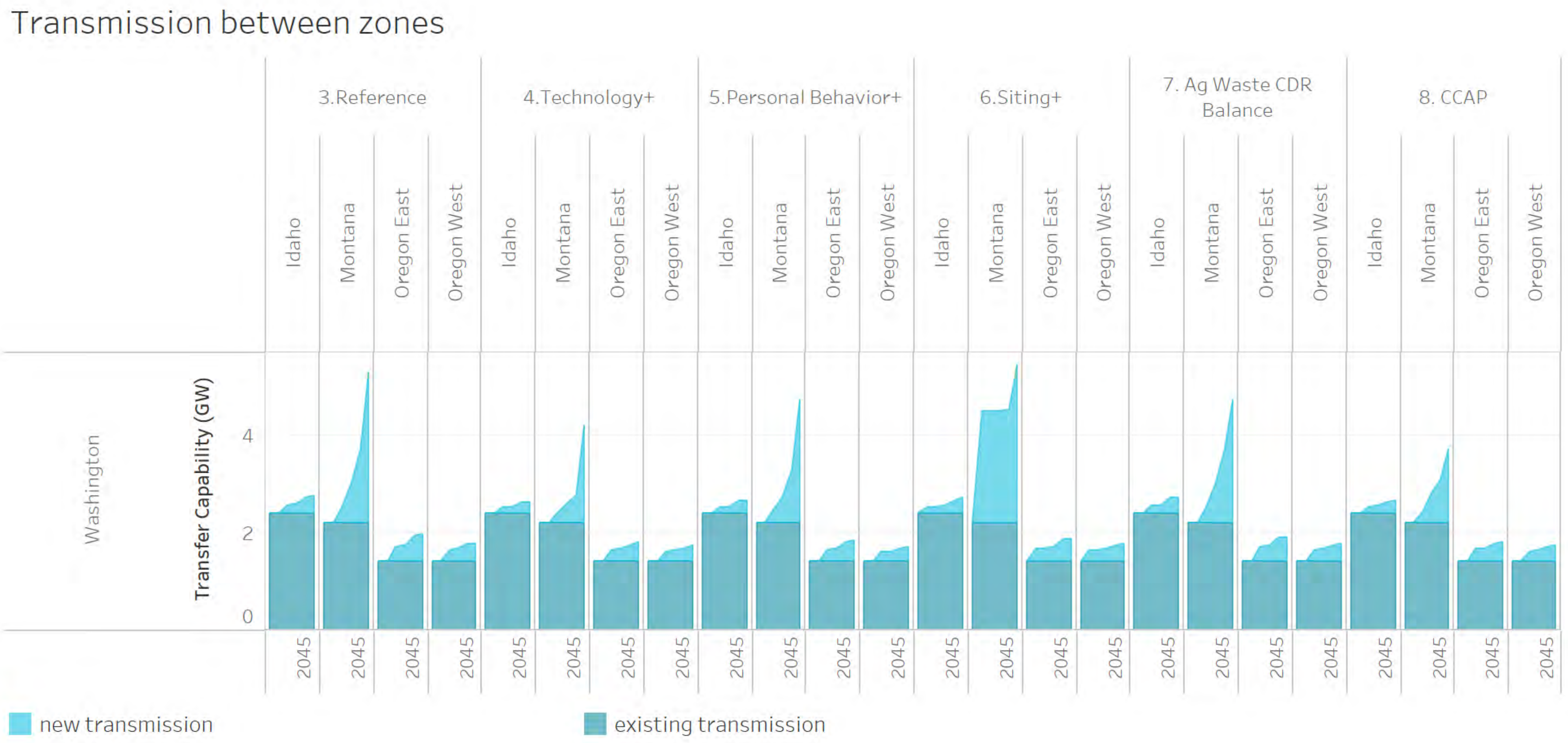
- Transmission expansion between Washington and surrounding states to import high quality wind as well as facilitate exports to Oregon load centers
- Largest transmission growth to Montana
  - 3 GW additional transmission in the Reference scenario
  - 1.5 GW in the CCAP scenario



Transmission Between Zones
Comparison to No Policy Scenario



Transmission Between Zones
Technology & Practice Scenarios



Washington Needs More Transmission Capacity

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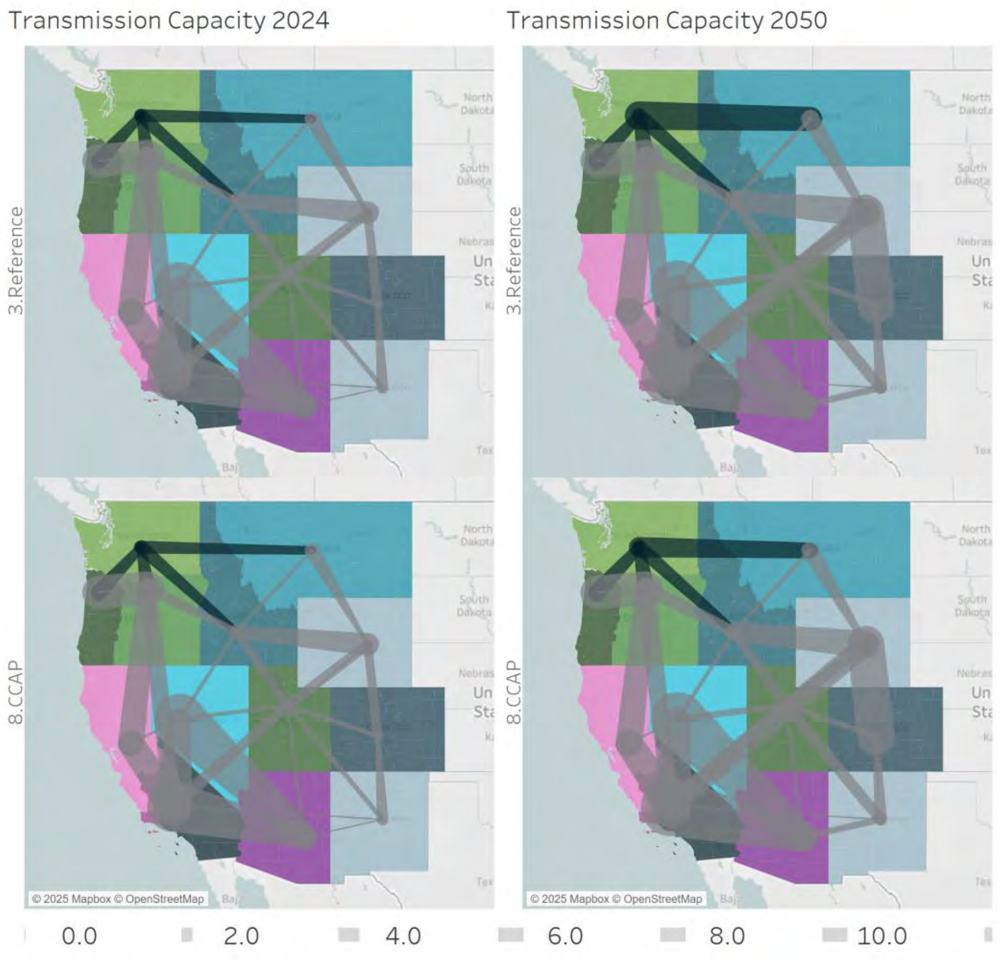
- Key transmission lines across the West expanded between 2024 and 2050
- In Washington, the largest additions are to Montana
- The transmission model is linear, so investments can be made in fractions of new transmission lines
- The CCAP Scenario builds more generation within Washington, halving the transmission built to Montana
- These results are indicative of transmission need but do not replace detailed transmission planning



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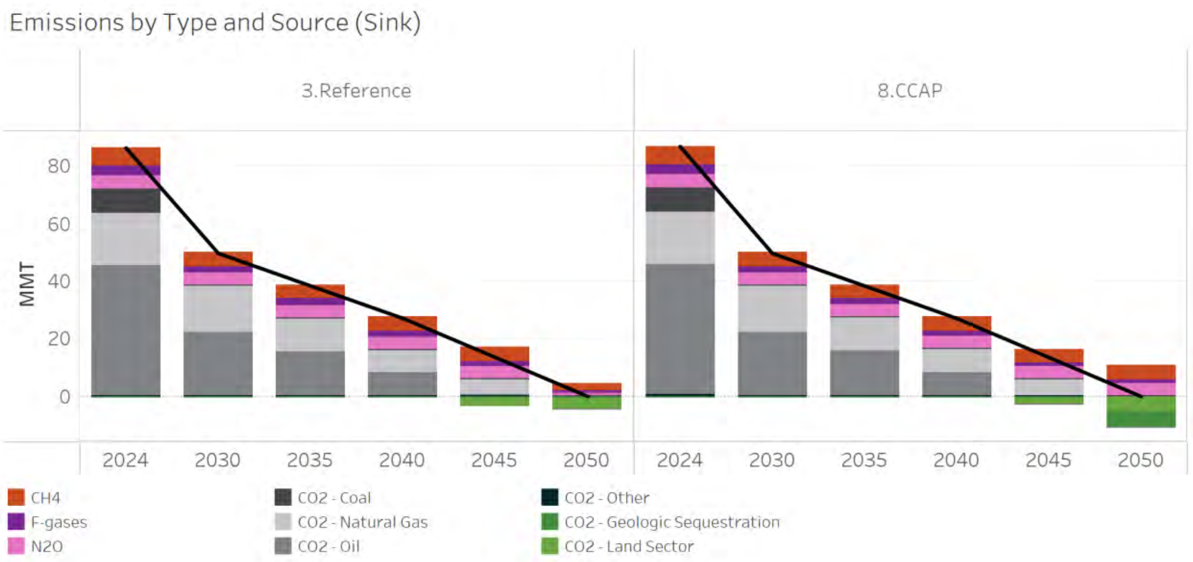
Emissions

Washington Emissions by Gas and Source Reference and CCAP Scenarios

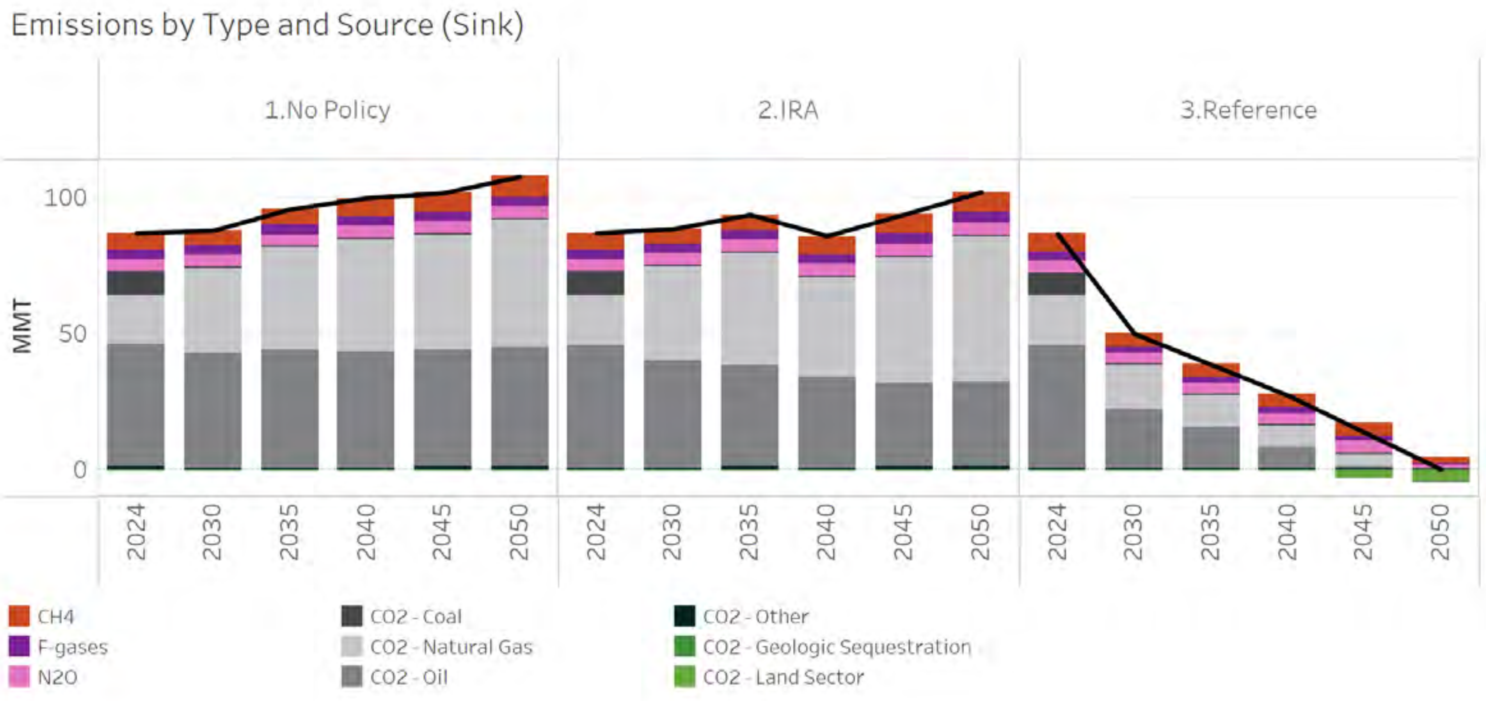
- Reductions in non-CO_2 gases based on EPA[1] identified potential through 2040
- 2050 target met with non-CO_2 reductions beyond EPA measures in Reference Scenario
  - 4.5 MMT target requires an additional 6.2 MMT of non-CO_2 reductions
- CCAP Scenario relies on geologic sequestration to cover the gap



[1]https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/us-state-level-non-co2-ghg-mitigation-report

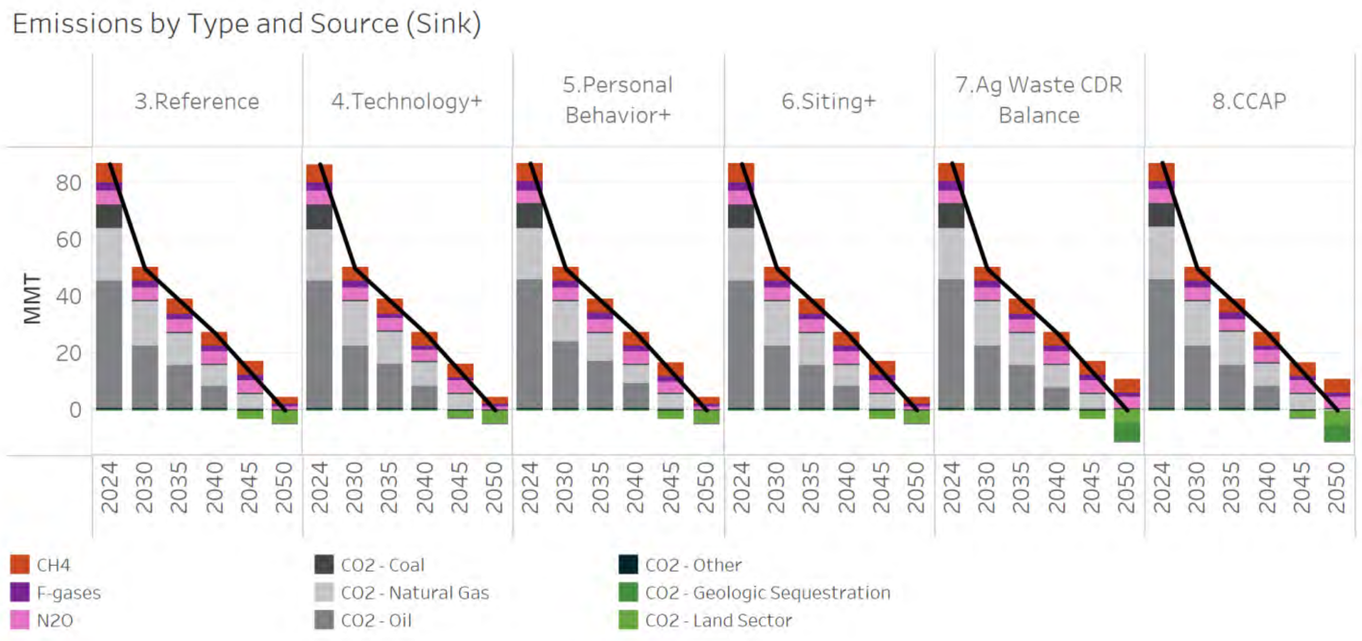
Washington Emissions by Gas and Source Comparison to No Policy Scenario

- IRA Scenario prevents increase in emissions but does not decrease them
  - Reduction in oil emissions as vehicles transition to electric
- Emissions grow in No Policy Scenario with population and productivity growth



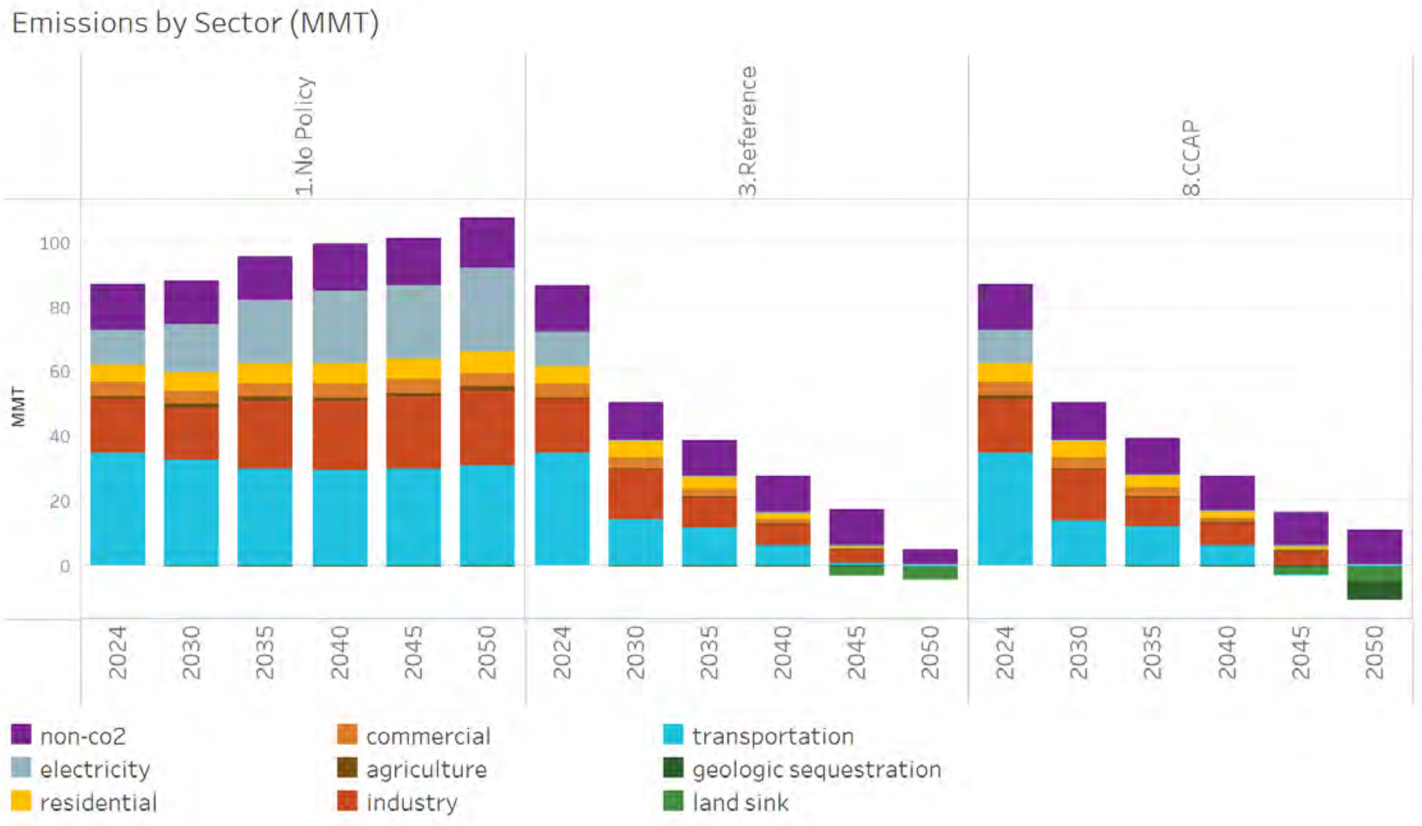
Emissions by Gas and Source Technology & Practice Scenarios

- Allowing CDR to achieve net zero, rather than unspecified non-CO_2 reductions results in 7.3 MMT of carbon sequestration
- BECCS primary source of CO_2
  - H2 from BECCS displacing electrolysis
  - See slide 223 for more details on BECCS

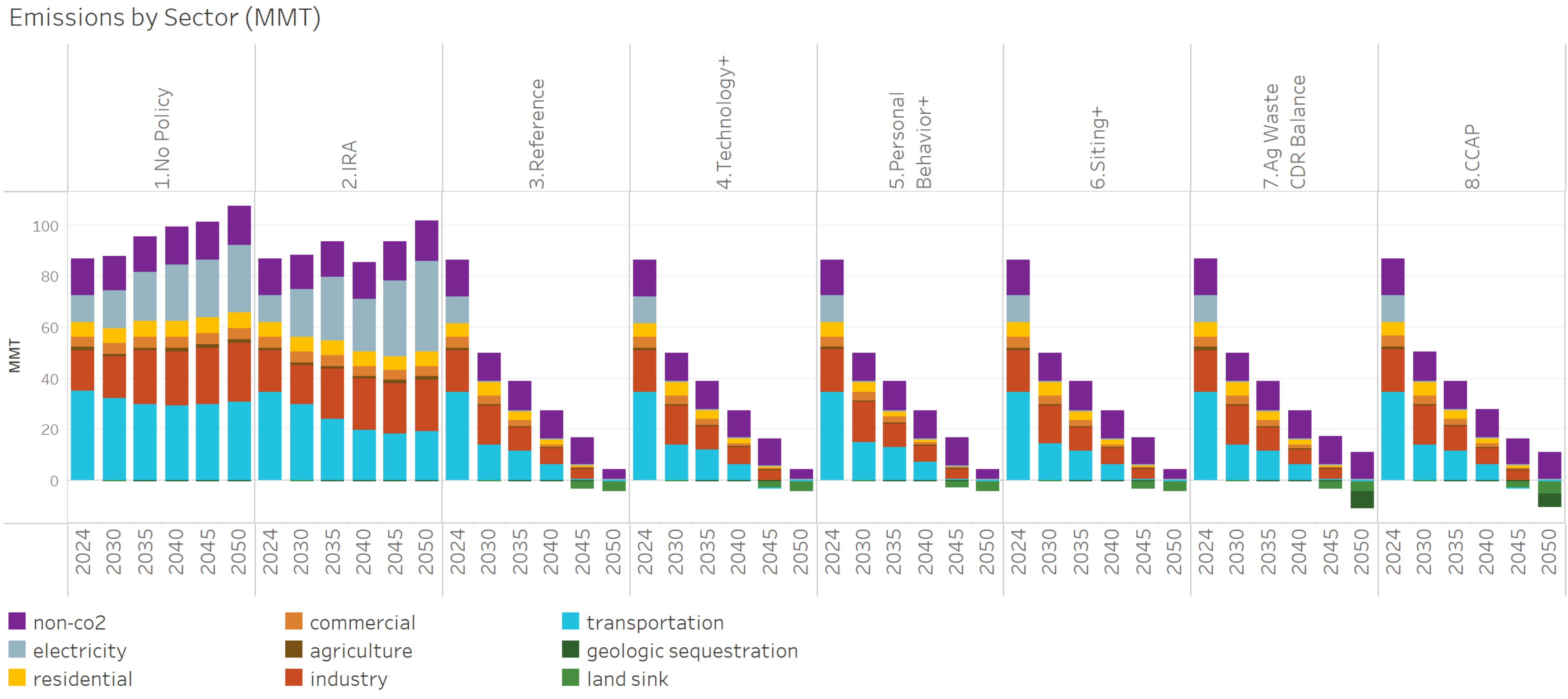


Emissions by Sector

- Emissions in 2024 retain coal in electricity
- By 2030:
  - Coal retirement and reduced gas generation significantly reduce electricity emissions
  - Transportation sector emissions reductions from electrification and clean fuel
- Steady reductions over time in commercial, residential, and industry from electrification and efficiency improvements



Emissions by Sector: All Scenarios



Focus on 2050 Emissions

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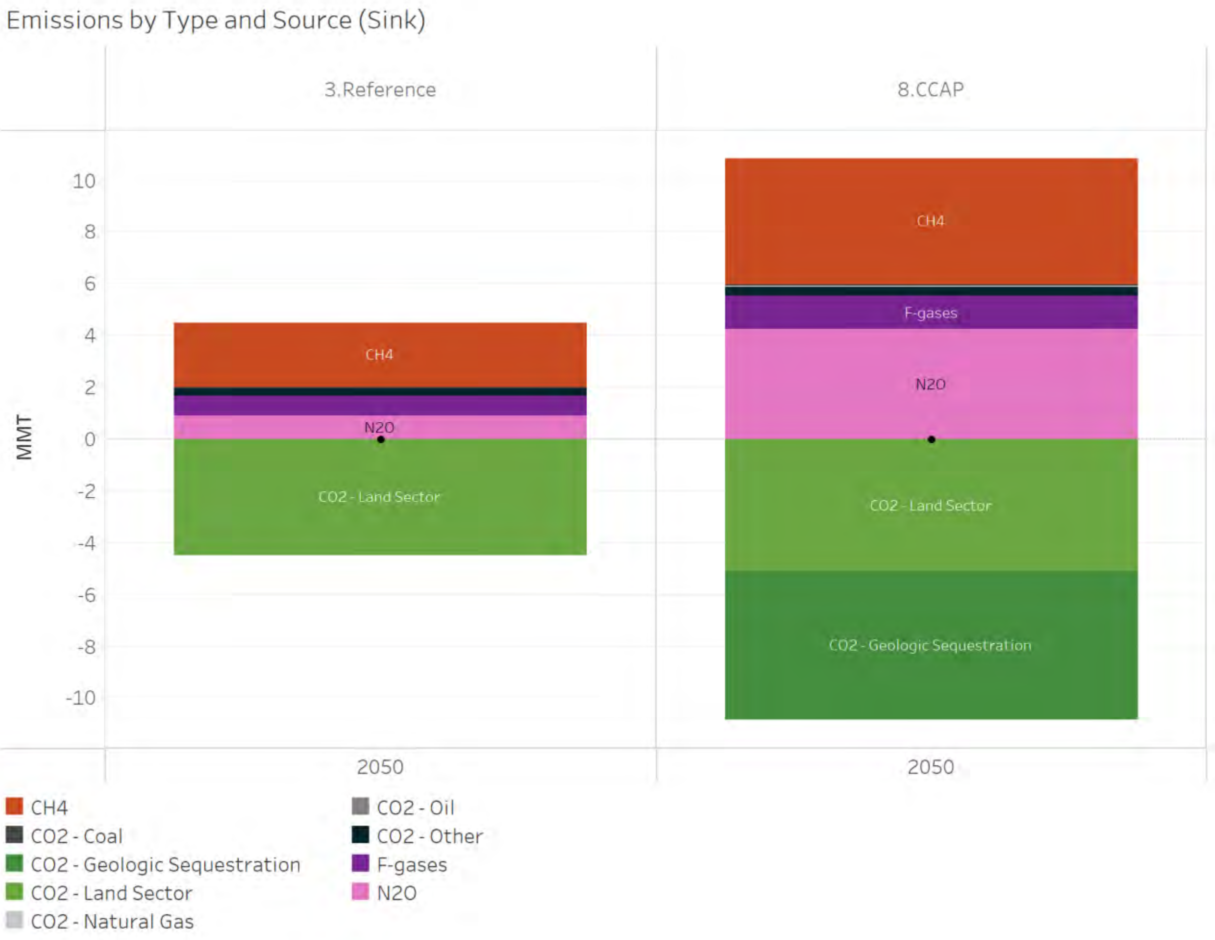
- In CCAP, gross emissions remain above 95% emissions reduction target
  - The availability of measures to reduce non-CO_2 emissions in the Reference Scenario is not enough to achieve the target based on EPA's estimates (see slide 249) and falls short by 6.2 MMT
  - The Reference Scenario assumes that 6.2 MMT gap is met with measures that are currently unidentified
  - The CCAP retains this 6.2 MMT of non-CO2 emissions
- Land sector measures capped at 4.5 MMT in Reference
  - 5.1 MMT potential in CCAP based on moderate potential from Robertson et al. (2021)
- Emissions reductions achieved instead with geologic sequestration in the CCAP
  - Uncertainty about availability of land sector measures
  - Several options for carbon dioxide removal



Land Sector Potential

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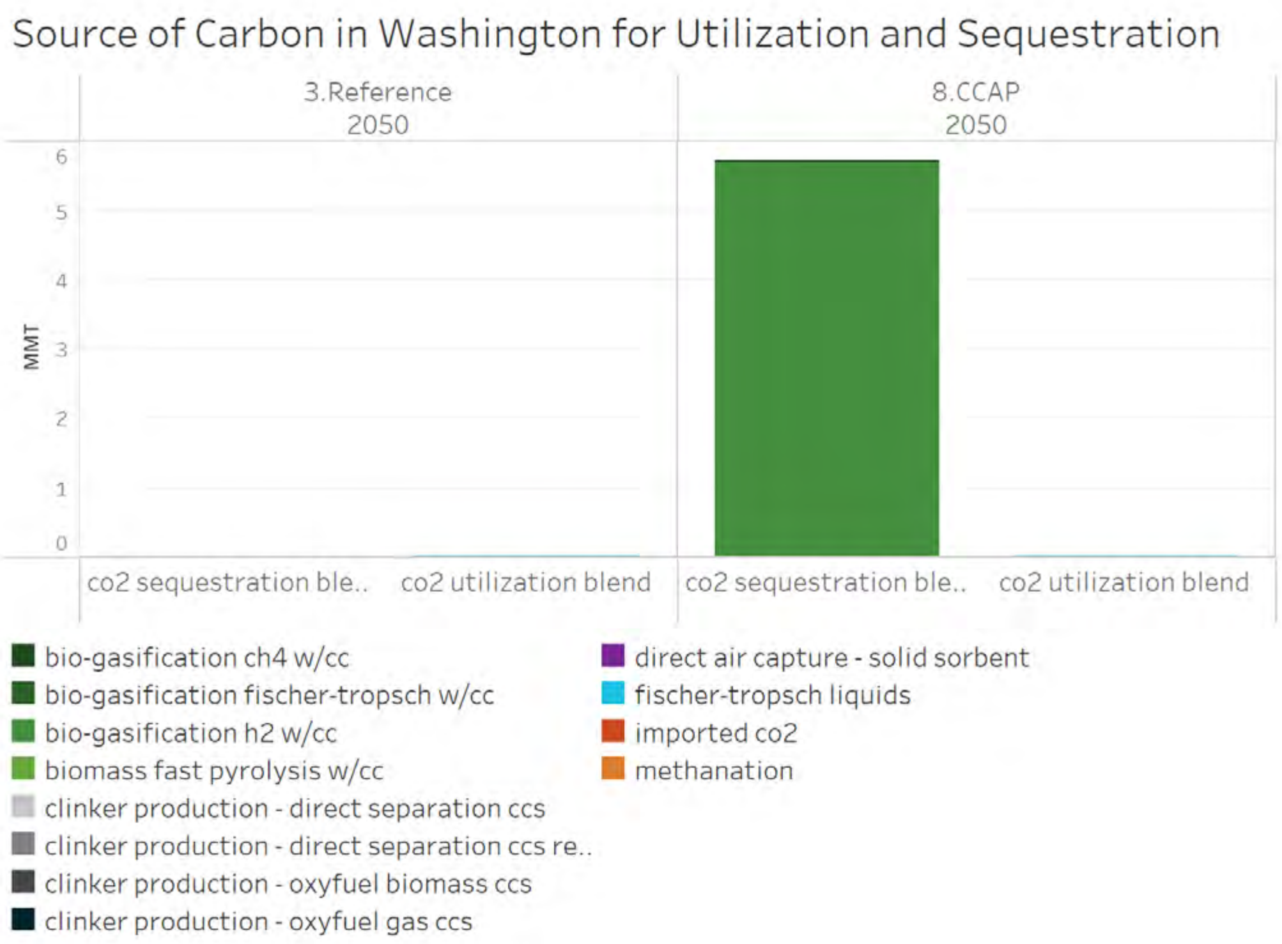
- Land sector measure availability
  - Reference Scenario: 4.5 MMT, equal to the gross emissions permitted under the 95% gross emissions cap
  - CCAP Scenario: 5.1 MMT, equal to the moderate potential scenario from Robertson et al. (2021) of land-based measure potential and approximately equal to alternative 5 MMT 2050 limit permitted in statute.
- Costs of land sector measures are highly uncertain
  - Without greater understanding of these costs, we set them at $50/ton
    - These measures are cheap enough that they are feasibility rather than cost constrained
    - In line with available cost estimates for land-based measures

Carbon Dioxide Removal Technologies

- Model considers many technology options for carbon dioxide removal, including different types of BECCS, industrial capture, and direct air capture
  - BECCS H2 selected based on price but could be a portfolio of these technologies depending on technological development
- Assumes sequestration potential exists within Washington, but an alternative is credits for sequestration out of state in the future



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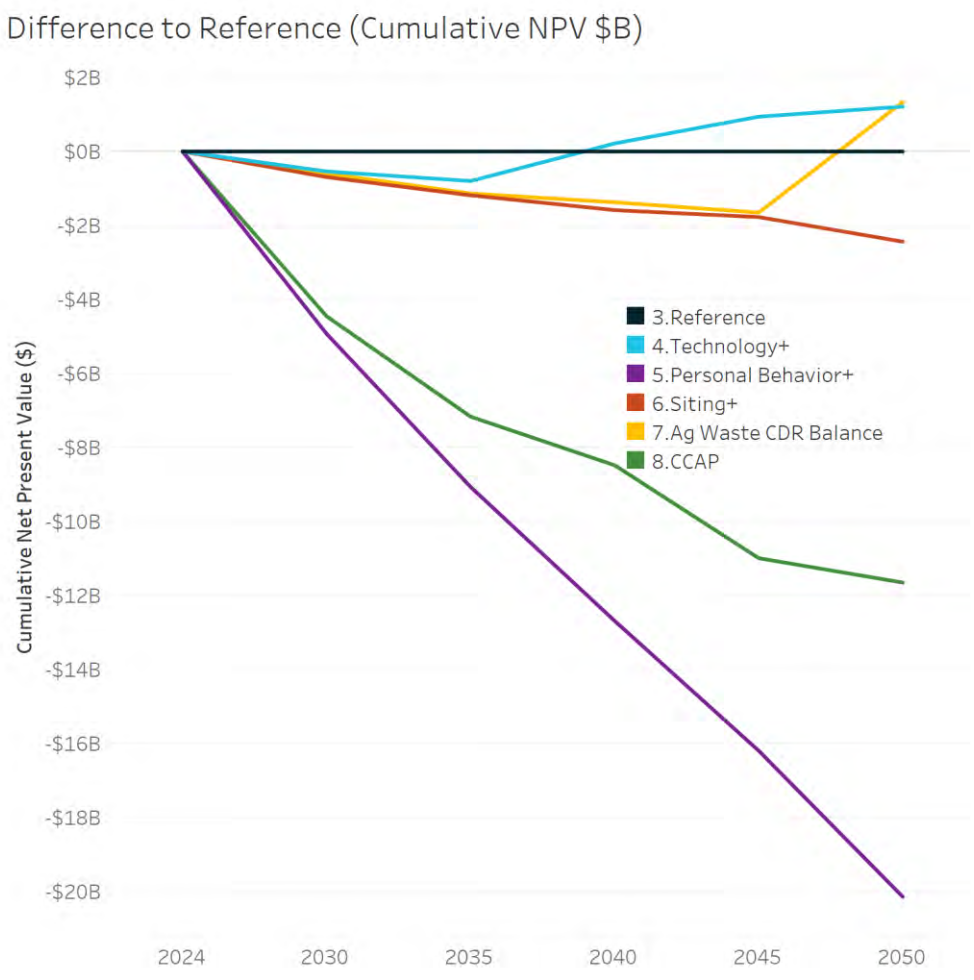
Costs

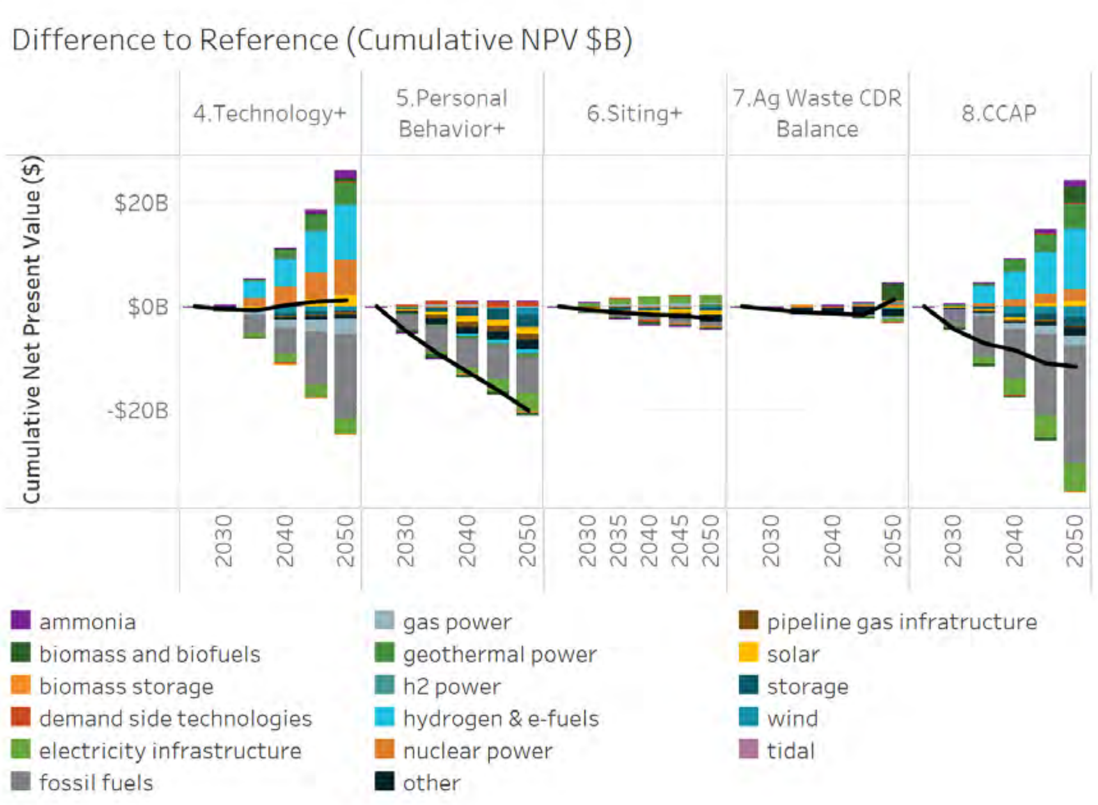
Cost Difference to Reference Scenario

- Net present value calculated with a 2% discount rate
- Cumulative benefits over time from reduced energy use in Personal Behavior+ Scenario
  - VMT reductions
  - Improved industrial efficiency
  - Reduction in air travel
  - Not counting the costs of achieving these outcomes (e.g., investments in public transport)
- Other scenarios are less impactful
- Caveat: The Ag Waste CDR Balance Scenario avoids non-CO_2 reduction measures. These are not factored into the costs. Estimates for the impacts of these costs are in the final slide of this section



Cumulative Cost Components

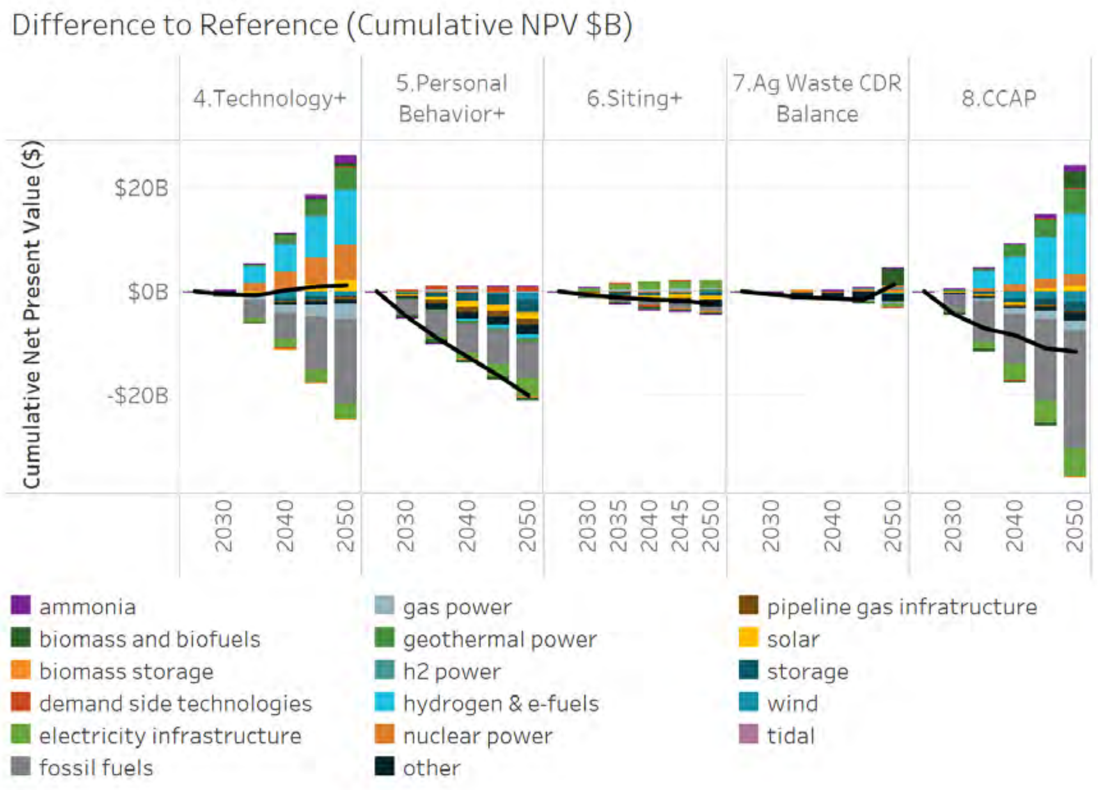
- Cumulative total cost not the whole picture
- Big shifts in investments in Tech+
  - Greater geothermal power, hydrogen, and nuclear investment
  - Reduced wind, gas power, fossil fuels, and transmission
- Personal behavior reduces fuels consumption
- Siting plus is limited impact but shifts investments to cheaper out of state resources with greater investment in transmission
- Ag Waste CDR Balance increases investment in BECCS H2 and avoids cost of reducing emissions from non-CO_2 (not shown)



Cumulative Cost Components

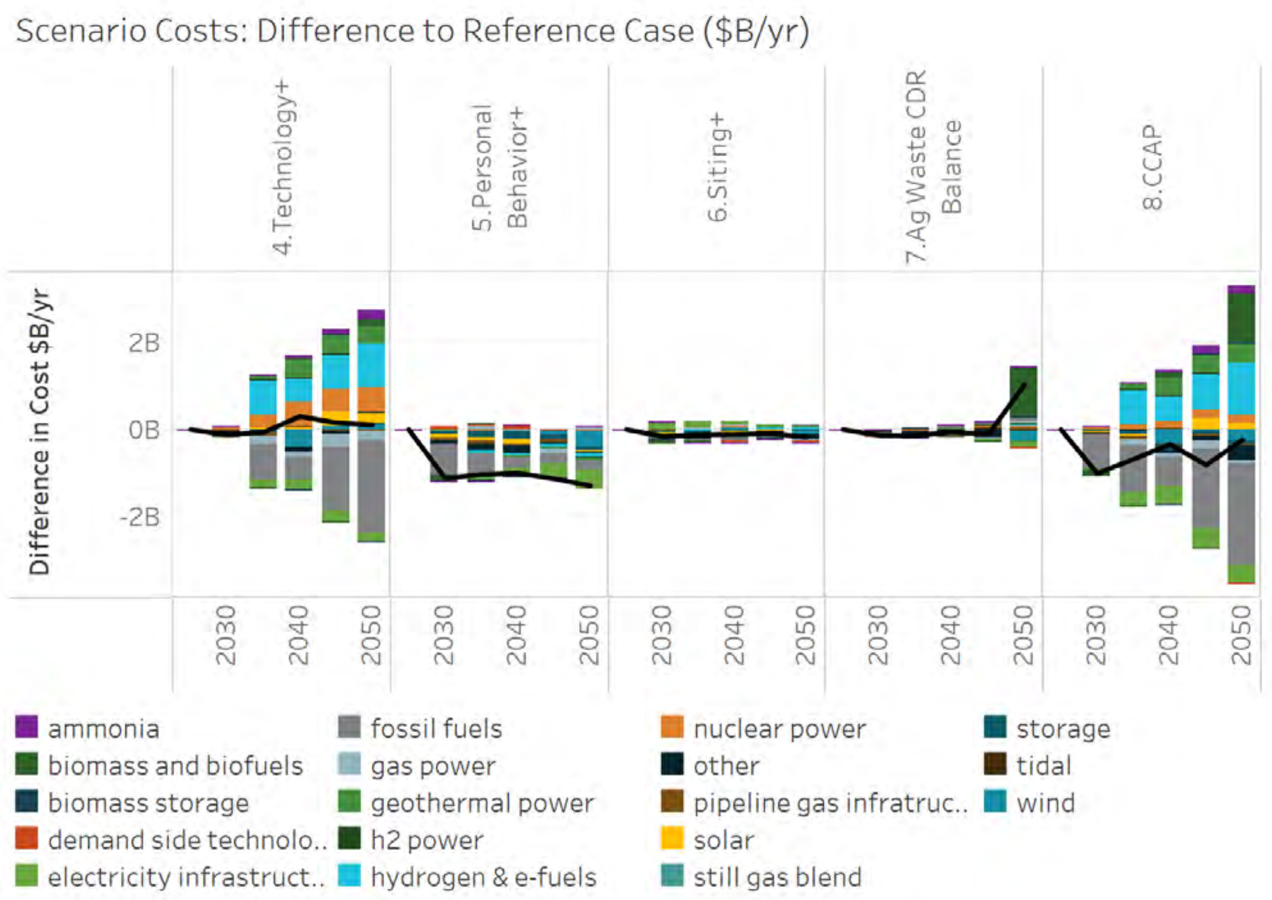
EVOLVED ENERGY RESEARCH

- Cumulative total cost not the whole picture
- Big shifts in investments in CCAP
  - Greater geothermal power, hydrogen, and nuclear investment
  - Reduced wind, gas power, fossil fuels, and transmission
- Reduced VMT, air travel, and greater efficiency in CCAP reduces fuels consumption
- CCAP increases investment in BECCS H2 and avoids cost of reducing emissions from non-CO_2 (not shown)



Annual Costs

- This figure shows annual costs rather than the cumulative costs of the previous slides
- Annual costs are akin to an electricity revenue requirement but for all forms of energy
  - Annual payments for capital investments are annualized over the lifetime of the investment
  - Operating costs are incurred in the year they happen, including commodity purchases and O&M



CCAP Non-CO_2 Measures

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- In the Reference Scenario, the 95% gross emissions reduction target is met with reductions in non-CO_2 emissions that exceed the potential identified by the EPA by 6.2 MMT
  - Emissions reduction measures on CH_4 and N_2O that are currently unidentified
- The CCAP scenario uses CDR instead to reach net zero emissions
- The increased cost of CDR is reflected in the cost charts above but not the avoided cost of the unidentified measures present in the Reference Scenario
  - The CCAP scenario would be even lower cost than the Reference if factoring in costs of achieving the CH_4 and N_2O reductions present in the Reference Scenario

Potential Cost Impacts of Non-CO_2 Measures

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- The unidentified and uncosted measures to achieve the 2050 in the Reference Scenario achieve 6.2 MMT
  - The following table shows this difference by gas between the CCAP Scenario that uses the EPA identified measure potential and the Reference Scenario

Gas	3.Reference	8.CCAP	Difference
CH_4	2.4	4.7	2.4
F-gases	0.7	1.3	0.6
N_2O	0.9	4.2	3.3
sum	4.0	10.3	6.2

- The impact on cost depends on how expensive these unidentified measures are. The following table shows the additional cost per year in 2050 for a range of $/ton of the Reference vs. CCAP Scenarios

$/ton	Cost/yr
50	$312M
100	$624M
300	$1,873M
500	$3,121M

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Air Quality Analysis

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Air Quality Methodology

Benefits Analysis: Health Impacts

- U.S. Environmental Protection Agency (EPA) CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) Analysis
- Health impacts of particulate matter from air pollutants including nitrogen oxides (NOx), sulfur oxides (SOx), and direct fine particulate matter emissions (PM2.5)

Air Quality Results from Evolved Models

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EnergyPATHWAYS

Demand technology emission changes

- Database of emissions factors for NOx, PM2.5 and SOx from key technologies
  - Vehicles emission factors taken from EPA Motor Vehicle Emission Simulator
  - Supplemental vehicle emission data from OECD (2020), Non-exhaust Particulate Emissions from Road Transport: An Ignored Environmental Policy Challenge, OECD Publishing, Paris, https://doi.org/10.1787/4a4dc6ca-en.
  - Building technologies adapted from EPA's Air Emissions Inventories for point sources
- Calculates emissions based on technology activity

RIO

Energy supply emission changes

- Database of emissions factors for NOx, PM2.5, SOx and mercury from existing and new power plants
  - Existing plant emission factors taken from EPA Avoided Emissions and Generation Tool (AVERT) and eGRID 2019 data
  - Existing energy conversion technologies (e.g., boilers for steam) are adapted from EPA's Air Emissions Inventories for point sources
  - New power plant data is a combination of NREL ATB data and National Electric Energy Data System data
- RIO calculates emissions based on least cost dispatch

EPA Co-Benefits Risk Assessment (COBRA)

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Develop Scenario

Construct air quality scenario →

COBRA

Changes in Air Quality (Particulate Matter) → **Health Outcomes** → **Economic Benefits**

- Combines data from results and inputs bundled with COBRA to develop AQ scenarios
  - Pollutant results address many but not all categories for COBRA
  - COBRA inputs are scaled or adjusted for missing data categories, with changes made to reflect how each pathway evolves differently.

- Reduced form air quality model called the Source-Receptor (S-R) Matrix
  - Estimates ambient concentrations of PM by county
- Estimates contribution from each pollutant source to air quality of each county

- Concentration response functions
  - Adult and infant mortality
  - Non-fatal heart attacks
  - Respiratory and Cardiovascular hospital admissions
  - Acute bronchitis and respiratory symptoms
  - Asthma exacerbations and emergencies
  - Restricted activity and work loss days

- Economic costs of health impacts
  - Value of statistical life (VSL)
  - Cost of illness
  - Hospital charges
  - Willingness to pay
    - Symptoms of illness
    - Restricted activity
    - Lost workdays

EPA COBRA: https://www.epa.gov/sites/default/files/2017-10/documents/cobra_training_eic_2017.pdf

Epidemiological Studies Behind COBRA Functions

- COBRA's concentration response functions are based on epidemiological studies of health outcomes when populations are exposed to changes in PM2.5
- More details can be found in the COBRA user guide and documentation at the following link (source of adjacent table)
  - https://www.epa.gov/system/files/documents/2021-11/cobra-user-manual-nov-2021_4.1_0.pdf

Endpoint	Author	Age
Mortality, All Cause	Krewski et al. (2009)	30-99
Mortality, All Cause	Lepeule et al. (2012)	25-99
Mortality, All Cause	Woodruff et al. (1997)	Infant
Acute Myocardial Infarction, Nonfatal	Peters et al. (2001)	18-99
Acute Myocardial Infarction, Nonfatal	Pope et al. (2006)	18-99
Acute Myocardial Infarction, Nonfatal	Sullivan et al. (2005)	18-99
Acute Myocardial Infarction, Nonfatal	Zanobetti and Schwartz (2006)	18-99
Acute Myocardial Infarction, Nonfatal	Zanobetti et al. (2009)	18-99
HA, All Cardiovascular (less Myocardial Infarctions)	Bell et al. (2008)	65-99
HA, All Cardiovascular (less Myocardial Infarctions)	Moolgavkar (2000b)	18-64
HA, All Cardiovascular (less Myocardial Infarctions)	Peng et al. (2008)	65-99
HA, All Cardiovascular (less Myocardial Infarctions)	Peng et al. (2009)	65-99
HA, All Cardiovascular (less Myocardial Infarctions)	Zanobetti et al. (2009)	65-99
HA, All Respiratory	Zanobetti et al. (2009)	65-99
HA, All Respiratory	Kloog et al. (2012)	65-99
HA, Asthma	Babin et al. (2007)	0-17
HA, Asthma	Sheppard (2003)	0-17
HA, Chronic Lung Disease	Moolgavkar (2000a)	18-64
Emergency Room Visits, Asthma	Mar et al. (2010)	0-99
Emergency Room Visits, Asthma	Slaughter et al. (2005)	0-99
Emergency Room Visits, Asthma	Glad et al. (2012)	0-99
Acute Bronchitis	Dockery et al. (1996)	8-12
Asthma Exacerbation, Cough	Mar et al. (2004)	6-18
Asthma Exacerbation, Cough	Ostro et al. (2001)	6-18
Asthma Exacerbation, Shortness of Breath	Mar et al. (2004)	6-18
Asthma Exacerbation, Shortness of Breath	Ostro et al. (2001)	6-18
Asthma Exacerbation, Wheeze	Ostro et al. (2001)	6-18
Minor Restricted Activity Days	Ostro and Rothschild (1989)	18-64
Lower Respiratory Symptoms	Schwartz and Neas (2000)	7-14
Upper Respiratory Symptoms	Pope et al. (1991)	9-11
Work Loss Days	Ostro (1987)	18-64

COBRA Methodology

- Reports the benefits attributed to emissions reductions in a single year versus 2023 (the latest year of air quality historical data in the COBRA model)
  - Reporting 2030 and 2050 in this study
  - Future gas generation additions are assumed to go into the same counties that have existing natural gas capacity for power plants
  - Benefits are attributed to the emissions reductions over 2023 experienced by the population in 2030 and 2050
- Fewer hospital visits, lost workdays, incidences of illness are determined for the year in which the emissions reductions are experienced
- Mortalities attributed to the emissions in a particular year are assumed to occur over the following 20 years
  - Benefits of emissions reductions are the present value of reduced mortalities over that time period
  - All attributed to the emissions reductions experienced within a single year
- This analysis does not address indoor air quality changes from the energy transition or the effect on air quality of changing wildfire frequency

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Air Quality Results

Impact on Health Metrics and Mortality: CCAP Scenario

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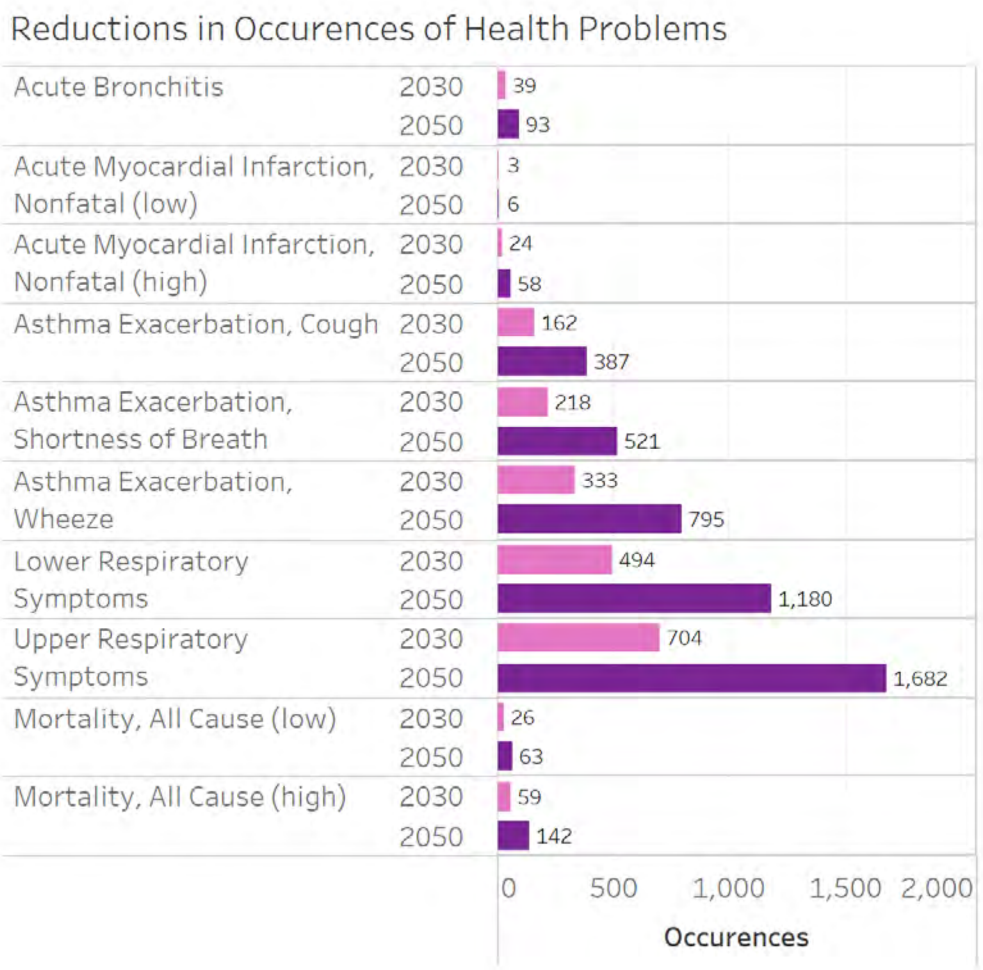
- Reduced occurrences of health problems due to reduced pollutant concentrations
- These result in economic benefits such as fewer missed workdays, fewer hospital admissions, and reduced mortality
- Reduced mortality is by far the largest economic benefit
  - Value of a statistical life (VSL) of $7.4M in 2006 dollars used by EPA
  - "How much people are willing to pay for small reductions in their risks of dying," EPA mortality risk valuation



Impact on Lost Workdays, Hospital Admissions, and Range of Mortality: CCAP Scenario

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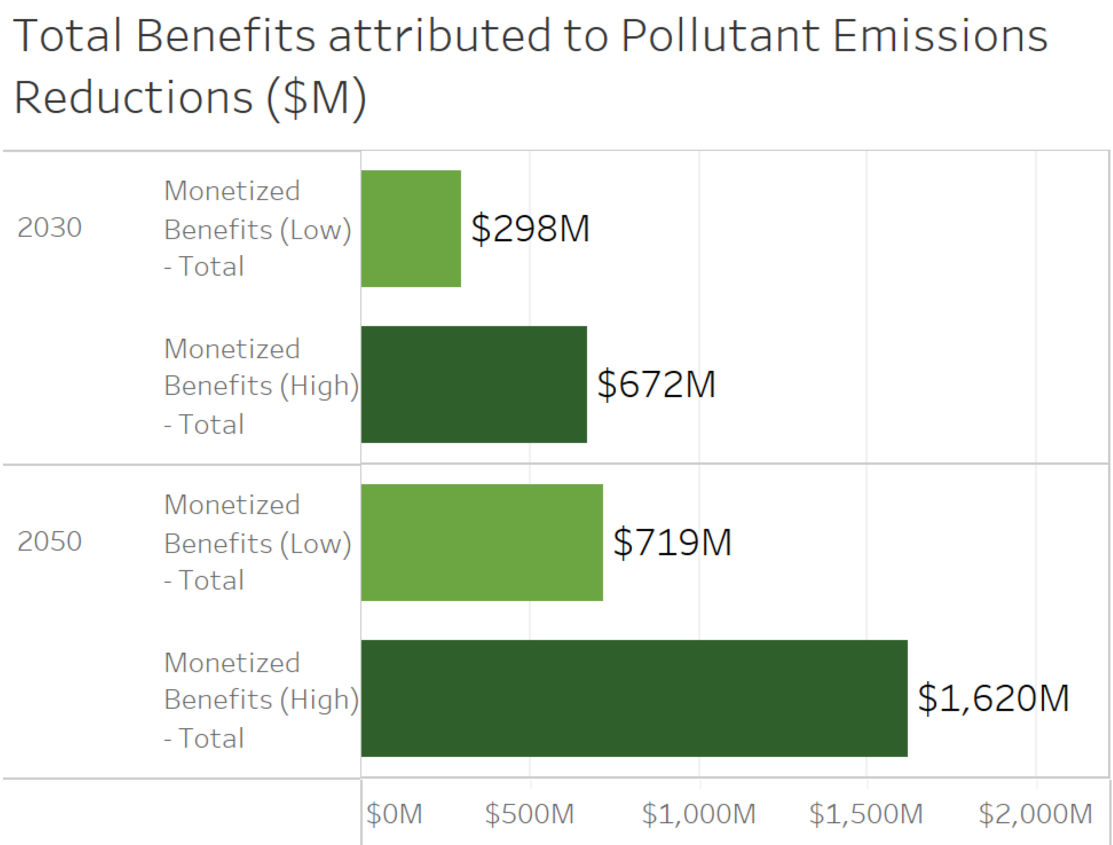
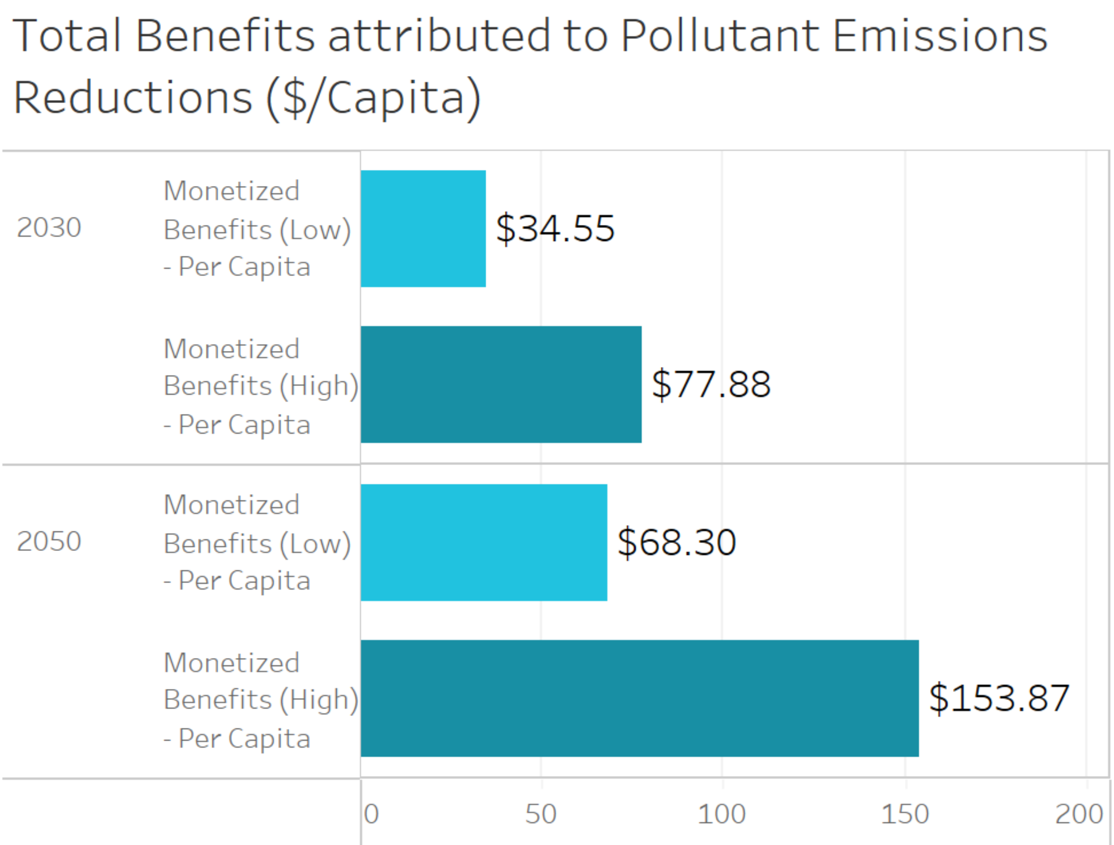
- Outcomes include fewer days of work lost, hospital admissions, and mortalities

