Washington State Energy Strategy Decarbonization Modeling Final Report

December 11th, 2020

EVOLVED ENERGY RESEARCH

Contents

Introduction

Transforming Washington's Energy System

- Transformational rather than incremental change
- Aggressive action needed across all energy sectors
- Many options to get there
  - Process designed to find the best path forward for Washington State's priorities
    - Equity, affordability, reliability, competitiveness
- Building on a foundation of past studies and efforts in other states

Emissions targets for State Energy Strategy:

2020: 1990 levels
2030: 45% below 1990
2040: 70% below 1990
2050: 95% below 1990
2050: Net zero

Approach to Modeling Decarbonized Energy Supply

- **Explores** how Washington can achieve deep decarbonization across all energy sectors to meet the emissions targets
- **Conservative** assumptions about existing technologies and cost projections from public sources
- **Modeling determines optimal investment** in resources with least-cost, constrained by scenarios that balance different state objectives
- **Decarbonizing energy supply**—electricity, pipeline gas, liquid fuels
- Models integrated electricity and fuels systems that extend beyond Washington's borders to **capture regional opportunities and challenges**

Investigate State Strategy through DDP Modeling: Three Framing Questions

- Where are we now?
  - *What is the current state of Washington's energy system?*
- Where do we want to go?
  - *What are Washington's most desirable pathways to meeting emissions goals?*
- How should we get there?
  - *What policies and actions get us to where we want to go?*

Where Are We Now?

What does the energy system look like today and what will shape it going forward?

Washington and WECC current energy resources and infrastructure	Existing Washington policies and targets through 2030 and 2050
➢ **Stock** of all energy producing and consuming technologies	➢ **Utility resource plans**
➢ **Patterns** of energy consumption	➢ **Energy code strategy**
➢ **Final energy demand of fuels and electricity** across the economy	➢ **Energy Independence Act**
➢ **WA and WECC electricity system**	➢ **Appliance standards**
➢ **Transmission between Washington, neighboring states, and beyond**	➢ **Power plant emission standards**
➢ **Fuel prices and sources**	➢ **Clean Energy Transformation Act**

EVOLVED ENERGY RESEARCH

Where Do We Want to Go?

Translate State objectives and potential policy pathways into constrained scenarios

- What is the best future we can envision for the state?
  - Balance of different, often competing objectives
    - Equity, affordability, reliability, competitiveness
  - Alternative least cost pathways examining different priorities
- Understanding the tradeoffs
  - How much does one pathway cost versus another?
    - Counterpoint for policymakers and stakeholders
  - Provides a target for near-term policy and action design to hit
- Understanding the uncertainties
  - How does an uncertain future impact our decisions?

Investigating policies & uncertainties through scenario analysis

100% clean electricity grid

Electrification of demand side equipment

Examples for illustration only

Constrained resource potentials

Behavior changes that lower service demands

EVOLVED ENERGY RESEARCH

How Should We Get There?

- By targeting favorable future pathways we can **develop and prioritize near-term policies and actions**
- Targets are not prescriptive, but provide the best guidance given current information and uncertainties
  - Common elements deployed 2020-2030: “no regrets”
  - Replace or avoid long-lived resources
  - Early action on long lead-time or hard to achieve energy transformations
- Policy development that favors Washington’s goals
  - Equity, affordability, reliability, competitiveness
- **“How should we get there?” not addressed in DDP modeling, but outputs of modeling inform development of the Washington State Energy Strategy**
  - Least-cost energy system planning, and policy/action design complement one another

State Targets

Clean Energy Transformation Act (CETA)

CETA Requirements

- 2025: Eliminate coal-fired electricity from state portfolios
- 2030: Carbon neutral electricity, >80% clean electricity with up to 20% of load met with alternative compliance:
  - Alternative compliance payment
  - Unbundled renewable energy certificates, including thermal RECs
  - Energy transformation projects
  - Spokane municipal solid waste incinerator, if results in net GHG reduction
- 2045: 100% renewable/non-emitting, with no provision for offsets

CETA Implementation in the Model*

- 2025: Retire all WA coal contracts
- 2030: Constrain delivered electricity generation serving WA loads to be 80% or more from clean sources
  - Accounting on retail sales rather than production, i.e., losses are not included
- 2030: Constrain the remaining 20% to come from non-delivered RECs
  - Linear transition to 100% delivered clean energy by 2045
- 2045: 100% delivered clean electricity
  - Accounting on all electricity production for in state consumption, i.e., losses are included
  - Fossil generation can supply out-of-state load

*Model assumptions on implementation developed prior to rulemaking and not indicative of final implementation

CETA Renewable Energy Credit Accounting in the Model

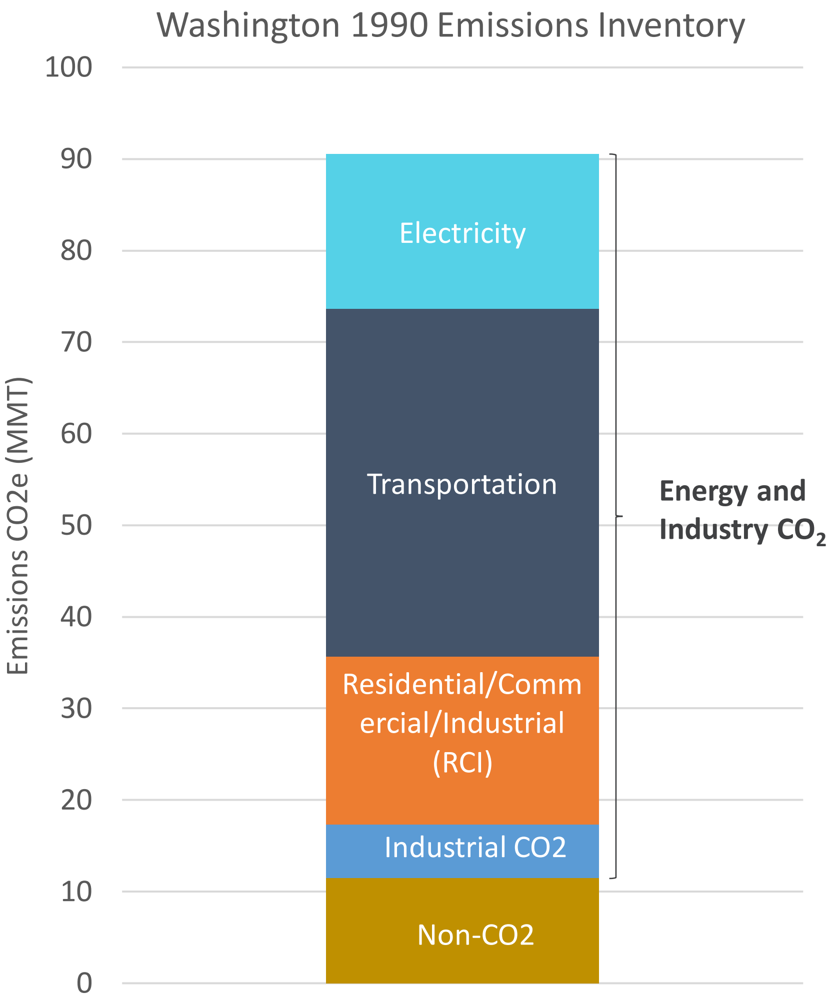
- **Implementation of delivered clean electricity (delivered RECs)***
  - Investments in new clean energy resources are specified, and only delivered MWhs to WA loads count towards CETA delivered energy compliance
  - Delivered RECs included in hourly system balancing
  - Available transmission required for delivery
- **Implementation of non-delivered RECs***
  - Accounting on an annual basis: WA requires clean energy credits equal to non-delivered portion of energy compliance each year
  - No hourly delivery or transmission required

*Model assumptions on implementation developed prior to rulemaking and not indicative of final implementation

West Wide RPS/CES Targets

	Reference Case						
Year	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Arizona	6%	15%	15%	15%	15%	15%	15%
California	33%		60%		87%	100%	100%
Colorado	30%		30%		30%		30%
Idaho	None						
Montana	15%	15%	15%	15%	15%	15%	15%
Nevada	22%	25%	50%		75%		100%
New Mexico	20%		50%		80%	100%	100%
Oregon	20%		35%		50%	50%	50%
Utah	0%	20%	20%	20%	20%	20%	20%
Washington	12%		80%			100%	100%
Wyoming	None						

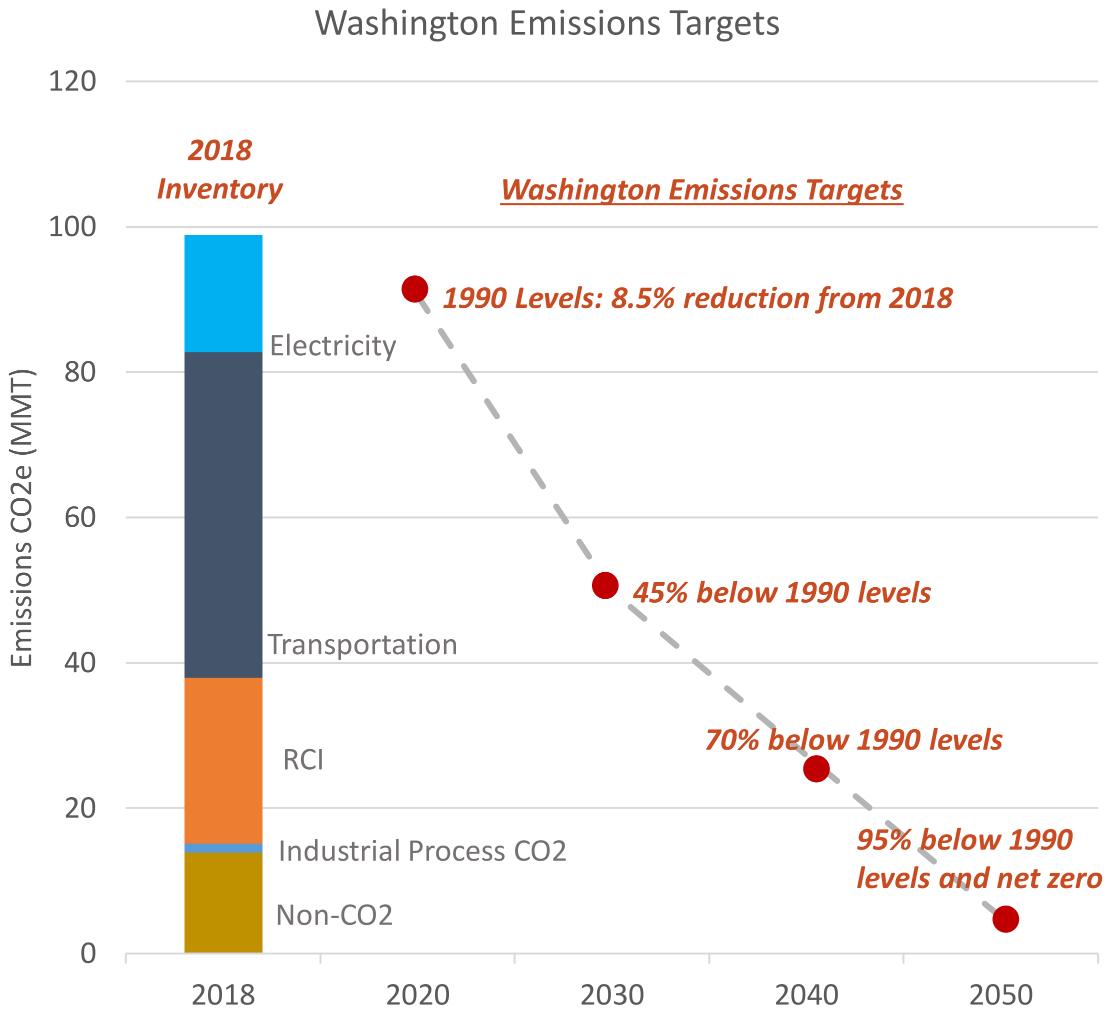
Emissions Targets Set Based on the State's 1990 GHG Footprint



- Washington's 1990 GHG emissions footprint was **90.5 million metric tons**
- Energy and industry related CO_2 emissions represent ~87% of all emissions
  - CO_2 emissions from **electricity generation** were from coal, representing 19% of total emissions
  - Transportation (42%), RCI (20%), and Industrial CO2 (6%) make up the remainder of energy and industry related CO_2 emissions
  - Non-CO_2 emissions (13%) make up the remainder
- Washington starts from a smaller share of emissions from electricity than other states because of the large hydro electric fleet producing clean energy

Notes: Industrial CO_2 includes industrial process emissions not from fuel combustion; non-CO_2 emissions includes agriculture, waste management, and industrial non-CO2 emissions

Washington Emissions Targets



- Washington established economy-wide emissions goals of net zero and 95% reduction in gross emissions by 2050
  - In line with IPCC targets
- Implementation of emissions goals:
  - 95% gross emissions reductions target is independent of land-based emissions reductions
  - Emissions reductions possible in non-energy and non-CO_2 sources are uncertain and need more research to develop reduction measures
    - We assume that the limited land use mitigation potential will offset the emissions from this category
- **Target for the energy sector: Net zero by 2050**

Emissions Targets by Year

Million Metric Tons

Forecasted from latest WA non-CO_2 inventory using EPA growth rates

Starting target of 76 MMT: COVID-19 drops emissions below this target

~50% reduction in energy emissions over 10 years

Year	Non-CO_2/Non-Energy Emissions	Incremental Land Sink	CO_2 Energy and industry	Economy wide CO_2 Target to reach statewide GHG limits
1990	11.4	0.00	79.2	90.5
2020	14.5	0.00	76.0	90.5
2025	12.8	-0.75	58.1	70.1
2030	11.1	-1.50	40.1	49.8
2035	9.5	-2.25	31.2	38.5
2040	7.8	-3.00	22.3	27.2
2045	6.2	-3.75	11.2	13.6
2050	4.5	-4.5	0.0	0.0

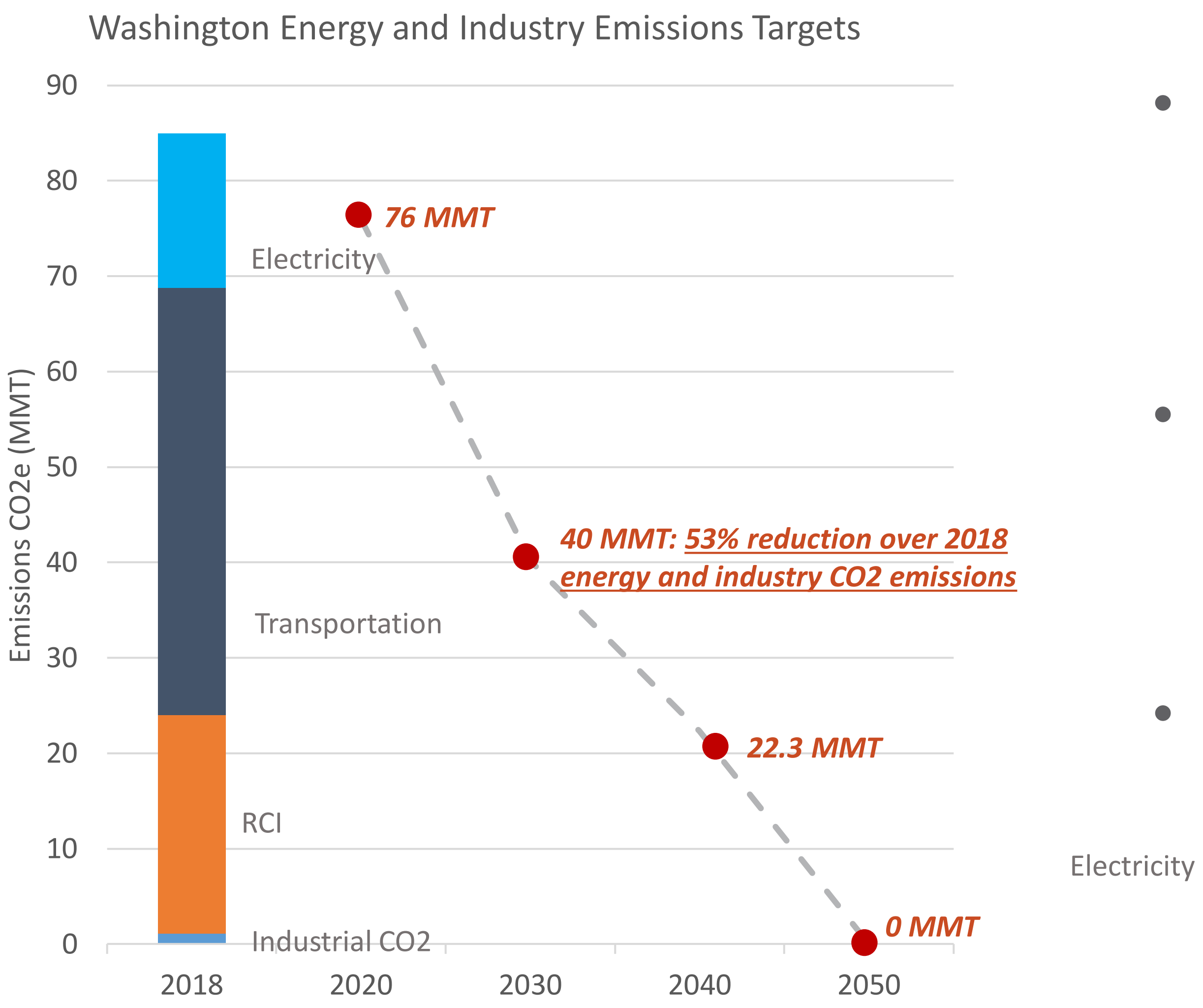
5% gross emissions from non-CO_2, 100% offset by incremental land sink

Non-CO_2 emissions reductions significant but uncertain and requires future research

Net zero target in energy and industry

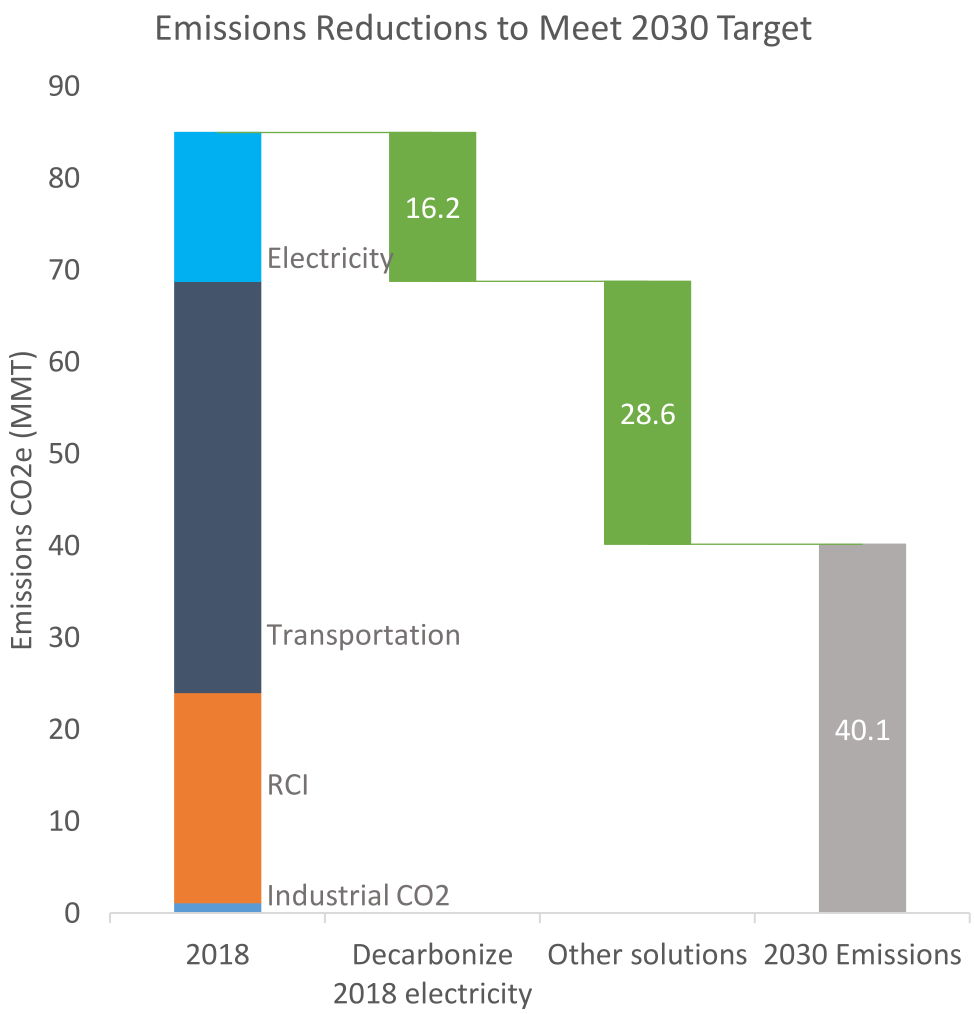
2030: The Energy Emissions Challenge

The DDP modeling analyzes how the CO2 energy and industry emissions targets can be met



- 2030 emissions target for energy and industry less than half of 2018 emissions
  - 40 MMT assumes linear decreases in non-CO_2 emissions and linear increases in incremental land sink through to 2050
- Washington's electricity sector is already very clean: Early emissions reductions are required from actions in other sectors to meet the 2030 target
- **The 2030 challenge: How to cut emissions in half in 10 years?**

Options and Obstacles to Reaching 2030 Targets



- Decarbonizing all electricity generation from 2018 leaves 28.6 MMT to decarbonize (40% of remaining emissions)
- What are the options?
  - **Energy Efficiency**: Reduce energy use through more efficient appliances, processes, and vehicles
  - **Electrification**: Electrify end uses and supply with clean electricity
  - **Decarbonize fuels**: Displace primary fossil fuel use with clean fuel
- What are the obstacles?
  - Efficiency and electrification require new demand-side technology investments
    - Dependent on customers replacing inefficient technologies with efficient and/or electrified options
    - Dependent on stock rollover: A customer with a new ICE vehicle won't replace it the next year with an electric one
  - Decarbonized fuels require bio or synthetic fuels technologies that have yet to be deployed at scale
  - **Limits to what can be achieved in 10 years**

EVOLVED ENERGY RESEARCH

West-Wide Emissions Targets

States without targets follow trajectory for 80% economy wide emissions reductions in decarb cases

	Reference Case							Decarbonization Cases						
Year	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Arizona	None									60		34.4		8.8
California	340		211		70.3	0	0	340		211		70.3	0	0
Colorado	95		47		23.2		-0.6	95		47		23.2		-0.6
Idaho	None							8.7		14.1		4.3		2.1
Montana	None							25		15.6		5.4		2.6
Nevada	45		26.7		9.1		0.3	45		26.7		9.1		0.3
New Mexico	60		30.5		10.2		0	60		30.5		10.2		0
Oregon	55		35.7		12.8		6.2	55		35.7		12.8		6.2
	None									41.3		24.4		7.6
Washington	None							75.3		39.6		27.2		0
Wyoming	None									43		25.5		7.9

EVOLVED ENERGY RESEARCH

Scenario Descriptions

Scenario Descriptions and Implications

Scenario	Summary	Key Question	Policy Mandates
Reference	**Business as usual**	Assumes current policy is implemented and no emissions target	No constraints on emissions.
Electrification	**Investigates a rapid shift to electrified end uses**	What if energy systems achieved aggressive electrification and aggressive efficiency, and relatively unconstrained in-state and out-of-state technology were available?	Meets 2050 net zero emissions target
Transport Fuels	**Investigates reaching decarbonization targets with reduced transportation electrification**	What alternative investments are needed when larger quantities of primary fuels remain in the economy?	
Gas in Buildings	**Investigates reaching decarbonization targets by retaining gas use in buildings**	What is the difference in cost of retaining gas appliances in buildings?	
Constrained Resources	**Investigates a future that limits potential for transmission expansion into Washington**	What alternative investments in in-state resources would Washington make if transmission expansion is limited due to siting/permitting challenges?	
Behavior Changes	**Investigates how lower service demands could impact decarbonization**	What if policy-driven or natural behavior changes (i.e., more telecommuting post COVID-19) lower service demands?	

EVOLVED ENERGY RESEARCH

Scenario Summary

Scenario Assumptions	Reference (R)	Electrification (E)	Transport Fuels (TF)	Gas in Buildings (GB)	Constrained Resources (CR)	Behavior Change (BC)
Clean Electricity Policy	CETA: Coal retirements 2025; 100% carbon neutral 2030 (with alternative compliance); 100% RE 2045					
Economy-Wide GHG Policy	None	Reduction below 1990: 45% by 2030; 70% by 2040; 95% and net zero by 2050				
Buildings: Electrification	AEO	Fully electrified appliance sales in most sub-sectors by 2050		**Gas appliances replaced with new gas sales**	Fully electrified appliance sales in most sub-sectors by 2050	
Buildings: Energy Efficiency	AEO	Sales of high efficiency tech: 100% in 2035				
Transportation: Light-Duty Vehicles	AEO	100% electric sales by 2035	**75% electric sales by 2045**	100% electric sales by 2035		
Transportation: Freight Trucks	AEO	Same as GB, CR, and BC Cases	**Half the electric sales/no hydrogen adoption**	HDV long-haul: 25% electric, 75% hydrogen sales by 2045 HDV short-haul: 100% electric sales by 2045 MDV: 70% electric sales by 2045		
Industry	AEO	Generic efficiency improvements over Reference of 1% a year; fuel switching measures; 75% decrease in refining and mining to reflect reduced demand				
Service Demand Reductions	Baseline service demand informed by AEO					**VMT by 2050: 29% LDV, 15% MDV/HDV 15% Com, 10% Res**
Resource Availability	NREL resource potential; 6 GW of additional transmission potential per path; SMRs permitted				**Washington: No new TX**	Same as R, E, TF, and GB Cases

EVOLVED ENERGY RESEARCH

Results

Structure of results

- The results are structured as follows:
  - **Economy-wide GHG emissions:** Emissions reductions by fuel to reach net zero by scenario
  - **Energy demand:** how energy demand evolves over time under the assumptions in each scenario
  - **Supply side:** Investments in and operations of electricity and fuels supply
    - **Electric and fuels sector metrics** show the scale and rate of change required
    - Grid balancing and the integration of electric and fuels sectors
  - **Costs:** Comparison of decarbonization scenario costs and the Reference Scenario
  - **Key Findings:** Implications of decarbonization overall and by sector

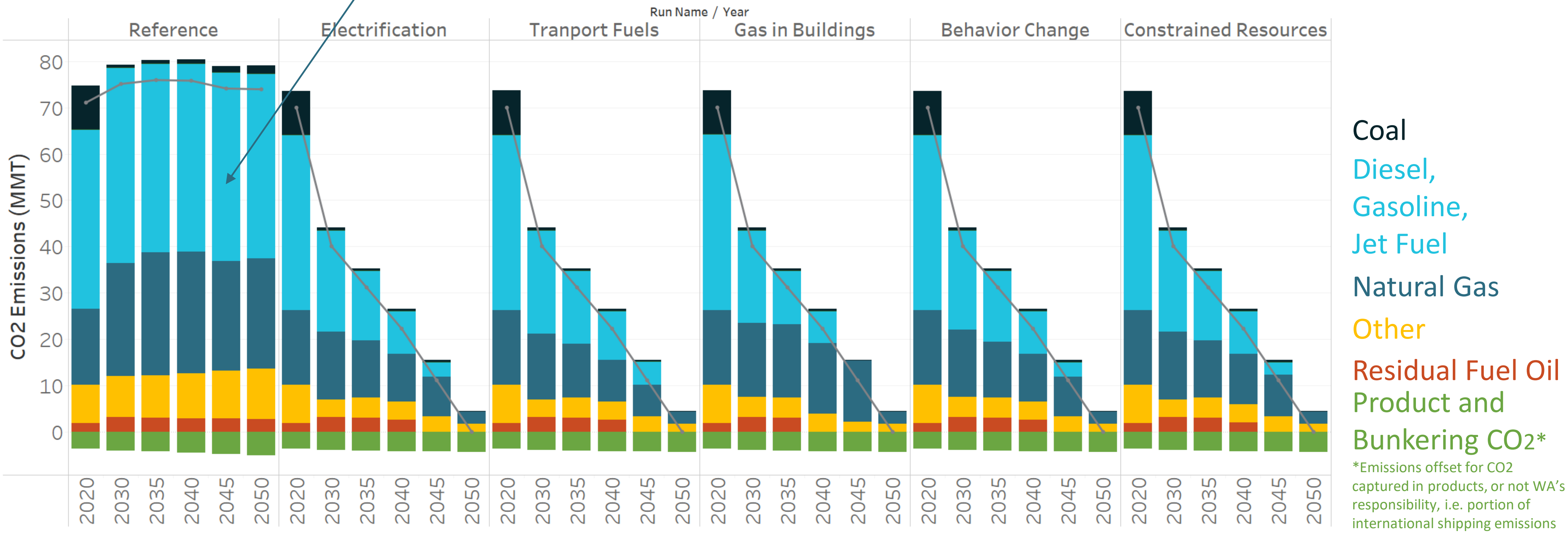
CO_2 Emissions by Scenario

Similar emissions profile to achieving net zero in energy by 2050 across scenarios

Emissions levels by fuel type remain relatively constant in Reference Case

Product and bunkering CO_2 provide negative emissions in accounting

Similar trajectories as end use demand drives reductions in gas use while liquid fuels are decarbonized



