NET-ZERO NORTHWEST TECHNICAL REPORT

06/21/23

Prepared by:

Evolved Energy Research

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Key Study Questions

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- What resources must be built to meet clean energy demand for different energy sectors in the Northwest by 2030 and 2050?
- What is the impact of accelerated or constrained transmission expansion across the Western grid?
- How does decarbonizing gas compare with electrification as a decarbonization strategy in buildings?
- What role can distributed energy resources (DERs) play in decarbonization?
- What are the tradeoffs between clean fuels, including biofuels and electrofuels/hydrogen?
- What is the impact of the pace of transportation electrification on the overall cost of decarbonization for the Northwest?
- What is the impact on health metrics in the Northwest if decarbonization reduces criteria pollutants?

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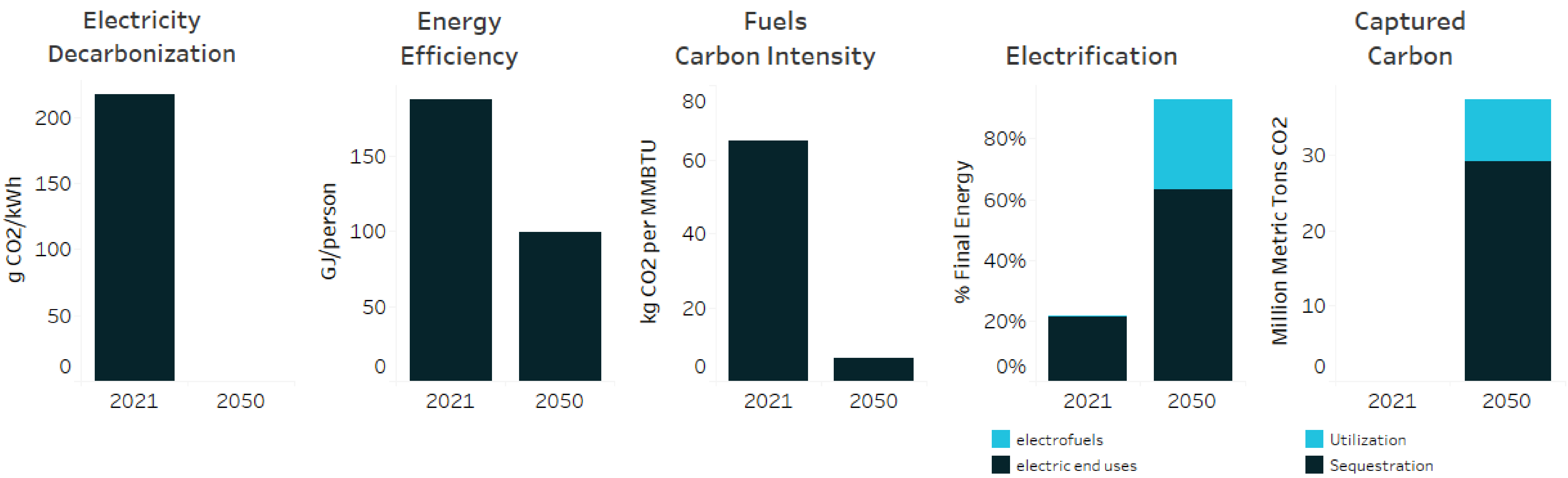
Key Findings

Key Findings
Pillars Of Deep Decarbonization



- Decarbonization in the Northwest hinges on clean electricity, energy efficiency, clean fuels, electrification, and carbon capture

Key Findings
Efficiency

- **Efficiency, including electrification, is key to decarbonization cost containment**
  - Scenarios with greater overall energy demand, including Gas in Buildings (Task 3), and Slow Transportation (Task 5) drive up decarbonization costs
- **Moving away from ICE vehicles is imperative to lowering energy costs when transitioning to Net-Zero**
  - Stalled transition to EVs and FCVs in the Slow Transportation scenario is $7.3b/yr in 2050 more expensive than when vehicle stocks transition fully to EVs and FCVs by 2050 in the Core Case
- **Retaining gas usage in building heat drives up energy demand and decarbonization costs**
  - Final energy demands in Gas in Buildings are 11% higher by 2050 than in the Core Case (Task 1), requiring more energy resources across the economy, and costs are $4.6b/yr higher in 2050
- **Pace of demand side efficiency improvements matters**
  - Rapid transition to electricity and high efficiency equipment required to avoid increased decarbonization costs
  - Moving even faster, as investigated in Fast Transport (Task 5), has limited benefits and comes with feasibility and political risk

Key Findings
Transmission

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- **Whether transmission can be expanded between states is a large source of uncertainty and impacts resource investments**
  - Expanding transmission, particularly for coastal states' access to wind in Montana and Wyoming, lowers decarbonization costs
  - Expanding transmission also increases the options available to meet state emissions targets – more can go wrong before emissions targets are not met
- **Transmission expansion does not play an important role in 2030, but investment is needed in the 2030s to ensure expanded transmission is available in 2040 and 2050**
  - Transmission planning must start now to overcome the challenges of building interstate transmission
  - The chicken and egg problem of requiring transmission access to develop new generation and requiring generation to justify investment in transmission is exacerbated when accessing remote resources across different planning jurisdictions, as well as relying on developing large amounts of renewables that themselves face uncertain siting and permitting processes
  - Expanding transmission will be difficult but, without it, feasibility challenges are shifted to permitting more local resources
    - Pursuing resources on all fronts will maximize the chances of meeting net-zero goals and minimizing overall decarbonization costs

Key Findings
Transmission

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- **Levels of transmission investment are impacted by factors that either constrain renewable build, reduce loads, or make transmission construction more difficult or more expensive**
  - 56 GW of wind are built in Montana in the Core Case (Task 1). If siting or permitting factors limit the amount of wind built in Montana and Wyoming to 10 GW each, transmission build in the Northwest is not as necessary. Transmission between Montana and Washington drops from 11.2 GW by 2050 to 2.6 GW
  - Slow Transport (Task 5) and Gas in Buildings (Task 3) both reduce electric loads, reducing the need for transmission. While energy demands are higher, the difference is met with clean fuels by 2050 that are primarily produced outside of the Northwest and transported via pipeline.
  - If transmission construction is limited to reconductoring, or costs for transmission are higher, total transmission expansion is limited
- **Feasibility Challenges: Reduced transmission expansion drives more local resource investments**
  - Transmission expansion will face permitting and siting challenges, however so will renewable energy investments. By achieving transmission expansion, the pressure on siting local resources will be mitigated. Pursuing transmission expansion not only lowers costs, but alleviates the pressure on local permitting and expands the number of available pathways to net-zero, reducing the risk of not meeting net-zero goals

Key Findings
Renewable Siting

- **Renewable builds in the Northwest total 138 GW by 2050**
  - New loads from electrification and fuels production while decarbonizing the electricity system drive large new investments including 92 GW of wind and 46 GW of solar
- **Electricity and fuels supply in the Northwest will be shaped by what renewable and transmission projects can be permitted**
  - When all options in the model are available, 56 GW of high-quality wind resources in Montana are used for both electricity exports and clean fuels production
  - Scenarios that limit renewables in Montana and Wyoming or restrict transmission build all simulate difficulty with permitting and shift more electricity production closer to loads and more clean fuels production to outside of the Northwest
- **High adoption of rooftop solar reduces some of the pressure on siting grid scale renewables and moves hydrogen and fuels production closer to loads**
  - Higher adoption of rooftop solar increases resource costs by $0.6b/yr, but with the benefit of increasing the number of options to achieve net zero should siting grid scale resources be more challenging
- **Siting renewables and other clean energy economy resources has local economic opportunities**
  - While siting renewables may come with environmental downsides, it does not come with the local health impacts that fossil facilities bring. High quality renewable resources will become more valuable as emissions caps tighten, presenting economic development and jobs growth opportunities to the regions where they are located
  - Montana, for example, sees large-scale investment in renewables, hydrogen, and fuels supply chain infrastructure, as well as nuclear by 2050

Key Findings
Distributed Energy Resources

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- **Flexible load provides up to $2b/yr of benefit in the Core Case (Task 1), avoiding investment in the distribution grid and storage for balancing the grid**
  - Flexible vehicle charging drives greater utilization of distribution infrastructure, spreading charging over the hours of the night and avoiding distribution system upgrades
- **Increased flexibility beyond what is in the Core Case has diminishing returns**
  - Savings over the Core Case by 2050 are $0.4B/yr in the High Flex Load scenario with significantly higher levels of flexibility
- **Distributed storage avoids distribution system investments, but has less value to the grid given the high amounts of grid scale flexibility in the Northwest**
- **Increased distributed solar investment reduces energy required from local grid-scale resources and increases investment in local hydrogen production**
  - Takes some of the strain off grid-scale resource permitting and reduces the need for imported hydrogen and clean fuels

Key Findings
Fuels Sector

- **Clean fuel markets beyond state borders lower costs and increase the feasibility of reaching emissions goals**
  - Requiring all clean fuels demand to be served by local production means significant investment in Washington to meet 2030 emissions targets, not only in biomass and clean fuels infrastructure, but also in carbon sequestration
  - Local clean fuels production requirements increase renewable investment significantly in Washington and Oregon, including an additional 40 GW of electricity capacity in Washington, with significant cost increases versus sourcing clean fuels from out-of-state
  - Additional siting challenges for local renewables, transmission, and other clean energy infrastructure mean that pursuing local clean fuels may be infeasible, as well as cost $5b/yr more through 2045
- **IRA incentives for hydrogen production, renewables, and carbon capture mean that hydrogen production is economic by 2030**
  - Hydrogen production is relatively insensitive to the cost of electrolyzers. Growth in electrolyzer capacity is constrained by growth limits in the model and not by economics
  - The favorable economics for hydrogen under IRA drive new hydrogen markets. Even if the market for end use hydrogen does not keep pace, hydrogen not used directly in end uses is converted into drop-in fuels via Fischer-Tropsch, replacing liquid fuels such as jet fuel, diesel, and gasoline
  - The economics of hydrogen reduce the amount of biomass use in the economy versus studies prior to IRA. Restricting biomass potential to a waste biomass only, a 68% reduction over the Core Case, has little impact on investments or overall costs
- **Clean fuel use in gasoline, diesel, and fuel oil depends on the rate of electrification of gas appliances in buildings**
  - Liquid fuels are preferentially decarbonized ahead of natural gas because the savings from avoiding fossil fuel purchases are greater with liquid fuels than with natural gas
  - Lower rates of building electrification drive higher emissions in the residential and commercial sectors. This shifts greater emissions reductions into liquid fuels where more is replaced with clean alternatives