Outcomes	2030	2050
Fewer days of work lost per million people	385	749
Fewer hospital admits per million people	0.9	1.9
Fewer mortalities per million people (high)	6.8	13.5
Fewer mortalities per million people (low)	3.0	6.0

Annual Pollutant Emissions Reduction Benefits: CCAP Scenario

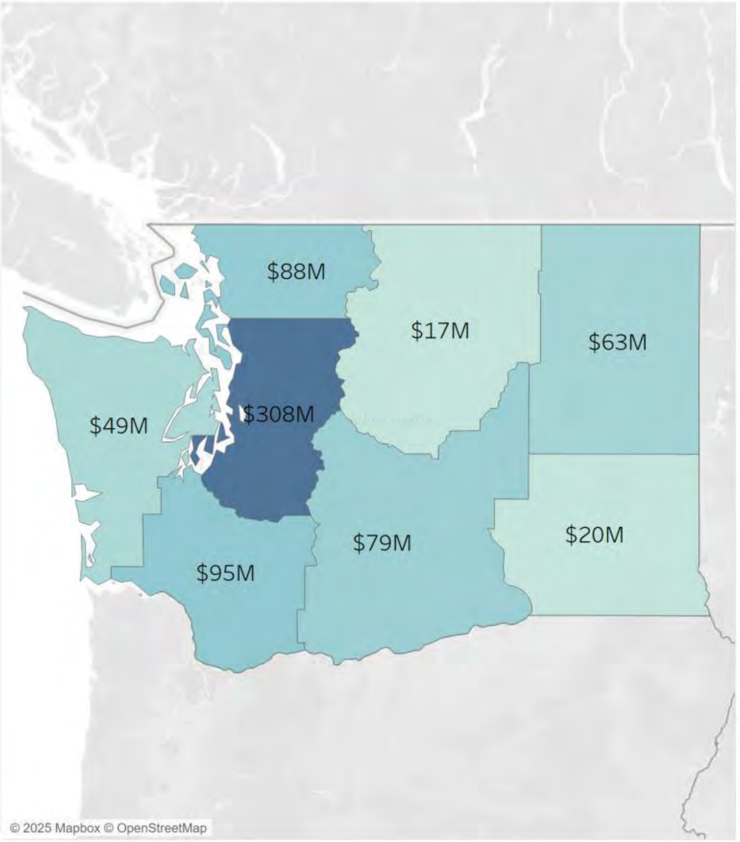




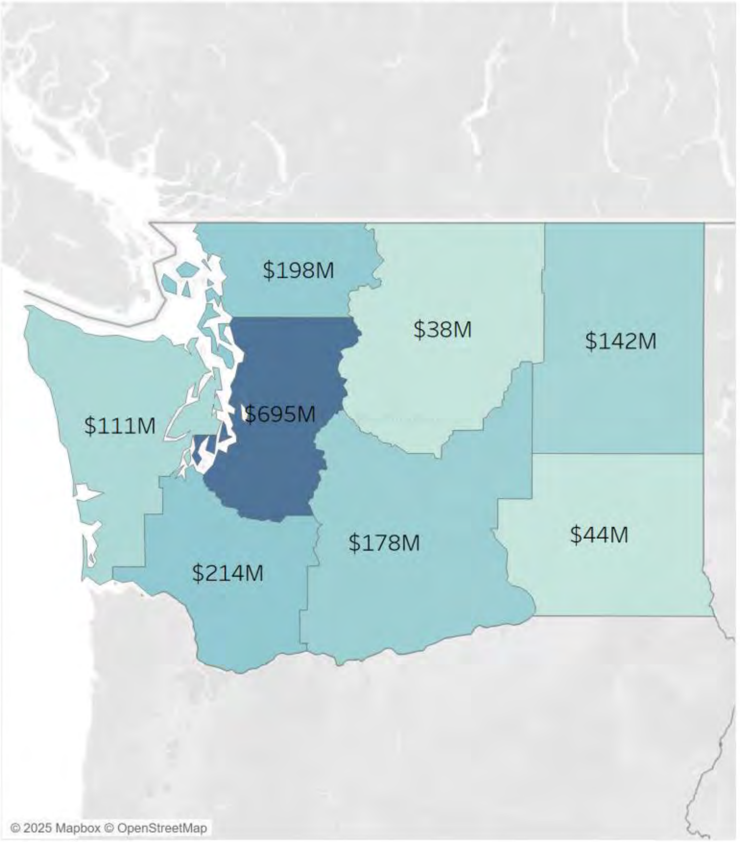
Total Health Benefits by Region in 2050: CCAP Scenario

- Distribution of health benefits follows population
- Largest benefits in Seattle metropolitan area
- Benefits relative to health impacts of particulate matter exposure in 2023

Total Health Benefits 2050 (Low)

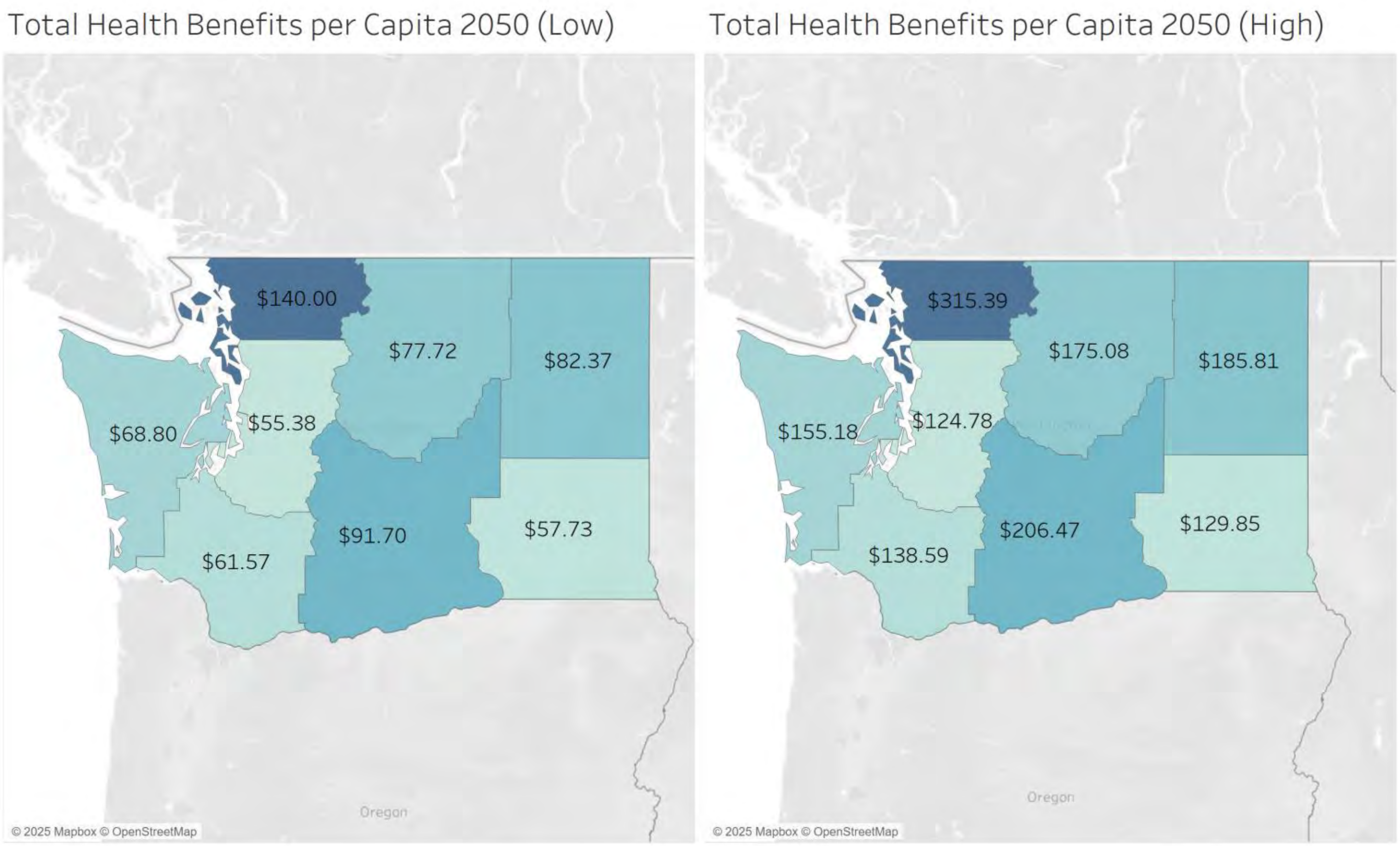


Total Health Benefits 2050 (High)



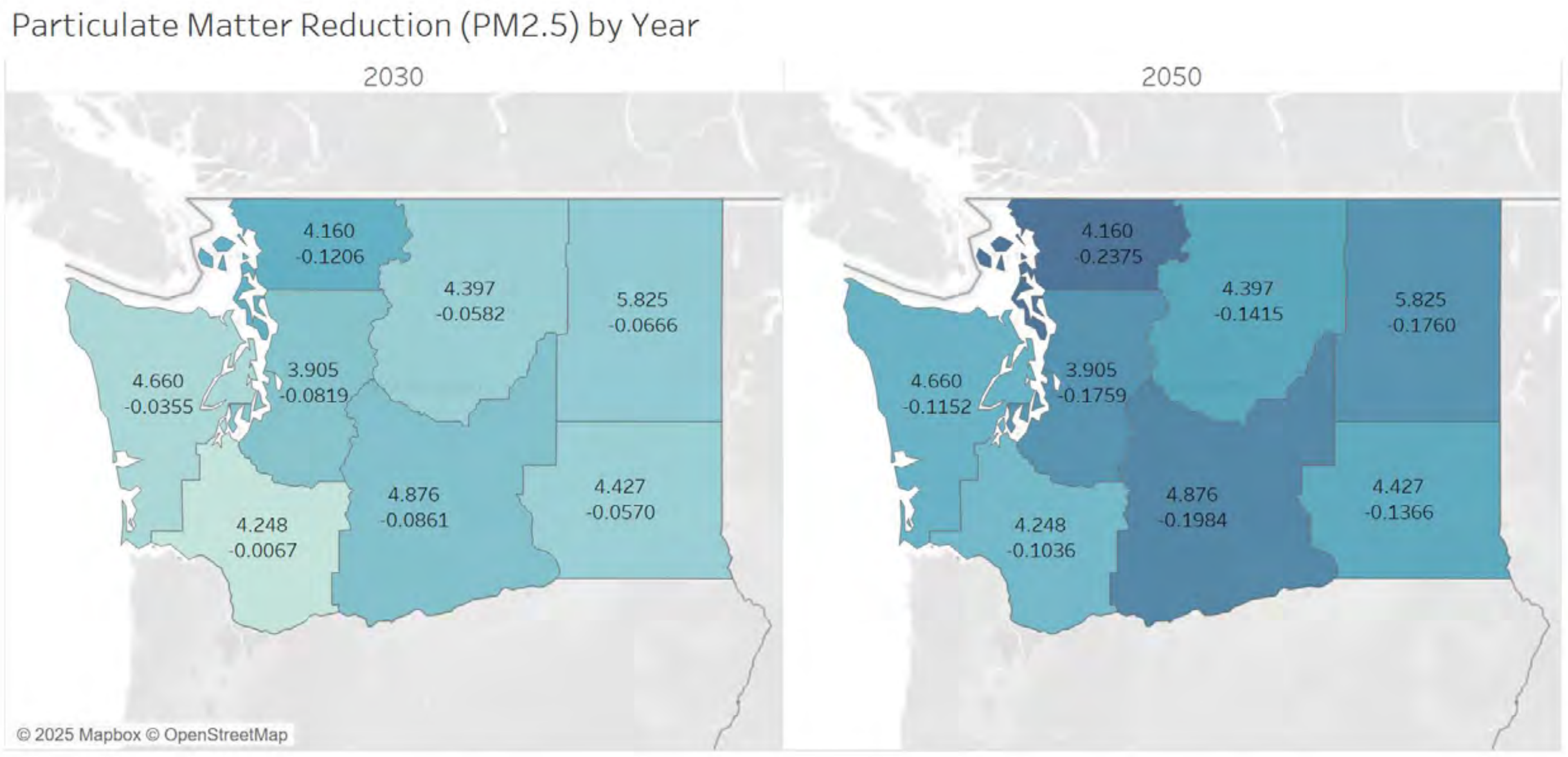
Health Benefits per Capita by Region in 2050: CCAP Scenario

- Per capita benefits greater in the southern regions of the state
- Benefits relative to health impacts of particulate matter exposure in 2023
- ~99% of the benefits come from reduced mortality



Particulate Matter Concentrations: CCAP Scenario

- COBRA calculates the change in PM2.5 concentrations and their impact on health outcomes
- The adjacent maps show the baseline PM2.5 concentrations in 2023 and the change in that baseline by 2030 and 2050
- The reduction in PM2.5 concentrations results in better health outcomes



Top: Baseline PM2.5 in 2023
Bottom: Change in PM2.5 from 2023 baseline

Key Takeaways

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- COBRA analysis indicates significant health benefits associated with achieving Washington emissions and clean energy targets
  - Between \$298M and \$672M monetized benefits in 2030
  - Between \$719M and \$1620M monetized benefits in 2050
  - Cumulative present value benefits of \$9.1B to \$23.7B over the next 25 years
- Absolute benefits follow population by region but per capita do not follow the same trend
- Most monetized dollar health benefits are attributed to mortality based on the high value of a statistical life

Energy Wallet Analysis

Energy Wallet Overview

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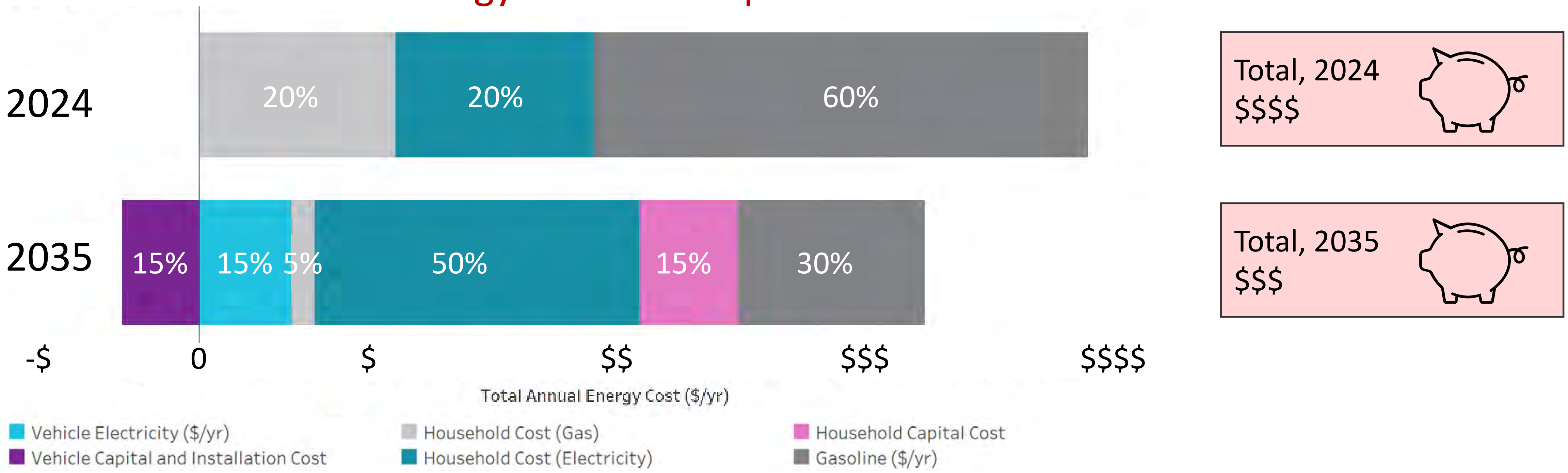
- Energy wallet examines a household's energy use and associated costs as they switch to an electric vehicle (EV) and heat pump
  - Includes household's use of electricity, natural gas, and gasoline
  - Includes all energy spending across fuels, as well the capital cost or savings of buying an EV or a heat pump (compared to buying other replacement technologies)
  - Analysis undertaken for five sample households

Energy Wallet Illustrates How Technology Adoption Affects Household Energy Costs

- Example household buys an EV and a heat pump in 2035. This changes the energy consumption and therefore costs. Households must also pay the difference between EVs/heat pumps and conventional technologies.

Energy Wallet Example



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Energy Wallet Methodology

Energy Wallet Sample Household Inputs

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Step 1. Determine **four sample households** to represent in the analysis

Step 2. Characterize the **following energy consumption inputs** for each sample household:

- Electricity (space heating, water heating, air conditioning, other)
- Natural Gas (space heating, water heating, other)
- Gasoline (vehicle miles traveled)

Step 1: Determine Sample Households

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- Households picked to represent different example homes across Washington
  - Single family home in urban coastal climate
  - Single family home in northeastern cold climate zone
  - Manufactured home in southeastern Washington
  - Rental apartment in Seattle
- These are examples and significant variation exists across households within each of these buckets
  - Not extendable to the entire Washington population

Step 2. Identify Sources for Input Data to Develop Each Sample Household

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Data Inputs needed for Energy Wallet:

- Energy Consumption (electricity, natural gas) and associated costs
- Vehicle Miles Traveled (VMT) and associated costs (gasoline)

From there, we worked backward to identify initial sample households that could be developed using publicly available data sources

- Utilized the Northwest Energy Efficiency Alliance's (NEEA) 2022 Residential Building Stock Assessment (2022 RBSA) as a starting point for defining sample households based on building type and energy consumption.
- NEEA's 2022 RBSA has extensive regional data, which includes, but is not limited to: building types, building location, energy consumption, utility information, equipment-level data and self-reported income.
- https://neea.org/data/residential-building-stock-assessment

Step 2. Determine sample household from NEEA RBSA and supplementary WA-specific data

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- Filtered NEEA RBSA sampled sites by characteristics determined by five sample household types
- Additionally, excluded from NEEA RBSA dataset:
  - Sites with N/A values for primary fields (electricity/gas usage)
  - Sites with unusual large loads (e.g., electric welder)
  - Sites relying on heat pump for heating and/or cooling (since Energy Wallet Analysis examines the switch to a heat pump)
- RBSA data includes *total fuel consumption* and *heating fuel consumption*
  - Developed ratios for breakdown of other fuel consumption between water heating, air conditioning, and other based on Energy Information Administration (EIA) Residential Energy Consumption Survey (RECS)
- Vehicle miles traveled by household taken from the Center for Neighborhood Technology (CNT) Housing and Transportation (H+T) Affordability Index
  - https://htaindex.cnt.org/download/data.php
  - County-specific, does not change with housing type

EIA RECS Ratios

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- Energy Information Administration (EIA) Residential Energy Consumption Survey (RECS) data used to determine relative ratios of air conditioning, other (including refrigerators), and water heating for homes with natural gas and electricity primary heating fuels

Table CE4.5 Annual household site end-use consumption by fuel in the West—totals, 2020

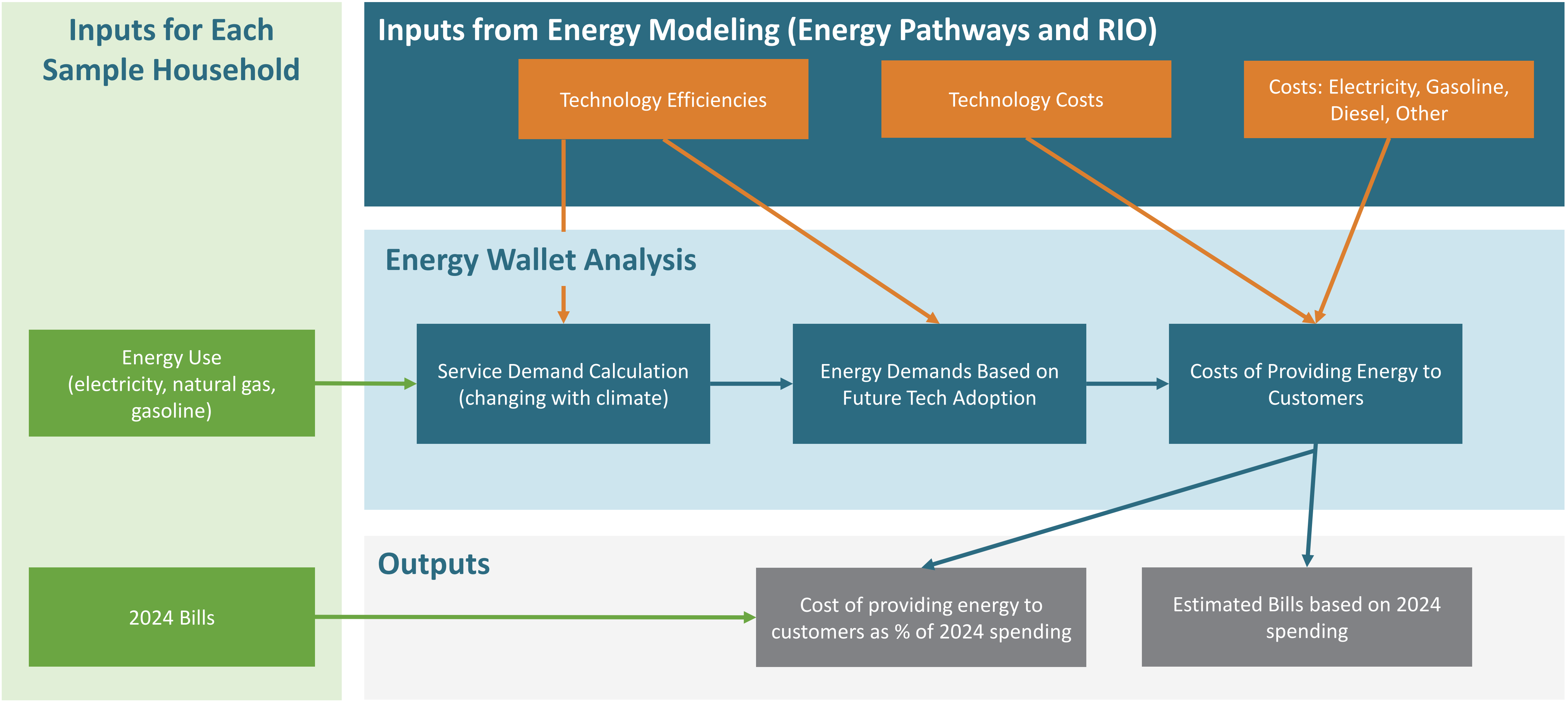
Main heating fuel: Natural Gas			
Total site energy consumption[a] (trillion Btu)			
Electricity		Natural Gas	
Air conditioning	Refrigerators + Other	Water heating	Other
92	329	281	68
21.9%	78.1%	80.5%	19.5%

Main heating fuel: Electricity		
Total site energy consumption[a] (trillion Btu)		
Electricity		
Water heating	Air conditioning	Refrigerators + Other
48	38	115
23.9%	18.9%	57.2%
29.4%	x	70.6%

Notes: Because of rounding, data may not sum to totals. See RECS Terminology for definition of terms used in these tables.
Btu = British thermal units
[a] Consumption and expenditures for biomass (wood), coal, district steam, and solar thermal are excluded. Electricity consumption from on-site solar photovoltaic generation (that is, solar panels) is included.

Data source: U.S. Energy Information Administration, Office of Energy Consumption and Efficiency Statistics, Forms EIA-457A, D, E, F, G of the 2020 Residential Energy Consumption Survey

Energy Wallet Approach



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Sample Households and Cost Inputs

Meet the Four Sample Households

Household Characteristic	Stacey's	Eileen's	Bill's	Jeremy's
				
Building Category	Single Family Detached	Single Family Detached	Single Family Manufactured	Multi-family
Region	Urban	Rural Cold Climate	Rural	Urban
Ownership	Own	Own	Own	Rent
Primary Heating Fuel Type	Natural gas	Electricity	Electricity	Electricity
Primary Heating System	Furnace	Unit Heater	Furnace	Wall Heater
Primary Cooling System	Central AC	Window AC	Window AC	None
Water Heater Technology	Fossil Fuel Non-Condensing	Fossil Fuel Non-Condensing	Electric Resistance	Electric Resistance
Water Heater Fuel	Natural gas	Electric	Electricity	Electricity
Conditioned Area (sq. ft.)	1649	1736	1299	-
Year	2000	1999	1997	2018
Stove/Oven	Natural gas	Electric	Electric	Electric
Occupants	4	4	2	1
Vehicles	2 SUVs	2 SUVs	2 Cars	1 Car

Energy Consumption of Four Sample Households

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Annual Household Usage	Stacey's	Eileen's	Bill's	Jeremy's
				
Electricity (kWh)	**7,761**	**38,123**	**14,950**	**9,729**
Space heating	-	19,114	6,517	3,357
Water heating	-	4,549	2,007	1,874
Air conditioning	2,168	3,613	1,594	-
Other	7,752	10,933	4,824	4,499
Natural Gas (therms)	**1,276**	**-**	**-**	**-**
Space heating	857	-	-	-
Water heating	337	-	-	-
Other	82	-	-	-
Vehicle Miles Traveled (VMT)	**17,866**	**25,359**	**26,059**	**15,655**

Notes on Sample Households

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- Energy consumption varies among sample households
- Housing characteristics impact a household's energy use, but they are not the only factors (e.g., behavior can also play a significant role)
- All households use either natural gas or electricity as the primary heating fuel
  - Does not capture the full range of heating fuels used by Washington residents (e.g., propane, oil, wood)
  - Considered additional fuels and found that natural gas and electricity are the most commonly used primary heating fuels
- Four sample households in this analysis describe a range of possible Washington households but are not representative of Washington's population
- Furthermore, each sample household is not necessarily representative of all households of the same type (e.g., all single family detached homes), rather it is just one example

Uncertainties Underpin the Analysis

Input to the Analysis	Uncertainty
Electricity rates: $0.14/kWh, $0.19/kWh, $0.24/kWh, $0.40/kWh • December 2024 rates averaged $0.14/kWh. We looked at two 5c increments above that as well as a very high $0.40/kWh rate • https://www.bls.gov/regions/west/news-release/2025/averageenergyprices_seattle_20250121.htm	• T&D infrastructure cost changes over time are uncertain and will have an effect on electricity rates • Electric vehicle economics are relatively insensitive to higher electric costs • Heat pump economics are more sensitive
Gas rates: $1.425/therm, $1.675/therm, $1.925/therm • December 2024 average rate of $1.425/therm • Investigated two higher rates at increments of 25c/therm	• Large uncertainties on future gas costs as volumes decrease • Will there be a managed decommissioning of gas infrastructure or will infrastructure costs remain similar to today, recovered from fewer and fewer natural gas sales? • How will costs be recovered? Cost recovery across electric rates? Through taxes? Fully though gas sales? Low-income rates?
Gasoline rates: $4.22/gallon • Held flat at today's gasoline price	• Large uncertainties on gasoline prices • Exposure to global market volatility • Refining and delivery network costs for lower gasoline volumes
Costs for appliances and vehicles: ACEEE and ICCT • Assumed average cost from databases, American Council for an Energy Efficient Economy (ACEEE) and the International Council on Clean Transportation (ICCT)	• Capital costs play a large role in customer economics • Large distribution around reported costs, particularly for heat pumps
Efficiencies: EPA and EIA • Assume miles per gallon (MPG) of internal combustion engine (ICE) vehicles increases in the future. Forecasted heat pump efficiency improvements	• Forecasted efficiency improvements in conventional internal combustion engine (ICE) vehicles and heat pumps have both technological and policy uncertainties

Cost Assumptions for EVs

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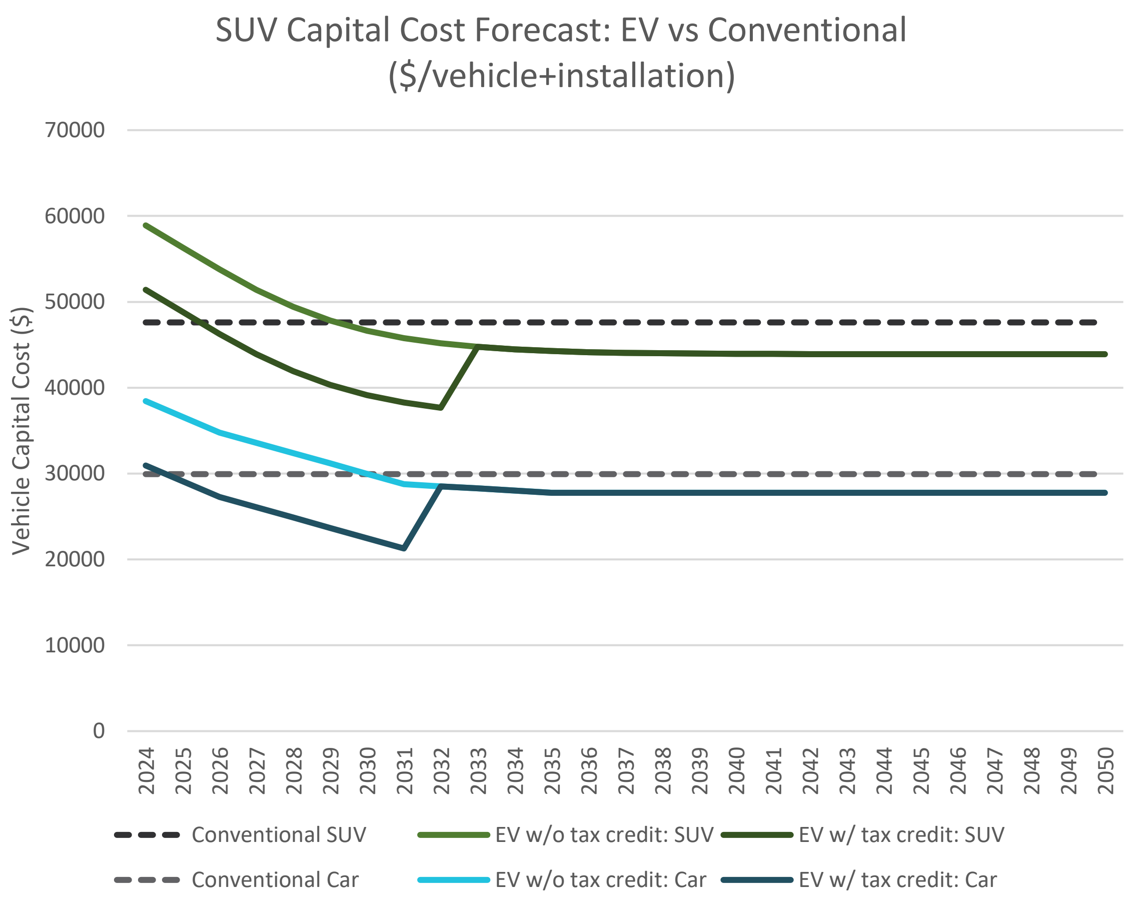
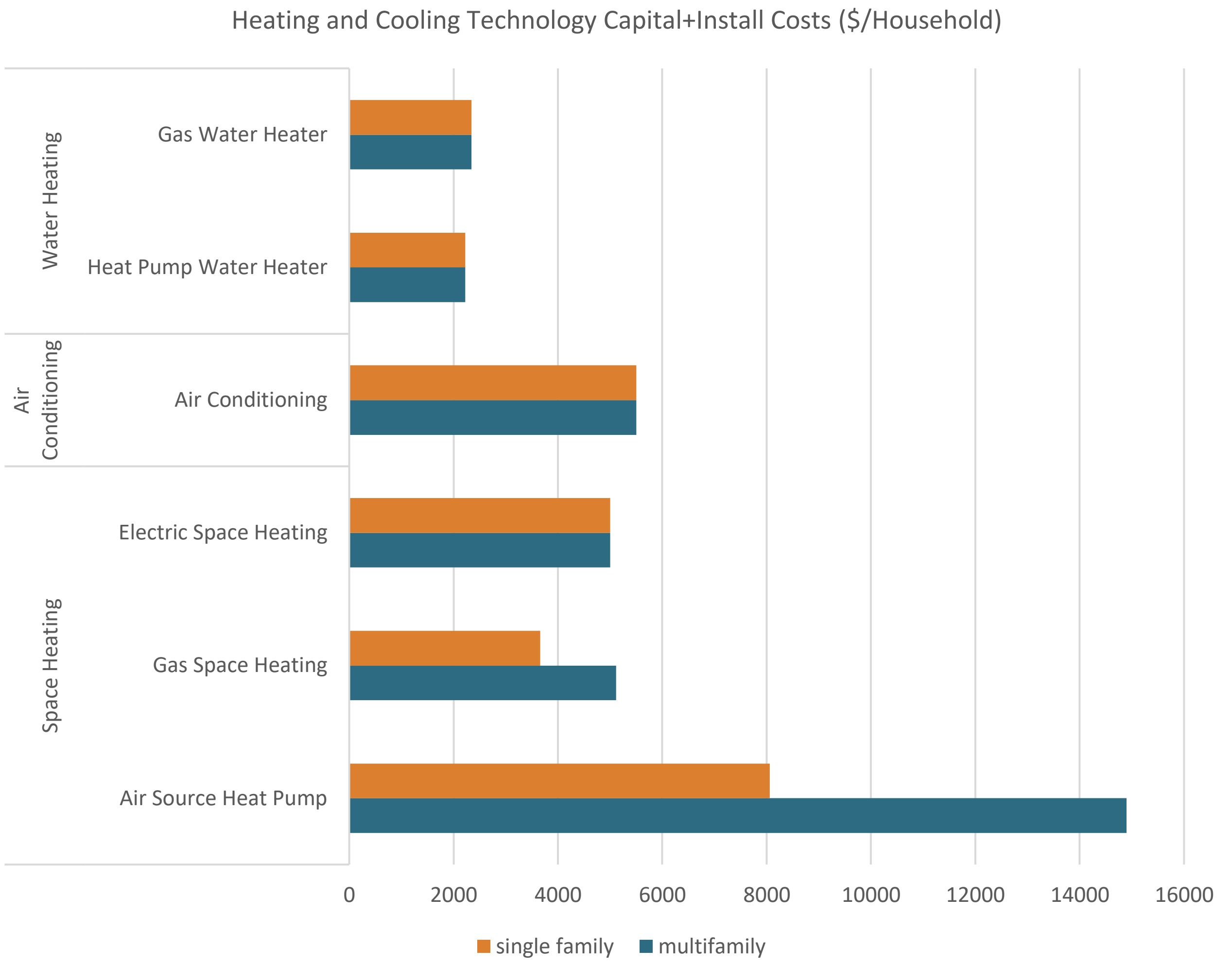
- Vehicle cost assumptions from ICCT
  - theicct.org/wp-content/uploads/2022/10/ev-cost-benefits-2035-oct22.pdf
- SUVs
  - Without Inflation Reduction Act (IRA) tax credits, the capital cost crossover point is forecasted for 2029
  - With IRA, the crossover point is forecasted for 2026
- Cars
  - Without IRA tax credits, the crossover point in 2030
  - With IRA, the crossover point is 2025



Cost Assumptions for Heat Pumps

- Heating and cooling technology costs from ACEEE
  - https://www.aceee.org/sites/default/files/pdfs/b2205.pdf
- Large uncertainties in installed costs for heating and cooling. We use these costs recognizing they can vary significantly household to household



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Vehicle Purchases

Fundamentals

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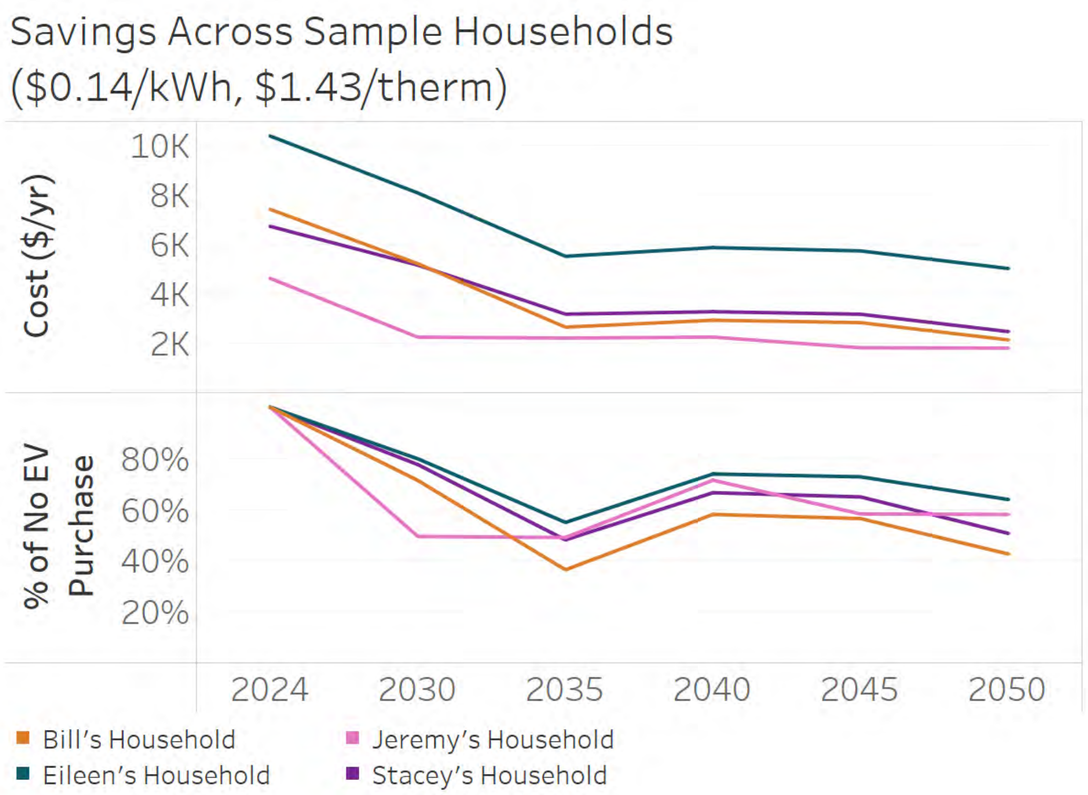
- Assumes gasoline prices at the pump remain flat at $4.22/gallon
  - All results in the analysis are presented in real dollars
- All technology replacements assumed to happen at the end of useful life
  - For example, households replacing a vehicle in 2030 are assumed to have bought their previous one in 2016 for a 14-year lifetime
  - Replaced technology has the average efficiency from the year of purchase
- Where households have 2 SUVs or 2 cars, each vehicle contributes half of the total household VMT
- Vehicle and household technology financing assumes a 7% loan rate over seven years
- The following vehicle results assume no heat pump purchase
  - When heating and cooling systems come to the end of their lives, they are replaced with the same, but more efficient technology, because it's newer

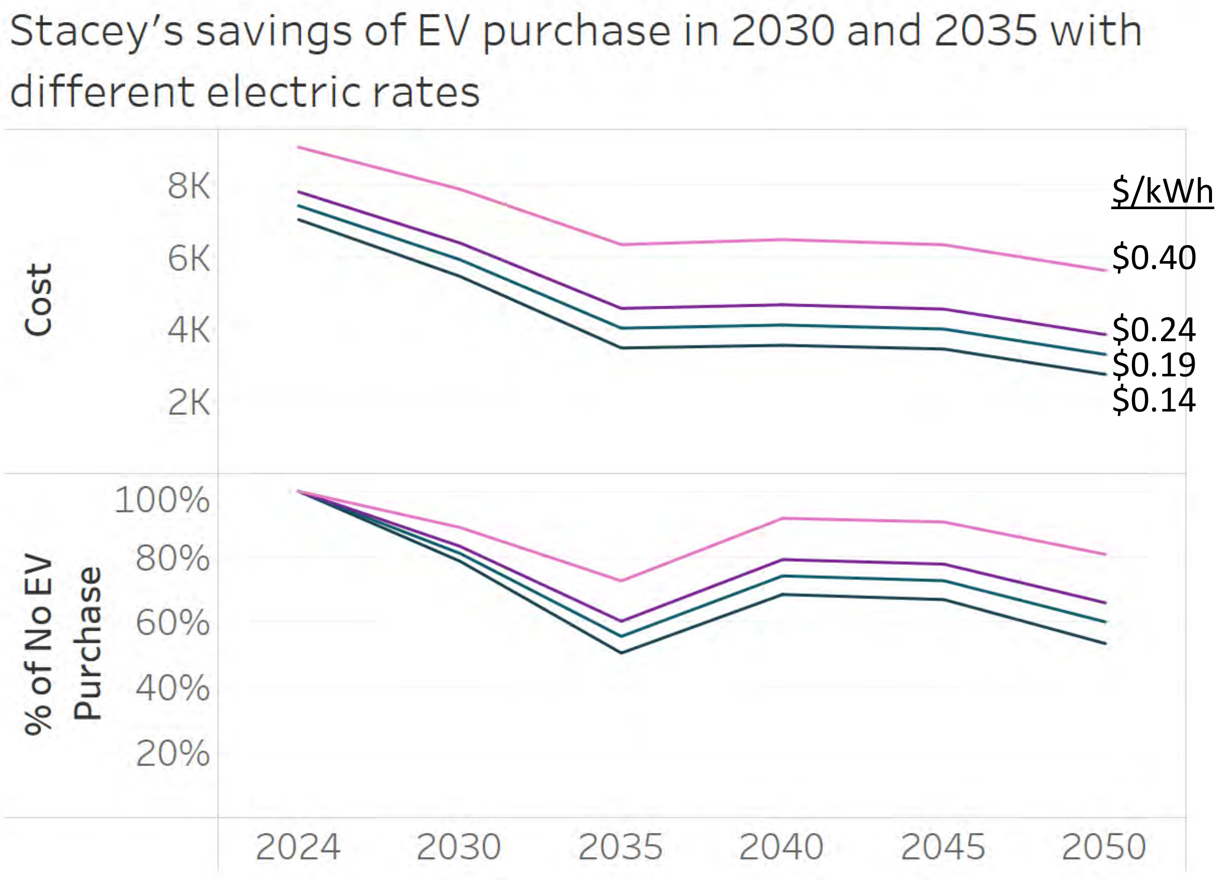
Transportation Electrification is the biggest opportunity for energy wallet savings

- With electricity at $0.14/kWh, all households experience savings if replacing their 2 vehicles with an EV in 2030 and 2035 (1 vehicle in 2030 for Jeremy's household)
  - Assumes customers do not receive IRA credit for either vehicle
  - Overall energy-related spending reduced by up to 64%. Includes the capital cost savings of buying an EV rather than an internal combustion engine vehicle
  - Assumes Jeremy's charging happens 80% outside of the home at a rate of $0.47/kWh. Jeremy's household could make higher savings with more home charging
- % of No EV Purchase compares energy costs to households retaining an ICE across all years



Vehicle electrification saves money even at higher electricity rates

- Focusing on Stacey's single-family home, under varying electric rates she is still better off purchasing an EV than an ICE
- Caveats
  - Compares purchasing a new EV with a new ICE. This may not be the decision a customer makes
  - Cost assumptions on vehicle capital cost and gasoline prices are uncertain



IRA tax incentives help with upfront capital cost

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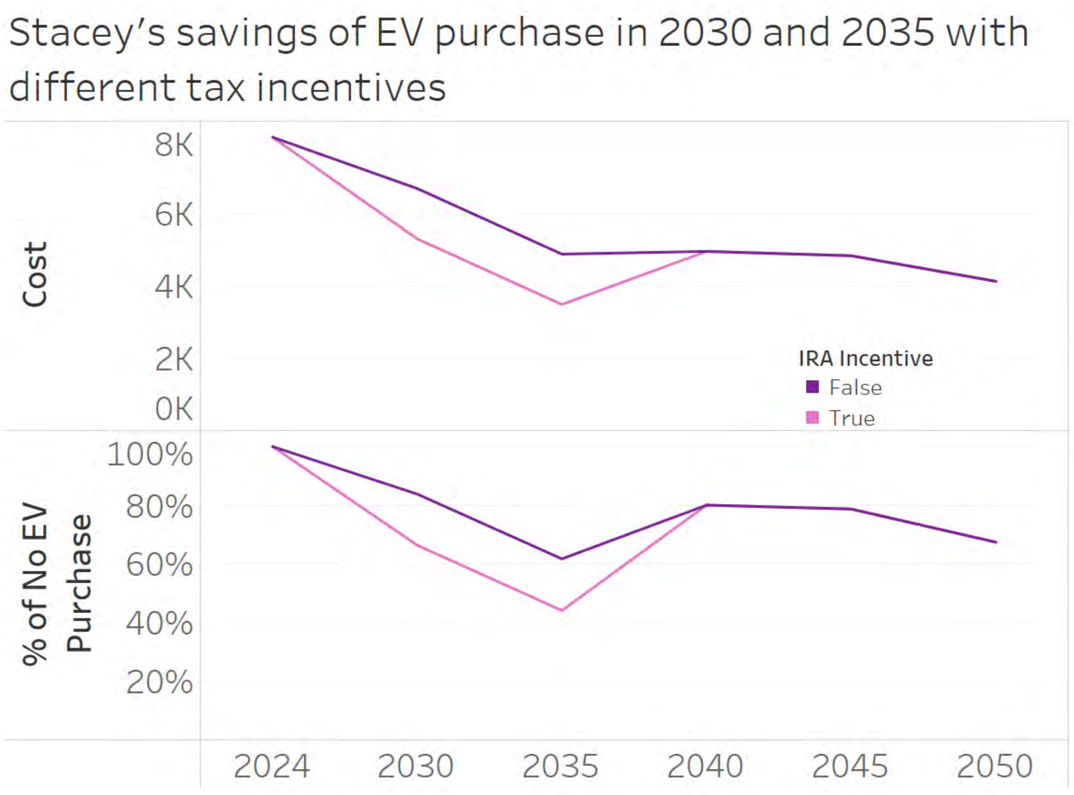
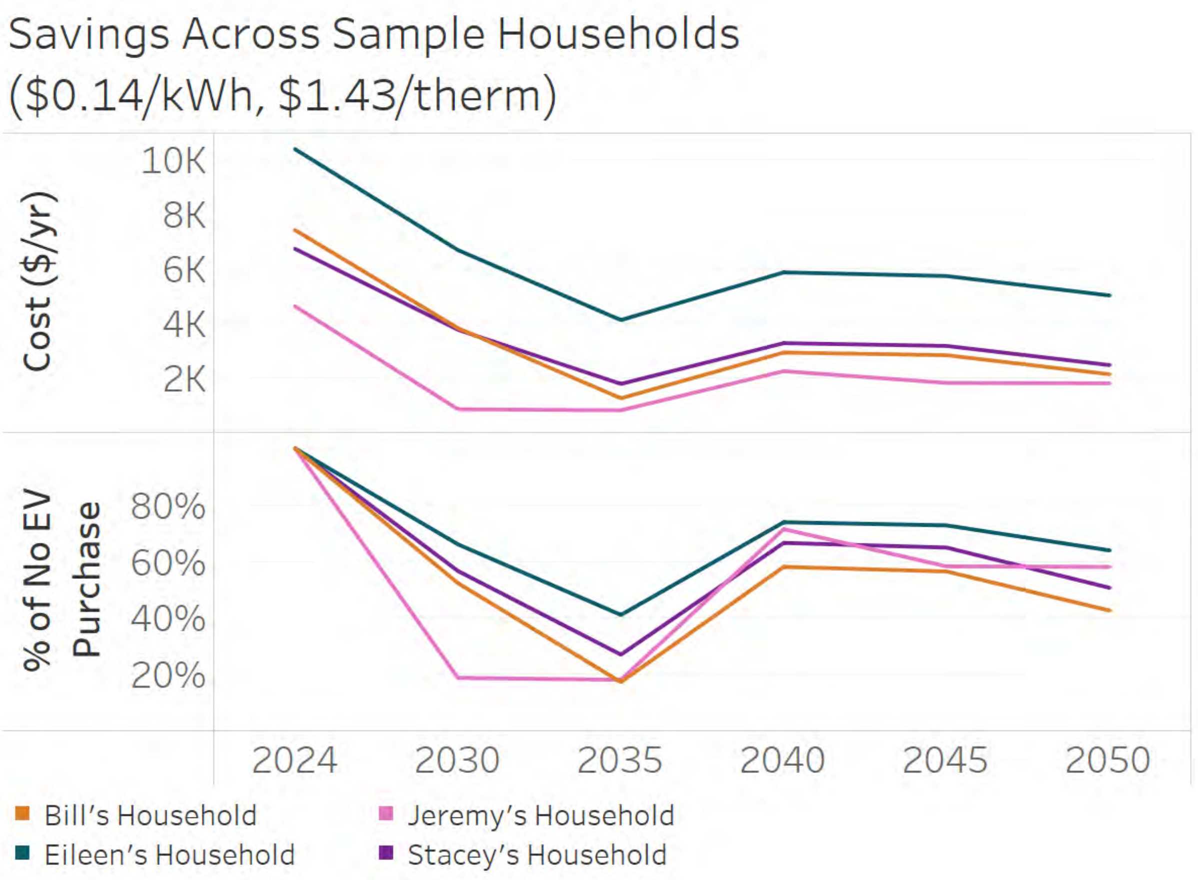
- Focus: Stacey buying one EV in 2030 and another in 2035, at an electric rate of $0.14/kWh and a gas rate of $1.43/therm
- Tax incentive has a large effect, though the EV purchases remain cost effective without it
- No vehicle cost sensitivities analyzed, but this shows that savings are sensitive to vehicle capital cost



False: Customer does not receive IRA incentive
True: Customer does receive IRA incentive

Vehicle electrification saves money for every household we analyzed

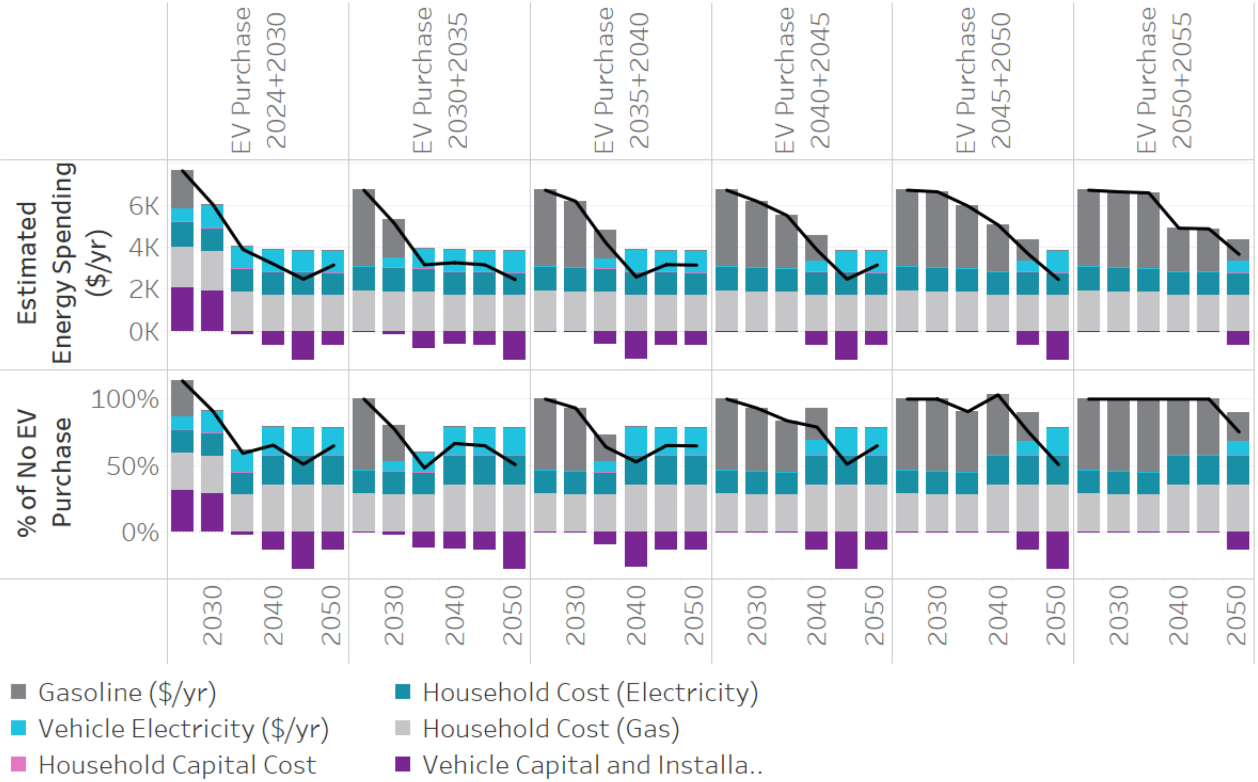
- Households with $0.14/kWh electricity, replacing with EVs in 2030 and 2035 (1 car in 2030 for Jeremy), and receiving the IRA tax credit
  - Assumes a vehicle loan period of 7 years resulting in a difference of $2,190/yr in car payment in 2035 across 2 vehicles
- Jeremy's energy spending at his rental unit is lower than others, and gasoline makes up more of his energy use, so the cost of charging (public or not) has outsized effects



The year of EV purchase matters

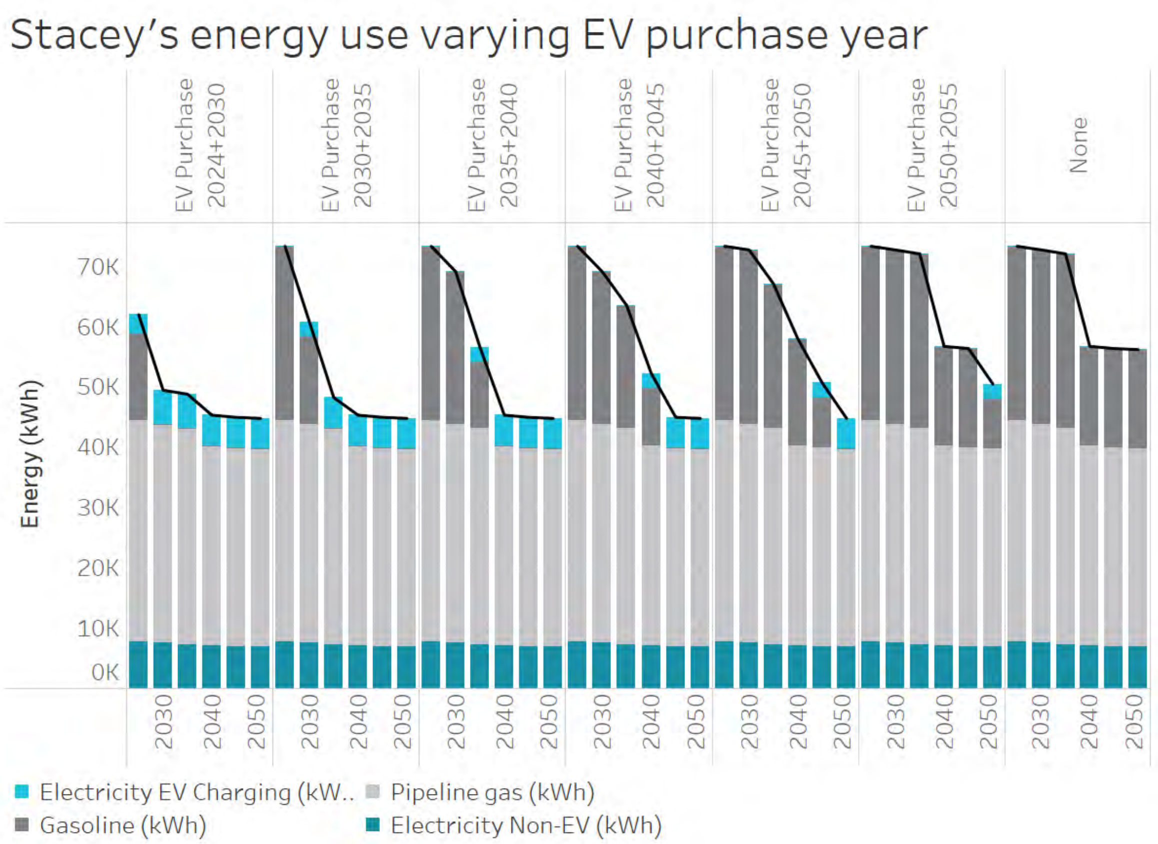
- Focus: Stacey's household at an electric rate of $0.14/kWh, $1.43/therm, no IRA tax incentive, and no heat pump purchase
- Replacing with an EV in 2030 and 2035 is most cost effective than replacing later
- Replacing with an EV in 2024 was not cost effective due to the currently higher EV capital costs

Stacey's estimated energy spending based on EV purchase year ($0.14/kWh, $1.43/therm, No IRA)



EVs significantly reduce energy demand

- Electric motor efficiency significantly reduces customer demand for transportation energy
  - Assuming EV: 98 mpge vs. ICE: 26 mpg in 2024, and EV: 119 mpge vs. ICE: 31 mpg in 2030 for an SUV
- Reduced gasoline use from 2 EV SUV purchases cuts Stacey's total energy use by ~20% by 2050 relative to continuing to drive ICEs
- Jeremy's demand reductions are even greater, at up to 44%



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Heating and Cooling

Fundamentals

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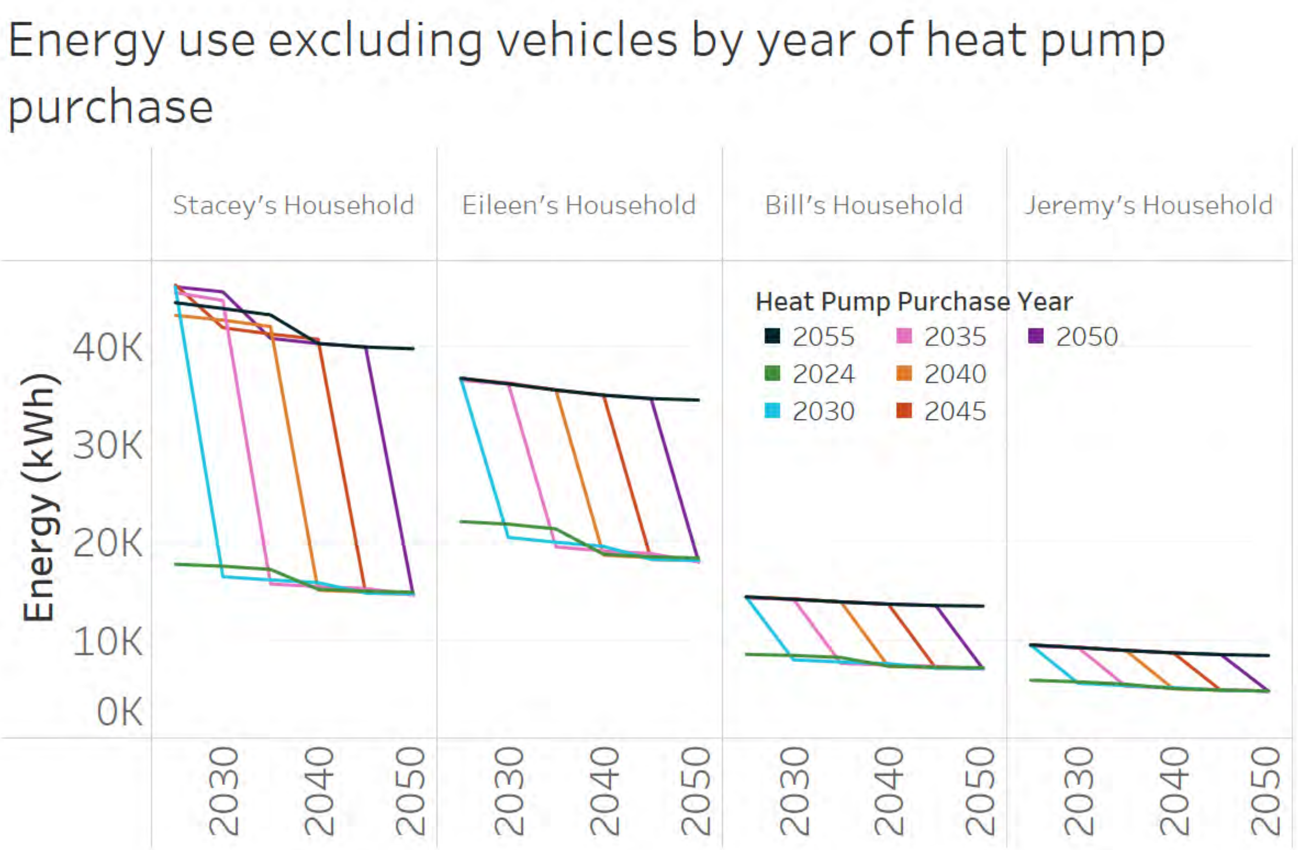
- All technology replacements assumed to happen at the end of useful life
  - For example, households replacing a furnace in 2030 are assumed to have bought their previous one in 2012 (assuming an 18-year lifetime)
  - Replaced technology has the average efficiency from the year of purchase
- Households can replace space heating, water heating, and air conditioning services with heat pumps
- Household technology financing assumes a 7% loan rate and a 7-year term
- The results in this section assume households make no EV purchase between now and 2050
- Natural gas rates are assumed to remain flat between now and 2050 (at three different levels tested)
  - This is conservative, likely forming a lower bound on benefits of heat pump adoption
- We assume the customers in the analysis do not receive an IRA incentive for their heat pump purchase