Total Gross Emissions: Reference vs Electrification Scenarios

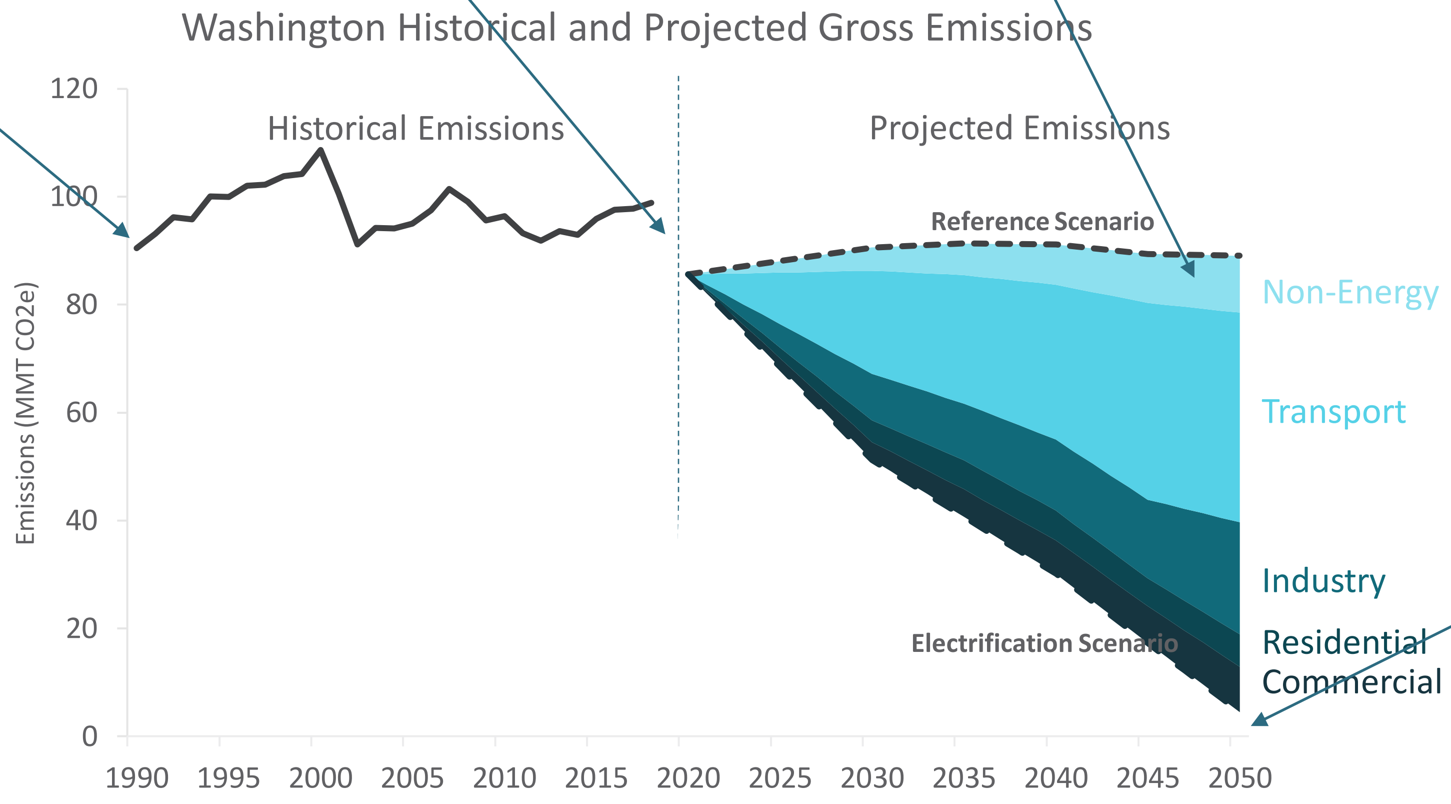
Emissions reduction shown by sector

Emissions targets relative to 1990 levels

Drop between 2018 and 2020 due to Covid-19

Non-energy reductions assumed in decarbonization cases

Incremental biological or geological sequestration measures assumed to offset remaining non-energy emissions in 2050



Demand Side

Final Energy Demand

Electrification and efficiency drive lower total energy demand

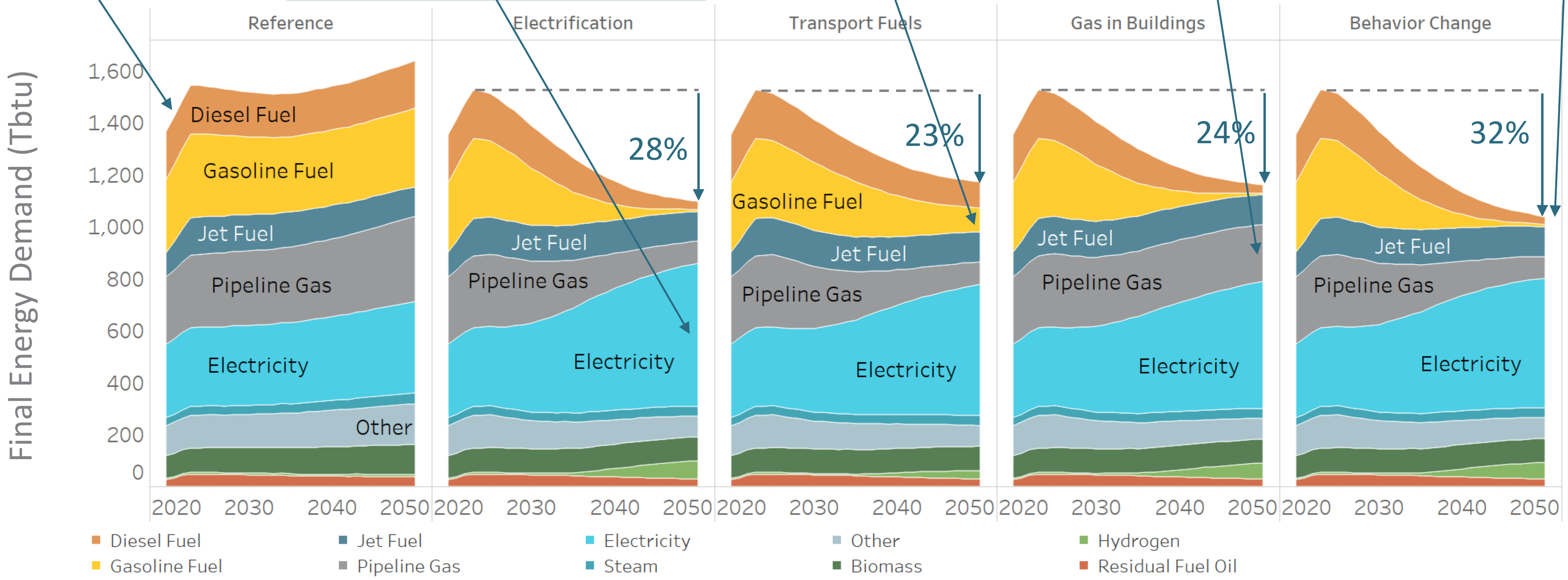
COVID: **10% drop in demand in 2020** due to COVID impact

Electrification: **90% growth in electricity sector** over 2020 levels, displacing fuels

Transport Fuels: Demand for **fuels remains in 2050**

Buildings: **Higher demand for gas** due to less electrification

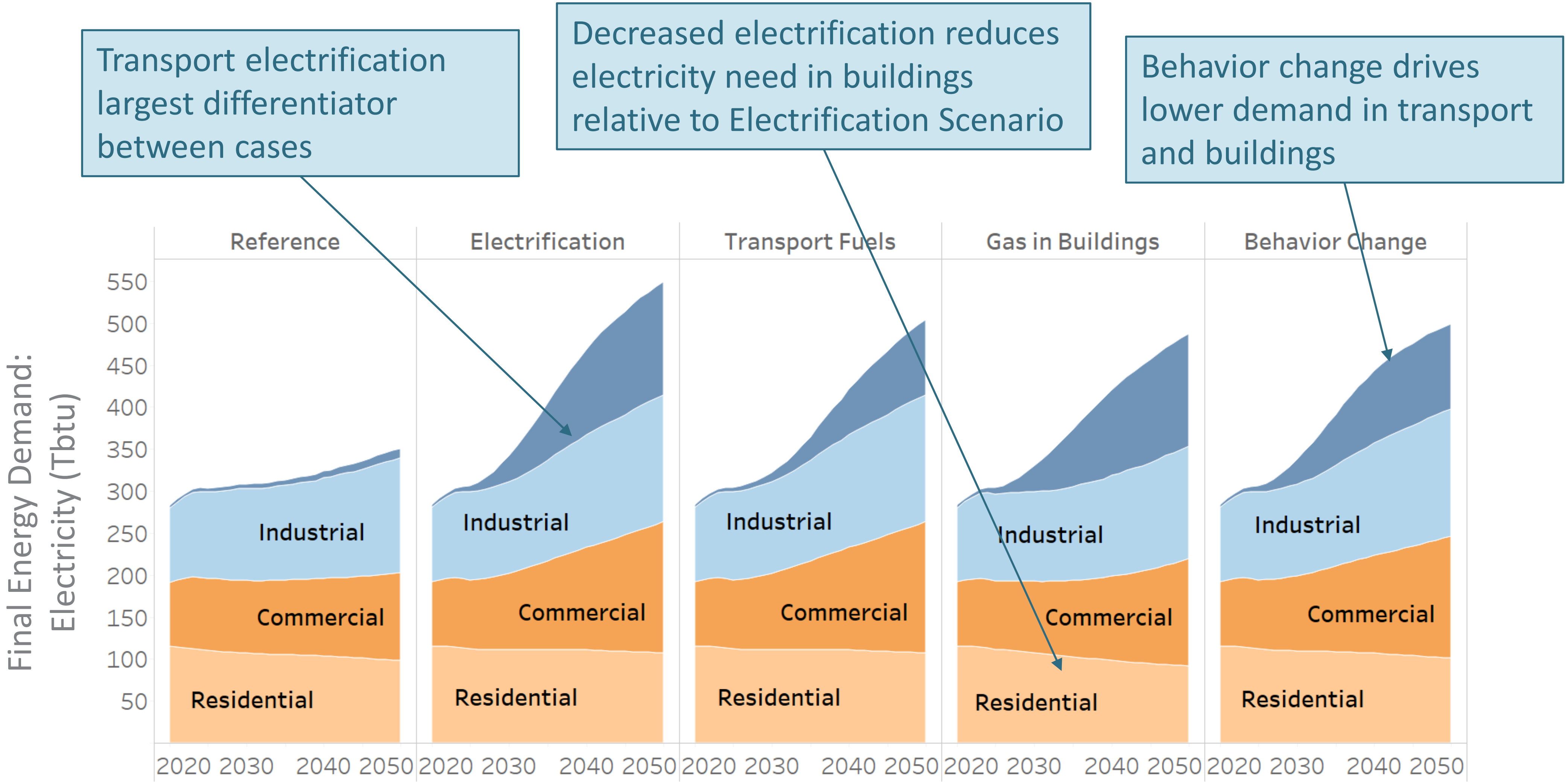
Behavior: Fewer energy services **drive demand lower**



EVOLVED ENERGY RESEARCH

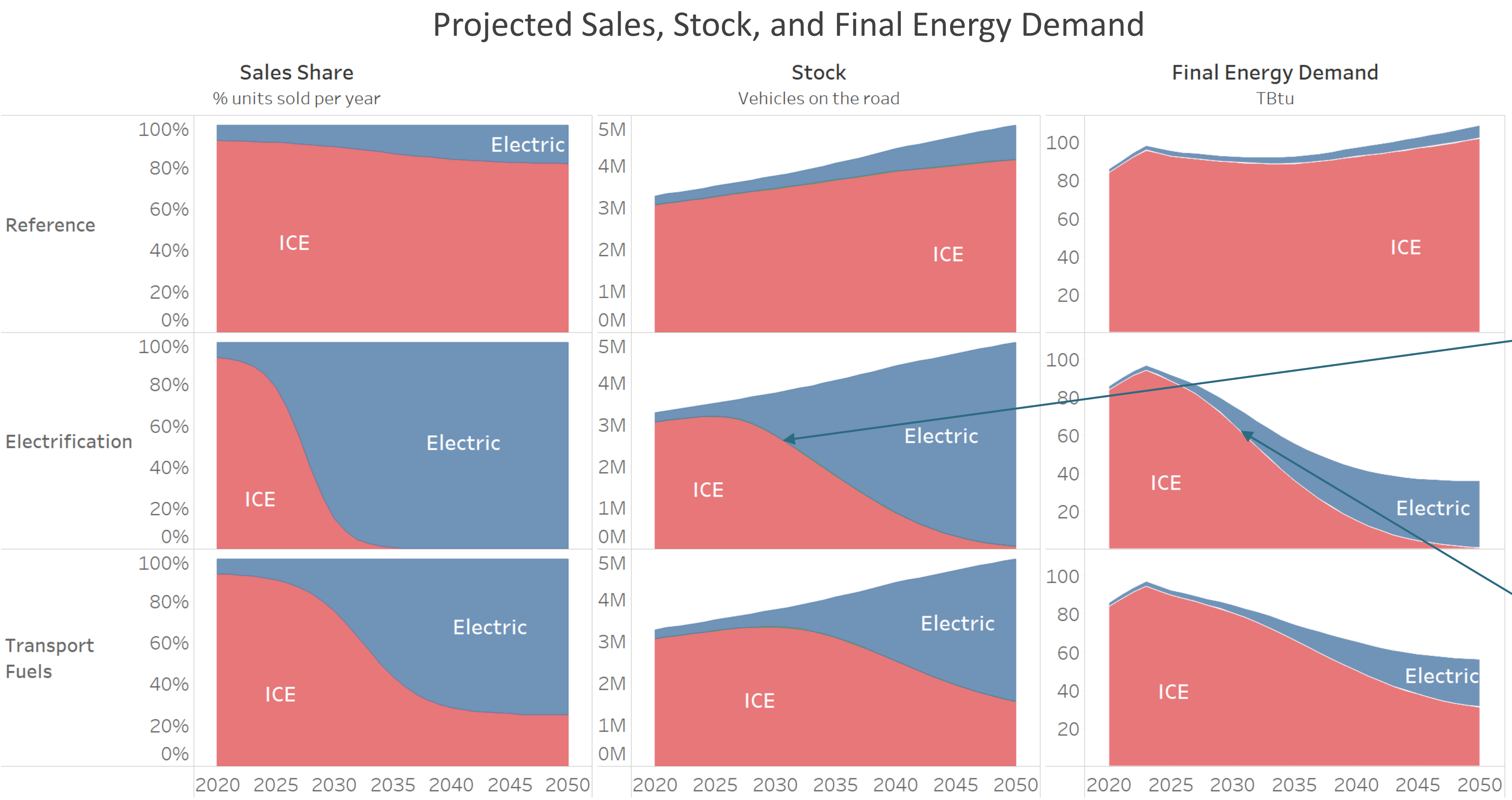
Final Energy Demand: Electricity

Electricity use in all decarbonization scenarios grows significantly



Light-Duty Vehicles: BEVs are Key to Lower Energy Demands

Lower energy demands reduce the need for investment in clean energy technologies to meet net zero



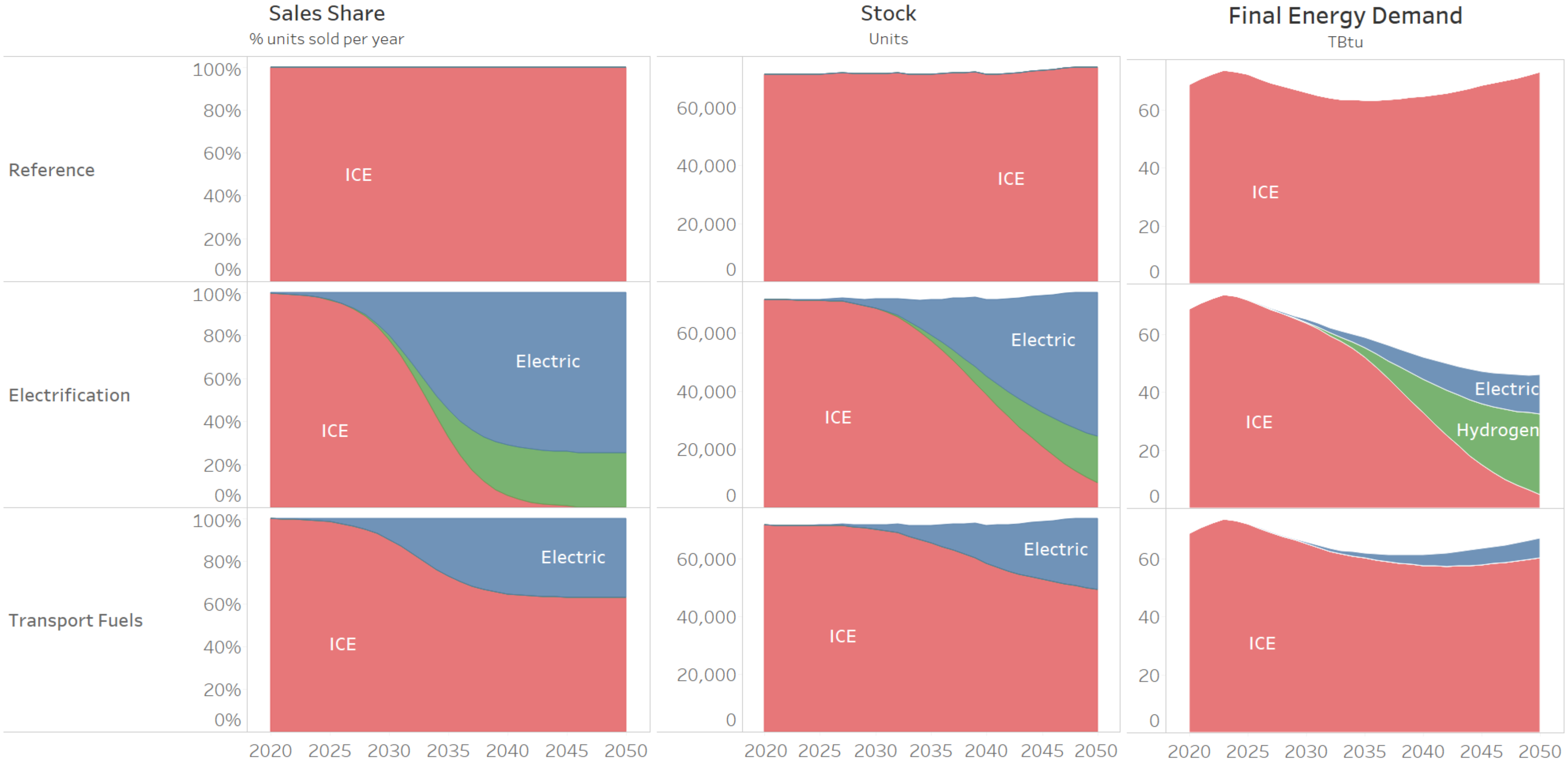
73% of vehicles are ICE in 2030 in the Electrification Case

Electrification Case final energy demand for fuels remains high in 2030: 74% of Reference in 2030

Heavy-Duty Vehicles: Hydrogen Demand in Long Distance by 2050

Adoption of hydrogen in long-haul and electric in long and short-haul drives changes in demand

Projected Sales, Stock, and Final Energy Demand



EVOLVED ENERGY RESEARCH

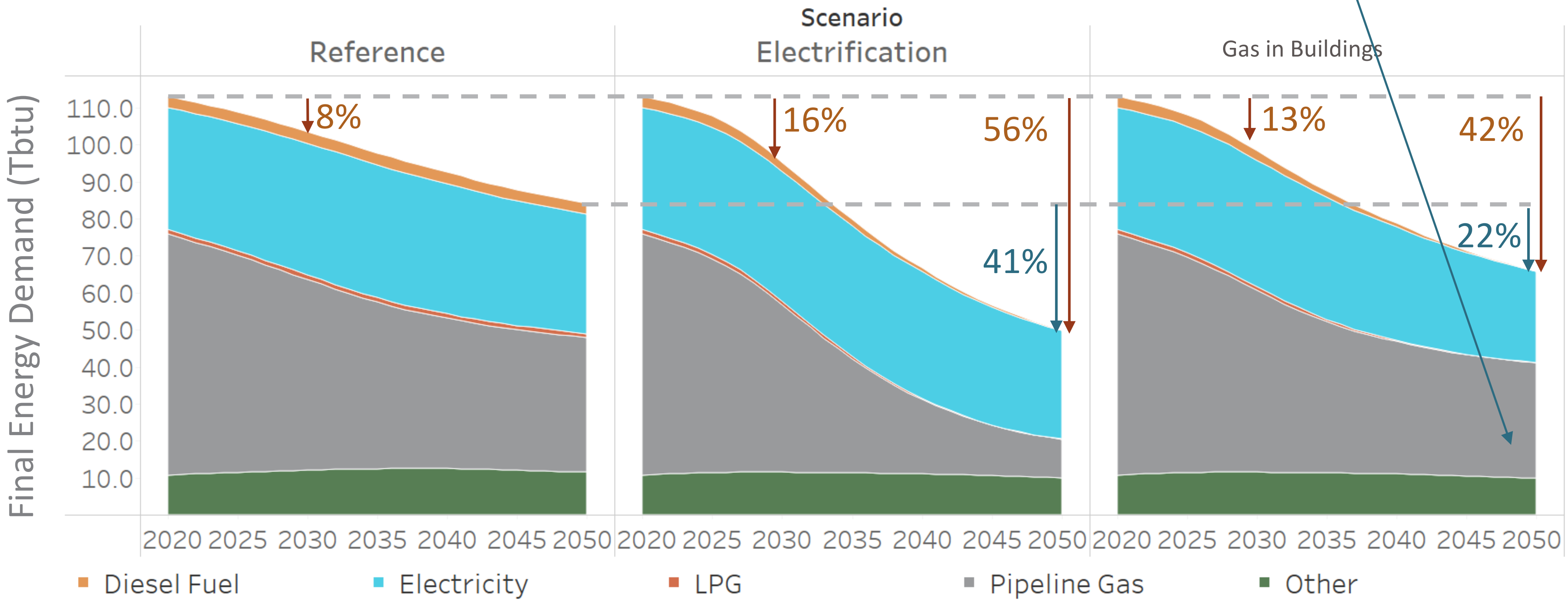
Residential Space Heating

More efficient home heating is driven by adoption of more efficient and/or electrified technologies

2030 Challenge: Delay in stock rollover turning sales into stock and energy changes

Significant reductions in energy demand by 2050 due to efficiency and electrification

Fuel use for heating can be served by fossil or clean fuel alternatives

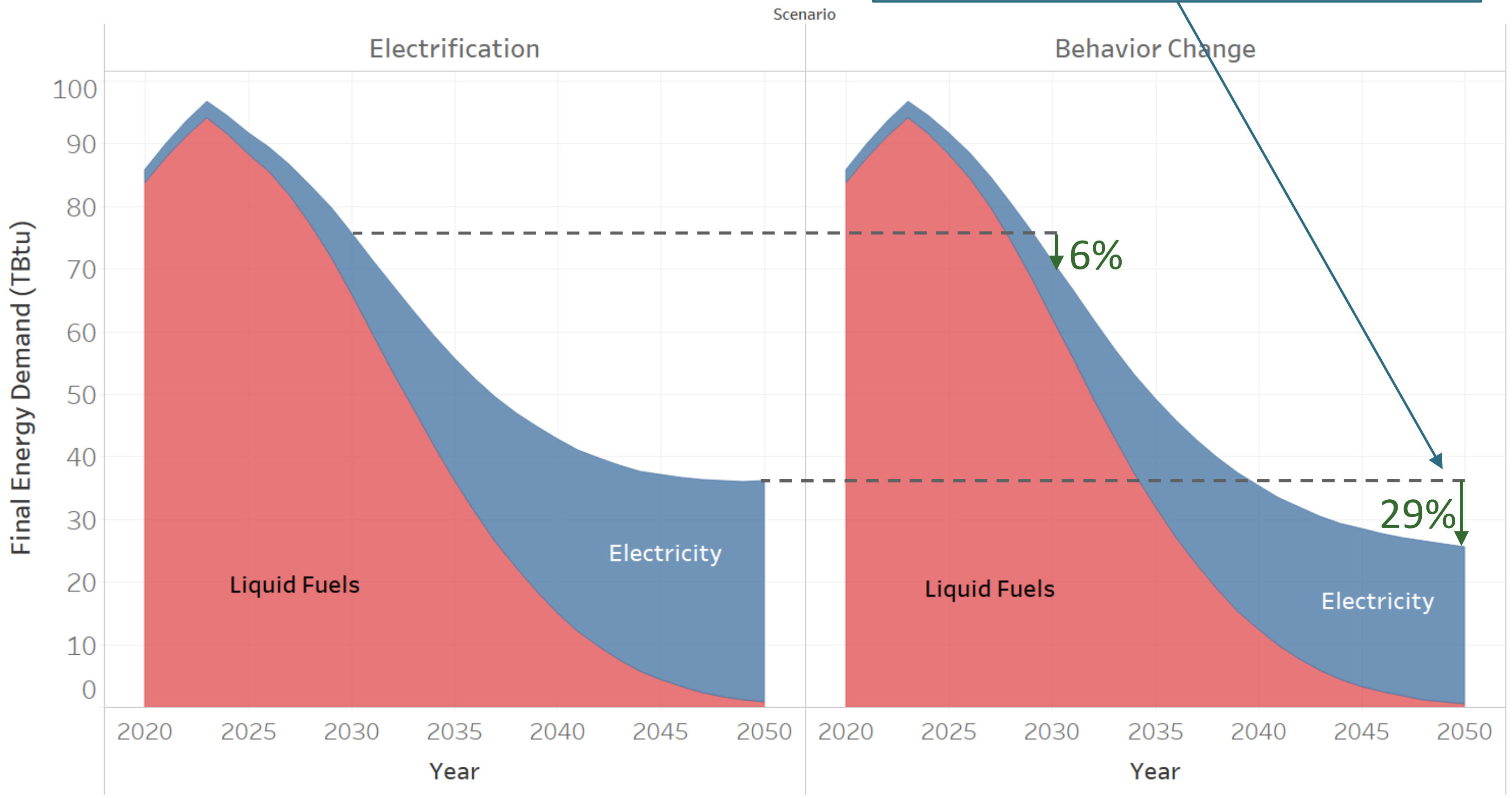


Behavior Change: Transportation

- VMT reductions increasing over time
  - 29% in light-duty vehicles by 2050
  - 15% in medium- and heavy-duty vehicles by 2050
- 2030 reductions are modest and provide little help to solving the 2030 Challenge
  - Are there more aggressive behavior change measures that can happen faster?