Key Findings
Health Metrics

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- **Benefits attributed to annual pollutant reductions range from:**
  - **\$2.8b/yr to \$6.2b/yr in 2030** relative to emissions remaining at 2021 levels
  - **\$4.0b/yr to \$8.9b/yr in 2050** relative to emissions remaining at 2021 levels
- **Pollutant reductions come from fossil fuel plant retirements and vehicle tailpipe emission reductions as the economy decarbonizes, but sources of pollutants remain in 2050:**
  - NH_3: Livestock, fertilizer
  - NO_2: Background biogenic sources
  - $PM_{2.5}$: Wildfires, road dust, agriculture
  - VOCs: Background biogenic sources
- **Biogenic and wildfire sources of pollutants will remain and may increase with climate change**

Key Findings
Emissions

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- **The Northwest needs negative emissions technologies to reach net-zero**
  - Not possible to reduce non-CO_2 emissions to zero without changing economic activity
  - Incremental land sink, geologic sequestration, and direct air capture offsets remaining emissions in the economy
  - Gross CO_2 emissions from energy and industry close to zero by 2050
- **Achieving 40% below 1990 emissions by 2030 in states with large agriculture sectors requires carbon sequestration and clean fuels**
  - Regional emissions targets are more efficient – Emissions reductions can come from lowest cost sources
- **Early investment in negative emissions technologies**
  - Incremental land sink – Uncertain, depends on changes to land use and climate impacts
  - Geologic sequestration – Need a carbon source, significant investment in direct air capture in Montana by 2035
- **Meeting 95% gross emissions levels in Washington will require new measures not currently identified**

Key Findings
Carbon Management

- **Carbon becomes a valuable commodity in a decarbonized energy system**
  - Emissions-neutral or net-negative carbon capture supplies carbon molecules to produce clean drop-in fuels for parts of the economy that are difficult or expensive to electrify or switch to alternative carbon free fuels
  - Reducing gross anthropogenic emissions to zero is not possible and carbon sequestration is required to offset those emissions to reach net-zero
- **Carbon demand increases in scenarios where fuels play a larger role, either because electrification is delayed or incomplete, or fossil fuel costs are low**
  - Higher fuel demand, especially liquid fuel, creates more demand for captured carbon for use in electrofuels production
  - Higher fossil fuel use creates more demand for carbon sequestration, offsetting emissions
- **Delaying carbon management investments by electrifying end uses lowers decarbonization costs**
  - Scenarios that require Carbon Dioxide Removal (CDR) earlier (Gas in Buildings (Task 3), Slow Transportation (Task 5)) rely on bio-gasification with carbon capture in 2030, because of the relative economics of industrial scale direct air capture. After 2030, direct air capture plays a prominent role in carbon supply
  - Bio-gasification facilities constructed through 2030 persist through 2050, becoming a lasting part of the Northwest's energy transition
  - Achieving greater emissions reductions through CDR and clean fuels production in Gas in Buildings and Slow Transportation increases costs relative to scenarios with greater electrification of loads

Key Findings
Non-CO_2 and Non-energy Emissions

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- **Max achievable reductions of non-energy non-CO_2 gases are relatively low based on EPA estimates**
  - 28% in Idaho, 13% in Montana, 27% in Oregon, and 37% in Washington
- **Negative emissions technologies required to offset them**
  - Increasing land sink, geologic sequestration, and carbon capture including direct air capture
- **Achieving 40% emissions reductions by 2030 in Montana and Idaho faces feasibility challenges**
  - Large agricultural sectors generating proportionally higher non-CO_2 emissions than other states are particularly difficult to target with reduction measures
  - Much deeper emissions cuts required in energy sectors in these states by 2030 than in those with lower non-CO_2 emissions proportionally. Clean fuels and carbon sequestration infrastructure investments required to reach 2030 targets
  - Modeled to align with targets in other states, but a pathway that targets emissions from power and electrification of the demand side early on, and emissions from remaining liquid fuels more gradually may be a better fit for these states than one size fits all
- **Further research into the potential for emissions reductions in non-CO_2 emitting sectors necessary**
  - Potential to avoid carbon sequestration and land sink measures if emissions from agriculture and other non-energy sources can be reduced further economically

Key Findings
Nuclear

- **Idaho and Washington invest in 0.7 GW and 1.1 GW of new small modular reactors (SMRs), respectively**
  - Idaho invests in retrofitting retiring coal plants
  - Question of which coal generators are eligible for retrofits
- **West-wide, nuclear electricity capacity is 9.5 GW in 2040 and 8.4 GW in 2050**
  - The West retrofits 4 GW of retiring coal and gas with small modular reactors
  - Retrofits happen before 2035 to leverage IRA incentives
- **Nuclear thermal heat used for more than electricity production**
  - Total nuclear reactor thermal capacity of 33.5 GW across the West
  - Non-electric heat used in direct air capture of carbon
- **Role of nuclear is uncertain**
  - Nuclear development is a question of feasibility as much as economics
  - Nascent technology with an uncertain development path. Role in the resource portfolio is subject to how project costs progress – larger opportunities economically if costs decline significantly

Key Findings
Inflation Reduction Act

- **Technologies previously forecast for the 2040s shifted forward in time**
  - Incentive to build nuclear, electrolysis, and direct air capture in the early 2030s
- **EER national studies of IRA show that ITC and PTC incentives drive rapid adoption of renewables through 2035, in line with a pathway to net-zero emissions**
  - Lowers costs in Western states with clean electricity policy, drives greater adoption in those without
- **Electrolysis to produce hydrogen is cost effective under IRA incentives**
  - Combined with lower cost renewables and incentives for captured carbon, states requiring near-term clean fuels to meet emissions targets will see significant economic benefits from IRA
- **Supplement to regional policy on a net-zero pathway**
  - Positions states well in renewables, transportation, and in supporting nascent technologies that are key to reach net-zero

Key Findings
Where are the Gaps in IRA Support?

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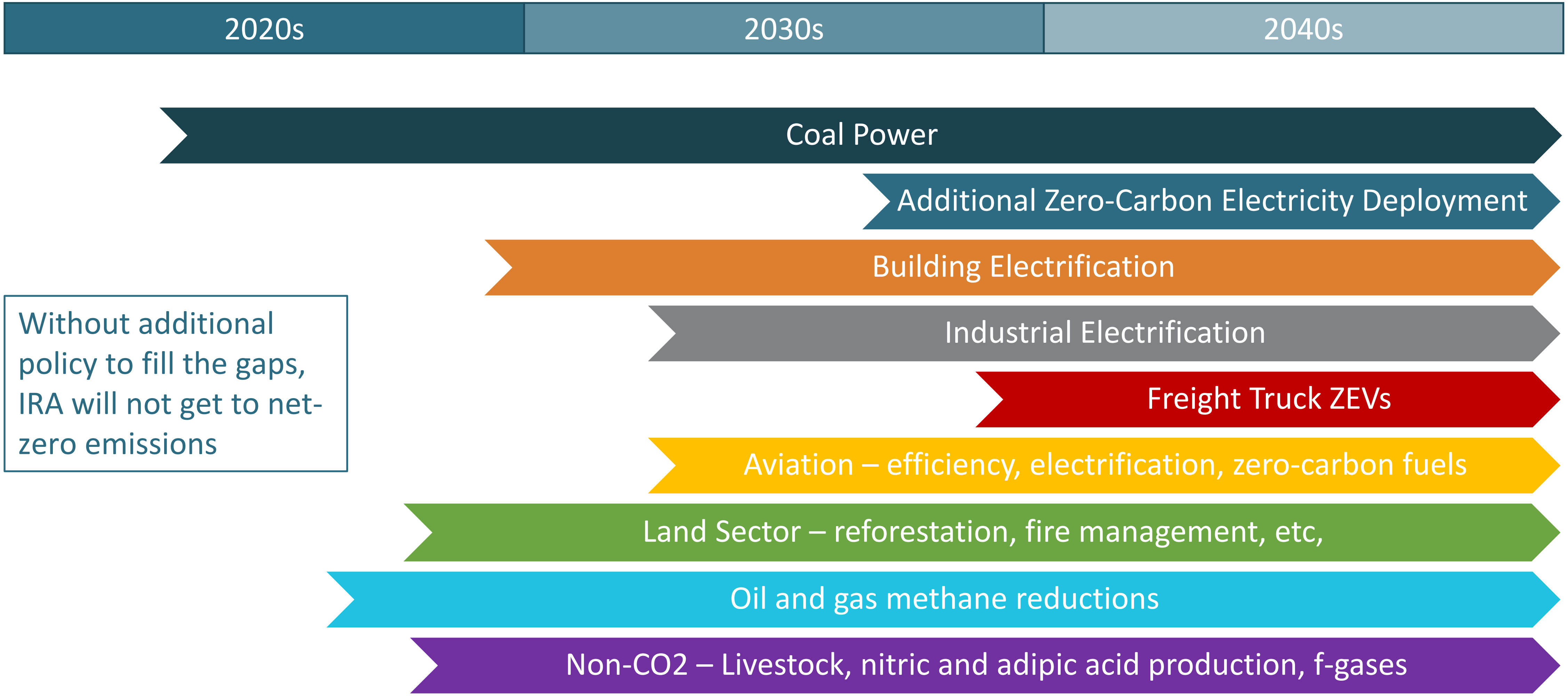

Without additional policy to fill the gaps, IRA will not get to net-zero emissions

Key Findings
Reliability

- **All scenarios in this analysis must meet electricity system reliability constraints**
  - Ensures reliable capacity contributions from resources meet or exceed load plus an additional margin for load forecast error in every hour
    - Factors in outage rates, renewable resource availability, energy availability risk, single largest contingencies
  - Tracks capability of energy constrained resources such as batteries to contribute to reliability across hours, days, and seasons
  - Uses high, medium, and low hydro years in the Northwest hydro system to build enough capacity to meet low hydro conditions
- **Not a substitute for rigorous loss of load probability modeling, but designed to approximate the results of a detailed reliability study**
- **Ensuring reliability will be best achieved by pursuing multiple paths to net-zero**
  - Maintaining reliability and meeting emissions targets requires large-scale siting and permitting of renewable and other clean energy resources
  - As shown in scenarios that limit transmission expansion or renewable availability, investing less in one area increases pressure on other areas. Limiting wind potential in Montana and Wyoming, for example, means greater pressure on siting resources in the rest of the Northwest
  - Challenges will be encountered, but pursuing the best resources, including transmission, renewables, and fuels, and regional coordination of those resources on all fronts will provide the best chance of meeting emissions targets reliably and cost effectively