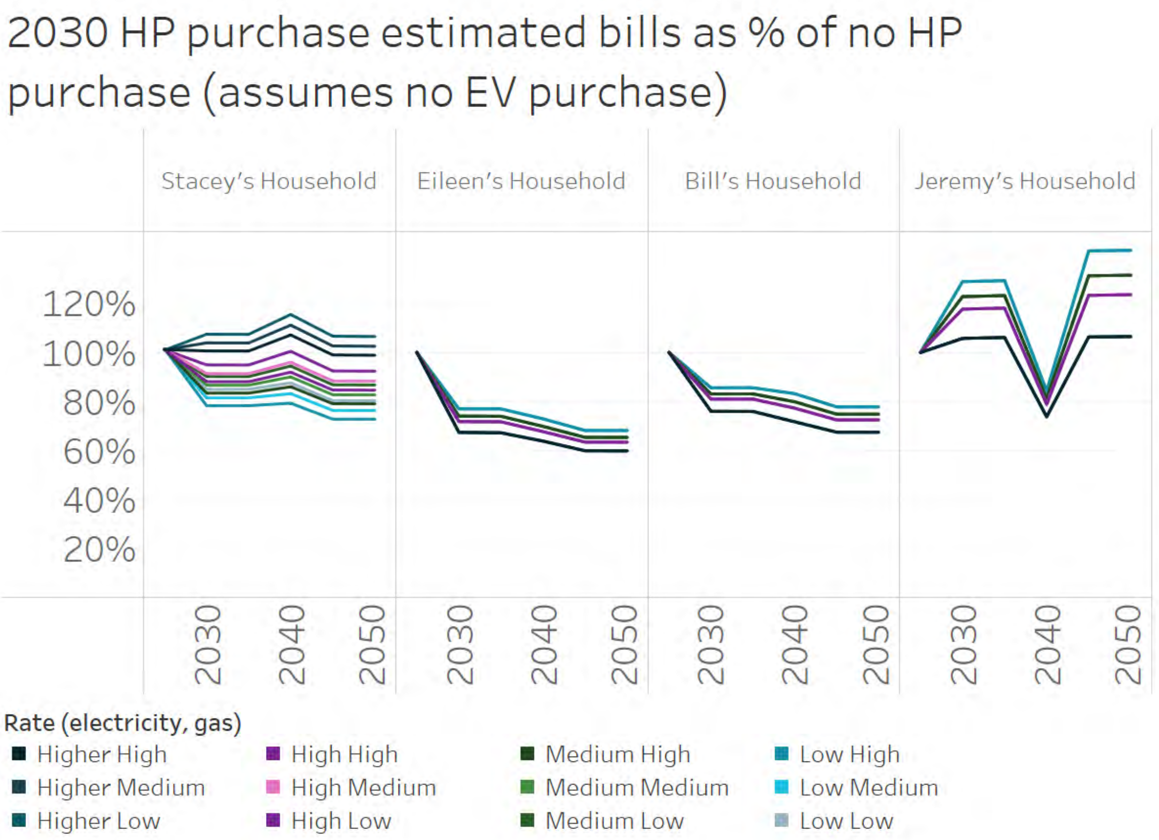
Significant energy savings across all households regardless of heating technology and fuel

- Energy use for heating and cooling declines significantly regardless of the starting technology
- Newer vintage technologies have greater efficiency across technologies, contributing to a downward trend even with no heat pump purchase
- When a customer can install a heat pump depends on when their current equipment reaches end of life



Heating cost uncertainty: Savings of heat pumps are rate- and technology-dependent

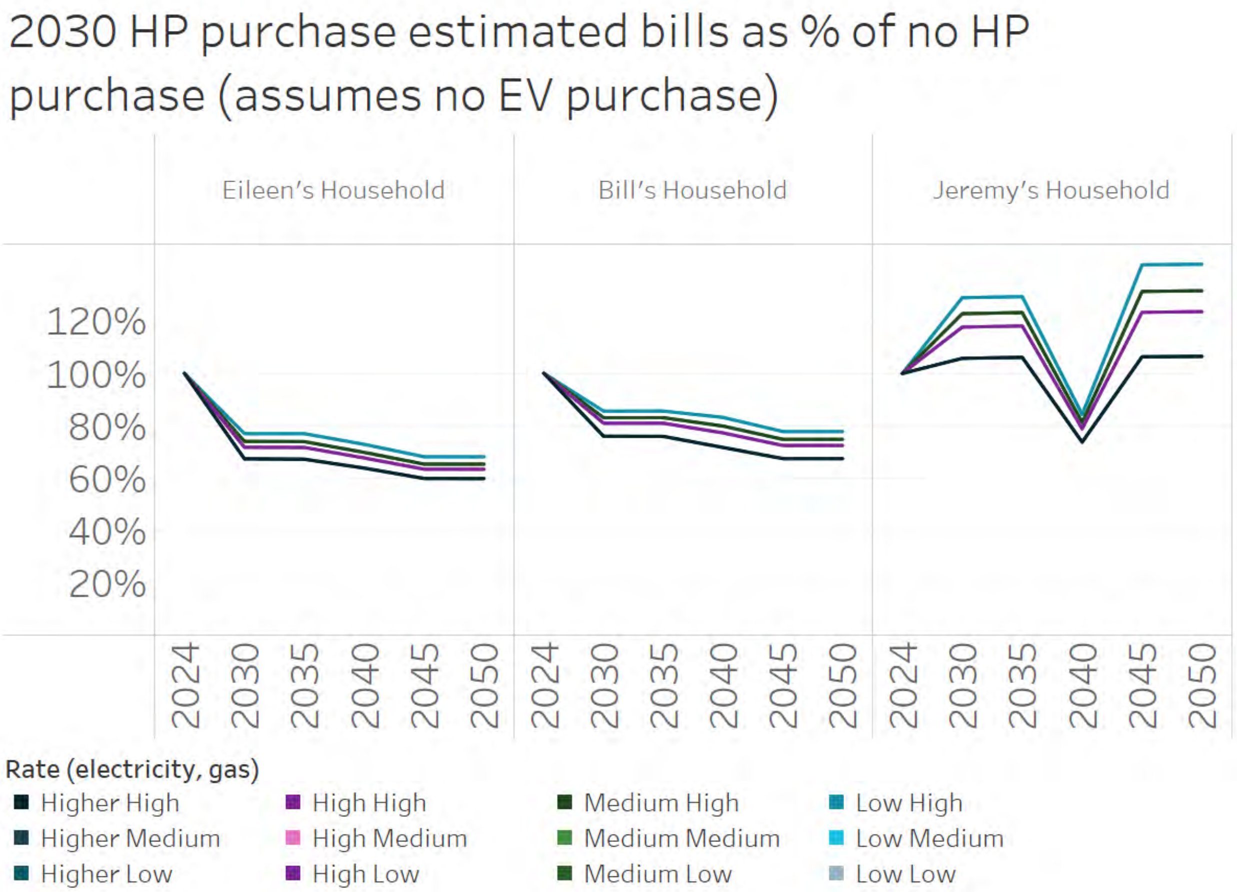
- Whether a heat pump saves a household money or not depends on rate, technology, and service demand
- Customers with electric heat save under all rates
  - The greatest savings under the highest electric rates
- Households with gas heating save the most under the lowest electric rates
  - Stacey's household saves in all but the "higher" electric rate
- Jeremy's rental unit has high costs for installation of a heat pump ($14,900/unit) and struggles to save even at the highest electric rates



Note: Spike downwards is in years when customers do not have a loan payment to make on heat pump equipment

Households heating with electricity likely to save money with heat pumps

- Heat pump efficiency far exceeds that of resistance heating
- Assuming ACEEE average technology and installation costs, Eileen's and Bill's households (which are heated by electricity) save money
  - This does not factor in the large distribution of costs that will vary household by household
- Multifamily ACEEE costs are much higher, assuming retrofit challenges in multifamily buildings, making all but the "higher" electricity rate more expensive for Jeremy's household
  - Shows savings are sensitive to capital cost



Savings for households with gas depend on rates

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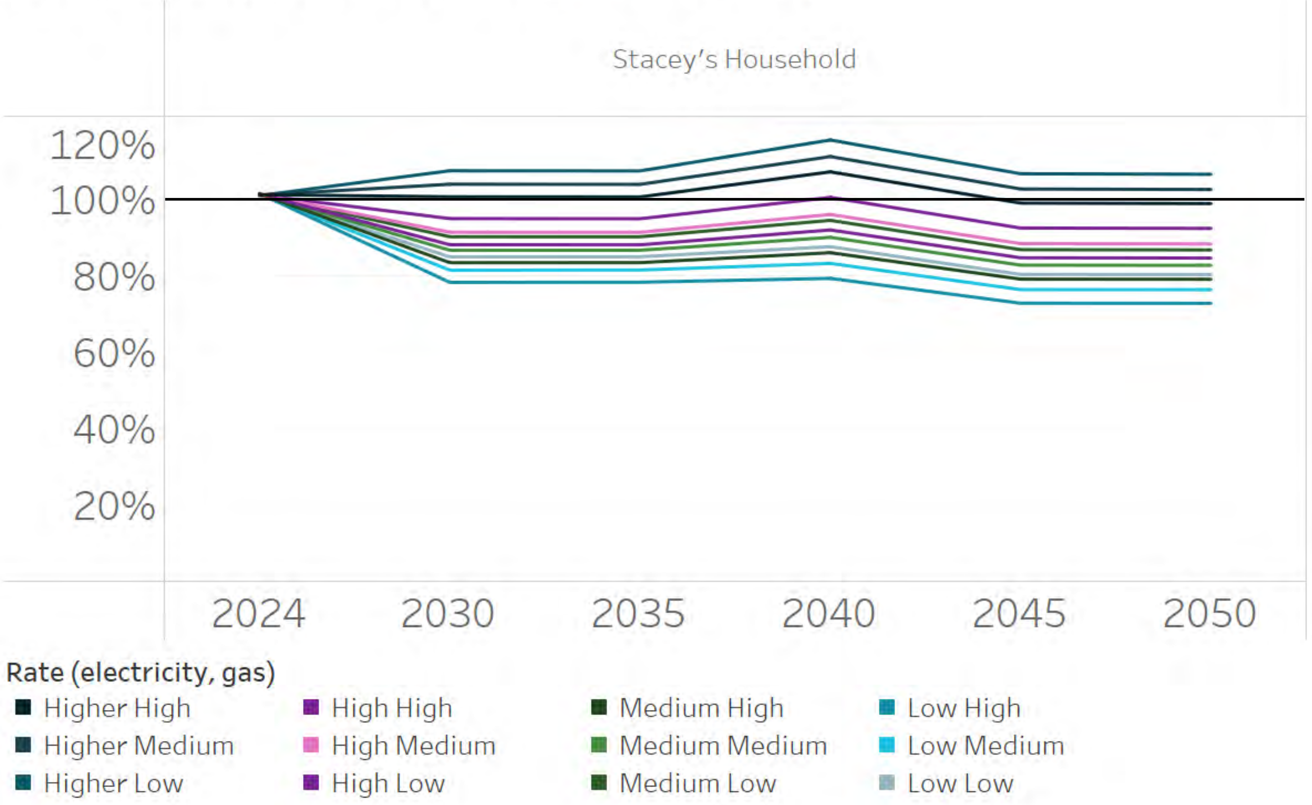
- Savings for homes with gas depend on both the gas rate and the electricity rate
- Households like Stacey's with both heating and air conditioning (AC) save in most cases, assuming ACEEE costs
  - Higher gas rates/lower electricity rates are more favorable
- Households with gas but without AC are less likely to save money when switching to heat pumps
  - However, homes without AC installing heat pumps will likely benefit from new AC service

2030 HP purchase estimated bills as % of no HP purchase (assumes no EV purchase)



What if electricity or gas rates are higher in the future?

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- This analysis looked at a range of rates, including an electric rate that is more than double the current average rate in Washington in 2024
- There is considerable uncertainty about rates in the future, including how the fixed costs of gas service are recovered over fewer total gas sales
  - If these costs are recovered through increases in gas rates over time, savings from heat pumps will be greater and that will incentivize heat pump installations
  - Increases in gas rates may burden households that cannot afford the capital cost of a heat pump
- Households where heat pump installation costs are lower can protect against future gas price uncertainty with heat pump installation
  - Consider two scenarios for Stacey's household: With higher electricity rates and low gas prices, costs are similar whether purchasing a heat pump or not; Conversely, with higher gas rates and lower electricity rates, savings are significant

The large distribution of install costs will make heating benefits/costs household specific

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- This study uses ACEEE costs of $8,060 for a single-family home and $14,900 per unit for a multifamily home
  - These are averages from past installations; however, the range of costs is large
  - The most favorable homes have existing equipment that can be repurposed and construction that is easy to retrofit
  - Costs may disproportionately reflect homes most conducive to retrofits
  - Some households pay significantly more for installed heat pumps
- Higher capital costs reduce the benefits
  - These benefits are household-specific

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Conclusions

High-Level Takeaways

- All four sample households save money with vehicle electrification in most circumstances
- All four sample households save energy from electrification of home heating, but not all sample households save money from heat pump installation, absent policy support
- Multiple factors impact how great the savings could be from electrification of home heating and transportation
  - Energy prices, cost and access to technology based on household income, technological development, production and supply chain challenges
- Policies are important to enable access to cost savings
  - Education, incentive programs, infrastructure development, access to useable technology, and workforce development

Conclusions

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- Purchasing an electric vehicle saves money in almost all cases
  - Even if electricity costs $0.40/kWh
  - Customers are better off purchasing an EV earlier vs. later starting in 2030, even if households do not receive IRA tax credits
  - Policy that explores readiness for vehicle adoption with charger infrastructure, as well as business models for customer financing, could support EV adoption
- Heat pump adoption lowers energy use, but cost effectiveness depends on several factors
  - Relative electricity and gas rates affect decisions. For Stacey's household with air conditioning and gas heating, heat pump adoption is cost-effective in most cases modeled and protects against uncertain gas rate increases in the future at ACEEE costs
  - The broad range of heat pump installation costs affects cost effectiveness
- Upfront costs of technology are important and not all options for customers are reflected in this analysis
  - Many buy their vehicles on the secondhand market. Stretching the lifetime of older vehicles and heating equipment may be more affordable than replacing with EVs

Biggest challenges

- Vehicles
  - EV purchase prices are assumed to decrease over time whereas prices for internal combustion engines remain steady
    - This could be affected by technological development, trade policy, commodities markets, etc.
  - Charging infrastructure is needed to make large-scale adoption viable
    - Rate of builds have been slower than expected to date. Challenges with T&D infrastructure support
  - Capital costs of a new vehicle may not be the decision that many households are making
- Buildings
  - The range of capital costs is broad and building-specific
  - Savings are dependent on uncertain future rates
  - High capital costs and split incentive problems for renter

Applicability of Results to a Broader Range of Households

- Many households will find they have energy consumption similar to one of the example households in this analysis, but others will differ substantially
- The analysis provides key findings that could be applied to different situations (e.g., to an urban household that does not own a vehicle)
  - Households with lower VMT than the sample households in this analysis will avoid fewer gasoline purchases, which would reduce the savings from switching to an electric vehicle, while higher VMT would equate to higher savings
  - The costs/benefits of switching to heat pumps in the home will depend on energy use but also rates and installation costs. Those with air conditioning and installation costs close to those used for a single-family home are more likely to save money under current rates
  - Future increases in gas prices would make heat pumps a good investment for a wider range of households. Factoring in the risk of higher gas prices is important when locking into new heating tech for the lifetime of the system
- Costs/benefits are specific to each household. Resources to support homeowners in making these calculations can help provide the information necessary to make an informed choice

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Economic Analysis

Contents

- Motivation
- Overview
- Research Methodology
- Results
- Conclusions

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Motivation for Economic Impacts Analysis

Economic Impact Analysis

- Decarbonization will shift energy investments, creating new markets while shrinking others
- Economic Impact Analysis provides high-level understanding of overall effects of these shifts on
  - Total Output
  - Jobs
  - Wages

Economic Impact Analysis

- Outputs from Economic Impact Analysis are a necessary first step toward workforce planning
  - Outline overall growth as well as target new and growing industries
  - Inform policies around education and training

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Overview of Economic Impact Analysis

Economic Impact Analysis Overview

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- Economic Impact Analysis measure the effect of an investment (or set of investments) on economic outcomes (e.g., total output, employment, wages)
- Our proposed Economic Impact Analysis measures
  - Total Economic Output
  - Job Creation / Transition
  - Labor Income Effects

Economic Impact Analysis Overview

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The total economic impacts of investments are generally decomposed into:

Direct Effects:
Those created by the investment.
e.g., Construction, Ongoing Operations & Maintenance of Solar Plant

Indirect Effects:
Those created in the supply chain.
e.g., Manufacturing of Solar Panels

Induced Effect:
Those created by increased spending from new jobs and higher wages

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Job Impact Analysis Methodology and Data

Economic Impact Methodology Overview

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Steps to measure job economic impacts:

1. Collect all demand- and supply-side investments from Washington CCAP scenario
2. Categorize investments into final demand increases across industries / products / commodities
   a. For energy investments, break down into Materials & Equipment, Installation Labor, Siting, Permitting, and Other
   b. For ongoing O&M break down investments into Labor, Materials & Equipment, Commodities (fuels), and Other
3. Use Washington Input-Output model (2012) to calculate Direct, Indirect, and Induced jobs

Total Investment Calculations

Economic Impact Methodology Overview

Steps to measure job economic impacts:

1. **Collect all demand- and supply-side investments from Washington CCAP scenario**
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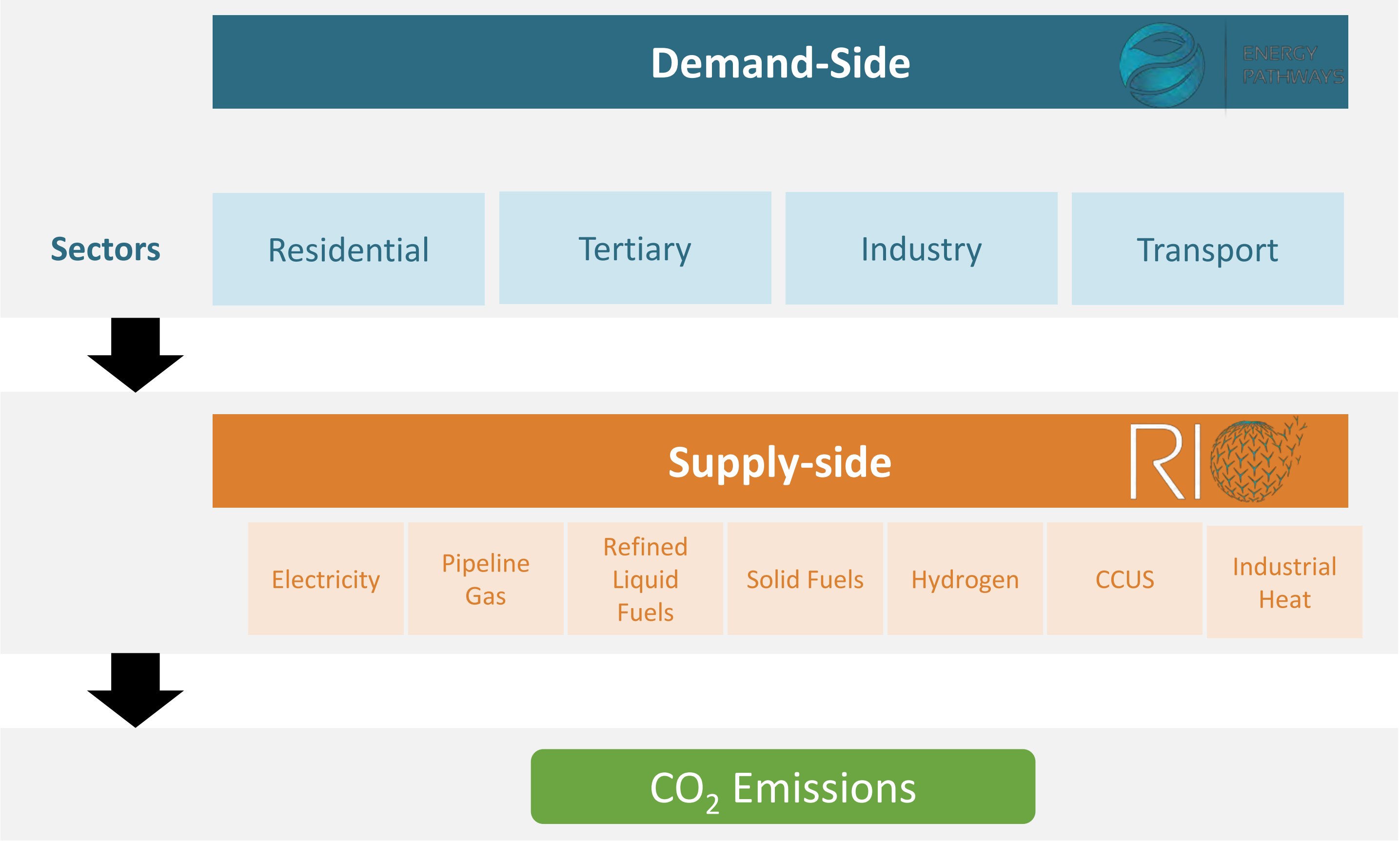
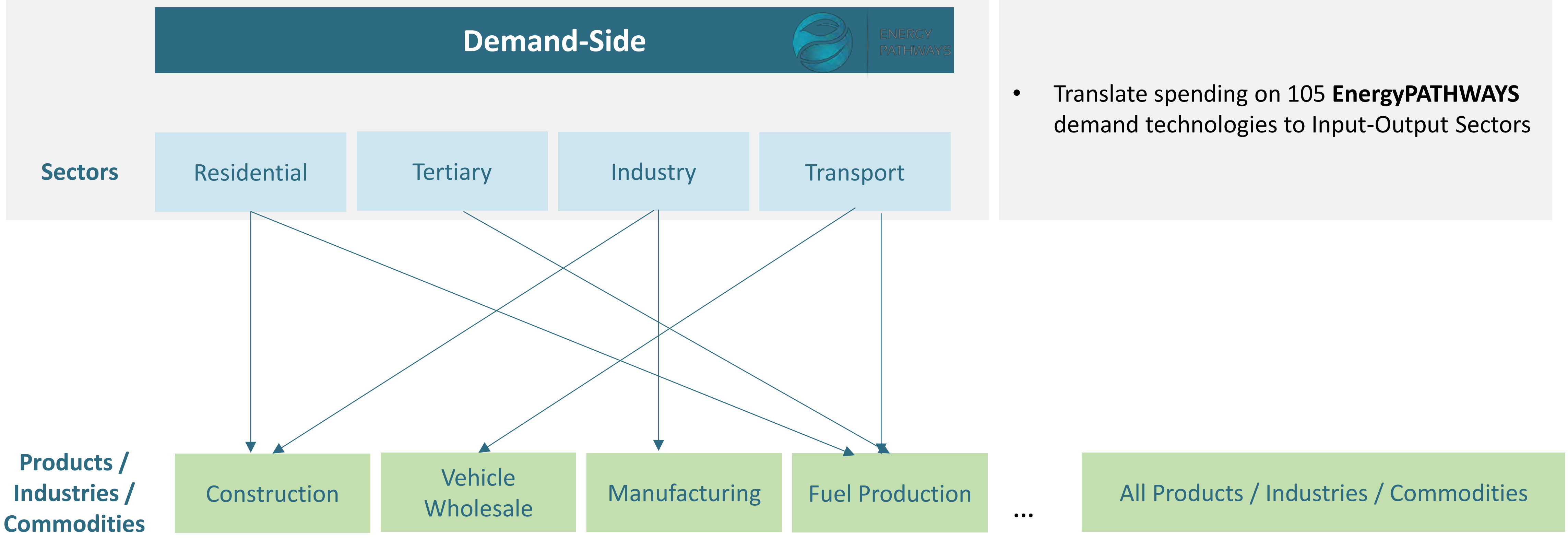
Energy systems modeling: high-level approach



- **EnergyPATHWAYS** model used to develop demand-side cases
- Apply fuel switching and energy efficiency levers
- Strategies vary by end-use (residential space heating to heavy-duty trucks)

- **Regional Investment and Operations (RIO)** model provides cost-optimal energy supply combining a comprehensive supply-side capacity expansion framework with hourly system operations

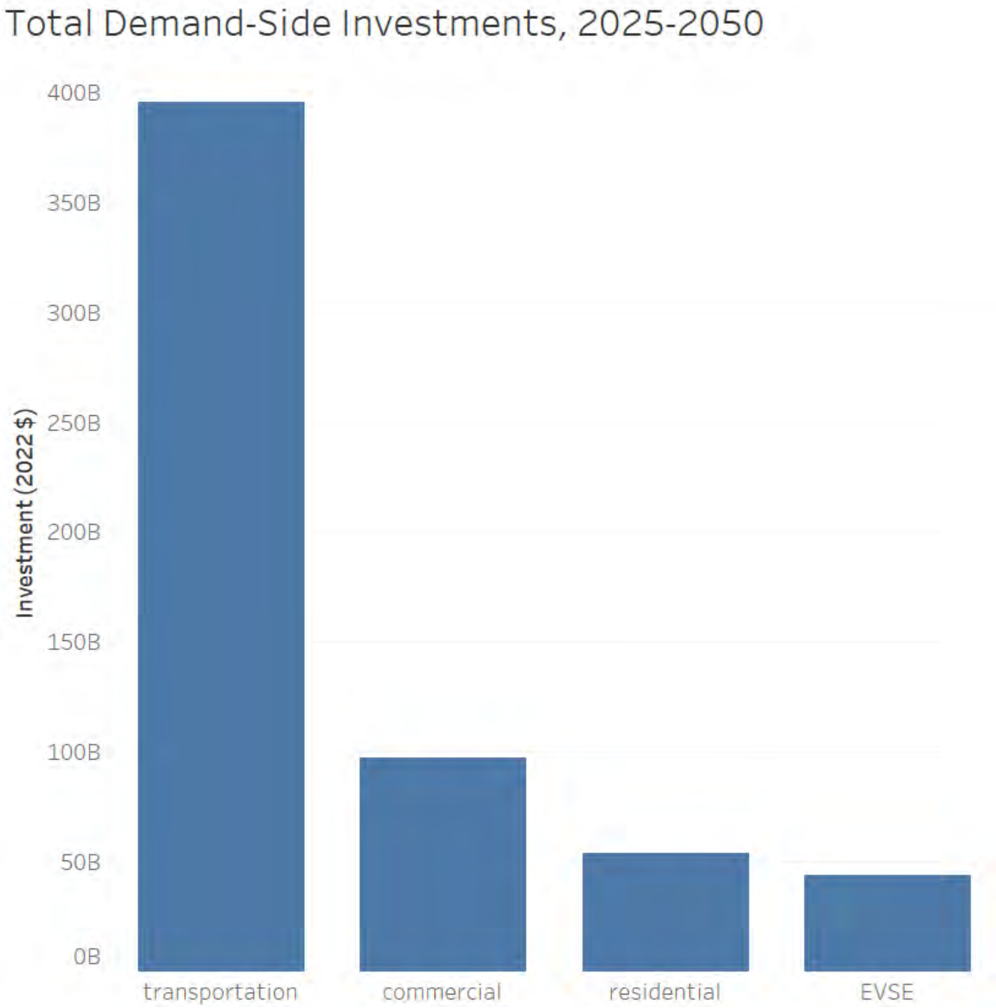
Energy systems modeling: high-level approach



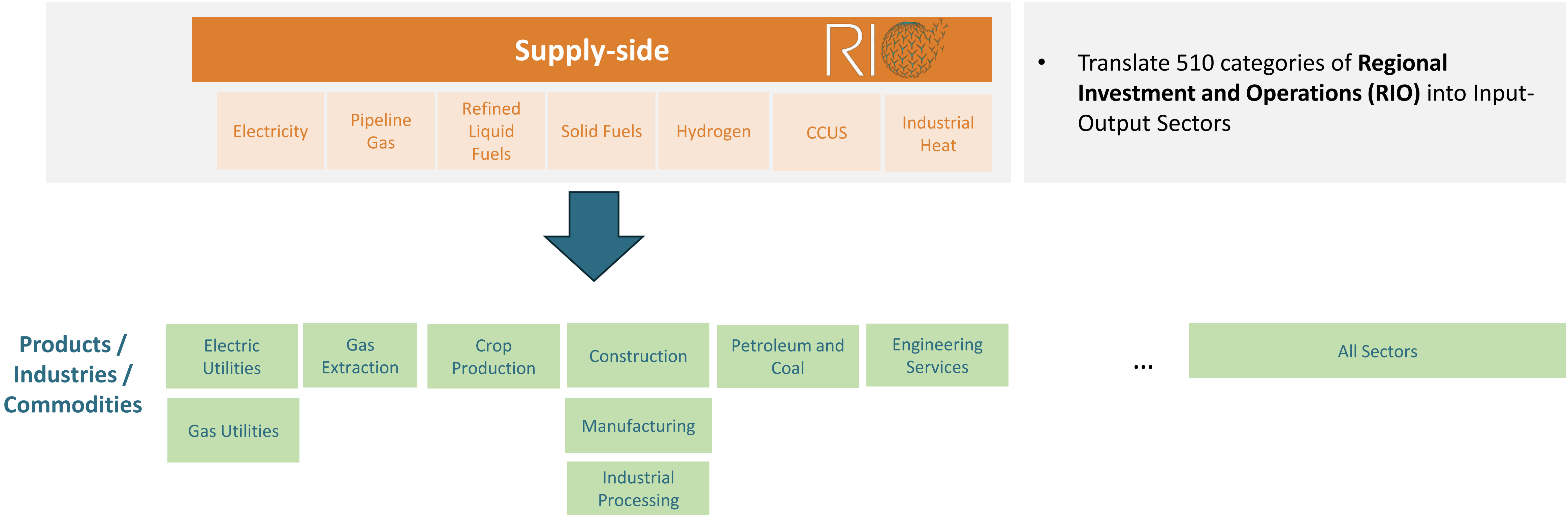
- Translate spending on 105 **EnergyPATHWAYS** demand technologies to Input-Output Sectors

Demand-side Investments

- Highest spending is on new vehicle stock: $395B from 2025-2050
- Commercial retrofits ($97.4B) higher than Residential retrofits and appliances ($53.7B)
    - Includes both capital and installation costs
- Electric Vehicle Supply Equipment (EVSE) smallest spending category but still substantial at $43.8B



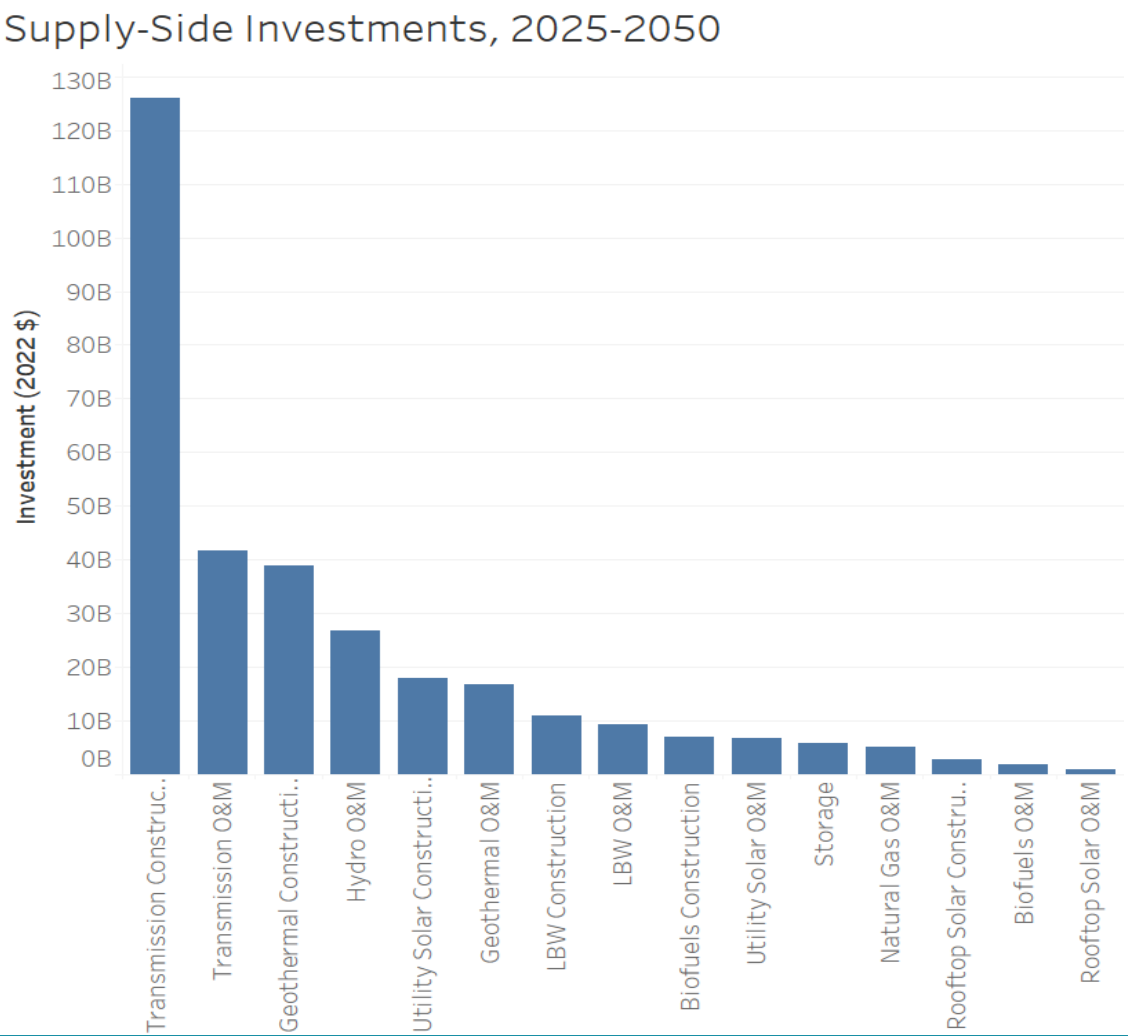
Energy systems modeling: high-level approach



- Translate 510 categories of **Regional Investment and Operations (RIO)** into Input-Output Sectors

Supply-side Investments

- Transmission, Distribution, & Interconnection are largest investments
  - $125B for Construction, $41B for O&M from 2025-2050
- Geothermal Construction $39B, O&M $16.9B
- Hydroelectric O&M, Solar, Wind, Biofuels also represent large investments



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Classify Investments

Economic Impact Methodology Overview

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Steps to measure job economic impacts:

1. Collect all demand- and supply-side investments from Washington CCAP scenario
2. **Categorize Investments into Final Demand increases across industries / products / commodities**
   a. **For energy investments, break down into Materials & Equipment, Installation Labor, Siting, Permitting, and Other**
   b. **For ongoing O&M break down investments into Labor, Materials & Equipment, Commodities (fuels), and Other**
3. Use Washington Input-Output model (2012) to calculate Direct, Indirect, and Induced jobs

Renewable Energy Investment Classification

- For each technology, use National Renewable Energy Laboratory (NREL) Job and Economic Development Impact Models (JEDI) to classify which industries are affected by new investment
- Models for Solar, Transmission, Geothermal, Biofuels, Natural Gas, Hydroelectric
- Employ default assumptions for Washington on locality of purchasing and manufacturing
- Construction and Installation Impacts measured:
  - Project Development and Onsite Labor
  - Supply Chain (Manufacturing, Trade, Professional Services, Other)
- Annual Operating and Maintenance (O&M) Impacts:
  - Onsite labor
  - Local Revenue and Supply Chain

Investment Classification Example

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- 100MW Utility PV Project in Washington
  - Total Project Investment: $103M
    - Materials and Equipment: $66M
    - Installation Labor: $14M
    - Siting, Permitting, Other: $23M
  - Annual O&M: $2M
    - $1.2M Labor
    - $800k Materials and Equipment

- Local Impact
  - Total Construction Impact: $37M
    - Materials and Equipment: $0M
    - Installation Labor: $14M
    - Siting, Permitting, Other: $23M
  - Annual O&M: $1.83M
    - $1.2M Labor
    - $630k Wholesale Purchases

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Input-Output Modeling

Economic Impact Methodology Overview

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- Steps to measure job economic impacts:
  1. Collect all demand- and supply-side investments from Washington CCAP scenario
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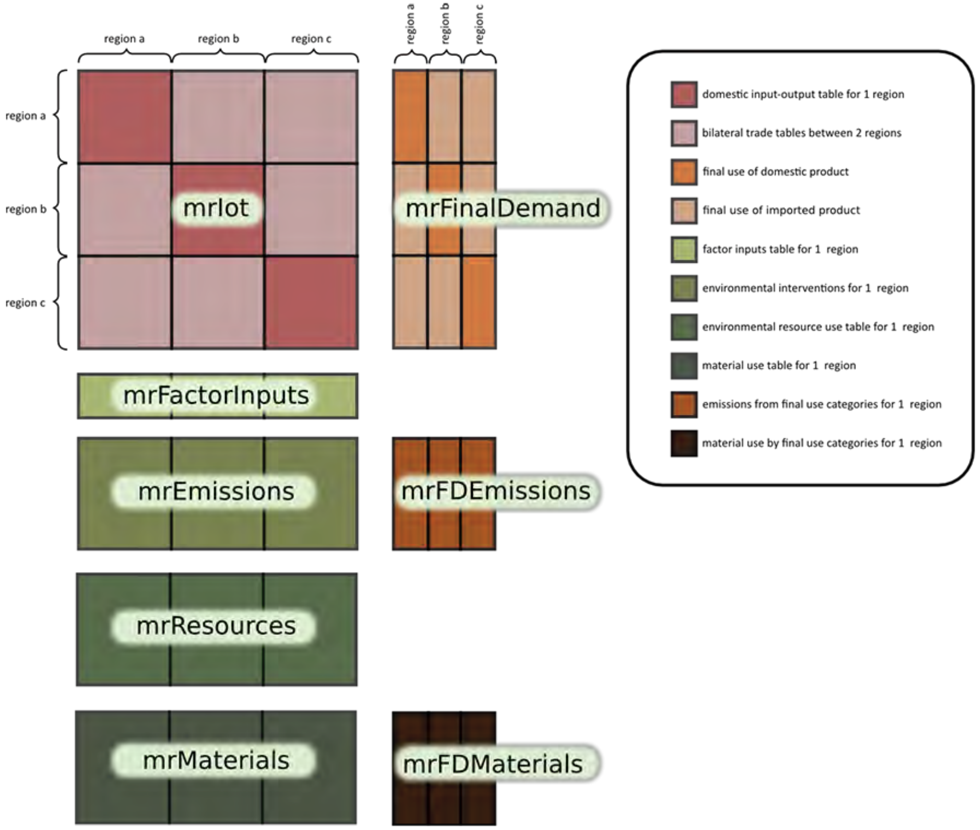
     a. For energy investments, break down into Materials & Equipment, Installation Labor, Siting, Permitting, and Other
     b. For ongoing O&M break down investments into Labor, Materials & Equipment, Commodities (fuels), and Other
  3. **Use Washington Input-Output model (2012) to calculate Direct, Indirect, and Induced jobs**

Input-Output Modeling Overview

- Input-Output models represent the relationships between sectors of the economy and can be used to model labor inputs needed to fulfill supply chain demand
- Key components of an I-O model:
  - Leontief Production Function: For a given level of final demand in an industry, how much output is needed from all other industry.
  - Employment Coefficients: Employment per unit of output for each sector.
  - Multipliers: Measure the total effect of a change in demand on the economy.



Input-Output Modeling Overview

- Key assumptions of an I-O model:
  - Constant Returns to Scale: Inputs scale linearly with growth in outputs.
    - Implication: Industry growth will continue at present costs.
    - Solution: Given the significant growth in several new industries in our modeling, we relax this assumption by applying NREL learning factors over time in those industries
  - Fixed Production Coefficients, Technology: Shares of Inputs will not change
    - Implication: Shorter-term predictions that require immediate workforce planning are more important for policy, and will be more accurate. Long-term predictions are less accurate but can continually be updated with new data.
    - Solution: Adjust labor requirements in certain industries (e.g., off-shore wind)
  - No Supply Constraints: Enough inputs (raw materials, labor) to produce unlimited product.
    - Solution: Scrutinize results to ensure that the labor components, at least, are feasible given current trends and population sizes.

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Economic Impact Analysis Results

Total Job Growth

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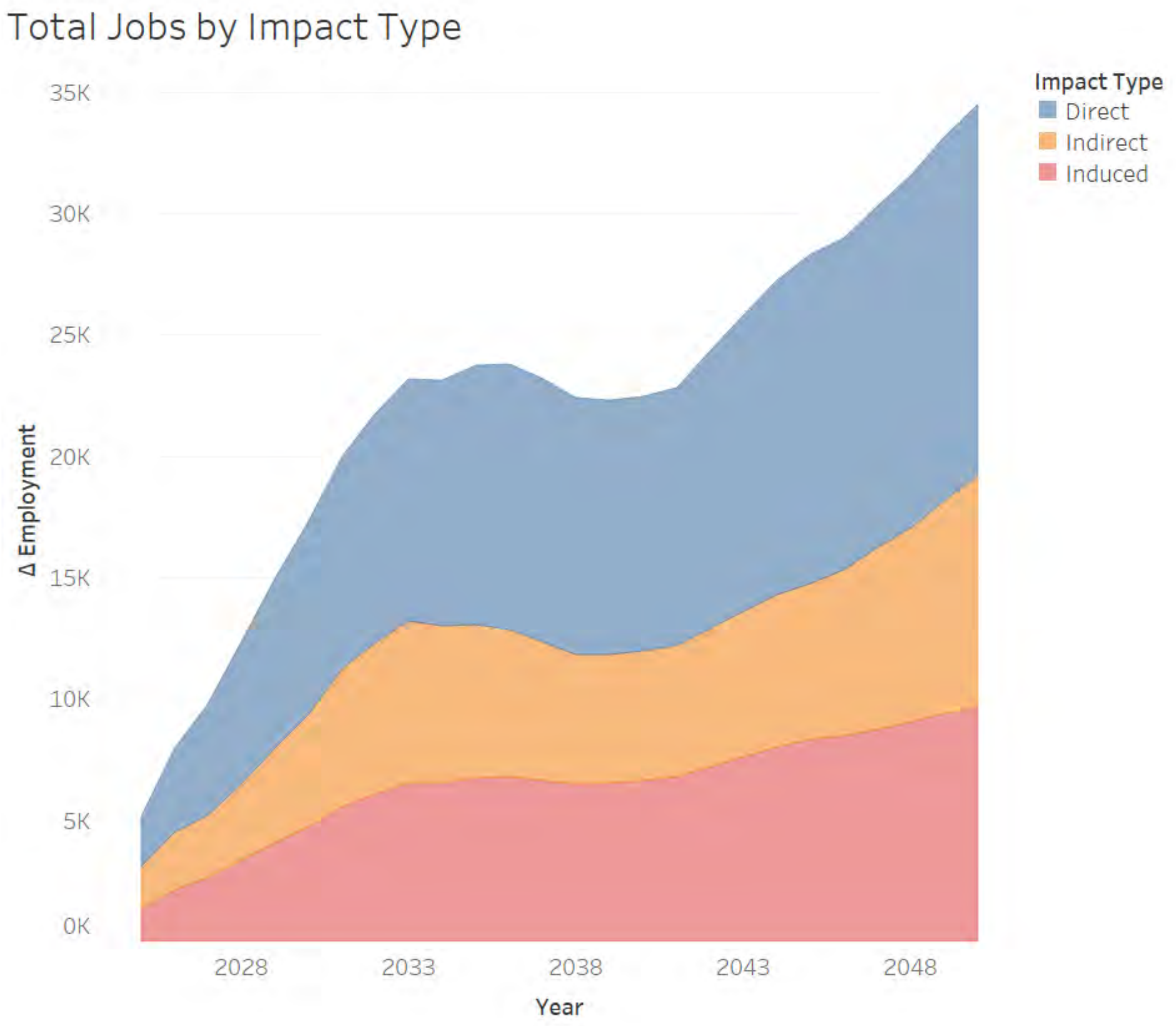
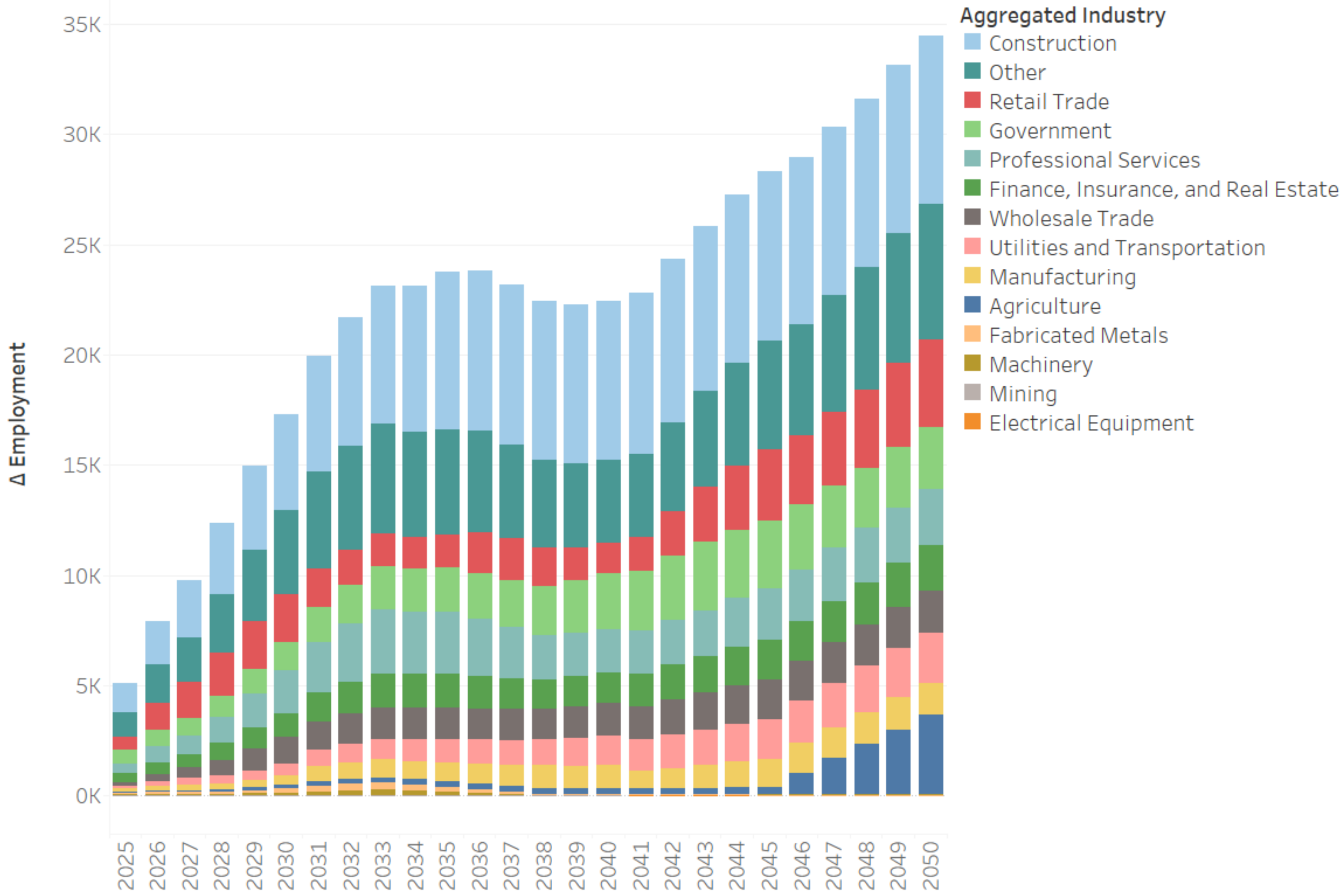
- WA CCAP plan will create 23.8k jobs by 2035 and 34.5k jobs by 2050, relative to 2023 baseline
  - 2035: 10.7k Direct, 6.3k Indirect, 6.7k Induced
  - 2050: 15.3k Direct, 9.5k Indirect, 9.7k Induced
- Significant investments in new technologies: EV Infrastructure and Transmission, Distribution, and Interconnection (T&D) account for over 60% of this growth



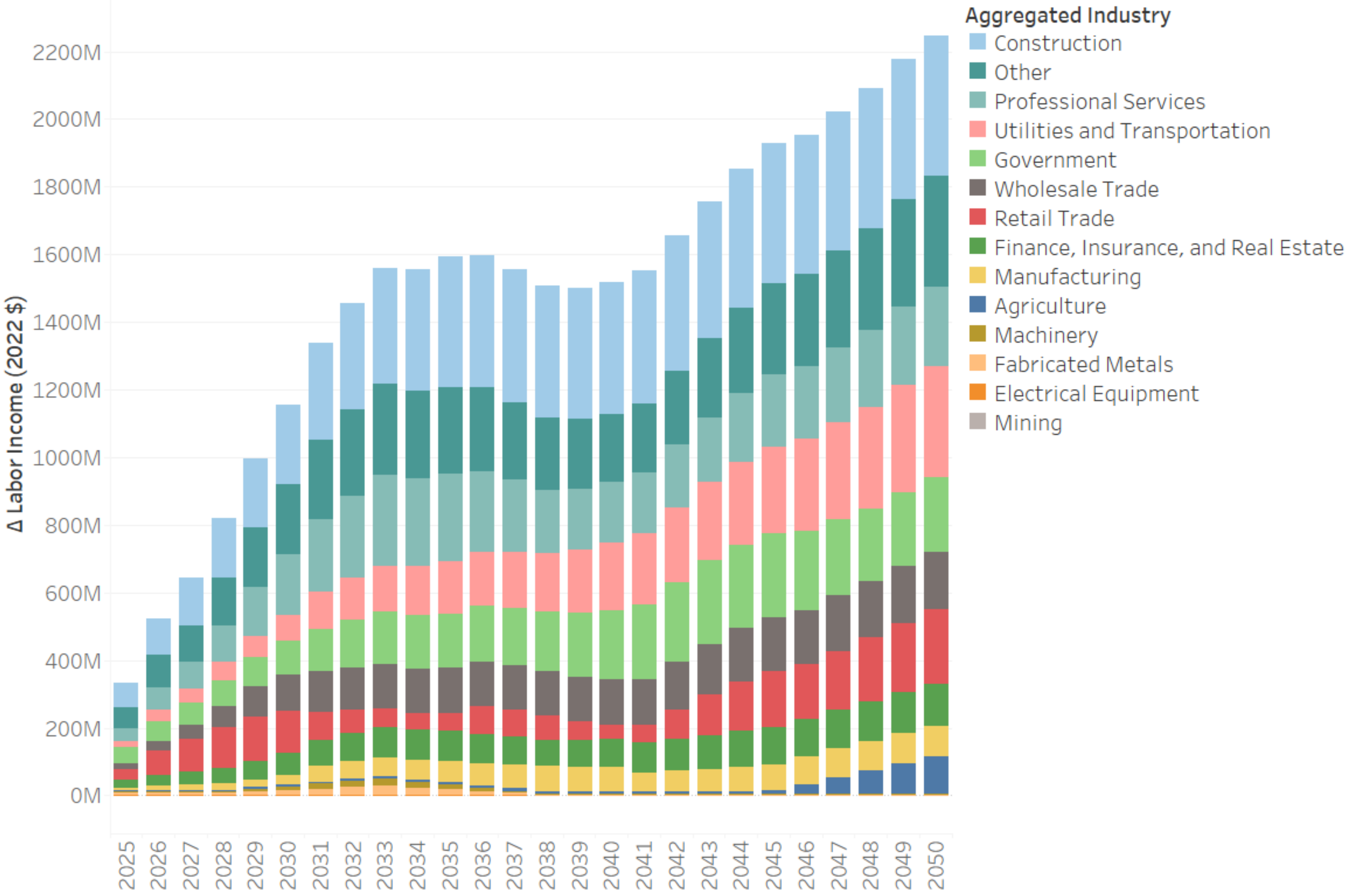
Job Growth by Industry

- Construction is the largest sector, sustaining over 7k new jobs from 2035-2050
  - 'Other' Industry is a catch-all of primarily induced jobs outside of Construction, Utilities, or related sectors
- No reductions in any specific aggregated industry, relative to 2024 baseline



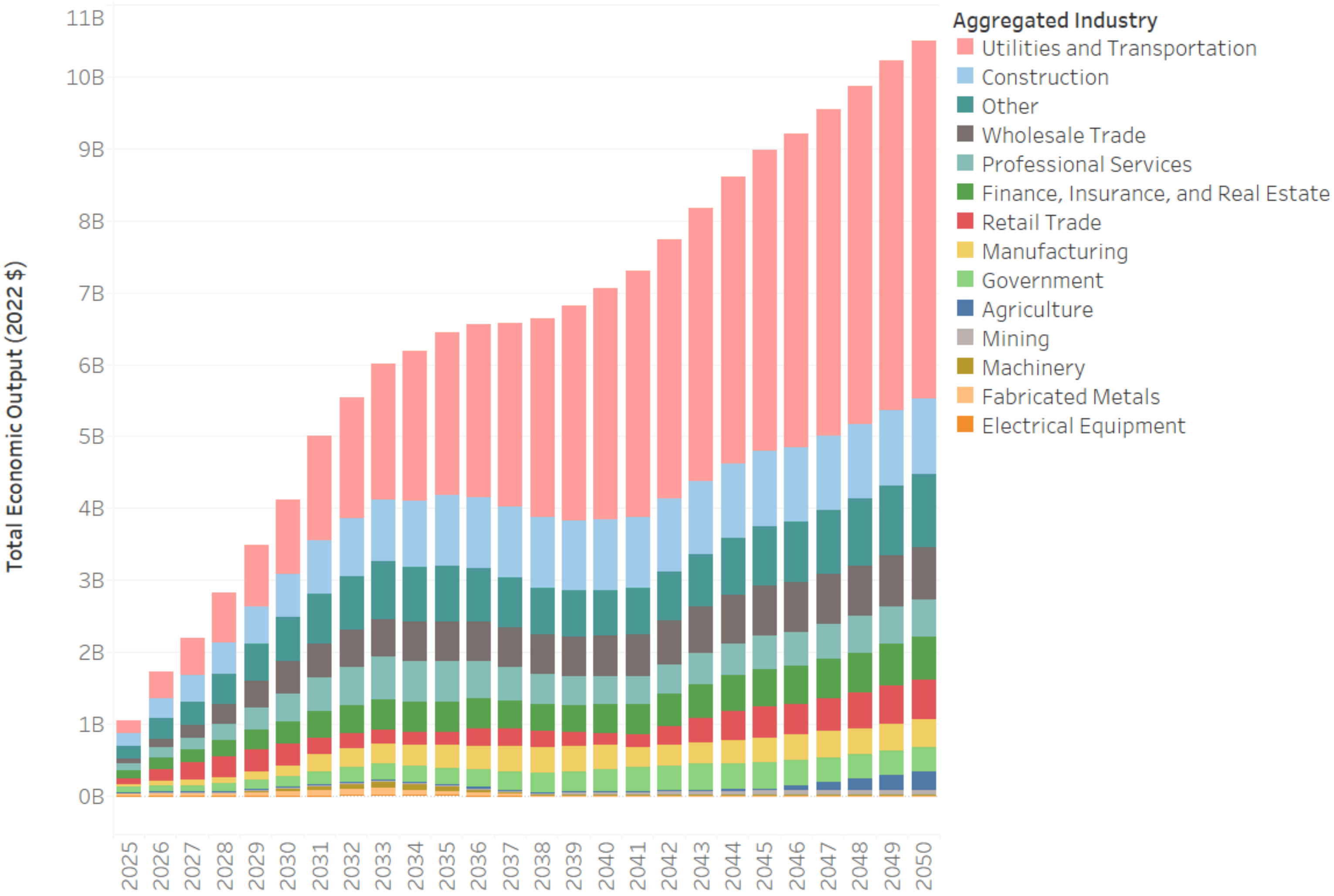
Labor Income

- Annual Labor Income follows job growth, with substantial gains across all industries totaling $38.9B between 2025 and 2050
- Construction, Professional Service, Utilities and Transportation industries represent largest Income growth



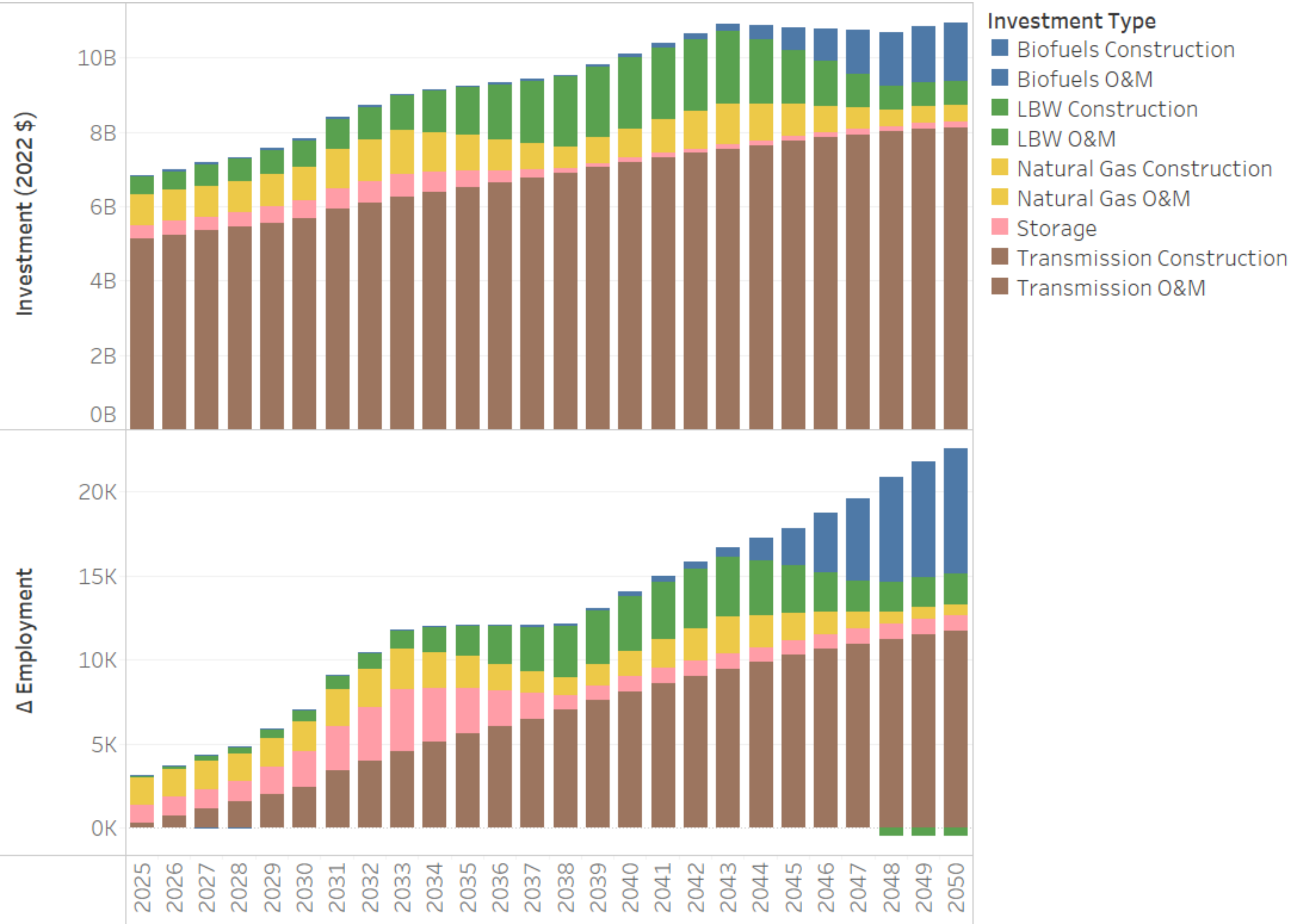
Total Output

- Total Economic Output (local GDP accounting) grows $6.4B by 2035 and $10.5B by 2050.
  - 2050 output represents 1.5% growth relative to Washington's 2023 GDP of $672B
- Much of this growth is attributed to the Utility and Transportation sectors, which includes the value of output from new generation resources



Supply Side: T&D, Geothermal

- Transmission, Distribution, and Interconnection are largest supply-side investments and result in most direct and indirect employment
  - Steady employment growth to over 8k new jobs in construction and O&M between 2040-2050
  - Over $6B annual investment between 2032-2050
- Biofuel, Wind, Natural Gas, and Storage investments represent additional employment drivers.