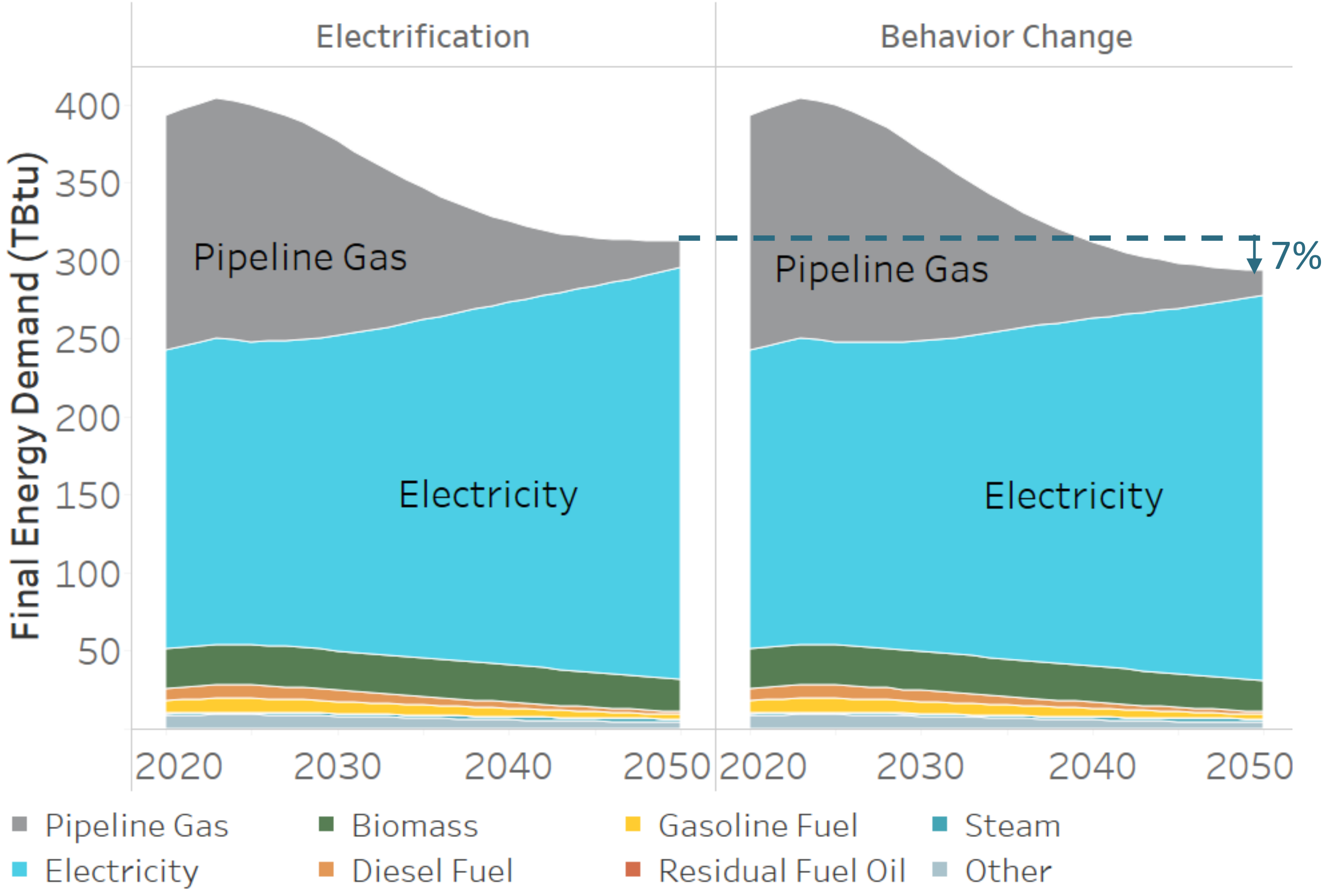
29% percent reduction in sales of fuels and electricity vs. Electrification Case by 2050

Example: Final Energy Demand from Light-Duty Autos



Behavior Change: Residential and Commercial

- Package of service demand measures for residential and commercial sectors
  - Reductions for several subsectors, including air conditioning, heating, lighting, and water heating
- Service demand measures achieve 7% overall reduction by 2050 in the residential and commercial sectors
  - 2% reduction in 2030



EVOLVED ENERGY RESEARCH

Supply Side

Electricity Capacity in Washington

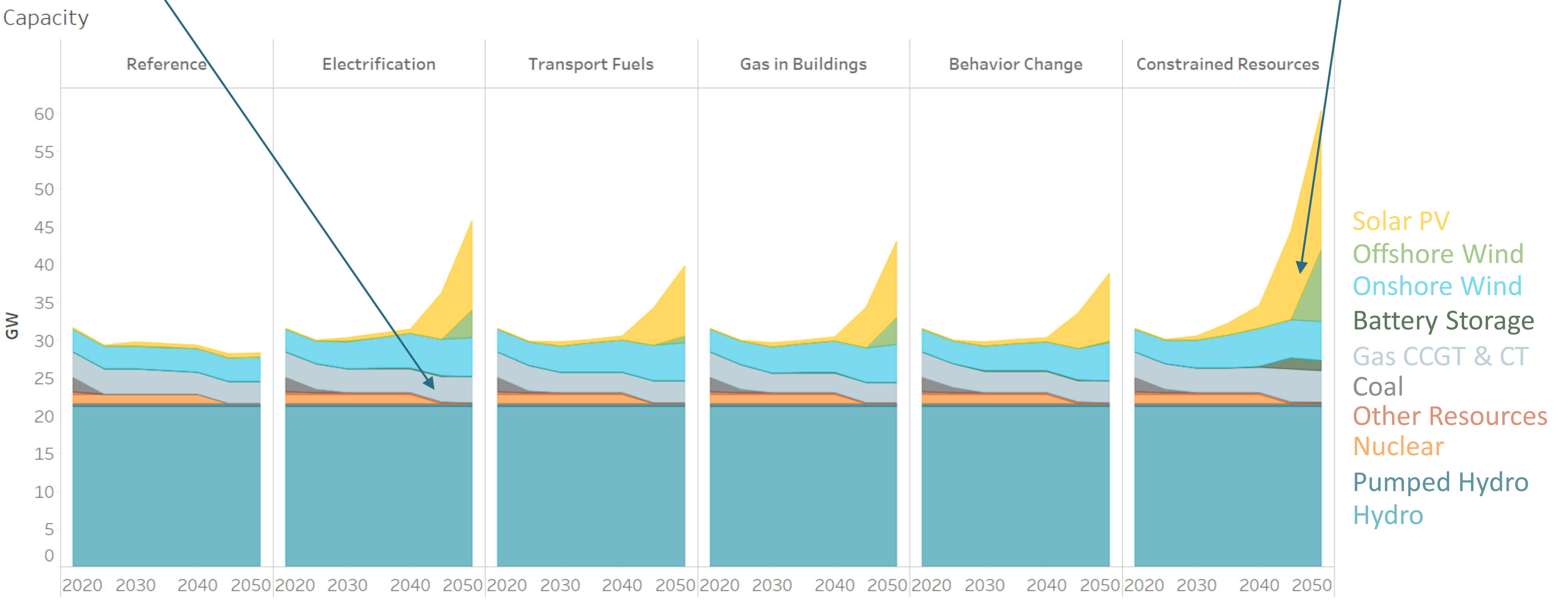
Washington relies heavily on imports of clean energy so capacity builds stay relatively flat

CGS not extended. O&M costs too high compared to alternatives

Similar builds across decarbonization cases other than Constrained Resource Case

Constrained Resource Case builds offshore wind and more solar to compensate for lost TX

Relatively little growth in capacity due to significantly increased imports



EVOLVED ENERGY RESEARCH

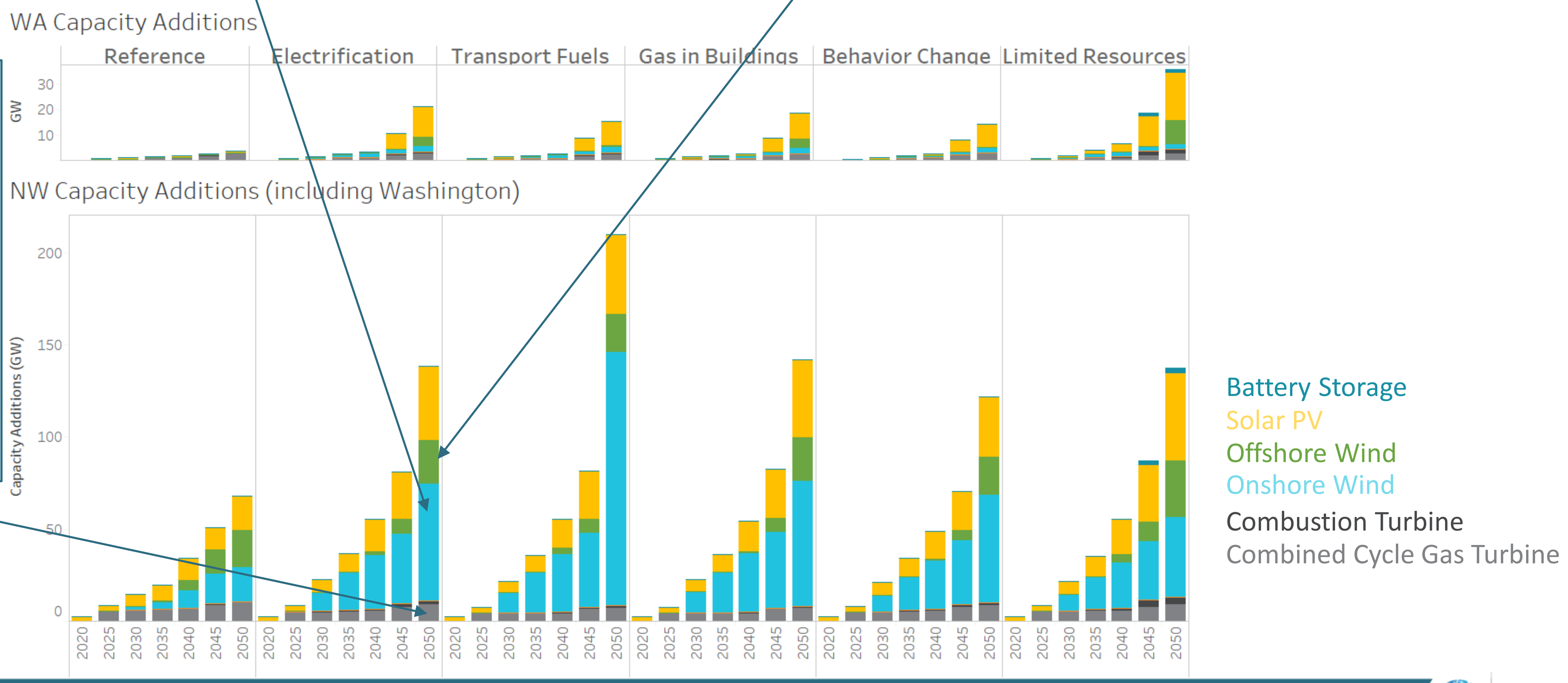
Capacity Additions in Washington and the Northwest

Washington part of a larger integrated electricity system

Wind-dominant system complements solar resource of the Southwest

Lower forecasted costs drive large offshore wind resource by 2050

11 GWs of gas capacity additions provide reliability in the Northwest, operated at low capacity factors. De minimus gas use in Washington, used only for rare reliability events



EVOLVED ENERGY RESEARCH

Generation and Load in Washington

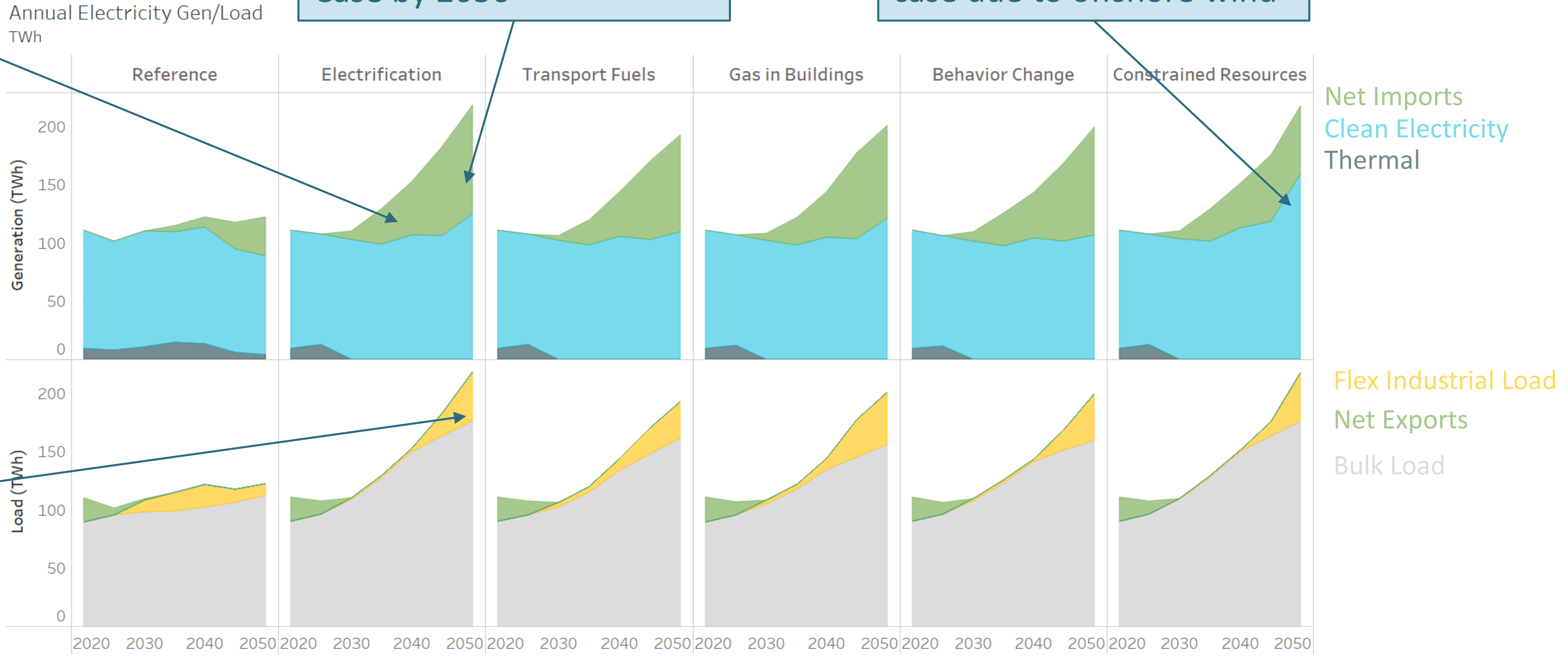
Increases in imports provide clean energy for expanding electricity sector

Growing reliance on clean imports to meet load growth, CETA, and emissions goals

Imports provide 43% of electricity in Electrification Case by 2050

Growth in clean electricity in Constrained Resources case due to offshore wind

Doubling of 2020 load by 2050, including new flexible loads (electrolysis, boilers)

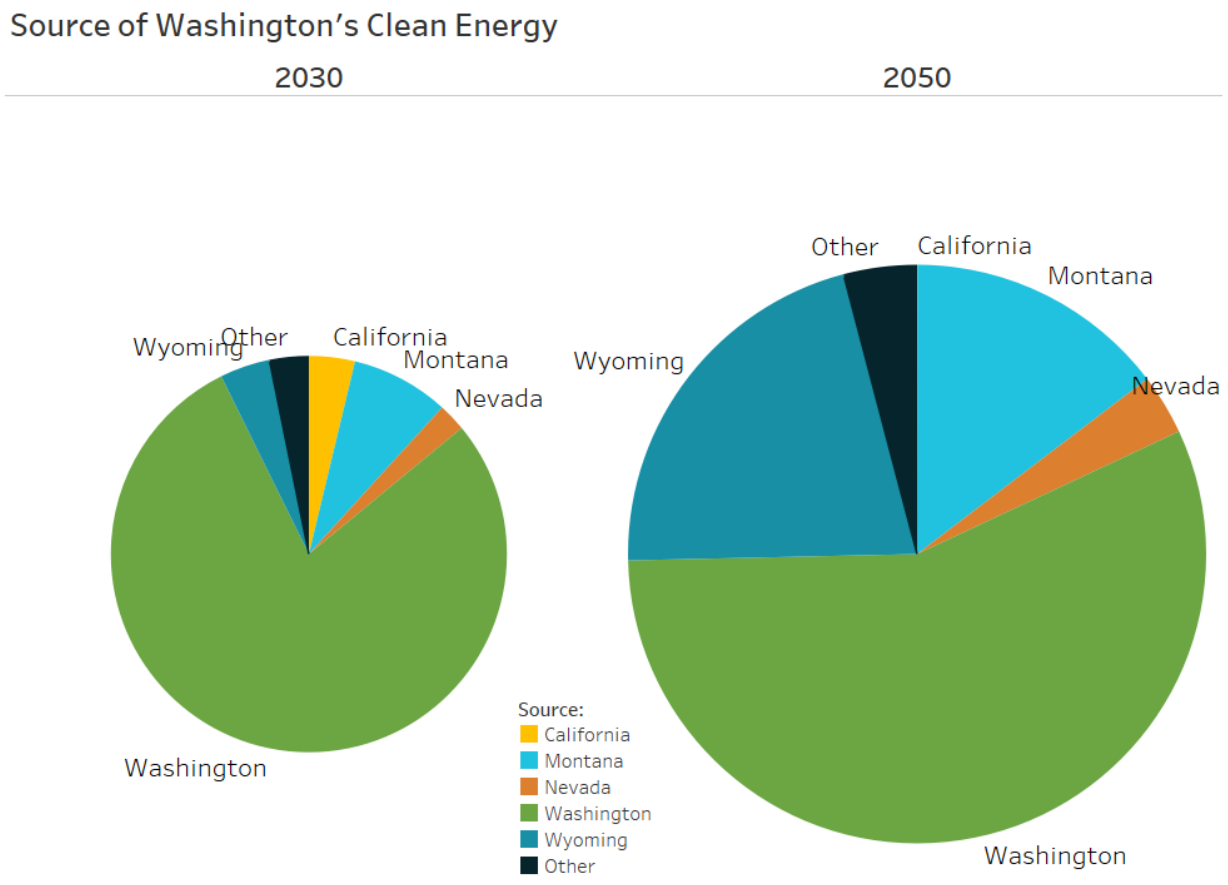


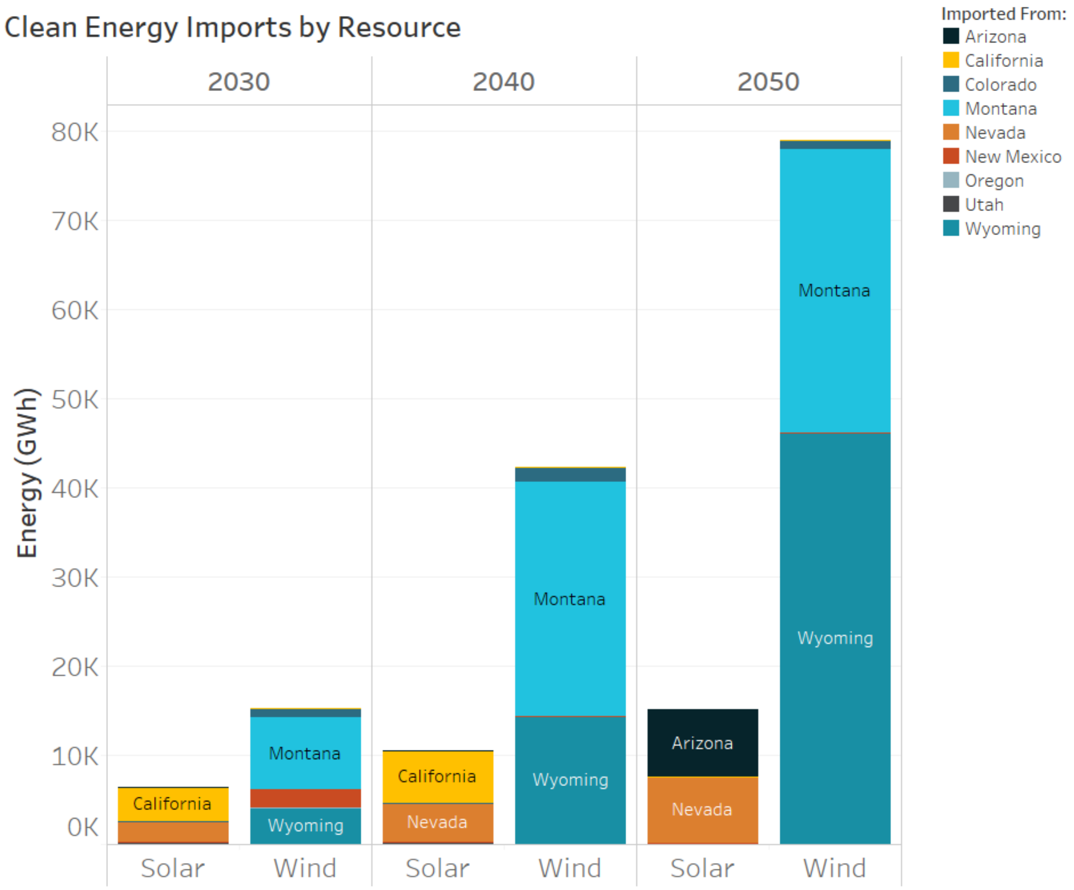
Gas exports not prohibited under CETA but model assumes emissions count towards state inventory in decarbonization cases

Where do Imports Come from?

Clean electricity imports from Electrification Case

High quality wind resources from Wyoming and Montana account for 36% of WA clean electricity in 2050



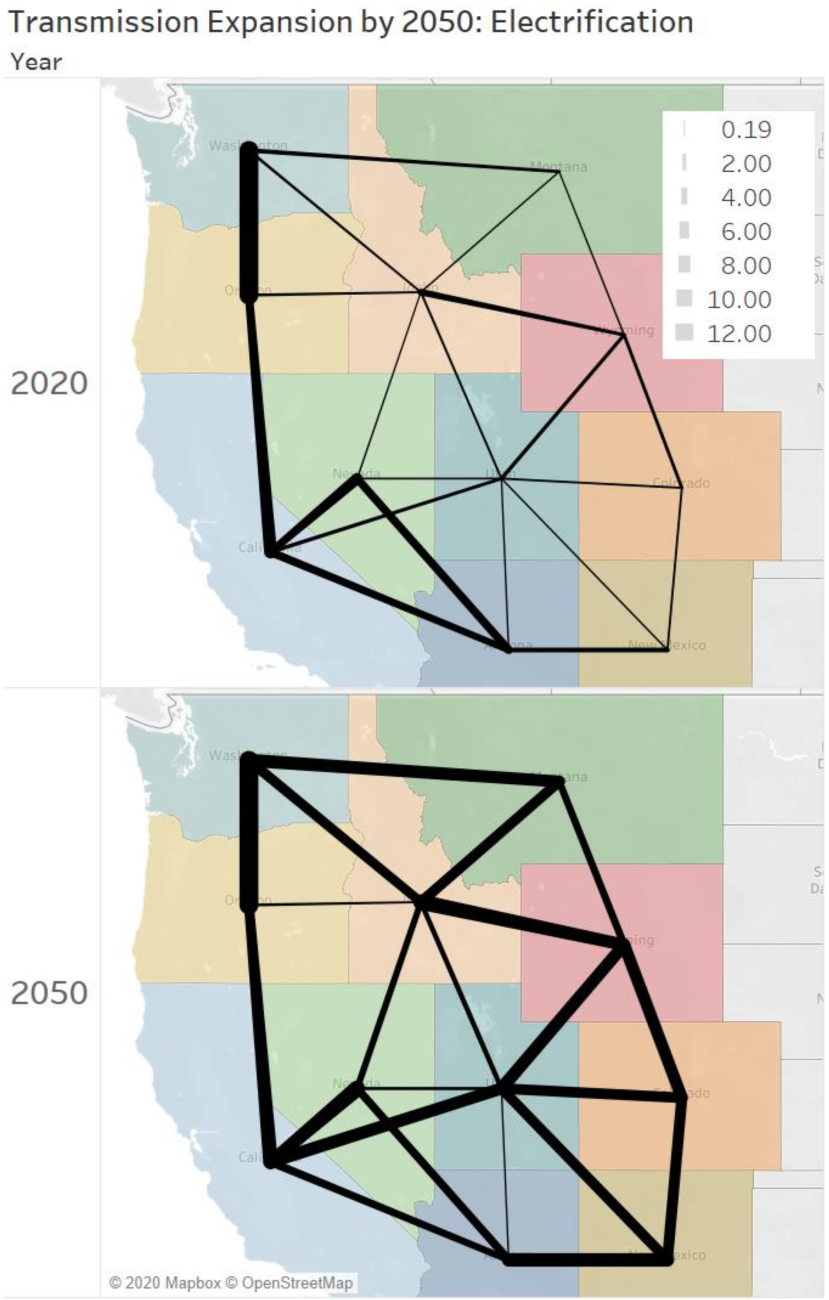


EVOLVED ENERGY RESEARCH

Expanding Transmission Facilitates Imports

Increased TX capacity required to import so much energy

- Expansion of up to 6 additional GWs of TX between states permitted in the model
  - MT->WA: Maximum 6 GW added by 2050
  - ID->WA: 5 GW added by 2050
- Western states become far more interconnected, taking advantage of least cost clean energy resources
- Additional solar and offshore wind build in Constrained Resources Case from inability to expand interties



EVOLVED ENERGY RESEARCH

Regional Capacity in 2050

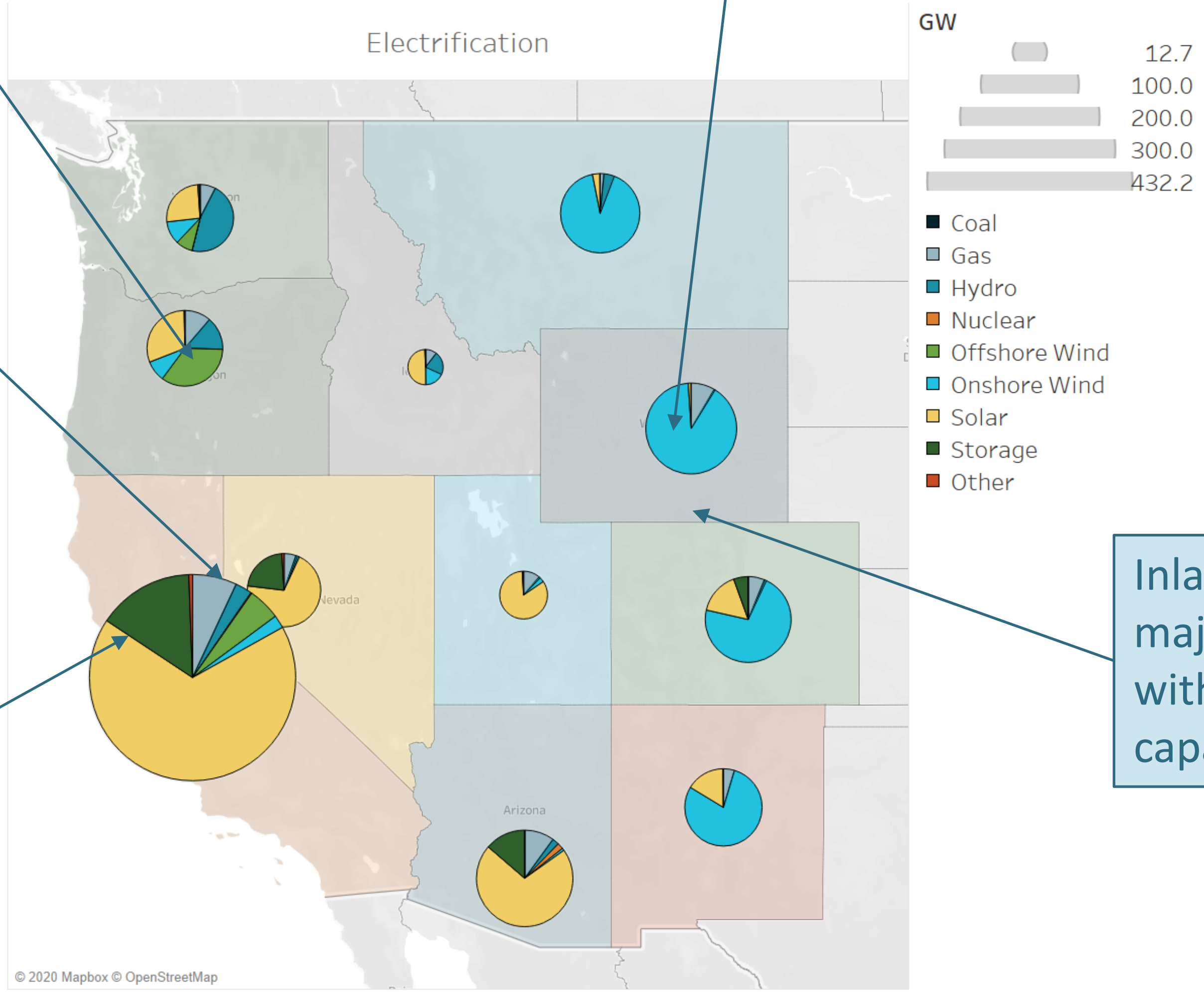
Electrification Case

Offshore wind built in Northwest and California to meet 2050 clean energy needs

Gas capacity provides reliability but very little energy in 2050

Large quantity of storage built in solar states for diurnal balancing

Large wind resource complements Southwestern solar resource



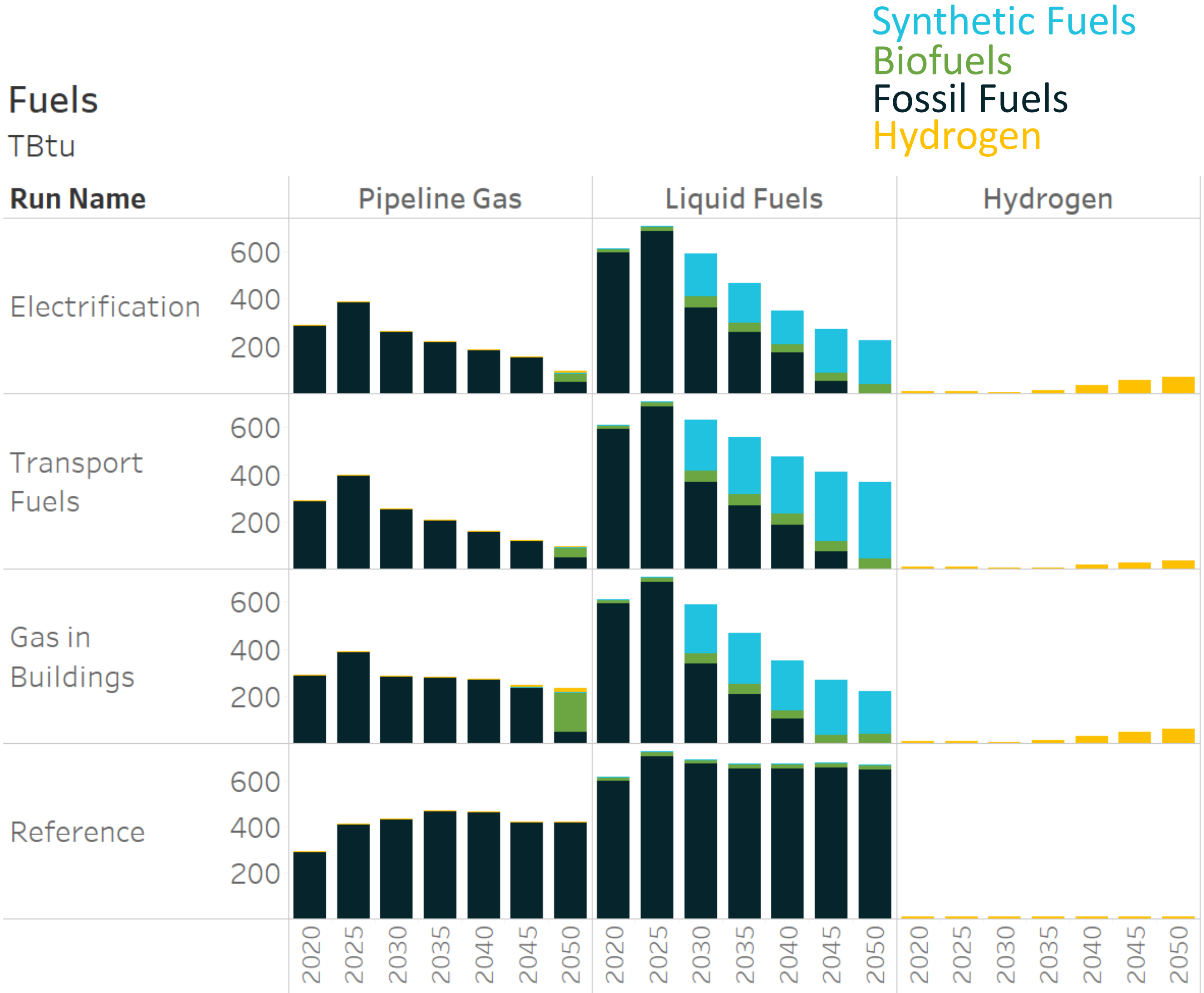
Inland states become major exporters of wind with majority wind capacity systems by 2050

EVOLVED ENERGY RESEARCH

Clean Fuels are Important to Reach Decarbonization Targets

Washington starts from a clean electricity sector and needs emissions reductions from other sectors

- All liquid fuels are fully decarbonized by 2050
- Decreasing fuel consumption over time with electrification and efficiency
- Liquid fuels (gasoline, diesel, jet fuel, others) significantly decarbonized by 2030 with synthetic and biofuels
  - Significant growth in clean fuels industries with few current commercial operations
  - Challenge for Washington to reach 2030 targets
- Hydrogen demand driven by long-haul trucking fleet
- Majority emissions in 2050 from natural gas in primary end uses



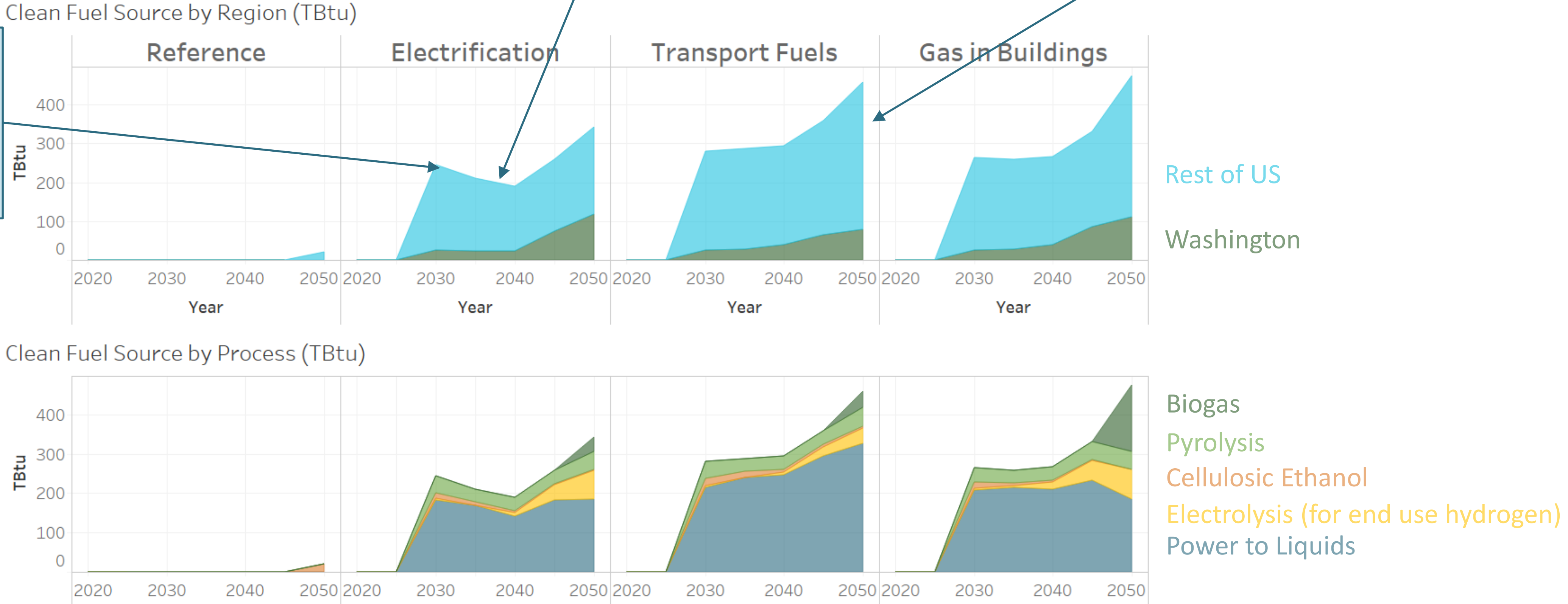
Where do Clean Fuels Come from?

