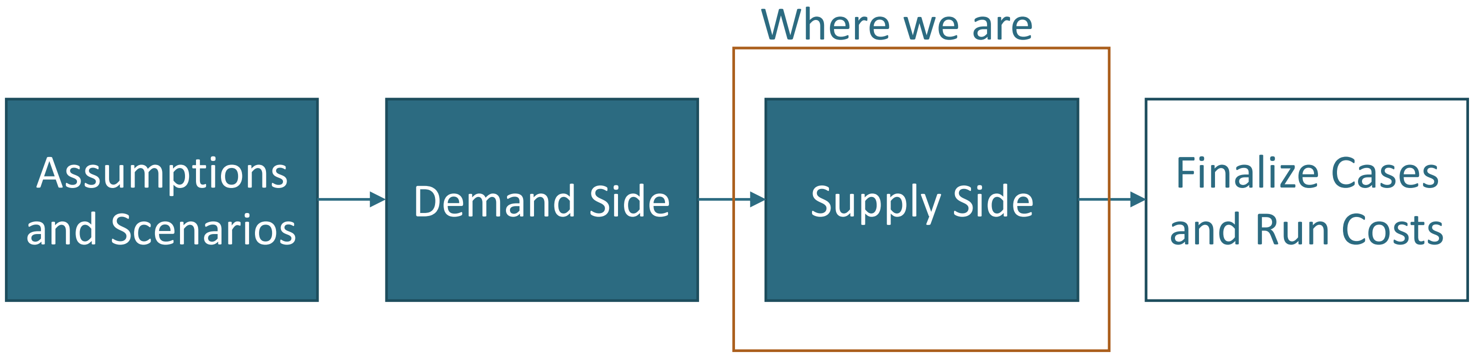
Washington State Energy Strategy Decarbonization Demand and Supply Side Results

August 25, 2020

EVOLVED ENERGY RESEARCH

Agenda

- Review of State Targets
  - Where is Washington going and how does it compare to present day?
- Scenario Descriptions
- Demand Side Review
- Supply Side Results
  - Draft findings
- Key Findings
- Technical Appendix
  - Methodology overview
  - Key assumptions



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

- 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

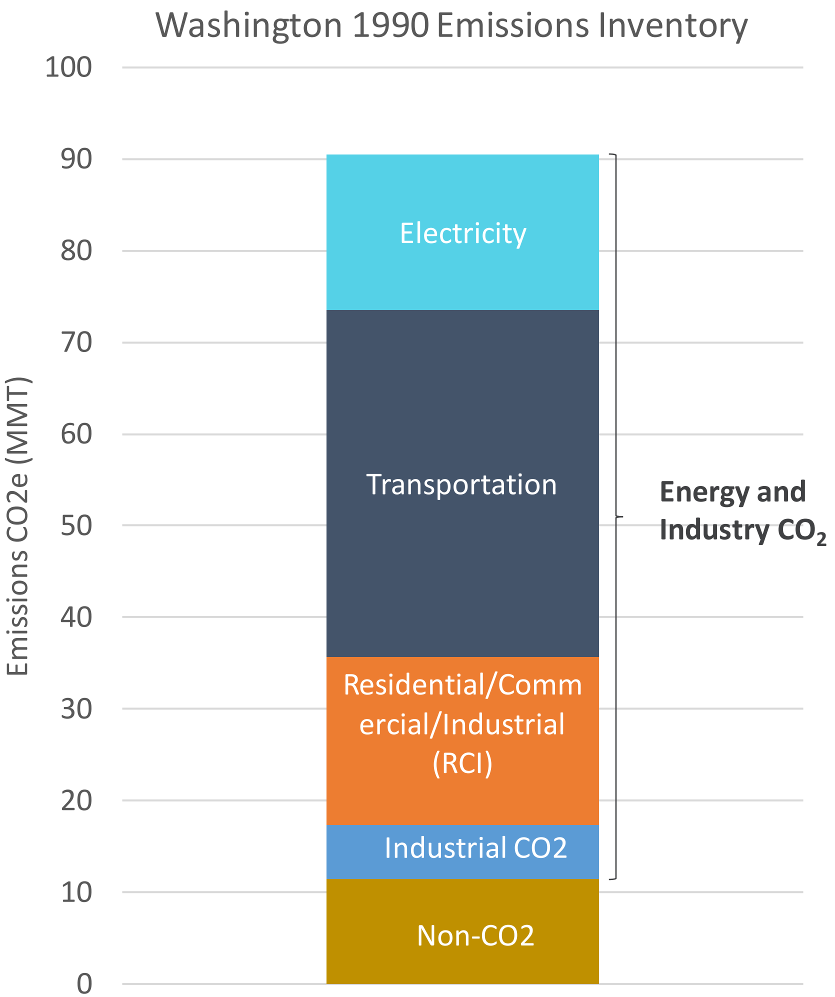
CETA Renewable Energy Credit Accounting

- **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

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						

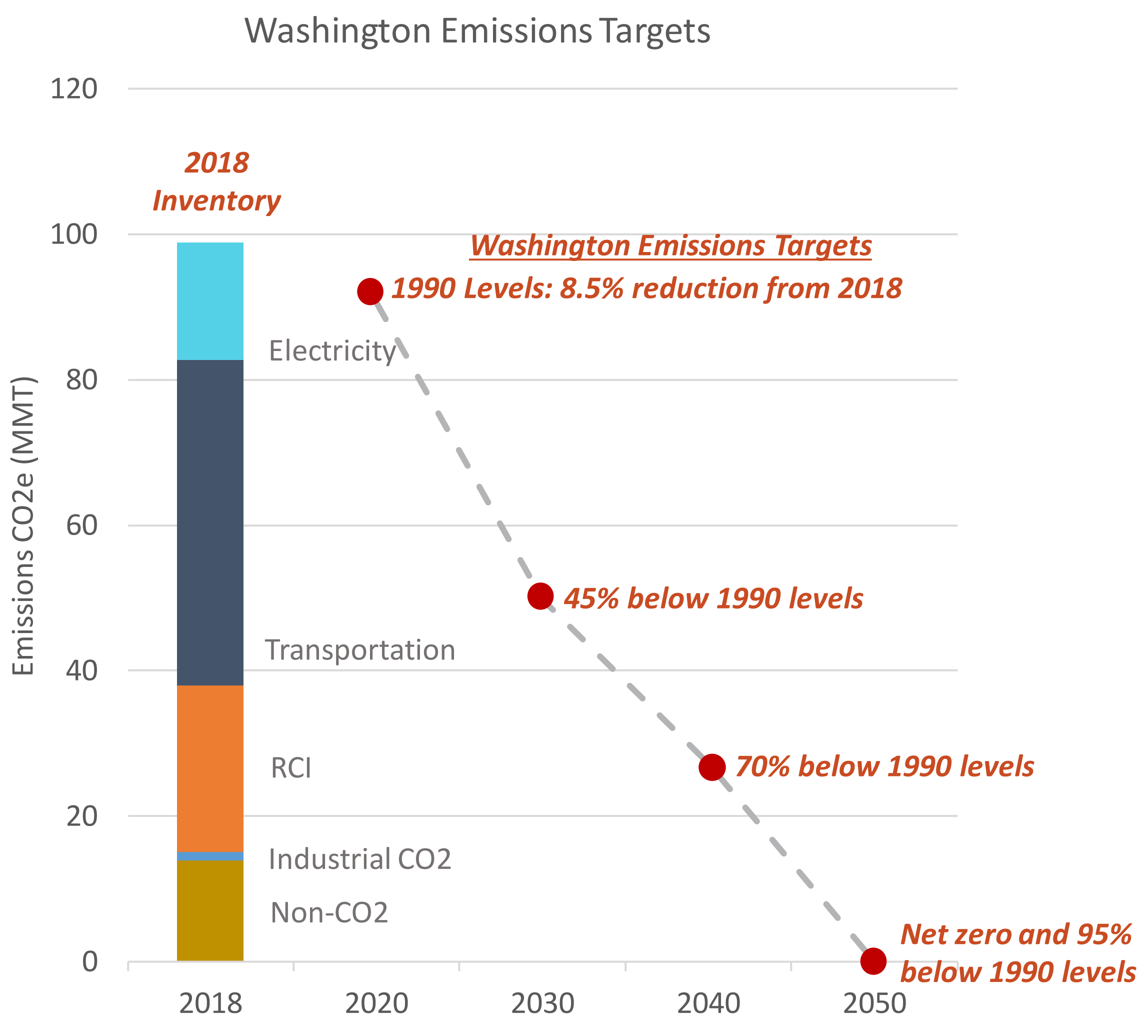
Emissions Targets Set Based on the State's 1990 GHG Footprint



- 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

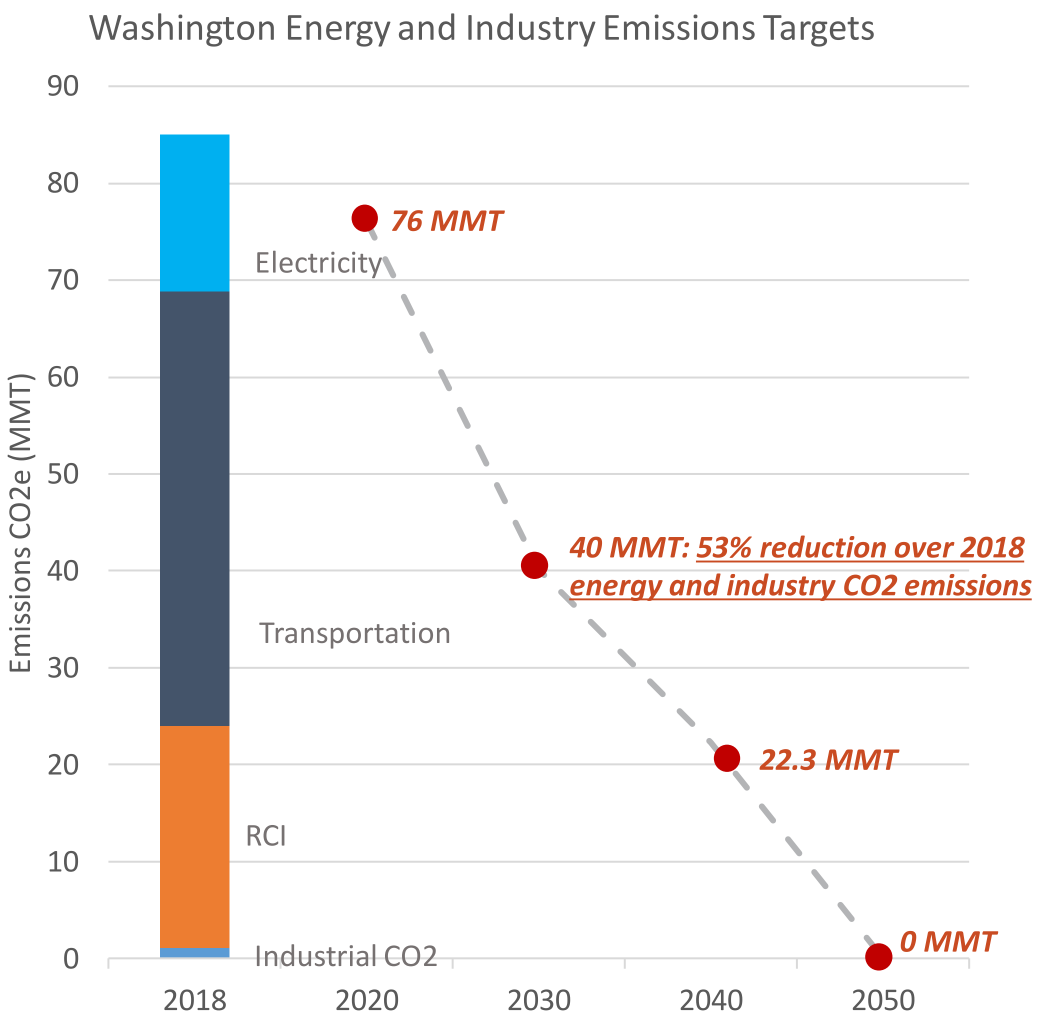
Year	Non-CO_2/Non-Energy Emissions	Incremental Land Sink	CO_2 Energy and industry	Economy wide CO_2 Target to reach statewide GHG limits
1990	11.4	0.00	79.2	90.5
2020	14.5	0.00	76.0	90.5
2025	12.8	-0.75	58.1	70.1
2030	11.1	-1.50	40.1	49.8
2035	9.5	-2.25	31.2	38.5
2040	7.8	-3.00	22.3	27.2
2045	6.2	-3.75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

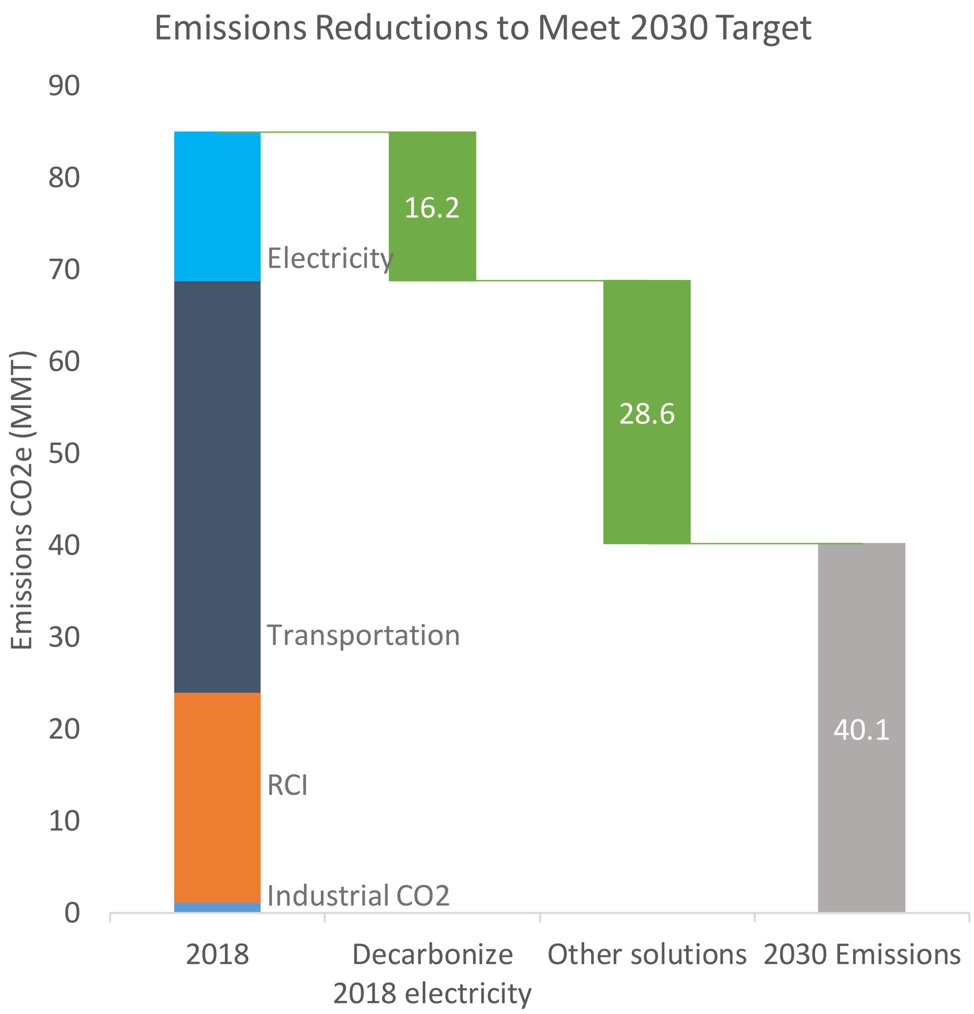
2030: The Energy Emissions Challenge



- 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?**

Electricity

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**

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

Scenario Descriptions

Scenario Descriptions and Implications

Scenario	Description
Reference	**Business as usual energy system through 2050** Assumes current policy is implemented
Electrification	**Investigates economics of a rapid shift to electrified end uses** Aggressive electrification, aggressive efficiency, relatively unconstrained technology availability in state and out of state
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 with lower building and industry efficiency and electrification** What is the impact of not achieving a transition from gas to electricity in the Electrification Scenario?
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** Shows the economic benefits in terms of reduced energy infrastructure and fuel burn of behavior change policy if social structure or economic changes naturally drive lower service demands (i.e., more telecommuting post COVID-19)