Supply-Side: All Other Investments

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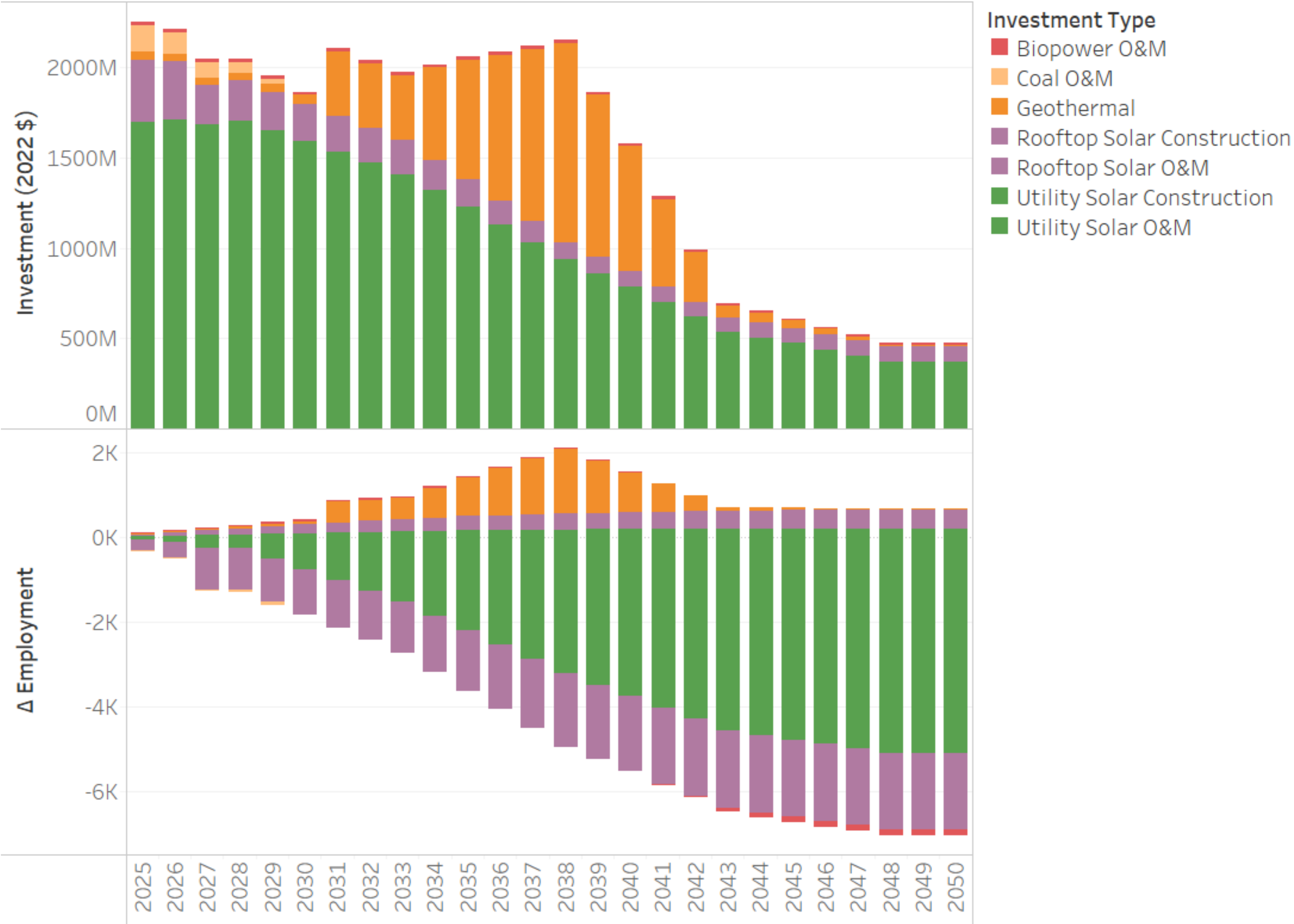
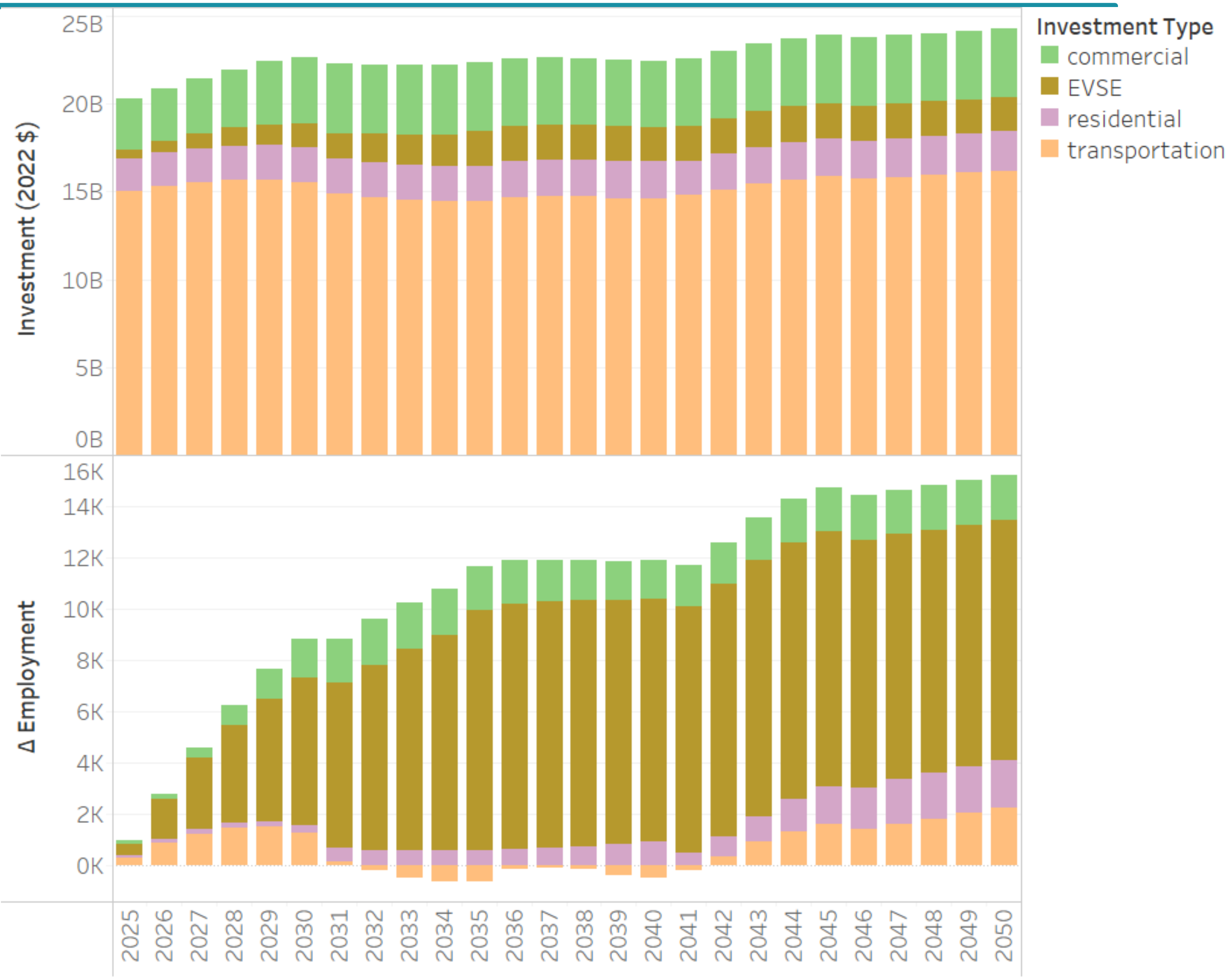
- Other supply-side investments have smaller, or negative, job impacts
  - Construction of Solar - Utility and Rooftop expected to decline relative to 2023
  - High Investment and Job growth in the Geothermal Industry between 2030-2040



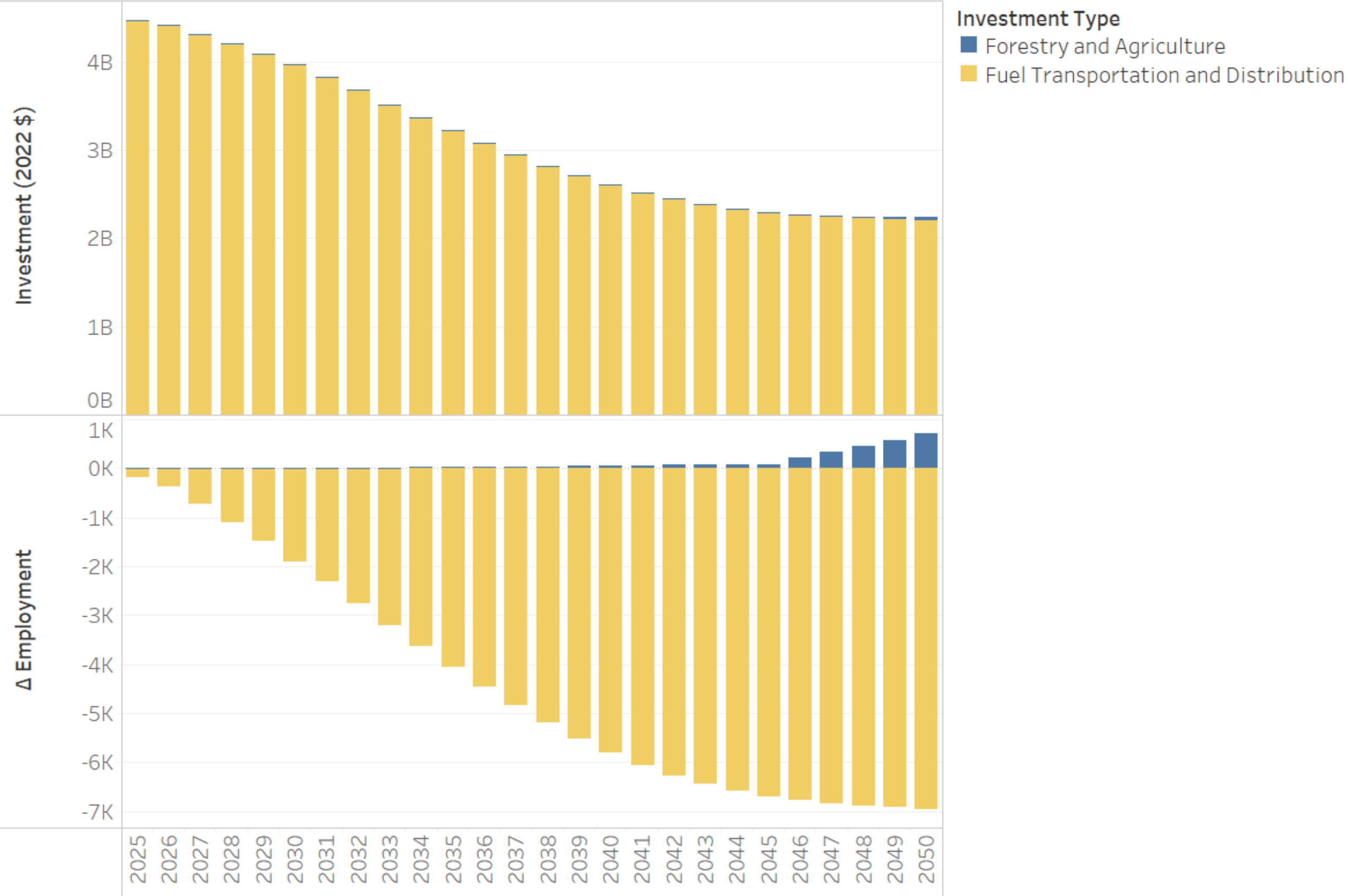
Demand-Side

- Large investments in Transportation vehicles and Charging (EVSE: Electric Vehicle Supply Equipment)
  - While vehicle purchases are the largest demand-side investment, jobs are in sales and maintenance, limiting employment impact
  - EVSE drives high employment through local engineering, design, and construction / installation, sustaining over 7k jobs from 2032-2050
- Job impact of residential and commercial retrofits and weatherization is small growth relative to baseline (consistent investment relative to 2024)



Fuels and Agriculture

- Large job losses related to fuel transportation and distribution, nearly 7k by 2050
- Small job gains later in study period related to forestry and agriculture



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Report Addendum: Updated Scenarios Post-OBBBA

Scenarios – Technical Report Addendum Update Post-OBBBA

- Updated federal incentives and expiry dates for IRA
- What emissions reductions are driven economically?

- Meets Washington's electricity and emissions policy targets
- Reference Scenario – common assumptions
- Explore barriers to achieving targets
- CCAP Scenario
- Updated with post-OBBBA assumptions

IRA: Inflation Reduction Act CDR: Carbon Dioxide Removal

Updates in Reference (final) and CCAP (final): Demand Side

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- Incorporated changed incentives from [Evolved Princeton REPEAT work on One Big Beautiful Bill Act (OBBBA)]
- Changes in incentives do not impact demand technology adoption in Washington in Reference (final) and CCAP (final) assumptions because adoption is driven by state policy targets rather than customer economics
  - However, achieving the same level of technology adoption will be more expensive
- Incentive assumptions impact adoption in states surrounding Washington without demand side targets, changing their loads
  - Phase out of electric vehicle tax credits
  - Phase out of heat pump tax credits
  - Resulting modified baseline technology adoption rates

Updates in Reference (final) and CCAP (final): Supply Side

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- Incorporated changed tax incentives and costs from Evolved Princeton REPEAT work on OBBBA
  - Phase out of IRA tax credits for wind, solar, and hydrogen, and modifications to other credits
  - Cost modifications for domestic content rules
- Previous approach to hydrogen adoption
  - Previous Reference included 800 MW of electrolyzers by 2030 in Washington, reflecting hydrogen hub investments and favorable economics for electrolyzer growth due to 45V tax incentives
  - Previous CCAP included 800 MW by 2030 and 4500 MW by 2035, reflecting the findings of the 2023 Washington Hydrogen Strategy that was based on continued IRA tax incentives and forecasted price declines for electrolyzers
- Modification of hydrogen electrolyzer adoption in Reference (final) and CCAP (final)
  - 2030 minimum electrolyzer capacity reduced from 800 MW to 340 MW in both scenarios to reflect expected reduced investment in hydrogen hub and other projects
  - 2035 minimum electrolyzer capacity reduced from 4500MW to 340MW in CCAP (final)
  - The model can still invest in electrolyzer capacity above these numbers if part of an economic portfolio

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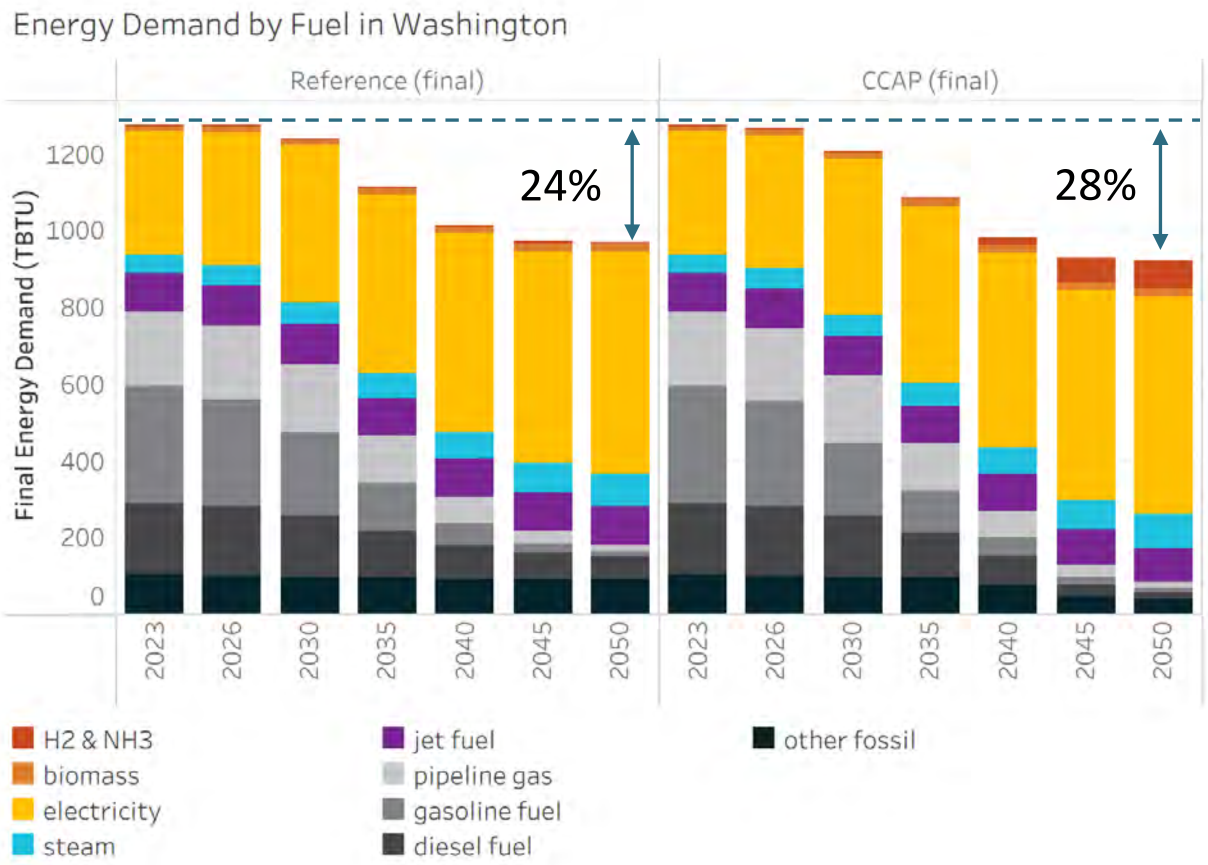
Demand-side Results

Demand-side Overview

- The demand-side results describe how transformation of energy-consuming technologies progresses through 2050
- The demand side in the Reference (final) and CCAP (final) is not impacted by the recent federal (OBBBA) changes because the rates of electrification of technologies are driven by state policy rather than economics
  - Adoption changes in states surrounding Washington, impacting competition for regional resources
- The greater cost of vehicles and heat pumps to the consumer may require more state policy intervention to achieve state targets in these sectors

Energy Demand by Fuel
Reference (final) & CCAP (final) Scenarios

- Overall energy demand decrease is driven by efficiency gains, mostly from fuel switching to electricity
- Economy-wide energy demand drops by 24% in the Reference (final) Scenario and 28% in the CCAP (final) Scenario
- Revision from OBBBA not impactful because electrification is driven by state policy, though it makes the transition more expensive and may require greater policy action



Note: "other fossil" includes fuel oil, LPG, oil, coal, and petroleum coke; H2 = hydrogen; NH3 = ammonia

Energy Demand by Sector
Reference (final) & CCAP (final) Scenarios

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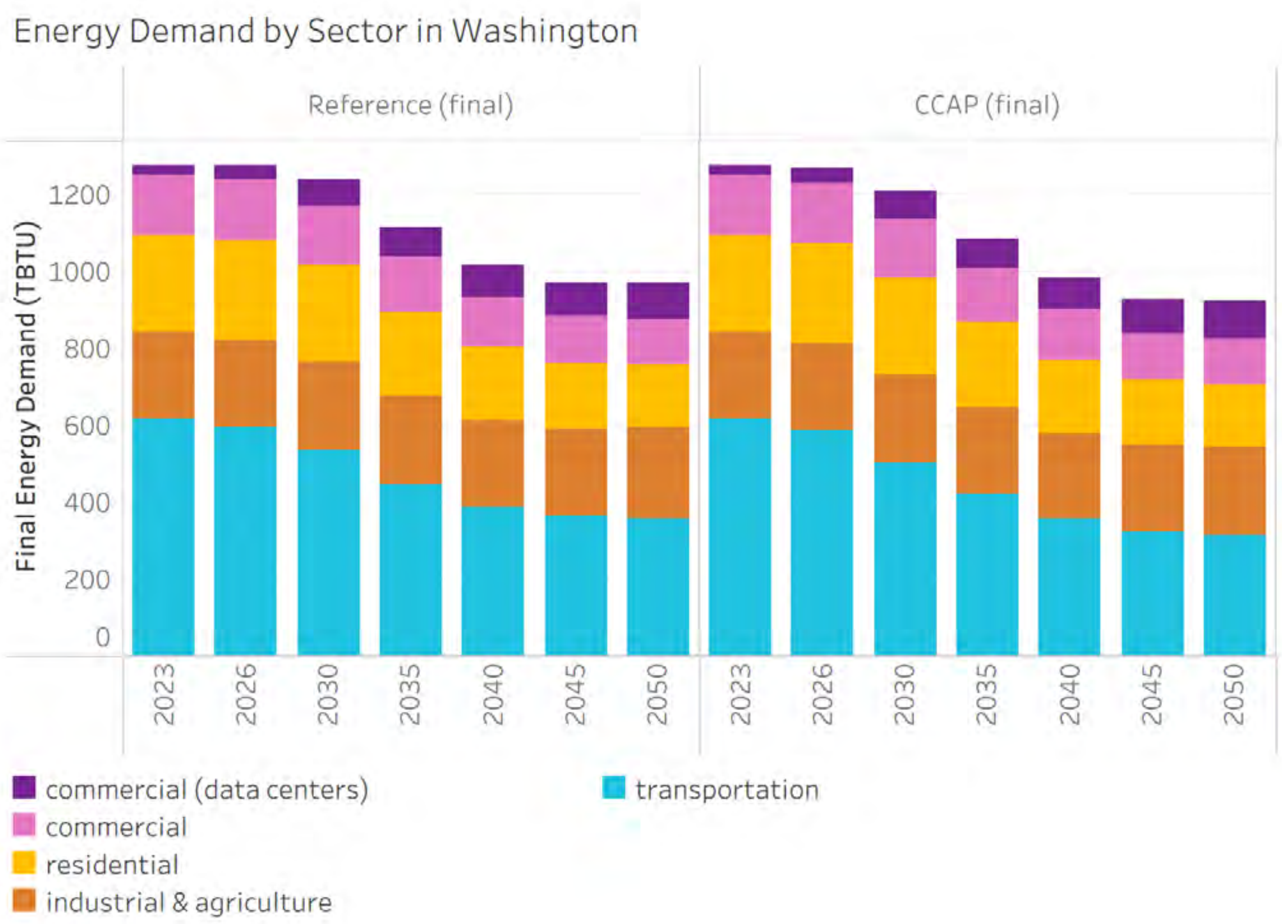
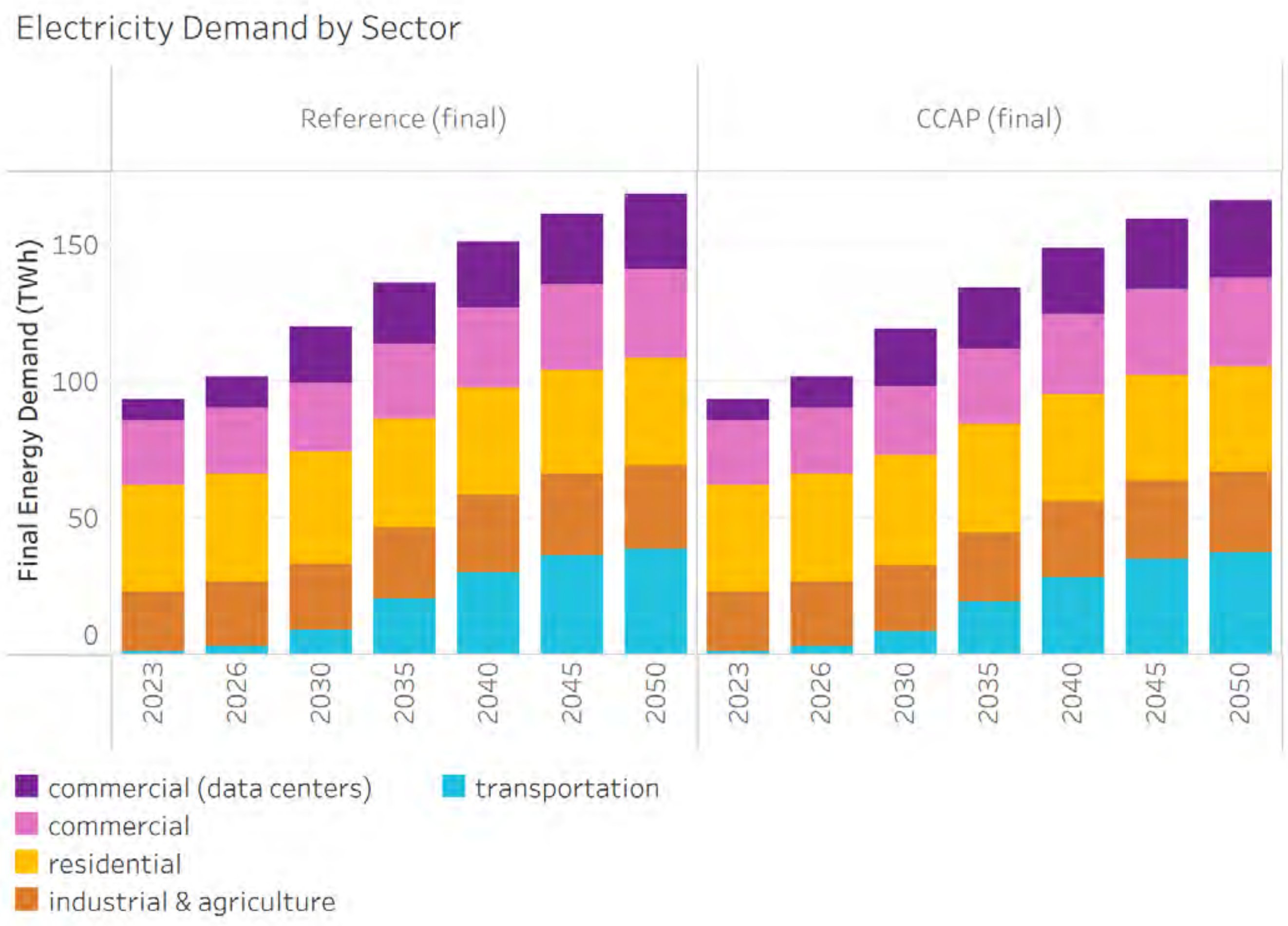
- Transportation efficiency gains are the largest contributor to energy demand reductions
    - Electric drivetrains are highly efficient compared to the internal combustion engines (ICE) they replace
- Residential and commercial appliances gain in efficiency as heat pump systems displace gas boilers, and appliances generally become more efficient



Electricity Demand
Reference (final) & CCAP (final) Scenarios

- Electricity final energy demand increases by 83% in the Reference (final) and 80% in the CCAP(final) Scenarios
  - Does not include electricity that is converted to other forms of energy before final demand, such as electricity for electrolysis
- Electricity demand grows in all sectors of the economy. In the Reference (final) Scenario:
  - New transportation loads drive 65% of all growth from 2023 to 2050, not including data centers
  - 260% growth of data centers



Supply-side Results

Demand and Supply Comparison with Draft CCAP

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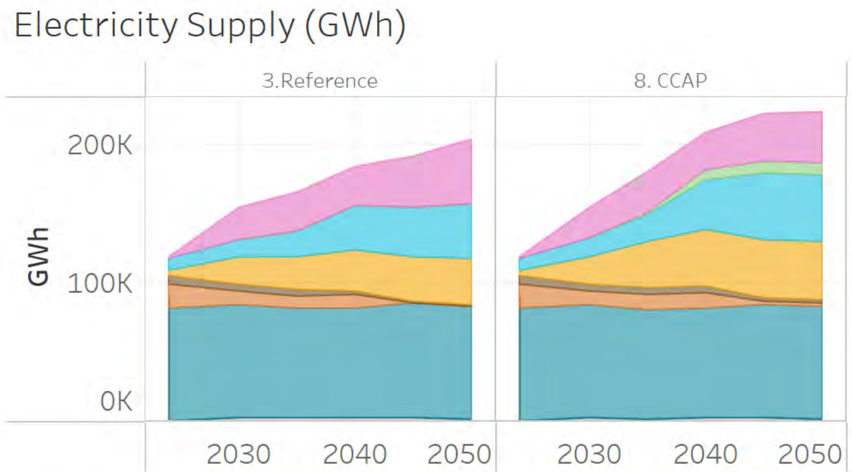
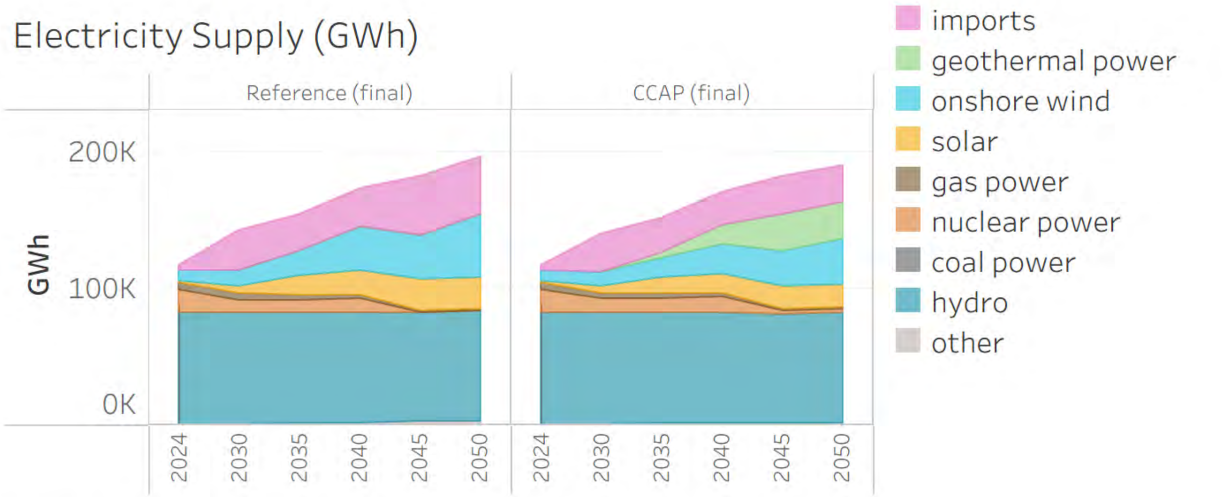
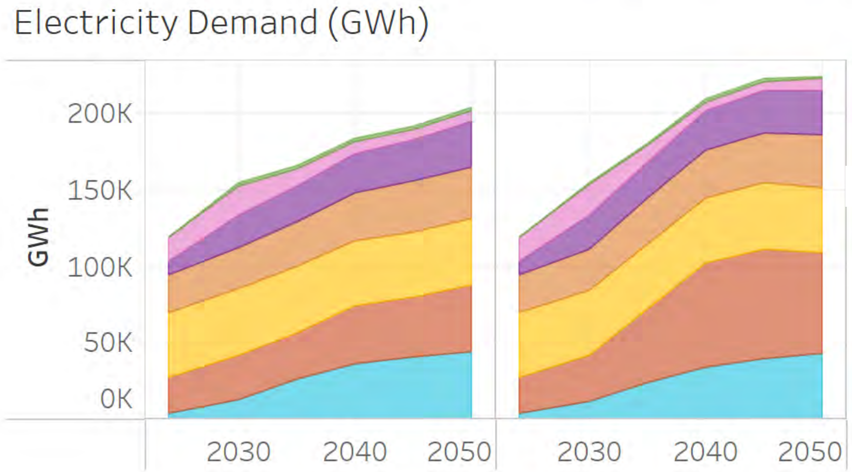
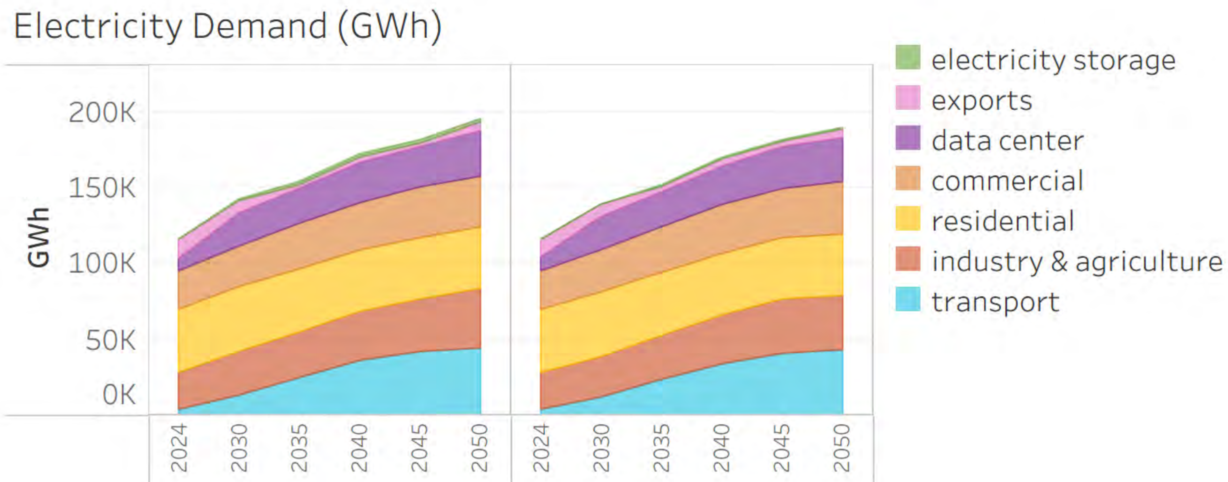


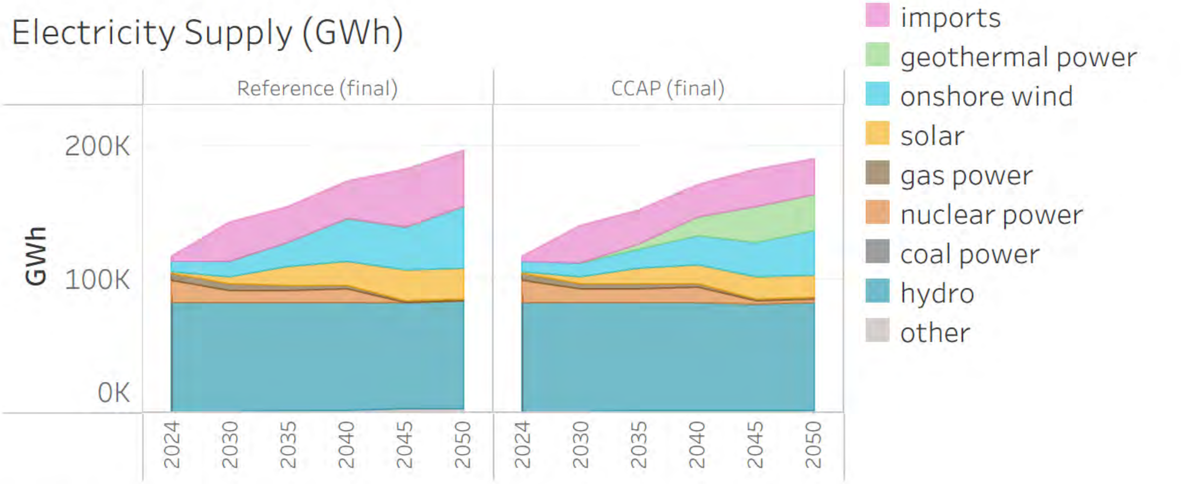


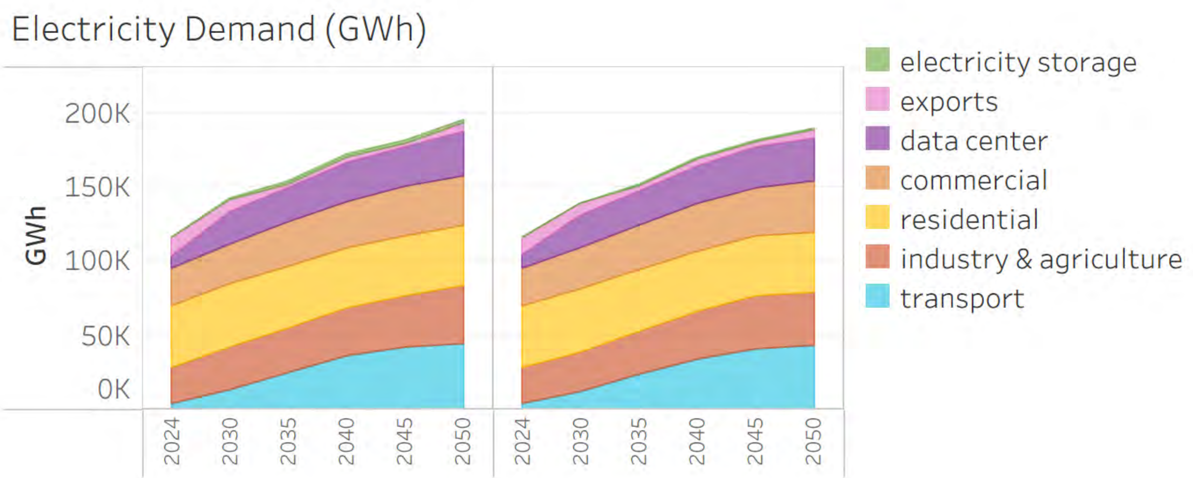




Washington Electricity Generation & Consumption Reference (final) and CCAP (final) Scenarios

- Differences to the Draft CCAP
  - Significantly less growth in industrial loads because of reduced electrolyzer build
  - Resulting smaller electricity sector in Washington in the CCAP scenario
  - While Washington still reaches clean electricity and emissions targets, the least cost path to achieve those targets changes with updated resource costs and incentives
    - Near-term in-state renewable resources, particularly solar, are significantly lower through 2030, with greater imported clean energy taking its place
    - This is an economic outcome but restrictions on siting and permitting clean energy resources quickly may favor an all-of-the-above procurement strategy, promoting near-term in-state resource development
  - Enhanced geothermal becomes a significant source of energy
    - Reduced investment in in-state wind and solar by 2050 driven by smaller electricity sector and displacement by greater investment in enhanced geothermal





Capacity Comparison of Final Reference and CCAP Scenarios with Draft

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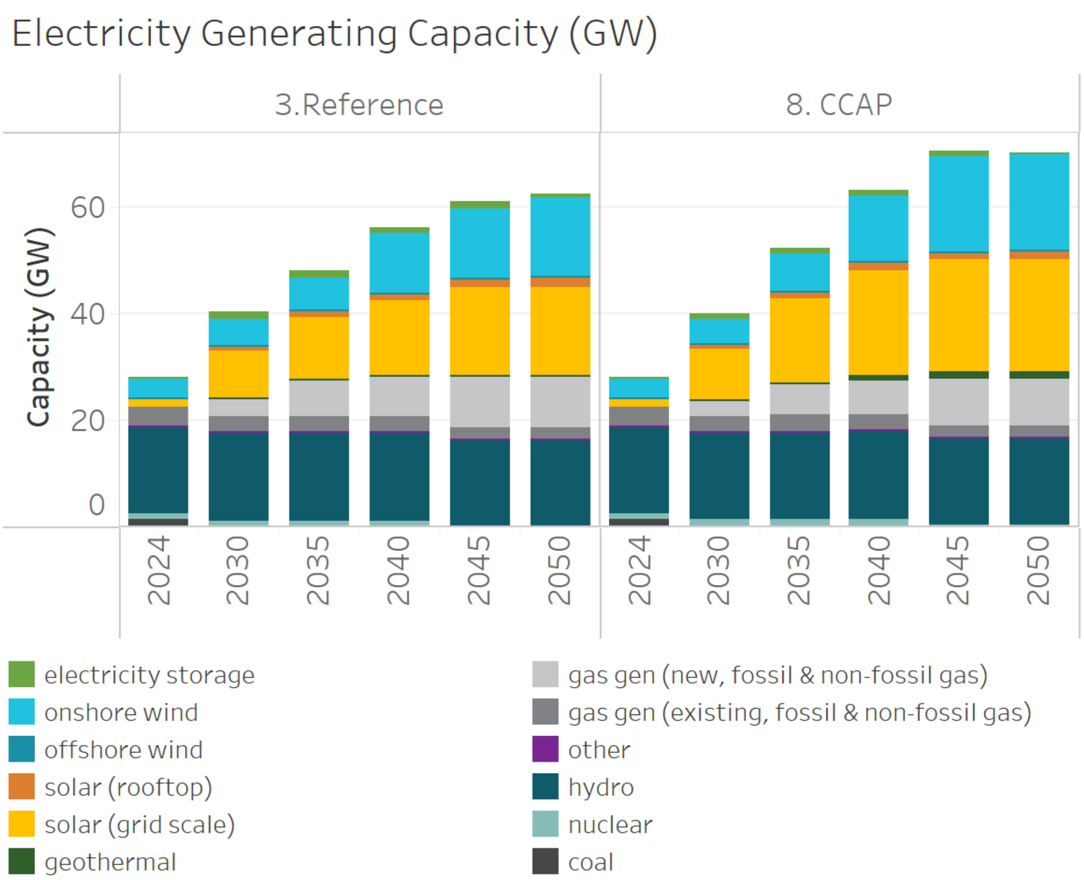
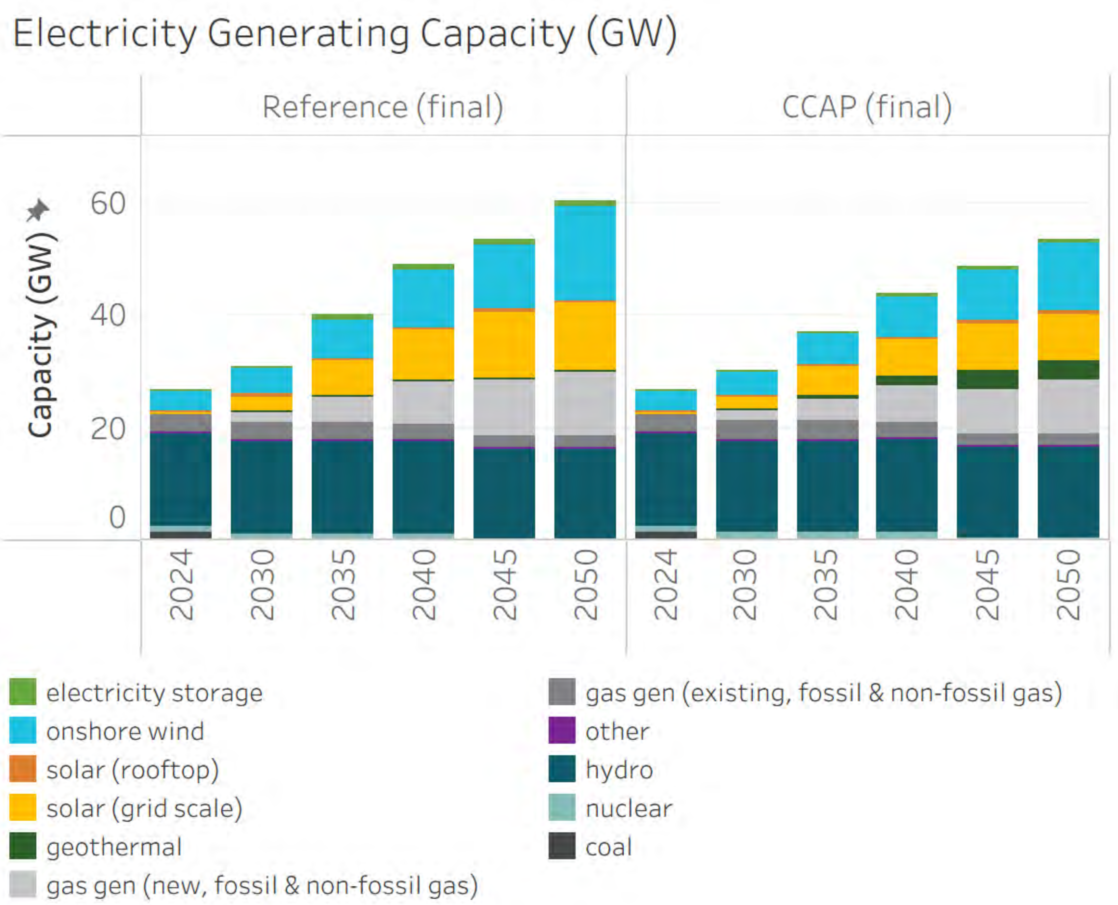
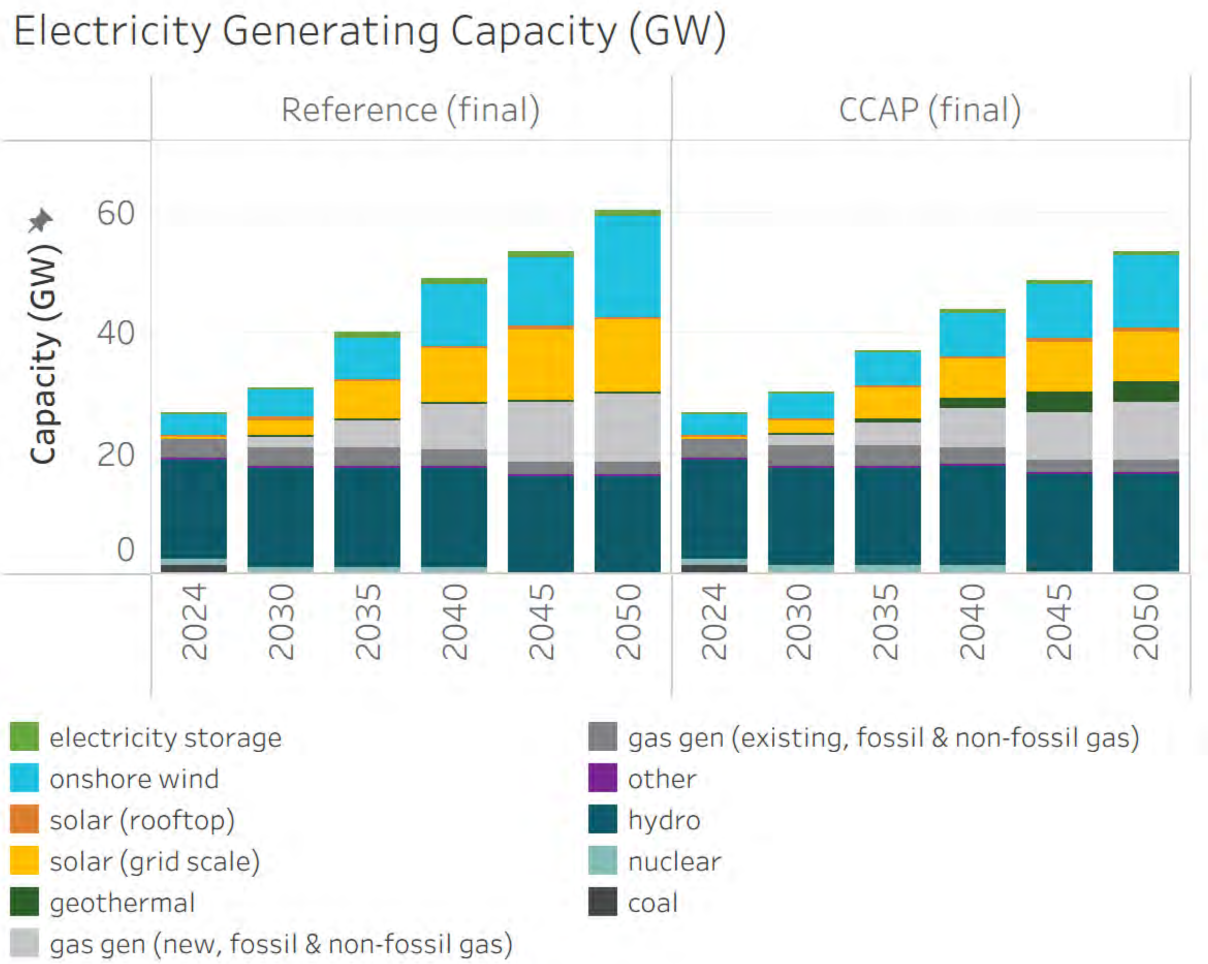




Washington Installed Capacity Reference (final) and CCAP (final) Scenarios

- Differences to Draft CCAP
  - Overall smaller electricity sector
  - Significantly reduced in-state solar capacity by 2030
  - Though an all-of-the-above solution to meeting capacity and energy needs with clean energy would support continued in-state development
  - Geothermal investments in the 2040s is economic and displaces the need for some of the previously built solar and wind



CCAP (final) Scenario Generation Capacity Map

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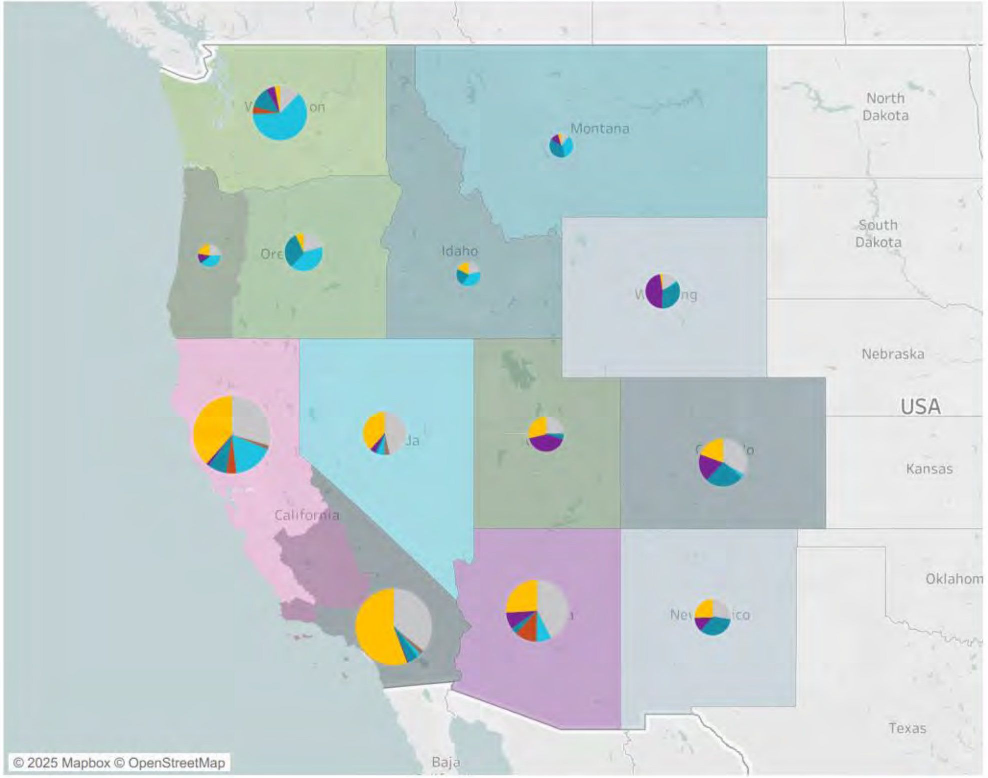
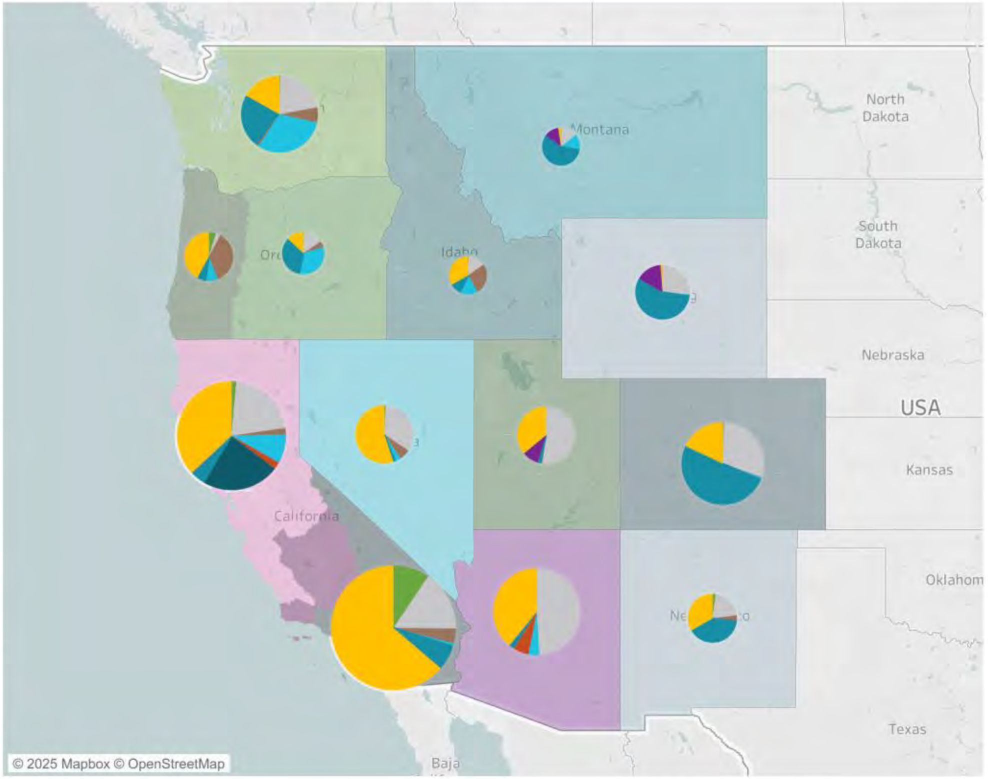
Electricity Generating Capacity: 2024



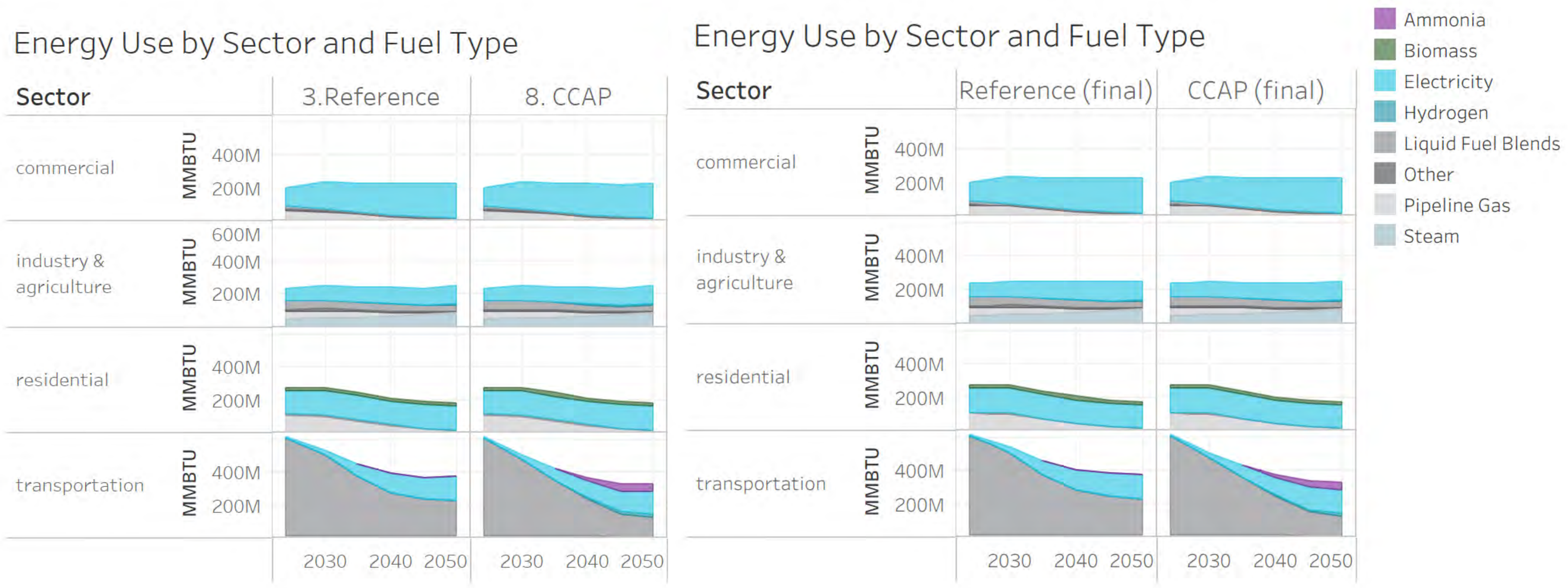
Electricity Generating Capacity: 2050



electricity storage
gas power
geothermal power
hydro
nuclear power
offshore wind
onshore wind
other
solar

Capacity (GW)
4.00
50.00
100...
153...

Energy Use by Sector and Fuel Type Comparison



Washington Energy Use by Sector and Fuel Type

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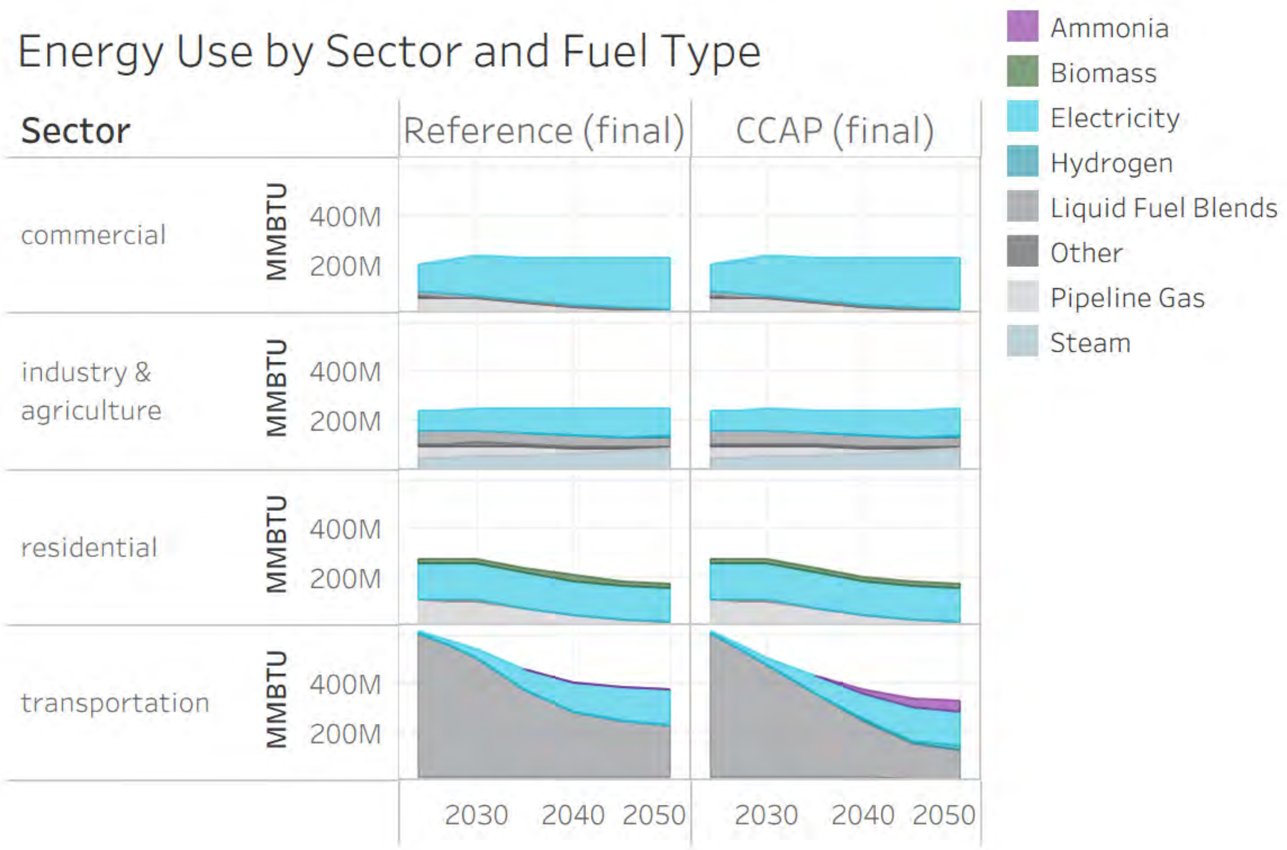
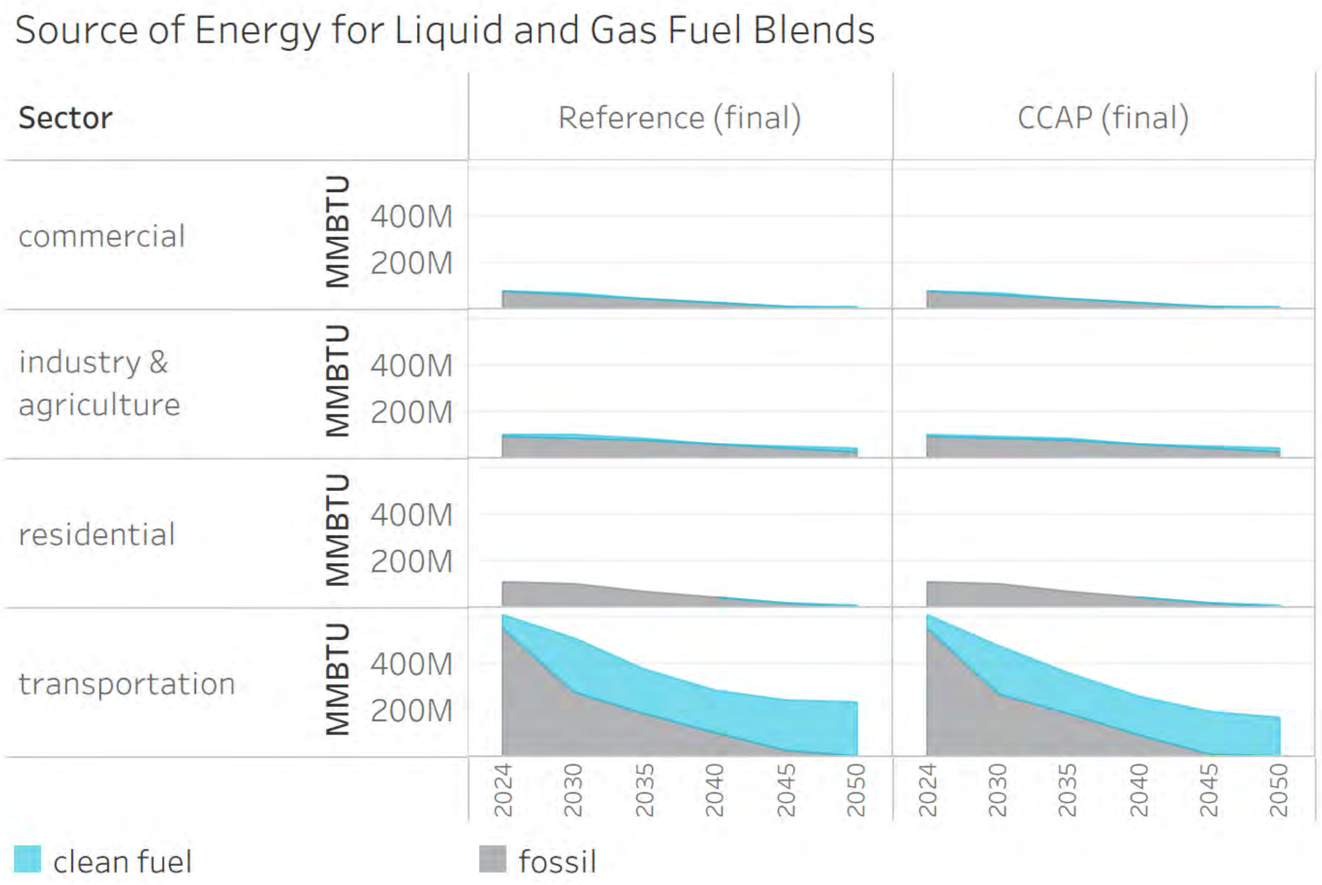
- Comparison to Draft CCAP
  - End use by sector and fuel type is not impacted by the updates because we assume that policy-driven technology adoption remains consistent in Washington

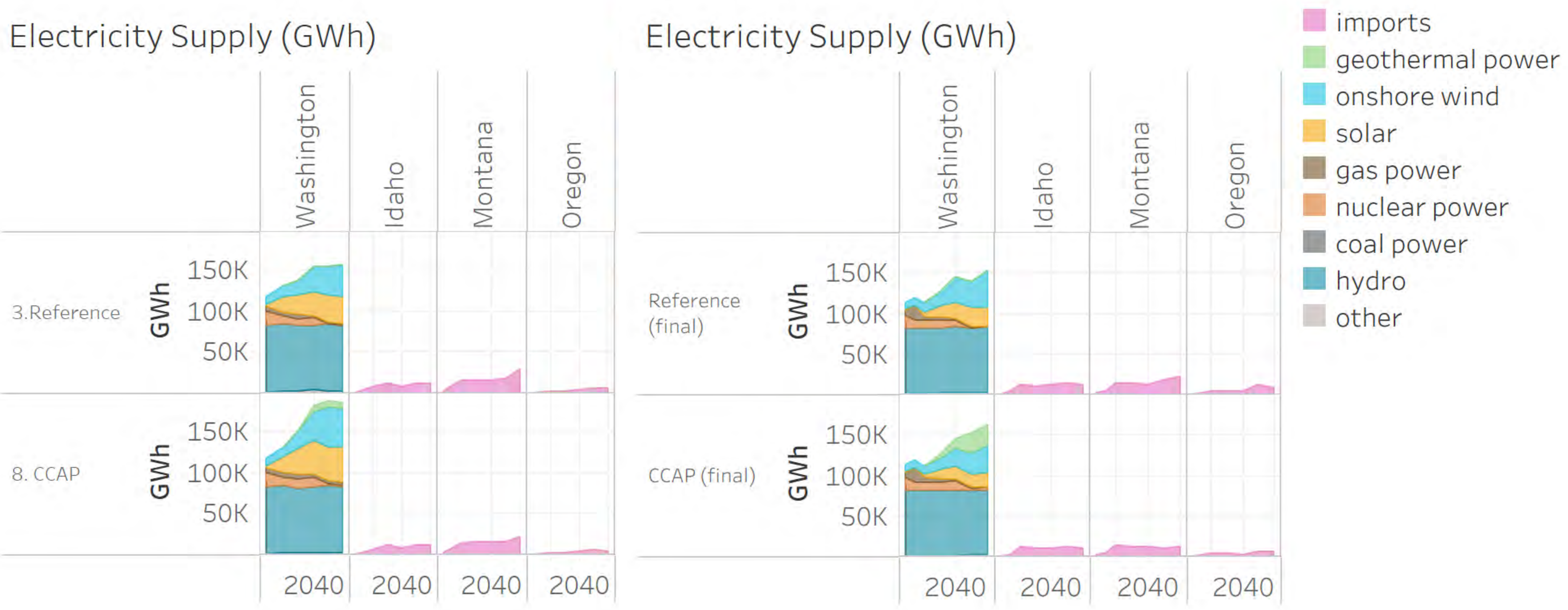


Washington Source of Liquid and Gas Fuel Blends

- Likewise, whether fuels are fossil or clean is not impacted because we assume the same technology adoption and Washington still reaches state emissions targets by decarbonizing fuels



Electricity Origin Comparison to Draft CCAP



Where does Washington's Electricity Come From?