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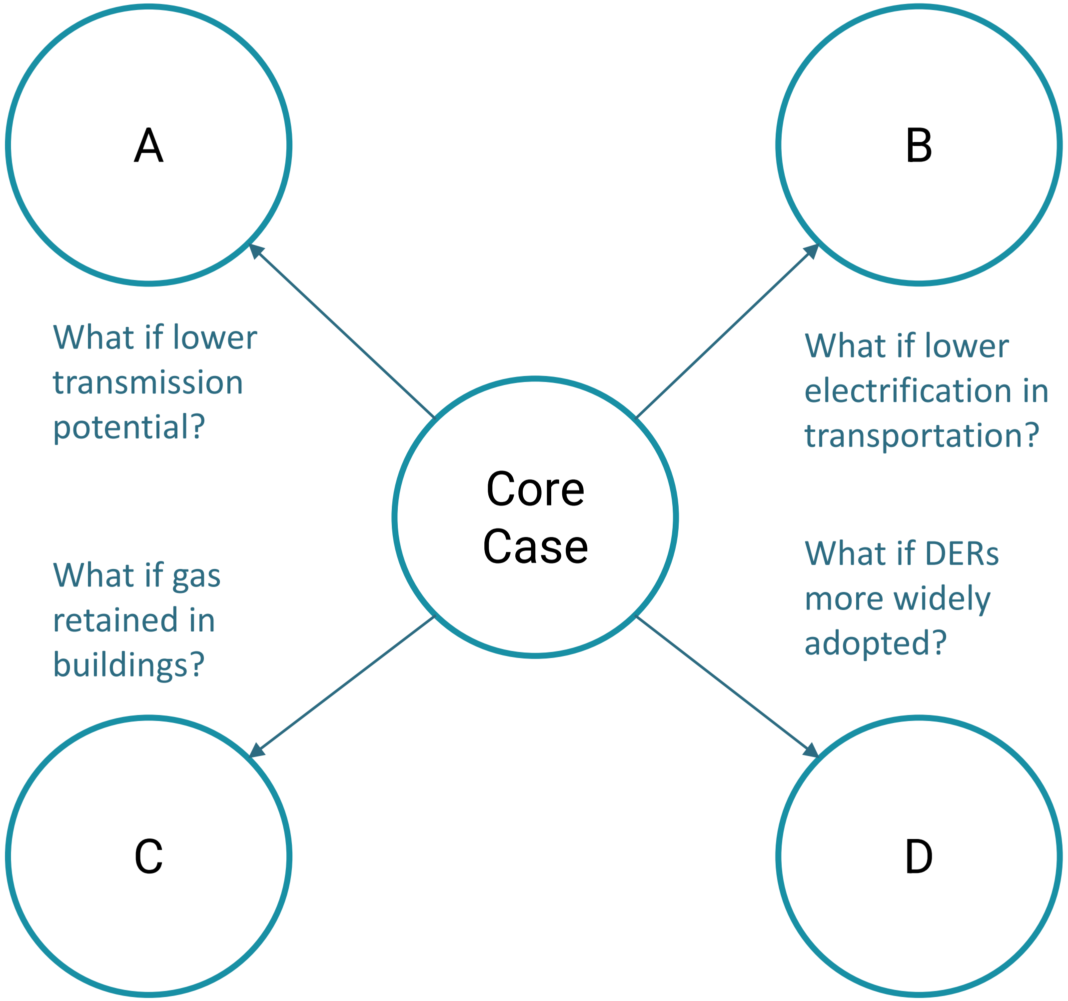
Task 1: Core Case

Task 1: Core Case Review

- Case that all other cases are compared to
- Relatively unconstrained technology availability in-state and out of state
  - Aside from technical potentials, infrastructure investments can be freely located according to lowest cost for the West
- Aggressive electrification and efficiency
- No measures taken to reduce service demands
  - Conservative, can we decarbonize even without behavior changes?
- Other scenarios change something about the Core Case
  - "What if?"
  - Unlikely that everything in the Core Case is achievable given siting and permitting, regional coordination, and other factors. How do things change if options are more constrained?



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Task 1: Core Case

Scenario Assumptions

Task 1: Core Case
Policy and Supply-side Assumptions

Assumption Type	Core Case Assumptions
Clean Electricity Policy	State-by-state clean electricity policy. Oregon: 100% clean electricity by 2040; Washington: CETA, 100% clean by 2045, coal retirements by 2025
Economy-Wide GHG Policy	State targets by 2030 (or 40% below 1990 for those without them), net-zero by 2050
Clean Resource Qualification	Renewables and 100% clean fuels, nuclear, fossil gas with carbon capture.
Inflation Reduction Act (IRA) Incentives	Supply-side incentives included for hydrogen production, renewable electricity generation, battery storage, carbon sequestration, clean fuels, and nuclear.
Resource Availability	TNC renewable resource potential; TNC new transmission supply curves; 4^{th} generation and SMR nuclear not permitted in Oregon or California. New gas build not permitted in Oregon.
Fuels	AEO Reference fuel prices; sequestration potential across the West where geologic formations exist; clean fuels have zero emissions associated with them, so sequestration credit is left in state of origin. Oregon and Washington low-carbon fuel standards incorporated
Land sink	Supply curve of land sink measures
Non-energy emissions	Non-energy emissions abatement curve

Task 1: Core Case Demand-Side Assumptions

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Assumption Type	Core Case Assumptions
Energy Service Demand	Annual Energy Outlook (AEO) 2022
Buildings: Electrification	Fully electrified appliance sales by 2035
Buildings: Technology Energy Efficiency	Sales of high efficiency tech: 100% in 2035 High efficiency building shell sales: 100% by 2035
Transportation: Light-Duty Vehicles	100% ZEV sales by 2035
Transportation: Freight Trucks	HDV long-haul: 50% hydrogen, 50% electric sales by 2045. HDV short-haul: 100% electric sales by 2045. MDV: 100% electric sales by 2035
Industry	Generic efficiency improvements over AEO of 1% a year; fuel switching measures; 1.5% a year efficiency improvement in aviation. Process heat storage opportunities
Distributed Energy Resources (DER) Schedule	State-by-state rooftop solar schedule, 75% of light duty vehicle load and 10% of heating and cooling load is flexible by 2050

Task 1: Core Case

Demand-Side Results

Task 1: Core Case Demand-Side Overview

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- The Core Case demand-side scenario describes how transformation of energy-consuming technologies progresses through 2050
- Incorporates sales shares specified in the Core Case assumptions
- Incorporates projected impact of IRA on technology adoption, particularly in vehicles
  - Rapid adoption prior to expiry in 2032
  - Temporary slow-down in clean technology adoption following 2032

Task 1: Core Case
Northwest Energy Demand by Fuel

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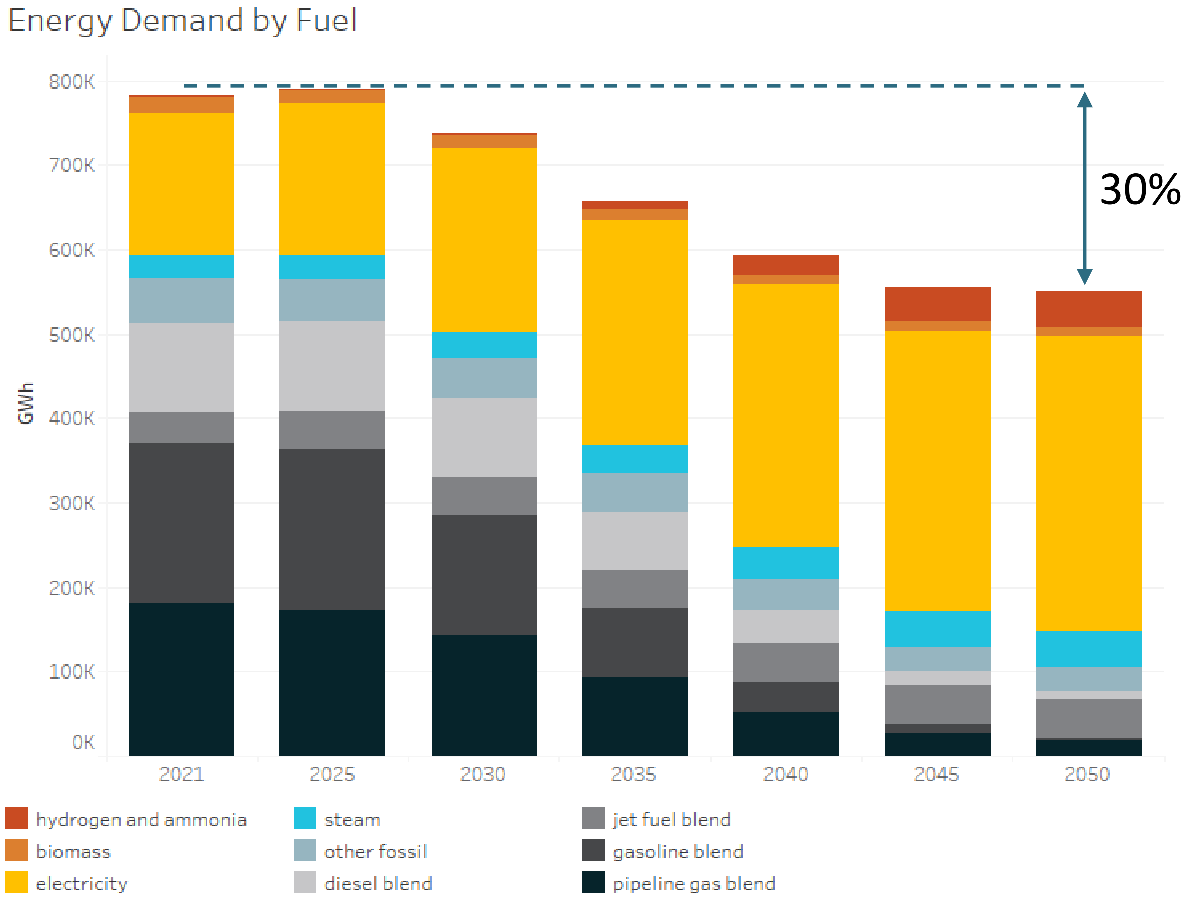
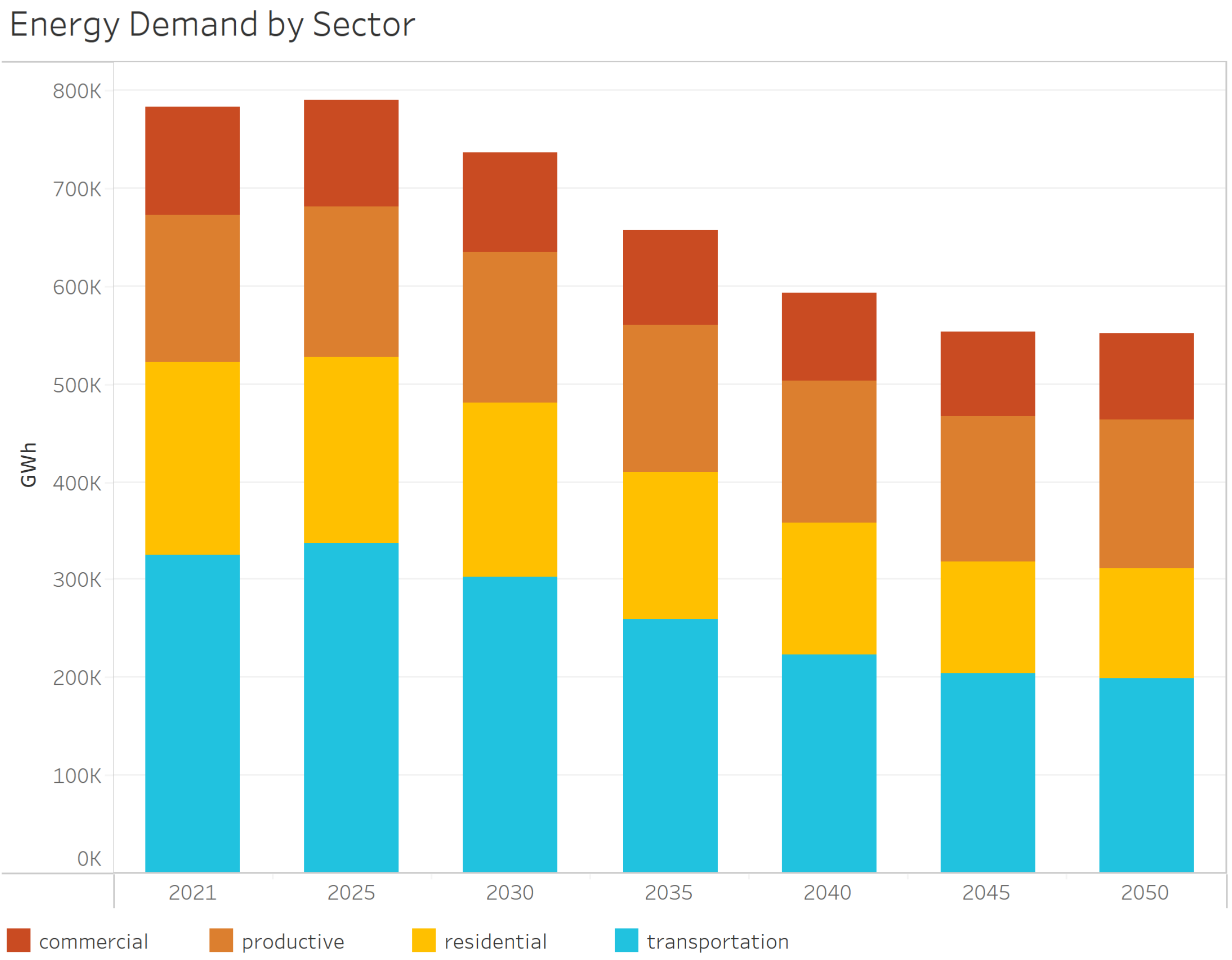
- Overall decrease in energy demand is driven by efficiency gains, mostly from fuel switching to electricity
- End use demand for electricity grows by 105% while economy-wide energy demand drops by 30%