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		**Half electrification of other four cases**	Fully electrified appliance sales in most sub-sectors by 2050	
Buildings: Energy Efficiency	AEO	Sales of high efficiency tech: 50% in 2025, 100% in 2030		**25% in 2025, 50% in 2030**	Sales of high efficiency tech: 50% in 2025, 100% in 2030	
Transportation: Light-Duty Vehicles	AEO	100% electric sales by 2035	**50% electric sales by 2035**	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, 50% of RE potential, no SMRs**	Same as R, E, TF, and GB Cases

Results

Structure of results

- The results in this section are structured as follows:
  - **Economy-wide GHG emissions** – Emissions reductions by fuel to reach net zero
  - Changes to **energy demand**
  - **Electric sector investments and operations** metrics are shown to better understand the scale and rate of change required
  - Transformation to **fuel demand and supply**, including gas, hydrogen and liquid fuels

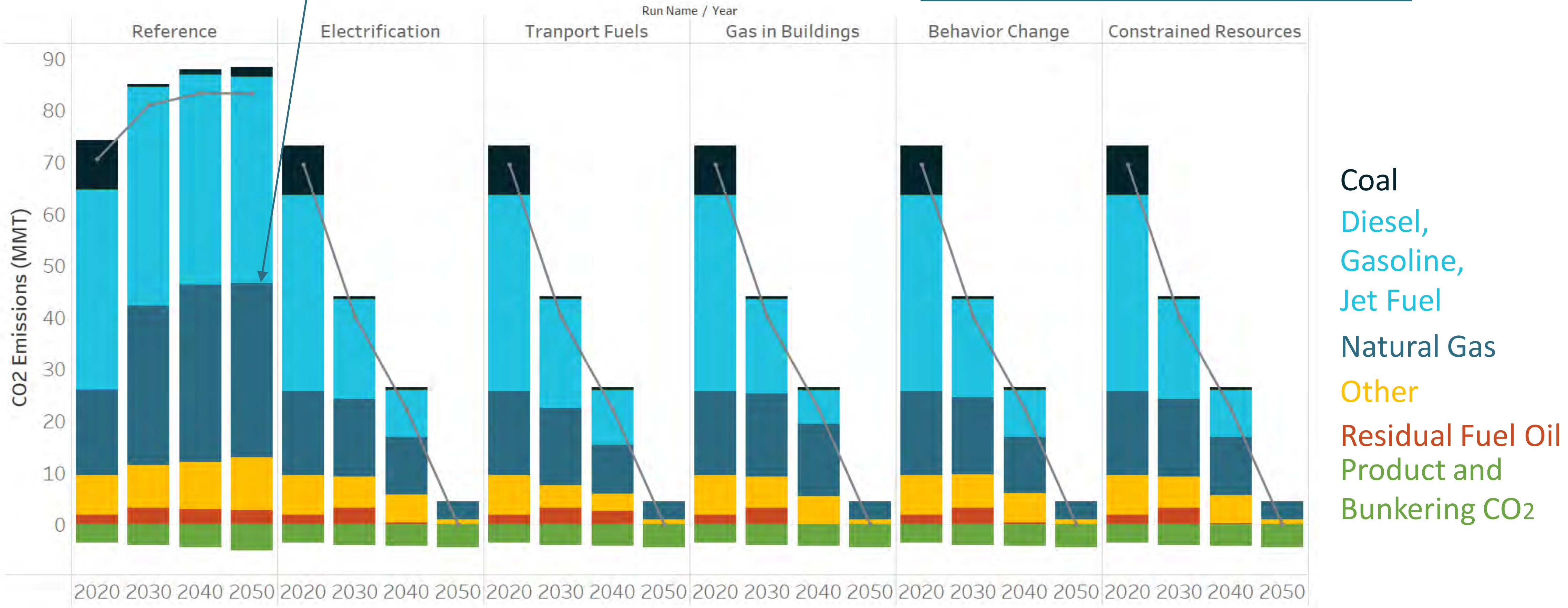
Emissions by Scenario

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

Additional gas emissions from exports in Reference Case: not counted in inventory

Product and bunkering CO_2 provide negative emissions in accounting

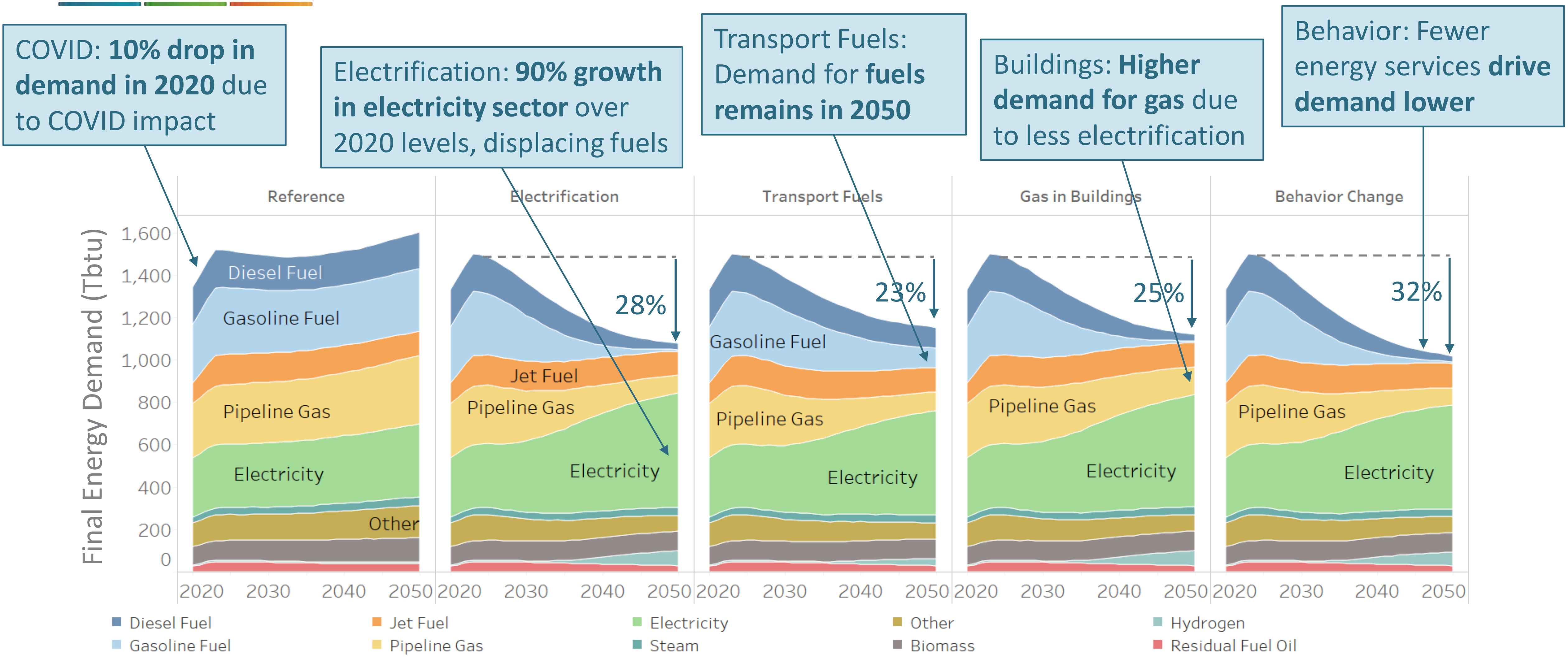
Similar trajectories as end use demand drives reductions in gas use while liquid fuels are decarbonized



Demand Side

Final Energy Demand

Electrification and efficiency drive lower total energy demand



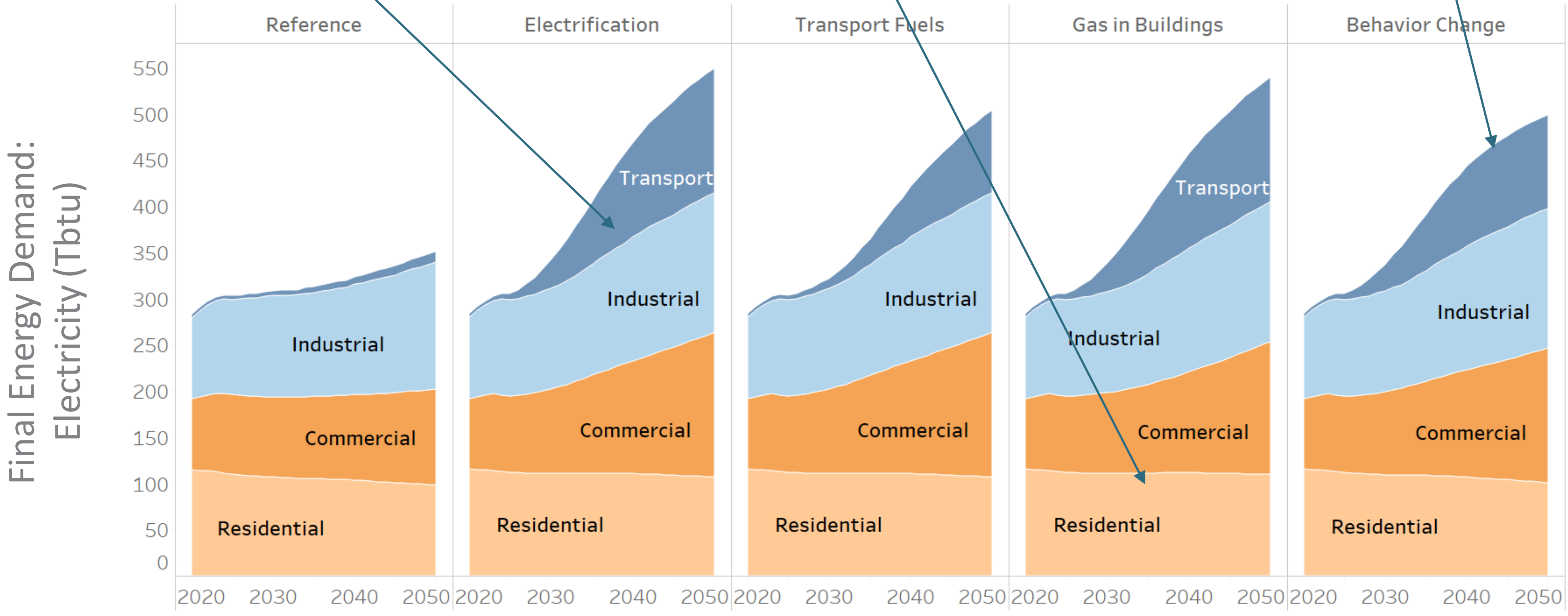
Final Energy Demand: Electricity

Electricity use in all decarbonization scenarios grows significantly

Transport electrification largest differentiator between cases

Lower electrification in buildings offset by lower levels of efficiency

Behavior Change drives lower demand in transport and buildings



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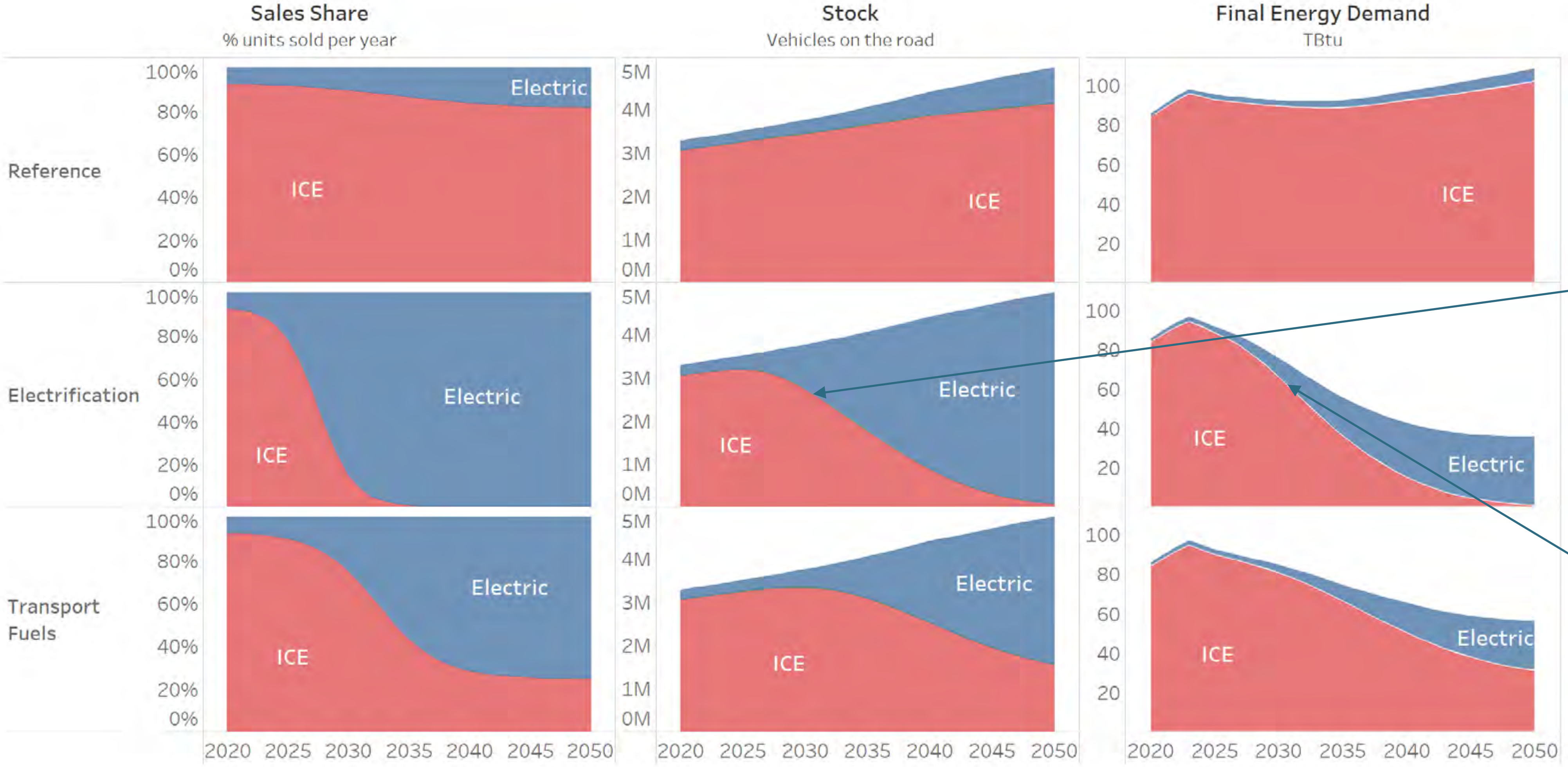
Light-Duty Vehicles: BEVs are Key to Lower Energy Demands