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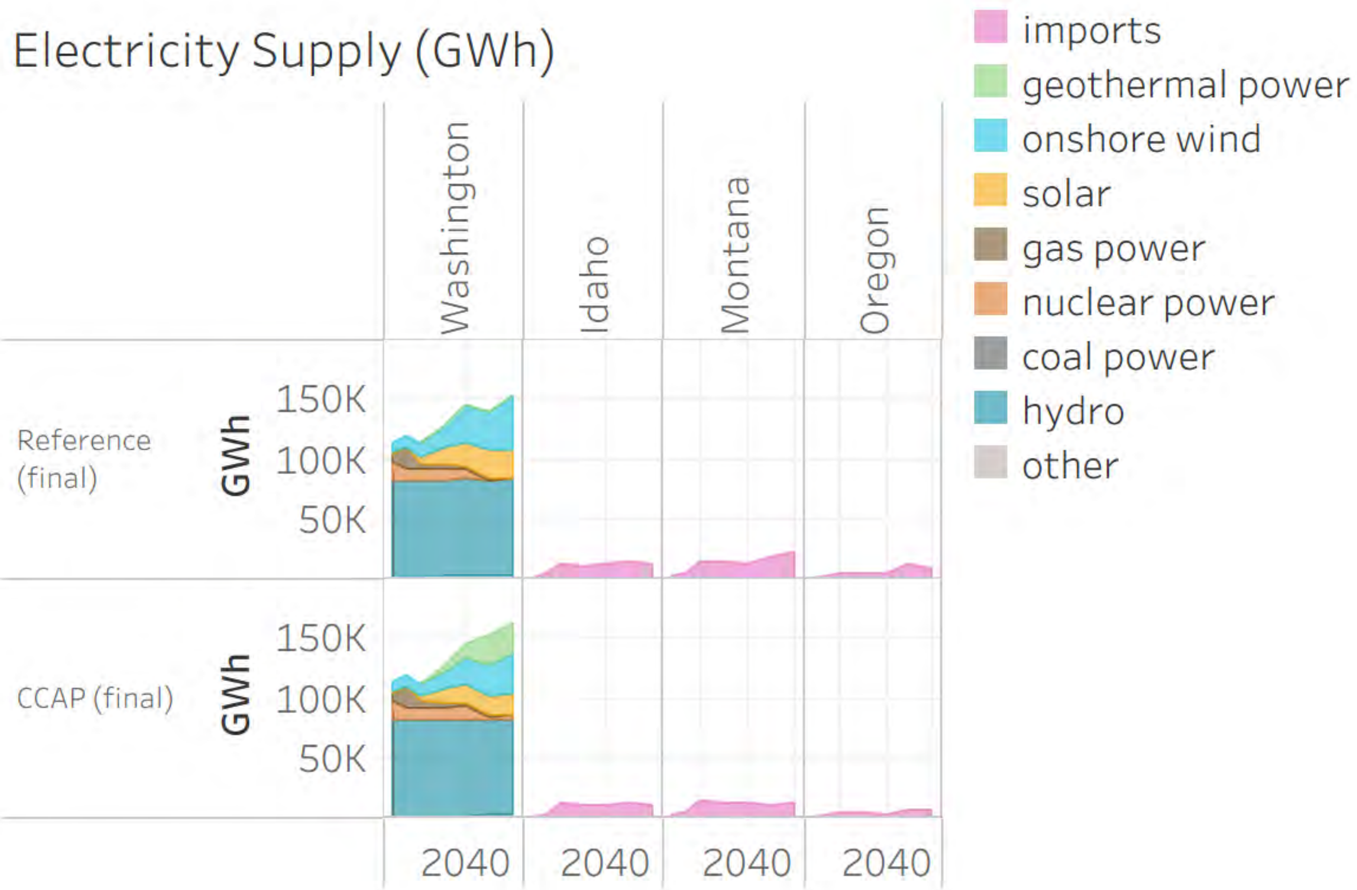
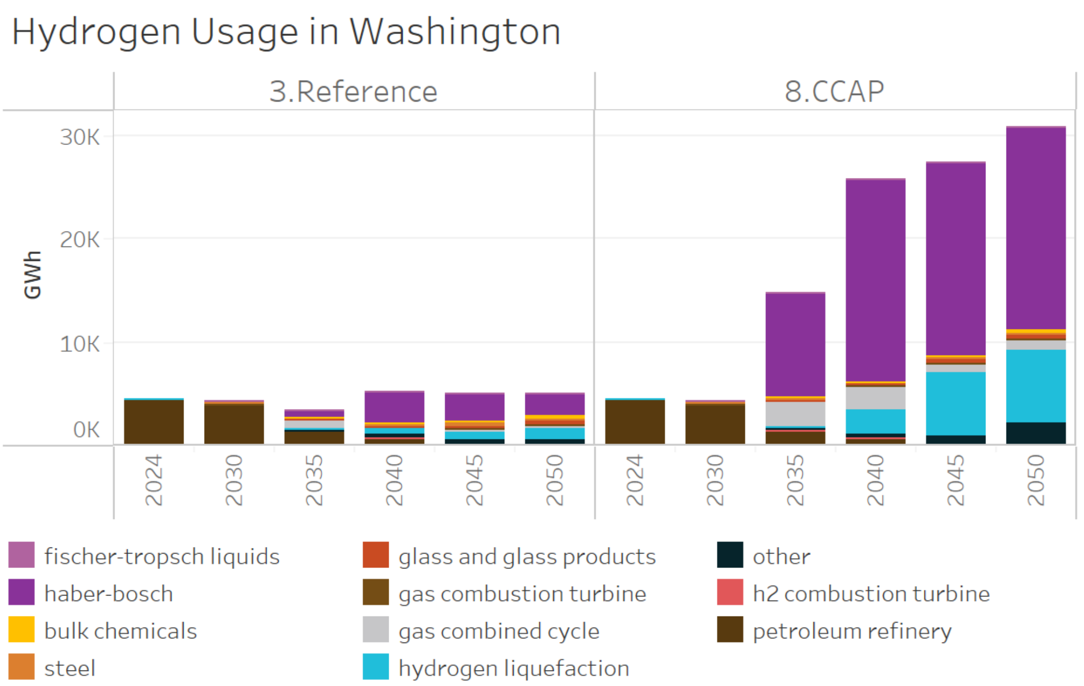
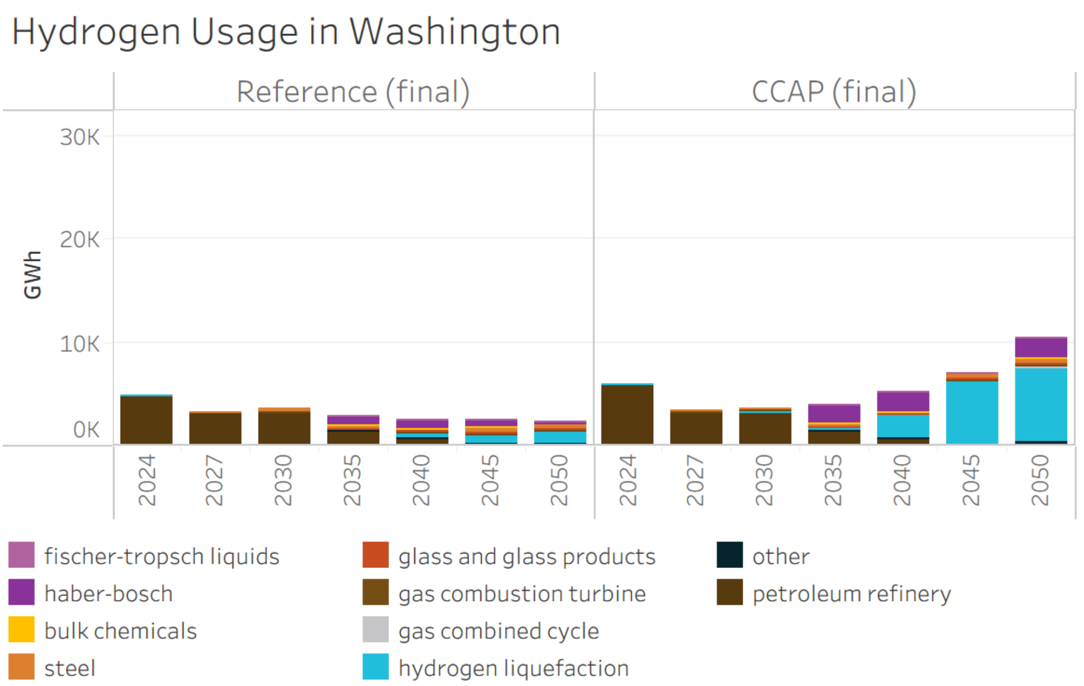
- The overall smaller electricity system and increased reliance on geothermal in the CCAP (final) scenario is accompanied by a decrease in imports from elsewhere by 2050
- By 2030, imports from other states increase, relying more on out of state clean energy



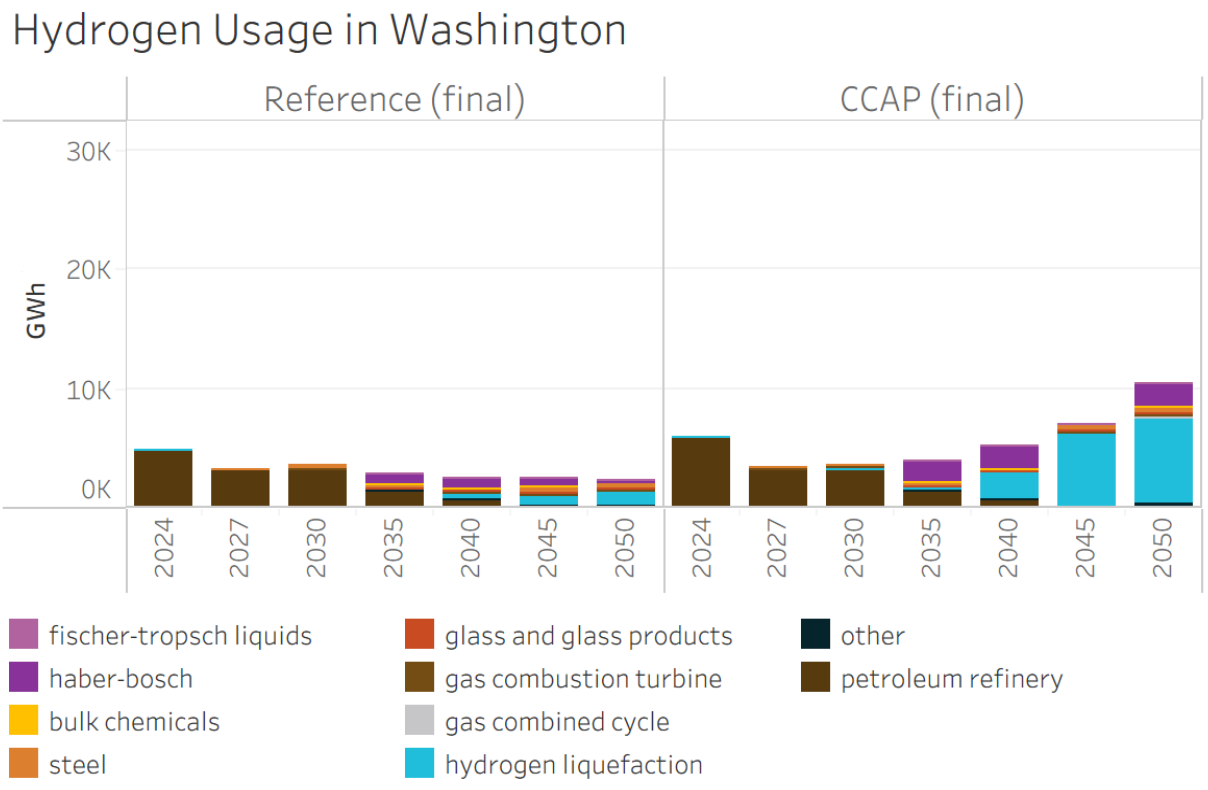
Hydrogen Comparison





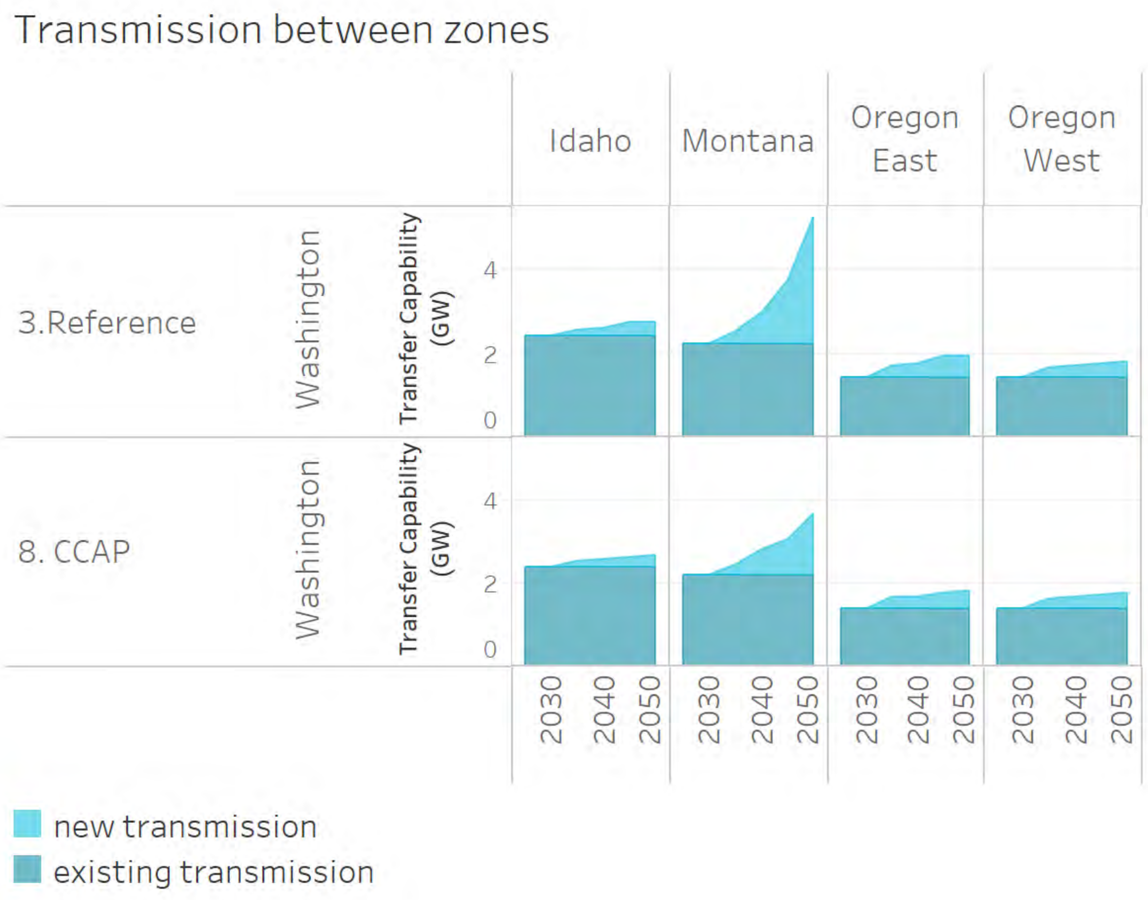
Hydrogen Use in Washington

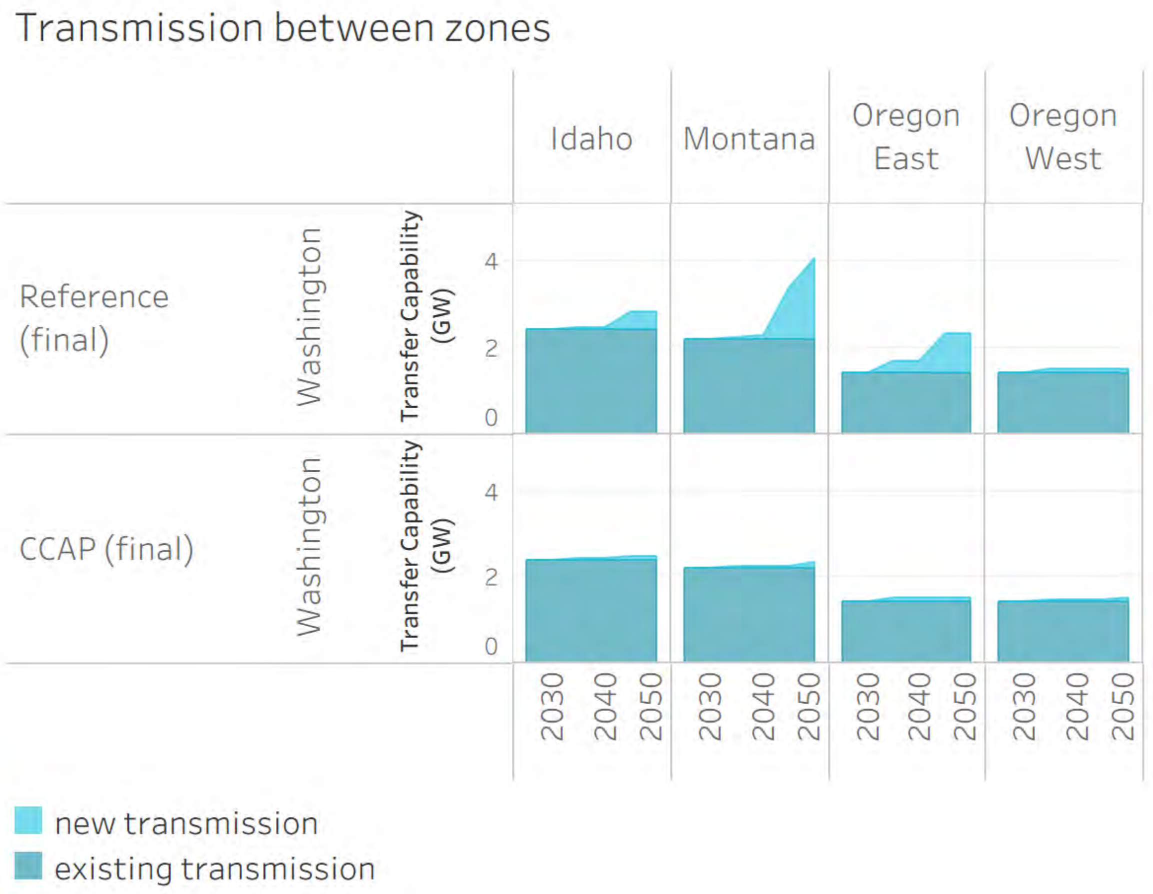
- Majority of hydrogen products imported from elsewhere
  - Fischer-Tropsch liquids and ammonia almost entirely imported
- Differences to Draft CCAP
  - The model chooses to build no more than the minimum 340MW of hydrogen production in-state based on changed economics of hydrogen
  - Ammonia production shifted to out of state
  - The source of hydrogen shifts from electrolytic to predominantly steam methane reforming (SMR) until 2050 when net zero must be achieved
    - Shifted economics and support for electrolytic hydrogen under new federal policy
    - Area of further study for Washington policymaking



[1]https://www.cleanenergytransition.org/programs/deep-decarbonization-pathways/green-electrolytic-hydrogen-report

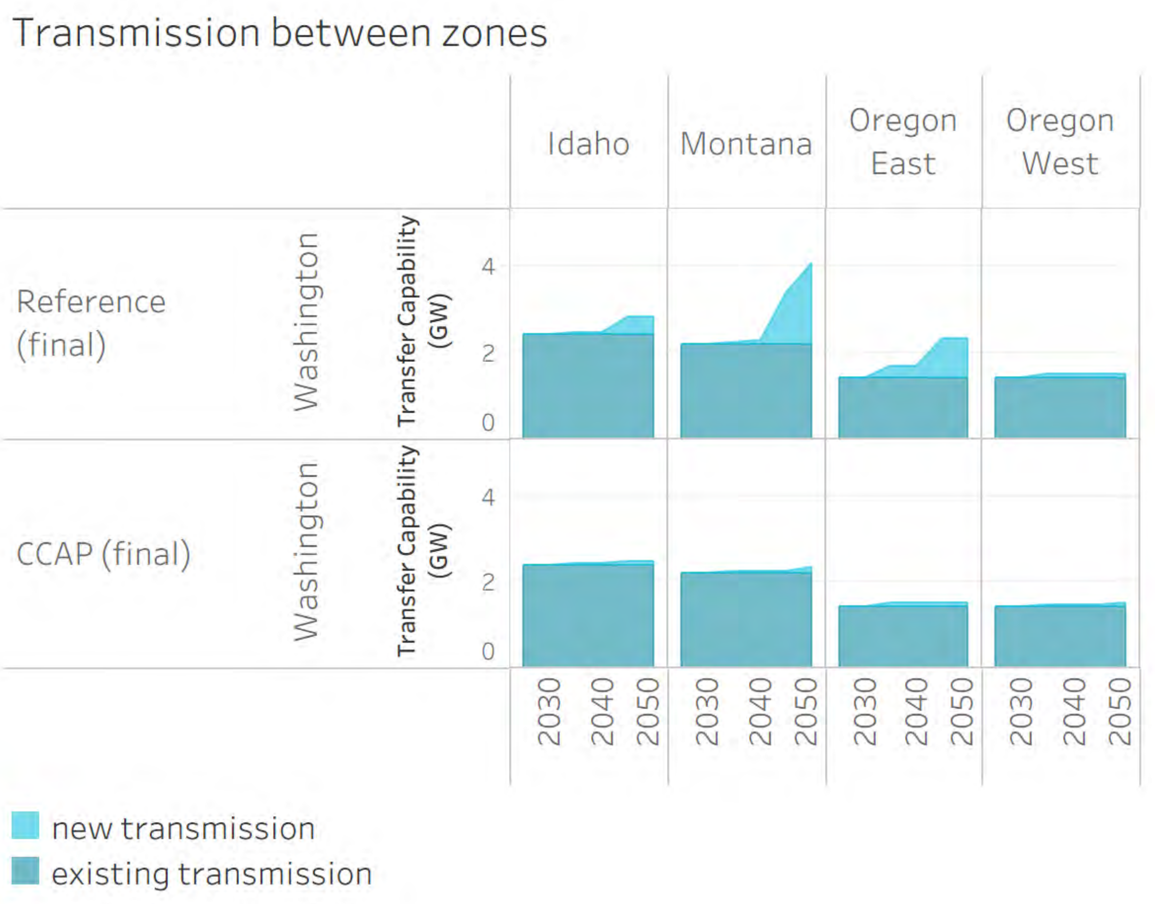
Transmission Comparison to Draft CCAP





Transmission Between Zones
Reference (final) and CCAP (final) Scenarios

- Changes to Draft CCAP
  - Reduced transmission need in the Reference scenario from reduction in electrolyzer load
  - CCAP (final) has minimal transmission expansion because of the overall smaller size of the electricity sector and the significantly increased capacity of enhanced geothermal plants compared to the draft CCAP



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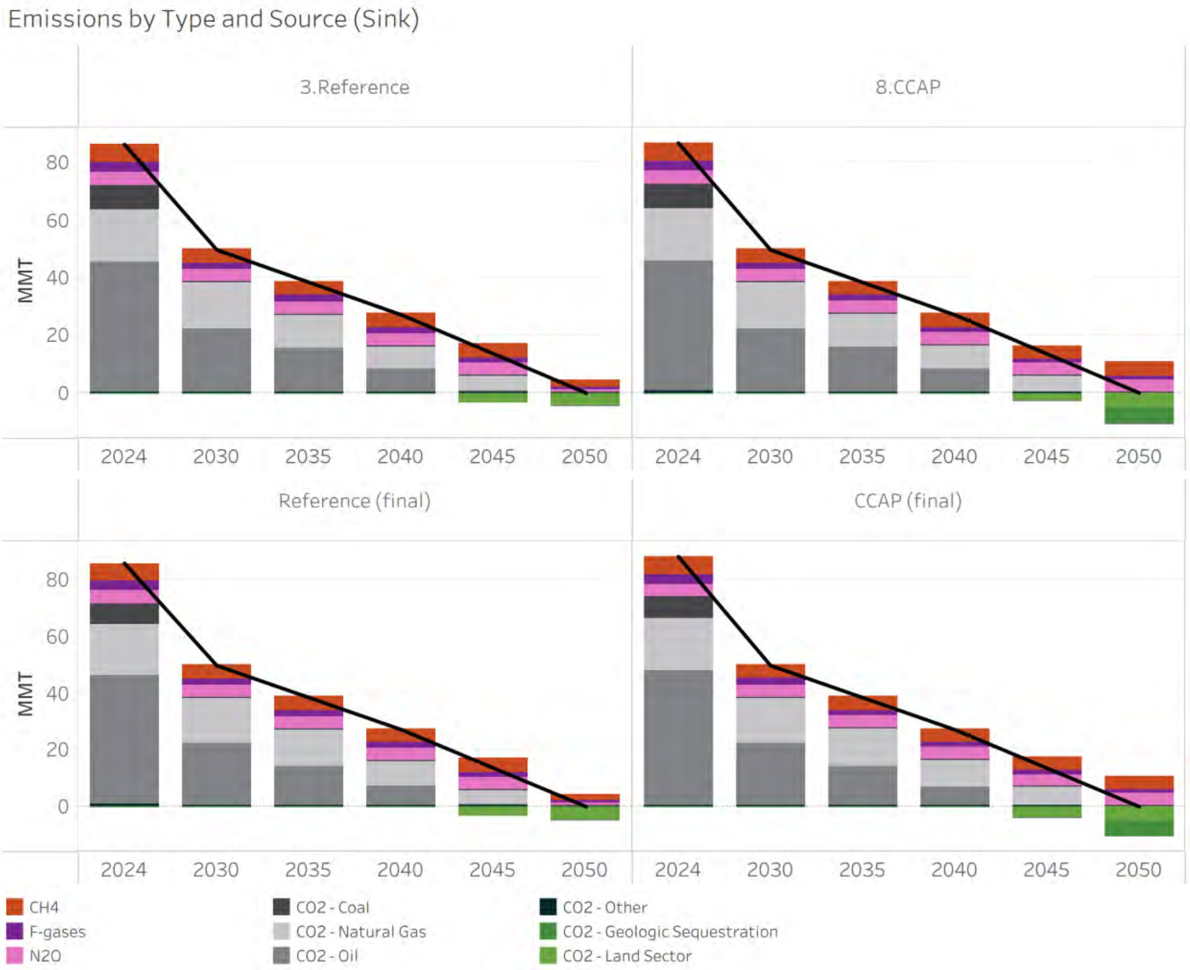
Emissions

Washington Emissions by Type and Source Reference (final) and CCAP (final) Comparison

- Comparison to Draft CCAP
  - Emissions remain unchanged
  - Driven by emissions targets
  - Largest impact of OBBBA modifications are on electricity sector through different resource choices and reduced electrolyzer load
    - Electricity sector still achieves the same level of emissions reductions because of policy targets



[1]https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/us-state-level-non-co2-ghg-mitigation-report

Emissions Reference (final) and CCAP (final)

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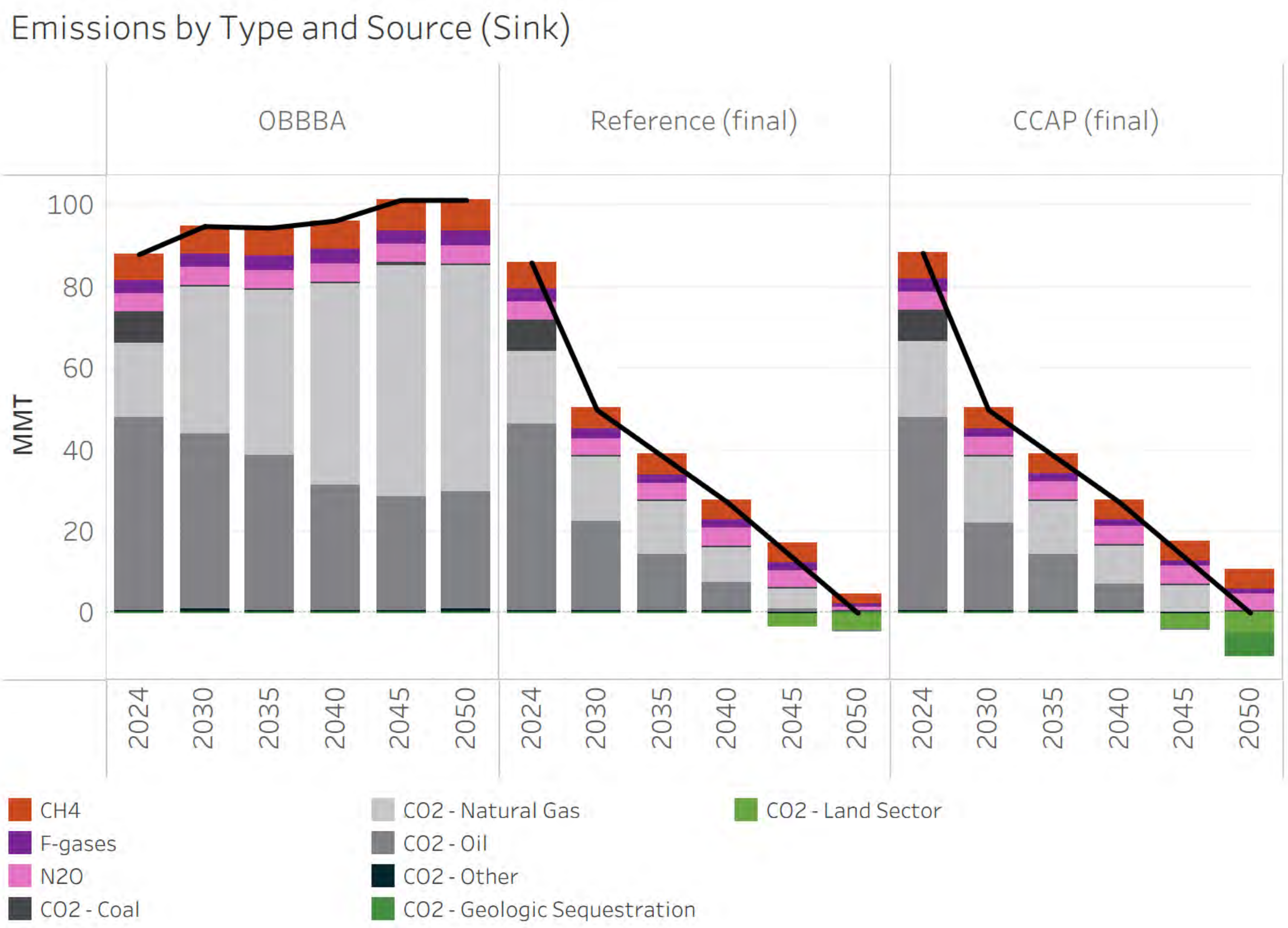
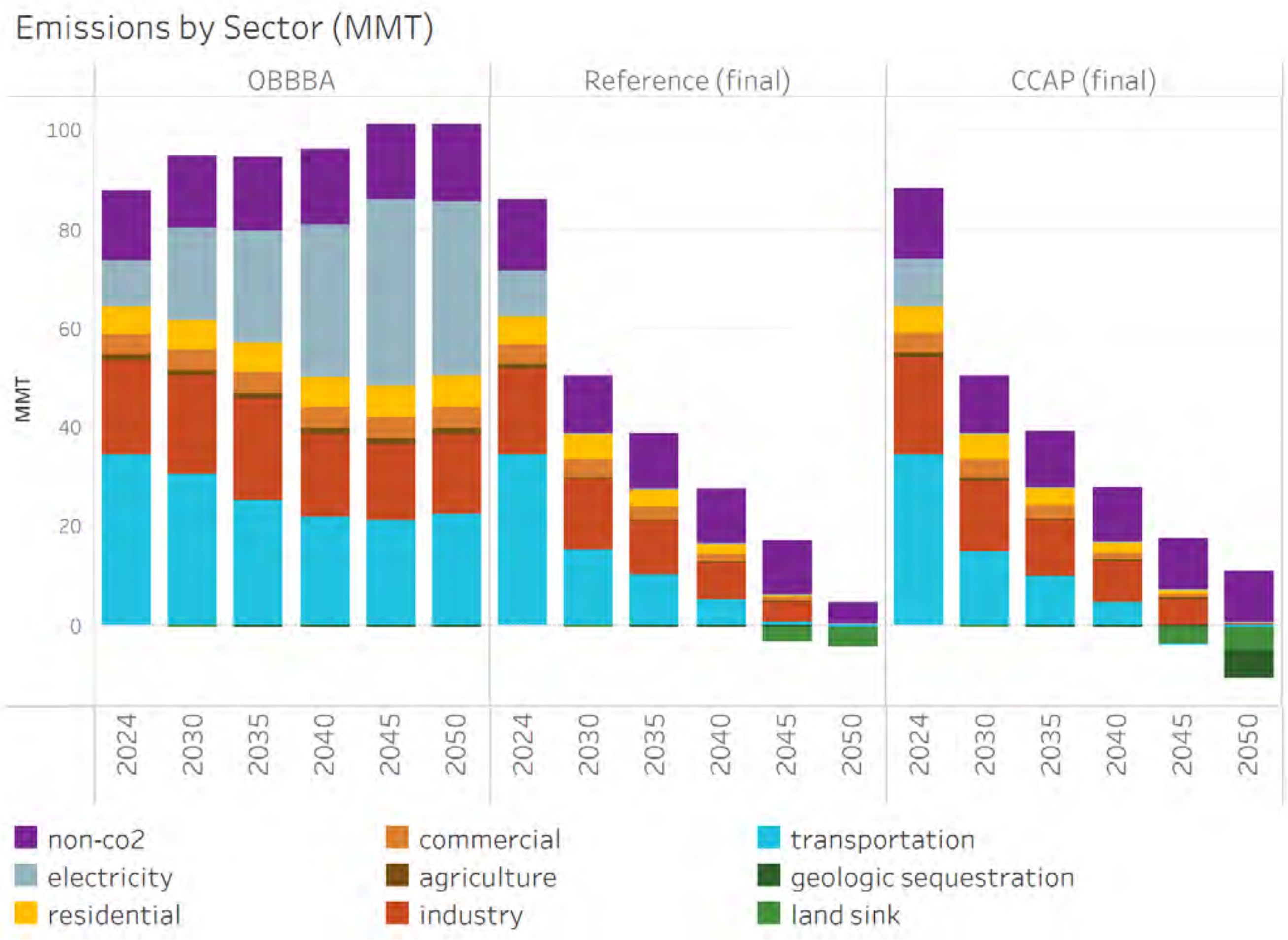


Sectoral Emissions

- Comparison to Draft CCAP
  - Emissions remain unchanged
  - Driven by emissions targets
  - Largest impact of OBBBA modifications on electricity sector through different resource choices and reduced electrolyzer load
    - Electricity sector still achieves the same level of emissions reductions because of policy targets



CCAP (final) Emissions Reductions by Sector

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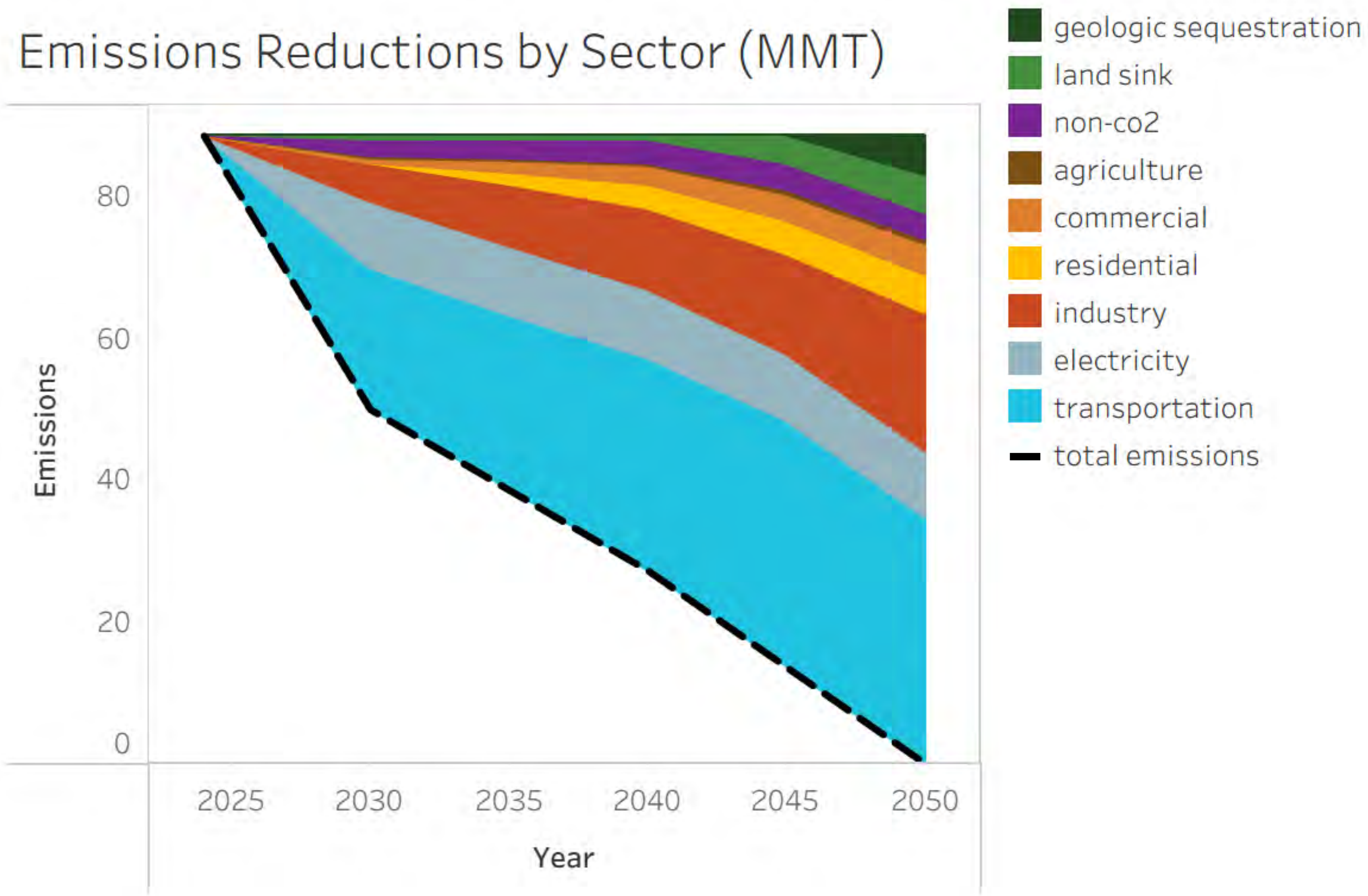

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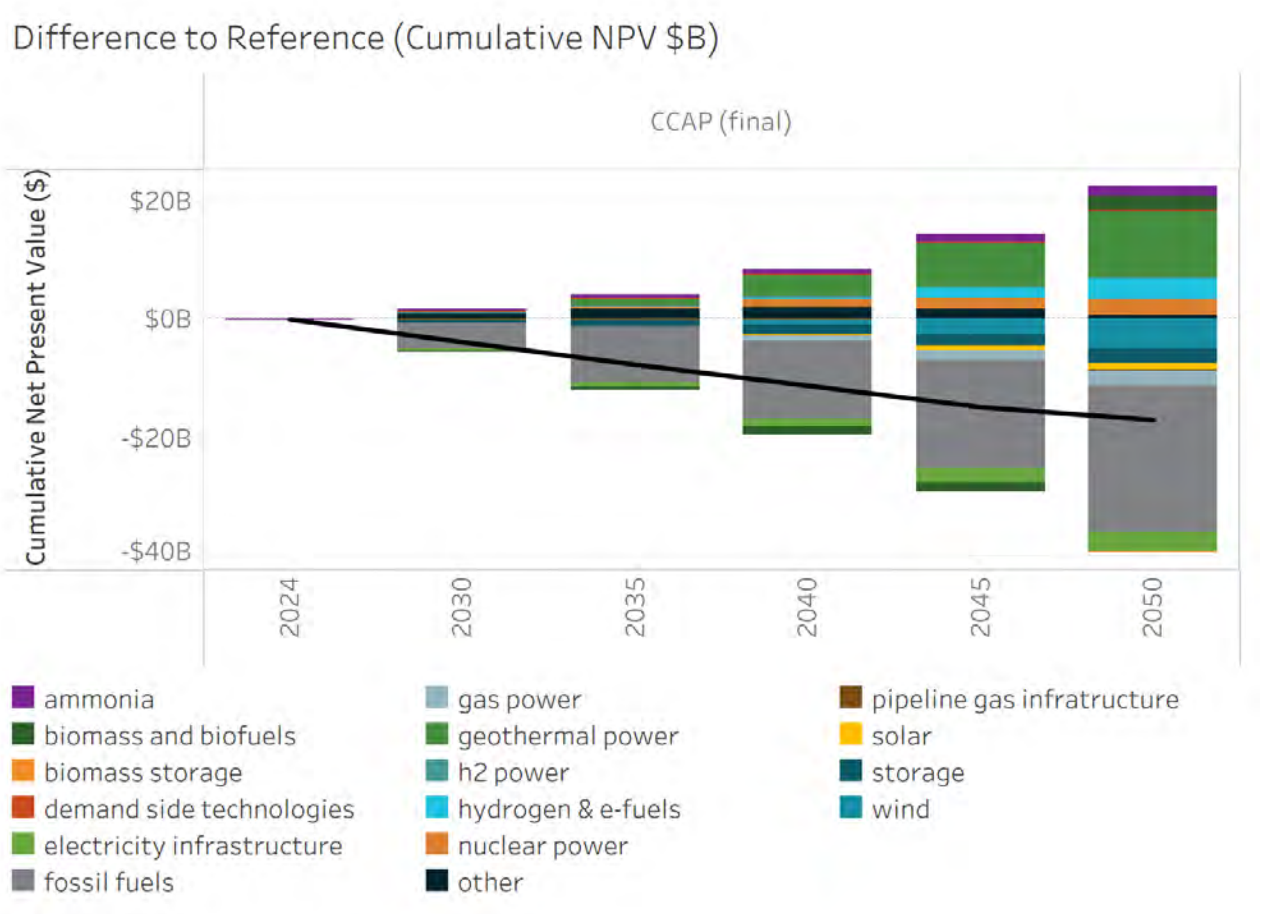
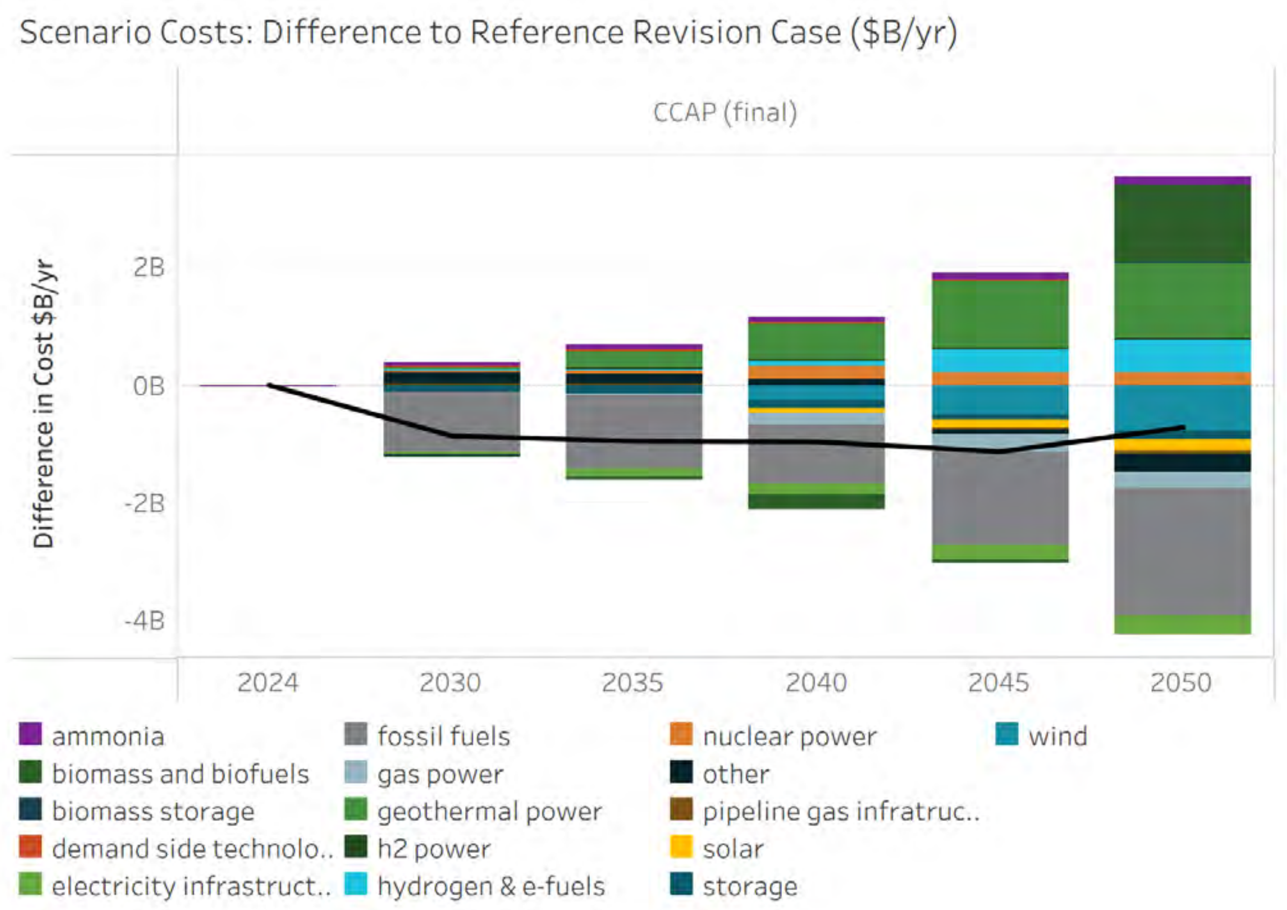
Costs

Cumulative Costs

- Net present value calculated with a 2% discount rate
- Cumulative benefits over time from reduced energy use in CCAP (final) Scenario
  - VMT reductions
  - Improved industrial efficiency
  - Reduction in air travel
  - Not counting the costs of achieving these outcomes (e.g., investments in public transport)



Annual Costs



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Takeaways from the Comparison with Draft CCAP

Key Takeaways: Comparison to Draft CCAP (1)

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- Electric load growth in end-use sectors unchanged in Washington because electrification is policy-driven
  - However, customers will now find electric vehicles and heat pumps more expensive, requiring more state policy support to achieve targets than before
  - Load growth from electrification in surrounding states without policy targets is lower
- Smaller overall electricity sector in Washington with reduced electrolysis loads
  - No electrolyzer investments made beyond 340MW minimum assumed in the state
- 2030 clean energy targets met with fewer in-state resources and greater imports of clean energy
  - Economic solution, but barriers to siting new resources and near-term resource crunch would suggest pursuing in-state resources is a prudent strategy to meet clean electricity goals

Key Takeaways: Comparison to Draft CCAP (2)

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- In the long term, changed relative economics between clean energy resources favors geothermal in CCAP (final) compared to the Draft CCAP
  - Greater geothermal builds provide clean firm power in Washington from 2035 through 2050
- Transmission builds are impacted by both smaller overall electricity system in-state and builds of enhanced geothermal
  - Reduced electrolyzer loads between 2035 and 2050 reduce the need for imported energy. Supply of ammonia previously produced in Washington shifts to out of state
  - Deployment of enhanced geothermal reduces the need for transmission. Limited interstate transmission build observed in the CCAP (final) Scenario
    - Note that this modeling only looks explicitly at interstate transmission and estimates only the cost of intrastate transmission. Large investments in intrastate transmission and distribution required to meet load growth.

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Key Takeaways: Technology and Practice Scenarios and final Reference and CCAP Scenarios

Key Takeaways: Reference (final)

- Load growth present in all scenarios, although highest in Reference (final) Scenario
  - Data centers are the largest driver of near-term load growth
- Washington's policies are drivers of clean energy and emissions reductions
  - Economics alone will not reach future emissions targets
  - Emissions increase in OBBBA scenario with no state policy represented
- Interstate transmission investment needed to access renewable energy, though if enhanced geothermal is available, it significantly reduces transmission need
  - Pursuing both transmission and geothermal would be prudent to avoid relying too heavily on any particular uncertain pathway
- 2050 emissions targets require reductions beyond currently identified potential for non-CO_2 emissions reductions

Key Takeaways: Technology+ Scenario

- Technology+ Scenario
  - Access to nascent clean baseload technologies, including enhanced geothermal and small modular reactors, reduces Washington's dependence on out-of-state resources and transmission to access them.
  - Likewise, for hydrogen electrolysis: Greater investment in-state avoids some development risk of resources in other states that can be better mitigated in state
    - Hydrogen becomes less important as a driver of new investment in CCAP (final) where the IRA incentives and favorable hydrogen forecast of Technology+ are removed
  - Fuel switching of maritime and rail transport reduces the need for hydrocarbon fuels

Key Takeaways: Personal Behavior+ Scenario

- Personal Behavior+ Scenario
  - Reduced service demands decrease the size of the energy system and investments needed to meet policy targets
    - But cost of achieving VMT and air travel reductions are not included in the model
    - Control over service demand reductions vary depending on the impact of state-led programs
  - Faster electrification is beneficial economically but may not be enough to counter political risk or to bear high distributional costs needed to achieve them

Key Takeaways: Siting/Infra+ Scenario

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- Results support prioritizing the rapid development of transmission
  - Lowers costs
  - Makes achieving Washington's policy goals less vulnerable to any roadblocks encountered in the transition – leaves more options on the table
- Siting/Infra+ Scenario
  - Transmission is built in large amounts by 2030 if the option is available showing its value to Washington as it decarbonizes
  - However, transmission and pipelines have long development timelines, and the limited likelihood of earlier development means Washington should not rely on any strategy requiring early transmission development

Key Takeaways: Ag/Waste/CDR Balance Scenario

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- Ag/Waste/CDR Balance Scenario
  - Removing the 5% gross emissions cap creates options for technological solutions, including carbon capture and sequestration as well as land use/land management solutions
  - Relies on known pathways to achieving reductions rather than direct non-CO_2 emissions reductions with no currently identified potential
  - Relies on BECCS in the model as the lowest cost option, but dependent on technology development over the next 20 years

Key Takeaways: CCAP (final) Scenario (1)

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- Tension between cost and feasibility, and between pace and customer acceptance
  - CCAP Scenario assumptions strike a middle ground between the Reference (final) Scenario and the Technology & Practice Scenarios
  - Balances at what rate might electrification and vehicle miles traveled (VMT) reductions happen based on customer choice and takes decarbonization measures in non-road transportation
  - Draws upon Technology+ Scenario resource availability assumptions, allowing for advanced geothermal deployment in Washington
  - CDR and NCS: Tension between achieving state policy and what studies of potential emissions reduction measures indicate are available
- The CCAP (final) Scenario shows emissions reduction measures and costs similar to both Technology+ Scenario and Personal Behavior+ Scenario

Key Takeaways: CCAP (final) Scenario (2)

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- Electric load growth in end-use sectors in Washington is driven by policy targets
  - However, customers will now find electric vehicles and heat pumps more expensive, requiring more state policy support to achieve targets than before
- The economics of hydrogen production do not support production of clean fuels like ammonia and hydrogen derived aviation fuels within the state
  - No electrolyzer investments made beyond 340MW estimate for hydrogen hub projects
  - Imported and in-state hydrogen production largely from steam methane reforming until being decarbonized in 2050 with biomass derived hydrogen under new federal policy landscape
    - Area of further study for Washington policymakers
- 2030 clean energy targets rely on imports of clean energy in the CCAP (final)
  - However, this is an economic solution and barriers to siting new resources and near-term resource crunch would suggest pursuing in-state resources is a prudent strategy to meet clean electricity goals

Key Takeaways: CCAP (final) Scenario (3)

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- In the long term, changed relative economics between clean energy resources from federal policy favors geothermal
  - Greater geothermal builds provide clean firm power in Washington from 2035 through 2050
- Transmission builds are impacted by federal policy changes to hydrogen economics and enhanced geothermal
  - Reduced electrolyzer loads between 2035 and 2050 reduce the need for imported energy. Supply of ammonia for international shipping in the 2040s sourced from out of state
  - Deployment of enhanced geothermal reduces the need for transmission. Limited interstate transmission build observed in the CCAP (final) Scenario
    - Note that this modeling only looks explicitly at interstate transmission and estimates only the cost of intrastate transmission. Large investments in intrastate transmission and distribution required to meet load growth

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Updated Air Quality Results

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Air Quality Methodology

Benefits Analysis: Health Impacts

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- U.S. Environmental Protection Agency (EPA) CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) Analysis
- Health impacts of particulate matter from air pollutants including nitrogen oxides (NOx), sulfur oxides (SOx), and direct fine particulate matter emissions (PM2.5)

Air Quality Results from Evolved Models

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EnergyPATHWAYS

Demand technology emission changes

- Database of emissions factors for NOx, PM2.5 and SOx from key technologies
  - Vehicles emission factors taken from EPA Motor Vehicle Emission Simulator
  - Supplemental vehicle emission data from OECD (2020), Non-exhaust Particulate Emissions from Road Transport: An Ignored Environmental Policy Challenge, OECD Publishing, Paris, https://doi.org/10.1787/4a4dc6ca-en.
  - Building technologies adapted from EPA's Air Emissions Inventories for point sources
- Calculates emissions based on technology activity

RIO

Energy supply emission changes

- Database of emissions factors for NOx, PM2.5, SOx and mercury from existing and new power plants
  - Existing plant emission factors taken from EPA Avoided Emissions and Generation Tool (AVERT) and eGRID 2019 data
  - Existing energy conversion technologies (e.g., boilers for steam) are adapted from EPA's Air Emissions Inventories for point sources
  - New power plant data is a combination of NREL ATB data and National Electric Energy Data System data
- RIO calculates emissions based on least cost dispatch

EPA Co-Benefits Risk Assessment (COBRA)

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Develop Scenario

Construct air quality scenario →

COBRA

Changes in Air Quality (Particulate Matter) → **Health Outcomes** → **Economic Benefits**

- Combines data from results and inputs bundled with COBRA to develop AQ scenarios
  - Pollutant results address many but not all categories for COBRA
  - COBRA inputs are scaled or adjusted for missing data categories, with changes made to reflect how each pathway evolves differently.