Heavy reliance on clean fuel imports from the rest of the country in Washington

Decline as ICEs are electrified followed by increase to reach full decarbonization

34% higher clean fuel demand in Transport Case vs Electrification

2030 peak in clean fuel demand due to large number of ICEs still on the road



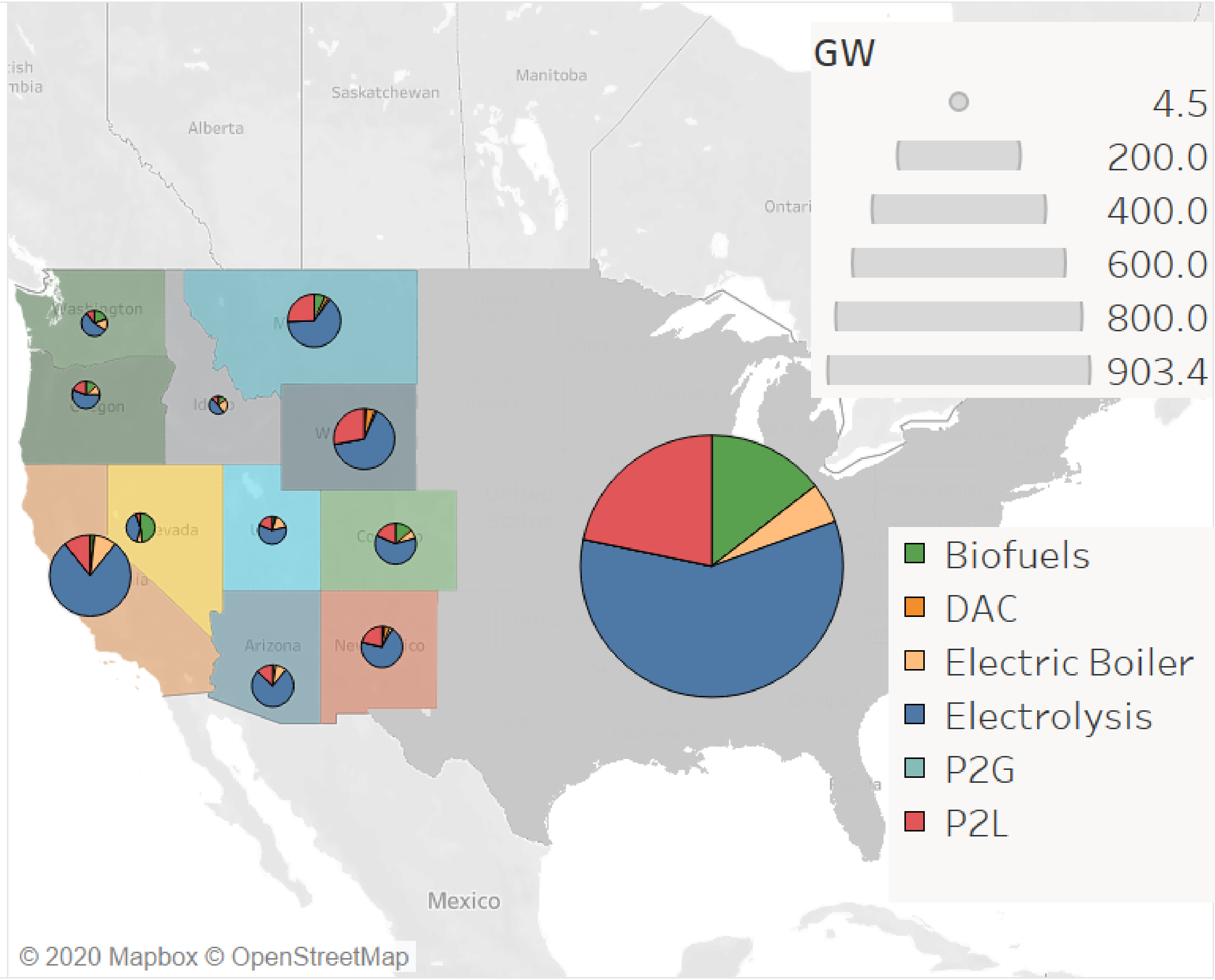
*Deployed fuels technology is sensitive to uncertain performance and cost assumptions. The type of fuels production processes used to displace fossil fuels will be a function of relative prices and the ability to retool existing refineries

EVOLVED ENERGY RESEARCH

Fuels Production Capacity by 2050

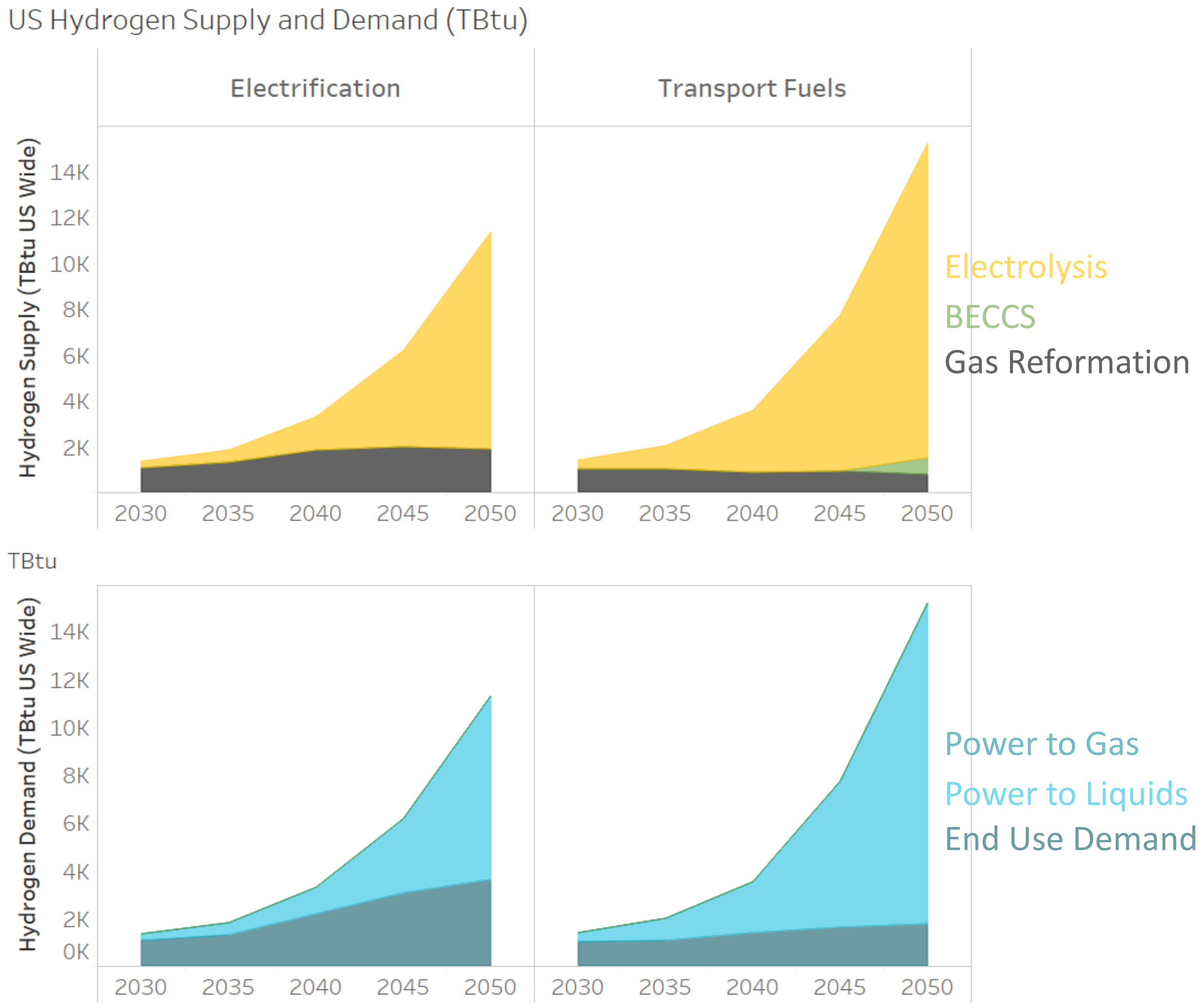
National production capacity to serve US needs: Electrification Case

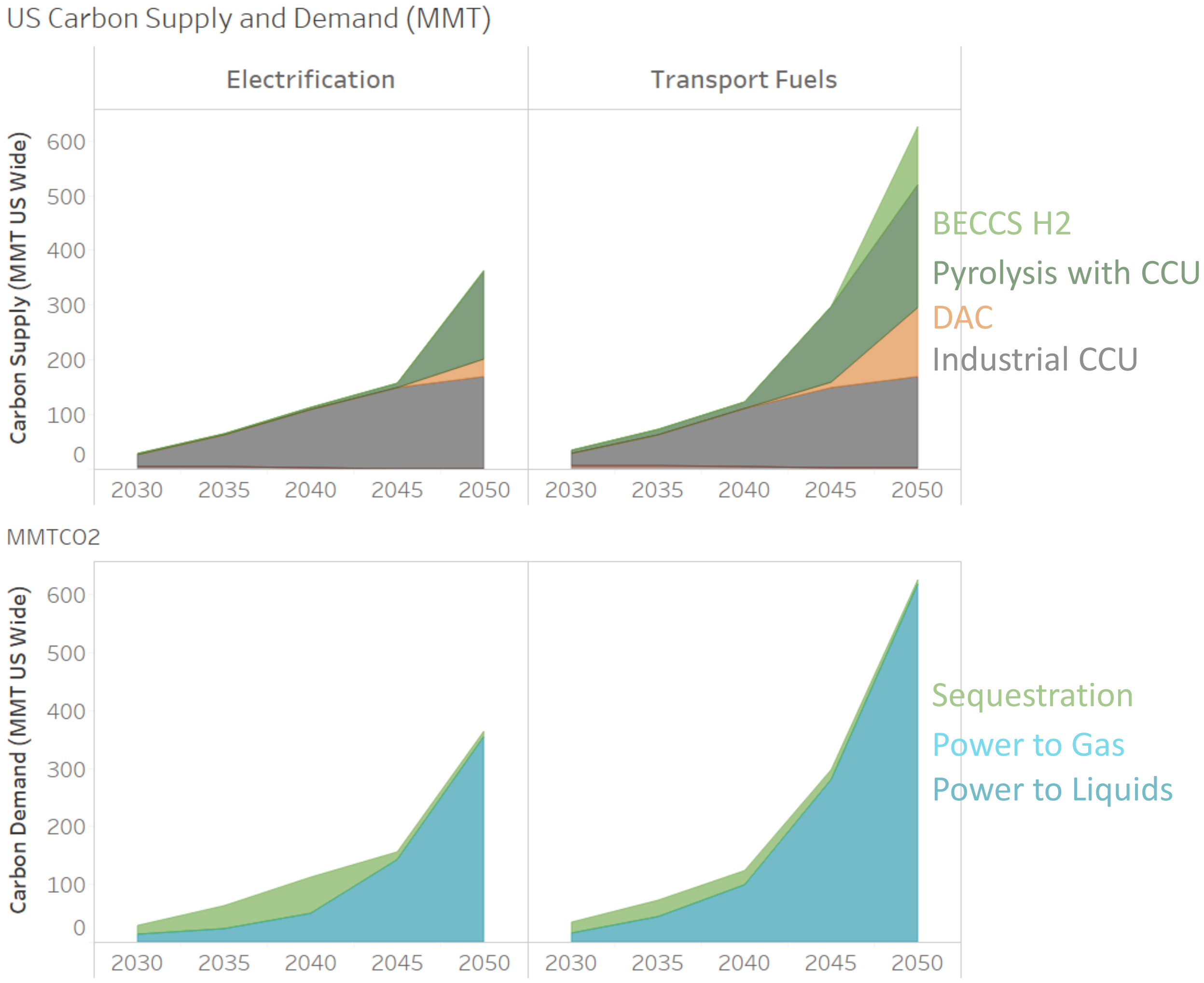
- Large total conversion capacity investment needed across the US to produce clean fuels
  - Includes demand from other states
- WA demand met with investment in fuels conversion infrastructure, biomass, and clean electricity
- Greater capacity investment needed to meet bio and synthetic fuels demand in Transport Fuels Case
  - Increased WA demand met with investment in fuels production infrastructure



National Fuels Industry in 2050: Hydrogen and Carbon

Building blocks of synthetic fuels, drives demand for biomass and renewable energy





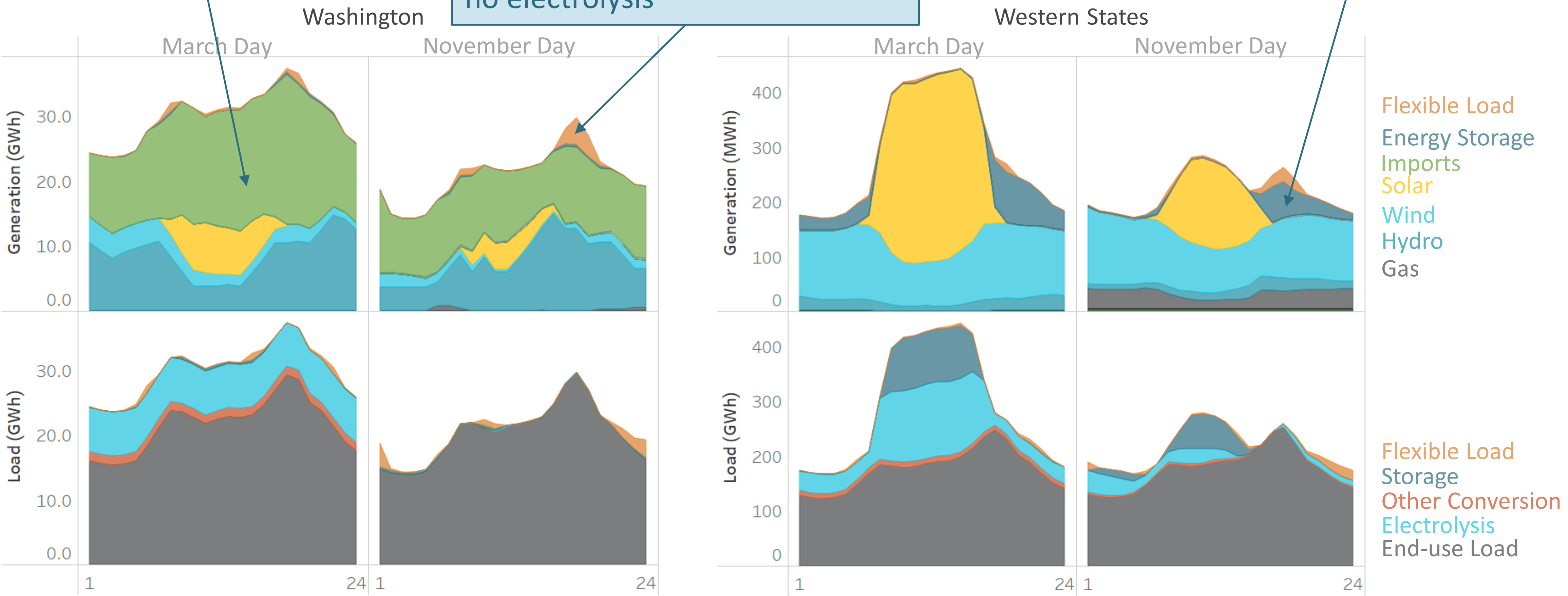
Balancing the System: High Energy and Low Energy Days in 2050

Washington relies on flexible loads, imports, hydro, and electrolysis to balance load

Unconstrained energy day in March: imports and electrolysis

Constrained energy day in November: flexible loads, clean gas generation, reduced imports, no electrolysis

Significant storage build in the rest of the west helps balance diurnal solar shape

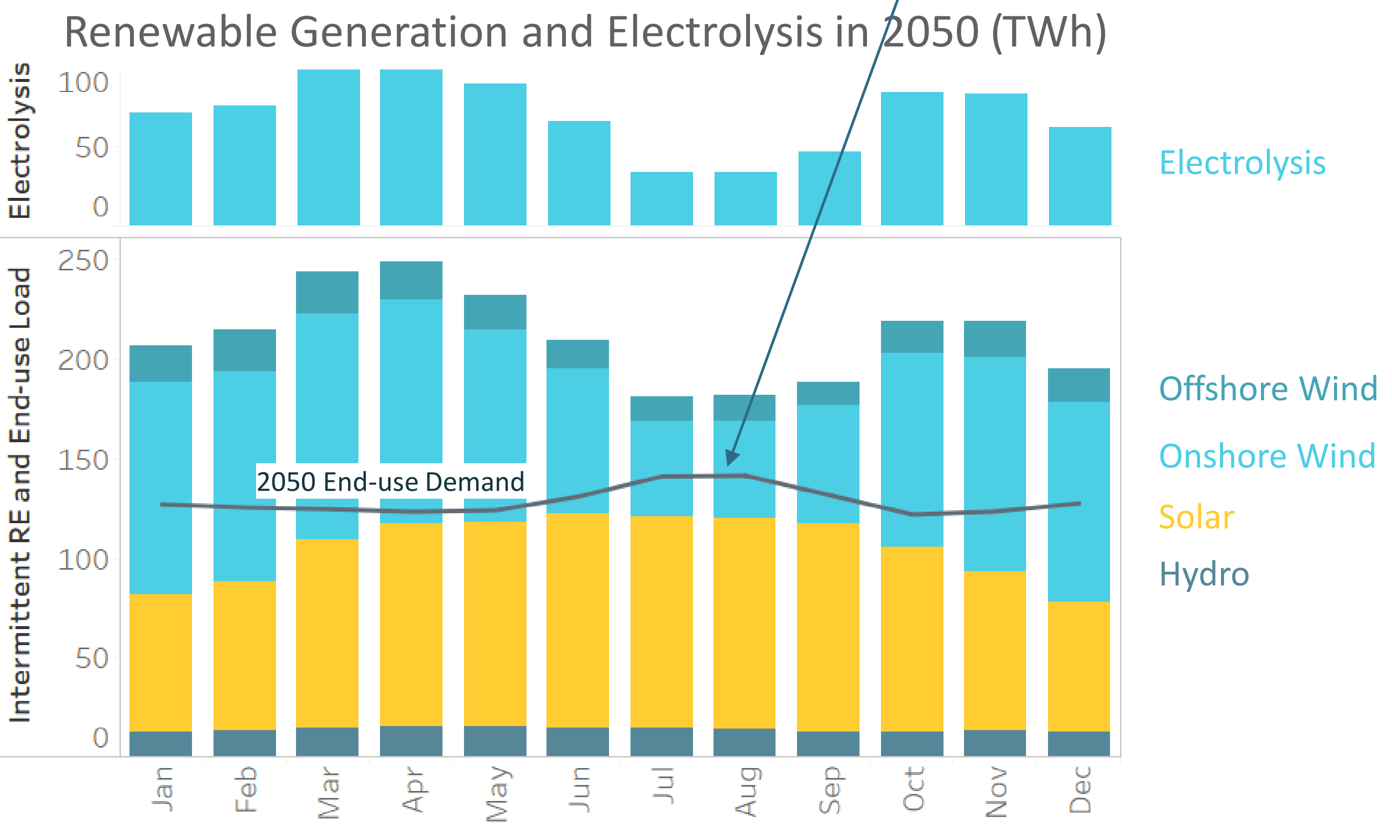


Seasonal Balancing in 2050: West Wide

Fuels production an integral part of balancing the electricity grid in 2050

- Seasonal imbalance of intermittent renewable energy availability
  - Shifting energy across seasons difficult with current storage technologies such as lithium ion
- Clean fuels demand is an opportunity for seasonal balancing
  - Store electricity in liquid fuels
- Large flexible electrolysis loads can help balance the grid over different time scales

Peak end-use demand in 2050 coincides with lowest renewable availability and decrease in fuels production



EVOLVED ENERGY RESEARCH

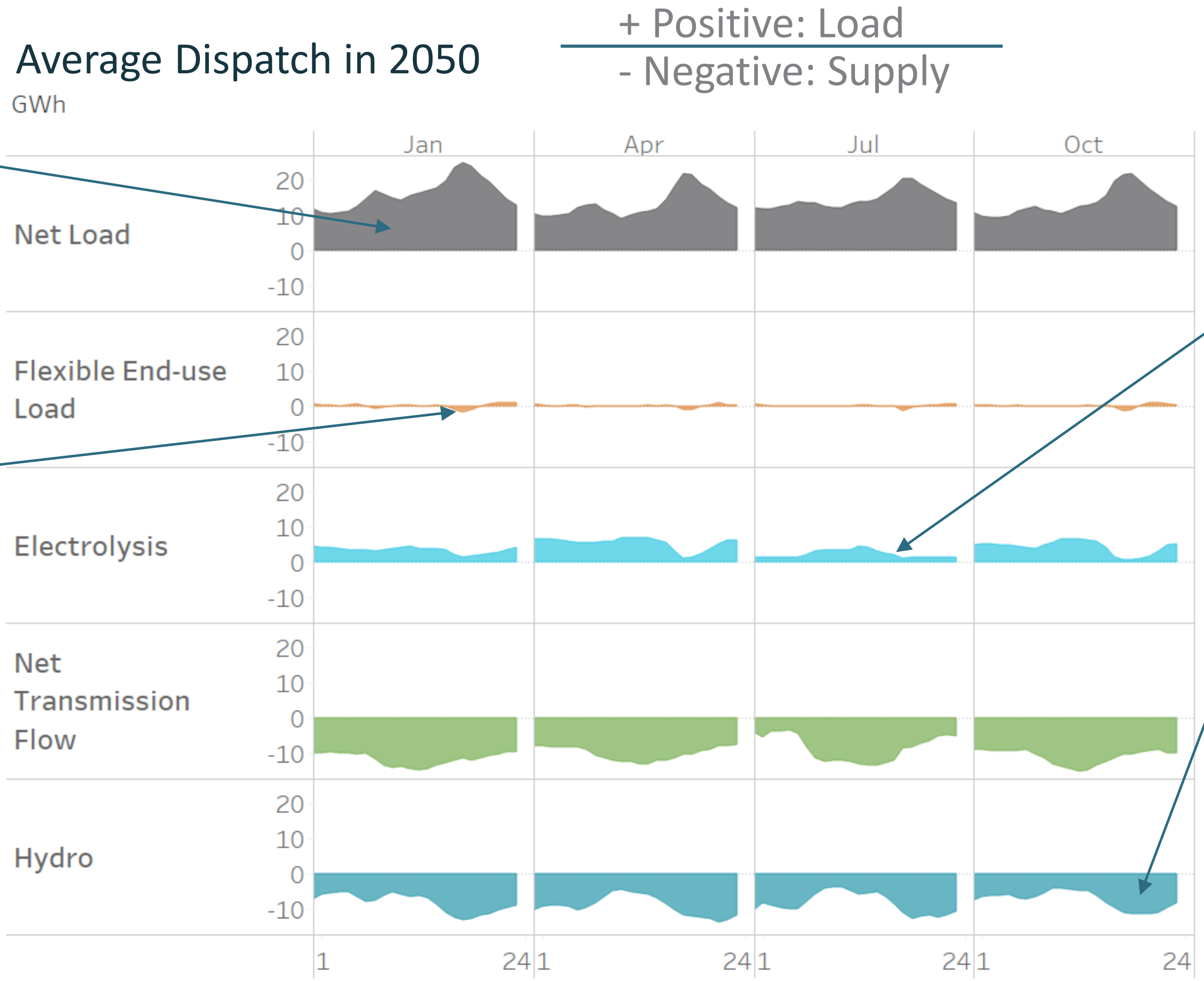
Washington’s Main Balancing Resources

Hydro, imports, electrolysis, and flexible loads are principal balancing resources in WA

Washington loads higher in the winter in contrast to the West as a whole

Flexible loads drive down peak loads

Gas generation provides capacity towards reliability requirements but does not deliver energy to Washington loads



Lower summer electrolysis due to reduced imports

Hydro operated flexibly, adhering to historically observed minimum flow, ramp, and energy constraints

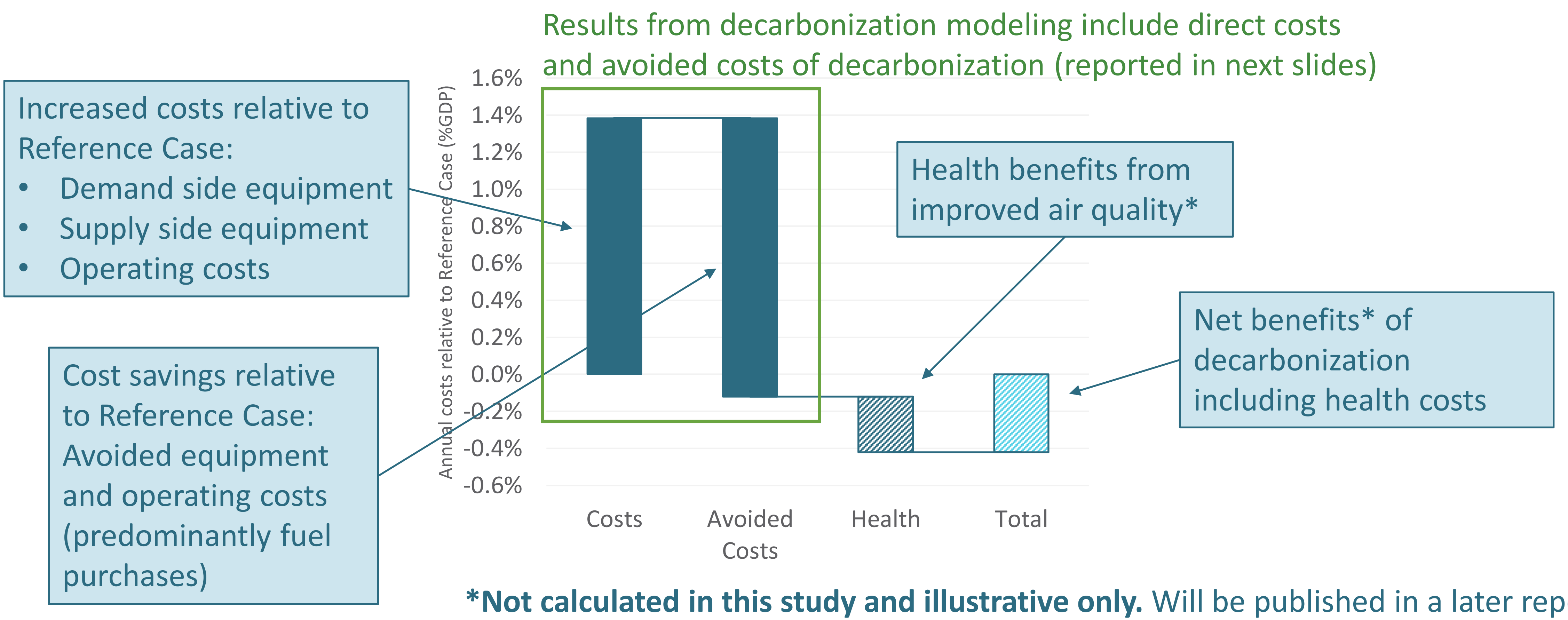
Takeaways by Scenario

- There are common trends across all scenarios
  - Strengthened Western grid to take advantage of resource and geographic diversity
  - Large build of solar in the Southwest and wind in the inland states (MT, WY)
  - A large clean fuels industry developed based on biofuels and hydrogen from electrolysis
- The scenarios show how Washington would respond differently under different conditions
  - The Transport Fuels Case drives a 32% increase in clean fuel use in the state with reduced electricity consumption
  - The Gas in Buildings Case drives clean gas production not seen in other cases to ensure decarbonization goals are met
  - The Behavior Change Case reduces Washington's need for clean energy and fuels
  - The Constrained Resources Case drives additional solar build and offshore wind in Washington
- Bottom line: how much do these solutions cost relative to one another?