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

Projected Sales, Stock, and Final Energy Demand



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

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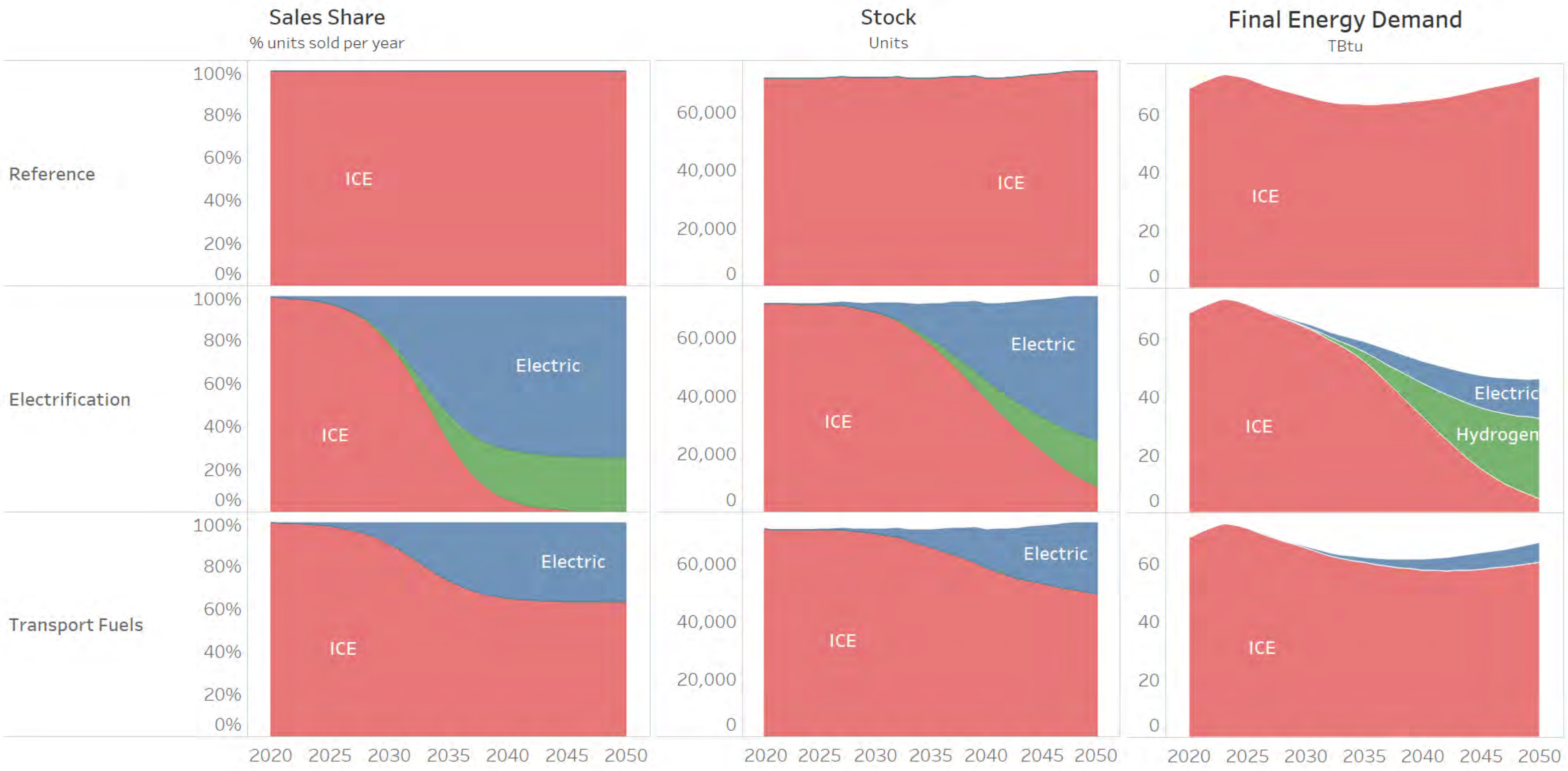
Heavy-Duty Vehicles: Hydrogen Demand in Long Distance by 2050

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

Projected Sales, Stock, and Final Energy Demand



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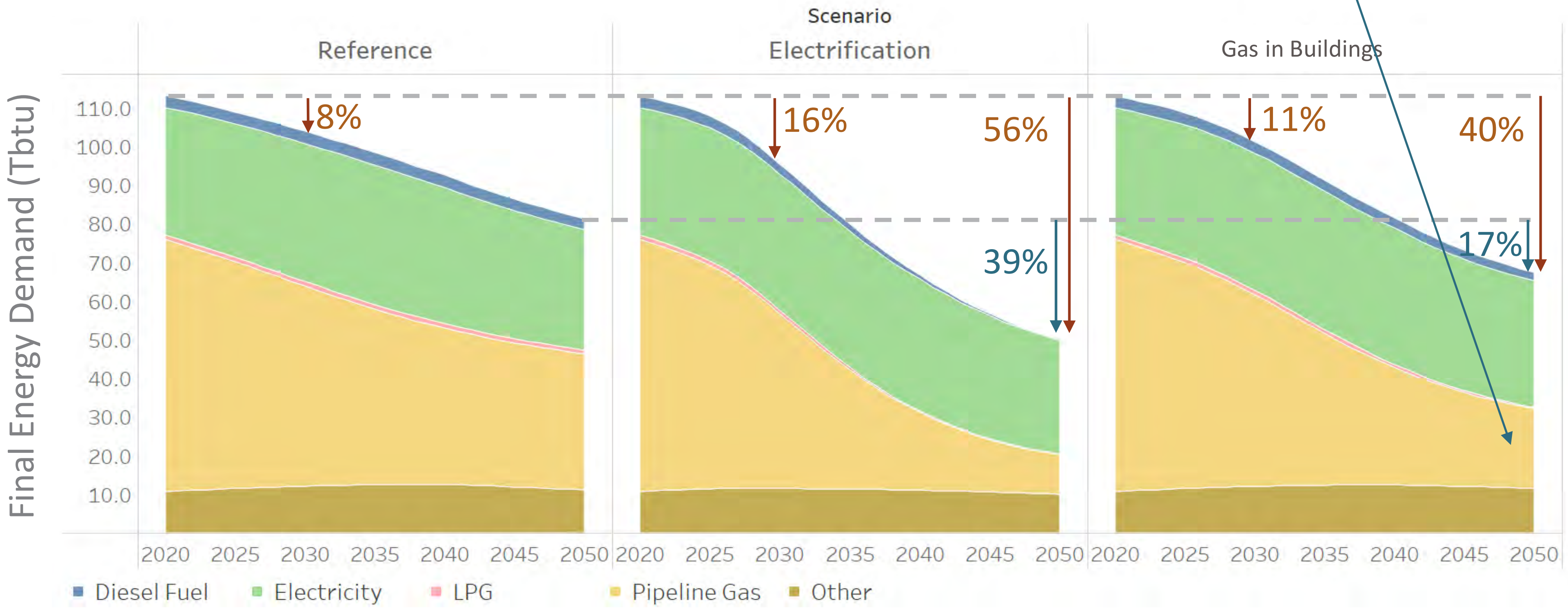
Residential Space Heating

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

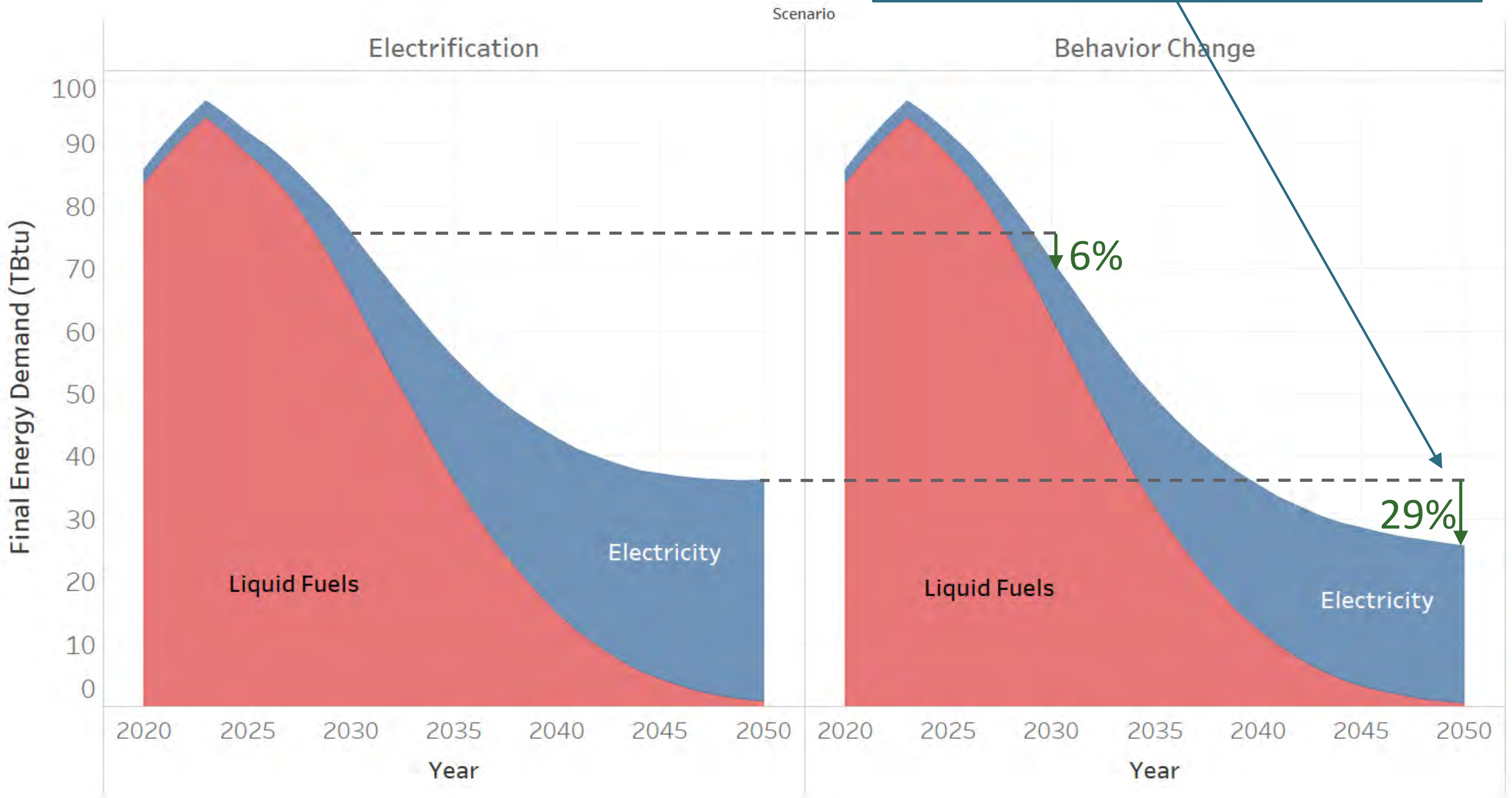


Behavior Change: Transportation

- 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?

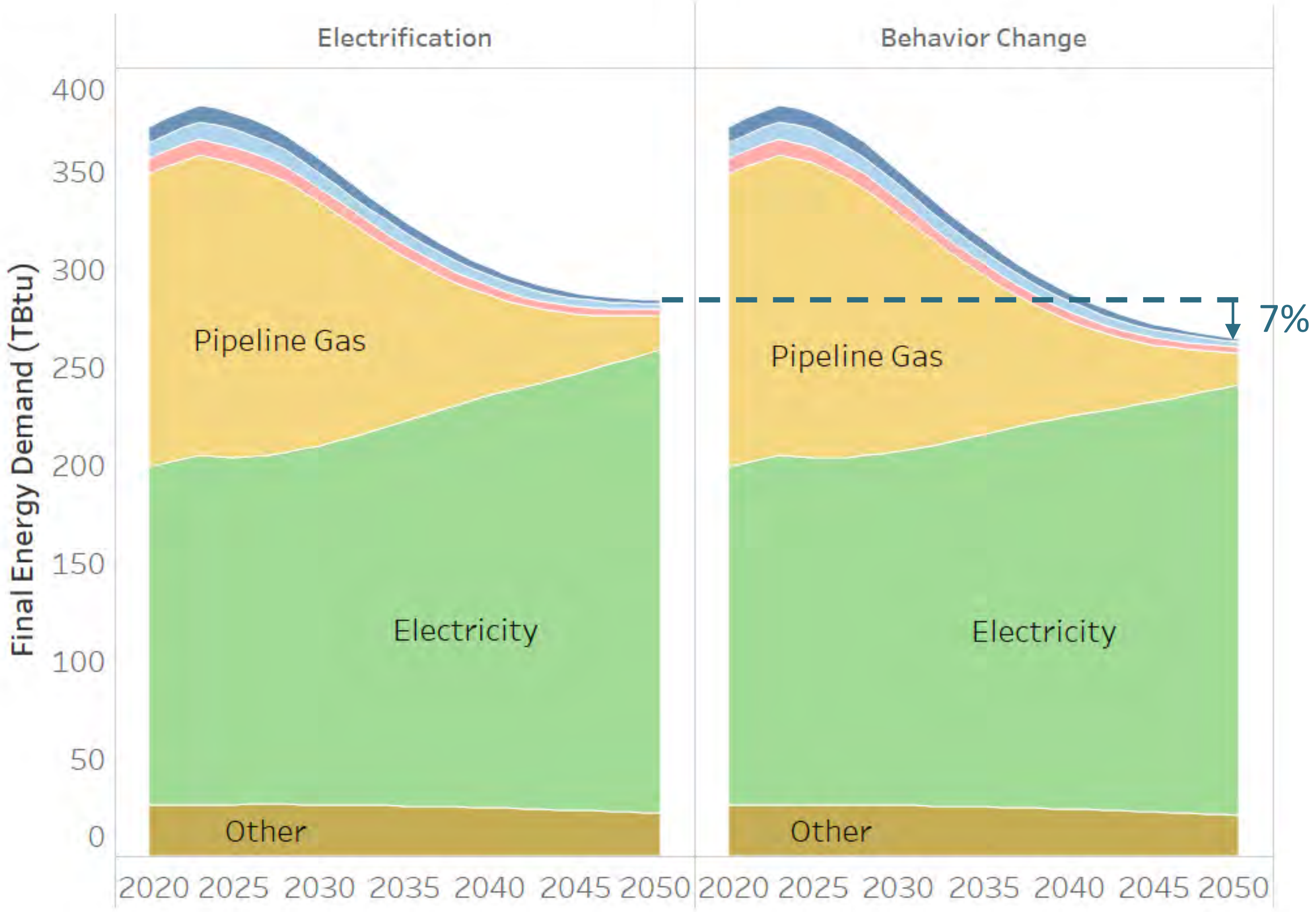
29% percent reduction in sales of fuels and electricity vs. Electrification Case by 2050