- Reduced form air quality model called the Source-Receptor (S-R) Matrix
  - Estimates ambient concentrations of PM by county
- Estimates contribution from each pollutant source to air quality of each county

- Concentration response functions
  - Adult and infant mortality
  - Non-fatal heart attacks
  - Respiratory and Cardiovascular hospital admissions
  - Acute bronchitis and respiratory symptoms
  - Asthma exacerbations and emergencies
  - Restricted activity and work loss days

- Economic costs of health impacts
  - Value of statistical life (VSL)
  - Cost of illness
  - Hospital charges
  - Willingness to pay
    - Symptoms of illness
    - Restricted activity
    - Lost workdays

EPA COBRA: https://www.epa.gov/sites/default/files/2017-10/documents/cobra_training_eic_2017.pdf

Epidemiological Studies Behind COBRA Functions

- COBRA's concentration response functions are based on epidemiological studies of health outcomes when populations are exposed to changes in PM2.5
- More details can be found in the COBRA user guide and documentation at the following link (source of adjacent table)
  - https://www.epa.gov/system/files/documents/2021-11/cobra-user-manual-nov-2021_4.1_0.pdf

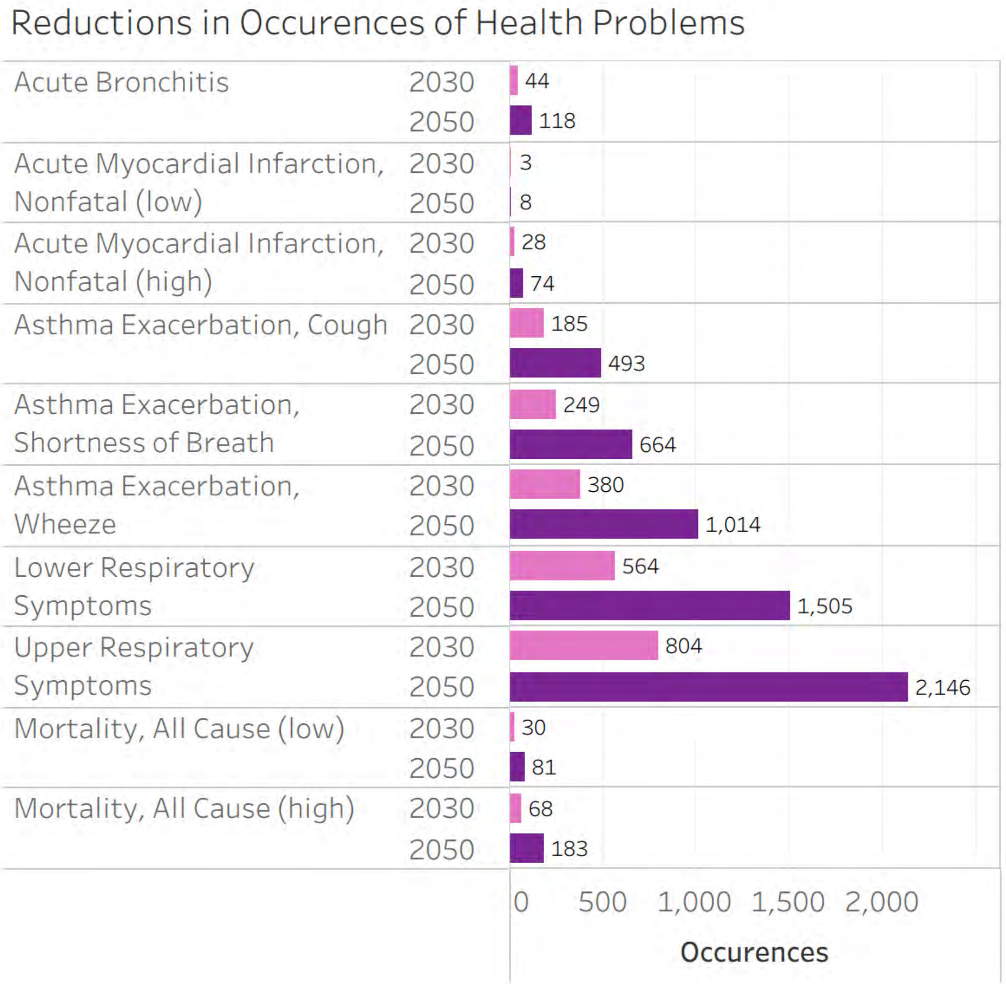
Endpoint	Author	Age
Mortality, All Cause	Krewski et al. (2009)	30-99
Mortality, All Cause	Lepeule et al. (2012)	25-99
Mortality, All Cause	Woodruff et al. (1997)	Infant
Acute Myocardial Infarction, Nonfatal	Peters et al. (2001)	18-99
Acute Myocardial Infarction, Nonfatal	Pope et al. (2006)	18-99
Acute Myocardial Infarction, Nonfatal	Sullivan et al. (2005)	18-99
Acute Myocardial Infarction, Nonfatal	Zanobetti and Schwartz (2006)	18-99
Acute Myocardial Infarction, Nonfatal	Zanobetti et al. (2009)	18-99
HA, All Cardiovascular (less Myocardial Infarctions)	Bell et al. (2008)	65-99
HA, All Cardiovascular (less Myocardial Infarctions)	Moolgavkar (2000b)	18-64
HA, All Cardiovascular (less Myocardial Infarctions)	Peng et al. (2008)	65-99
HA, All Cardiovascular (less Myocardial Infarctions)	Peng et al. (2009)	65-99
HA, All Cardiovascular (less Myocardial Infarctions)	Zanobetti et al. (2009)	65-99
HA, All Respiratory	Zanobetti et al. (2009)	65-99
HA, All Respiratory	Kloog et al. (2012)	65-99
HA, Asthma	Babin et al. (2007)	0-17
HA, Asthma	Sheppard (2003)	0-17
HA, Chronic Lung Disease	Moolgavkar (2000a)	18-64
Emergency Room Visits, Asthma	Mar et al. (2010)	0-99
Emergency Room Visits, Asthma	Slaughter et al. (2005)	0-99
Emergency Room Visits, Asthma	Glad et al. (2012)	0-99
Acute Bronchitis	Dockery et al. (1996)	8-12
Asthma Exacerbation, Cough	Mar et al. (2004)	6-18
Asthma Exacerbation, Cough	Ostro et al. (2001)	6-18
Asthma Exacerbation, Shortness of Breath	Mar et al. (2004)	6-18
Asthma Exacerbation, Shortness of Breath	Ostro et al. (2001)	6-18
Asthma Exacerbation, Wheeze	Ostro et al. (2001)	6-18
Minor Restricted Activity Days	Ostro and Rothschild (1989)	18-64
Lower Respiratory Symptoms	Schwartz and Neas (2000)	7-14
Upper Respiratory Symptoms	Pope et al. (1991)	9-11
Work Loss Days	Ostro (1987)	18-64

COBRA Methodology

- Reports the benefits attributed to emissions reductions in a single year versus 2023 (the latest year of air quality historical data in the COBRA model)
  - Reporting 2030 and 2050 in this study
  - Future gas generation additions are assumed to go into the same counties that have existing natural gas capacity for power plants
  - Benefits are attributed to the emissions reductions over 2024 experienced by the population in 2030 and 2050
- Fewer hospital visits, lost workdays, incidences of illness are determined for the year in which the emissions reductions are experienced
- Mortalities attributed to the emissions in a particular year are assumed to occur over the following 20 years
  - Benefits of emissions reductions are the present value of reduced mortalities over that time period
  - All attributed to the emissions reductions experienced within a single year
- This analysis does not address indoor air quality changes from the energy transition or the effect on air quality of changing wildfire frequency

Impact on Health Metrics and Mortality: CCAP (final) Scenario

- Reduced occurrences of health problems due to reduced pollutant concentrations
- These result in economic benefits such as fewer missed workdays, fewer hospital admissions, and reduced mortality
- Reduced mortality is by far the largest economic benefit
  - Value of a statistical life (VSL) of $7.4M in 2006 dollars used by EPA (~$10.7M in 2022 $ that the modeling results are reported in)
  - "How much people are willing to pay for small reductions in their risks of dying," [EPA mortality risk valuation]



Impact on Lost Workdays, Hospital Admissions, and Range of Mortality: CCAP (final) Scenario

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- Outcomes include fewer days of work lost, hospital admissions, and mortalities

Outcomes	2030	2050
Fewer days of work lost per million people	438	961
Fewer hospital admits per million people	1.1	2.4
Fewer mortalities per million people (high)	7.9	17.4
Fewer mortalities per million people (low)	3.5	7.7

Annual Pollutant Emissions Reduction Benefits: CCAP (final) Scenario

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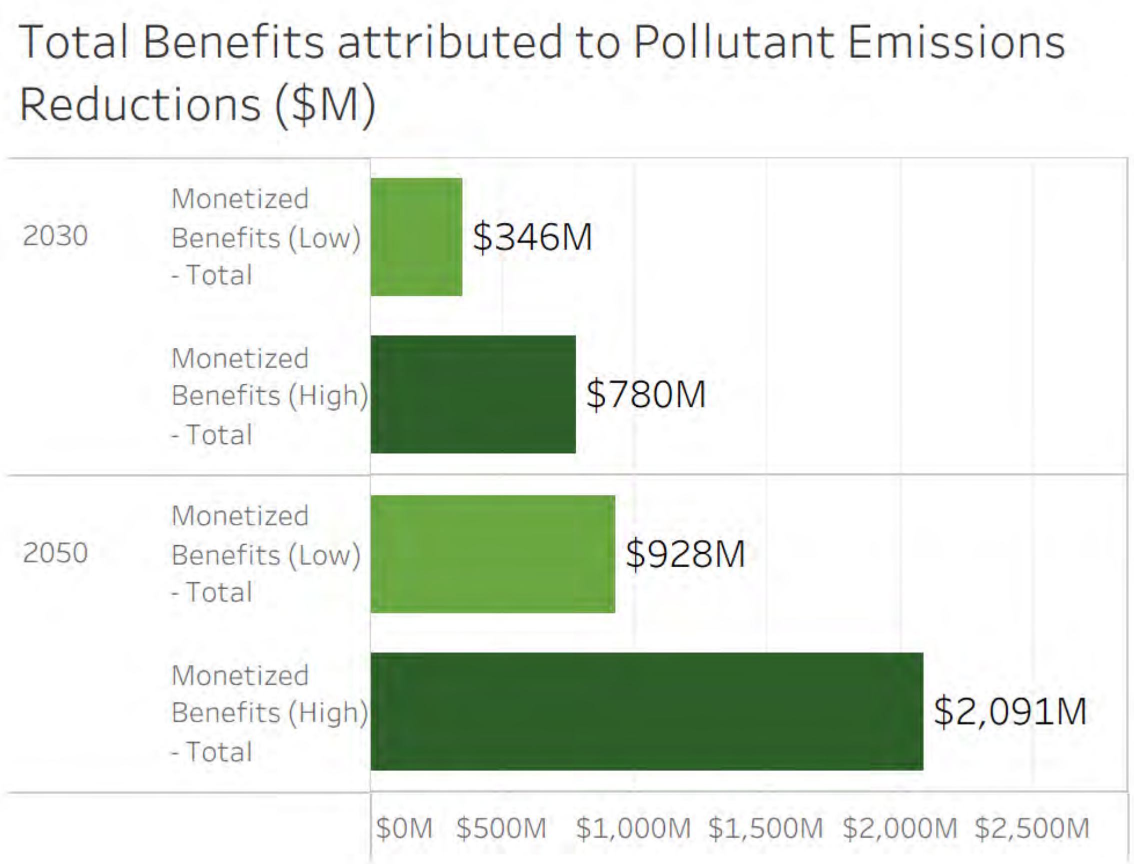
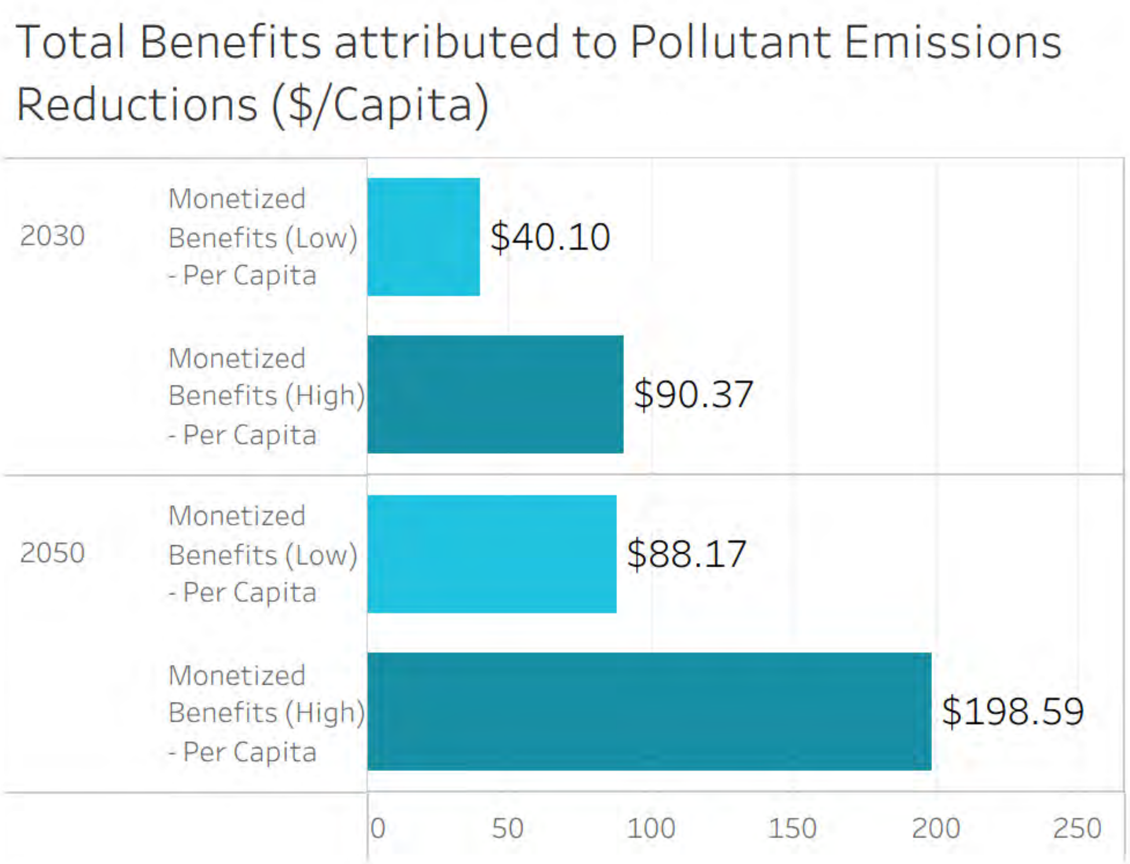
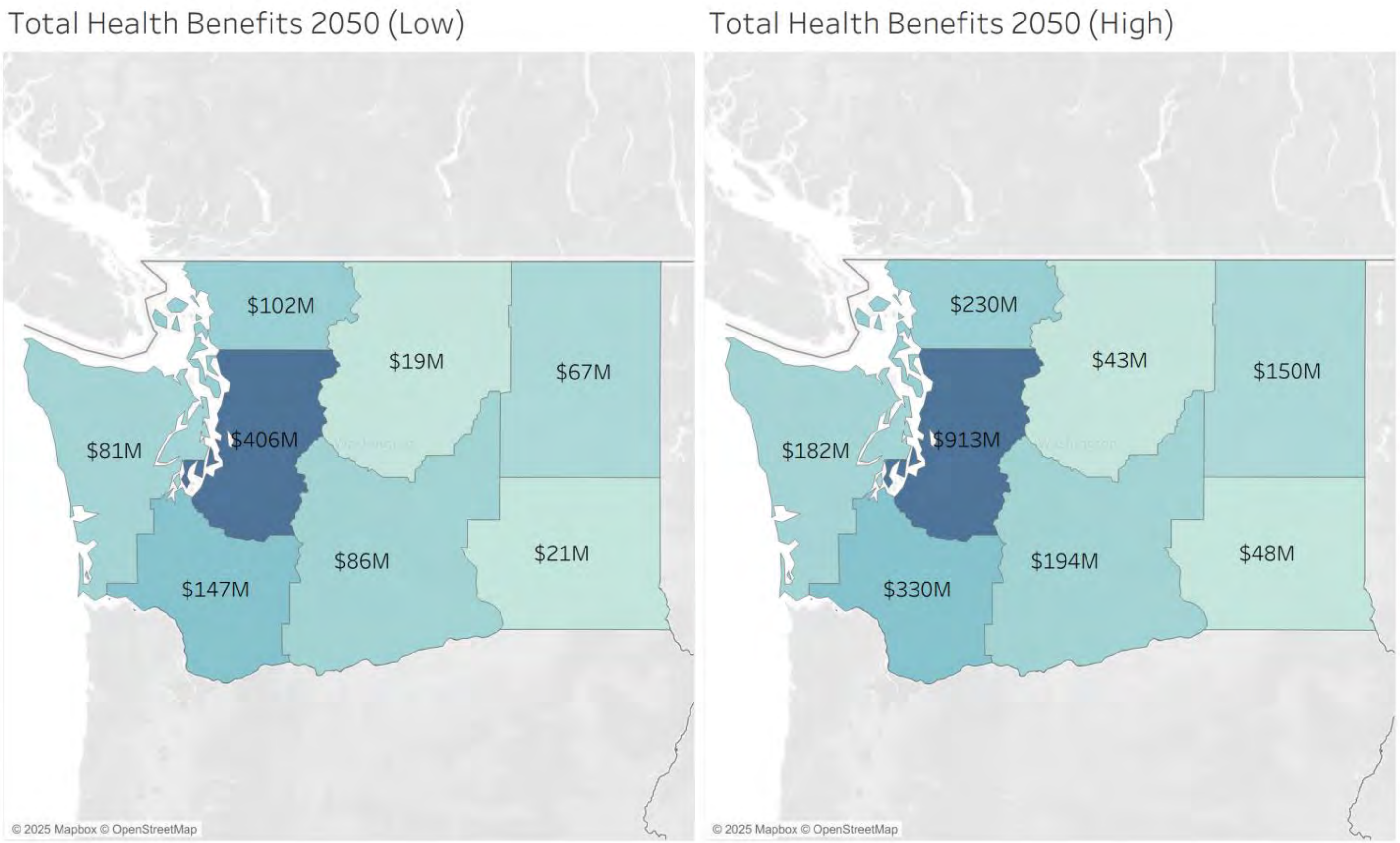




Total Health Benefits by Region in 2050: CCAP (final) Scenario

- Distribution of health benefits follows population
- Largest benefits in Seattle metropolitan area
- Benefits relative to health impacts of particulate matter exposure in 2024



Reported costs are annual benefits in 2050 and in 2022 $

Health Benefits per Capita by Region in 2050: CCAP (final) Scenario

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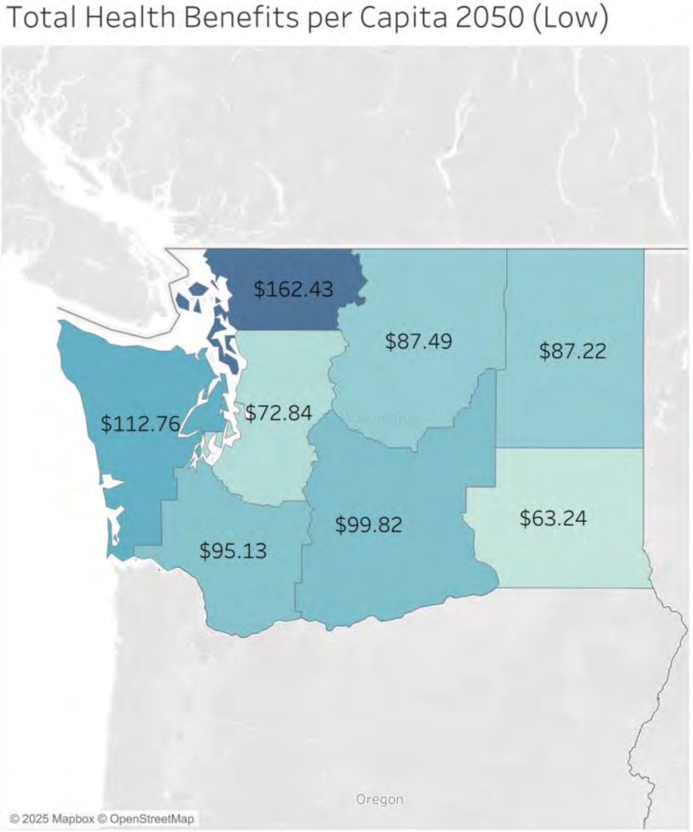
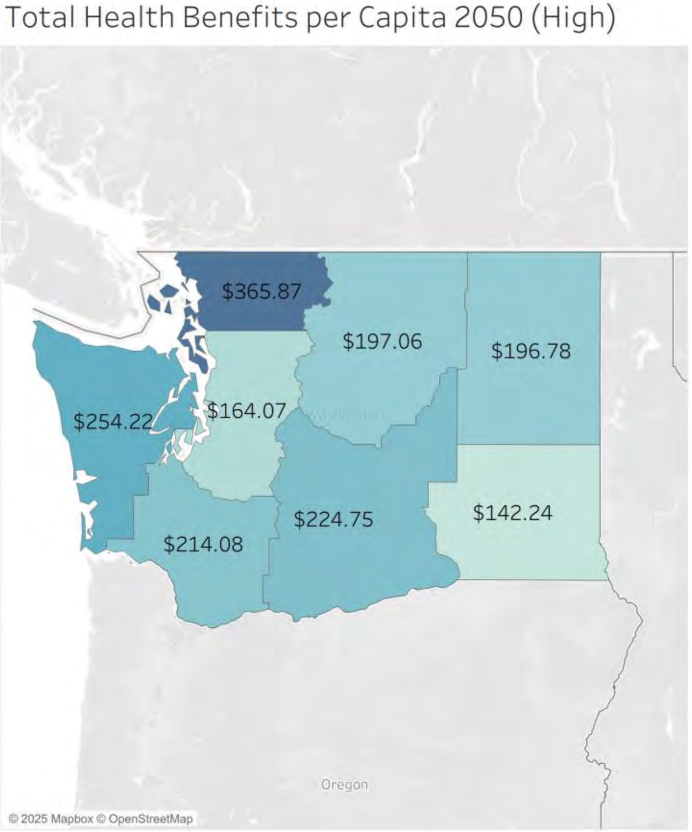
- Per capita benefits greater in the southern regions of the state
- Benefits relative to health impacts of particulate matter exposure in 2024
- ~99% of the benefits come from reduced mortality





Reported costs are annual benefits in 2050 and in 2022 $

Particulate Matter Concentrations: CCAP (final) Scenario

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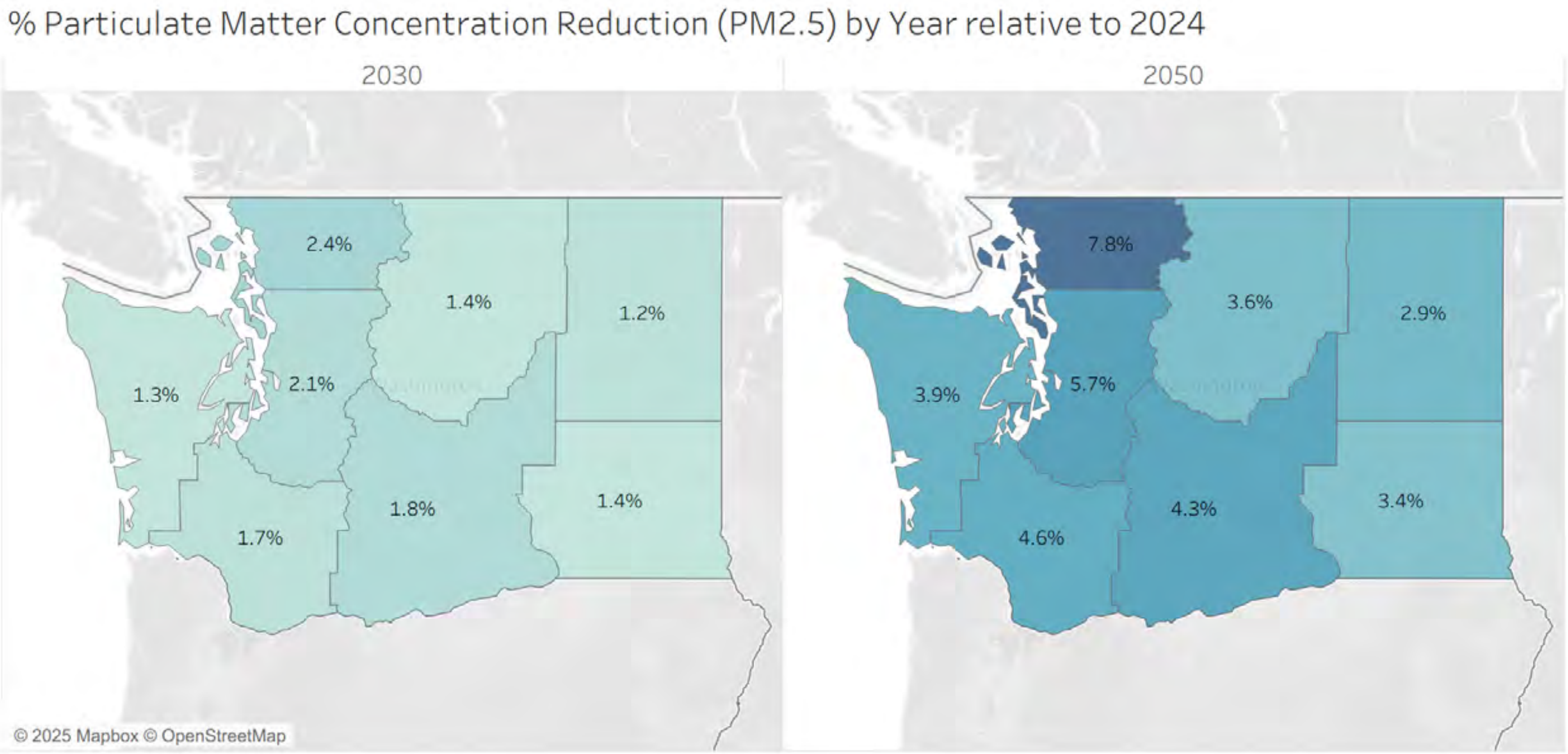
- COBRA calculates the change in PM2.5 concentrations and their impact on health outcomes
- The adjacent maps show the change in PM2.5 concentrations in the CCAP (final) scenario versus 2024 levels
- Statewide, reductions in PM2.5 concentration are:
  - 1.6% in 2030
  - 4.2% in 2050
- The reduction in PM2.5 concentrations results in better health outcomes



Key Takeaways

- COBRA analysis indicates significant health benefits associated with achieving Washington emissions and clean energy targets
  - Between $346M and $780M monetized benefits in 2030
  - Between $928M and $2091M monetized benefits in 2050
  - Cumulative present value benefits of $11.0B to $24.8B over the next 25 years
- Absolute benefits follow population by region but per capita do not follow the same trend
- Most monetized dollar health benefits are attributed to mortality based on the high value of a statistical life

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Updated Economic Impact Analysis Results

Total Job Growth

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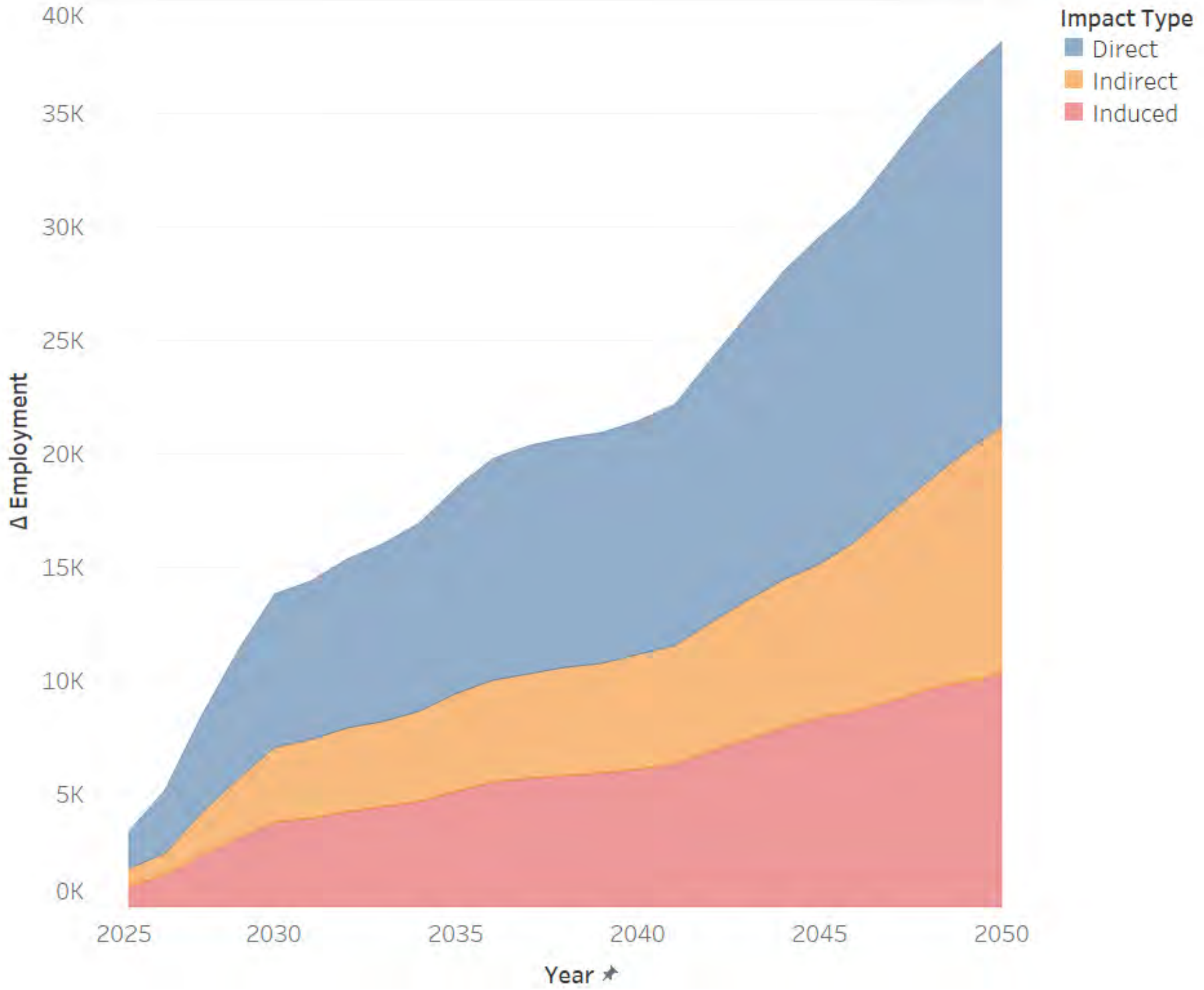
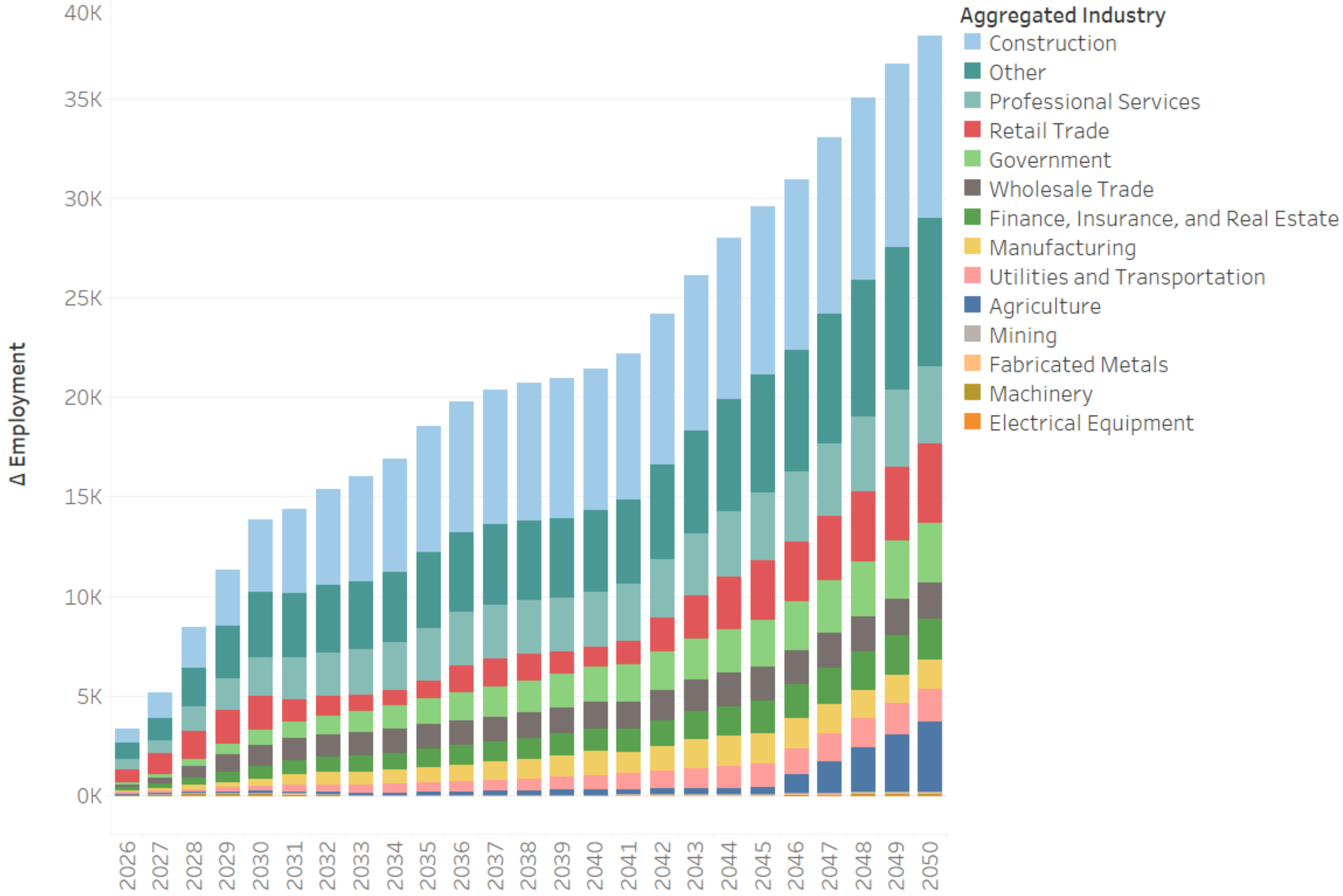
- WA CCAP plan will create 18.5k jobs by 2035 and 38.2k jobs by 2050, relative to 2025 baseline
  - 2035: 9.1k Direct, 4.3k Indirect, 5.1k Induced
  - 2050: 17.0k Direct, 10.9k Indirect, 10.3k Induced
- Significant investments in new technologies: EV Infrastructure and Transmission, Distribution, and Interconnection (T&D) account for over 60% of this growth



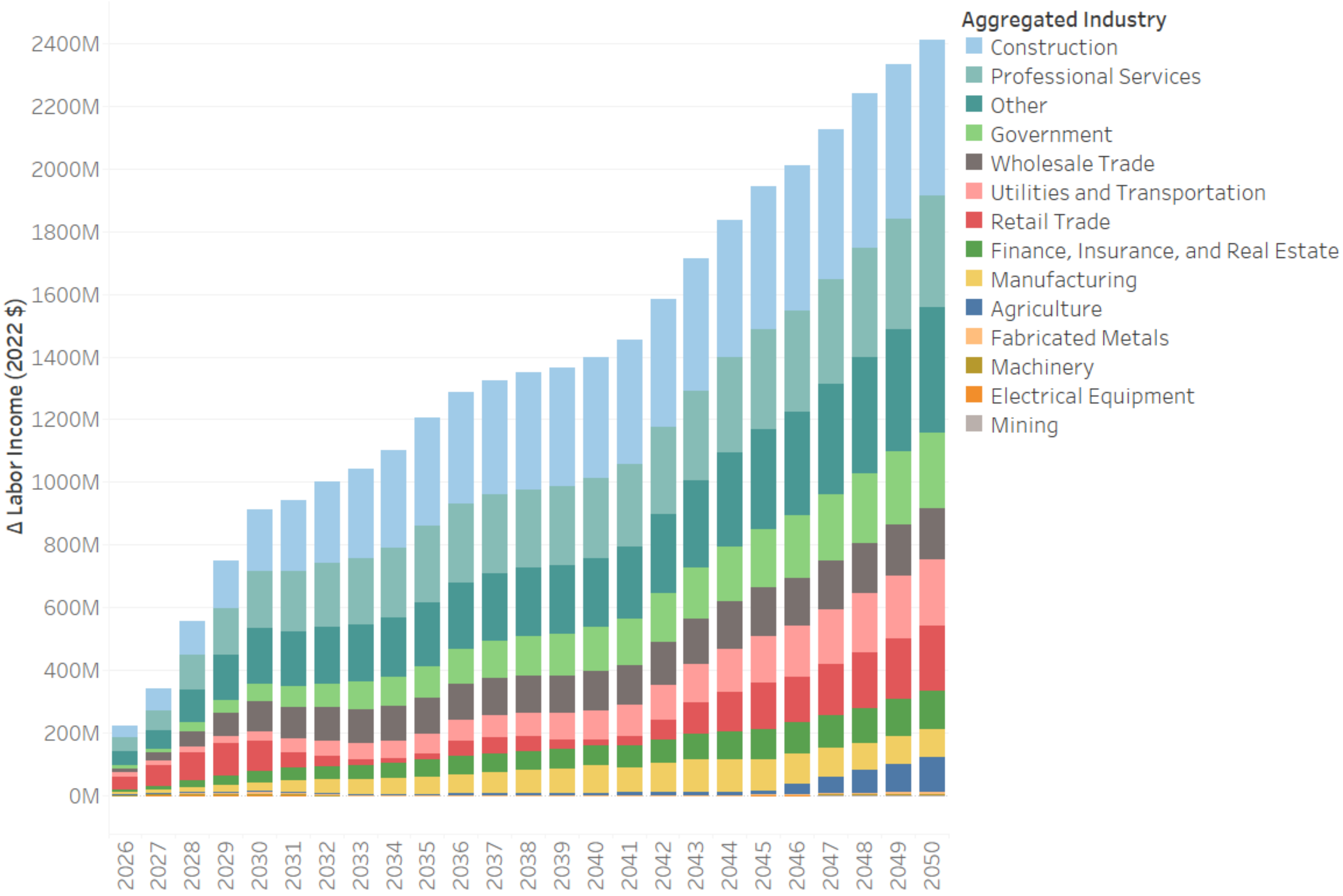
Job Growth by Industry

- Construction is the largest sector, sustaining over 6k new jobs from 2035-2050
  - ‘Other’ Industry is a catch-all of primarily induced jobs outside of Construction, Utilities, or related sectors
- No reductions in any specific sectors, relative to 2025 baseline



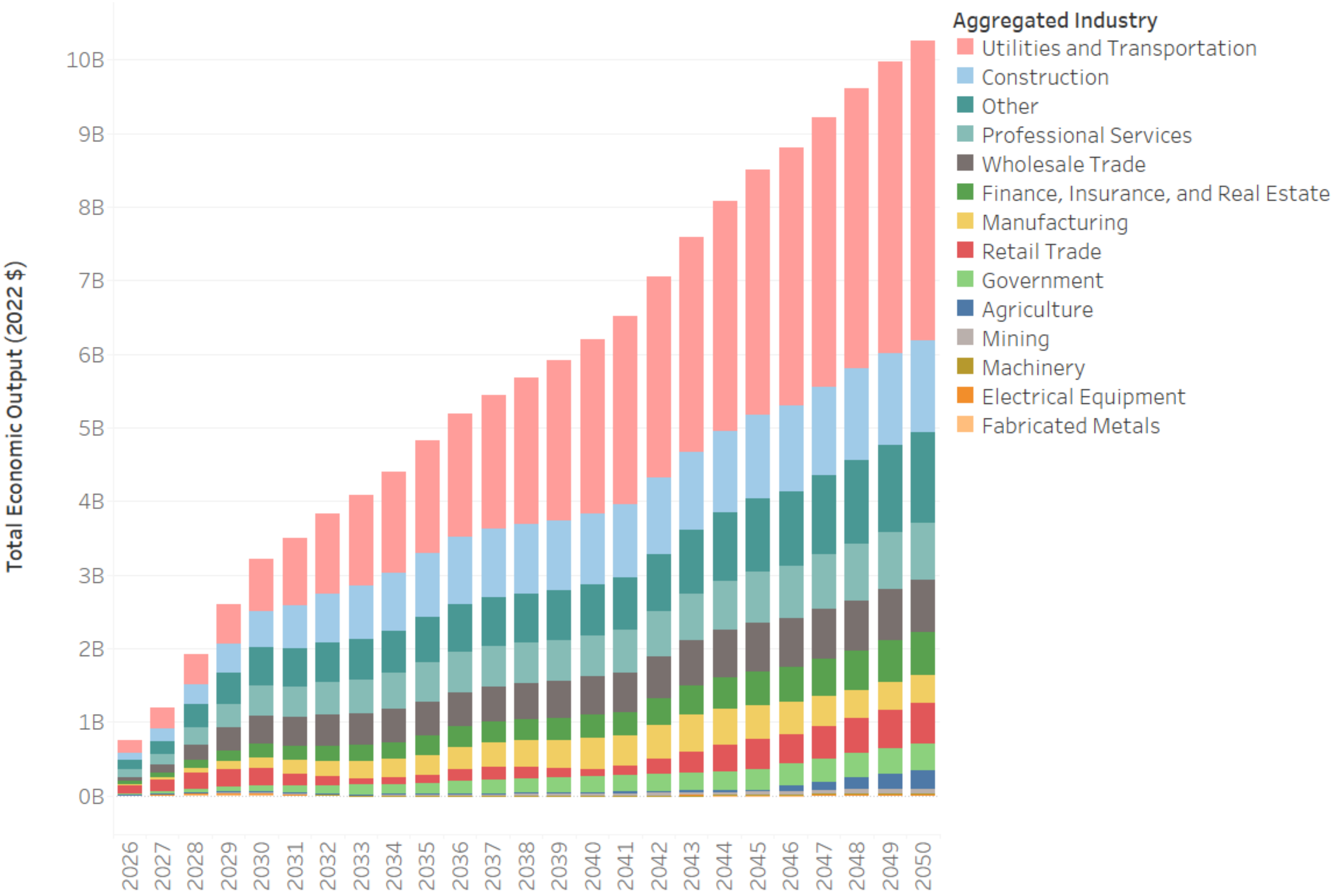
Labor Income

- Annual Labor Income follows job growth, with substantial gains across all industries totaling $44.4 Billion between 2026 and 2050
- Construction, Professional Service, Utilities and Transportation industries represent largest Income growth



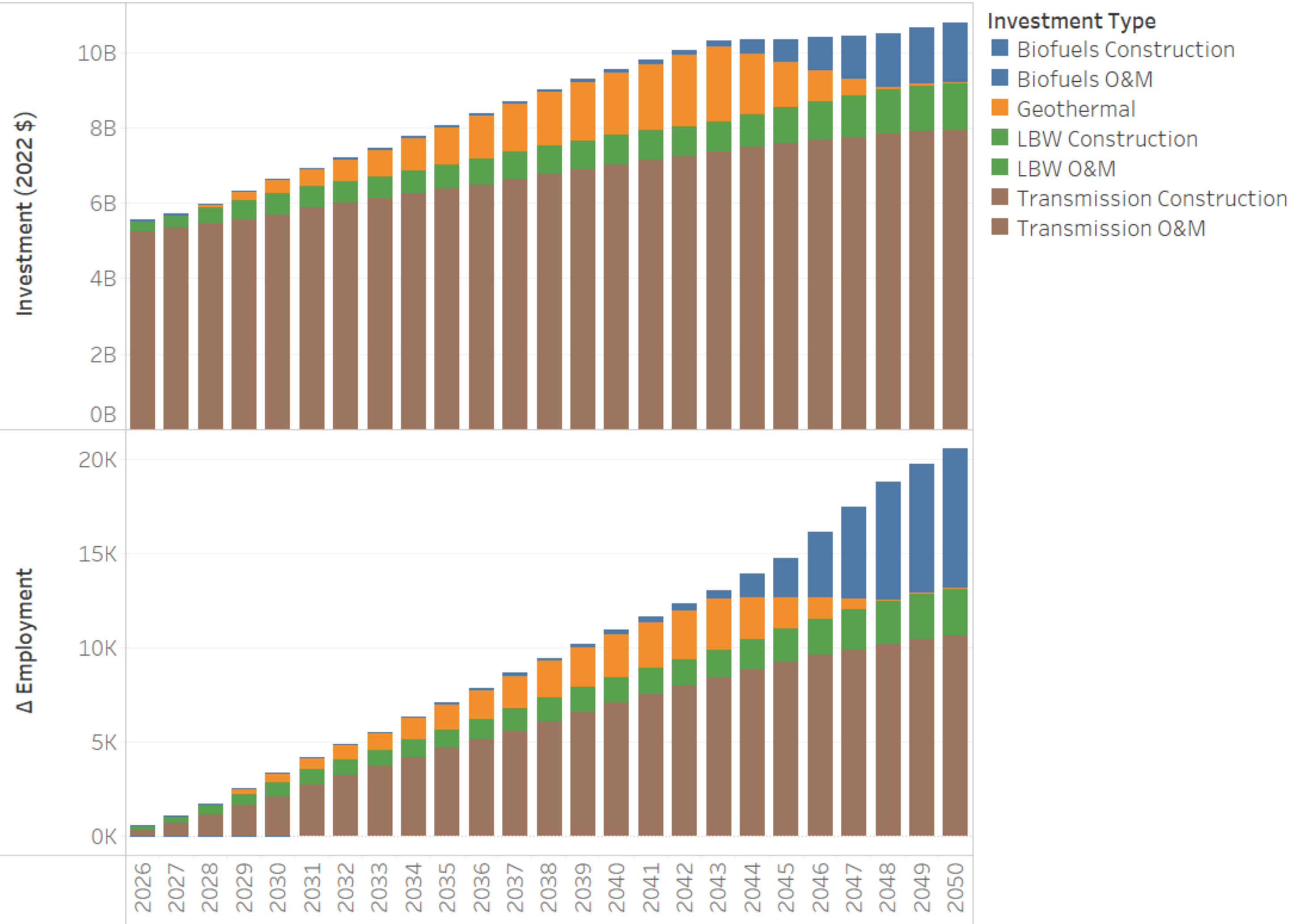
Total Output

- Total Economic Output (local GDP accounting) grows $4.8B by 2035 and $10.3B by 2050.
  - 2050 output represents 1.5% growth relative to Washington's 2023 GDP of $672B
- Much of this growth is attributed to the Utility and Transportation sectors, which includes the value of output from new generation resources



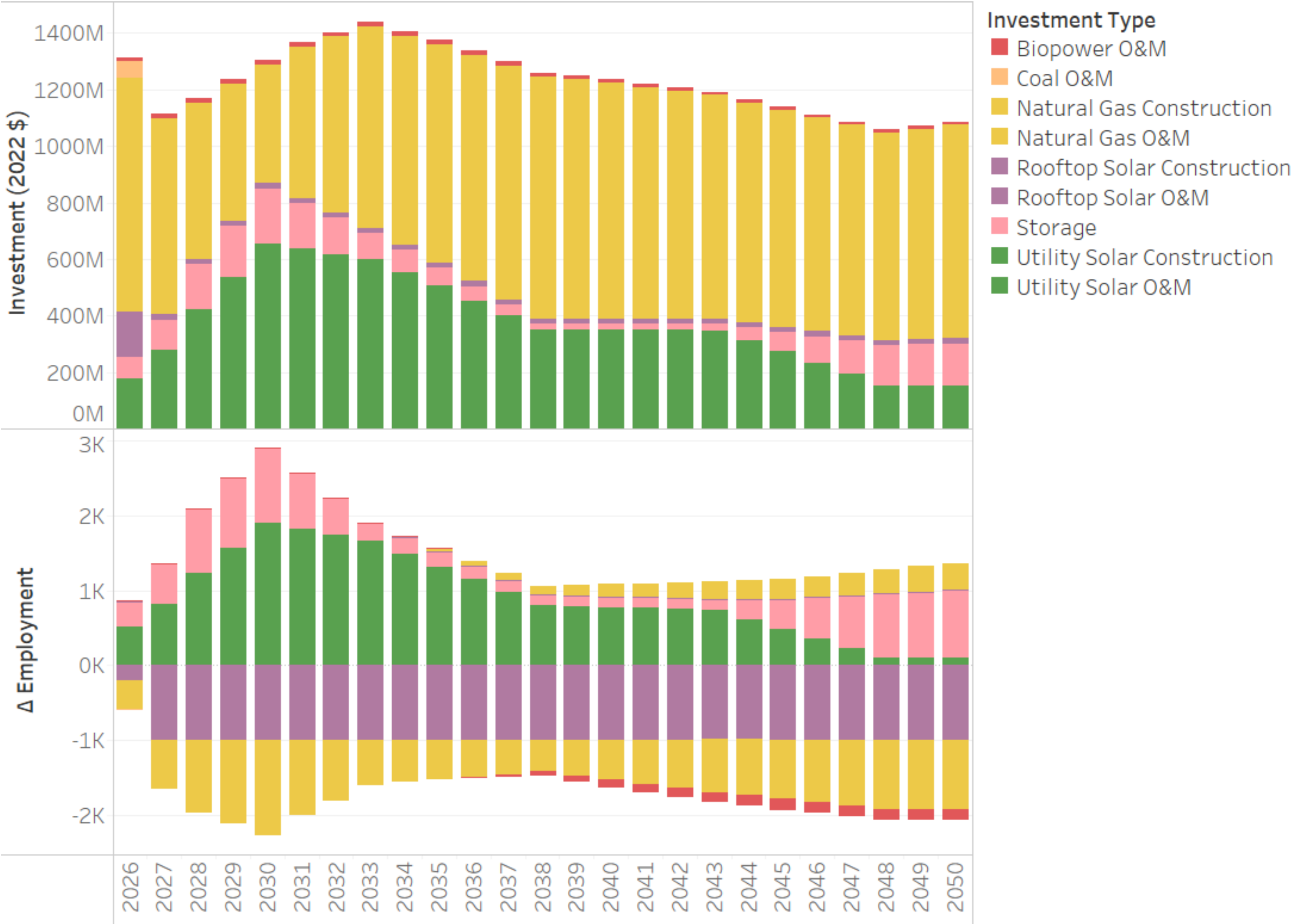
Supply Side: T&D, Geothermal

- Transmission, Distribution, and Interconnection are largest supply-side investments and result in most direct and indirect employment
  - Steady employment growth to over 7k new jobs in construction and O&M between 2040-2050
  - Over $6 billion annual investment between 2033-2050
- Biofuel, Wind, and Geothermal investments represent additional employment drivers.



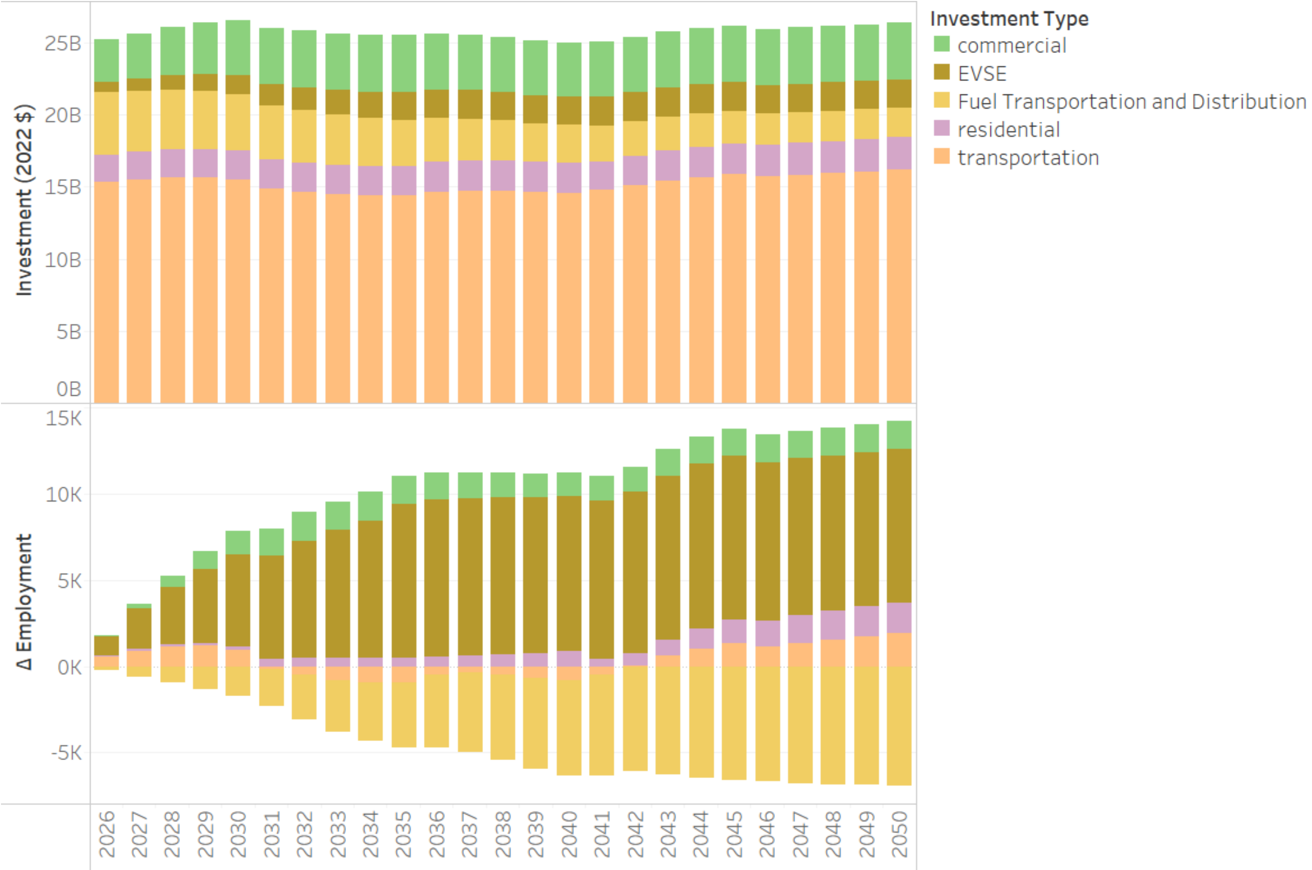
Supply-Side: All Other Investments

- Other supply-side investments have smaller, or negative, job impacts
  - Construction of Solar – Rooftop Solar declines while Utility Solar peaks in 2030, relative to 2025
  - Biopower and Storage represent smaller investments under OBBB
  - Decreasing Natural Gas employment



Demand-Side

- Large investments in Transportation vehicles and Charging (EVSE: Electric Vehicle Supply Equipment)
  - While vehicle purchases are the largest demand-side investment, jobs are in sales and maintenance, limiting employment impact
  - EVSE drives high employment through local engineering, design, and construction / installation, sustaining over 7k jobs from 2033-2050
  - Reductions in Fuels employment during transition to EVs
- Job impact of residential and commercial retrofits and weatherization is small growth relative to baseline (consistent investment relative to 2025)



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Overburdened Community Analysis Methodology

Overburdened Community Analysis

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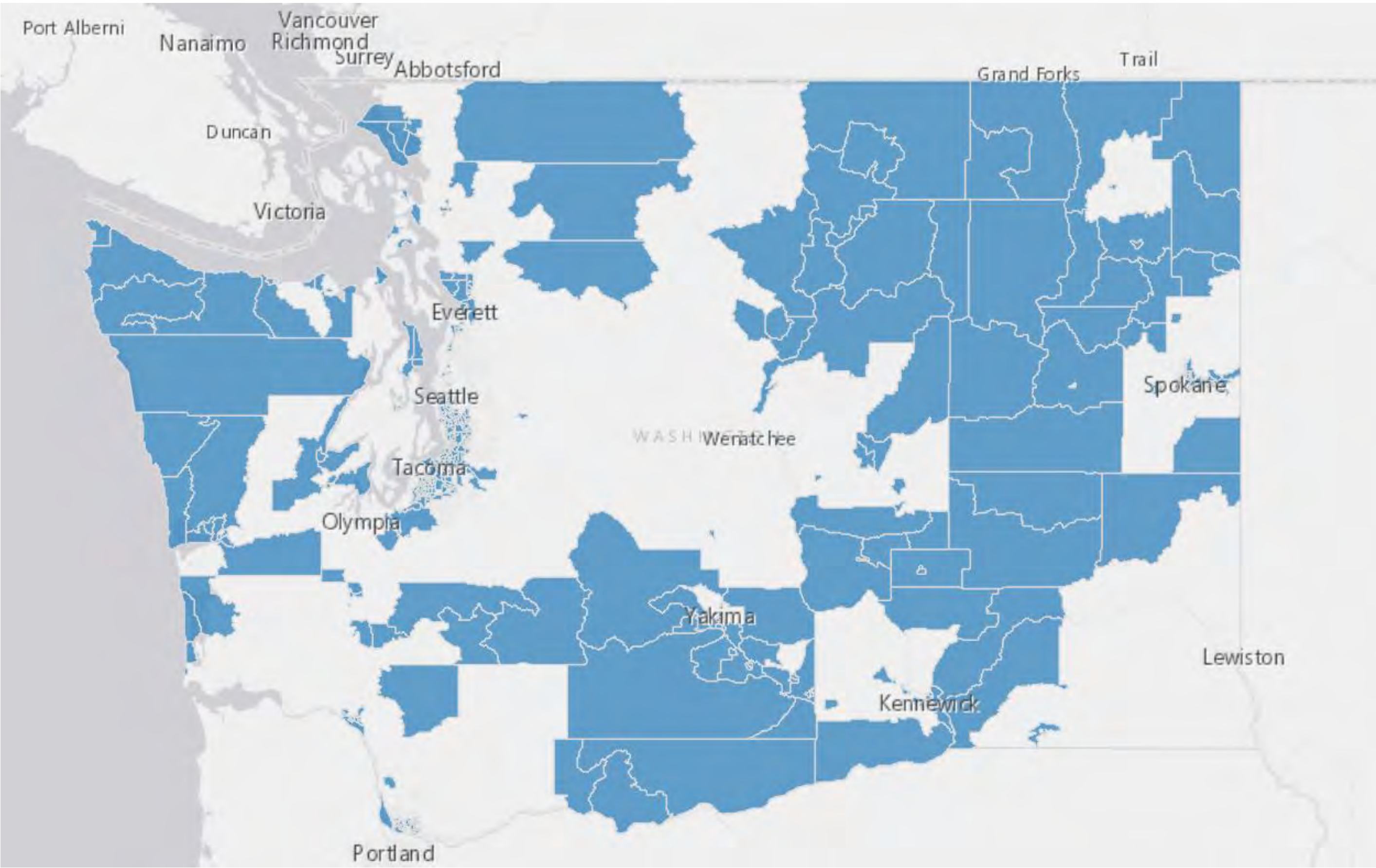
- Goal: Measure the proportion of calculated benefits that accumulate to Overburdened Communities (OBCs) of Washington State



OBC Calculation Methodology

- For each metric, estimate the benefits at the census tract level. Sum the benefits (OBCs and Total), then calculate the portion of benefits accrued to OBC communities:
  - Calculate the total benefits by metric across the entire State.
  - Calculate the total benefits by metric accrued to OBCs across the State.
  - Proportion of benefits to OBCs for given metric = OBC Benefits / Total Benefits
- Assumptions / Caveats:
  - Downscale economic benefits to the county level based on industry-level employment, then to the census block level based on population
  - No commuting – jobs and benefits accrue to a geographic location rather than to individuals
  - There is significant uncertainty in these calculations – the assumptions are neutral, meaning the actual outcomes will be determined by decisions / policies

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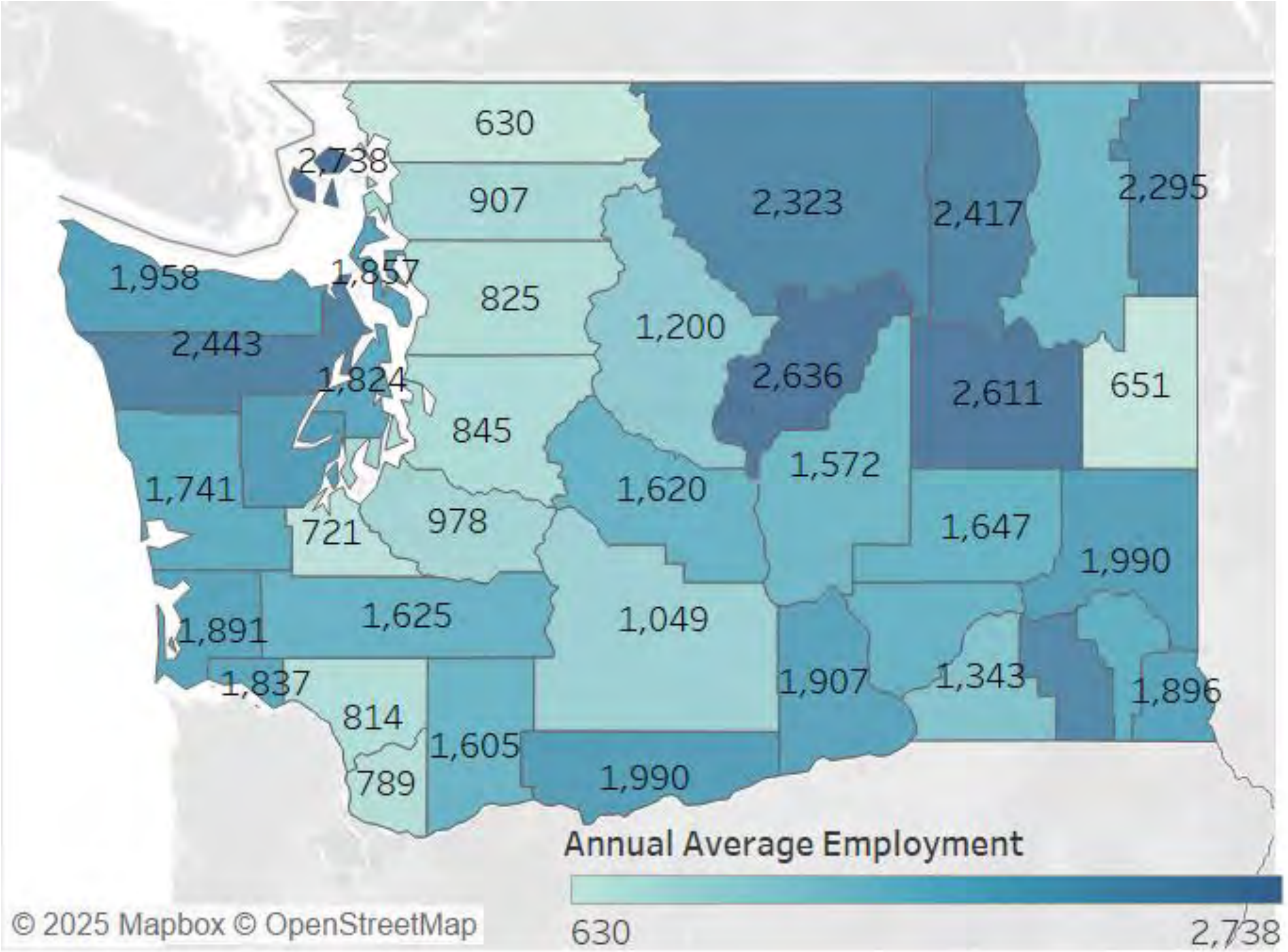
Overburdened Community Analysis Results

Economics Impacts by Geography

Benefit Subcategories	Total Impact (Annualized)	OBC Impact (Annualized)	% OBC of Total
Employment	67k	28k	41.6%
Labor Income	$4.4 Billion	$1.8 Billion	41.8%

Economic Impacts: Spatial Distribution

- To further change the distribution of benefits, options include:
  - New generation site-selection, affecting Construction and O&M jobs
  - County-level incentives, tax incentives, and / or training programs to encourage low-income community locations for site-agnostic jobs, such as profession / employment services
  - Developing additional capabilities around manufacturing and final assembly for energy infrastructure, locate in low-income communities



Total Benefits by Geography

EVOLVED ENERGY RESEARCH

Benefit Subcategories	Total Impact (Annualized)	OBC Impact (Annualized)	% OBC of Total
Labor Income	$4.4 Billion	$1.8 Billion	41.8%
Health Benefits (High-Estimate)	$337 Million	$108 Million	32.2%
Health Benefits (Low-Estimate)	$149 Million	$48 Million	32.2%
Total (High-Estimate)	$4.7 Billion	$1.9 Billion	41.1%
Total (Low-Estimate)	$4.5 Billion	$1.9 Billion	41.4%

- Presented as benefits accrued across all years through 2050 and annualized
- Health benefits follow population distribution more closely than Income benefits
- Overall quantitative % overburdened community impact ~41%

THANK YOU

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Appendix-Methodology and Data Assumptions

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Modeling Overview

Evolved Energy Research

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Past partners

NGOs

NRDC, TNC, SDSN, GridLab, Sierra Club, CETI, OCT, UCS, EDF, CATF, BPC, Audubon Society, Breakthrough Energy Foundation, Third Way, RMI, and others

State & Local Energy Offices

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

Utilities

PGE, DTE, Hydro Quebec, and others

Others

Princeton University, University of Queensland, Breakthrough Energy Ventures, Inter-American Development Bank, DOE, NREL, UVA

What are Energy Pathways Modeling Characteristics?