Note: “other fossil” includes fuel oil, lpg, oil, coal, and petroleum coke.

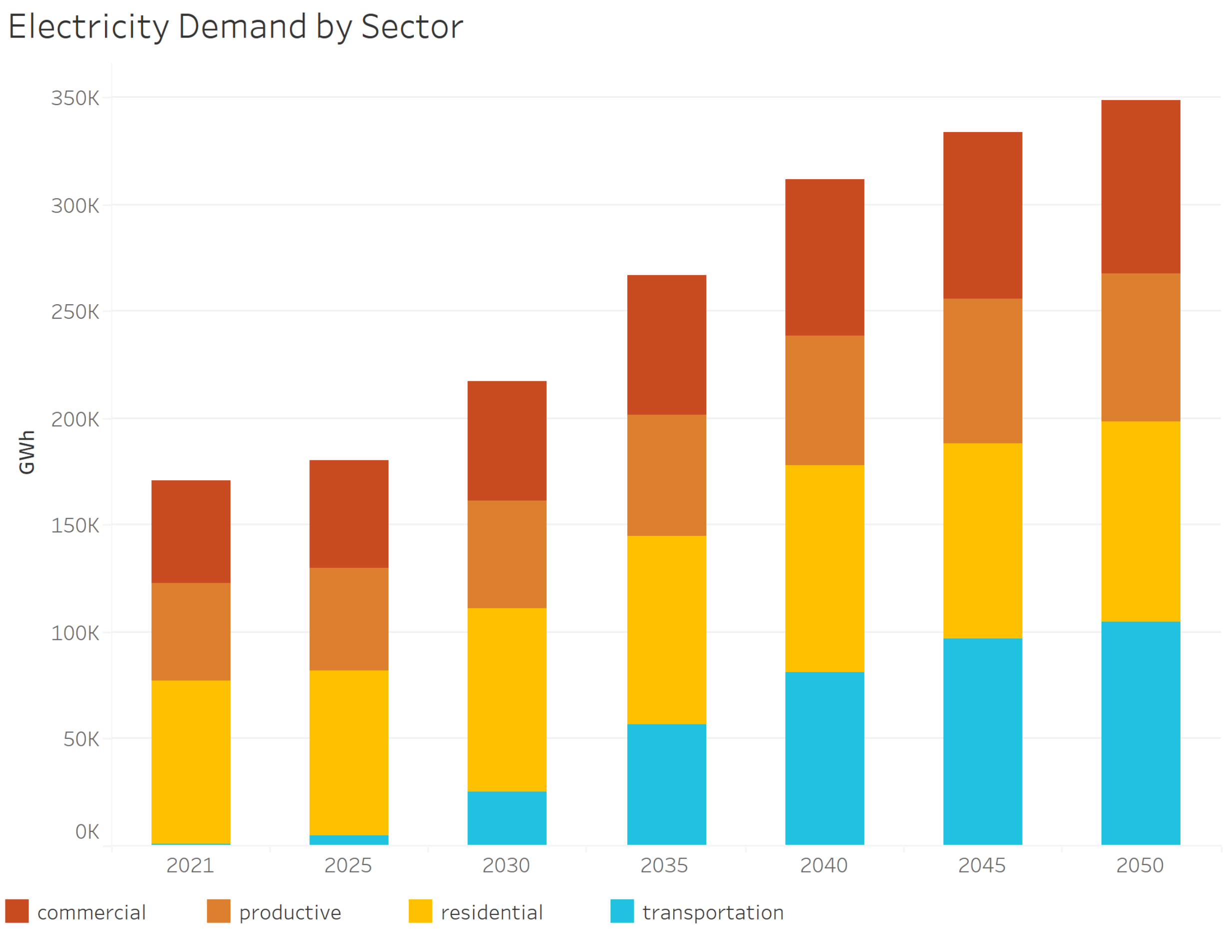
Task 1: Core Case
Energy Demand by Sector

- Transportation efficiency gains are the largest contributor to energy demand reductions
  - Electric drivetrains are highly efficient compared to internal combustion engines they replace
- Productive sector gains from generic efficiency improvements year-on-year, as well as fuel switching
- Residential and commercial appliances gain in efficiency as heat pumps/heat pump hybrid systems displace gas boilers, and appliances generally become more efficient



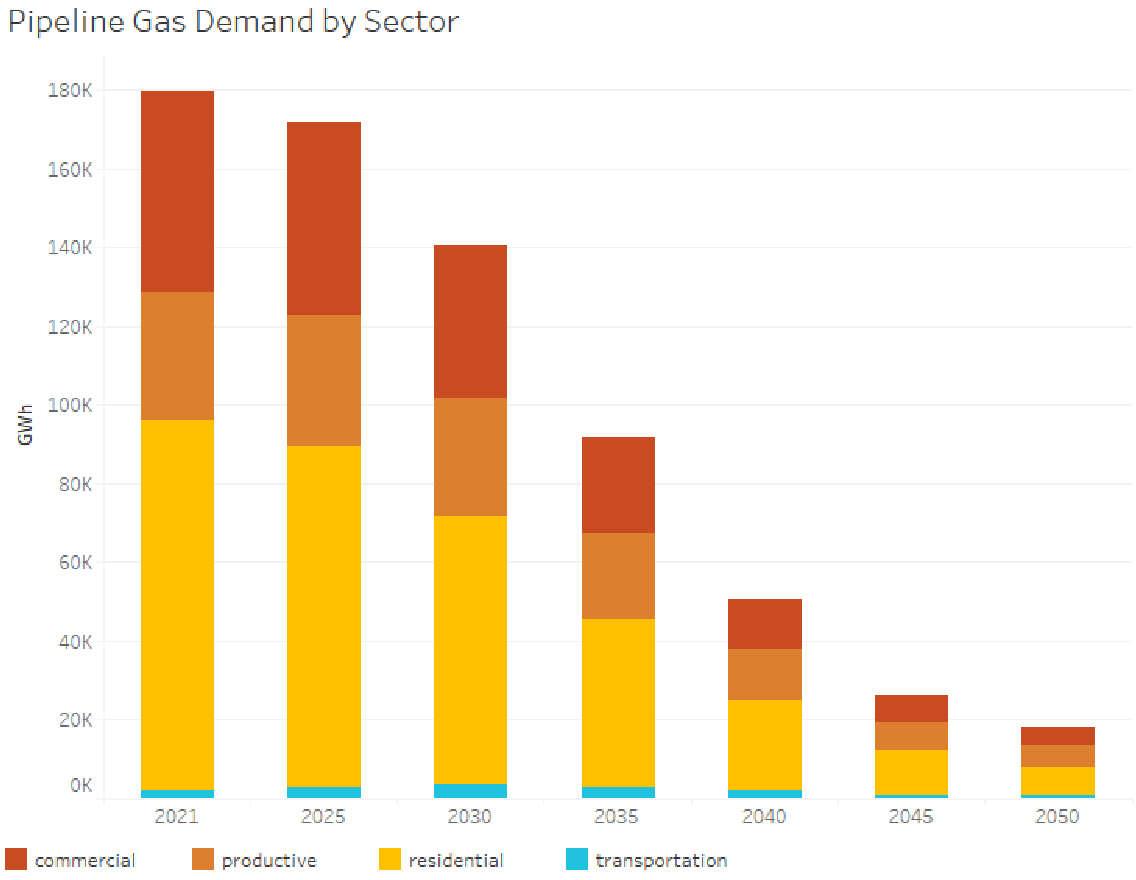
Task 1: Core Case Electricity Demand

- Total electricity demand more than doubles from 2021 to 2050
- Electricity demand grows in all sectors of the economy
  - New transportation loads drive just over half of all growth from 2022 to 2050