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



Supply Side

Electricity Capacity in Washington

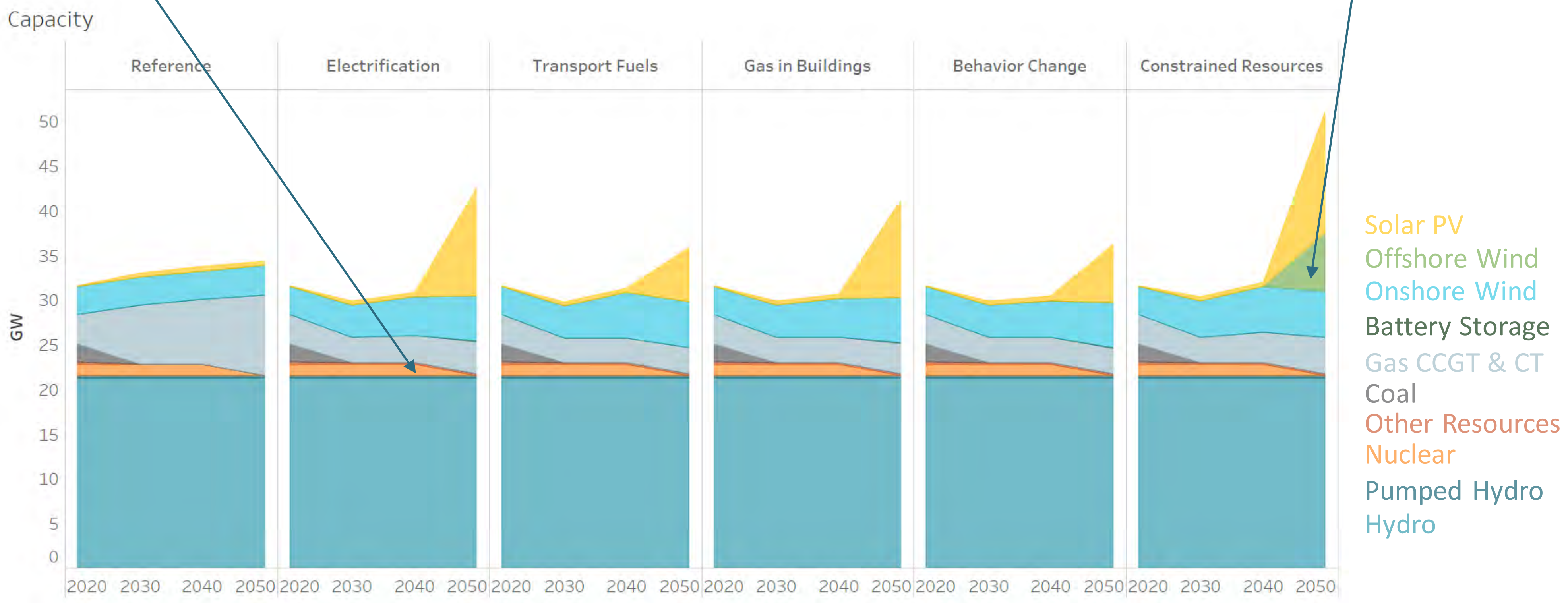
Washington relies heavily on imports of clean energy so capacity builds stay relatively flat

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

Similar builds across decarbonization cases other than Limited Resource Case

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

Relatively little growth in capacity due to significantly increased imports



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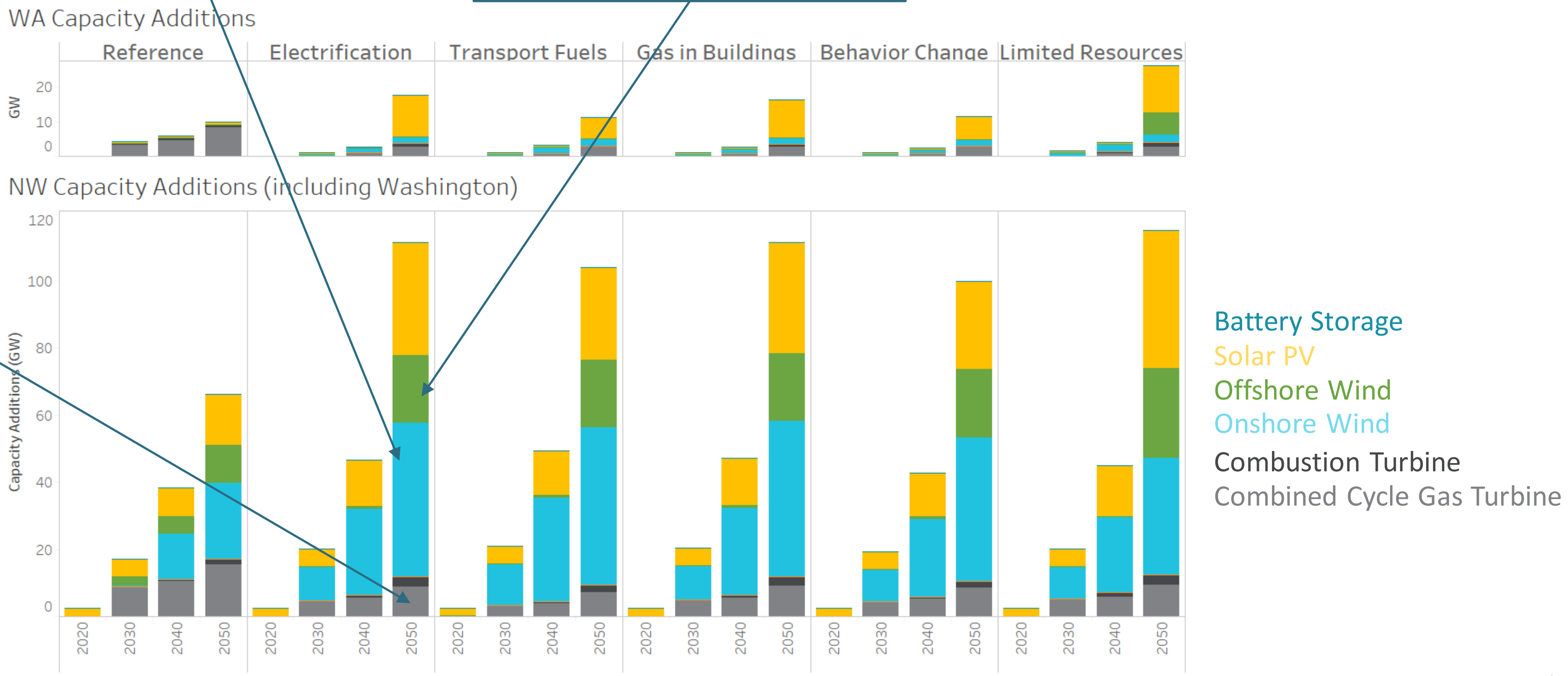
Capacity Additions in Washington and the Northwest

Washington past 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

9 GW of gas capacity additions provide reliability, operated at low capacity factors



Generation and Load in Washington

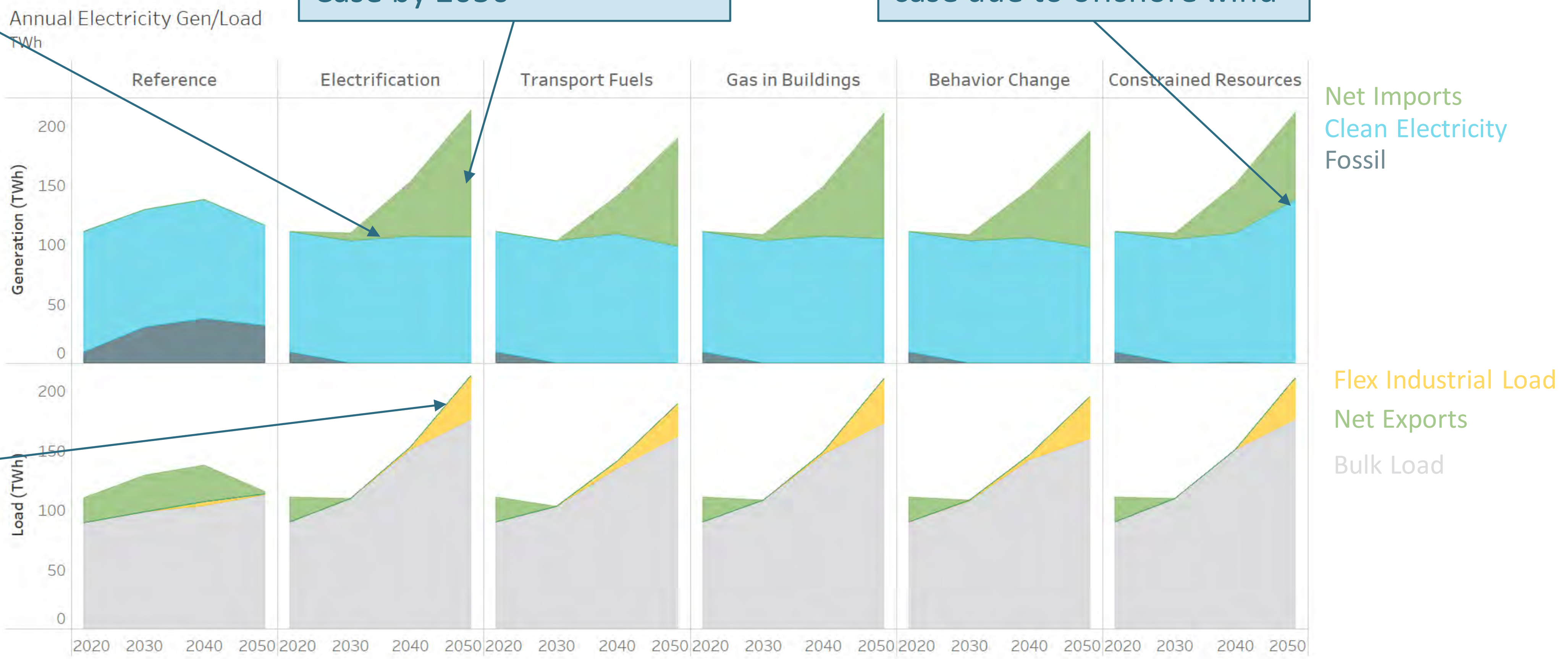
Rapid increases in imports provide clean energy for expanding electricity sector

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

Imports provide 50% of electricity in Electrification Case by 2050

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

Added flexible loads by 2050 (electrolysis, boilers) more than double 2020 load



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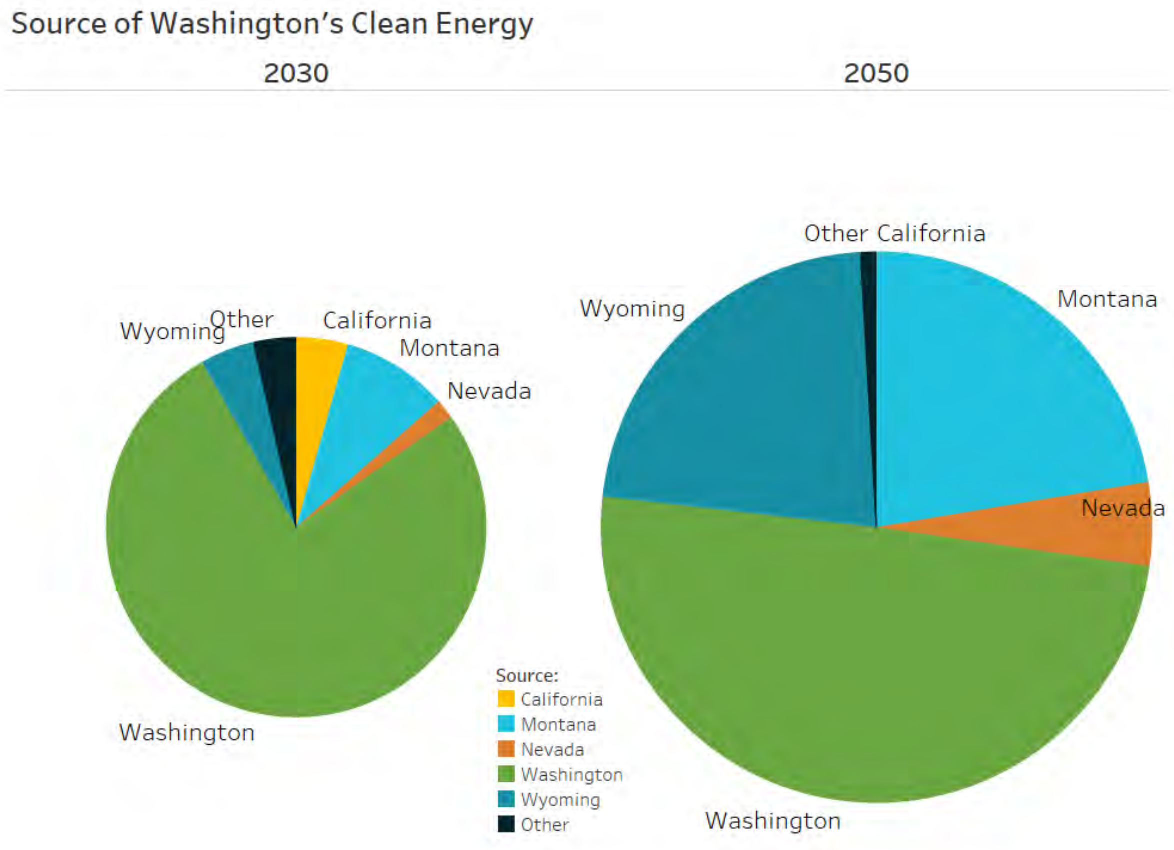
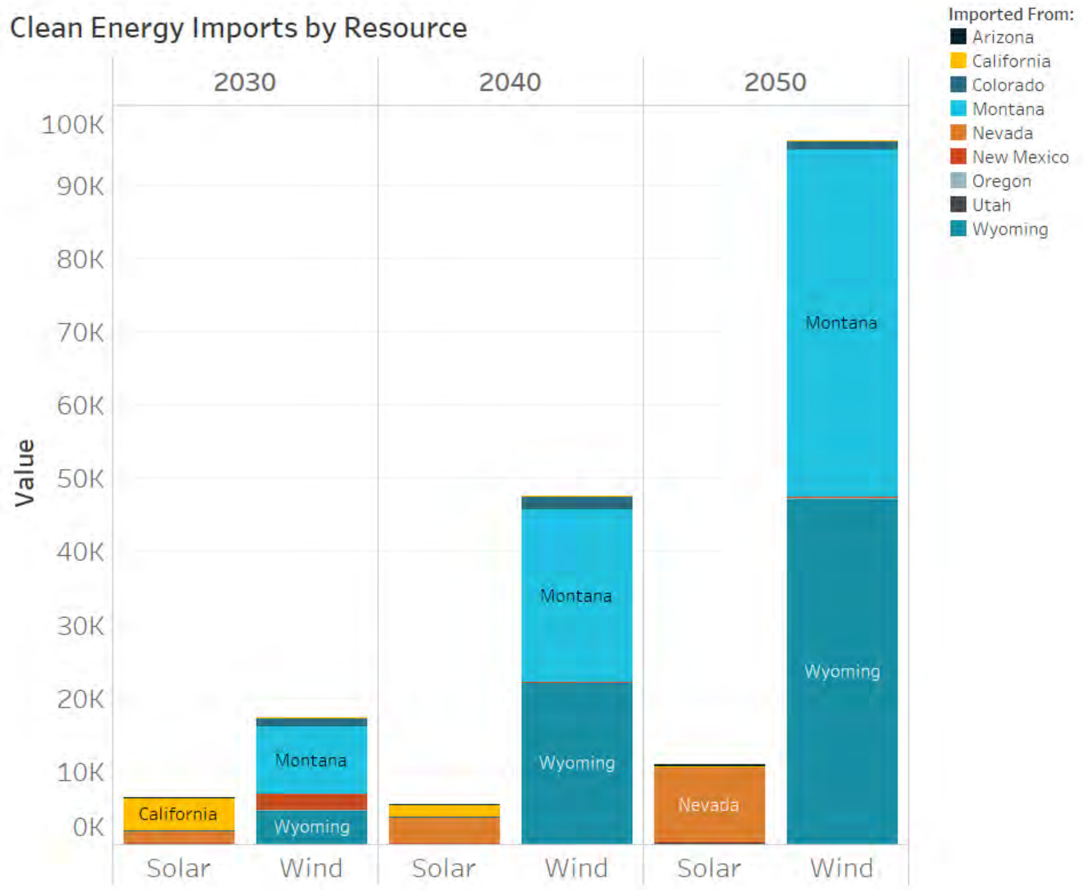
Where do Imports Come from?