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- Least-cost, energy system optimization that matches Washington-specific energy supply and demand from now until 2050 (5-yr timesteps) in the context of the 11 Western states:
  - Considers the whole energy sector and economy and all forms of energy
  - Structured to meet Washington's energy policy objectives and emissions goals
  - Grounded in ensuring reliability and looking for least-cost solutions
  - All emissions counted and modeled to be reduced over time to achieve GHG emissions targets
  - Integrated and holistic, indicates future energy supply across a specific geographic area
  - Includes supply and demand of all forms of energy, not just electricity sector
  - Uses publicly available datasets, including national resources, and Washington specific data collected through meetings with Commerce and Modeling Advisory Committee

What Energy Pathways Modeling Does

EVOLVED ENERGY RESEARCH

- Calculates energy needed to power an economy while meeting policy targets
- Finds least-cost ways to provide needed energy with efficiency, clean electricity, electrification, clean fuels, and carbon sequestration
- Includes detailed electricity sector modeling integrated with optimized fuels supply for an economy-wide perspective
- Does not answer all questions, but provides direction and a framework to understand trade-offs between different pathways, policies, and strategies

What Energy Pathways Modeling Doesn't Do

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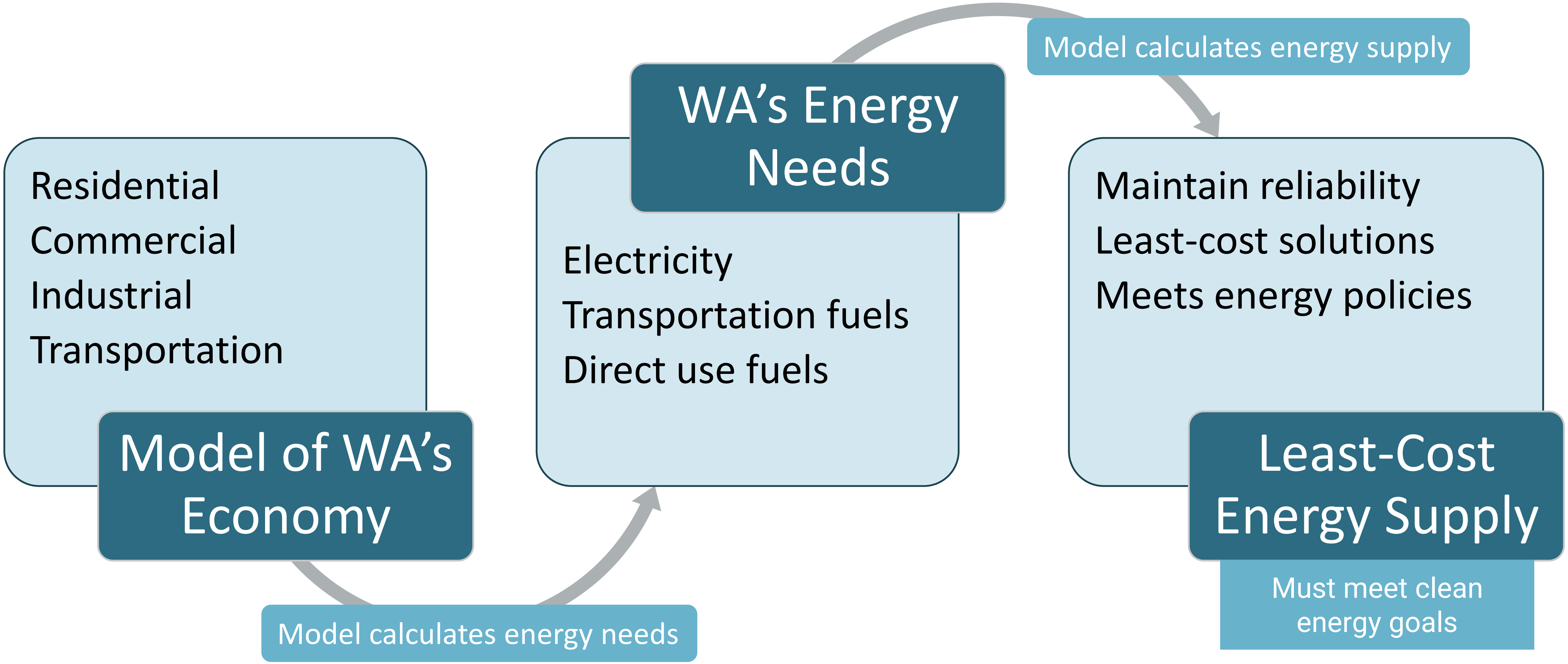
- Not focused on one state or a single utility service territory in isolation
- Does not model liquid or gaseous fuels and electrification separately
- Complementary to and does not replace integrated resource planning models that utilities use
  - Not a loss-of-load probability model
  - Not a nodal production simulation
- Not a forecast
  - Helps inform near-term decision-making in the face of uncertainty
  - Determine the best way forward across multiple potential futures
  - Examines different scenarios to inform near-term decisions in the context of future goals

Overview of Modeling Approach



Modeling Summary (EnergyPATHWAYS and RIO)

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ENERGY PATHWAYS

EnergyPATHWAYS model used to develop demand-side cases

- Apply fuel switching and energy efficiency levers
- Strategies vary by end-use (residential space heating to heavy-duty trucks)

Demand-Side

Sectors

Residential | Commercial | Industry | Transportation

RIO

Regional Investment and Operations (RIO)

- Model provides cost-optimal energy supply combining a comprehensive supply-side capacity expansion framework with hourly system operations

Supply-side

Electricity | Pipeline Gas | Refined Liquid Fuels | Solid Fuels

Hydrogen | CCUS | Industrial Heat

Economy-Wide Energy Modeling

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Scenario Assumptions

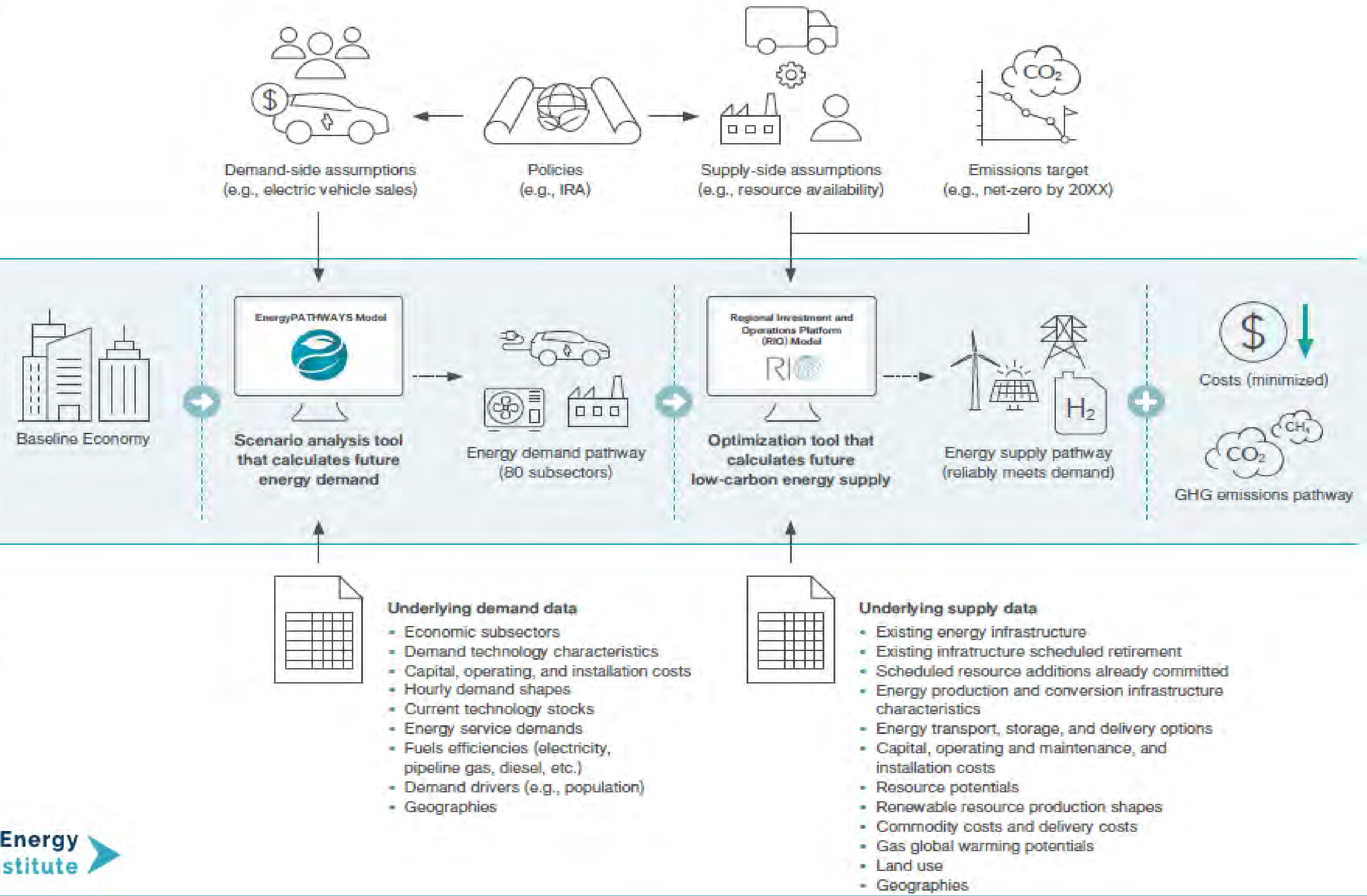
Model incorporates assumptions about demand-side uses, clean energy policies and incentives, and supply-side resources.

Energy Modeling

Evolved Energy Research uses two models to calculate the least-cost way to provide energy under an emission target: Energy Pathways for demand and RIO for supply.

Best Available Data

Model incorporates relevant and up-to-date energy data from reputable sources, substituted with local data where possible.



End-Use Sectors Modeled

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- Approximately 81 demand sub-sectors represented
- The major energy consuming sub-sectors are listed below:

Key energy-consuming subsectors:

Residential Sector
- Air-conditioning
- Space heating
- Water heating
- Lighting
- Cooking
- Dishwashing
- Freezing
- Refrigeration
- Clothes washing
- Clothes drying

Commercial Sector
- Air-conditioning
- Space heating
- Water heating
- Ventilation
- Lighting
- Cooking
- Refrigeration

Industrial Sector
- Boilers
- Process heat
- Space heating
- Curing
- Drying
- Machine drives
- Additional subsectors (e.g., machinery, cement)

Transportation Sector
- Light-duty autos
- Light-duty trucks
- Medium-duty vehicles
- Heavy-duty vehicles
- Transit buses
- Aviation
- Marine vessels

Source: CETI, NWDDP, 2019

Forecasting vs. Backcasting

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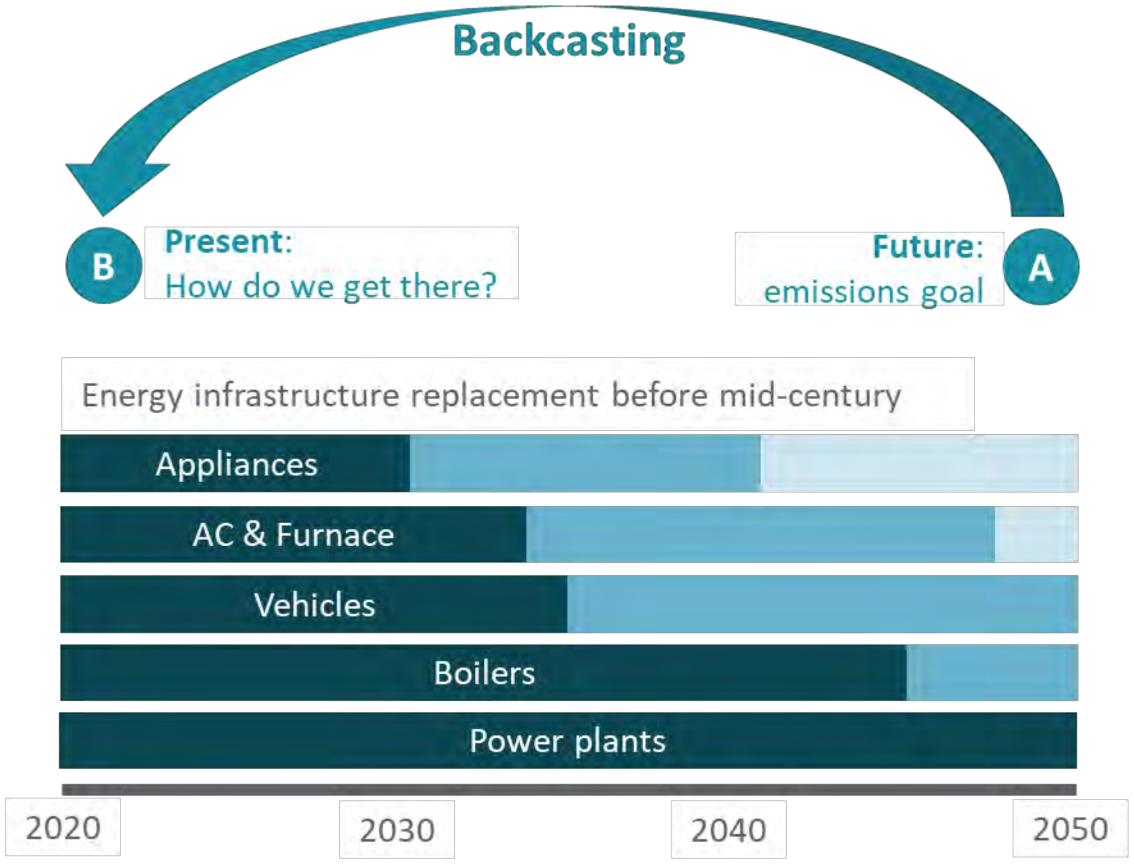
- **Forecasting**: project changes based on expected customer behavior given incentives/technology
  - e.g., result of current policy
- **Backcasting**: start with an end-point and work backwards to infer customer adoption over time
  - What is the best path to be on?
  - Target for future policymaking: Where is current policy falling short?
  - All options available in the long term



Supply-side Overview

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- Supply-side modeling answers the question "**How do we reliably serve the energy demands of the economy at least cost?**"
  - Subject to the constraints defined for the Reference Scenario, such as electricity policy, emissions policy, resource availability, etc.
- Supply-side analysis is concerned with investments in physical infrastructure and system operating costs
  - e.g., how many MWs of solar/batteries/transmission/conversion technologies, etc., should we invest in? How much fuel should we purchase?
- Analysis does not answer questions about distributional impacts of investments
  - e.g., What rate do customers pay for electricity for their electric vehicles?
  - However, it does aim to minimize the size of the total cost pie that must be distributed among customers – a strong basis for further work in policy design

Understanding Modeled Costs (1)

EVOLVED ENERGY RESEARCH

- The cost charts in this report answer the question "**How much more or less costly is following one future energy pathway versus another?**"
- Net costs are annualized, akin to a revenue requirement for energy across the economy
  - Annualized capital costs + operating costs
- We present the costs as relative to the Reference Scenario to illustrate the differences between scenarios
- The cost components used to generate these costs are based on forecasts from publicly available data sources. How these costs will manifest in the future is uncertain, and the uncertainty grows the further into the future we go

Understanding Modeled Costs (2)

EVOLVED ENERGY RESEARCH

- Cost increases and decreases are all attributed to changes in policy or realized uncertainties within Washington
  - Assumptions in all other states are held constant
- Cost changes can therefore be attributed in their entirety to Washington specific changes in assumptions
  - Some of the investments caused by Washington policy changes may happen outside of Washington. For example, restricting renewable development in state can drive more renewable growth outside of Washington
  - These costs would be born by Washington in the form of increased electricity costs through increased imports and changes to overall infrastructure investment
- Assuming efficient markets, the change in cost between scenarios would all be born by Washington consumers
- Present value costs are calculated using a 3% societal discount rate

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Technical Approach

Demand-side Modeling

- Scenario-based, bottom-up energy model (not optimization-based)
- Simulates the change in total energy demand and load shape for every end-use
- Characterizes rollover of stock over time
- Illustration of model inputs and outputs for light-duty vehicles

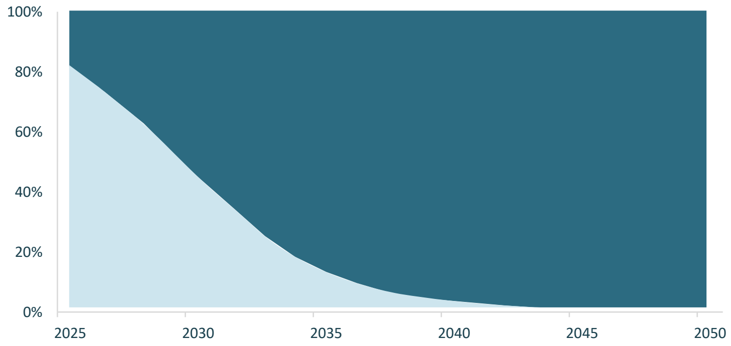
ENERGY PATHWAYS

Input: Consumer Adoption
EV sales are 100% of consumer adoption by 2045 and thereafter

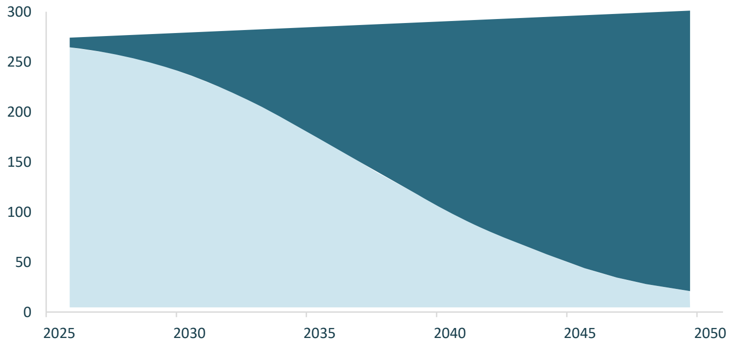
Output: Vehicle Stock
Stocks turn-over as vehicles age and retire

Output: Energy Demand
EV drive-train efficiency results in a drop in final-energy demand

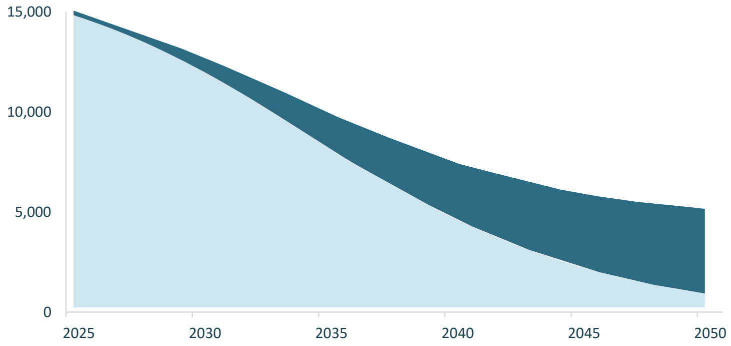
Sales Share
%



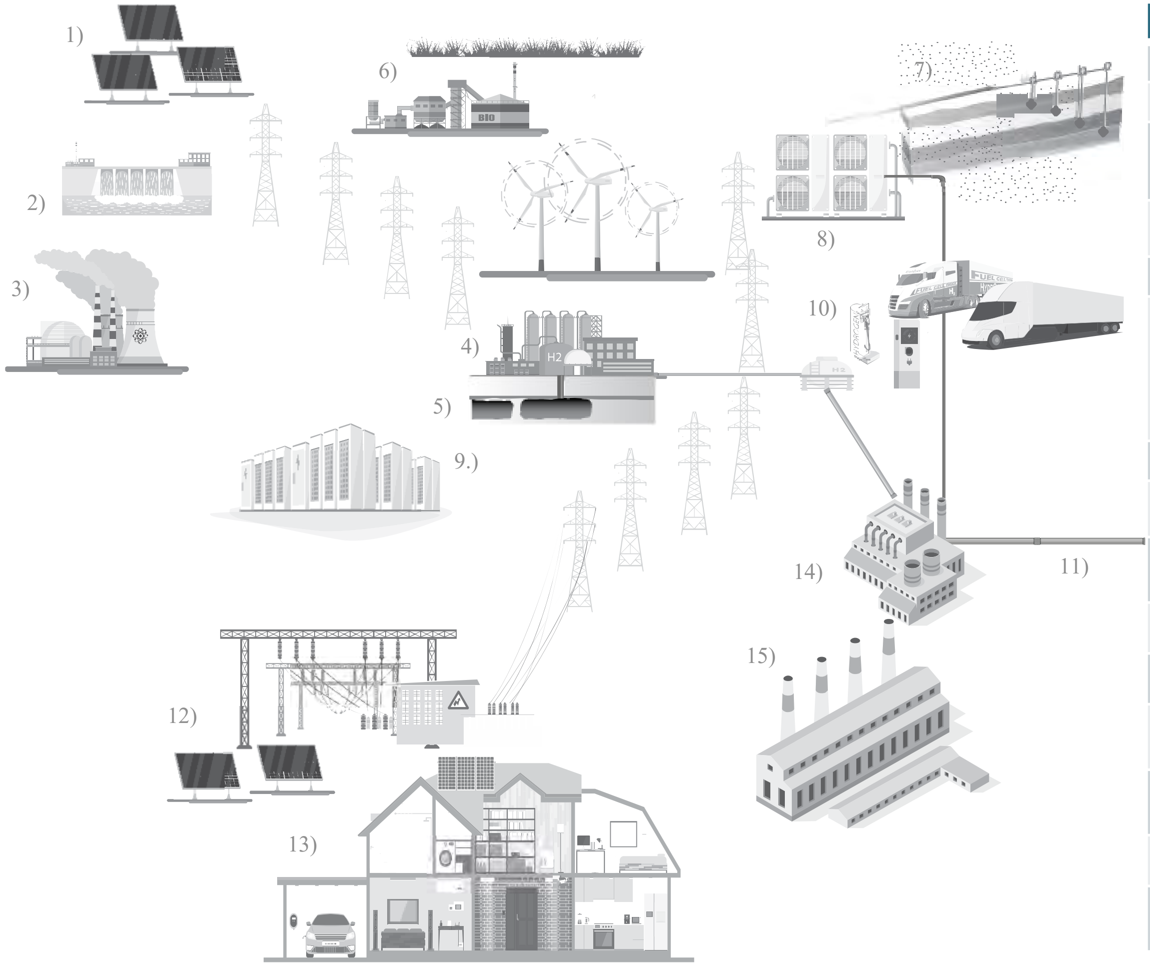
Stock
Vehicles on the road



Energy Demand
TBtu



Economy-Wide Optimization Scope

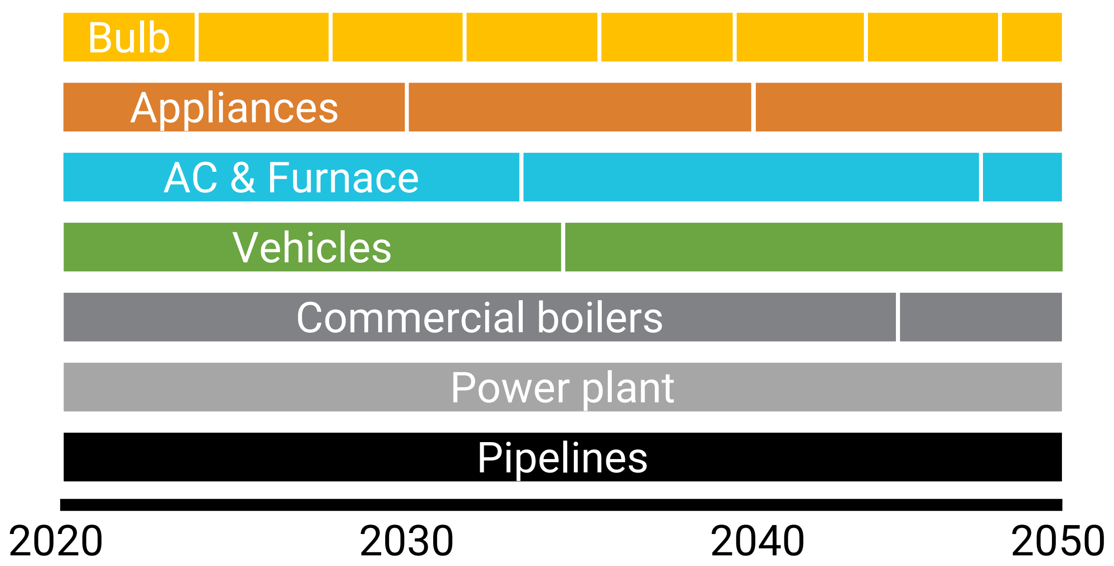


	Resource Categories	Examples
1.	Utility-Scale Renewables	Solar PV, Onshore Wind, Offshore Wind, Geothermal
2.	Dispatchable Hydroelectric	Reservoir hydro, On-Stream Pumped Hydro
3.	Thermal Power Plants	Gas CT, Gas CCGT, Coal, Coal w/CC, Gas w/;CC, Gas w/CC (Allam), SMR, Gen IV nuclear, Biomass, Biomass w/CC, Biomass w/CC (Allam), Gas and Coal CC retrofits
4.	Hydrogen Production	Electrolysis, BECCS H2, SMR, SMR w/CC, High-Temp Electrolysis, ATR w/CC
5.	Hydrogen Storage	Aboveground tanks, underground pipes, salt cavern storage
6.	Biomass/Biomass Conversion	Biomass supply curves including existing woody and waste resources, new woody/herbaceous/waste resources, corn ethanol land displacement, anaerobic digestion feedstocks (LFG, water resource recovery facilities, food waste, animal manure). Conversion technologies including Fischer-Tropsch, pyrolysis, BECCS H2, cellulosic ethanol, corn ethanol, and biochar.
7.	Geologic Sequestration	EOR, onshore saline, offshore saline
8.	Direct Air Capture	DAC for synthetic hydrocarbon production (e-fuels), DAC for geologic sequestration
9.	Electricity Storage	Li-Ion, Flow batteries, long duration energy storage (LDES), pumped hydro, thermal storage
10.	Zero Emission Vehicles	Light-duty, medium-duty, heavy-duty, and bus vehicle types
11.	Pipelines	Ammonia, hydrogen, CO_2
12.	Electric T&D Infrastructure	Distribution upgrades, generator interties, existing corridor upgrades, new AC and DC corridors
13.	Distributed Energy Resources	Flexible end-use loads (EVS, water heating, space heating, air conditioning, appliance loads)
14.	Zero-Carbon Fuel Synthesis	Ammonia, synthetic hydrocarbons (refined and unrefined), methanol
15.	Industrial Decarbonization solutions	Industrial carbon capture, solar thermal heat, dual-fuel boilers, hydrogen

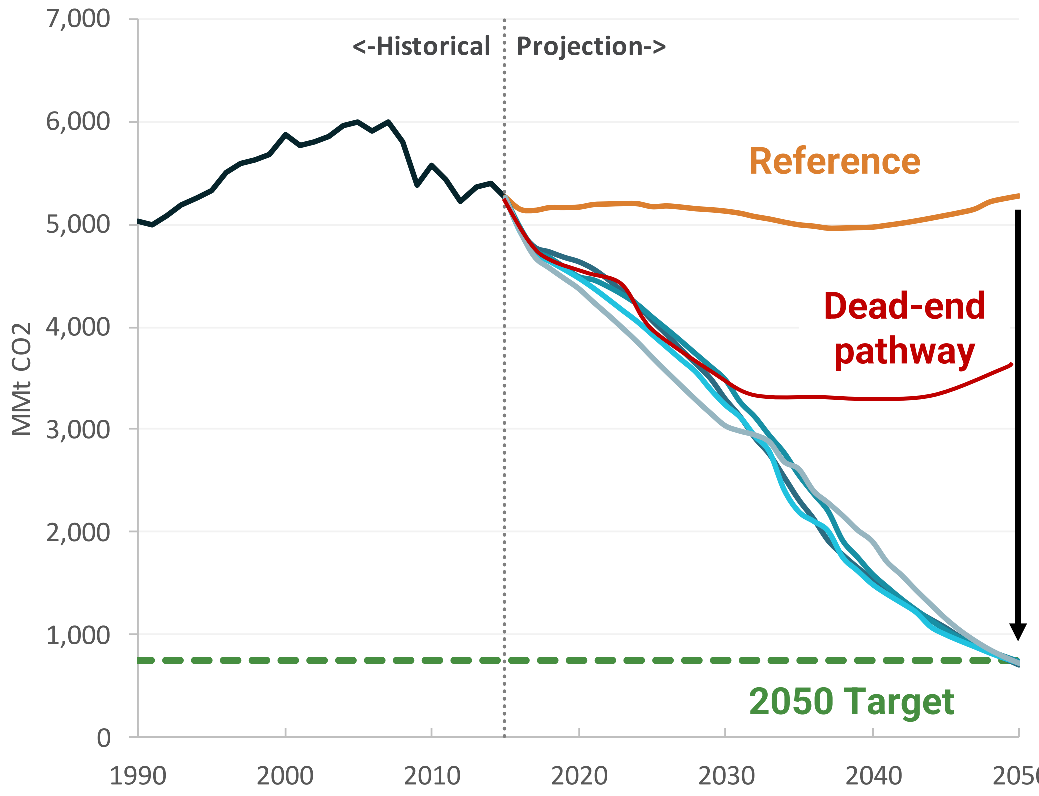
Near-Term Focus on Long-Lived Assets

- Long-lived infrastructure should be an early focus to avoid carbon lock-in or stranded assets

Stock replacement count before mid-century



U.S. Energy-related CO_2 Emissions



Integrated Supply Side: Electricity and Fuels

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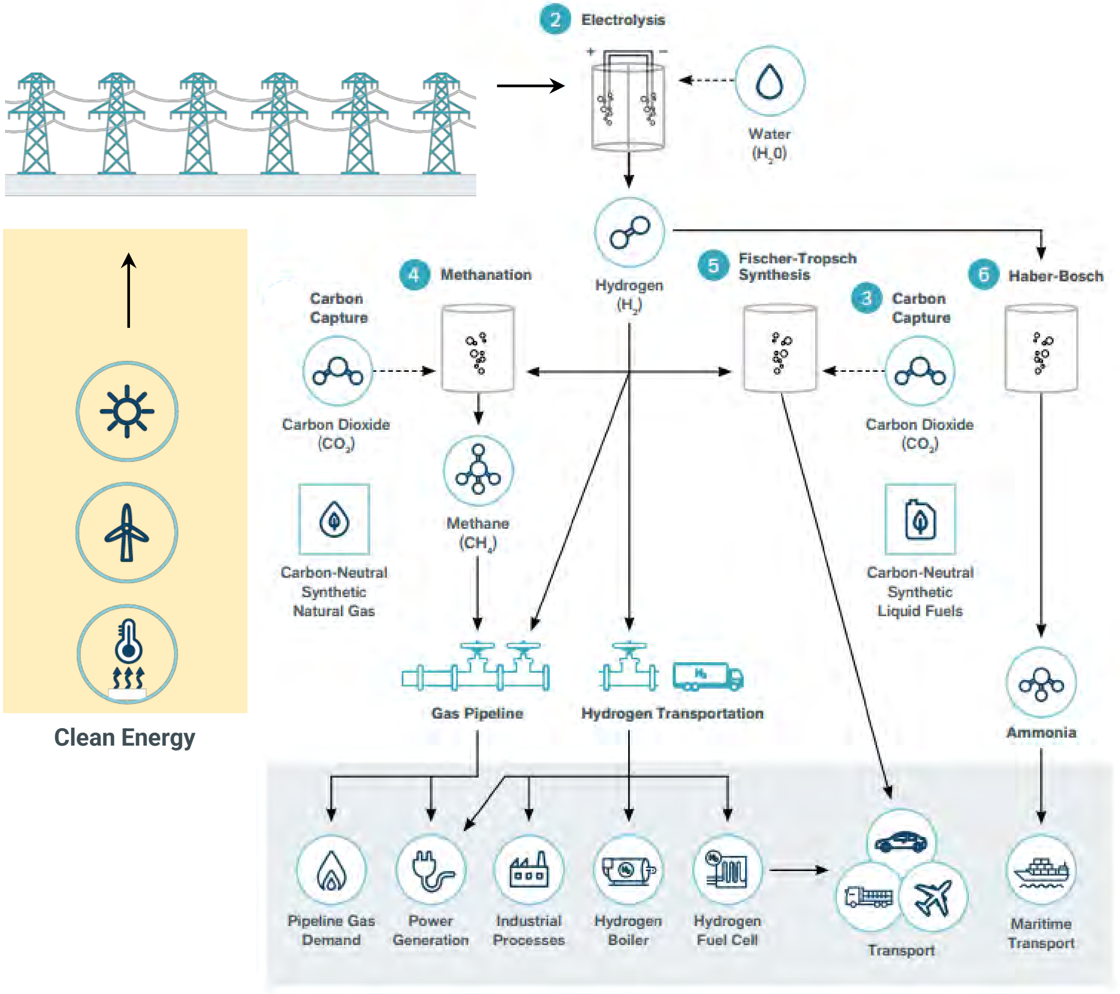
- What are the supply side investments that best meet energy demands?
- Conventional means of “balancing” the electricity grid may not be the most economic or meet clean energy goals
- New opportunities: Storage and flexible loads
- Fuels are another form of energy storage
- Large flexible loads from producing decarbonized fuels:
  - Electrolysis, synthetic fuels production



Source: CETI, NZNW, 2023

Sector Coupling: Challenges and Opportunities

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- Economy-wide approach needed to plan for electricity and clean fuels growth and operations when targeting Washington's emissions targets
  - What are the regional implications of fuel and electric sector coupling?
  - Future-proof investments and manage risk by understanding new opportunities and speed of change
- Make decisions in an economy-wide, temporal, and spatial context
  - Explore the tradeoffs between strategies that incorporate load growth, clean fuels, carbon management, electrification opportunities, and new industry
  - Chicken and egg: What comes first, what are the barriers to development, where should near-term efforts be focused?
  - Whack-a-mole: Doing less in one part of the economy requires more in another, understand cost and feasibility consequences of decision making

Clean Fuels Supply

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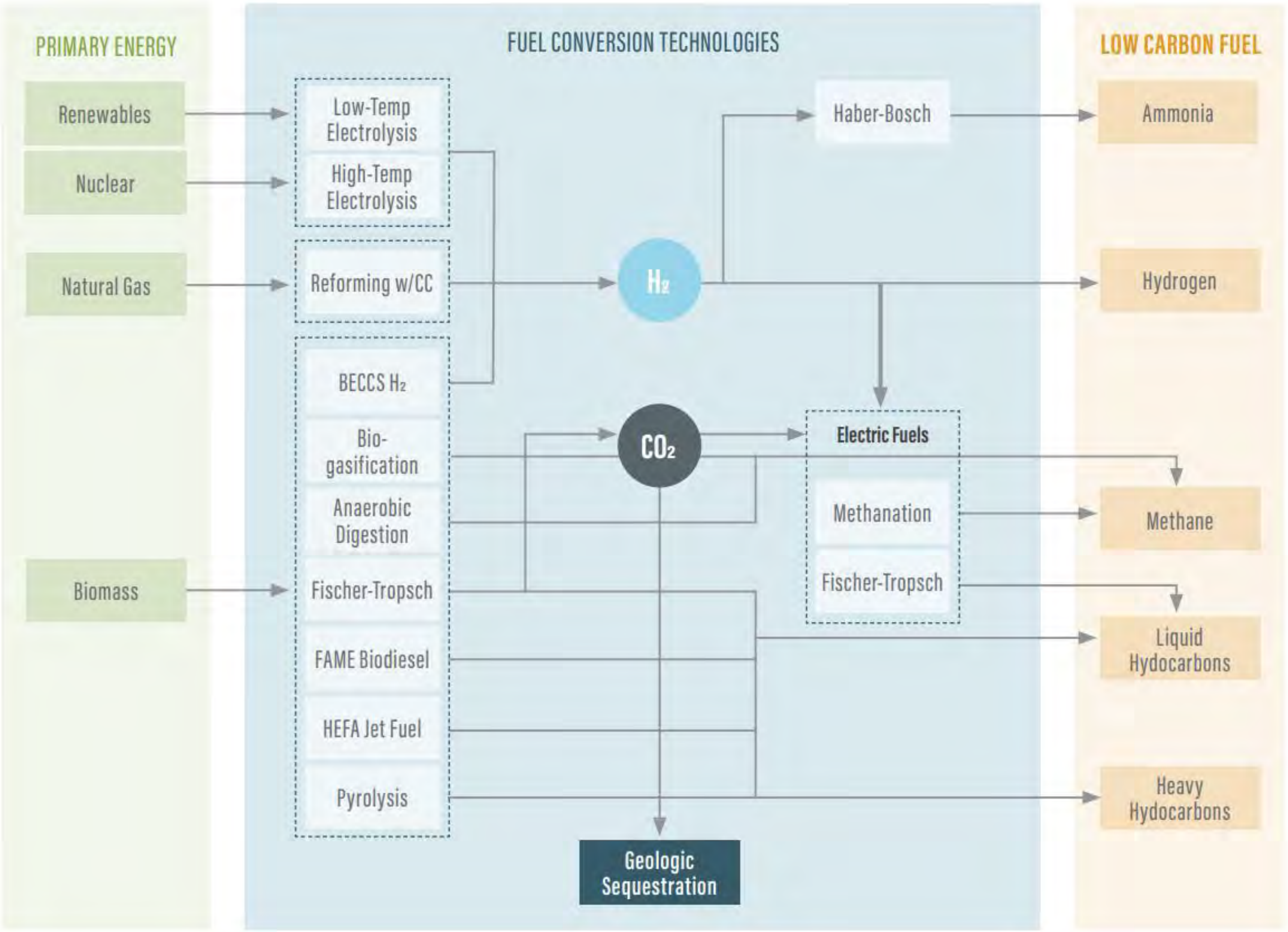
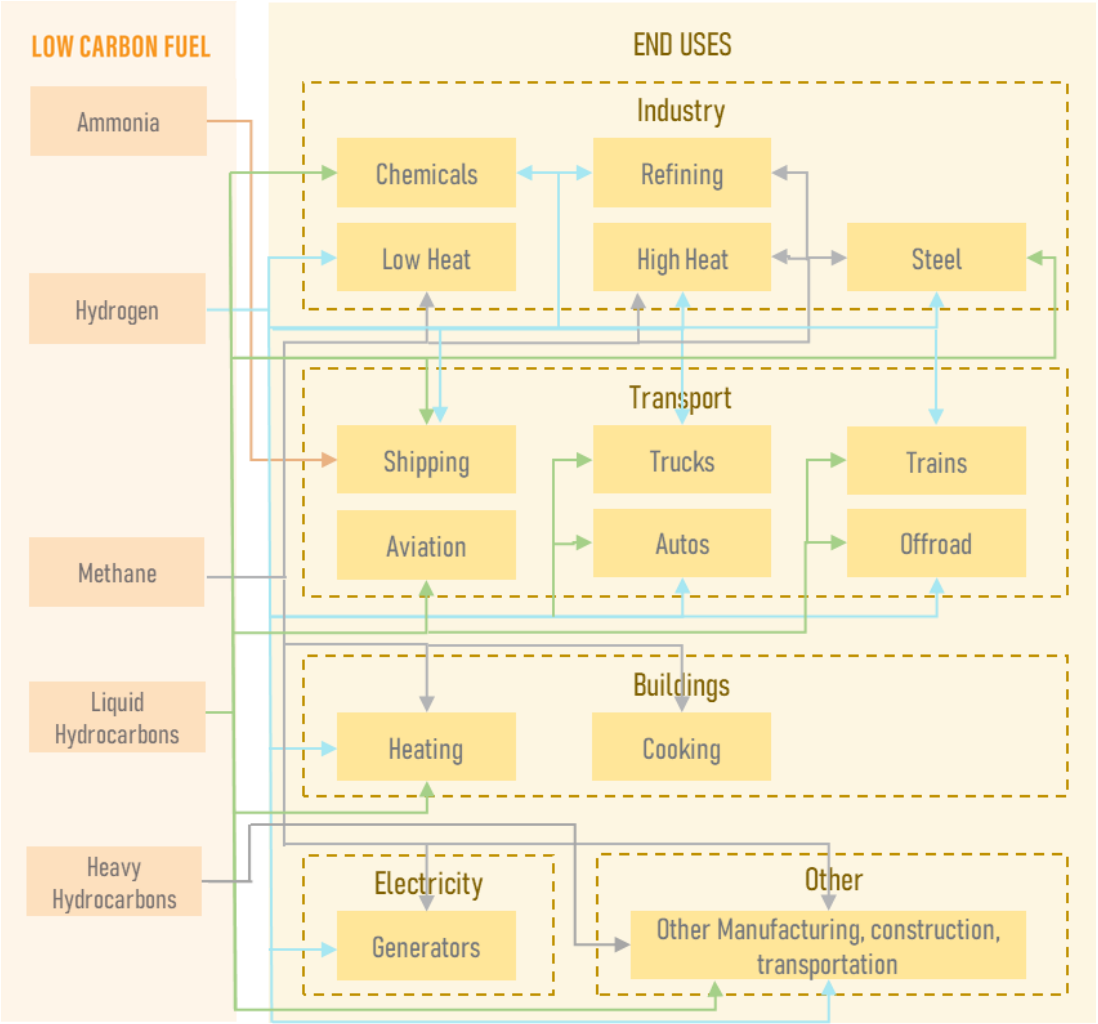
- Optimize capital investments and operations across all elements of clean fuel supply chains
  - Renewables/biomass
  - Transportation and storage
  - Conversion processes
- Scenarios used to constrain opportunities for clean fuels supply chains and electric sector development



Clean Fuels Demand

- Where are clean fuels used?
  - Replacing blue hydrogen with green
  - Drop in fuels: decarbonizing fuel blends
  - New markets for direct hydrogen use
  - New markets for ammonia
- Direct use of 100% hydrogen/ammonia blend in the economy defined with input assumptions
  - Fuel cells, 100% ammonia in maritime propulsion
- Share of clean fuels in fuel blends optimized by the model



Biomass Feedstocks: Billion Ton Study Update and LURA Model

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2023 Billion-Ton Report is the default source of cost and potential data for biomass

- https://www.energy.gov/sites/default/files/2024-03/beto-2023-billion-ton-report_2.pdf
- Supply curve by state and year developed for the US, supporting modeling of a biomass and biofuels market

Woody biomass estimates refined with Washington State University updated estimates for woody biomass in the Northwest using the LURA model, developed for the Washington 2021 State Energy Strategy

Within Zone Transmission

- No physical representation of within zone transmission or distribution
  - High-level approach to estimating electric and gas T&D costs
  - Correlates in-state electric transmission and distribution capacity expansion costs with the total increase in net distribution system peak
- Captured with historical transmission and distribution costs
  - Uses historical $/MWh from EIA
- Model optimization decisions are not impacted by electric T&D cost assumptions; flexible load is a notable exception
  - Higher distribution upgrade cost assumptions will drive more load shifting in the model; lower costs will drive less load shifting

How Does RIO Approach Reliability?

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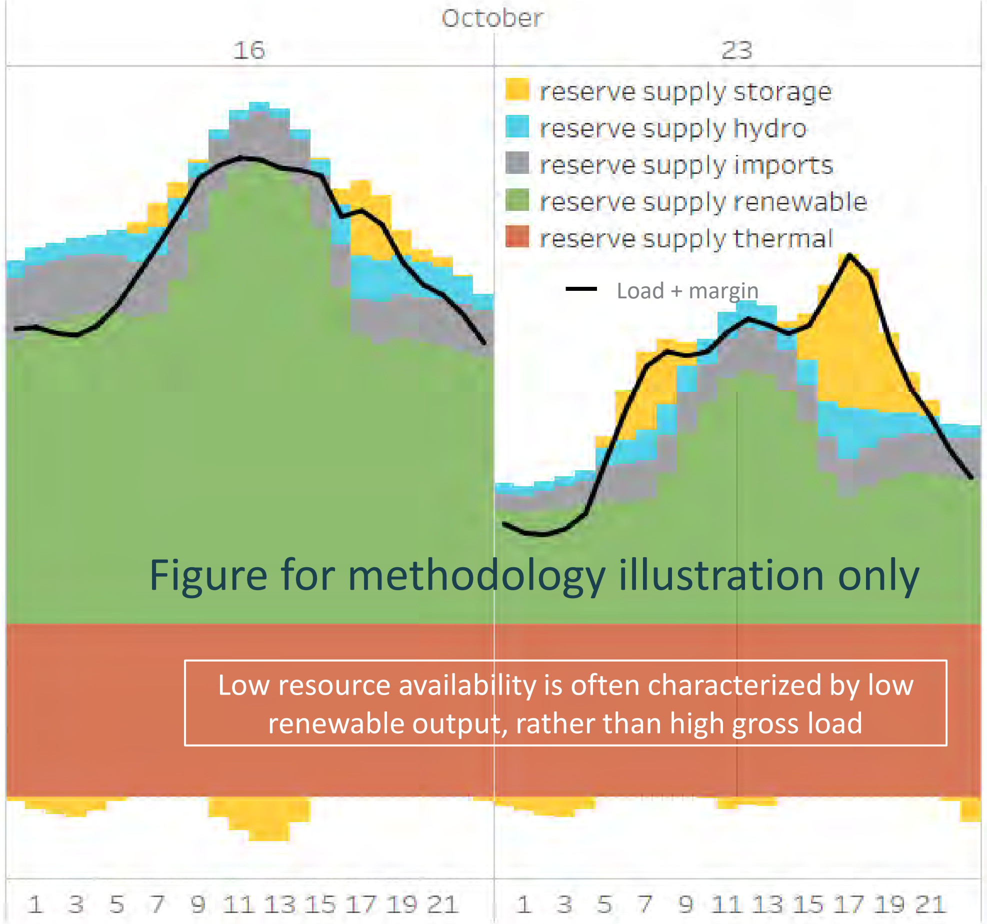
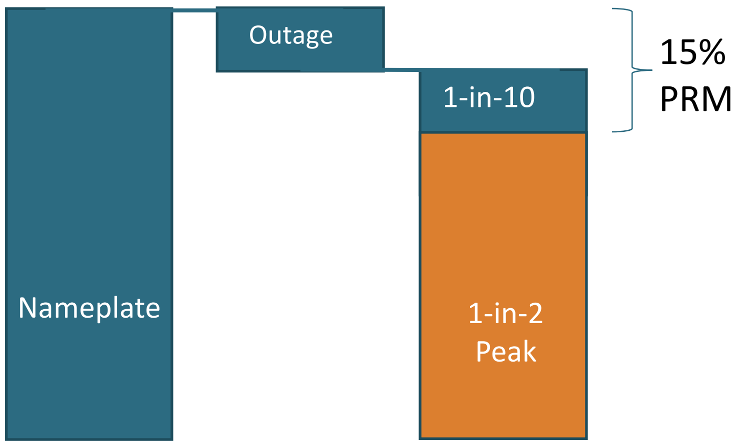
- Reliability is assessed across all modeled hours with explicit accounting for:
  - Demand side variations – higher gross load than sampled
  - Supply side availability – outage rates, renewable resource availability, energy availability risk, single largest contingencies
- Multiple years used in day sampling adds robustness
- Advantage over pre-computed reliability assessments because it accommodates changing load shapes and growing flexible load
  - Any pre-computed reliability assessment implicitly assumes a static load shape, which is not a realistic assumption
- No economic capacity expansion model can substitute fully for a LOLP study, but different models offer different levels of rigor

Hourly Reliability Snapshot

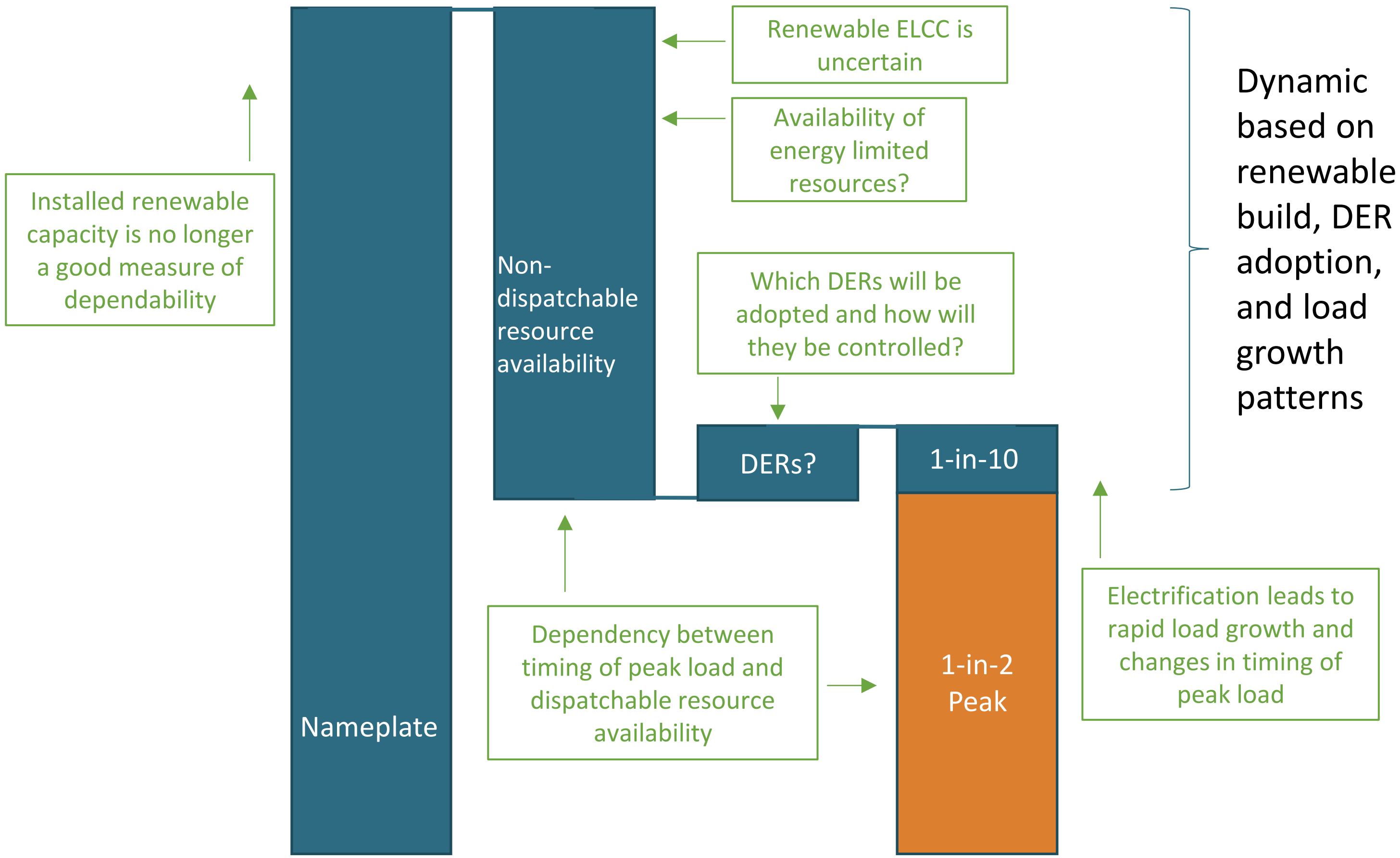


Hourly Reserve Margin Constraints by Zone

Traditional Reserve Margin



Future System Reliability Assessment



Hydroelectric System

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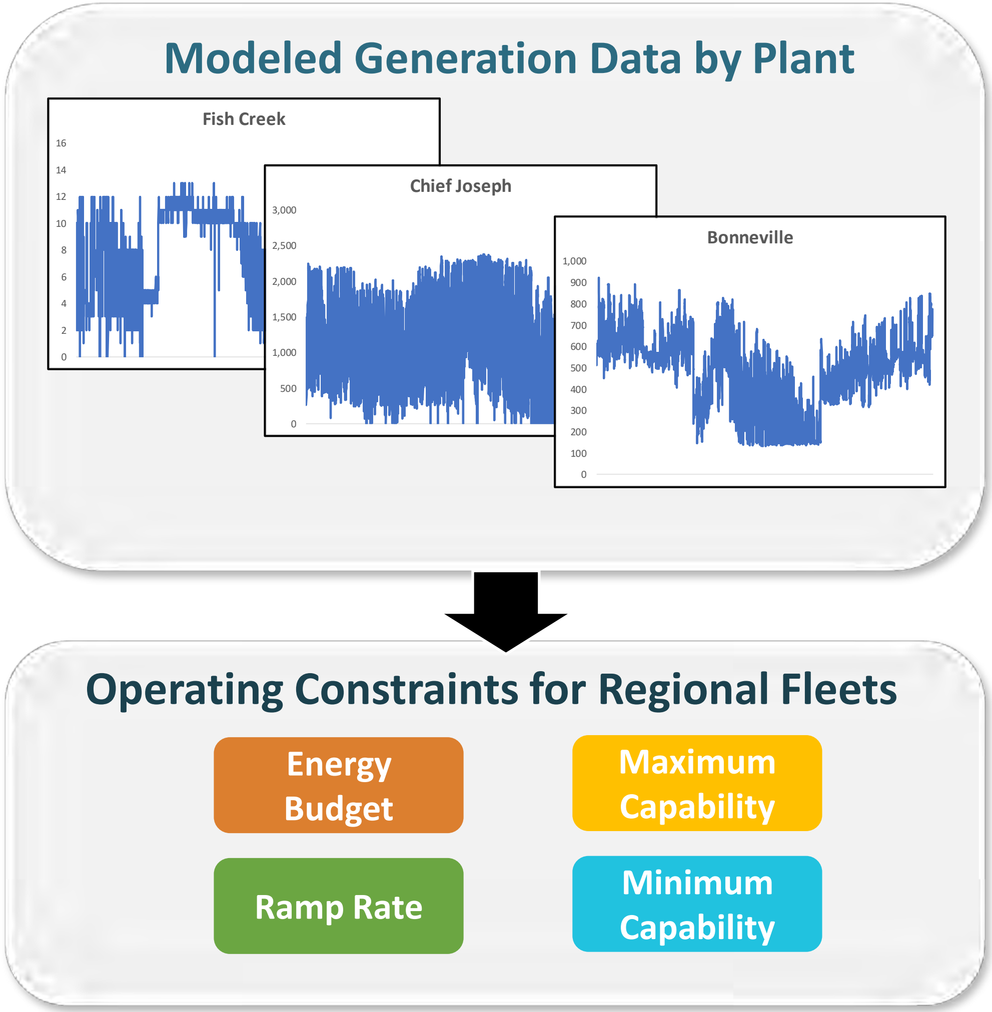
- The Pacific Northwest's hydroelectric system includes more than 30 GW of capacity, but its operational flexibility and generating capability varies year-to-year
- We model each study zone's hydro resources as an aggregated fleet and apply constraints based on historical operations
  - Maximum 1-hour and 6-hour ramp rates
  - Energy budgets
  - Dry, average, and wet hydro years
- Operational constraints for regional hydro fleets are derived using Northwest Power and Conservation Council hourly modeled generation data for 30 modeled years that incorporate climate change impacts
  - Operational constraints vary by week of the year (1 through 52) and hydro year (dry, average and wet)



Transmission Detail

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- Economy-wide capacity expansion modeling becomes intractable at some point as more detail is added
  - What level of detail both provides the insights for the Energy Strategy while also remaining solvable?
- Nodal transmission is not compatible with economy-wide capacity expansion
  - We use zonal pipe flow constraints representing path ratings and opportunity to expand
  - Dependability factor in the model to represent reliability of line
- Characterize existing capacity, transmission under construction, and expansion opportunities, recognizing that the underlying system is more complex
  - Detailed transmission data underpinning more aggregate representation

Rio Optimizes across Time-scales

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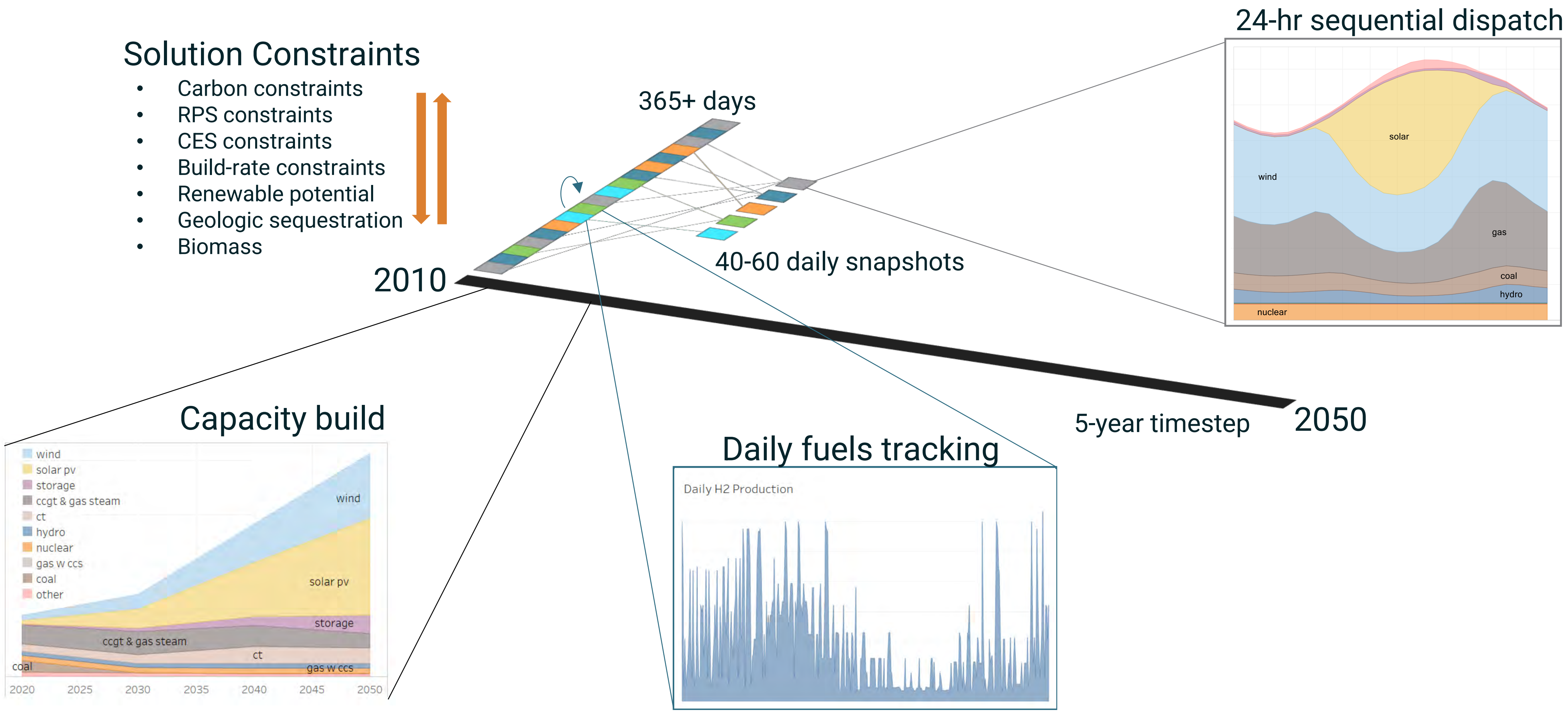
Solution Constraints

- Carbon constraints
- RPS constraints
- CES constraints
- Build-rate constraints
- Renewable potential
- Geologic sequestration
- Biomass