Task 1: Core Case
Pipeline Gas Demand

- Total pipeline gas demand declines by 90% from 2021 to 2050
- Industrial demand for pipeline gas declines by 83%, while commercial and residential demand decline by 92%



Task 1: Core Case
Light Duty Vehicle Sales, Stock, Energy

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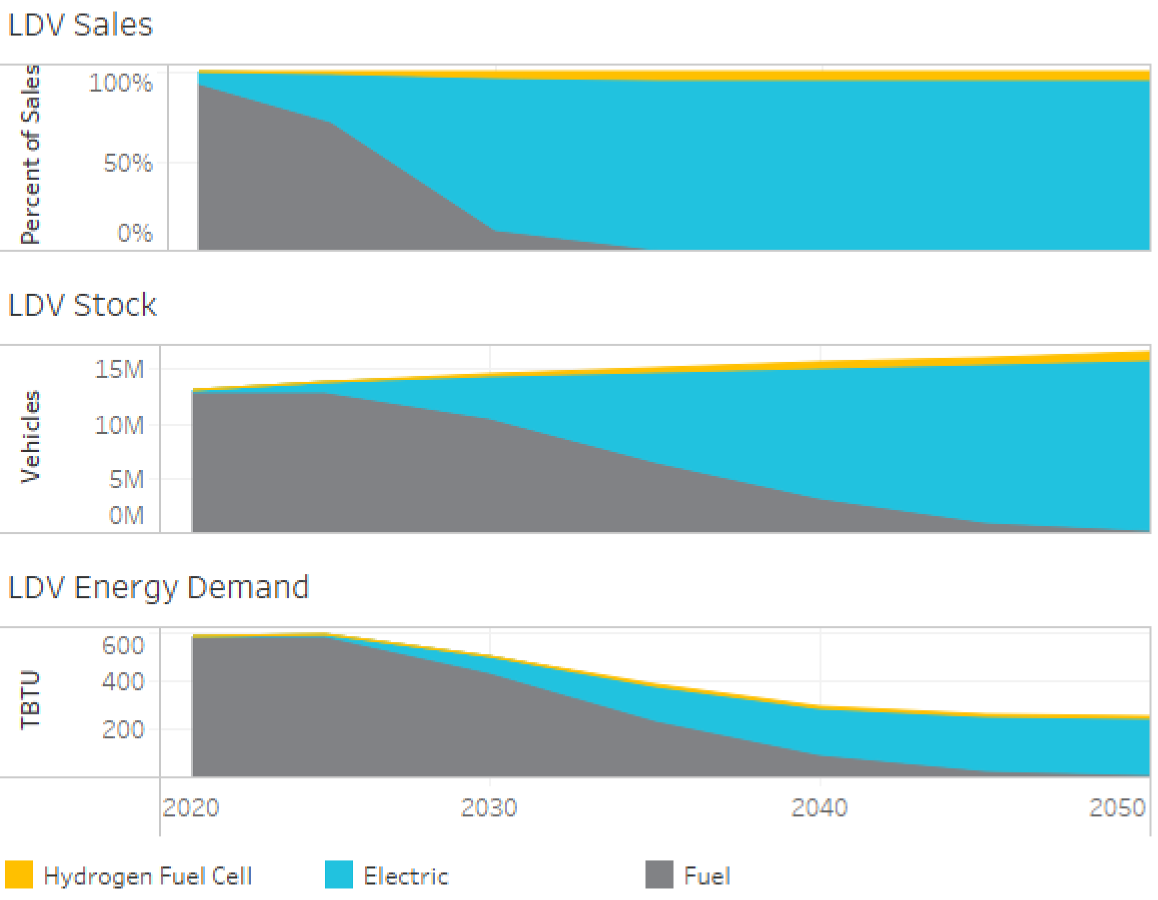
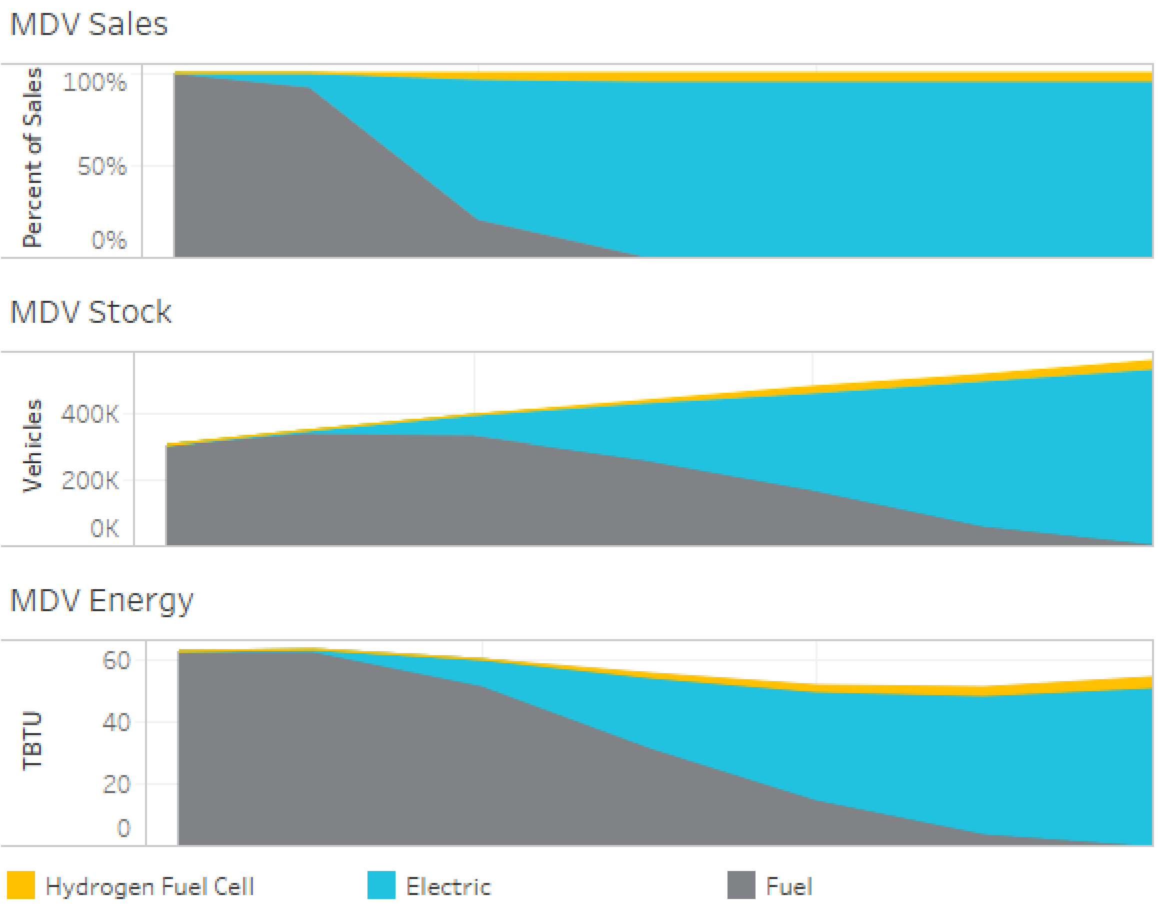
- 100% zero emissions vehicle sales achieved in 2035
- IRA hydrogen incentives result in some adoption of hydrogen fuel cell light duty trucks



Task 1: Core Case
Medium-Duty Vehicle Sales, Stock, Energy

- 100% zero emissions vehicle sales achieved in 2035
- Efficiency gains from fuel switching and result in relatively flat energy demand even as stock grows