Clean electricity imports from Electrification Case

High quality wind resources from Wyoming and Montana account for 45% of WA clean electricity in 2050





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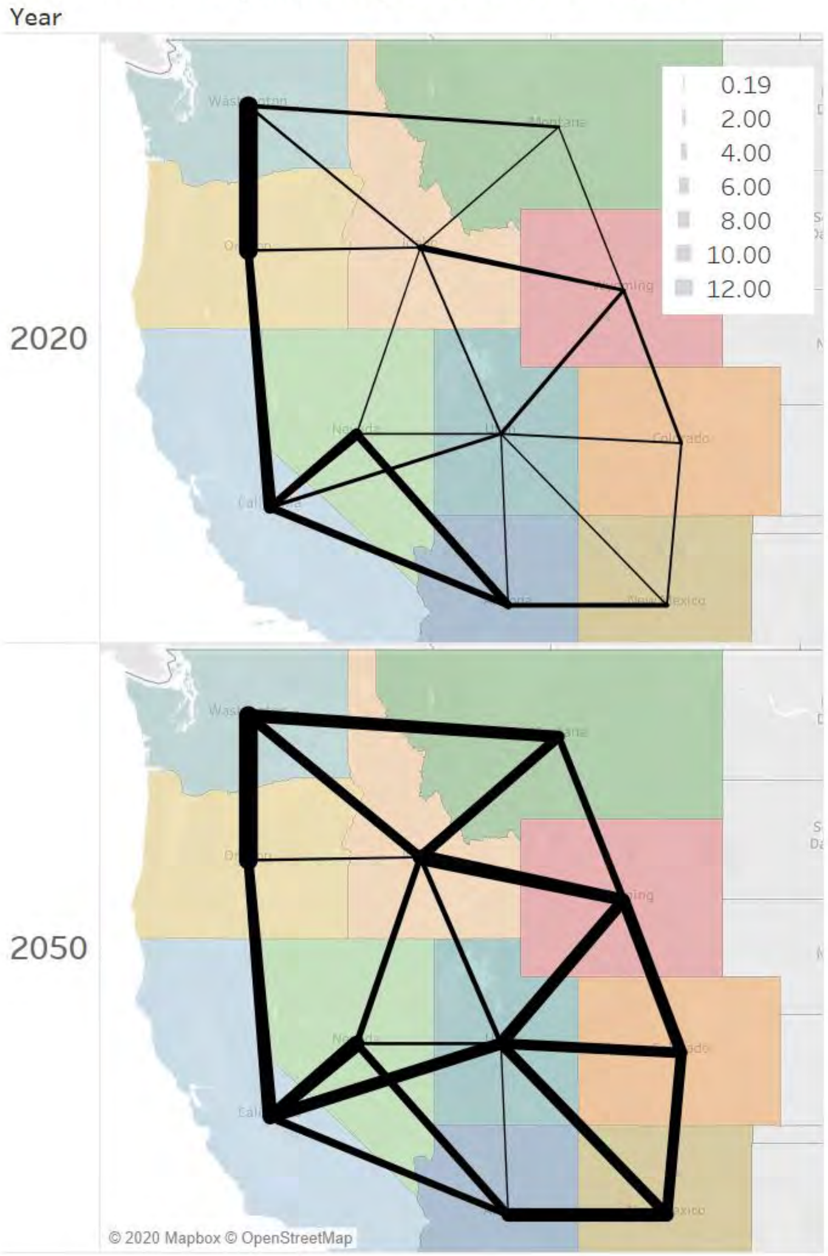
Expanding Transmission Facilitates Imports

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
  - ID->WA: 5 GW added
- 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

Transmission Expansion by 2050: Electrification



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Regional Capacity in 2050

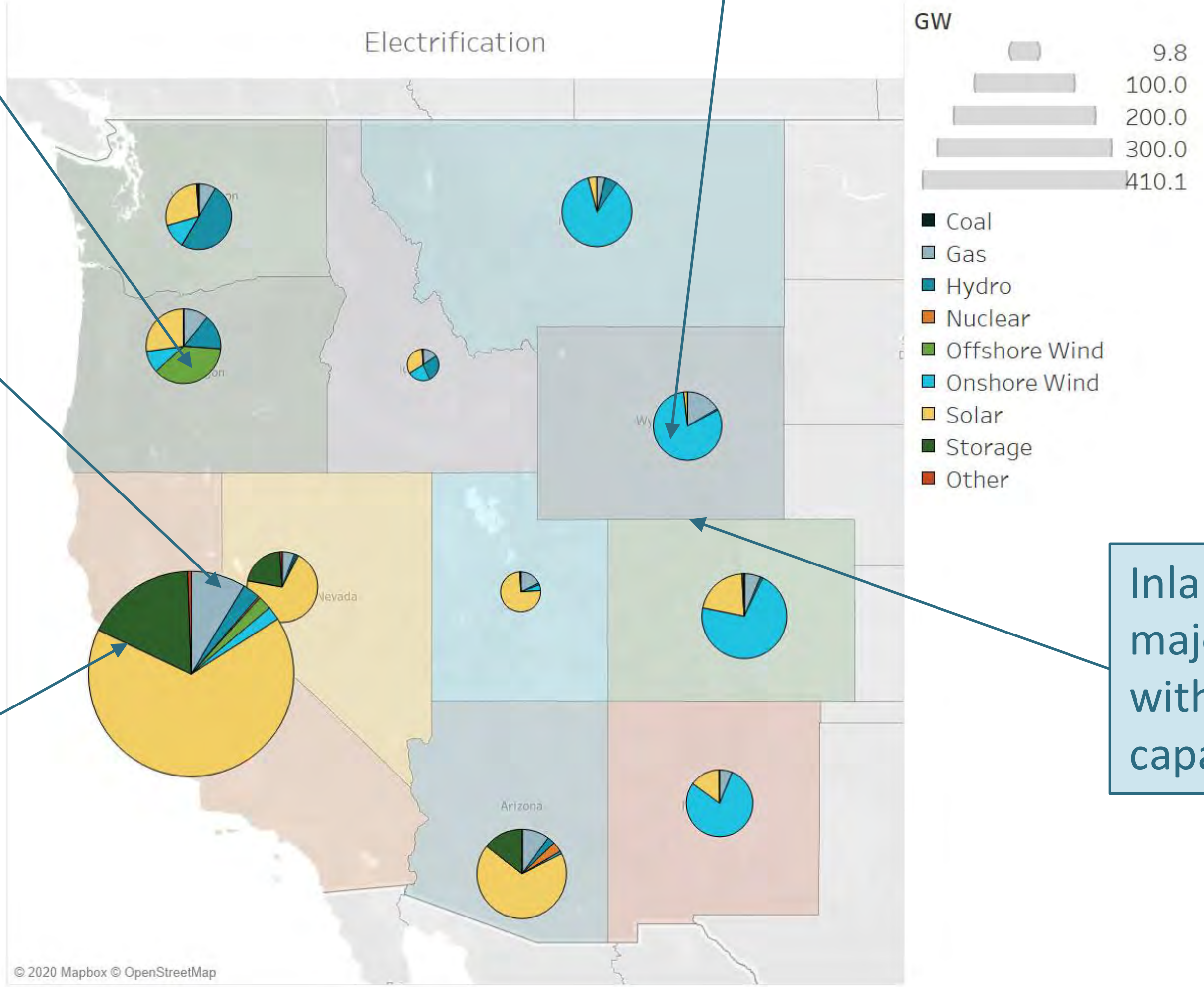
Electrification Case

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

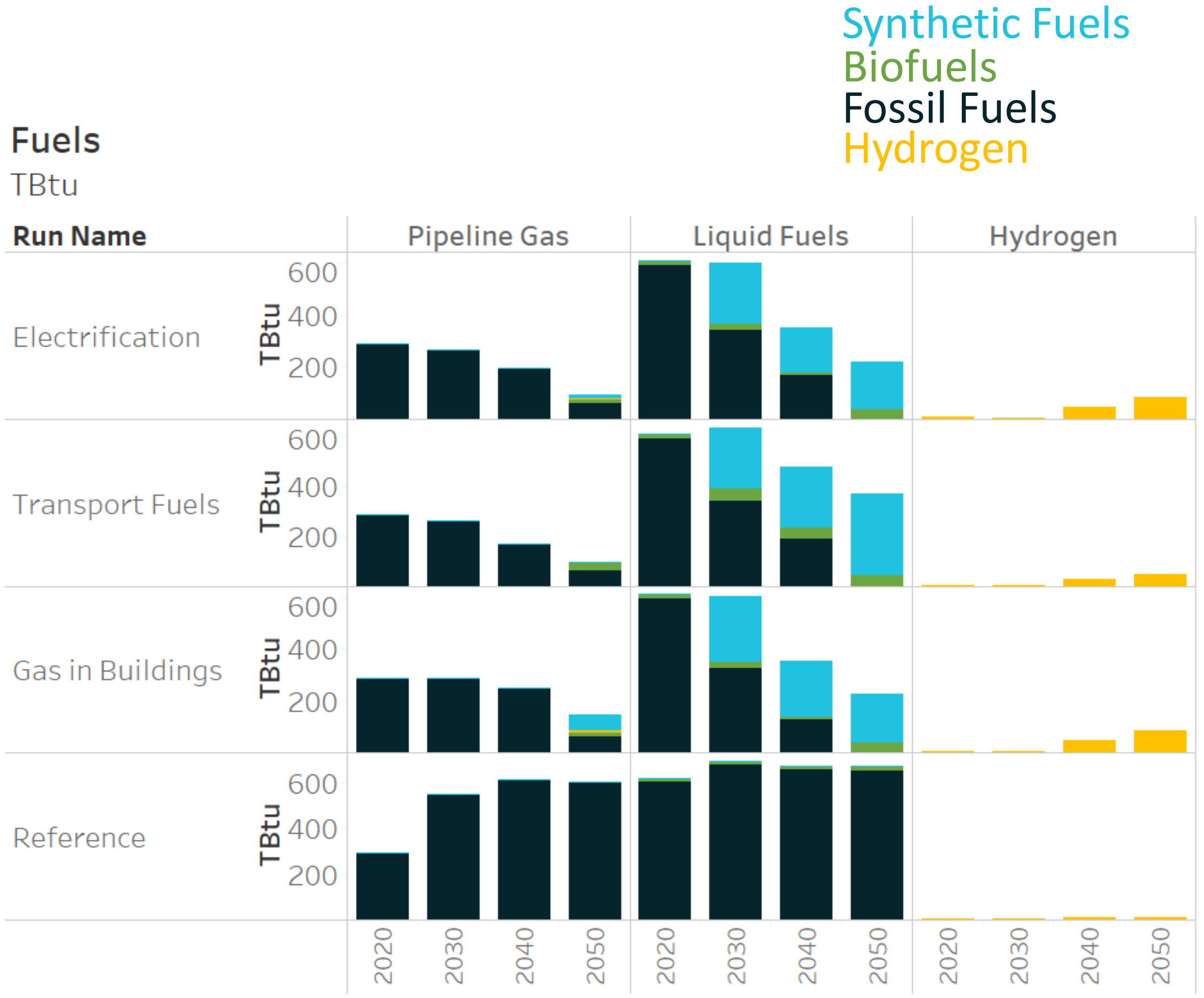


Inland states become major exporters of wind with majority wind capacity systems by 2050

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
  - Significant growth in synthetic and biofuels 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