Flexible Load Operations

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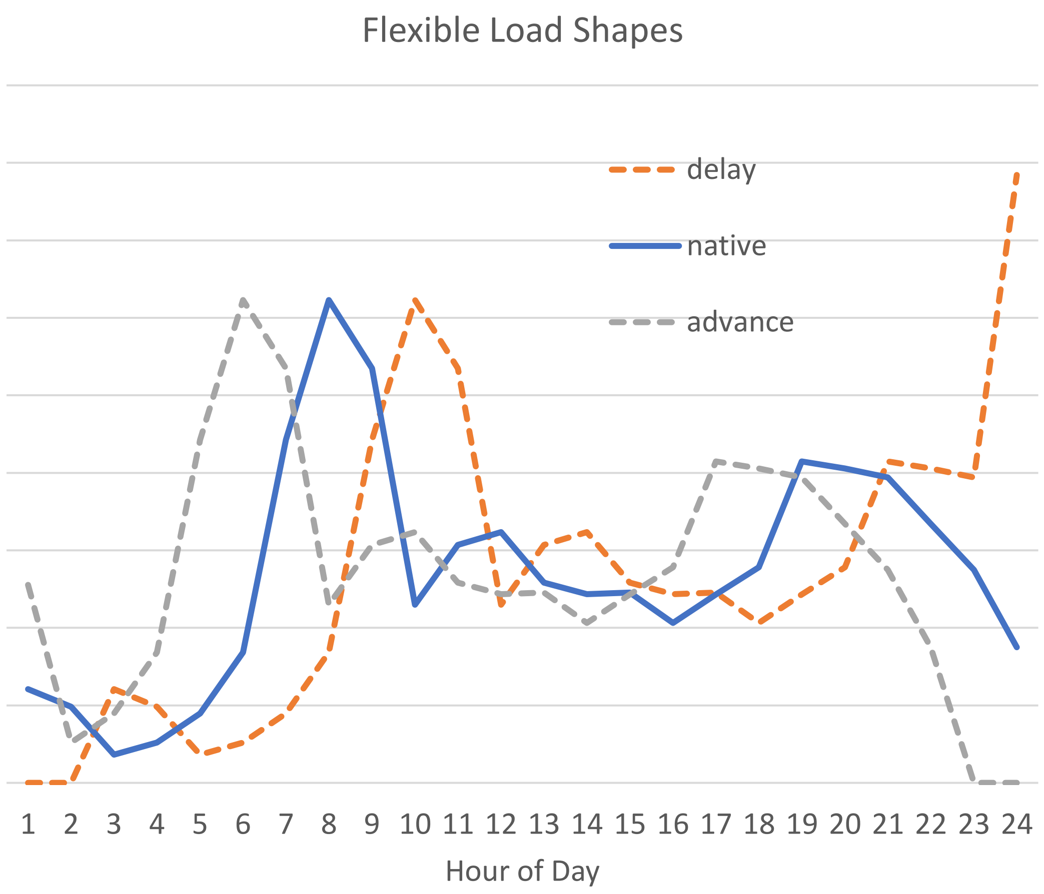
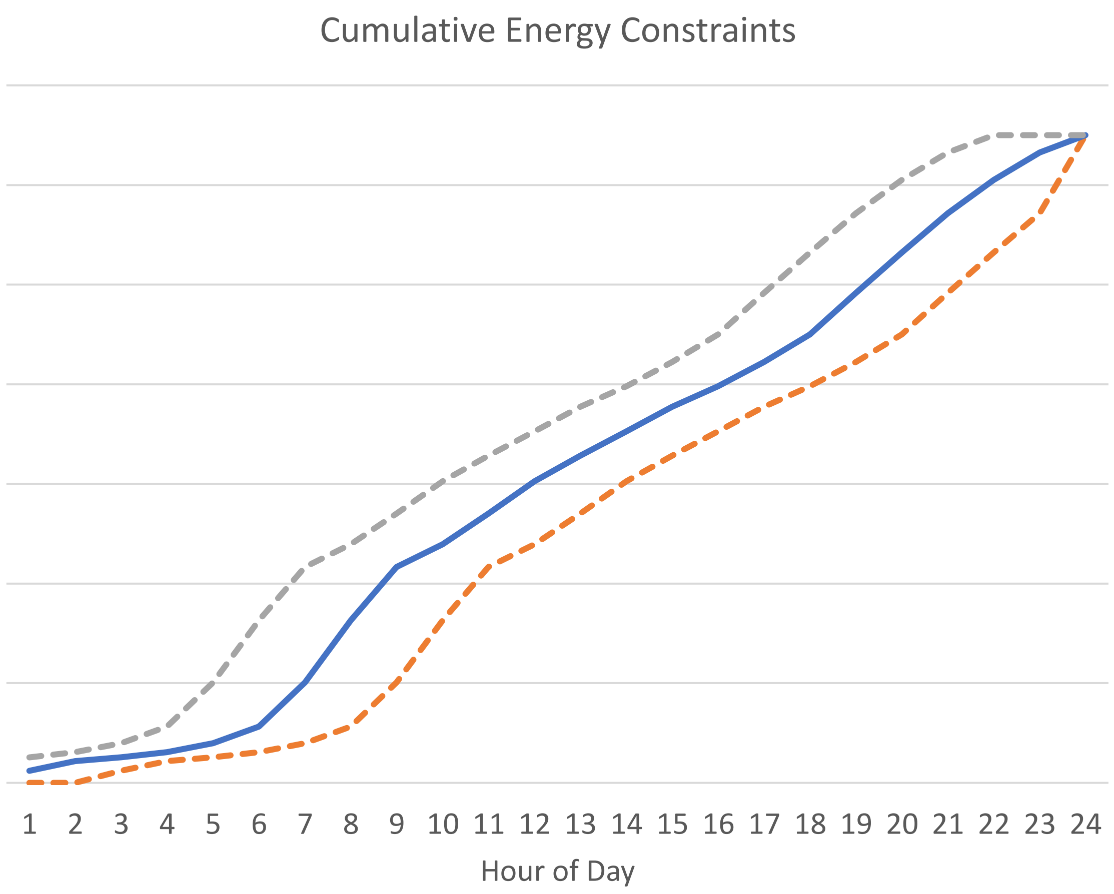
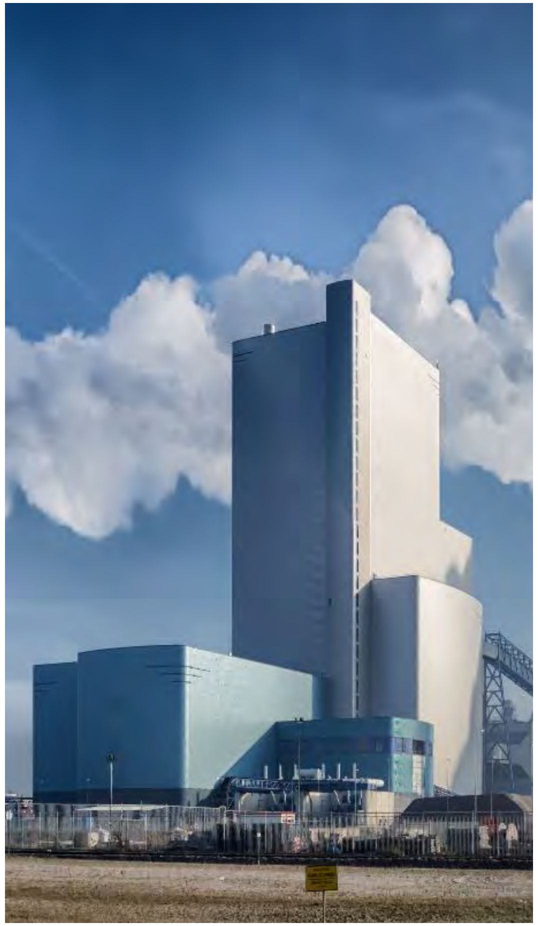
Figure for methodology illustration only

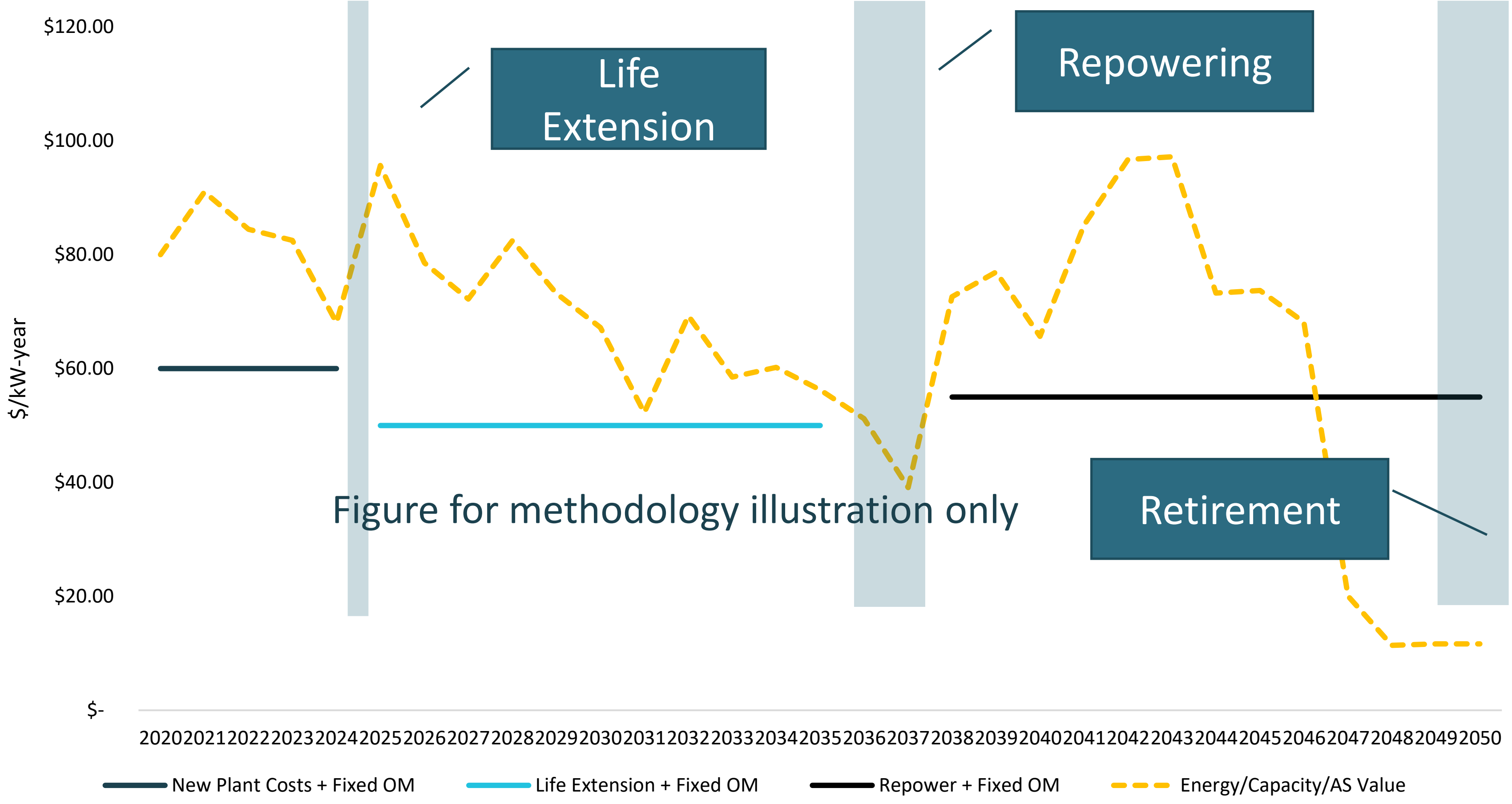




Economic Generator Lifecycles

RIO optimizes plant investment decisions including life extensions, repowering, and retirements based on system value and ongoing costs





RIO Commodities Module Definitions

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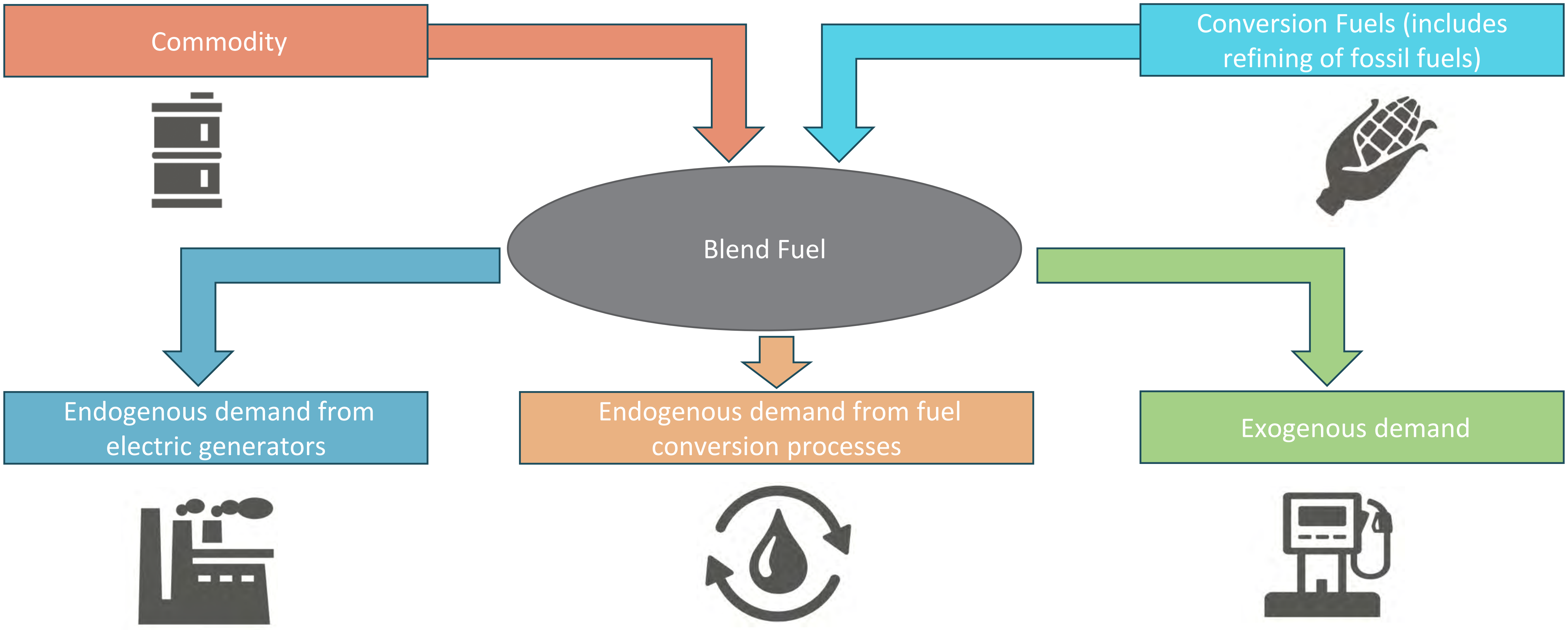
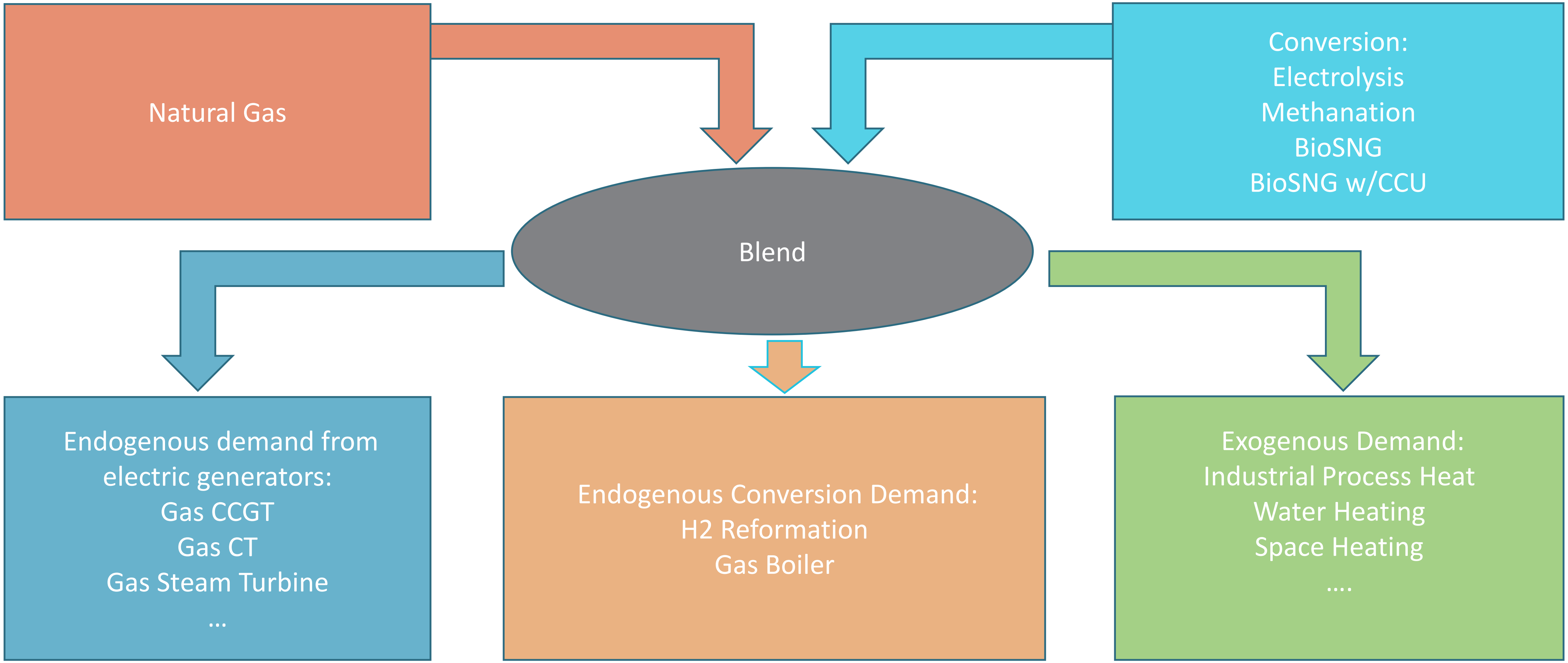
Category	Definition	Examples
Commodity	Exogenously specified commodity type defined with price supply curve, emissions rates, and available volumes	Natural Gas; Oil; Coal; Biomass
Conversion	Capital investment defined with cost of production capacity and efficiency of production (blend x -> blend y and/or electricity->blend y)	Biomass SNG; Power-to-Gas; Direct Air Capture
Blend	Aggregation point for product and conversion commodities. All inputs (conversion and products) are drop-ins for an individual blend.	Pipeline Gas; Diesel Fuel; Hydrogen; Captured CO_2

RIO Fuels Structure

Optimally invest in fuels transportation, storage, and conversion infrastructure



RIO Commodities Structure: Pipeline Gas Blend Example



Renewable Resource Quality and Potentials

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- The study uses renewable resource hourly shapes, capacity factors, and potentials, binned by resource quality and cost in each state, developed for The Nature Conservancy Power of Place (PoP) West study by Montara Mountain Energy
  - These used historical hourly insolation and wind speed data as well as GIS mapping of developable resource sites
- PoP used transmission cost information to develop interconnection cost estimates for these resource bins

Rooftop Solar

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- Reference Scenario rooftop solar adoption from NWPCC 2024 solar rooftop projections
- In addition, the model can select solar as part of the optimization
- Though bulk system solar is cheaper than rooftop and will be selected ahead, we do not preclude rooftop solar as part of a future resource portfolio
  - Model does not pick up all of the benefits of rooftop solar because the RIO distribution model represents average benefits of deferring distribution infrastructure and not the full distribution
  - Rooftop may be desirable for other reasons such as promoting jobs within state, or avoiding land use challenges siting bulk system level solar

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Data and Assumptions

Reference Scenario Database Development with Washington-Specific Data

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- Washington-specific data collected from up-to-date Washington datasets, past studies, and consultations
  - Transportation Data (Washington Department of Transportation, EPA MOVES)
  - Building Data (NEEA RBSA & CBSA, EIA RECS & CBECS)
  - EIA State Energy Data System (SEDS)
  - Washington Department of Ecology Emissions Inventory
  - Planned resource investments
  - Data center and crypto forecast data (NWPCC)

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Transportation Assumptions

Transportation Sales and Stocks

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Input	Reference Case inputs and data assumptions	Technology+	CCAP
Light Duty Vehicle Sales Shares	Carb Tailpipe Rule 100% ZEV sales by 2035 (Align with WA Dept of Commerce TES assumptions and ACCII) DMV registration data for current vehicle stocks: https://data.wa.gov/Transportation/Vehicle-Registration-Transactions-by-Department-of/brw6-jymh/data_preview		
Medium Duty Vehicle Sales Shares	100% ZEV sales by 2036 (TES assumptions superseded by ACF, reaching 100% 9 years earlier)		
Heavy Duty Vehicle Sales Shares	100% ZEV sales by 2036 (TES assumptions superseded by ACF, reaching 100% 9 years earlier)		
Maritime Shipping	EIA Annual Energy Outlook 2023	**Maritime: Ammonia 50% domestic, 60% international by 2050, 20% liquid H2, 10% electric**	**Maritime: Ammonia 50% domestic, 60% international by 2050, 20% liquid H2, 10% electric.**
Vehicle Lifetimes	EER standard assumption (15-year average life with normal distribution)		
Transit Buses	EPA MOVES, Washington Transportation Electrification Strategy		
Rail	EIA Annual Energy Outlook 2023	**Rail 40% H2, 20% electricity by 2050. Passenger rail: 80% electric, 20% H2**	**Rail: 33% H2, 20% electricity by 2050. Passenger rail: 75% electric, 20% H2.**
Aviation	EIA Annual Energy Outlook , IATA Roadmap Efficiency		

Transportation Fuel Economy, VMT, CFS

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Technology	Reference Case inputs and data assumptions	Personal Behavior+	CCAP
Light duty cars and trucks	Alignment of vehicle fuel economy assumptions with California		
Medium duty vehicles	Latest federal fuel economy regulations		
Heavy duty vehicles	Latest federal fuel economy regulations		
Buses	Latest federal fuel economy regulations		
VMT Assumption	6% decline per capita by 2035 (TES)	**18% decline per capita by 2030, 28% by 2040, 45% by 2050**	**18% decline per capita by 2030, 28% 2040, 32% 2050**
Clean Fuels Standard	20% carbon intensity reduction by 2034. Carbon credit accounting to assess compliance with program		**Updated 2025 CFS targets**
Air Travel	Annual Energy Outlook 2023	**10% reduction in air travel by 2035**	**8% reduction in air travel by 2035**

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CDR, Carbon Sequestration, and Natural Working Lands Assumptions

Carbon Management and GHG Emissions

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Input	Reference Case inputs and data assumptions
Economy-wide gross emissions constraint	45% below 1990 levels by 2030, 70% by 2040, 95% by 2050
Carbon neutrality	Net Zero by 2050
Clean fuels	Biomass-derived fuels, hydrogen, and hydrogen-derived fuels qualify as clean (if green hydrogen used). Imported fuels are counted as zero emissions (credit for negative emissions from processes like BECCS are retained by producing state). Clean Fuel Standard incorporated
CCS	Retrofits permitted, sequestration opportunities limited to saline aquifer formations using NETL supply curve with none in Washington. Washington can offset emissions with sequestration in other states.
Non-CO2, non-energy	WA CH_4 rule and HFC rule EPA developed supply curves of measures to reduce other non-CO2 and non-energy emissions, e.g., reducing N_2O from soil management. Optimized by the model against energy emissions reduction measures.

Key Challenges in Washington 2030

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- Washington's 2030 target is hard to meet
- Clean electricity sector drives a need for more ambitious near-term emissions reduction measures
  - Limited opportunity to ramp up demand-side electrification in 6 years
  - How to tackle emissions from fuels?
- Biofuels, hydrogen, natural climate solutions (NCS)
  - Uncertainty about availability of existing biofuel imports
  - Uncertainty about rate of building out hydrogen, H2 derived fuel supply chains, and renewables
  - Uncertainty about availability and acceptability of NCS
- All of these are stretch goals in volume that will hit barriers to implementation

Key Challenges in Washington 2050

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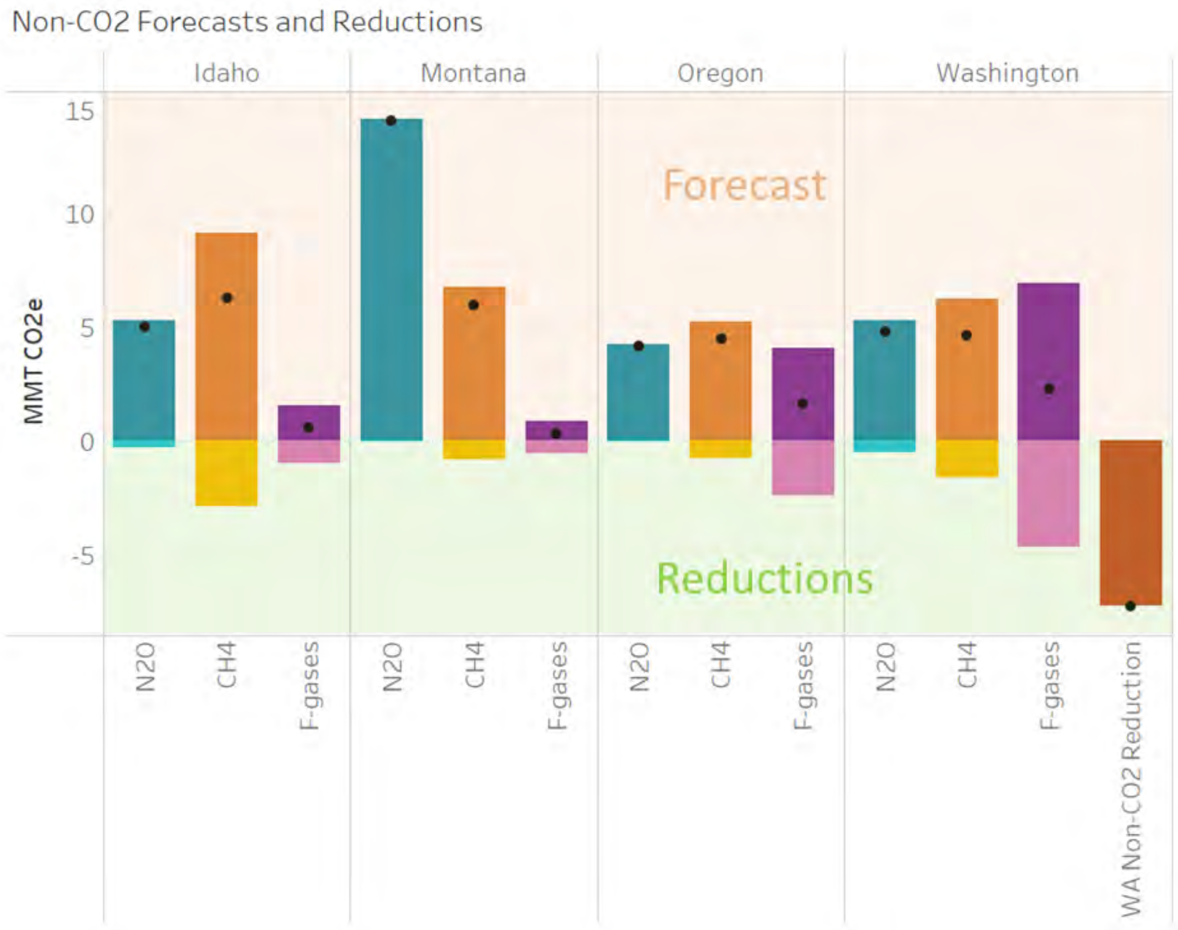
- 2050 emissions target requires currently unidentified measures to achieve
  - 5% gross emissions target limits remaining gross emissions to 4.5 MMT in 2050
  - All remaining emissions will be non-CO2 given the challenge to reduce them
  - ~7 MMT gap between estimated available reduction measures and the emissions target



Net Zero Northwest, 2023

Natural Climate Solutions and CDR

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Input	Reference Case inputs and data assumptions	Ag/Waste/CDR Balance	CCAP
Natural Climate Solutions (agricultural practices, forestry, land management)	Robertson et al. (2021) "moderate" potential for NCS in Washington Opportunities limited by 5% gross emissions cap	**Remove 5% gross emissions cap**	**Remove 5% gross emissions cap**
CDR (technological)	Direct air capture, BECCS, biochar, biomass burial Opportunities limited by 5% gross emissions cap	**Remove 5% gross emissions cap**	**Remove 5% gross emissions cap**

Bioenergy with Carbon Capture and Sequestration (BECCS/BECCS H2)

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- BECCS/BECCS H2 is Bioenergy with Carbon Capture and Sequestration. It includes a range of technologies. In our modeling, BECCS includes pyrolysis and bio-gasification of biomass, though bio-gasification is the selected technology in 2050 in the results
  - Biomass gasification is a mature controlled process involving heat, steam, and oxygen to convert biomass to hydrogen and other products, without combustion. The process produces hydrogen gas, carbon monoxide, carbon dioxide, and methane in varying quantities depending on the type of biomass. Hydrogen can be separated, the carbon monoxide converted to carbon dioxide, and the carbon dioxide sequestered or utilized in other processes.
- More information on the group of technologies that fall under BECCS is available in a recent Clean Air Task Force issue brief

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Electric Power Sector Assumptions

Electric Supply Resource Eligibility / RPS / CES

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Input	Reference Case inputs and data assumptions	Technology+	Siting/Infra+	CCAP
Clean Electricity Policy	State-by-state clean electricity policy. Washington: Clean Energy Transformation Act (CETA), 100% clean by 2045, coal retirements by 2025			
Economy-Wide GHG Policy	State targets by 2030; net-zero by 2050 Washington: 45% below 1990 levels by 2030, 70% by 2040, 95% by 2050, Net Zero by 2050			
Clean Electricity Resource Eligibility	Renewables and 100% clean fuels, nuclear, fossil gas with carbon capture			
Resource Availability	Retain thermal resources if economic and allow new build, TNC TX and RE potential. NREL ATB mid resource prices. Tx and pipeline expansion available in 2035 and onwards. No SMRs. CGS extension option	**Accelerate in state hydrogen adoption to 4.5GW by 2030 (stretch goal from 2024 Commerce Hydrogen Study).Accelerate CCUS. SMRs (8 modules at CGS, 960 MW). 1 GW offshore wind target. Enhanced Geo: min 25 MW by 2030, 75 MW by 2040, 175 MW by 2050. 2 MW Tidal**	**Tx and pipeline expansion available in 2030 and onwards**	**Tx expansion from 2033, H2 pipelines from 2032, CO2 pipelines from2033, NH3 pipelines from 2035. Accelerated in state hydrogen adoption to 0.8 GW of electrolyzers by 2030, 4.5 GW by 2035. SMRs – Amazon Phase I build out only, 4 SMRs = 320 MW by 2040. No Offshore wind. Enhanced Geo: min 25 MW by 2030, 75 MW by 2040, 175 MW by 2050. 2 MW Tidal**
CES Constraint	CETA: Coal retirements 2025; 100% carbon neutral 2030 (with alternative compliance); 100% RE 2045			
Inflation Reduction Act Incentives	Supply-side incentives included for hydrogen production, renewable electricity generation, battery storage, carbon sequestration, clean fuels, and nuclear			

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Distributed Energy Resources Assumptions

DER Adoption and Participation

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Input	Reference Case inputs and data assumptions	Personal Behavior+	CCAP
BTM PV	NWPCC 2024 Power Plan rooftop solar forecast		
BTM Storage Adoption	Installed systems but none participate in offering grid services so not tracked by the model		
BTM Storage Parameters	N/A		
Flexible Loads	10% of electric appliance installations by 2050, including space heating, water heating, and air conditioning (linear growth from 0 in 2025) 2/3 of residential electric vehicles in all years and 1/3 commercial vehicles can participate in managed charging No V2G	**50% of electric appliance installations by 2050**	**25% of electric appliance installations by 2050, 2/3 of all electric vehicles in all years can participate in managed charging**
V2G	None (charging only)	**Residential electric vehicle managed charging is V2G**	**50% of residential electric vehicle managed charging is V2G**
Flexible Load Parameters	Space heating loads can be delayed or advanced by 1 hour Water heating loads can be delayed or advanced by up to 2 hours Air conditioning can be delayed or advanced by 1 hour Residential vehicle charging can be delayed by up to 8 hours and commercial vehicle charging up to 3 hours		
Data Centers	NWPCC Forecast on top of existing data center loads		

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Building Sector Assumptions

Building Electrification

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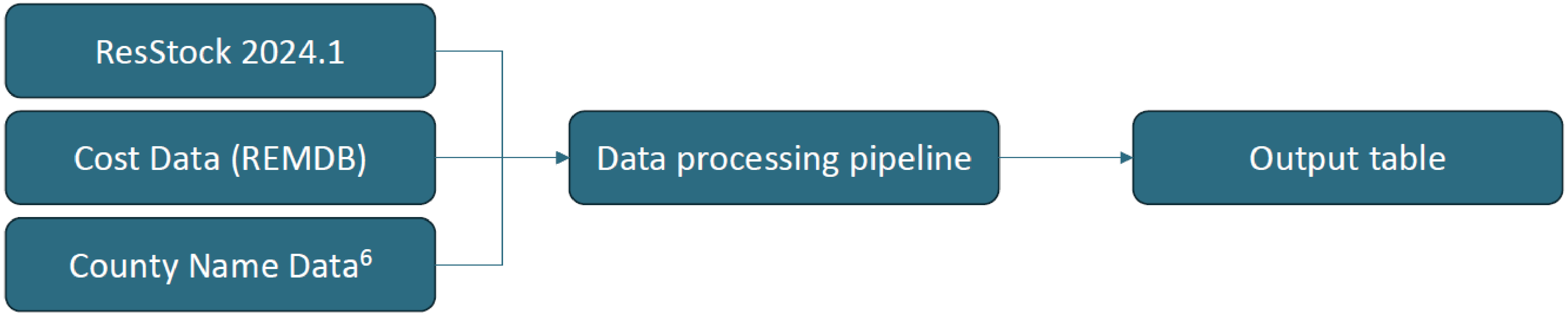
Input	Characterizing existing stocks, energy demand, and emissions	Reference Case inputs and data assumptions	Technology+	Personal Behavior+	CCAP
Residential Space Heating	NEEA RBSA, benchmarked with EIA SEDS for Washington	Fully electrified appliance sales by 2035, woodstoves remain by are supplemented with heat pump for hybrid heating shape	**Heat pump sales: 100% CO2 heat pumps by 2035 (reduced f-gas emissions)**	**Fully electrified appliance sales by 2030**	**Heat pump sales: 50% CO2 heat pumps by 2035 (reduced f-gas emissions)**
Commercial Space Heating	NEEA CBSA, benchmarked with EIA SEDS	Fully electrified appliance sales by 2035	**Heat pump sales: 100% CO2 heat pumps by 2035 (reduced f-gas emissions)**		**Heat pump sales: 50% CO2 heat pumps by 2035 (reduced f-gas emissions)**
Residential Water Heating	NEEA RBSA, benchmarked with EIA SEDS	Fully electrified appliance sales by 2035	**Heat pump sales: 100% CO2 heat pumps by 2035 (reduced f-gas emissions)**		**Heat pump sales: 50% CO2 heat pumps by 2035 (reduced f-gas emissions)**
Commercial Water Heating	NEEA CBSA, benchmarked with EIA SEDS	Fully electrified appliance sales by 2035	**Heat pump sales: 100% CO2 heat pumps by 2035 (reduced f-gas emissions)**		**Heat pump sales: 50% CO2 heat pumps by 2035 (reduced f-gas emissions)**
Cooking	NEEA RBSA and CBSA	Fully electrified appliance sales by 2035			
Other Appliances	NEEA RBSA and CBSA	Fully electrified appliance sales by 2035			

Residential and Commercial Energy Efficiency

EVOLVED ENERGY RESEARCH

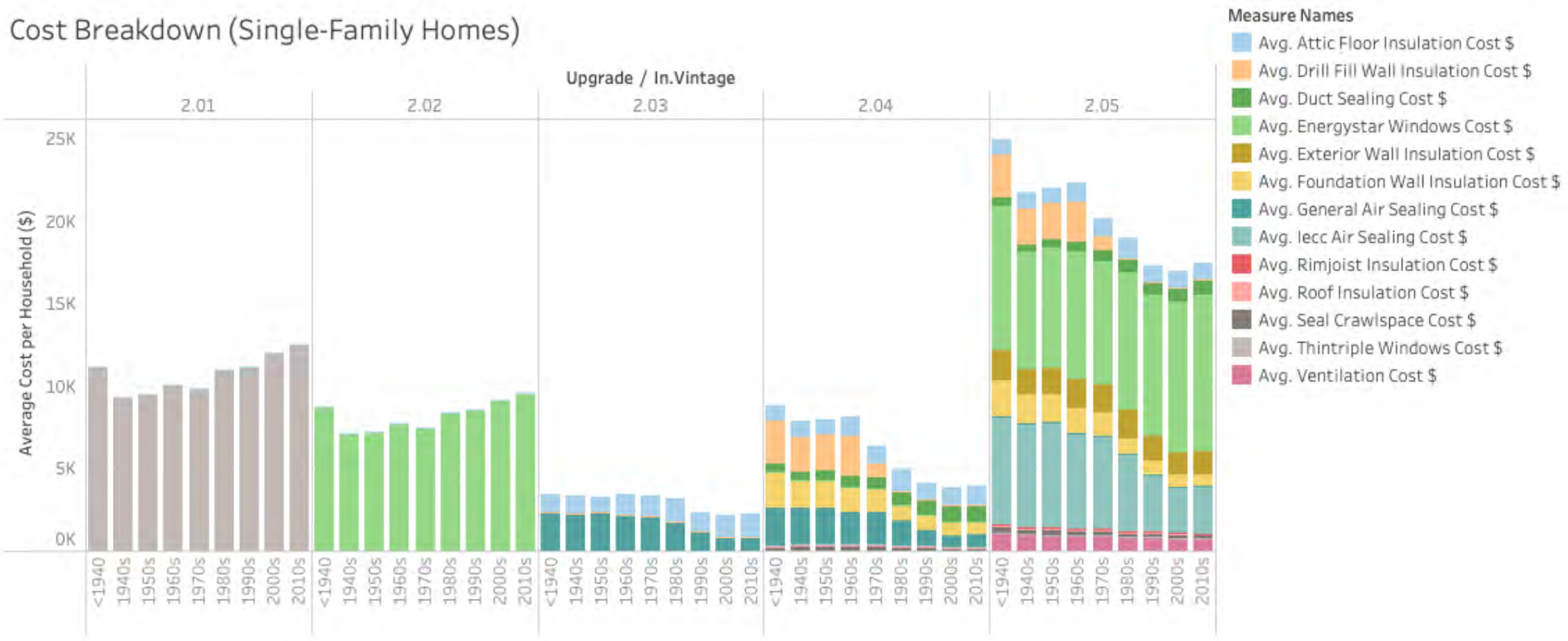
Input	Characterizing existing stocks, energy demand, and emissions	Reference Case inputs and data assumptions
Technology stock replacement	NEEA RBSA and CBSA	Focus is on heat pump adoption and electrification of other appliances. No requirement for adoption of high efficiency gas appliances
Building shells	Evolved building shell stocks and retrofit options	Under review
Lighting		100% LED sales by 2025

Evolved Approach to Building Shell



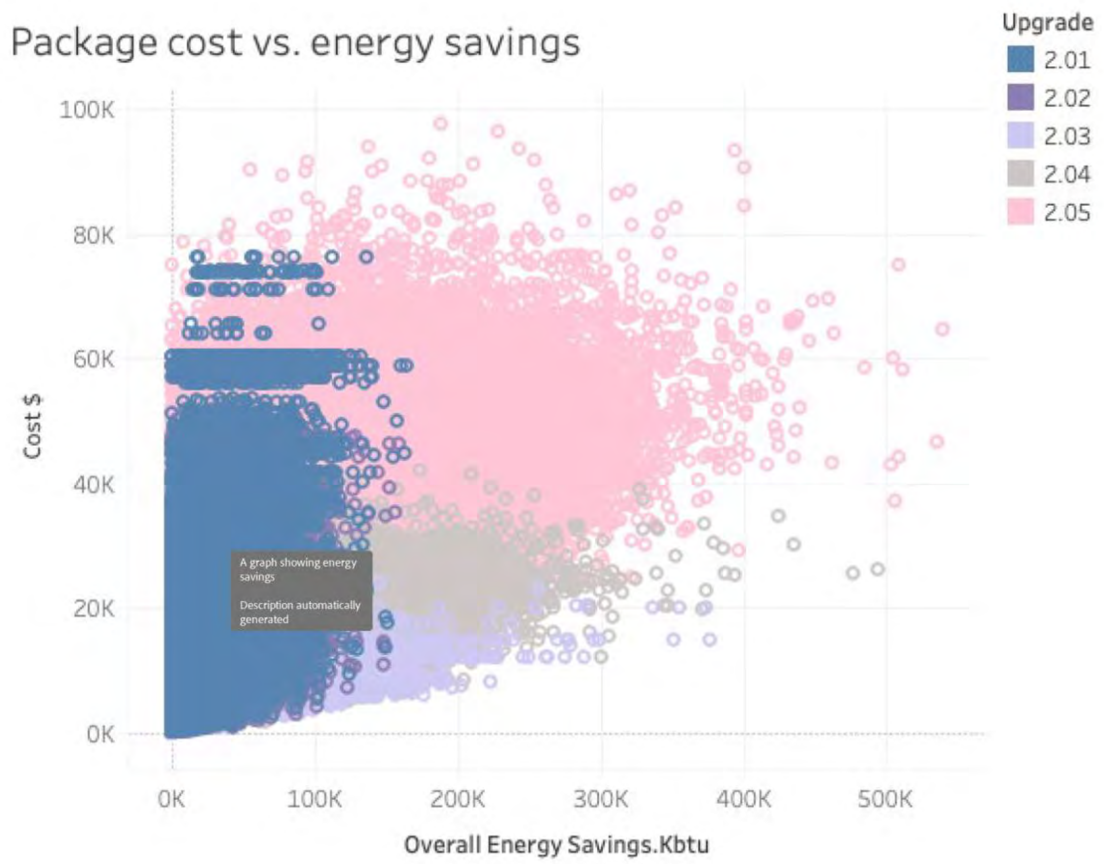
- Building characteristics: location, vintage, occupants, building geometry, input and upgraded measure attributes (insulation levels, windows, air sealing levels
- Costs and service demand reductions calculated for each measure
  - Packaged together into building shell retrofit options

Evolved Building Shell Package Options



What Building Shell Assumptions to Use?

- Varied cost effectiveness based on package of measures used in building shell retrofits
- What should we assume about building shell measures in the Reference Case?
  - Should the Technology+ case include any more aggressive measures?
- Rate of adoption, type of measure



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Industrial Sector Assumptions

Industrial Efficiency and Electrification

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Input	Reference Case starting point inputs and data assumptions	Technology+	CCAP
Industrial Process Efficiency	1% efficiency improvements per year in all sectors	**1.5%/yr process efficiency improvements**	**1.25%/yr process efficiency improvements**
Electrification	100% of machine drives by 2035 100% of low temperature heat by 2050 50% of integrated steam production, and 80% of integrated steam production in food manufacturing, by 2045 100% of refrigeration by 2040 90% of industrial HVAC loads across industrial subsectors 80% of industrial vehicles including in agriculture by 2050		
Switch to Hydrogen	50% of heat in bulk chemicals 20% of construction energy demand 20% of industrial vehicles by 2050		

Industrial Efficiency and Electrification

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Input	Reference Case inputs and data assumptions
Cement	Cement process is optimized in the model, including retrofits and new build rotary kilns to include direct separation, oxy-combustion, biomass fuel, and CCS, as well as limestone calcined clay cement (LC^3) technology
Thermal Energy Storage	Economic adoption modeled in industrial sector
Hybrid Boilers	Model can invest in dual fuel electric and gas boilers as well as hydrogen boilers

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Policy Assumptions

Economy-wide GHG Policy

Assumption Type	Reference Scenario Assumptions
Economy-Wide GHG Policy	State targets, include EO 20-04 in Oregon

(MMT)	2025	2030	2035	2040	2045	2050	Benchmark Year	Notes
Arizona	None							
California		40%			Net-zero		1990	Executive target
Colorado	26%	50%				Net-zero	2005	Statutory target
Idaho	None						N/A	
Montana	None						N/A	Executive target
Nevada	28%	45%				Net-zero	2005	Statutory target
New Mexico		45%				Net-zero	2005	Executive target
Oregon			45%			80%	1990	Executive target
Utah	None						N/A	
Washington		45%		70%		95%/ net-zero	1990	Statutory target
Wyoming	None							

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Land Use Assumptions

Power of Place Study – The Nature Conservancy

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- West-wide energy modeling incorporating detailed land use and habitat information to assess the land impacts of decarbonization. Questions asked include:
  - "How much clean energy will be needed to achieve economy-wide net-zero emission reductions by 2050?"
  - "How much land and ocean area will be required for the clean energy transition?"
  - "How will protecting sensitive natural areas and working lands affect energy costs?"
  - "What are the implications of renewable and carbon-neutral energy technology choices for natural and working lands, costs, and the pace of build-out?"
- Transmission options for the West examined with detailed GIS analysis and the latest transmission capacity studies

Potential Expansion Of Interties

- Power of Place-West: Identified major substations for interties between states, the existing corridors, the potential to reconductor or co-locate transmission in those corridors, and new potential right of ways for additional transmission expansion

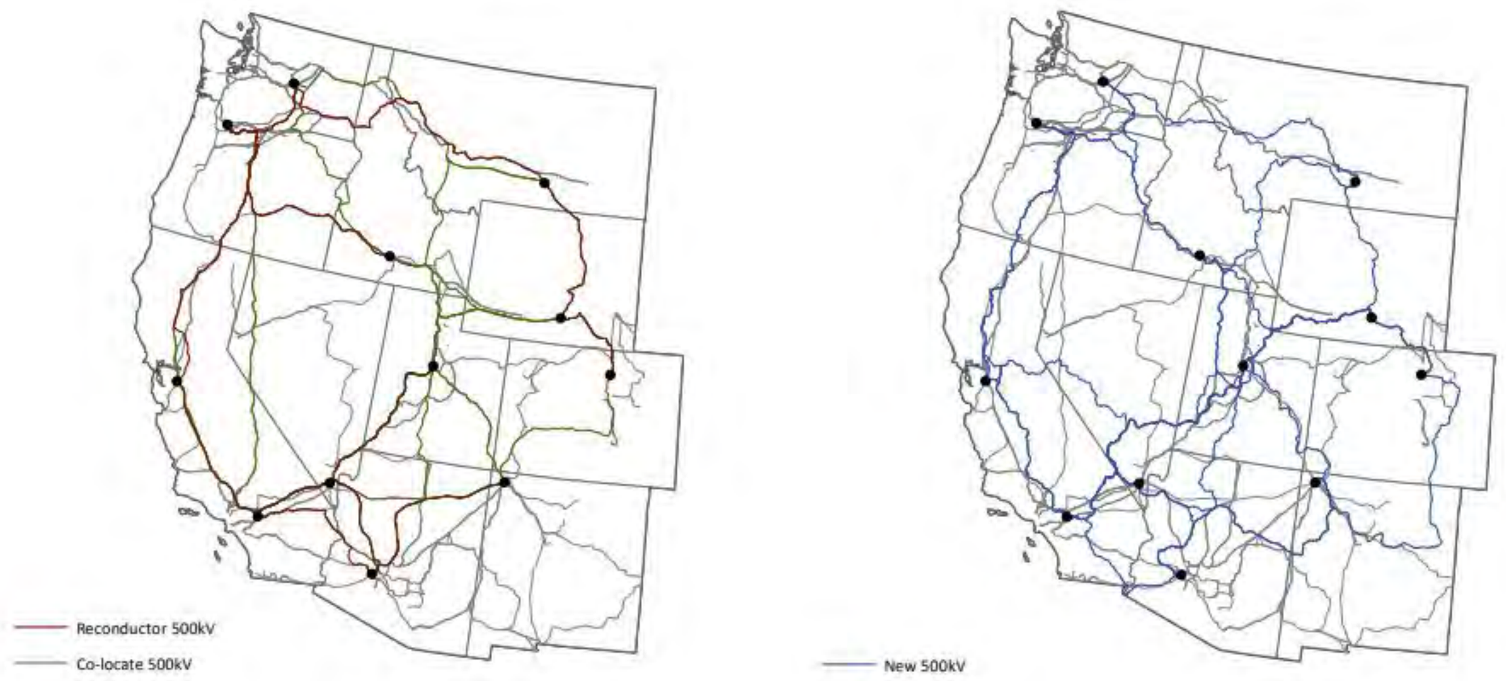


Fig. S8. Least cost path model results showing 500 kV transmission lines. Left: reconductored and co-located 500 kV lines only. Right: new 500 kV lines only.)

Source: Power of Place-West

Identifying Corridor Options

- Corridor options and their costs developed using GIS analysis of land use
- Costs developed using Black and Veatch Transmission Cost Calculator developed for the WECC transmission planning forums (TEPPC)
- Multipliers applied to costs based on terrain and type of land use
- Terrain broken up into 250km^2 grid cells and least-cost path for new transmission calculated

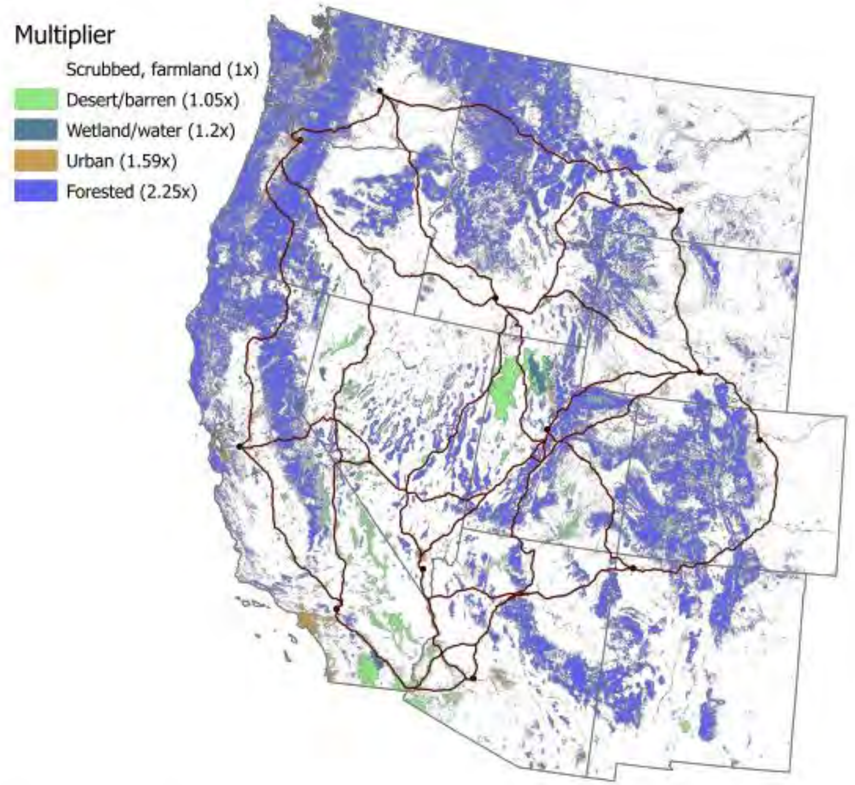
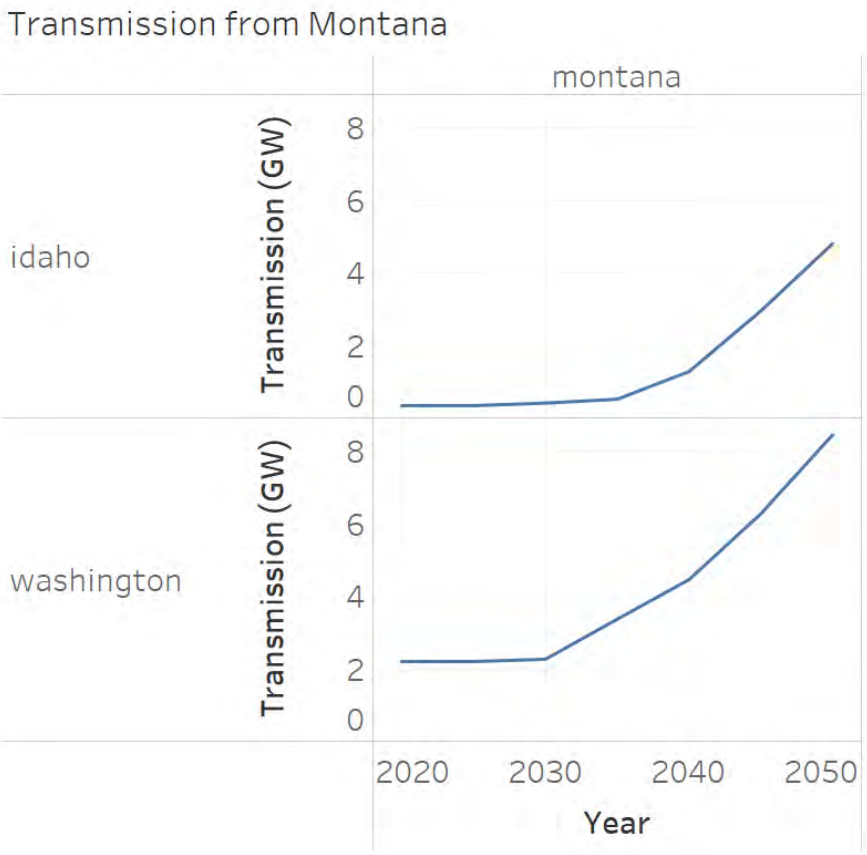


Fig. S7. Least cost path model results showing selected cost surface mutlipliers and new 500 kV transmission lines.

Source: Power of Place-West

Why we Rely on Power of Place–West

- Detailed study encompassing all interstate Tx options in the West
  - Consistency in cost estimations across varied terrain, line lengths, etc.
  - Price availability for multiple types of lines/upgrades
  - Leans towards conservatism on pricing



Power of Place – West Screens

Categories of Exclusion	Definition of Category	Examples	Biomass
Level 1	Legally protected: Areas with existing legal restrictions	National Wildlife Refuges, National Parks, Marine Sanctuaries, Military Training Areas	All feedstocks included, exclude potential supply from conservation reserve program land
Level 2	Administratively protected: Level 1 + areas with existing administrative and legal designations where state or federal law requires consultation or review and lands owned by non-governmental organizations (NGOs) on which there are conservation restrictions.	Critical Habitat for Threatened or Endangered Species, Sage Grouse Priority Habitat Management Areas, vernal pools and wetlands, tribal lands	No net expansion of land for purpose-grown herbaceous biomass crops. Specifically, land available for herbaceous biomass crops (miscanthus and switchgrass) is limited to the share of land currently cultivated for corn that is eventually consumed as corn ethanol, which is phased out in all net zero scenarios by 2050.
Level 3	High conservation value: Level 1 + Level 2 + areas with high conservation value as determined through multi-state or ecoregional analysis (e.g., state, federal, academic, NGO) and lands with social, economic, or cultural value.	Prime Farmland, Important Bird Areas, big game priority habitat and corridors, TNC Ecologically Core Areas, "Resilient and Connected Network"	Same as Level 2

https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/power-of-place/

Modeling is Structured to Reflect Land Use and Natural Resource Constraints

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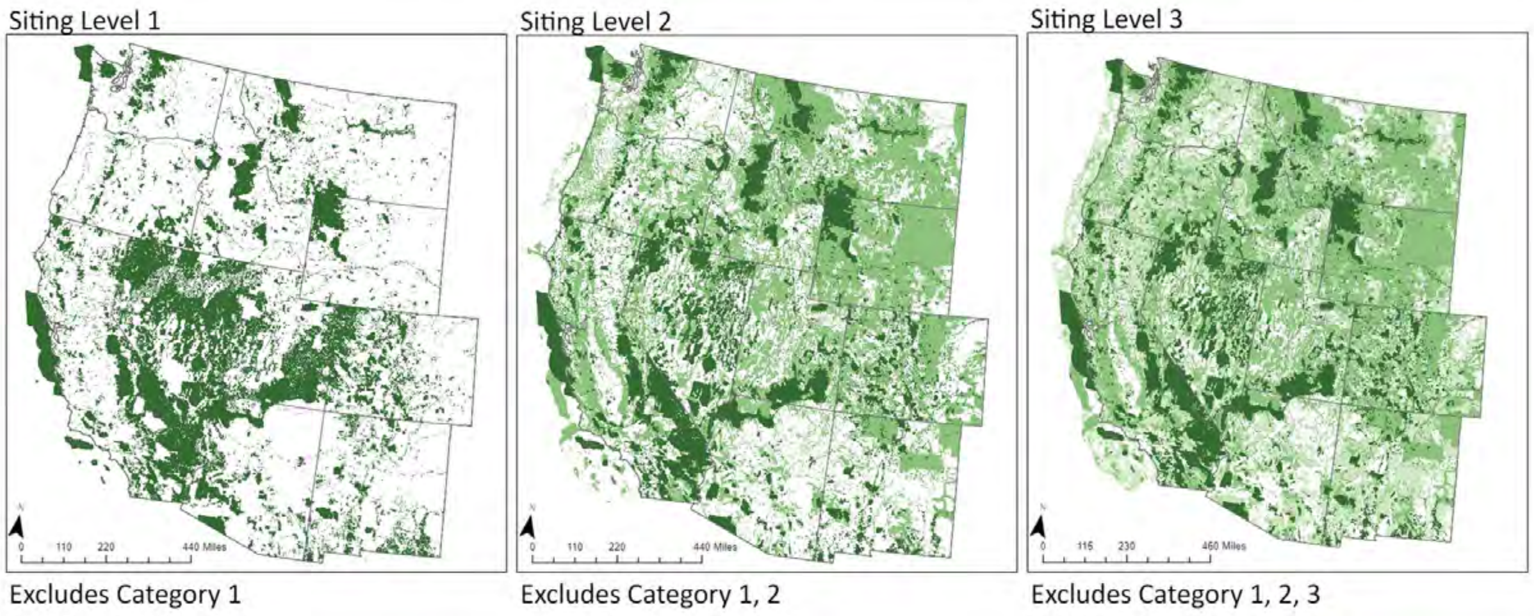
- Land use considerations are an input to the model through screening at a disaggregated level of where infrastructure projects could be located
- Every scenario complies with most restrictive land use constraints in The Nature Conservancy's *Power of Place-West* study: legally protected, administratively protected, and high conservation value lands (Levels 1 – 3) (See methodology on pages 204-209.)



PoP West – Sources of Screens, General

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Area Type	Description	Source	URL
Administratively protected areas (Environmental Category 2)	Administratively protected under current policy	Wu et al 2023, WECC Environmental Data Task Force, BLM West-Wide Wind Mapping Project	https://www.pnas.org/doi/10.1073/pnas.2204098120
High conservation value areas (Environmental Category 3)	Land with high conservation value that may not be currently protected	Wu et al 2023, Wu et al 2023, WECC Environmental Data Task Force, BLM West-Wide Wind Mapping Project	https://www.pnas.org/doi/10.1073/pnas.2204098120
Wetlands	National Wetlands Inventory (NWI)	USFWS National Wetlands Inventory	https://www.fws.gov/program/national-wetlands-inventory
Forests	Areas where the existing vegetation type life form is classified as tree	Landfire 2020	https://landfire.gov/evt.php
Conifer forest	Areas where the existing vegetation type physiognomy is conifer or conifer-hardwood	Landfire 2020	https://landfire.gov/evt.php
Shrublands	Areas where the existing vegetation type life form is classified as shrub	Landfire 2020	https://landfire.gov/evt.php
Grasslands	Areas where the existing vegetation type life form is classified as herbaceous	Landfire 2020	https://landfire.gov/evt.php
Resilient and connected network	A subset of The Nature Conservancy's Resilient Connected Network, including only Prioritized Network areas with Resilient, Concentrated Flow (Climate Informed), Recognized Biodiversity	The Nature Conservancy Resilient, Connected, Network	https://www.conservationgateway.org/ConservationPractices/ClimateChange/Pages/RCN-Downloads.aspx
Intact lands	Areas largely undisturbed by human modification. HMI < 0.082, except where modified per Hise et al 2022 (central U.S.)	Theobald Human Modification Index, others	https://datadryad.org/stash/dataset/doi:10.5061/dryad.n5tb2rbs1, https://www.mdpi.com/2073-445X/11/4/462
Intact tallgrass prairie	Landscapes in the eastern Great Plains with largely intact natural vegetation	Ostlie, W. Untilled Landscapes of the Great Plains; The Nature Conservancy: Minneapolis, MN, USA, 2003.	87

https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power_of_Place_National_Technical_Briefing.pdf

PoP West – Sources of Screens, Species

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Area Type	Description	Source	URL
Grouse habitat (e.g., sage grouse and prairie chicken)	Habitat with conservation importance for grouse and prairie chicken species	Hise et al 2022, Wu et al 2023	https://www.mdpi.com/2073-445X/11/4/462, https://www.pnas.org/doi/10.1073/pnas.2204098120
Sensitive desert species habitat (e.g., desert and gopher tortoises)	Habitat with conservation importance for imperiled tortoise species	Wu et al 2023, USGS Southeast gopher tortoise habitat mode	https://www.pnas.org/doi/10.1073/pnas.2204098120, https://www.sciencebase.gov/catalog/item/5d0d4ba0e4b0941bde52a306
Sensitive whooping crane habitat	Key whooping crane stopover sites	Hise et al 2022	https://www.mdpi.com/2073-445X/11/4/462
Bat habitat	Key bat roosting areas in the central U.S. per Hise et al 2022, USFWS critical habitat for threatened and endangered species	Hise et al 2022	https://www.fws.gov/endangered/what-we-do/critical-habitats.html

https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power_of_Place_National_Technical_Briefing.pdf

PoP West – Sources of Screens, Social

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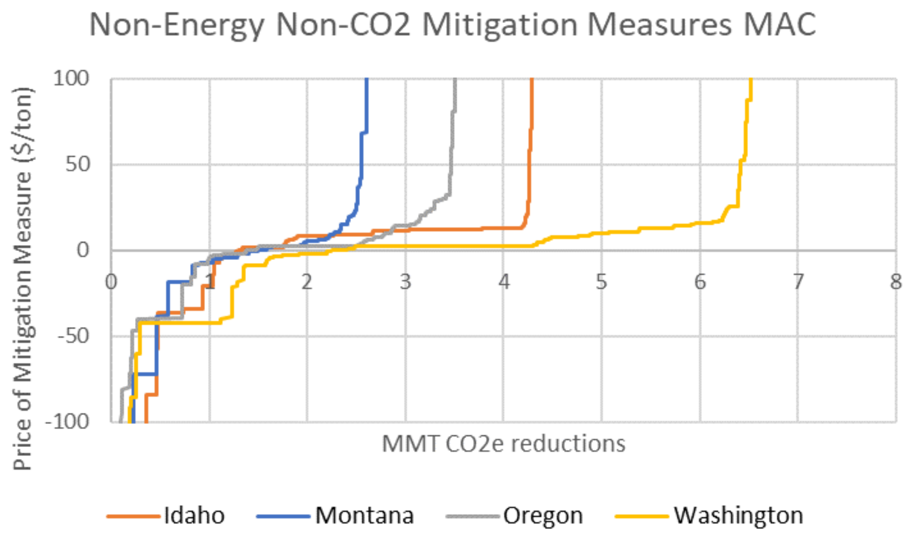
Area Type	Description	Source	URL
Energy Communities	Brownfields [not mapped], areas with significant fossil fuel employment, and areas with retired coal power plants	2022 Inflation Reduction Act	https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf
Low-Income Communities	Areas with high poverty rates according to the U.S. Census	2022 Inflation Reduction Act	https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf
Croplands (general)	Vegetation of agricultural lands, including row crops, intensive pastures, orchards, vineyards, plowed or harvested fallow fields, rice paddies, and farm ponds	Landfire 2020	https://landfire.gov/evt.php
Productive farmland	Productive Versatile Resilient farmland (value = 0.53 on a scale of 0-1)	American Farmland Trust "Farms Under Threat" Report	https://farmlandinfo.org/publications/farms-under-threat-the-state-of-the-states/ https://farmlandinfo.org/wp-content/uploads/sites/2/2020/05/AFT_FUT_PVR_Fact_Sheet.pdf
Marginal farmland	Challenging soil' based on USDA Gridded Soil Survey Geographic Database	USDA Gridded Soil Survey Geographic Database	https://www.nrcs.usda.gov/resources/data-and-reports/gridded-soil-survey-geographic-gssurgo-database

https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power_of_Place_National_Technical_Briefing.pdf

Non-CO_2 and Land Use

- Non-CO_2 emissions are part of the state's emissions inventory and the modeling included both forecasts for how these might change over time and opportunities to avoid them
- These include methane emissions, fluorinated gas emissions, and nitrous oxide
- We used EPA Non-CO_2 Emissions and Mitigation Measures to project baseline non-CO2 emissions and identify opportunities to reduce them
  - Supply curve of mitigation measures for non-CO_2 reductions starts negative
    - Some measures taken have economic benefits. Examples include gas recovery, better maintenance practices, leak reduction
  - Majority of non-energy non-CO_2 measures are achievable at less than $25/ton



THANK YOU

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