Task 1: Core Case
Commercial Space Heating

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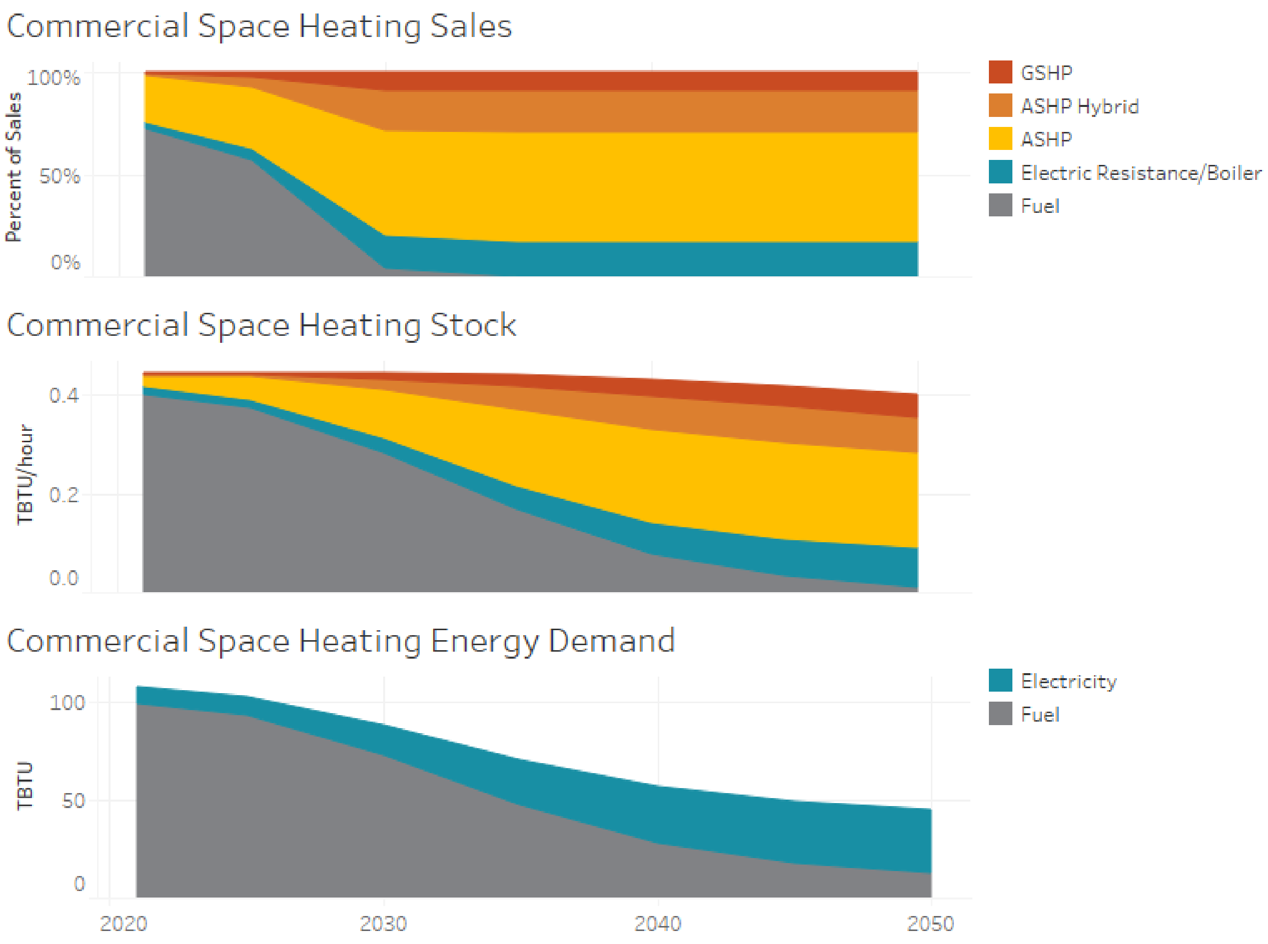
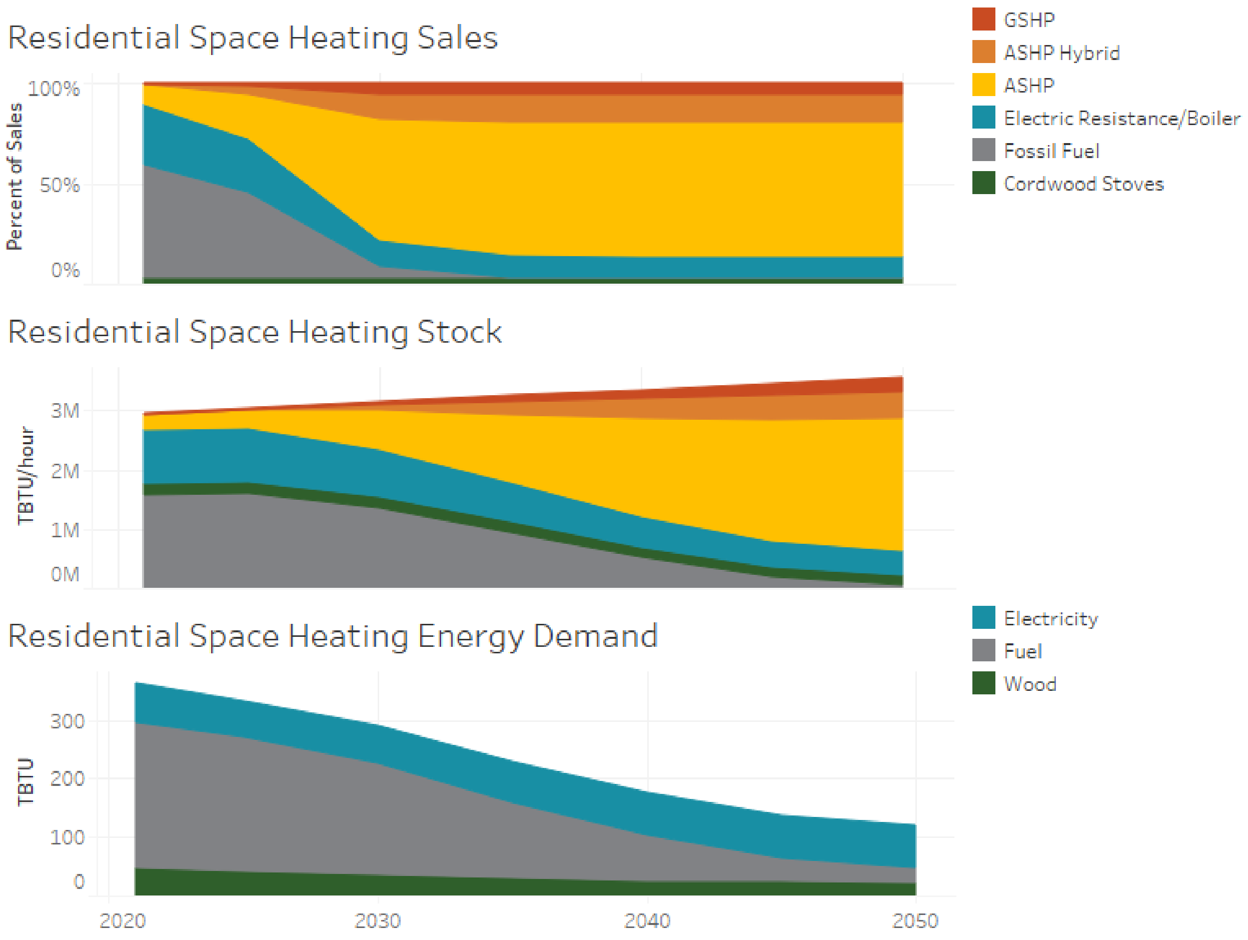
- Electric heating appliances make up over 95% of new sales by 2030
- Fuel switching to electricity drives down overall energy demand



Task 1: Core Case
Residential Space Heating

- Fuel switching to electric heat pumps, including from resistance heat, drives down overall energy demand
- Gas demand remains even with low stock of fossil fuel boilers due to hybrid ASHP



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Task 1: Core Case

Supply-Side Results

Task 1: Core Case
Supply-side Overview

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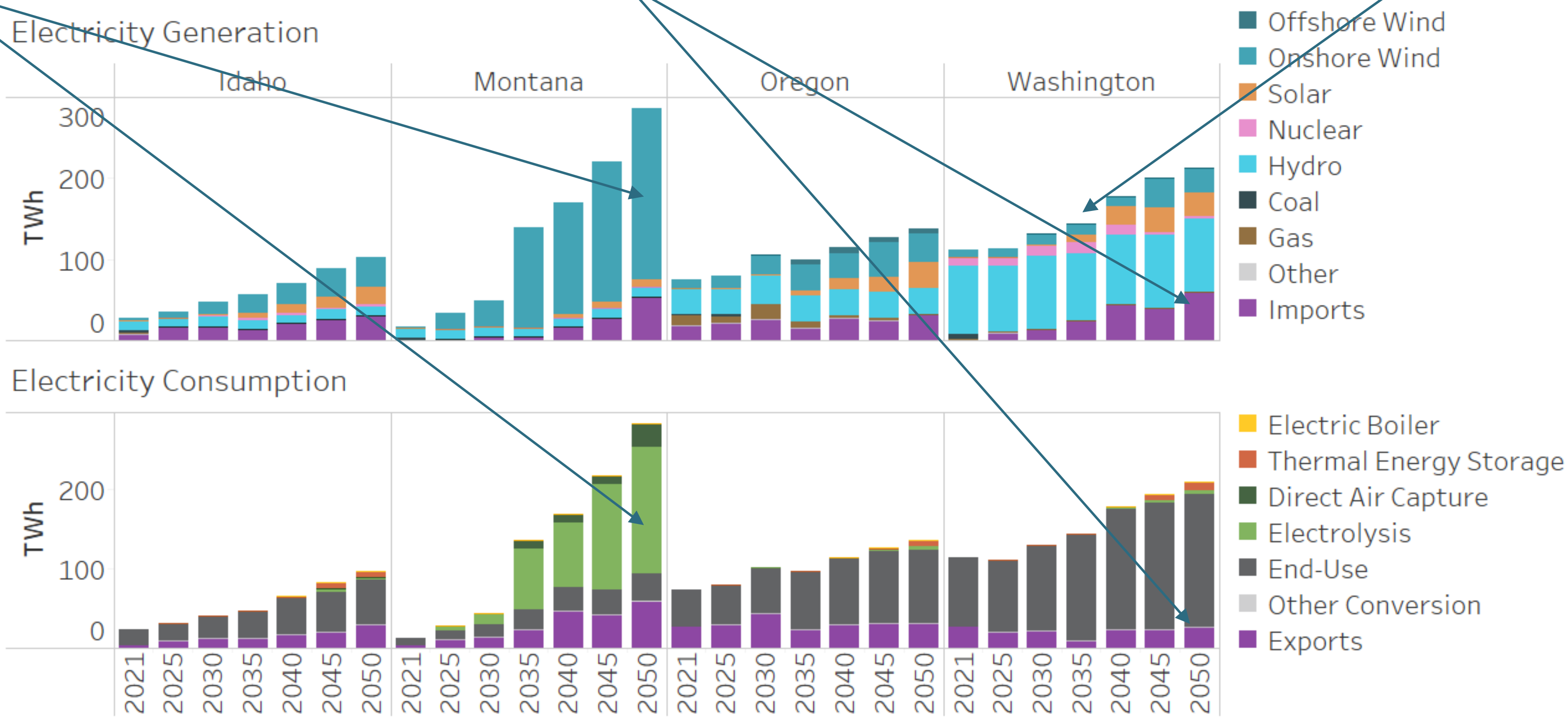
- This section answers the question "**How do we serve the energy demands of the economy at least cost?**"
  - Subject to the constraints defined for the Core Case, such as electricity policy, emissions policy, resource availability, etc.
- Supply-side analysis is concerned with investments in physical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

Task 1: Core Case Electricity Balance

Montana becomes a major hydrogen producer and electricity exporter

Washington switches from a net exporter of electricity in 2021 to a net importer from 2035 onwards