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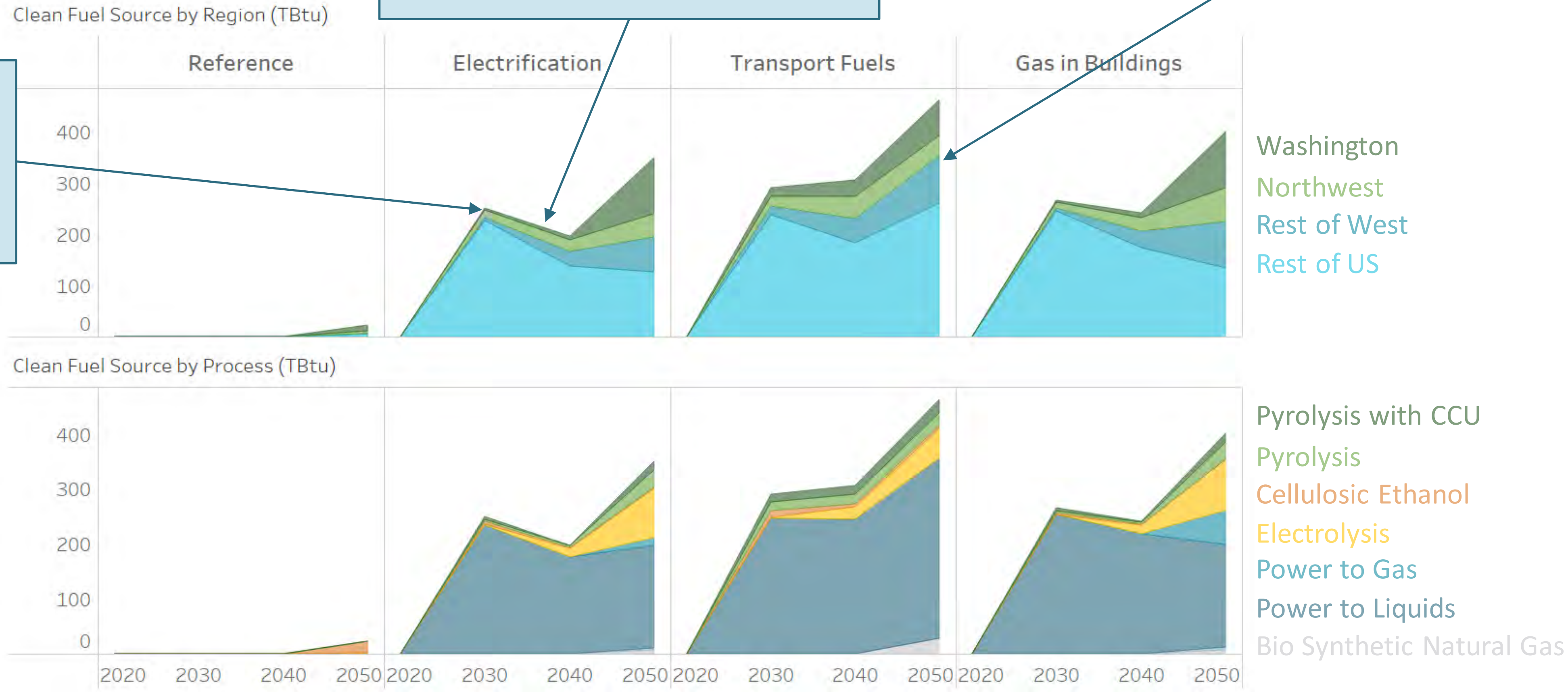
Where do Clean Fuels Come from?

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

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

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

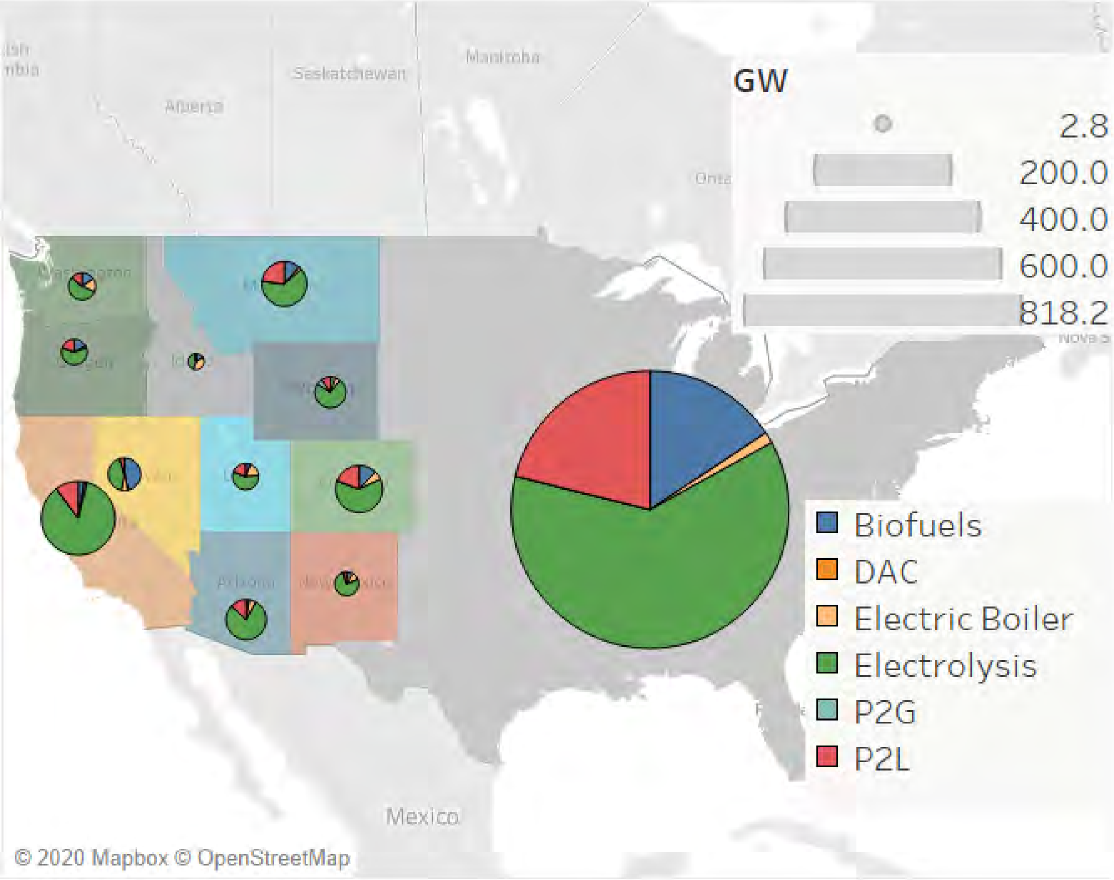
33% higher clean fuel demand in Transport Case vs Electrification



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



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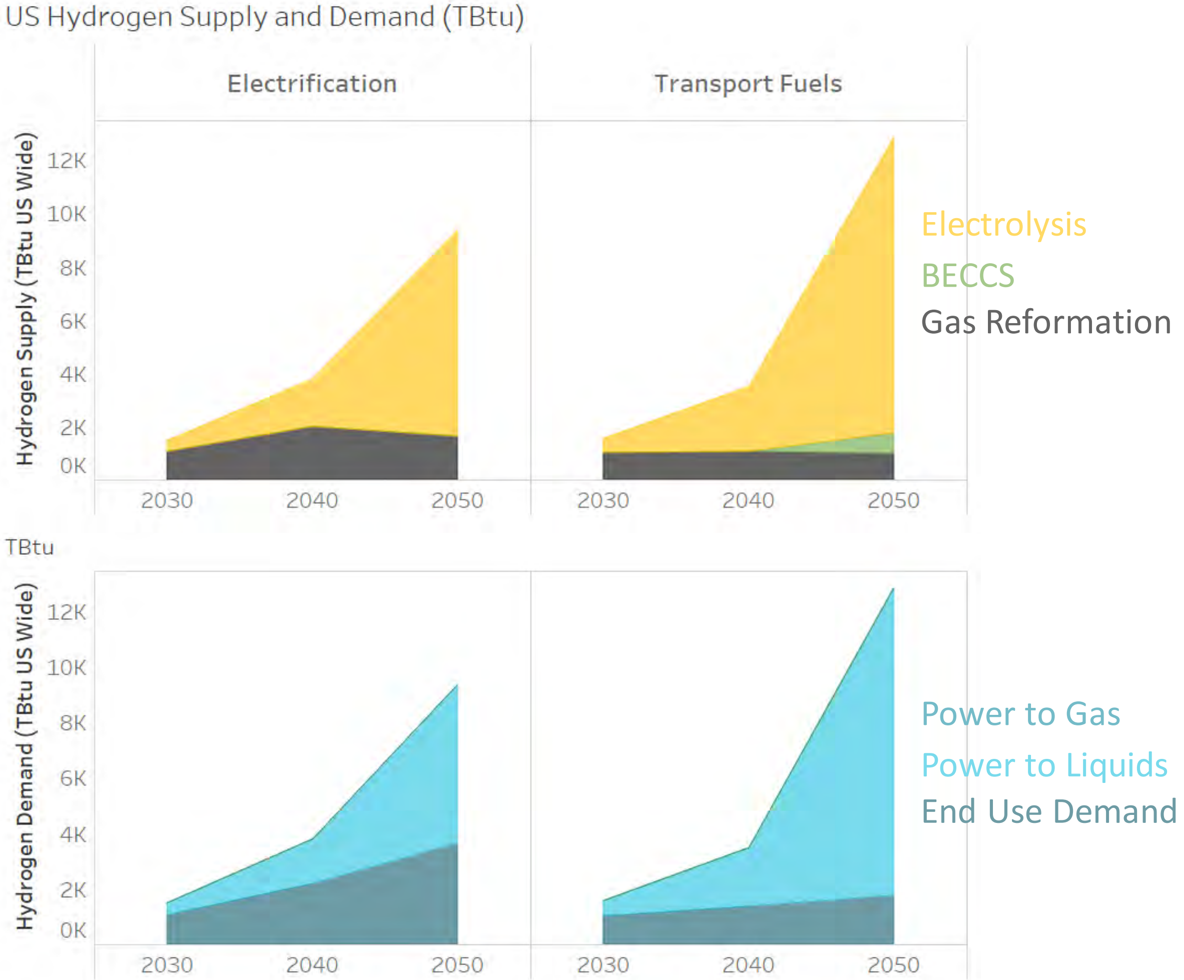
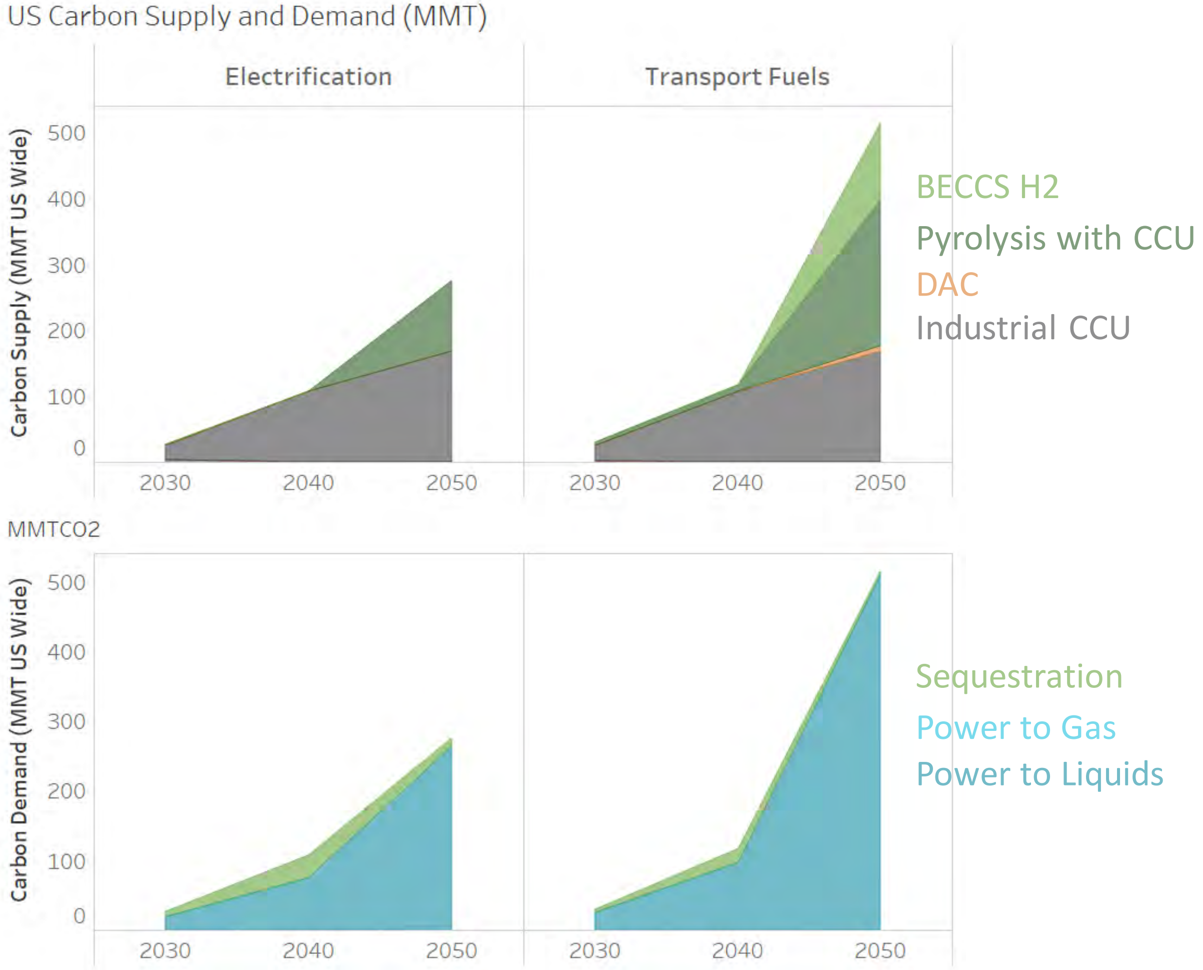
National Fuels Industry in 2050: Hydrogen and Carbon