Costs

Understanding the Costs of Decarbonization

Costs and benefits of Electrification Case relative Reference Case in 2050 shown



***Not calculated in this study and illustrative only.** Will be published in a later report and include the economic impacts of decarbonization. If the rest of the world takes similar action, Washington may receive additional climate mitigation benefits

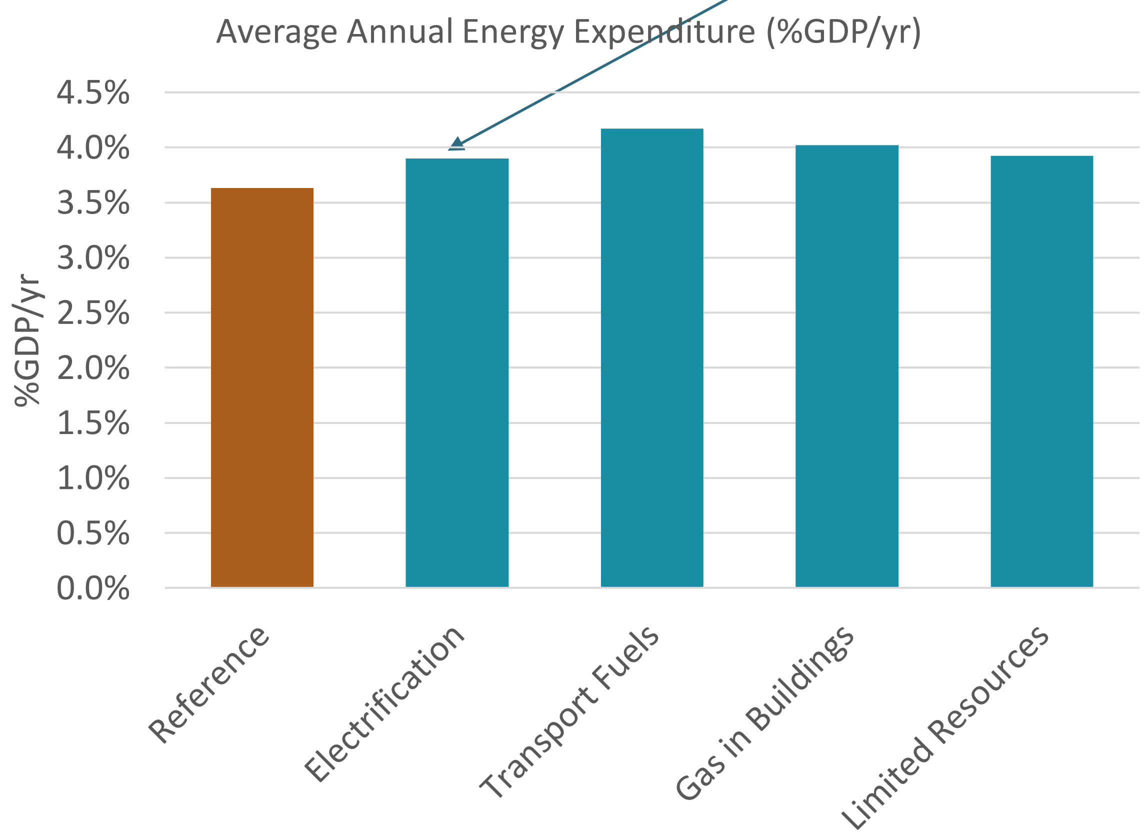
How much does Decarbonization Cost?

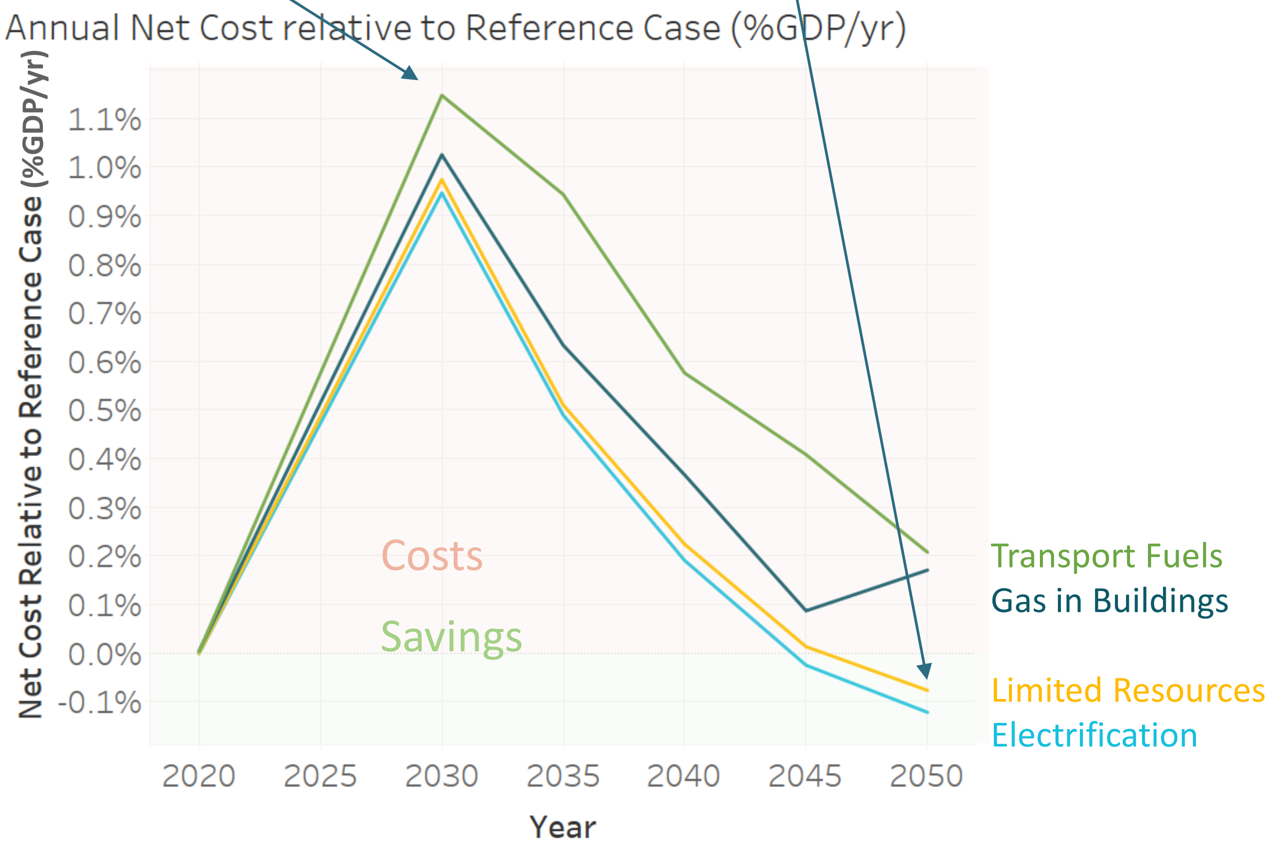
Increase in average energy expenditures vs Reference Case. Early costs followed by later savings

On average, spending slightly higher than Reference Case

Driven by increased costs to reach 2030 target

Decarbonization net benefit in the 2040s





Cost Drivers by Scenario

Scenario	Net Cost (GDP/2018$B/yr) Relative to Reference Scenario*: 2030	Net Cost (GDP/2018$B/yr) Relative to Reference Scenario*: 2050	Cost Drivers
Electrification	**0.9%/$6.8B**	**-0.1%/-$1.4B**	Rapid electrification and efficiency measures, transmission expansion, and access to out of state resources achieve the lowest costs of the scenarios run.
Transport Fuels	**1.0%/$8.2B**	**0.2%/$2.4B**	Reduced demand side equipment costs from slower transition to EVs and hydrogen vehicles. Increase in synthetic fuels production and subsequent larger electricity sector drives higher costs more than offsetting the benefits
Gas in Buildings	**1.0%/$7.3B**	**0.2%/$2.0B**	Not pursuing building electrification avoids investments in electricity distribution but relies on higher consumption of synthetic and biofuels. Net costs increase between 2045 and 2050 when biogas displaces fossil gas to achieve net zero
Constrained Resources	**1.0%/$7.0B**	**-0.1%/-$0.9B**	Cost impacts of not expanding transmission to other states are not significant, though WA still dependent on large quantities of imported energy. Additional investments in offshore wind in 2045 and 2050 are reasonably competitive based on forecasted prices.

*Costs reflect changes in investments in demand and supply side equipment, operations costs, and avoided fuel costs versus the Reference Scenario. Not reflective of ratepayer costs, economic impacts, health benefits, or climate mitigation.

Cost Components of Decarbonizing Relative to Reference Case

Costs by component

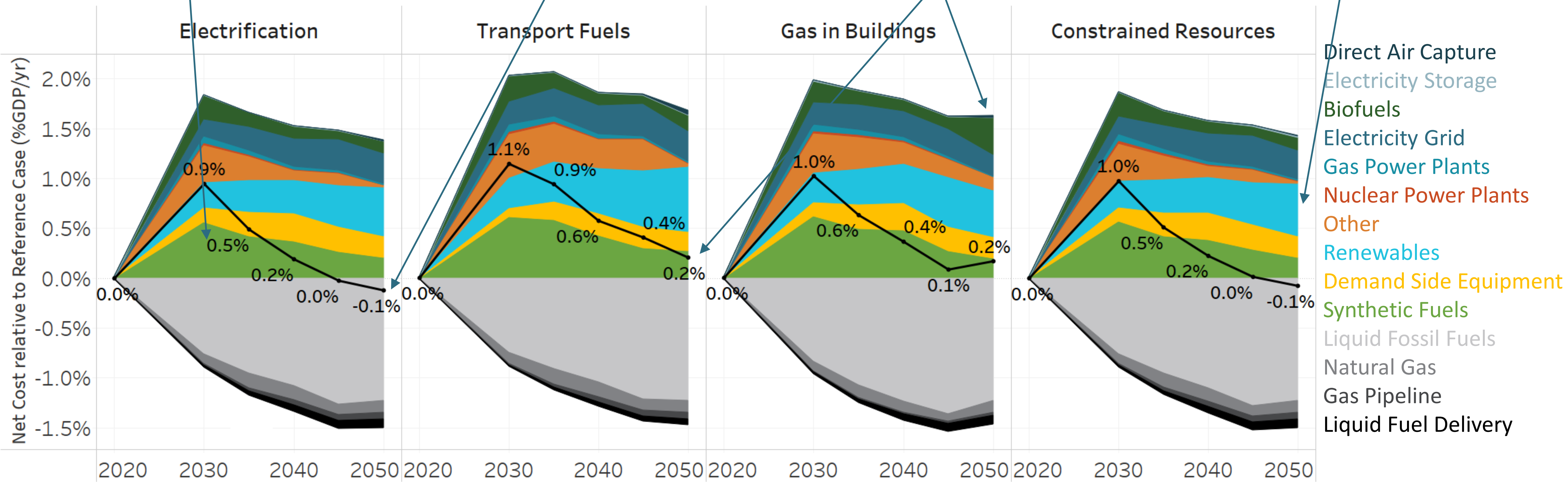
Cost increases in 2030 driven by demand for clean fuels

Projected technology cost decreases by 2050 result in net savings over reference case

Transport Fuels and Gas in Buildings: greater demand for synthetic and biofuels

Constrained Resources: Greater spend on renewables but reduced investment in new transmission

Annual Net Cost relative to Reference Case (%GDP/yr)



Historical Context: Total Energy Spending as Percentage of Washington GDP

Forecasted decarbonization spending stays below historical average in all years

Decarbonization spending in Electrification Case stays below historical average in all years

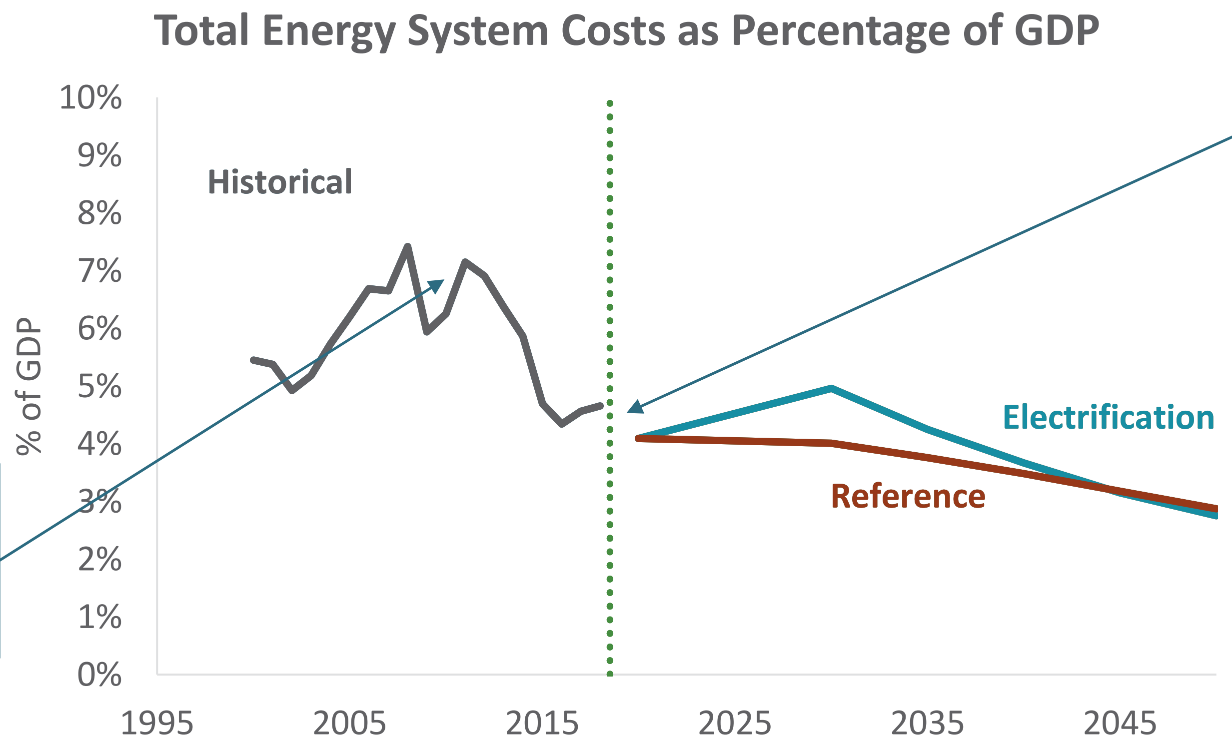
Significant increase in GDP spending in the near-term with benefits in the long-term

Drop in % of GDP from 2018 to 2020 because of COVID: 0.3% GDP contraction* and assumed 10% drop in energy demand

Historical energy spending between 4-8% of GDP

Spikes in GDP from fossil fuel price volatility and the 2008 recession

GDP rebound in 2021 of 3.9%. GDP growth rates annually of between 2% and 3%*

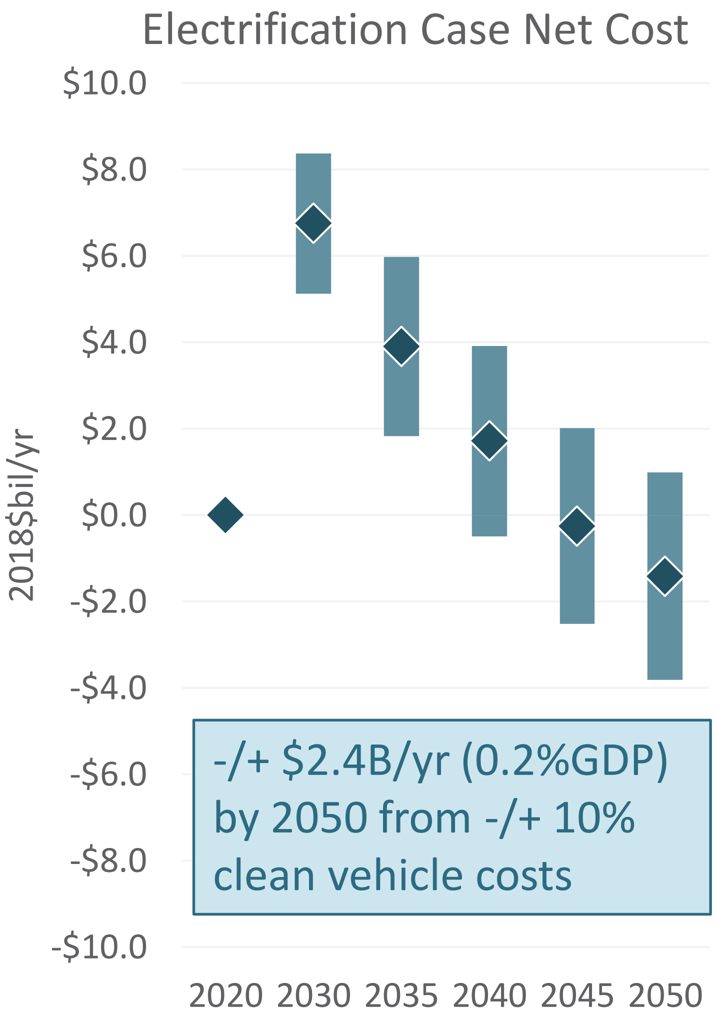


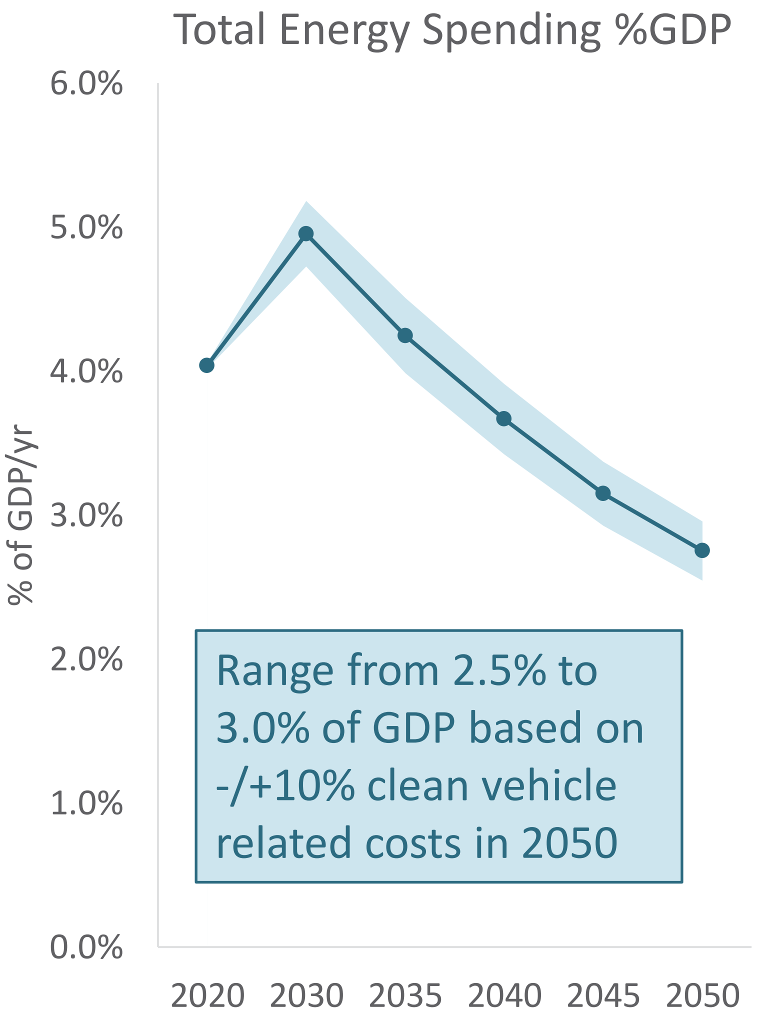
*GDP projections for Washington sourced from REMI

Uncertainty in Cost Inputs

Decarbonization costs are uncertain

- Increasing uncertainty over time
- Results are particularly sensitive to some inputs, e.g.,
  - Fossil fuel costs
  - Vehicle prices
- Example: +/-10% on clean vehicle and vehicle infrastructure costs (EVs and hydrogen)
- Decarbonization acts as hedge against fuel prices from volatility in international markets





Behavior Change Case

Significant savings but unknown costs. Further work: what service demand options does the state have?

Scenario	Net Cost (GDP/2018$B/yr) Relative to Reference Case*: 2030	2050	Cost Drivers
Electrification	**0.9%/$6.8B**	**-0.1%/-$1.4B**	Rapid electrification and efficiency measures, transmission expansion, and access to out of state resources achieve the lowest costs of the scenarios run.
Behavior Change case does not include the costs of achieving VMT reductions			
Behavior Change	**0.8%/$6.0B**	**-0.3%/-$3.0B**	Benefits of 29% VMT and 7% res/com reduction ~$1.5B/yr (0.2%GDP) by 2050. Benefits would be even higher with reduced vehicle sales as well.

- 2030 behavior change impact is 6% VMT and 2% in res/com, so relatively small changes have significant value
- Not directly comparable to the other decarbonization cases because the results do not include the cost of achieving behavior change
- Results show the value of achieving service demand reductions
  - Spending up to the value of the reductions to achieve them would be cost effective, i.e. can spending <$1.5B/yr by 2050 achieve 29% VMT and 7% res/com reductions?
  - Additional benefits if vehicle sales as well as VMT were reduced
  - Not accounting for ancillary benefits such as reduced road maintenance, local pollution etc.
- Topics for further study: what types of measures could achieve service demand reductions cost effectively? How fast could these be implemented?

Key Findings

Key Findings

- Challenges of decarbonization are pace of action in the near-term (2030) and scale in the long-term (2050)
- Washington's electricity supply emitted 16.2 MMT CO2e in 2018 of the 44.8 MMT CO_2e required to reach the 2030 goal, so decarbonizing the 2018 electricity supply cannot play a large role in accomplishing the 2030 goal
- Even with GHG-neutral electricity under CETA, 2030 emissions target is challenging
  - Focus must be on demand side and fuels: Energy efficiency, electrification, decarbonized fuels
  - Stock rollover of technologies with long lives raise the question of how much efficiency and electrification can be accomplished in 10 years
- Some actions to meet 2030 target may not contribute to 2050 target
  - Diesel and gasoline use reduces dramatically with electrification of transportation by 2050
  - Infrastructure to decarbonize fuels should focus on fuels that remain in the economy through 2050
- Washington requires regional energy solutions to accomplish the emissions targets
  - Significant imports of clean energy in the form of electricity and fuels are present in all scenarios

Key Findings

- Significant imports of clean energy from wind-rich states support Washington's electricity needs – 43% by 2050 in Electrification Case
  - Regional coordination is key to Washington and Western decarbonization
- Synthetic fuels production plays a major role in decarbonizing Washington's economy as well as balancing the electricity grid
  - Balancing through electrolysis in the state and as part of the regional balancing solution
  - Early need for clean fuels to meet Washington targets, displacing transport and industrial fuels
- 11 GW (3 GW in Washington) of natural gas plants added in the Northwest for reliability by 2050. Washington burn de minimus quantities of gas after 2030 because of the need to reduce emissions and the large balancing capabilities of both the hydro system and electrolysis built for fuels production by 2030
  - However, these gas generators provide capacity during infrequent reliability events. CETA requires 100% clean electricity delivered to loads by 2045 in Washington. By 2045, all gas burned during these events is clean gas
- Washington state resource balancing provided by hydro, electrolysis, flexible loads, and imports as part of the integrated balancing capability of the rest of the West

Transportation

- Transportation electrification key to cost effectively decarbonizing Washington's economy
  - Average spend 0.2% of GDP more annually in Transport Fuels Case than in Electrification Case
- 2030 decarbonization costs driven by expensive clean fuels production
  - Early electrification measures avoid investment in hydrogen and associated infrastructure and the energy needed for it. Early action that reduces clean fuel demand has significant benefits
- Demand for gasoline and diesel decrease through electrification, whereas jet fuel remains harder to replace because of technological challenges
  - Focusing early clean fuel production on jet fuel may avoid stranding assets or retooling because long-term demand is higher probability
- Small changes in vehicle cost projections have large impacts on forecasted decarbonization costs
  - Vehicles are the largest energy consuming infrastructure purchase that many customers and businesses make.

Buildings

- Electrification of buildings lowers costs over retaining gas use
  - Long-term benefits of avoiding the need for clean gas: 0.2% of GDP savings annually in Electrification case vs. Gas in Buildings case by 2050
- Investment in clean fuels in 2030 can be avoided through greater efficiency and electrification in buildings
  - Stock rollover of technologies limits action that can be taken prior to 2030
  - Benefits of measures in buildings that reduce energy use is high in the near-term and long-term, supporting early and aggressive action
- Not all efficiency measures will be cost effective
  - However cost effectiveness should be evaluated in the context of the lifetime of the measure and the changing environment it will encounter, including the higher avoided costs from marginal clean fuels production in 2030 and beyond

Industry

- Measures taken to reduce energy consumption in industry are not well defined in the model due to lack of information about the opportunities
  - Results indicate the value of the opportunities for industry rather than suggested policy
- Large quantities of synthetic fuels are required in 2030 to reach the 45% target
  - Avoided cost of carbon reductions from industry in 2030 comes from avoiding synthetic fuel production
  - Cost effective electrification and/or efficiency measures that avoid fuels production will lower total decarbonization costs
- A significant fraction of the carbon stream used to produce synthetic fuels comes from industrial carbon capture
  - Is there potential for that in Washington and if so, how much and how fast can it be implemented?
- New industrial flexible loads are a major new industry in the future, producing hydrogen through electrolysis

Electricity

- Expanding the electricity sector by electrifying end uses is a cost effective decarbonization strategy
  - Demand for electricity increase by 97% over 2020 levels and 143% including new industrial loads (e.g., electrolysis) by 2050 in the Electrification Case
- Washington meets these new loads by increasing clean energy imports through 2040 from low cost renewable sources, primarily Montana and Wyoming wind
  - In state solar and offshore wind is built in 2045 and 2050 to supplement out of state energy
  - 43% of electricity comes from out of state in 2050 of which 36% is from Montana and Wyoming wind
- Lowest cost compliance with electricity and economy wide clean energy targets requires these large imports of clean energy from other states
  - Increased flows of energy across multiple states/balancing areas
  - Investment in new transmission
  - Efficient use of imports as balancing resource, single BA operations West wide assumed in the model

Electricity

- Transmission expansion across the West is a key part of lowering costs in the model results
  - Expanding transmission, however, is a long, difficult process with many hurdles to overcome
  - Early planning and determination of feasible projects and project costs should begin now to prepare for transmission in the future
- Savings from expanding WA interties are relatively low ($0.5B/yr by 2050) however planning for expansion of the interties is recommended
  - Planning for expansion of WA transmission is shown to be cost effective and retains optionality in decarbonizing the grid
  - Optionality leaves more than one pathway open in case of unforeseen hurdles in other pathways

Electricity

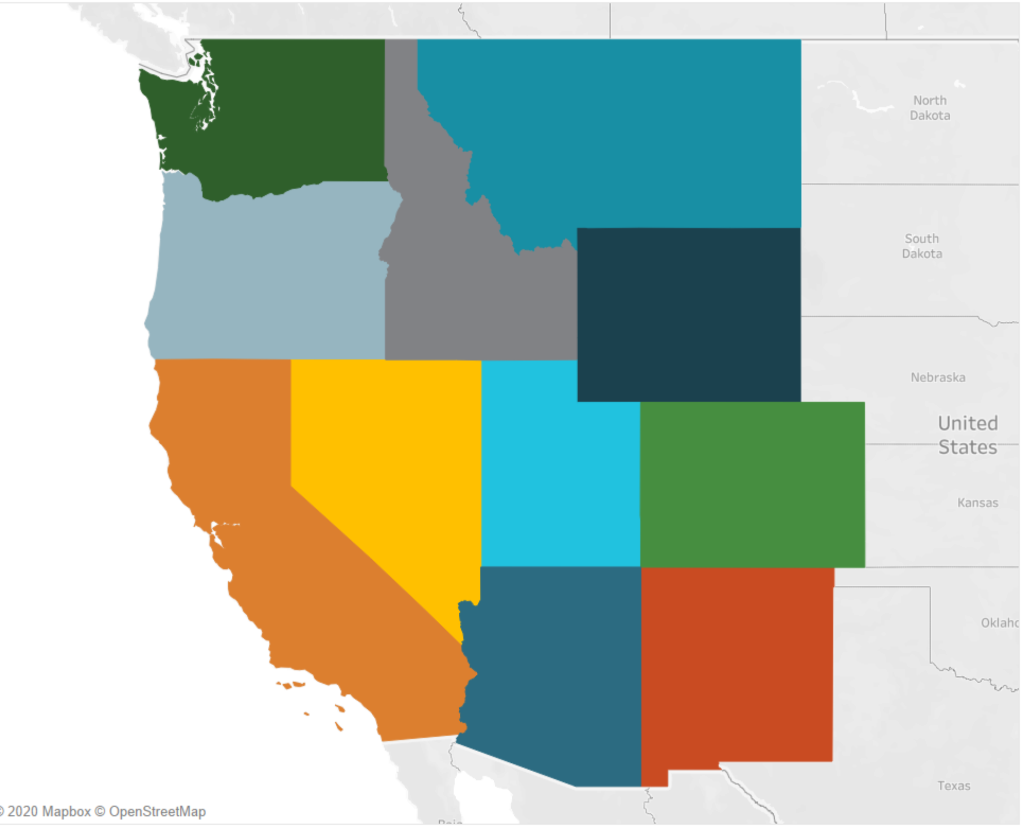
- The emissions cap drives thermal generation to negligible amounts in 2030 and beyond
  - The Constrained Resource Case continues to burn small amounts of gas in state for reliability. By 2045, this gas is 100% clean
- 11 GW of gas capacity exists in the Northwest by 2050, with 3 GW in Washington in the Electrification Case
  - Washington gas capacity is not used other than at low capacity factors in the Constrained Resource Case when clean gas is burned, but offers low cost capacity for meeting reliability requirements
- In the Reference Case, electricity is generated from gas in Washington and exported to the rest of the West. By 2045, all electricity delivered to Washington loads is 100% clean.