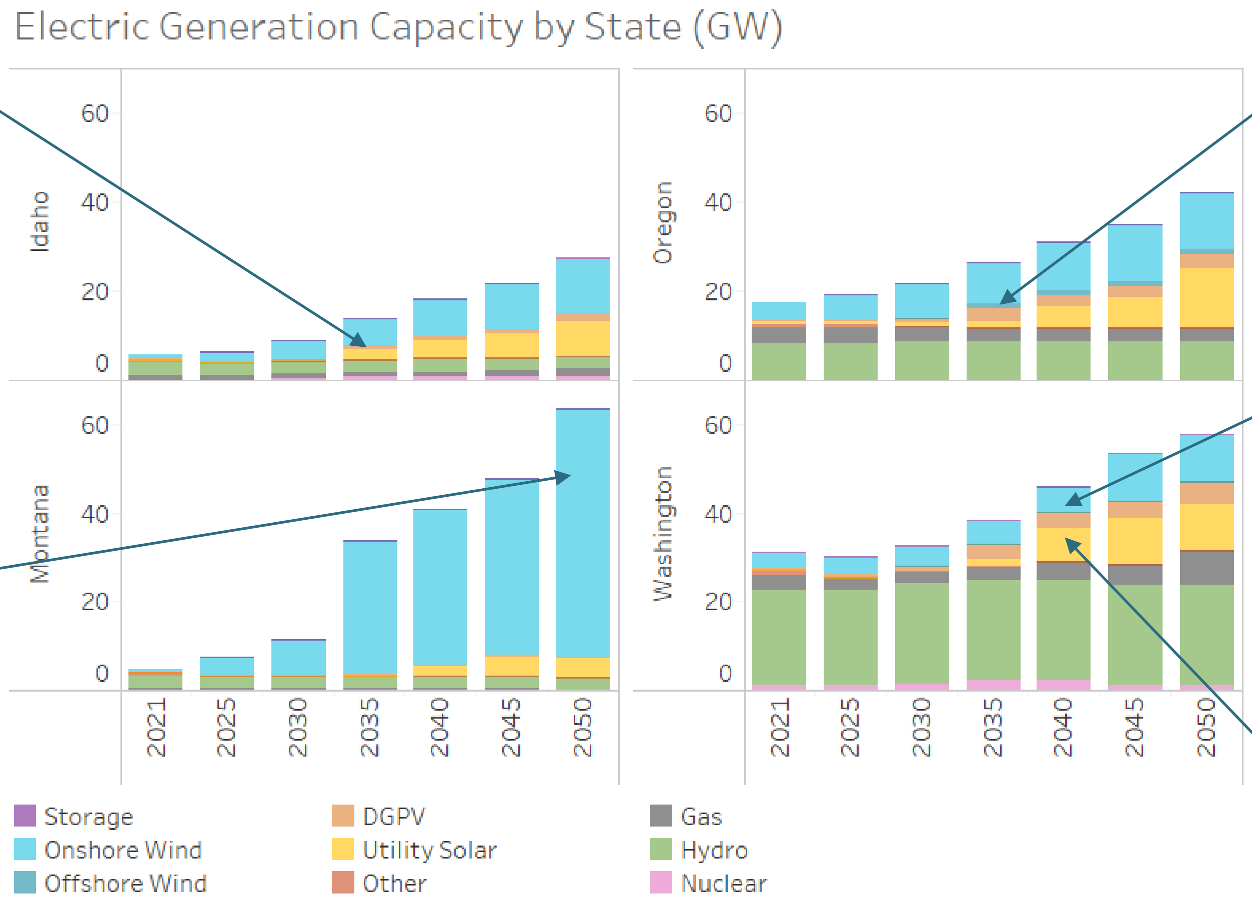
Greater reliance on in-state resources results from higher Tx prices than used in previous studies



Task 1: Core Case Generation Capacity

Retrofits of retiring coal and gas in Idaho with nuclear SMRs

56 GW of onshore wind in Montana for hydrogen production and electricity export market. Feasibility may drive alternative resource decisions



1.2 GW of offshore wind in Oregon by 2035 CA Wind Mandate reduces need for OR wind versus previous studies*

More resource additions in WA by 2040 than past studies because of increased Tx costs

Washington renewables develop after 2035 due to national build rate constraint: best national resources built out first under IRA

*An OR Wind Mandate is investigated in a separate scenario exploring 10 GW of offshore wind added in OR

Task 1: Core Case Generation Capacity Map

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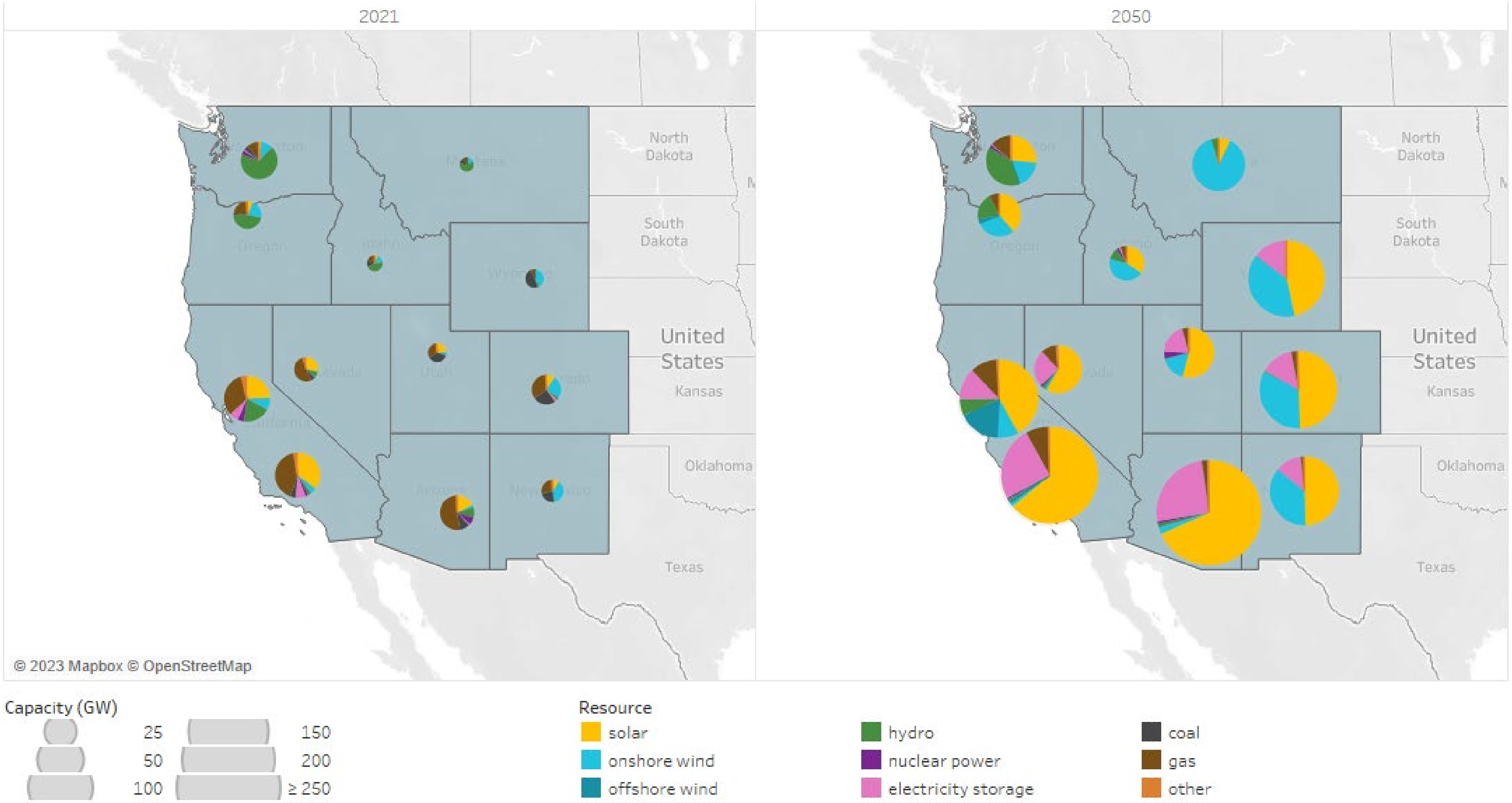
- From 2021 to 2050, total generation capacity grows dramatically in the West and renewables dominate



Task 1: Core Case
Nuclear Technical Representation

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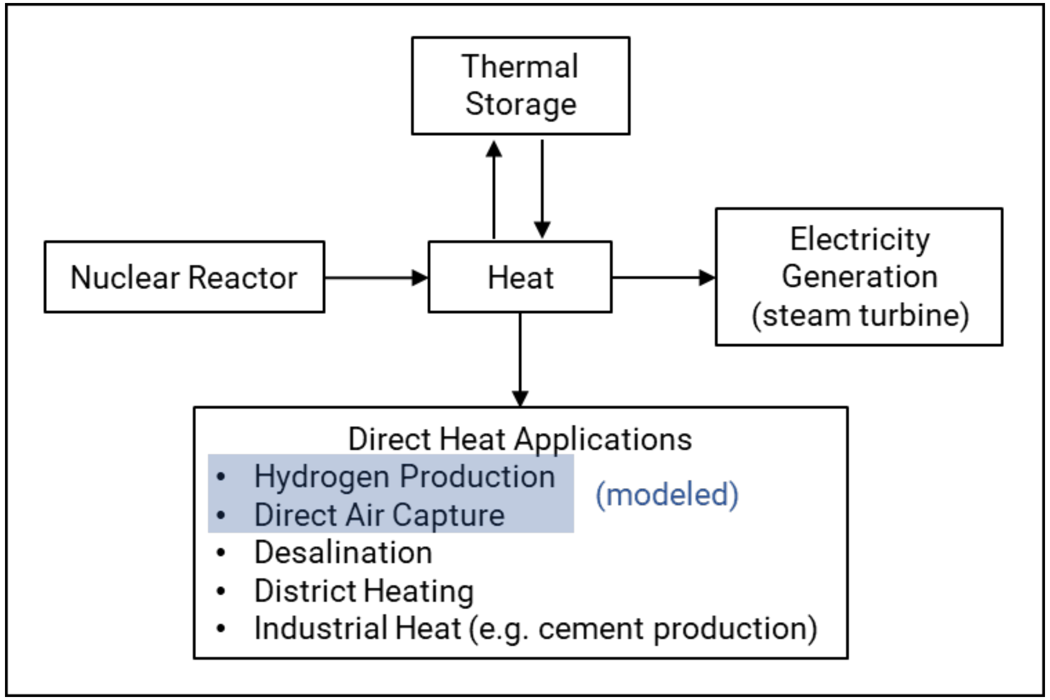
IRA incentives for nuclear, including additional incentive for retrofits of coal and gas plants

- Model can make separate capacity build and operational decisions for reactor technologies; heat storage; and electricity generation technologies (i.e., steam turbine)
  - Small Modular Reactors (SMRs) produce heat for electricity generation or thermal energy storage
  - High Temperature Gas Reactors (HTGRs) can produce heat for DAC and hydrogen
- Nuclear heat can be used in electricity generation or in other industrial applications
- Representation of non-electric sectors and sector coupling opportunities key to nuclear economics