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





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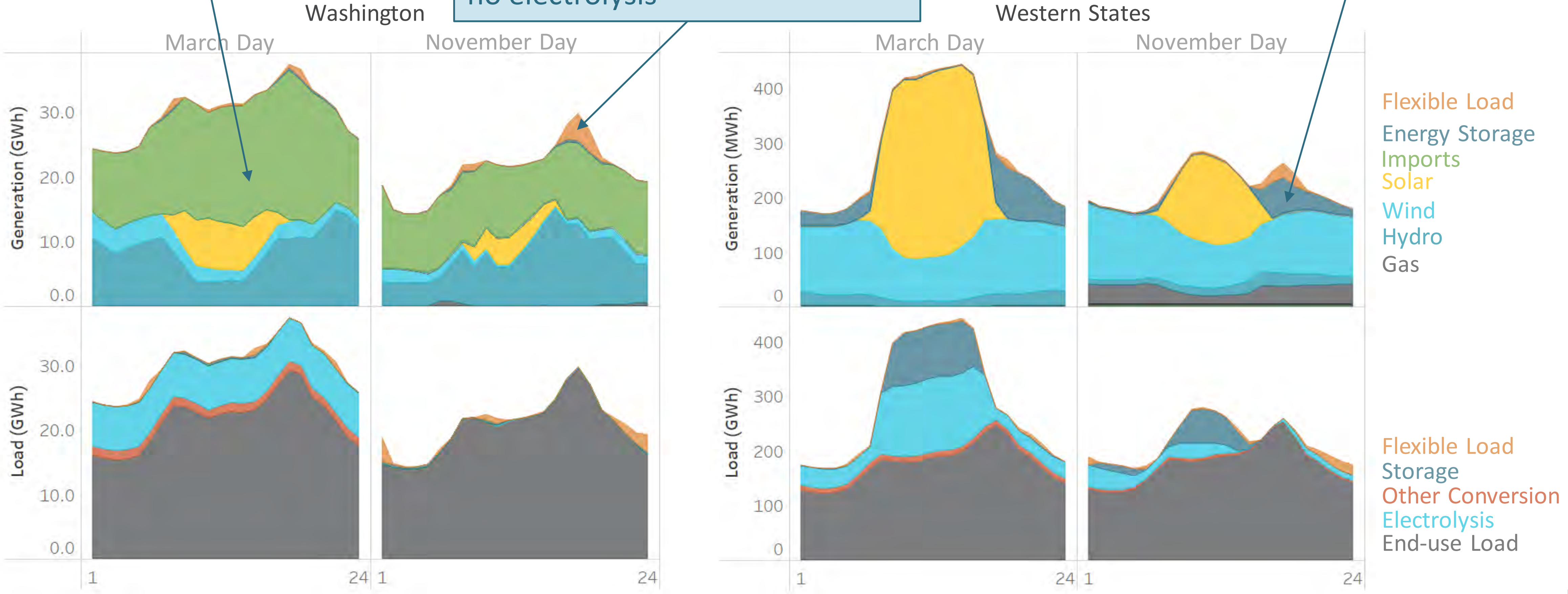
Balancing the System: High Energy and Low Energy Days in 2050

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



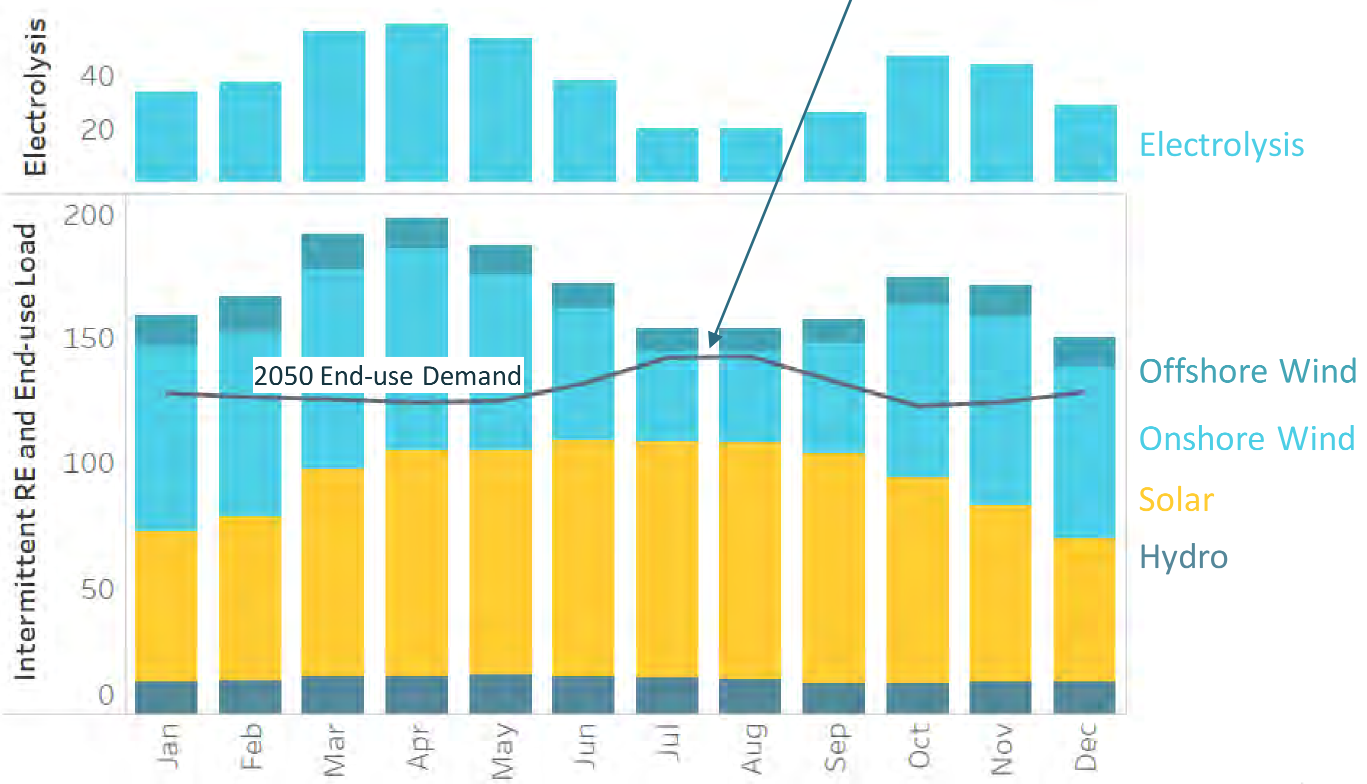
Seasonal Balancing in 2050: West Wide

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

Renewable Generation and Electrolysis in 2050

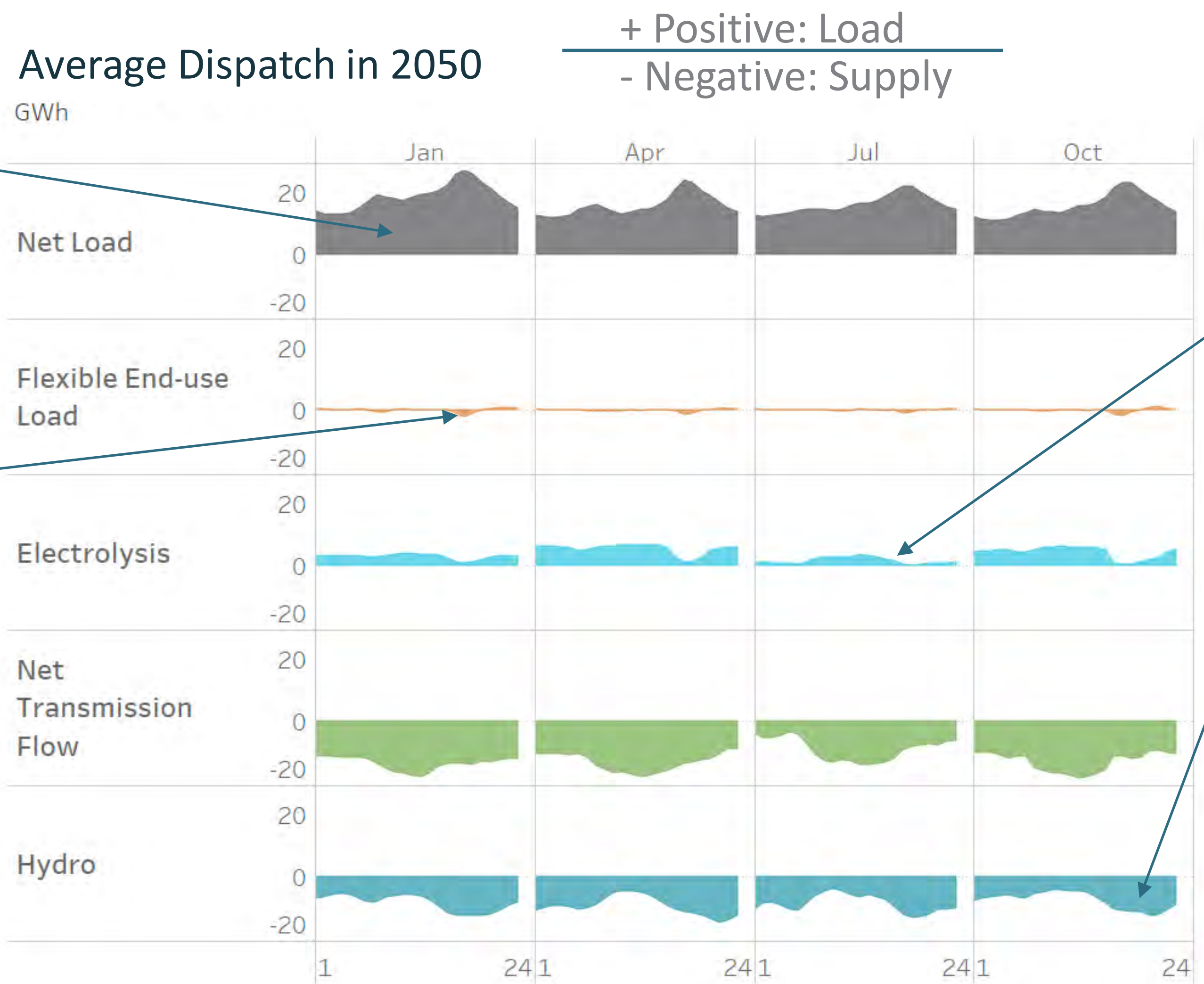


Washington's Main Balancing Resources

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

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

Flexible loads drive down peak 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 of the 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
  - A large synthetic fuels industry developed based on hydrogen and carbon from electrolysis and biofuels
- The scenarios show how Washington would respond differently under different conditions
  - Transport fuels drive a 33% increase in clean fuel use in the state with reduced electricity consumption
  - Gas in buildings drives synthetic gas production not seen in other cases to ensure decarbonization goals are met
  - Behavior change reduces Washington's need for clean energy and fuels
  - Constrained resources drives additional solar build and offshore wind in Washington
- Bottom line: how much will these solutions cost relative to one another?
  - Next step in the analysis

Key Findings

Key Findings

- Because Washington's electricity supply is 80% clean to begin with, decarbonizing electricity cannot play a large role in accomplishing the 2030 goal
- Even with GHG-neutral electricity under CETA, 2030 emissions target is very 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 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

Key Findings

- Significant imports of clean energy from wind-rich states support Washington's electricity needs – 48% by 2050 in Electrification Case
  - Regional coordination is key to Washington and Western decarbonization
  - By how much and how fast can transmission be expanded?
- Synthetic fuels production plays a major role in decarbonizing Washington's economy as well as balancing the electricity grid
  - Both through electrolysis in the state and as part of the regional balancing solution
  - Early need for clean fuels to meet Washington targets
- 9 GW of natural gas added for reliability by 2050
- 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

Initial Policy Direction

- What policies can we put in place in 2020 to push as hard as possible on energy efficiency, electrifying end uses, flexible loads, and low-carbon fuels to get on the path to 2030 emissions goals and beyond?
- What policies can help develop a clean fuels industry rapidly and cost effectively?
- What are the policies that would encourage behavior changes that could be done early, fast, and cost effectively?
- What actions need to be taken to develop greater regional coordination and interregional balancing?

Thank you

Jeremy Hargreaves, Principal, Evolved Energy Research

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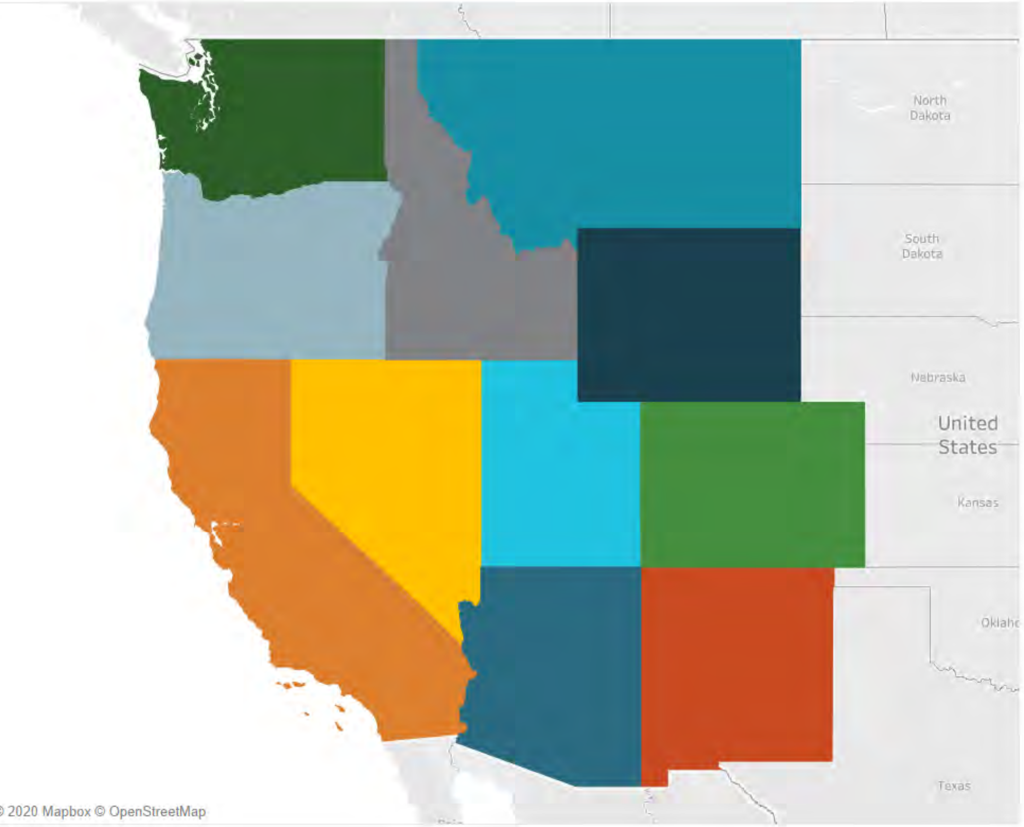
Appendix: Study scope and methodology