Electricity

- In the Electrification and other decarbonization cases, a combination of hydro, flexible loads, electrolysis, and transmission flows balance loads in Washington by 2050
  - Integrated Western grid balancing using strengthened interties
- Seasonal imbalances of wind and solar become more impactful on system balancing needs across the West as the grid becomes cleaner
  - Shifting energy across seasons is difficult with current storage technologies such as lithium ion
  - Clean fuels demand is an opportunity for seasonal balancing
    - Store energy from times of plentiful renewable production using electrolysis to produce liquid fuels that can be stored cheaply
    - Back off electrolysis loads during times of limited renewable production, using these new large flexible loads to balance the grid and stored fuels for liquid fuel end uses

Appendix: Study scope and methodology

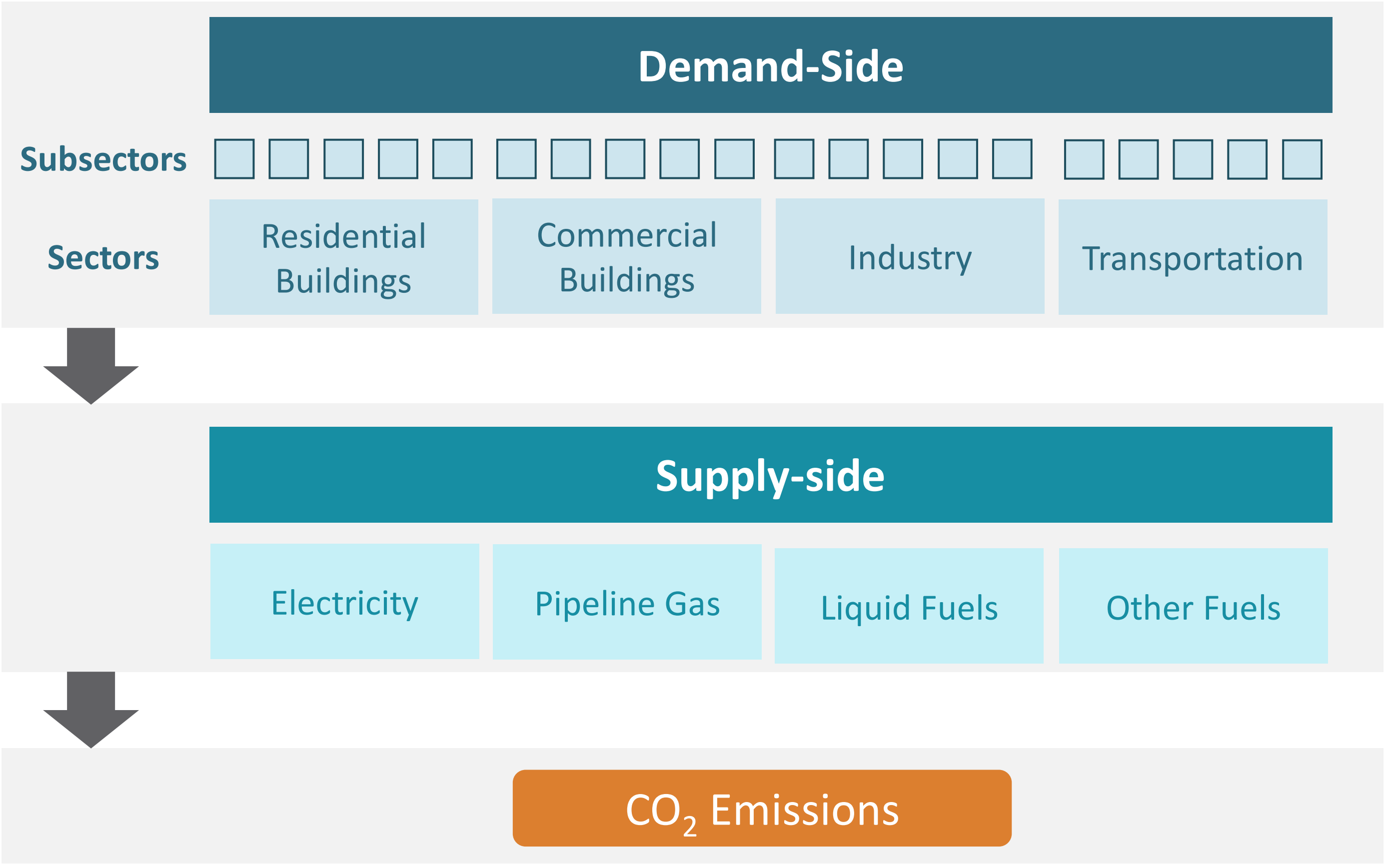
Study Evaluates Deep Decarbonization of Washington's economy



- All energy sectors represented
  - Residential and commercial buildings, industry, transportation and electricity generation
- Regional representation
  - Other state's actions will impact the availability and cost of solutions Washington has to decarbonize
  - State representation in the west captures electricity system operations and load, transmission constraints, biofuel and sequestration potential, and competition for resources as others meet their own targets
- Remainder of the U.S.: also modeled to factor in electricity sector dynamics and the availability of renewable resources, biofuels and sequestration

EVOLVED ENERGY RESEARCH

Analysis Covers Washington's Entire Energy System



- **EnergyPATHWAYS** model used to develop demand-side cases
- Applied electrification and EE levers
- Strategies vary by sub-sector (residential space heating to heavy duty trucks)

- **Regional Investment and Operations (RIO)** model identifies cost-optimal energy supply
- Net-zero electricity systems
- Novel technology deployment (biofuels; hydrogen production; geologic sequestration)

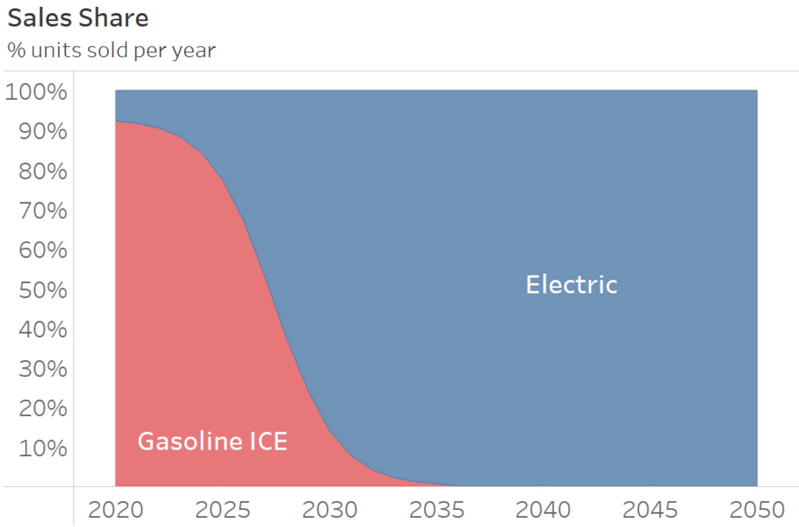
Demand-Side Modeling

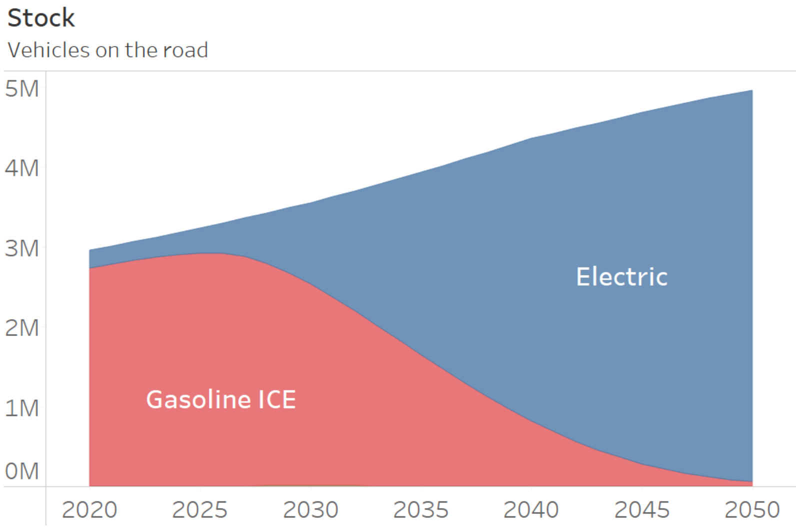
- Scenario-based, bottom-up energy model (not optimization-based)
- Characterizes rollover of stock over time
- Simulates the change in total energy demand and load shape for every end-use
- Illustration of model inputs and outputs for light-duty vehicles

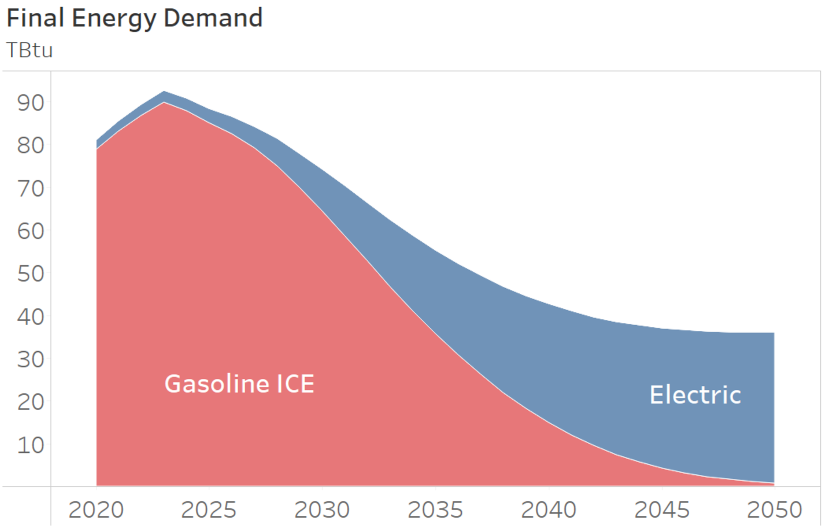
Input: Consumer Adoption
EV sales are 100% of consumer adoption by 2035 and thereafter

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



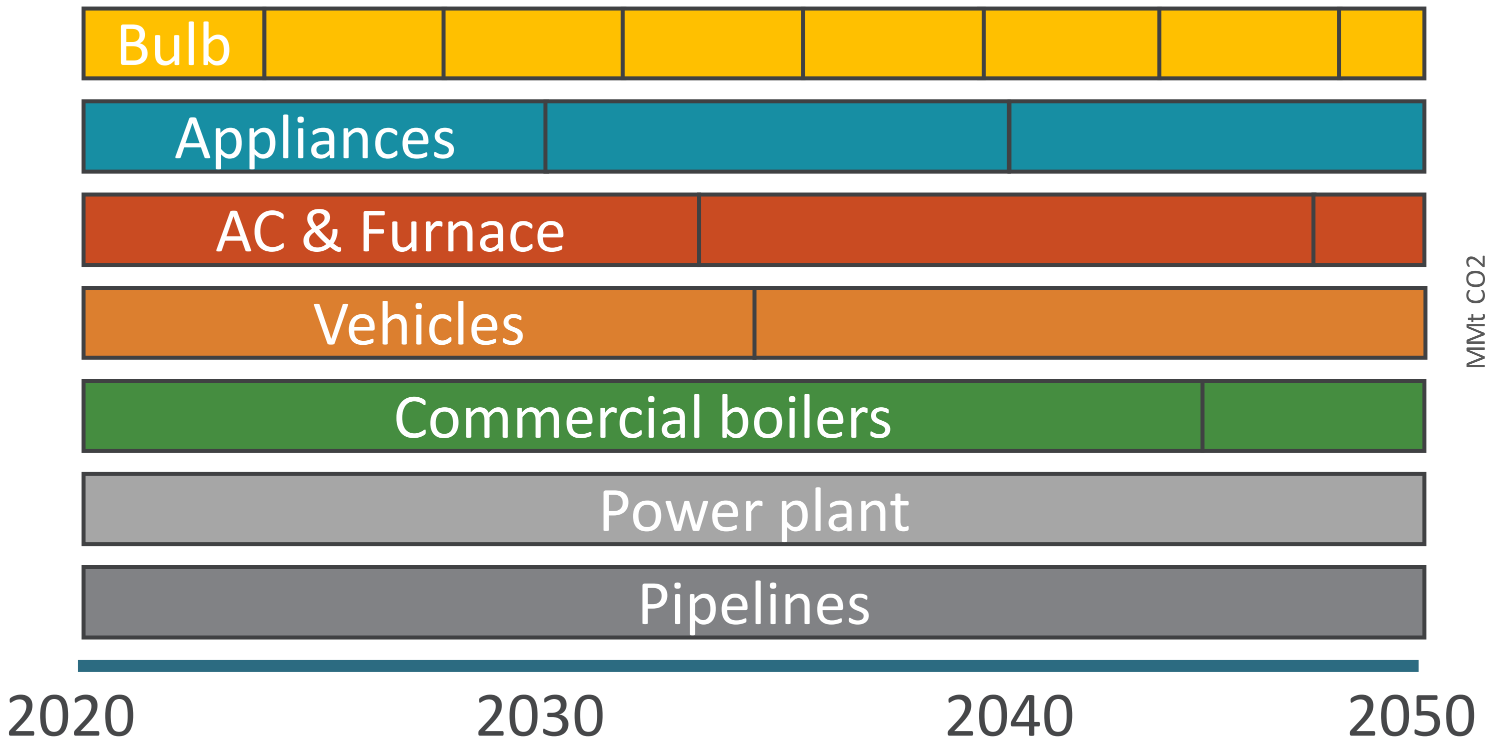




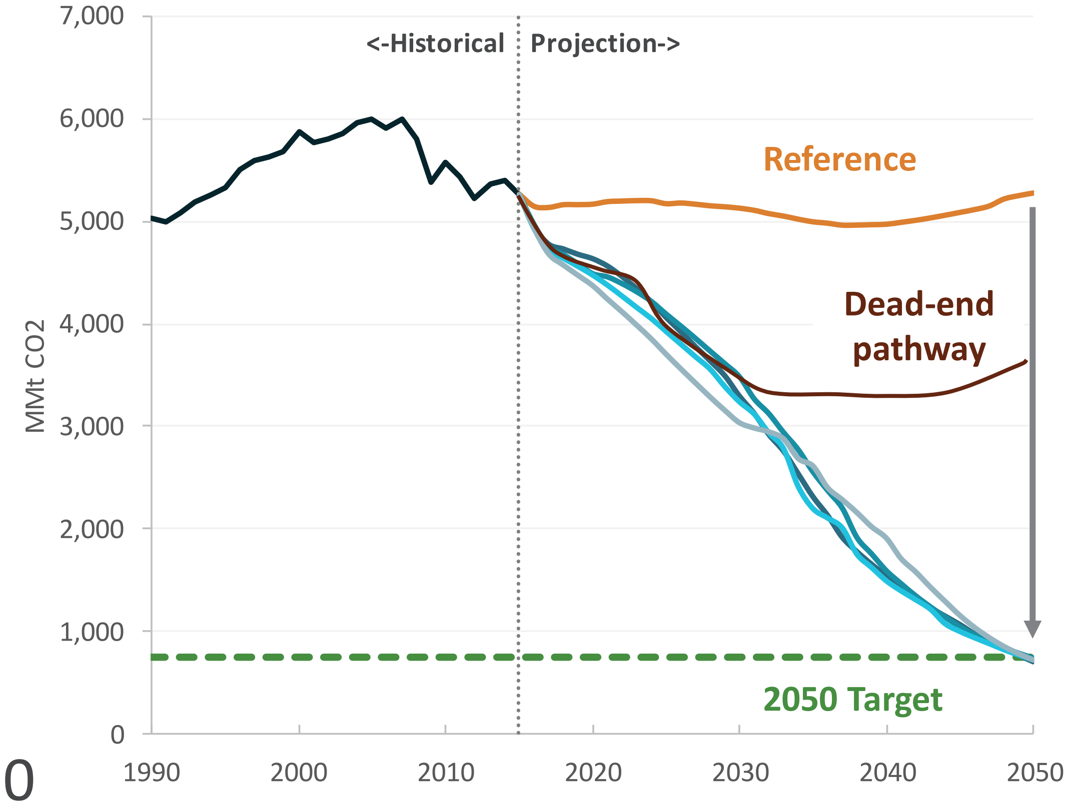
Near-Term Focus on Long-Lived Assets

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



EVOLVED ENERGY RESEARCH

Supply-Side Modeling

- Capacity expansion tool that produces cost optimal resource portfolios across the electric and fuels sectors
  - Identifies least-cost clean fuels to achieve emissions targets, including renewable natural gas and hydrogen production
- Simulates hourly electricity operations and investment decisions
  - Electric sector modeling provides a robust approximation of the reliability challenges introduced by renewables
- Electricity and fuels are co-optimized to identify sector coupling opportunities
  - Example: production of hydrogen from electrolysis

Co-optimized energy supply

- Electricity
- Pipeline Gas
- Gasoline Fuel
- Diesel Fuel
- Jet Fuel
- Hydrogen

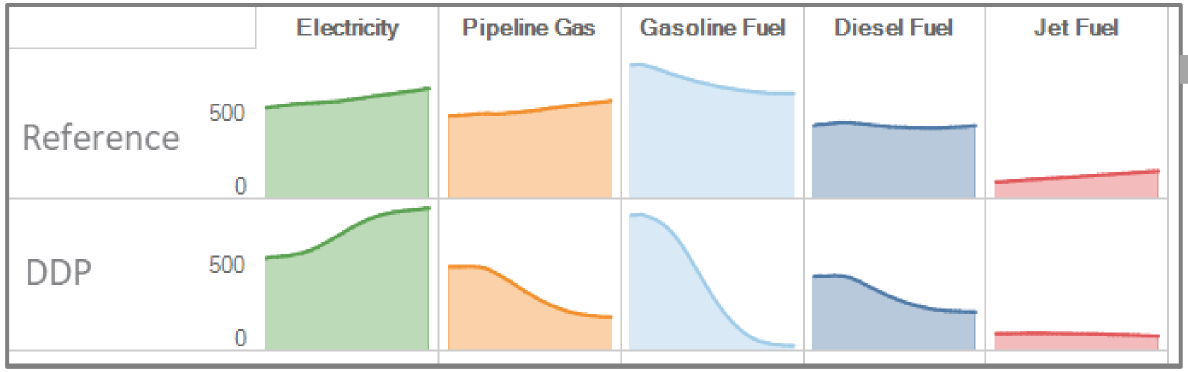
Energy Pathways and RIO

	ENERGY PATHWAYS	RIO
Description	Scenario analysis tool that is used to develop economy-wide energy demand scenarios	Optimization tool to develop portfolios of low-carbon technology deployment for electricity generation and balancing, alternative fuel production, and direct air capture
Application	EnergyPATHWAYS (EP) scenario design produces parameters for RIO's supply-side optimization: • Demand for fuels (electricity, pipeline gas, diesel, etc.) over time • Hourly electricity load shape • Demand-side equipment cost	RIO returns optimized supply-side decisions to EP: • Electricity sector portfolios, including renewable mix, energy storage capacity & duration, capacity for reliability, transmission investments, etc. • Biomass allocation across fuels

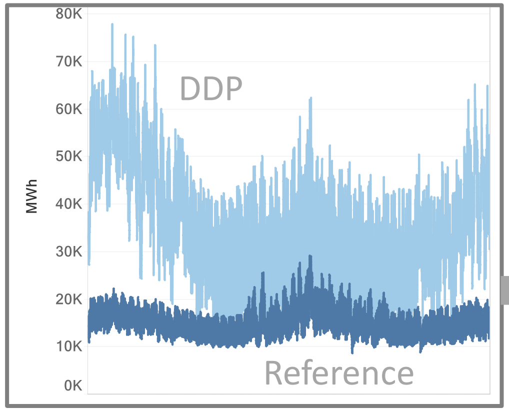
Demand- and Supply-Side Modeling Framework

EnergyPATHWAYS (EP)

Annual End-Use Energy Demand



Hourly Load Shape



Regional Investment and Operations (RIO)

Inputs

- End-use energy demand
- System emissions constraints
- RPS or CES constraints
- Technology and fuel cost projections
- New resource constraints
- Biomass and CO_2 Sequestration costs
- Hourly load shape

Outputs

Electricity sector
- Wind/solar build
- Energy storage capacity/duration
- Capacity for reliability
- Curtailment
- Hourly operations

Hydrogen production

Synthetic electric fuel production (H2/SNG)

Biomass allocation

CO_2 sequestration

EVOLVED ENERGY RESEARCH

RIO & EP Data and Methods Have Improved across Many Past Studies

Project	Geography		EP	RIO
Risky Business Project From Risk to Return	National	U.S./Census Division	☑	
National Renewable Energy Laboratory Electrification Futures Study	National	U.S./50 states	☑	
National Renewable Energy Laboratory North American Renewable Integration Study	National	Canada/Mexico	☑	
Our Children's Trust 350 PPM Pathways for the United States	National	U.S./12 regions	☑	☑
Hydro Québec Deep Decarbonization in the Northeastern U.S.	Regional	Northeast	☑	
State of Washington: Office of the Governor Deep Decarbonization Pathways Analysis	State	WA	☑	
Confidential California utility Economy-wide GHG policy analysis	State/Utility Service Territory	CA	☑	☑
Clean Energy Transition Institute Northwest DDP Study	Regional	ID, MT, OR, WA	☑	☑
New Jersey Board of Public Utilities Integrated Energy Plan	State	NJ	☑	☑
Portland General Electric Deep Decarbonization Pathways Analysis	Utility territory	PGE	☑	
Inter-American Development Bank Deep Decarbonization of Mexico	National	Mexico/5 Regions	☑	☑
Confidential Client Zero Carbon European Power Grid	Regional	EU/8 Regions		☑
Confidential Client Low Carbon Electricity in Japan	National	Japan/5 Regions		☑
Natural Resource Defense Council, Inc Deep Decarbonization Pathways Analysis (ongoing)	National	US/14 Regions	☑	☑
Princeton University Low-Carbon Infrastructure Project (ongoing)	National	US/16 Regions	☑	☑
Pathways for Florida	State	U.S./16 regions	☑	☑
Massachusetts State Energy Plan	State	Northeast & Canada (11 states and provinces)	☑	☑
State of Washington: State Energy Strategy	Regional	U.S. West (11 states)	☑	☑

RIO Decisions Variables and Outputs

Hours

24 hr * 40 – 60 sample days
= 960 – 1440 hr

Decision Variables	Key Results
Generator Dispatch	Hourly Dispatch
Transmission Flows	Transmission Flows
Operating Reserves	Market Prices
Curtailment	Curtailment
Load Flexibility	

Days

365 days * 1-3 weather years
= 365 – 1095 days

Decision Variables	Key Results
Fuel Energy Balance and Storage	Daily Electricity Balances
Long Duration Electricity Storage	Daily Fuel Balances
Dual Fuel Generator Blends	

Years

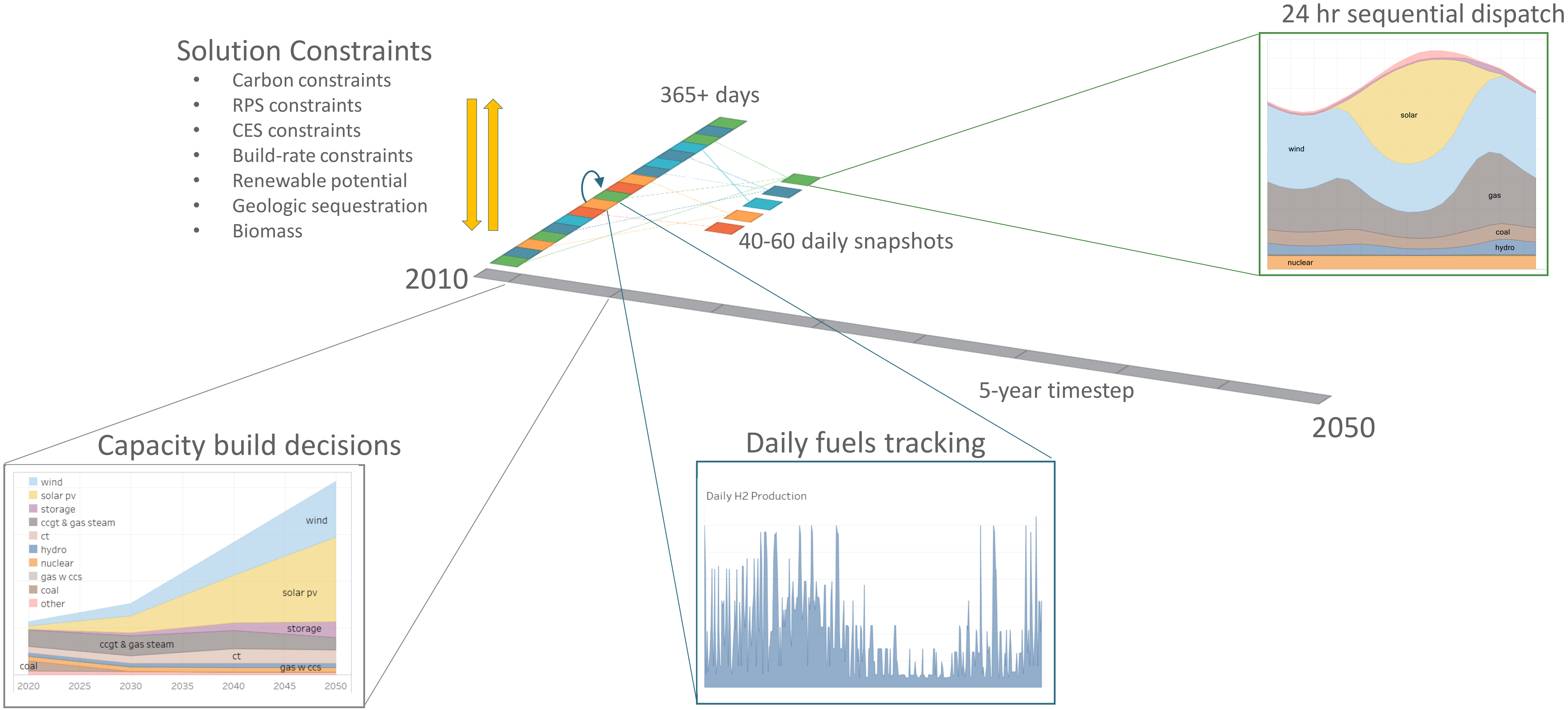
30 yr study / 2 – 5 yr timestep
= 6 – 15 years

Decision Variables	Key Results
Emissions from Operations	Total Annual Emissions
RPS Supply and Demand	RPS Composition
Capacity Build, Retirement & Repower	Incremental Build, Retirement, & Repower
	Thermal Capacity Factors
	Annual Average Market Prices
	Marginal Cost of Fuel Supply