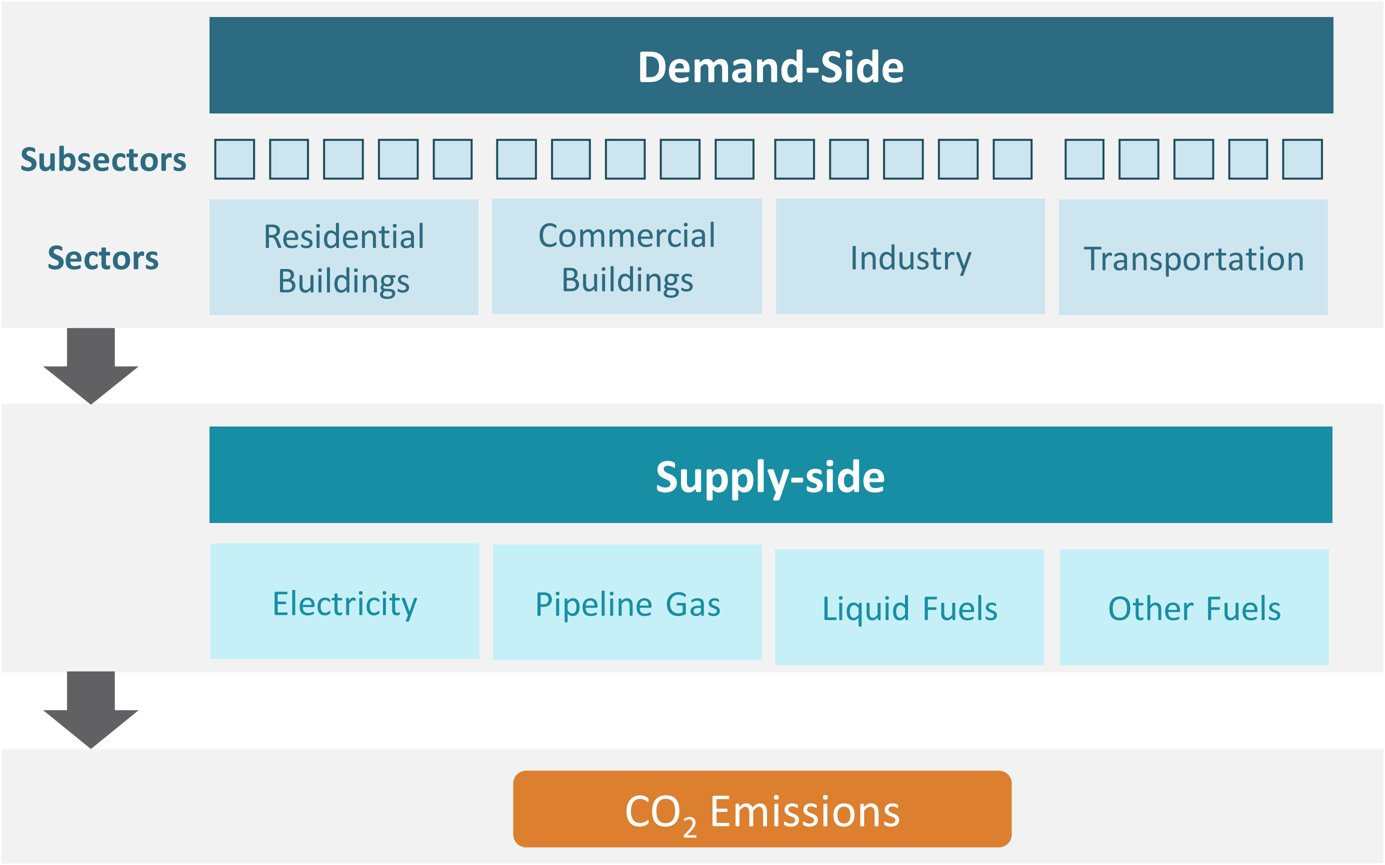
Study evaluates deep decarbonization of Washington's economy



- 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

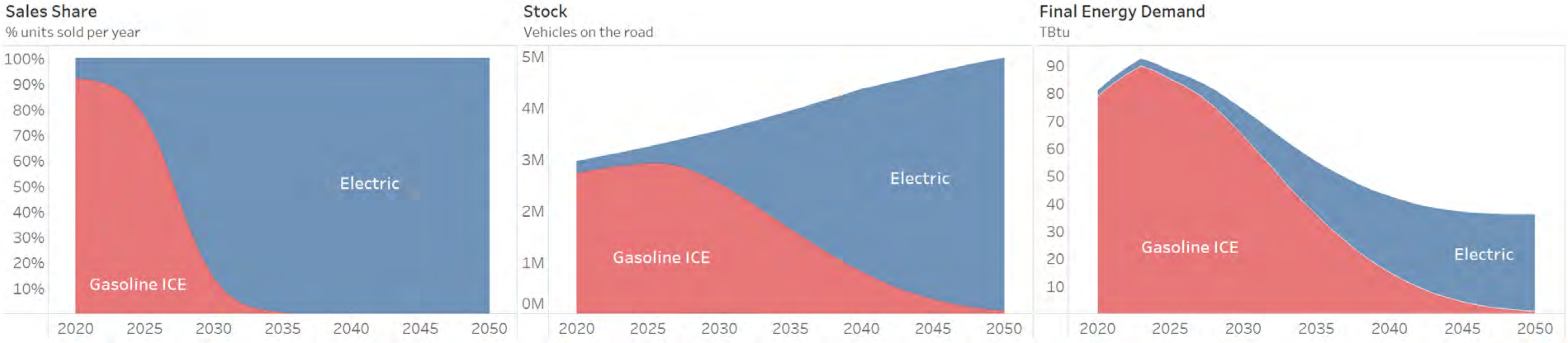
ENERGY PATHWAYS

- 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



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

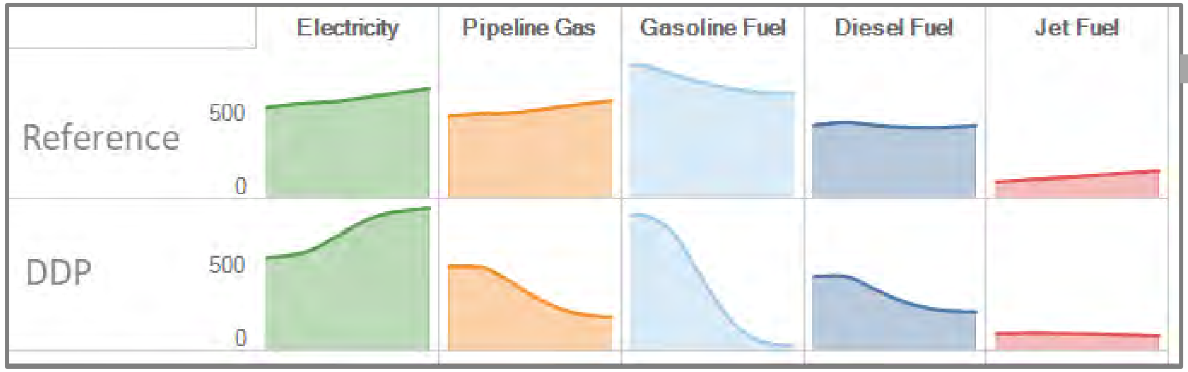
Co-optimized energy supply

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

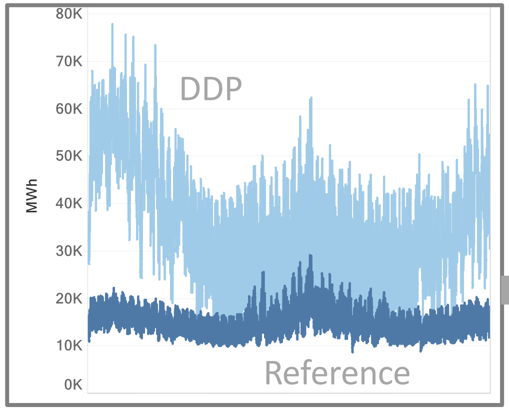
Demand- and supply-side modeling framework

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

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)

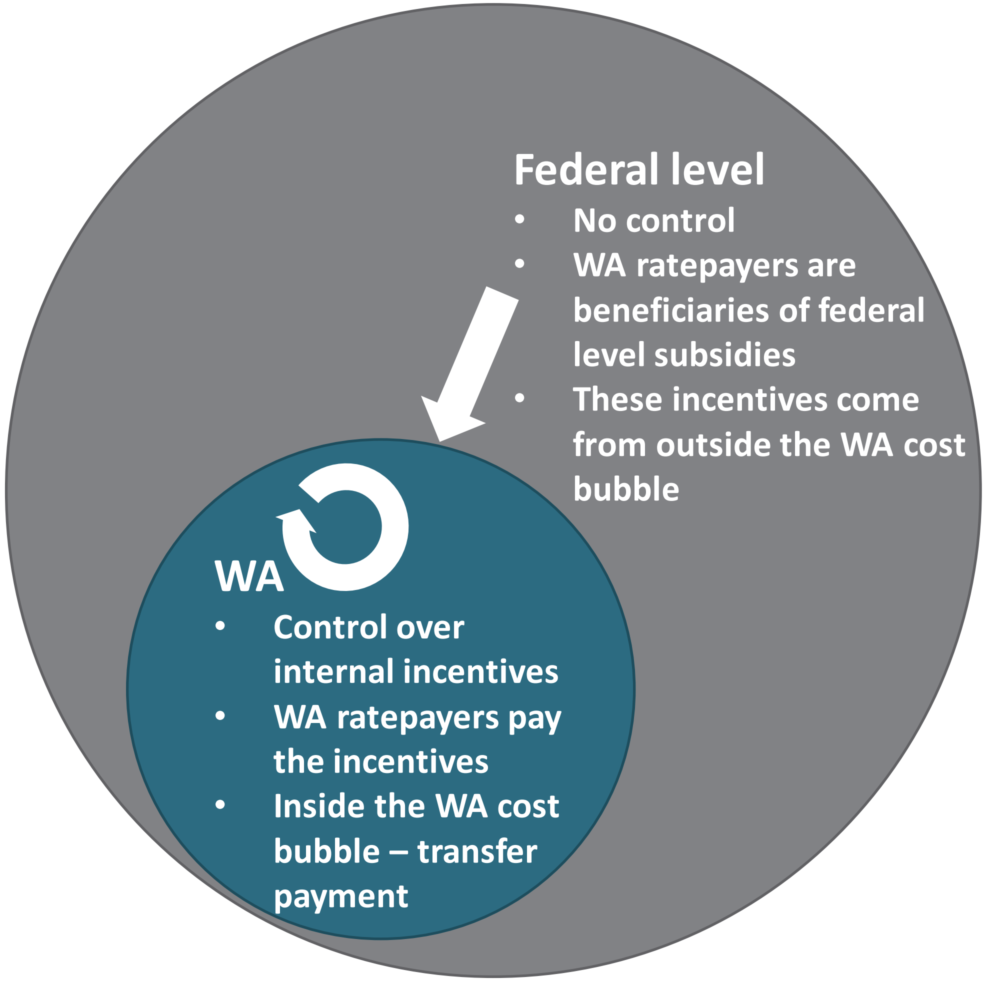
Supply-Side Data Continued

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 2020)
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 developed 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

Columbia Generating Station (CGS) Extension

- We assume that the CGS can be extended for an additional 20 years of life at 1210 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: $5400
- 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 forecast

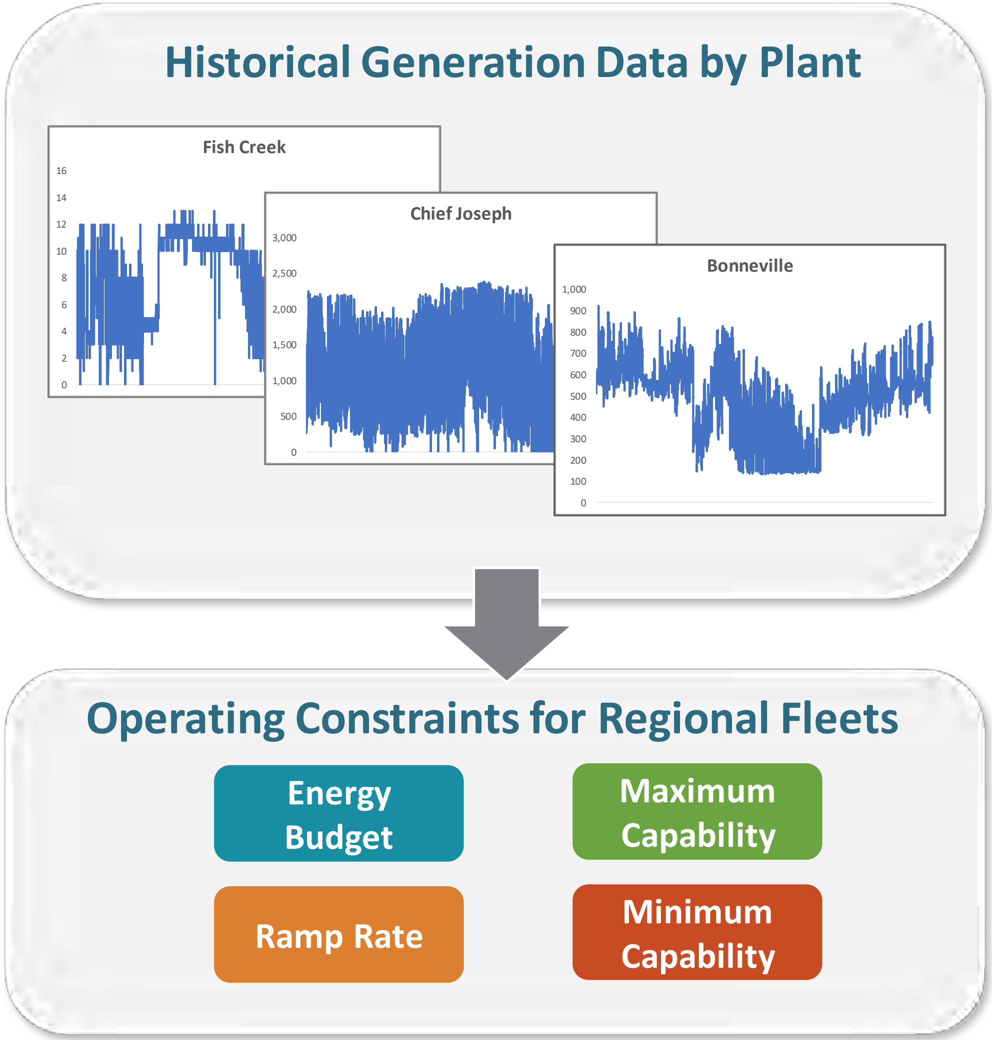
- We investigated the climate impact assumed in the load forecasts used in the study to ensure that climate change is adequately accounted for, as it is by NWPCC
- Rhodium Group has also looked at impacts on load due to climate change by region
- EIA incorporates climate impacts into AEO based on extrapolated change in heating degree days (HDD) and cooling degree days (CDD) from the past 30 years (p17)
  - For the Pacific region, change in number of HDD: -0.7%/year, number of CDD: 1.2%/year
    - https://www.eia.gov/outlooks/aeo/pdf/appa.pdf (table A5)
  - Comparing to the Rhodium estimates is imperfect given the available data, however these roughly align with a continued fossil fuel use scenario (RCP8.5)
  - Increases in CDD in AEO are slightly higher than in the NWPCC work, but approximately aligned (https://www.nwcouncil.org/sites/default/files/2019_0917_p1.pdf p6)
- We use the EIA AEO load forecasts because of their alignment on climate change with other forecasts and the consistency of load forecasting methodology used across the study region (though RCP8.5 is not a likely pathway with climate action taken, it is not significantly different in regional HDD and CDD from RCP4.5)

Climate Impacts on Hydro

- 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 3 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% by 2035
  - Low Electrification Case: 10-year delay over electrification case, 75% sales HE by 2045
- Electrification Rates
  - Reference Case: No electrification
  - Electrification Case: NREL EFS High scenario
  - Low Electrification Case: 15% of sales electrified by 2035, 30% of sales electrified by 2045

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
  - 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
  - Designed to model some benefits of reductions in energy efficiency 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% 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 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
- Freight reduction: 15%
- We assume that people retain vehicles but drive them less, thus total vehicle numbers are not impacted

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

Biomass: 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