RIO Optimizes across Time-Scales

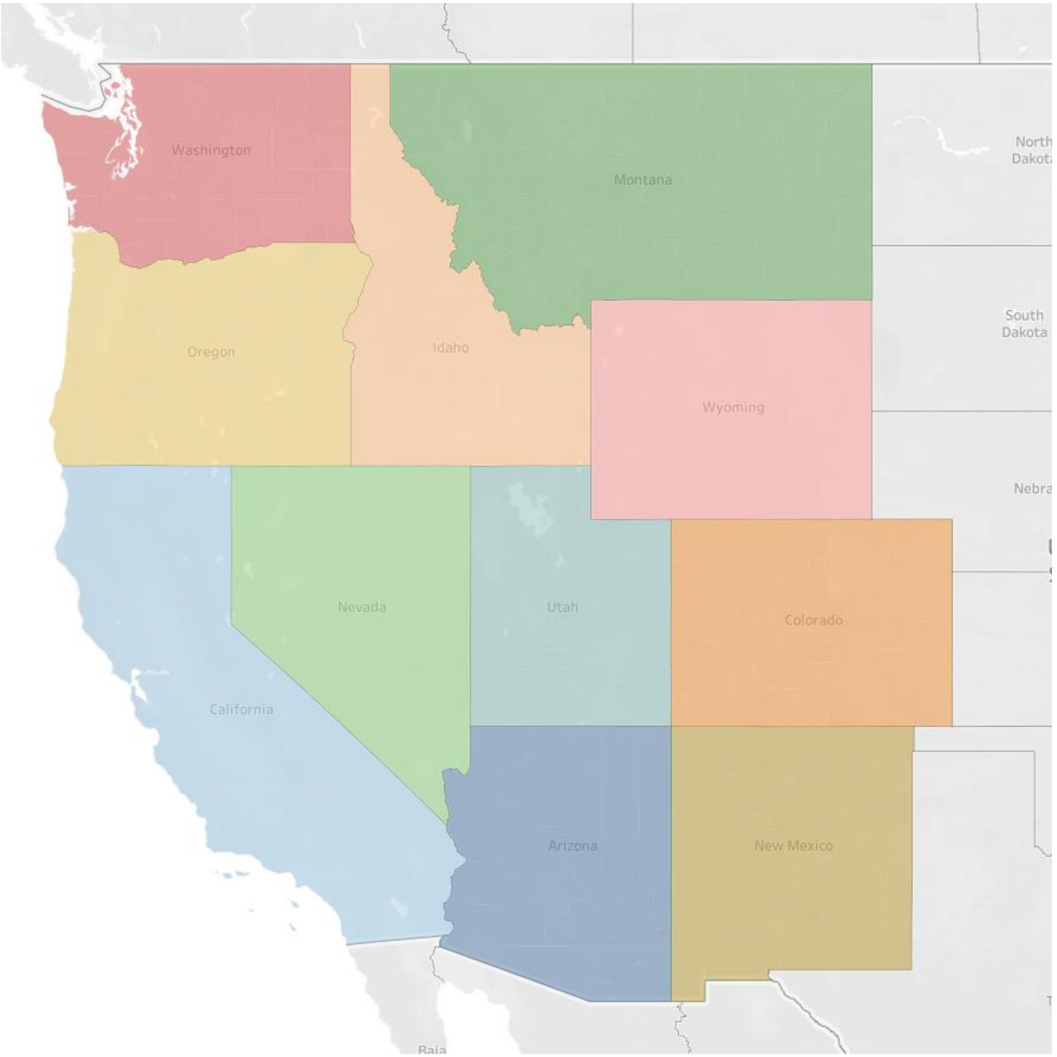
Solution Constraints

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



RIO Optimizes across Geographic Constraints

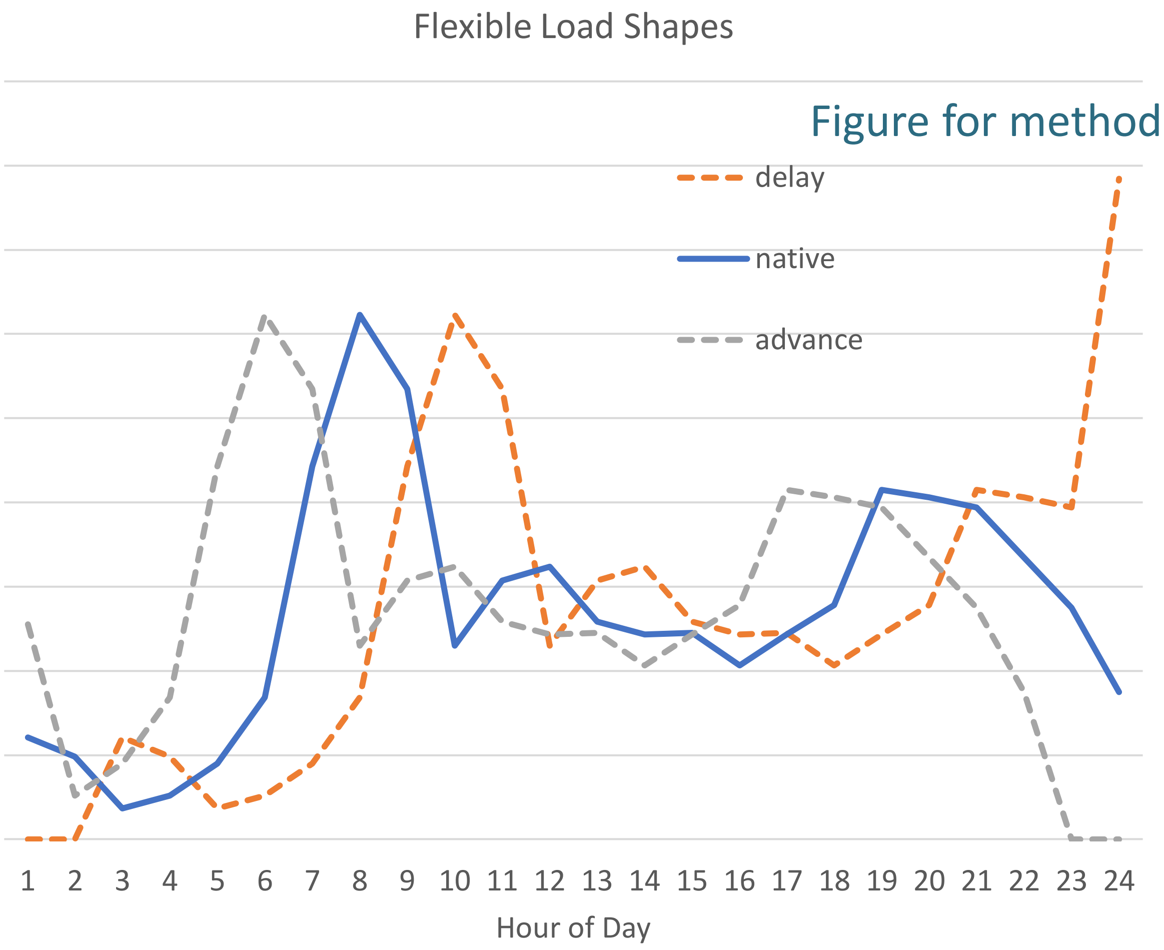
- Transmission constraints and potential between states
  - Model can optimally expand interties and fuels delivery infrastructure
- Loads, resources, and new resource potentials by state
  - Captures unique geographic advantages and local conditions by state

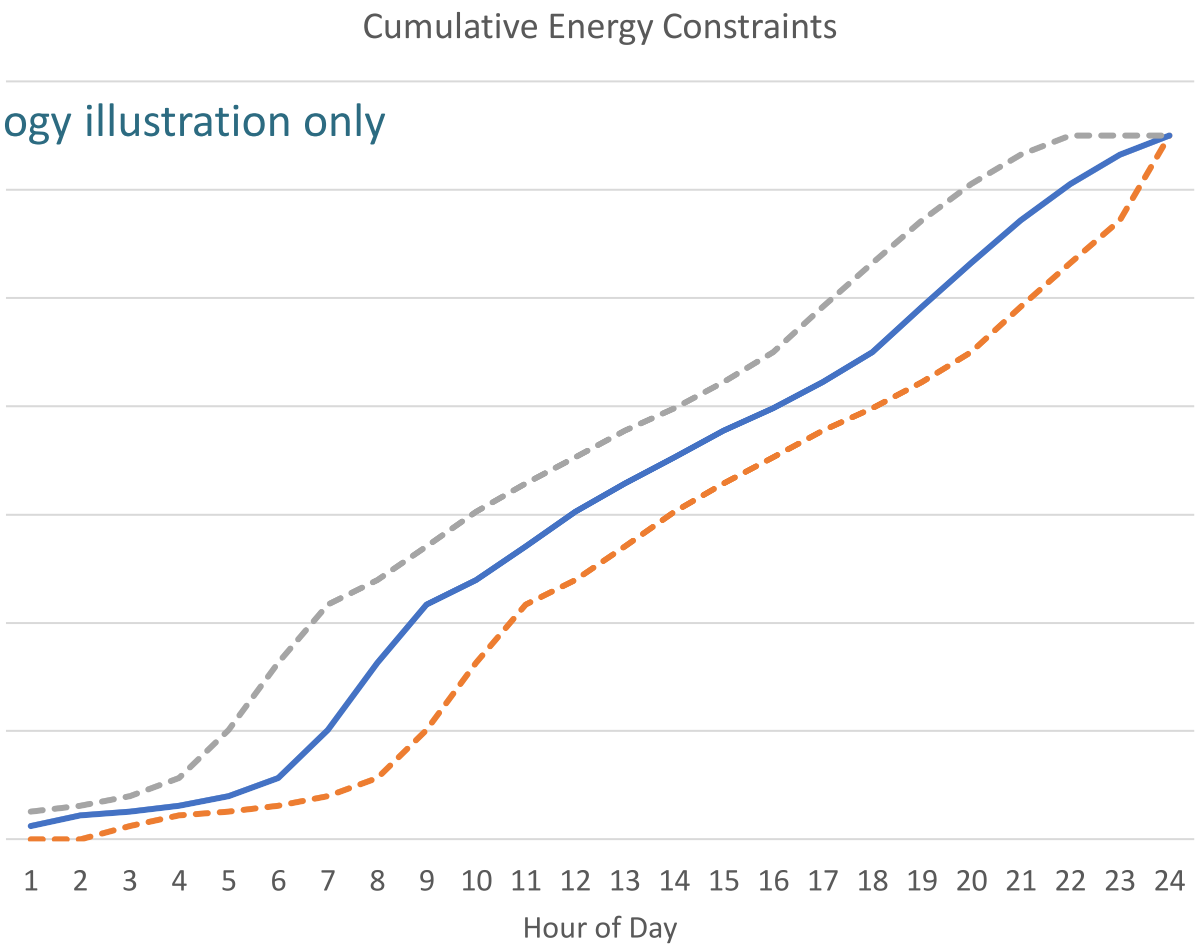


EVOLVED ENERGY RESEARCH

Flexible Load Operations

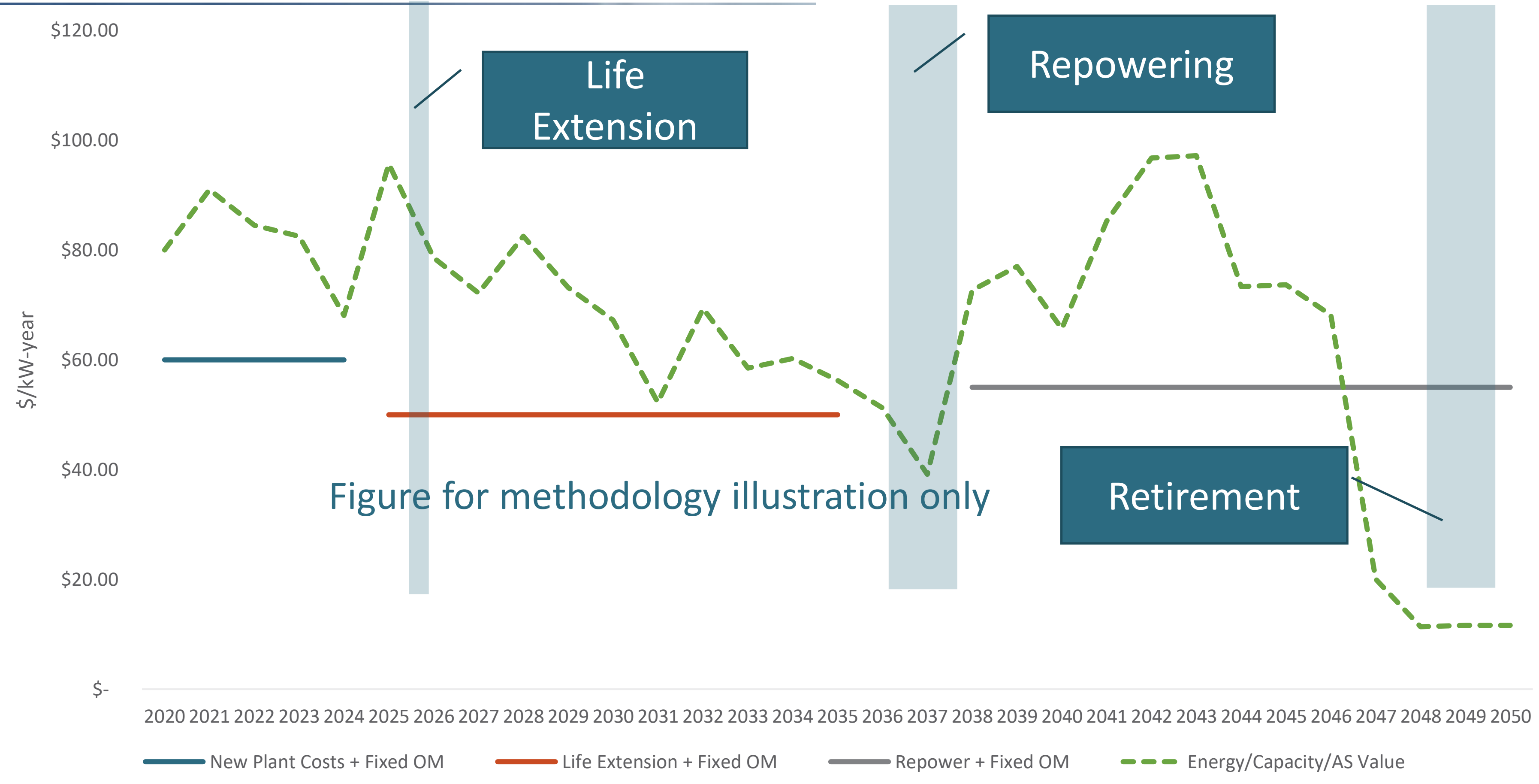
Figure for methodology illustration only





Economic Generator Lifecycles

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



Electricity and Fuels Sector Integration

- Traditional capacity expansion approaches have narrowly defined their problem in terms of the electric sector
- Decarbonization and pushes towards 100% renewables has revealed the inadequacy of that approach as both will require sectoral integration
- A key opportunity for sectoral integration is in the fuel-supply sector, as it may be counted on to provide low-carbon fuels for thermal generation/primary end uses and provide electricity balancing services to the grid
- Endogenizing decisions in both allows us to explore opportunities for sectoral integration that have escaped other modeling frameworks

Focus: Electricity and Commodities Sector Integration

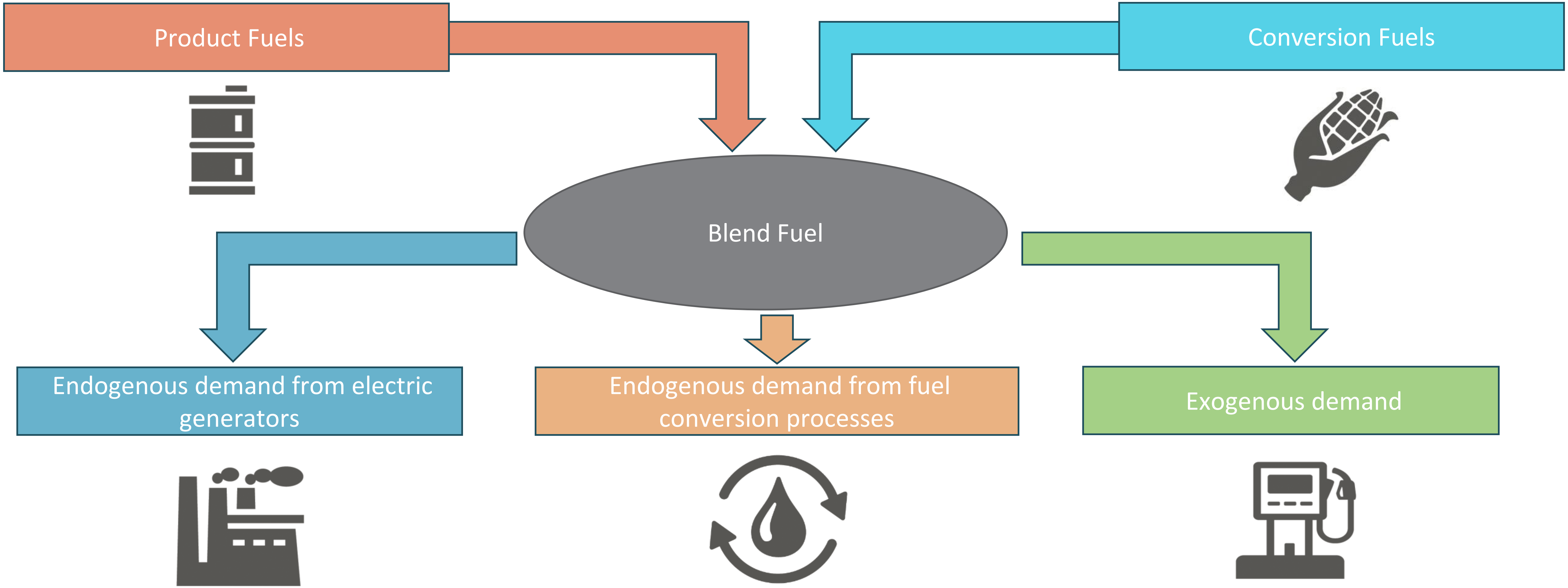
- Traditional capacity expansion approaches have narrowly defined their problem in terms of the electric sector
- Goals of economy-wide decarbonization and push towards 100% zero-emissions electricity generation requires sectoral integration
- A key opportunity for commodity sector integration is in the fuels sector, as it may be counted on to provide low-carbon fuels for thermal generation and provide electricity balancing services to the grid

RIO Commodities Module Definitions

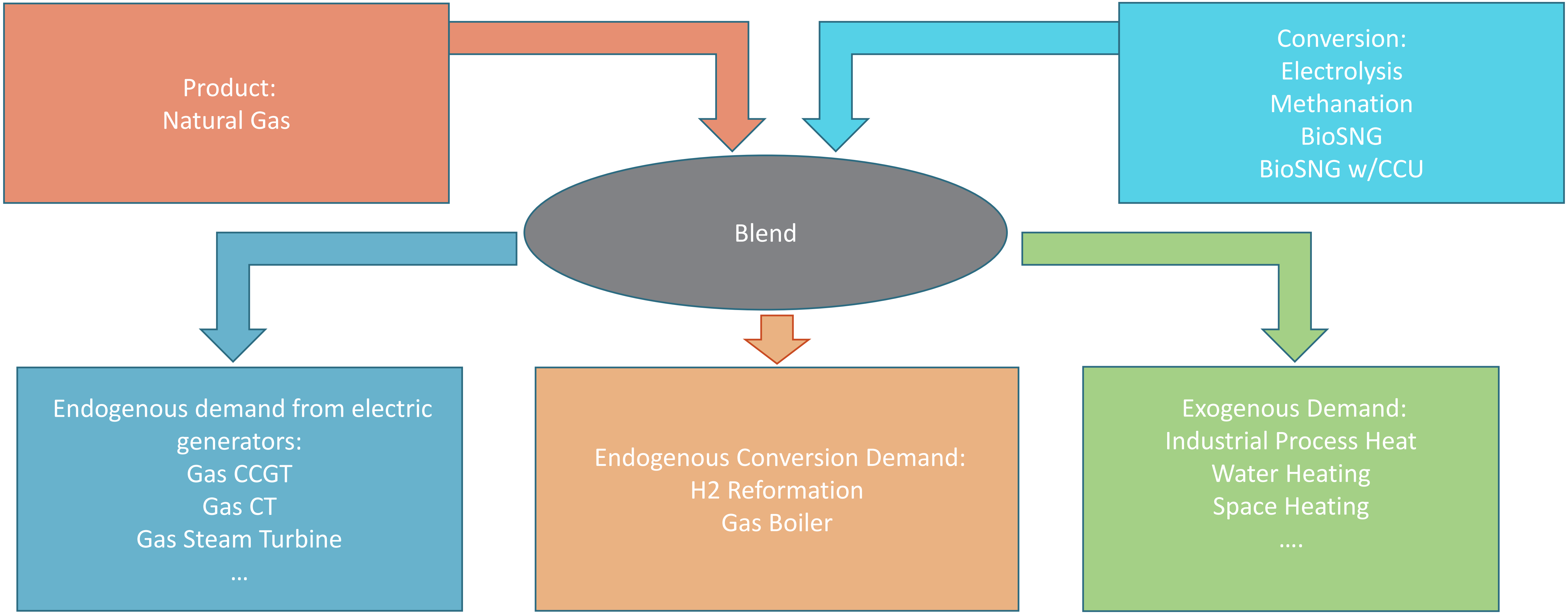
Category	Definition	Examples
Product	Exogenously specified commodity type defined with price, emissions rates and available volumes	Natural Gas; Refined Fossil Diesel; Coal; Biomass
Conversion	Capital investment defined with cost of production capacity and efficiency of production (blend x -> blend y 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 CO2

RIO Fuels Structure

Optimally invest in fuels transportation, storage, and conversion infrastructure

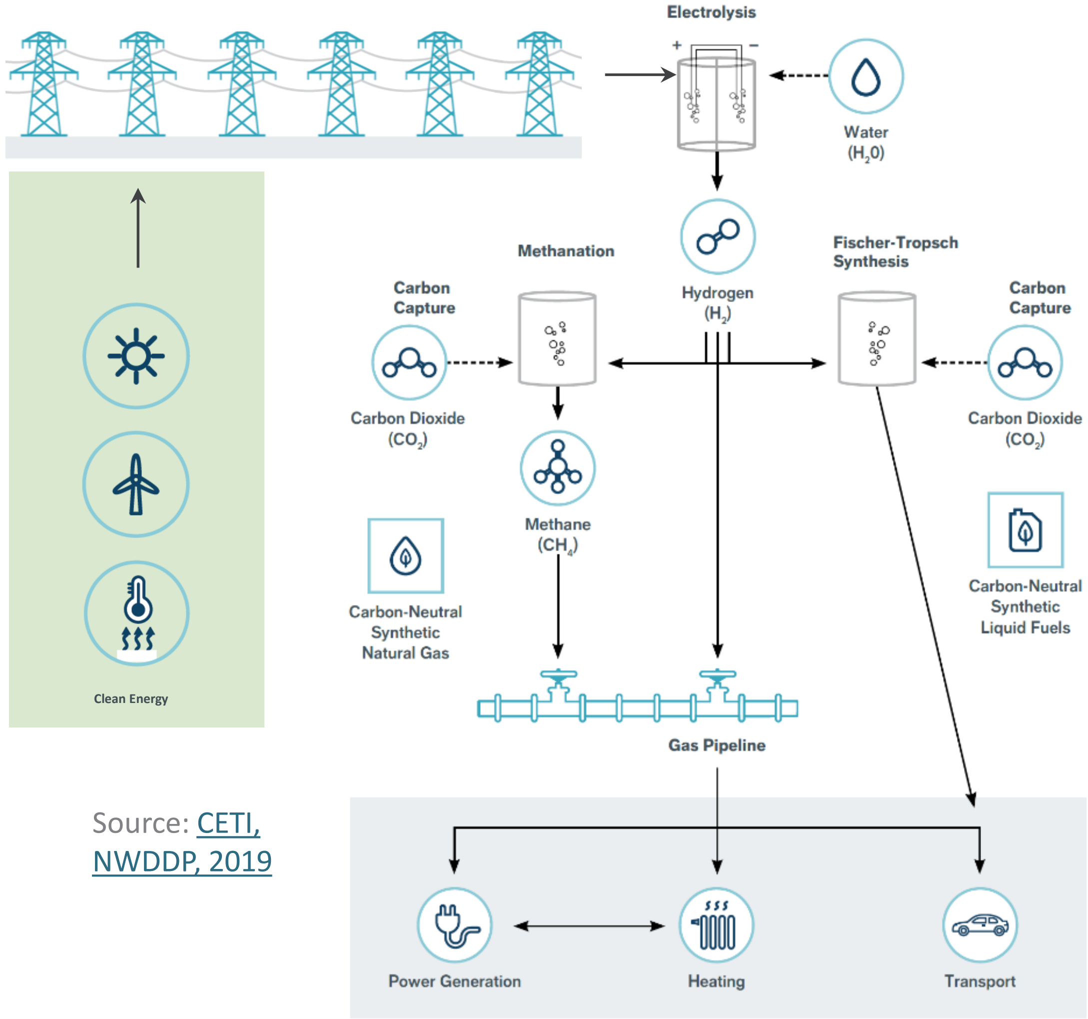


RIO Commodities Structure: Pipeline Gas Blend Example



Integrated Supply Side: Electricity and Fuels

- Conventional means of "balancing" 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

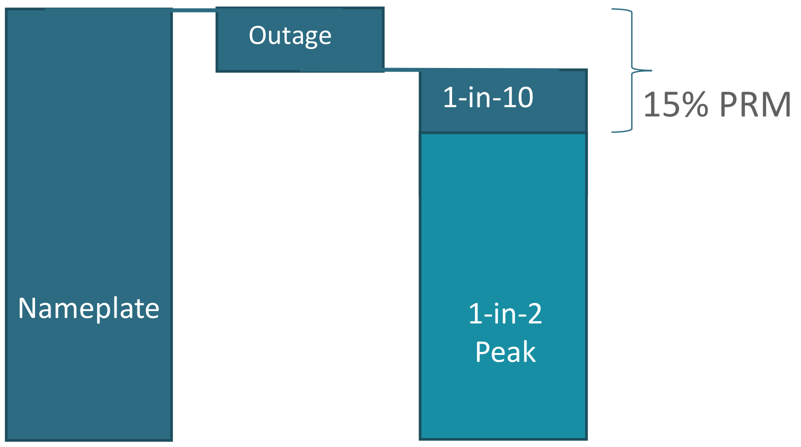


Source: CETI, NWDDP, 2019

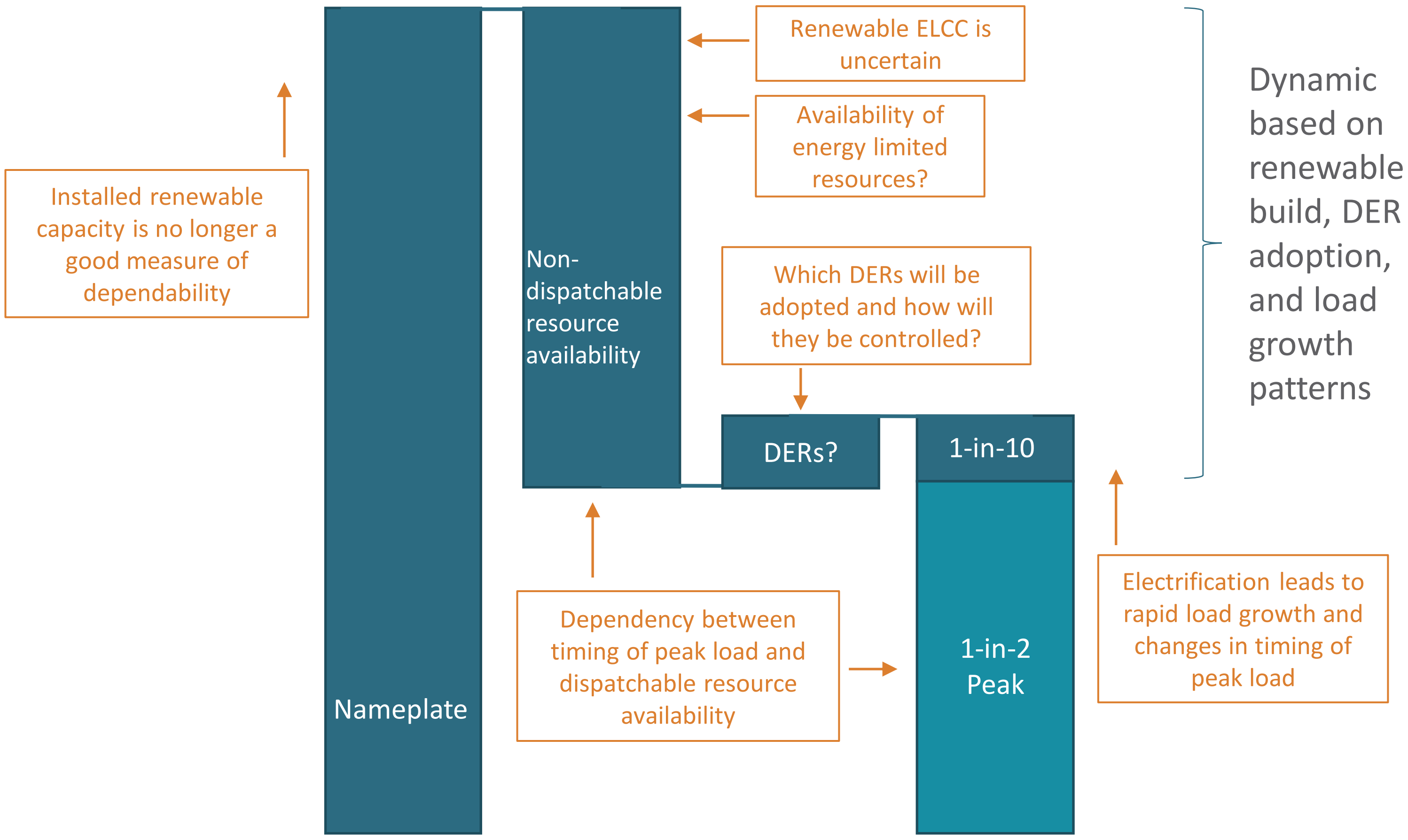
Hourly Reserve Margin Constraints by Zone

Assessing Reliability Becomes Challenging in Low-Carbon Electricity Systems

Traditional Reserve Margin



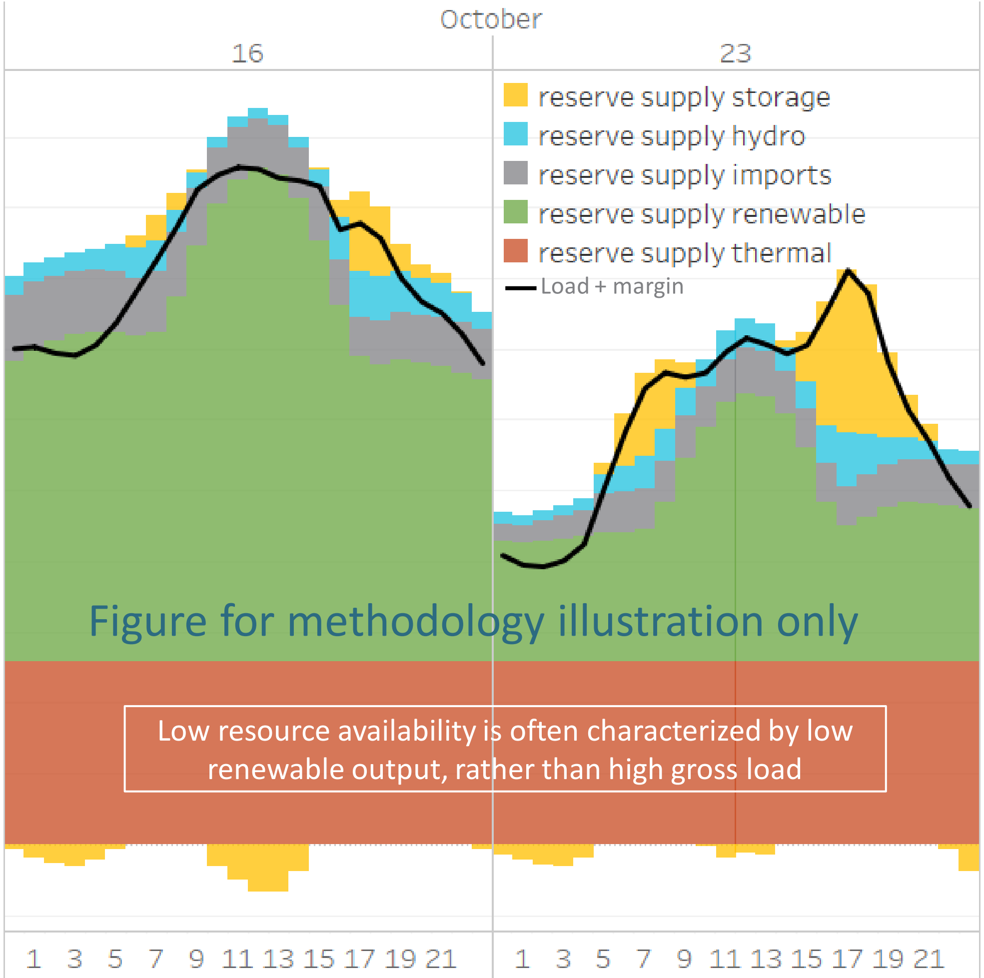
Future System Reliability Assessment



How Does RIO Approach Reliability?

- 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



Appendix: Key Assumptions

Demand Subsectors

- EnergyPATHWAYS database includes 67 subsectors
  - Primary data-sources include:
    - Annual Energy Outlook 2020 inputs/outputs (AEO; EIA)
    - Residential/Commercial Buildings/Manufacturing Energy Consumption Surveys (RECS/CBECS/MECS; EIA)
    - State Energy Data System (SEDS; DOE)
    - NREL
  - 8 industrial process categories, 11 commercial building types, 3 residential building types
  - 363 demand-side technologies w/ projections of cost (capital, installation, fuel-switching, O&M) and service efficiency

commercial air conditioning
commercial cooking
commercial lighting
commercial other
commercial refrigeration
commercial space heating
commercial ventilation
commercial water heating
district services
office equipment (non-p.c.)
office equipment (p.c.)
aviation
domestic shipping
freight rail
heavy duty trucks
international shipping
light duty autos
light duty trucks
lubricants
medium duty trucks
military use
motorcycles

residential clothes washing
residential computers and related
residential cooking
residential dishwashing
residential freezing
residential furnace fans
residential lighting
residential other uses
residential refrigeration
residential secondary heating
residential space heating
residential televisions and related
residential water heating
Cement and Lime CO2 Capture
Cement and Lime Non-Energy CO2
Iron and Steel CO2 Capture
Other Non-Energy CO2
Petrochemical CO2 Capture
agriculture-crops
agriculture-other
aluminum industry
balance of manufacturing other

food and kindred products
glass and glass products
iron and steel
machinery
metal and other non-metallic mining
paper and allied products
plastic and rubber products
transportation equipment
wood products
bulk chemicals
cement
computer and electronic products
construction
electrical equip., appliances, and components
passenger rail
recreational boats
school and intercity buses
transit buses
residential air conditioning
residential building shell
residential clothes drying

Load Shape Sources

<table>
<tr><th>Shape Name</th><th>Used By</th><th>Input Data Geography</th><th>Input Temporal Resolution</th><th>Source</th></tr>
<tr><td>Bulk System Load</td><td>initial electricity reconciliation, all subsectors not otherwise given a shape</td><td>Emissions and Generation Resource Integrated Database (EGRID) with additional granularity in the western interconnection</td><td>hourly, 2012</td><td>FERC Form No. 714</td></tr>
<tr><td>Light-Duty Vehicles (LDVs)</td><td>all LDVs</td><td rowspan="13">United States</td><td>month-hour-weekday/weekend average, separated by home vs. work charging</td><td>Evolved Energy Research analysis of 2016 National Household Travel Survey</td></tr>
<tr><td>Water Heating (Gas Shape)[a]</td><td>residential hot water</td><td rowspan="15">month-hour-weekday/weekend average</td><td rowspan="9">Northwest Energy Efficiency Alliance Residential Building Stock Assessment Metering Study (Northwest)</td></tr>
<tr><td>Other Appliances</td><td>residential TV & computers</td></tr>
<tr><td>Lighting</td><td>residential lighting</td></tr>
<tr><td>Clothes Washing</td><td>residential clothes washing</td></tr>
<tr><td>Clothes Drying</td><td>residential clothes drying</td></tr>
<tr><td>Dishwashing</td><td>residential dish washing</td></tr>
<tr><td>Residential Refrigeration</td><td>residential refrigeration</td></tr>
<tr><td>Residential Freezing</td><td>residential freezing</td></tr>
<tr><td>Residential Cooking</td><td>residential cooking</td></tr>
<tr><td>Industrial Other</td><td>all other industrial loads</td><td rowspan="3">California Load Research Data</td></tr>
<tr><td>Agriculture</td><td>industry agriculture</td></tr>
<tr><td>Commercial Cooking</td><td>commercial cooking</td></tr>
<tr><td>Commercial Water Heating</td><td>commercial water heating</td><td rowspan="3">North American Electric Reliability Corporation (NERC) region</td><td rowspan="3">EPRI Load Shape Library 5.0</td></tr>
<tr><td>Commercial Lighting Internal</td><td>commercial lighting</td></tr>
<tr><td>Commercial Refrigeration</td><td>commercial refrigeration</td></tr>
</table>

Load Shape Sources, Continued

Shape Name	Used By	Input Data Geography	Input Temporal Resolution	Source
Commercial Ventilation	commercial ventilation			
Commercial Office Equipment	commercial office equipment			
Industrial Machine Drives	machine drives			
Industrial Process Heating	process heating			
electric_furnace_res	electric resistance heating technologies	IECC Climate Zone by state (114 total geographical regions)	hourly, 2012 weather	Evolved Energy Research Regressions trained on NREL building simulations in select U.S. cities for a typical meteorological year and then run on county level HDD and CDD for 2012 from the National Oceanic and Atmospheric Administration (NOAA)
reference_central_ac_res	central air conditioning technologies			
high_efficiency_central_ac_res	high-efficiency central air conditioning technologies			
reference_room_ac_res	room air conditioning technologies			
high_efficiency_room_ac_res	high-efficiency room air conditioning technologies			
reference_heat_pump_heating_res	ASHPs			
high_efficiency_heat_pump_heating_res	high-efficiency ASHPs			
reference_heat_pump_cooling_res	ASHP s			
high_efficiency_heat_pump_cooling_res	high-efficiency ASHPs			
chiller_com	commercial chiller technologies			
dx_ac_com	direct expansion air conditioning technologies			
boiler_com	commercial boiler technologies			
furnace_com	commercial electric furnaces			
Flat shape	MDV and HDV charging	United States	n/a	n/a

[a] natural gas shape is used as a proxy for the service demand shape for electric hot water due to the lack of electric water heater data.

Supply-Side Data

Data Category	Data Description	Supply Node	Source
Resource Potential	Binned resource potential (GWh) by state with associated resource performance (capacity factors) and transmission costs to reach load	Transmission – sited Solar PV; Onshore Wind; Offshore Wind; Geothermal	(Eurek et al. 2017)
Resource Potential	Binned resource potential of biomass resources by state with associated costs	Biomass Primary – Herbaceous; Biomass Primary – Wood; Biomass Primary – Waste; Biomass Primary – Corn	(Langholtz, Stokes, and Eaton 2016)
Resource Potential	Binned annual carbon sequestration injection potential by state with associated costs	Carbon Sequestration	(U.S. Department of Energy: National Energy Technology Laboratory 2017)
Resource Potential	Domestic production potential of natural gas	Natural Gas Primary – Domestic	(U.S. Energy Information Administration 2020)
Resource Potential	Domestic production potential of oil	Oil Primary – Domestic	(U.S. Energy Information Administration 2020)
Product Costs	Commodity cost of natural gas at Henry Hub	Natural Gas Primary – Domestic	(U.S. Energy Information Administration 2020)
Product Costs	Undelivered costs of refined fossil products	Refined Fossil Diesel; Refined Fossil Jet Fuel; Refined Fossil Kerosene; Refined Fossil Gasoline; Refined Fossil LPG	(U.S. Energy Information Administration 2020)
Product Costs	Commodity cost of Brent oil	Oil Primary – Domestic; Oil Primary - International	(U.S. Energy Information Administration 2020)
Delivery Infrastructure Costs	AEO transmission and delivery costs by EMM region	Electricity Transmission Grid; Electricity Distribution Grid	(U.S. Energy Information Administration 2020)
Delivery Infrastructure Costs	AEO transmission and delivery costs by census division and sector	Gas Transmission Pipeline; Gas Distribution Pipeline	(U.S. Energy Information Administration 2020)
Delivery Infrastructure	AEO delivery costs by fuel product	Gasoline Delivery; Diesel Delivery; Jet Fuel; LPG Fuel Delivery; Kerosene Delivery	(U.S. Energy Information Administration 2020)

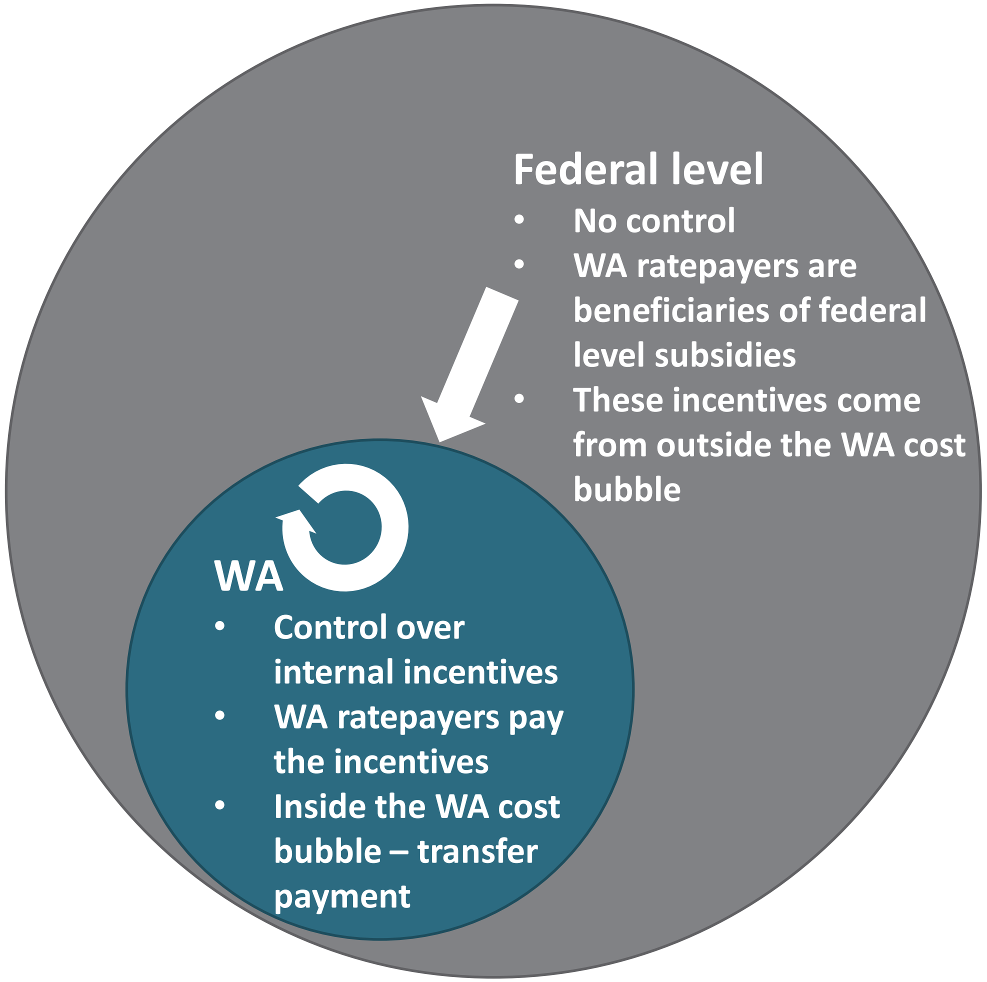
Supply-Side Data, Continued

Data Category	Data Description	Supply Node	Source
Technology Cost and Performance	Renewable and conventional electric technology installed cost projections	Nuclear Power Plants; Onshore Wind Power Plants; Offshore Wind Power Plants; Transmission – Sited Solar PV Power Plants; Distribution – Sited Solar PV Power Plants; Rooftop PV Solar Power Plants; Combined – Cycle Gas Turbines; Coal Power Plants; Combined – Cycle Gas Power Plants with CCS; Coal Power Plants with CCS; Gas Combustion Turbines	(National Renewable Energy Laboratory 2019)
Technology Cost and Performance	Electric fuel cost projections including electrolysis and fuel synthesis facilities	Central Hydrogen Grid Electrolysis; Power – To – Diesel; Power – To – Jet Fuel; Power – To – Gas Production Facilities	(Capros et al. 2018)
Technology Cost and Performance	Hydrogen Gas Reformation costs with and without carbon capture	H2 Natural Gas Reformation; H2 Natural Gas Reformation w/CCS	(International Energy Agency GHG Programme 2017)
Technology Cost and Performance	Nth plant Direct air capture costs for sequestration and utilization	Direct Air Capture with Sequestration; Direct Air Capture with Utilization	(Keith et al. 2018)
Technology Cost and Performance	Gasification cost and efficiency of conversion including gas upgrading.	Biomass Gasification; Biomass Gasification with CCS	(G. del Alamo et al. 2015)
Technology Cost and Performance	Cost and efficiency of renewable Fischer-Tropsch diesel production.	Renewable Diesel; Renewable Diesel with CCS	(G. del Alamo et al. 2015)
Technology Cost and Performance	Cost and efficiency of industrial boilers	Electric Boilers; Other Boilers	(Capros et al. 2018)
Technology Cost and Performance	Cost and efficiency of other, existing power plant types	Fossil Steam Turbines; Coal Power Plants	(Johnson et al. 2006)

Federal Tax Incentives

We include federal incentives but not local incentives

- Federal incentives included because they benefit WA by lowering total costs
  - ITC 26% in 2020, then 10% afterwards (for commercial solar only)
  - PTC expires too soon to impact build decisions
- Any local incentives are not included because they are transfer payments and do not lower total costs
- In current policy 10% ITC is available in perpetuity. We roll off ITC in 2030, forecasting a change in policy
  - Near term support for renewable investments, driving recovery in jobs and investment coming out of Covid
  - Won't last forever, particularly as renewable prices continue to drop
  - Federal incentives may be better spent on emerging clean technologies in the future



In-state Solar

- NWPCC has estimates of rooftop solar through 2045
  - https://www.nwcouncil.org/sites/default/files/2019_0917_p1.pdf
- We schedule NWPCC adoption of rooftop solar for WA through 2030 of 500 MW
  - Simulation, assumes customer behavior based on existing trends, rates etc. through 2030
- 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 no detailed distribution system model
  - Rooftop may be desirable for other reasons such as promoting jobs within state, or avoiding land use challenges siting bulk system level solar
- Bulk system solar potential capped using NREL's Regional Energy Deployment System database

Columbia Generating Station (CGS) Extension

- We assume that the CGS can be extended for an additional 20 years of life at 1,210 MW gross output
- Extending CGS:
  - Cost assumptions developed by Energy Northwest and consistent with NWPCC 2021 Power Plan
  - License renewal
    - $50M extension capital cost
    - $400M fixed O&M based on O&M estimates in the Energy Northwest Fiscal Year 2021 Budget

Small Modular Reactors (SMRs)

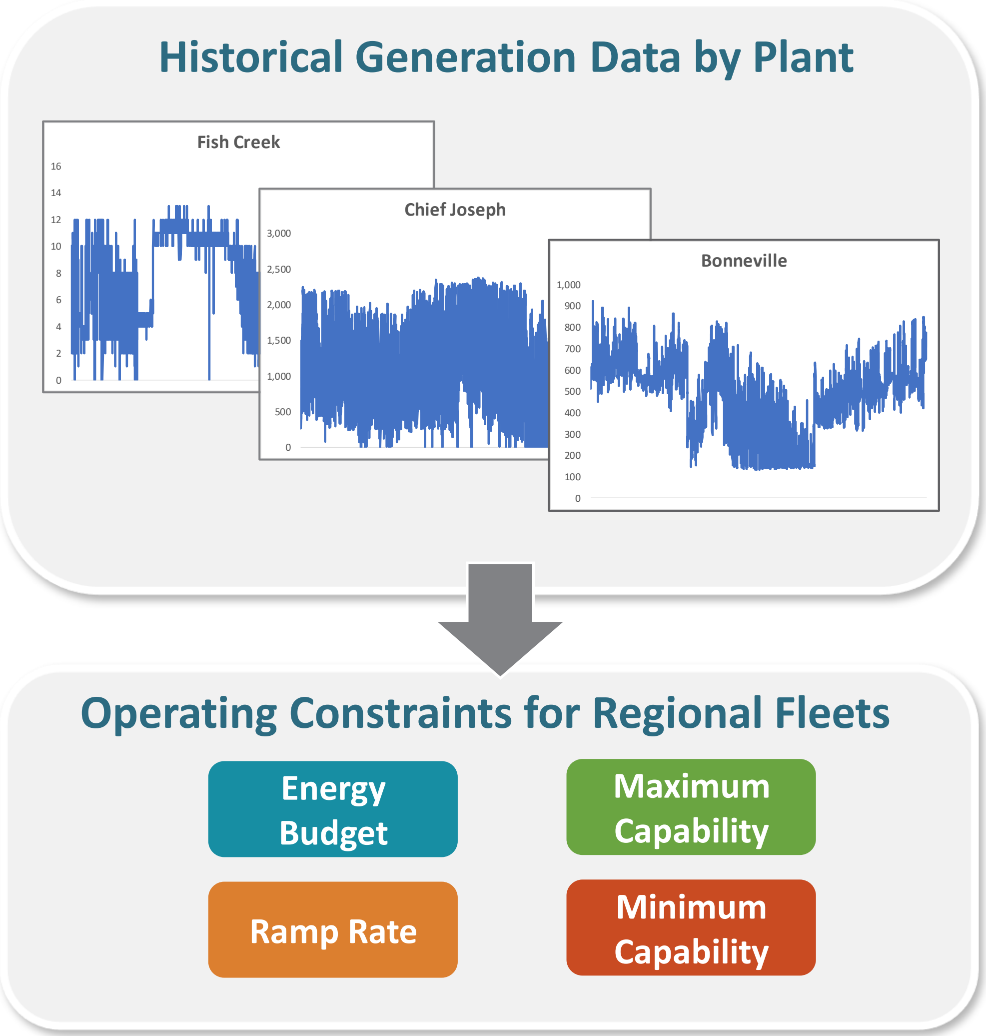
- SMRs are included as a resource option in the model for Washington State
- Costs assumptions from NWPCC 2021 Power Plan
  – https://nwcouncil.app.box.com/s/nnfkfiq9vuqg3umtb2e8np0tqm78ztni
- Capital Cost: $5,400/kW
- Earliest online date: 2030
- Maximum resource build by 2030: 500 MW
- Maximum resource build by 2050: 3420 MW
- Operating costs from NREL

Climate Impacts on Load and Hydro

- EIA incorporates climate impacts into the Annual Energy Outlook based on extrapolated change in heating degree days (HDD) and cooling degree days (CDD) from the past 30 years
  - For the Pacific region, change in number of HDD: -0.7%/year, number of CDD: 1.2%/year
- Seattle City Light finds no clear trend in impacts on hydro across models reviewed – some models project wetter conditions, others predict drier conditions
  - Lower summer rainfall predicted (6% to 8%, with some models predicting >30%) but rainfall is very low in the summer anyway
  - Predicted changes in precipitation extremes – more frequent short-term heavy rain
  - Predicted reduced snowpack, increased fall and winter stream flows and reduced summer stream flows
  - Not a clear path forward to adjustments in hydro availability
    - Shape changes as well as total energy availability
  - More work needed to characterize this impact for future studies
- We use three hydro years – low, average, and high hydro energy availability to capture challenges of meeting clean energy requirements

Hydroelectric System

- 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
- Operational constraints for regional hydro fleets are derived using hourly generation data from WECC for 2001, 2005 and 2011, which represent dry, average and wet hydro years, respectively
  - Operational constraints vary by week of the year (1 through 52) and hydro year (dry, average and wet)



EVOLVED ENERGY RESEARCH

Existing Efficiency Policy in Buildings

What are the efficiency policies that impact Reference and Decarbonization case assumptions?

- Energy Independence Act (EIA) I-937
  - *“Utilities must pursue all conservation that is cost-effective, reliable and feasible. They need to identify the conservation potential over a 10-year period and set two-year targets.”*
- Clean Energy Transition Act (CETA)
  - Same requirement as EIA but applicable to all utilities, not just those over 25000 customers
- Clean Buildings Bill
  - Incentives and mandates applied to commercial buildings over 50000 square feet and incentives applied to multi family buildings
    - 2021-2026: voluntary incentive program
    - 2026 onwards: mandatory requirements (for large commercial buildings)
  - Require demonstration of energy reduction to below energy use intensity target
- Efficiency standards

Modeled Efficiency

- NWPCC work in efficiency
  - https://www.nwcouncil.org/sites/default/files/2020_03_p2.pdf
  - Lays out achievable potential by sector and year
  - Not directly useful for inputs
- Aggressive efficiency improvements are being driven through existing policy
  - Not modellable with the complexity of the compliance process and the way that the programs are defined
- Modeling approach: set high level targets that reasonably align with levels of ambition in Reference and other cases

Buildings

- Energy Efficiency
  - Reference Case: 50% sales HE by 2035, 75% sales HE by 2050
  - Electrification Case: 100% high efficiency by 2035
  - Gas in Buildings: 100% high efficiency by 2035
- Electrification Rates
  - Reference Case: No electrification
  - Electrification Case: 90% - 100% electric sales by 2035 depending on sub sector
  - Gas in Buildings: Replace gas appliances with new efficient gas appliance rather than electrify

Renewable Resources

- Candidate onshore wind and solar resources
  - State-level resource potential, capacity factor and transmission costs are derived from NREL's Regional Energy Deployment System database
  - Capital cost projections are from NREL's Annual Technology Baseline 2019
- We incorporate hourly profiles for wind and solar resources throughout the WECC for weather years 2010 through 2012
  - Wind profiles are from NREL's Wind Integrated National Dataset (WIND) Toolkit
  - Solar profiles are derived using data from the NREL National Solar Radiation Database and simulated using the System Advisor Model

Vehicle Electrification Targets

Scenario	Class	Sub class	Target Sales Share	By Year
Electrification	HDV	long haul	25% Electric	2045
Electrification	HDV	long haul	75% Hydrogen FCV	2045
Electrification	HDV	short haul	100% Electric	2045
Low Electrification	HDV	long haul	12.5% Electric	2045
Low Electrification	HDV	long haul	0% Hydrogen FCV	2045
Low Electrification	HDV	short haul	50% Electric	2045
Electrification	MDV		70% Electric	2045
Electrification	MDV		30% Hydrogen FCV	2045
Low Electrification	MDV		35% Electric	2045
Low Electrification	MDV		0% Hydrogen FCV	2045
Electrification	LDV	autos	100% Electric	2035
Electrification	LDV	trucks	100% Electric	2035
Low Electrification	LDV	autos	75% Electric	2045
Low Electrification	LDV	trucks	75% Electric	2045
Electrification	Buses		100% Electric	2040
Low Electrification	Buses		50% Electric	2040

Industrial Sector Targets

- Great deal of uncertainty about industrial opportunities
  - Not a lot of information
  - Specific to industry/company/geography
  - Tied to competitiveness/labor force considerations
- Using “keep it simple” approach
  - 1% per year improvement in energy intensity across industrial subsectors
  - Fuel switching to electricity in 50% of process heating, 100% of machine drives, and 75% of building heating and cooling in industry by 2050
  - Designed to model some benefits of reductions in energy from efficiency and electrification while acknowledging industrial sector improvements will come from negotiation
- Maintaining industrial activity as forecast by AEO, except mining and refining
  - Refining in Washington assumed to drop by 75% by 2050 from reduced fossil fuel demands

Data Center Loads

- Data center load not well represented in the AEO load representation of Washington
  - Updated to NWPCC data center assumptions for Washington and Oregon from 7th Power Plan
    - https://www.nwcouncil.org/sites/default/files/7thplanfinal_appdixe_dforecast_1.pdf
  - Washington and Oregon total assigned to each state based on population

Vehicle Miles Traveled Reduction

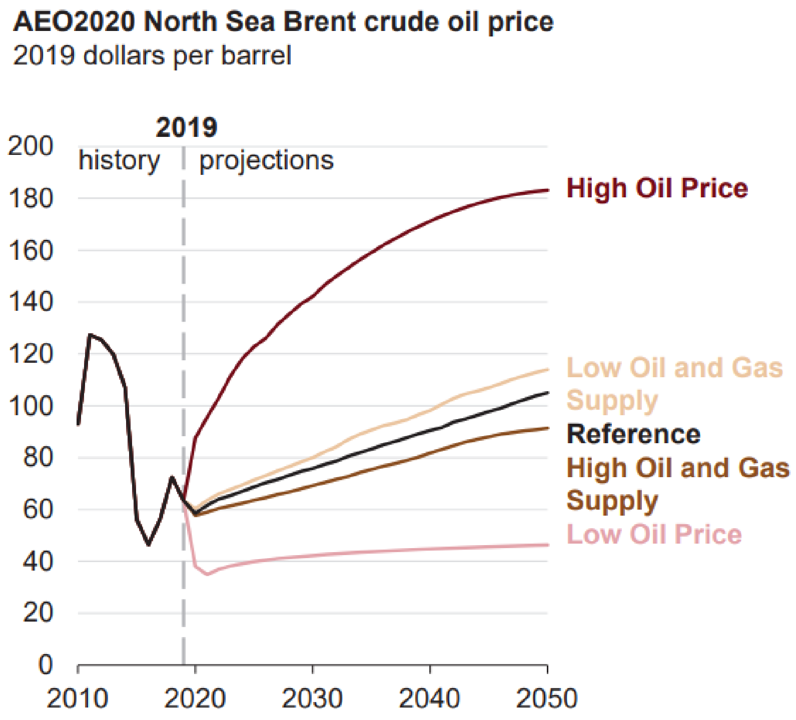
Included in the Behavior Change Case

- Vehicle miles traveled reductions in Behavior Change case based on consultation with Climate Solutions on their report on Washington and Oregon Transportation Modeling
  - personal and freight vehicle assumptions about what reductions in vehicle miles traveled may be possible
- Overall total for the state: 29% personal VMT reduction by 2050
- Freight reduction: 15%
- We assume that people retain vehicles but drive them less, thus total vehicle numbers are not impacted
  - Conservative, reduced numbers of vehicles purchased would increase cost savings

Category	Passenger Miles Traveled Reduction	Equivalent Vehicle Miles Traveled Reduction	Equivalent to Region
Urban	35%	47%	London
Suburban	35%	39%	Washington DC and London Average
Small City	15%	20%	New York State
Rural	10%	10%	CA, CT, NJ, IL

Fossil Fuel Price Projections

- AEO 2020 Reference scenario is the starting point for projections through 2050
- The advantage of using AEO across fuel types is that all prices are internally consistent



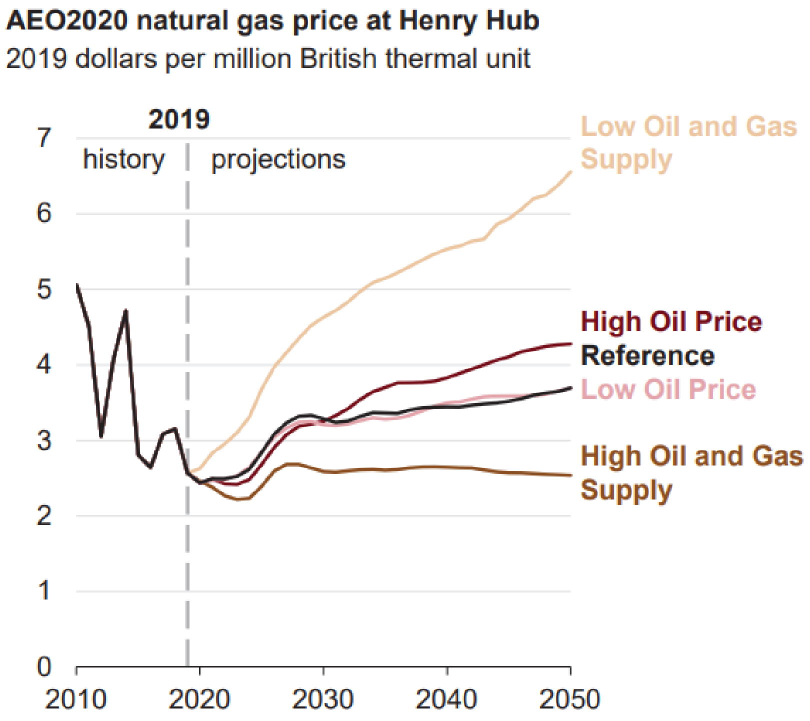


Figure source: https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf

Conversion Technology Cost and Performance

- EU ASSET: Technology Pathways in Decarbonisation Scenarios
  - Hydrogen electrolysis
  - Hydrogen gas reformation
- IEA Bioenergy: Implementation of bio-CCS in biofuels production
  - Biomass Fischer-Tropsch
  - Biomass synthetic natural gas
- IRENA: Advanced Liquid Biofuels
  - Cellulosic ethanol
- Princeton University
  - Autothermal reforming
  - BECCS hydrogen
  - Biomass pyrolysis

EVOLVED ENERGY RESEARCH

Biomass Feedstocks: Updated Estimates for Woody Biomass using LURA Model

Northwest woody biomass potential update

- Billion Ton Study 2016 Update the default source of cost and potential data for biomass
  - https://www.energy.gov/eere/bioenergy/2016-billion-ton-report
  - Supply curve by state and year developed for the US, supporting modeling of a biomass and biofuels market
- Reviewed by WSU and Commerce: Inadequate representation of Northwest woody biomass potential
- Michael Wolcott and team at WSU updated estimates for woody biomass in the Northwest using the LURA model for this study
  - These have been incorporated into the assumptions

Acronyms used in this Presentation

- BEV: Battery Electric Vehicle
- CES: Clean Energy Standard
- CETA: Clean Energy Transformation Act
- HDV: Heavy-Duty Vehicle
- ICE: Internal Combustion Engine
- IPCC: Intergovernmental Panel on Climate Change
- LDV: Light-Duty Vehicle
- MDV: Medium-Duty Vehicle
- MMT: Million Metric Tons
- O & M: Operations and Maintenance
- RCI: Residential, Commercial, Industrial
- RE: Renewable Energy
- RECs: Renewable Energy Credits
- RPS: Renewable Portfolio Standard
- SMR: Small Modular Reactor
- TBtu: Trillion British Thermal Units
- TX: Transmission
- VMT: Vehicle Miles Traveled

THANK YOU

2443 Fillmore Street, No. 380-5034
San Francisco, CA, 94115

(415) 580-1804

info@evolved.energy

www.evolved.energy

EVOLVED
ENERGY
RESEARCH