Task 1: Core Case
Nuclear Electric Generation Capacity

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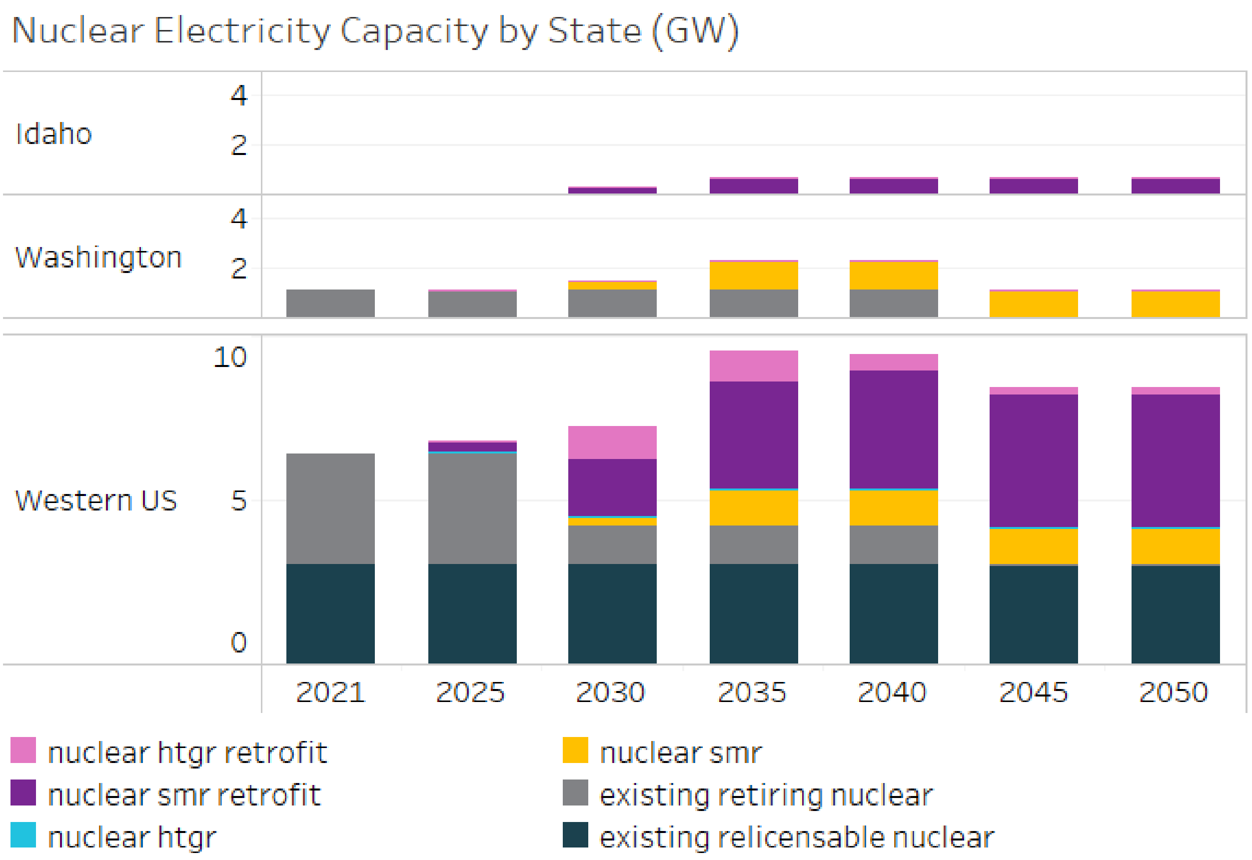
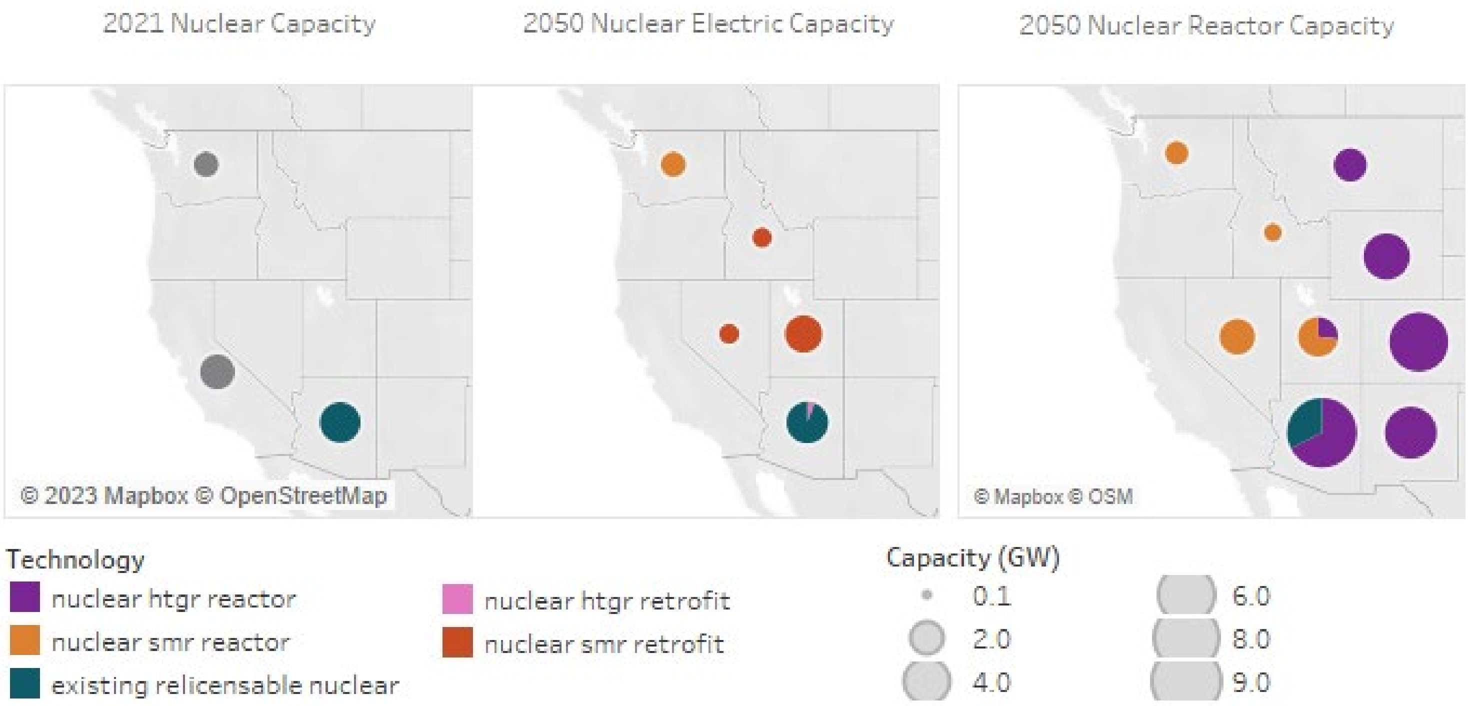
- Coal and gas plant retrofits are part of an economic resource build
  - Total new nuclear electricity generating capacity across the West: 5.3 GW by 2040, 5.4 GW by 2050
  - Incentive to develop these sites under IRA
- Idaho and Washington add new nuclear electricity generation in the Northwest
  - SMR Retrofits of coal generators in Idaho
  - New SMRs in Washington
- Nascent technology, uncertain costs, and permitting will drive future buildout



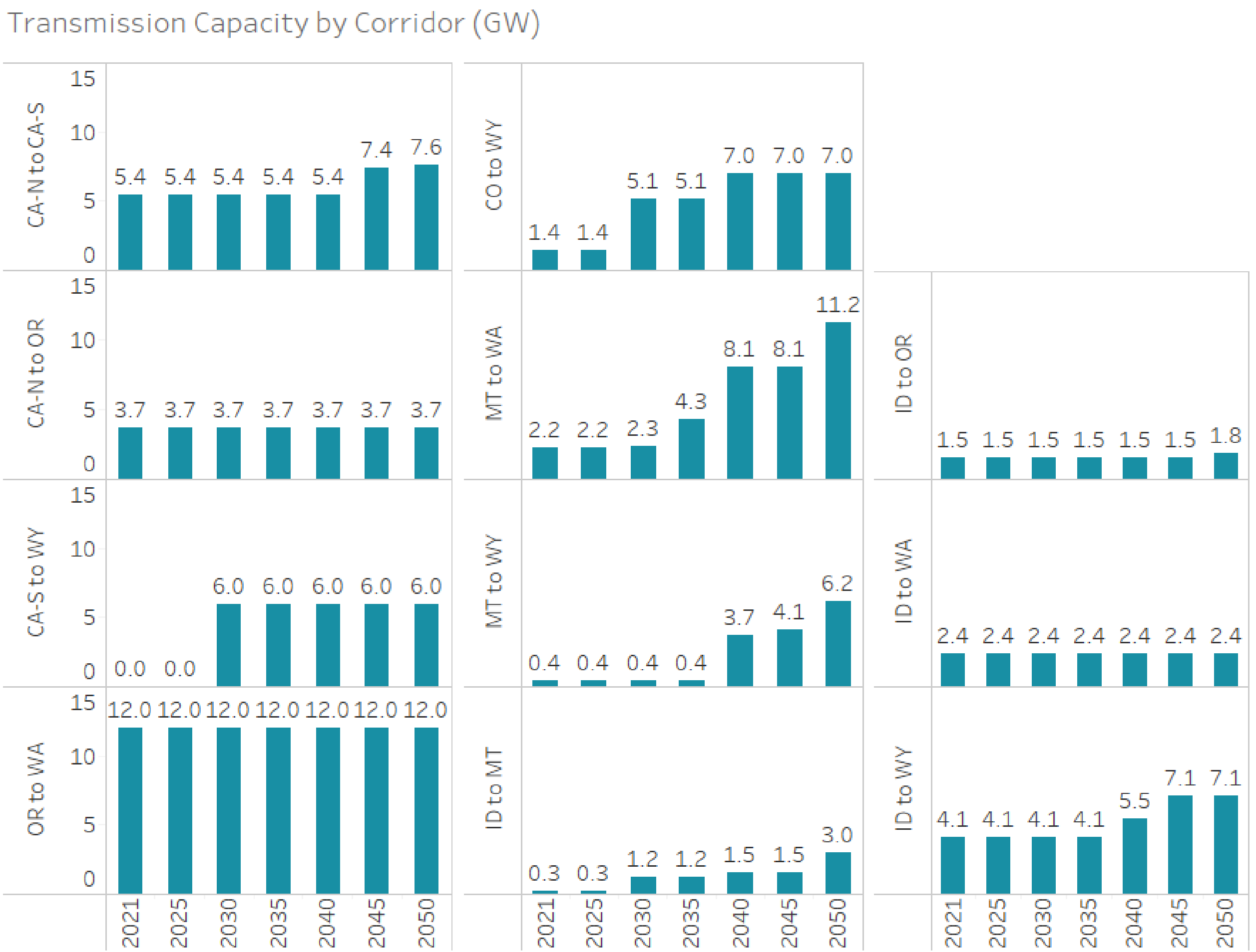
Task 1: Core Case
Nuclear Electric and Reactor Capacity Map

- In 2021, all nuclear reactor capacity is used to generate electricity
- In 2050, reactor capacity can be used for either electricity generation or direct heat production
- Nearly all nuclear electricity generation in 2050 is SMR and existing, relicensed nuclear
- Analysis sites 1 GW SMR in Washington—this result is driven by economics, but other factors may make it infeasible to construct new nuclear in WA
- In Montana, Wyoming, Colorado, New Mexico, and Arizona, HTGR reactors are used to generate heat in 2050, but not electricity



Task 1: Core Case Transmission

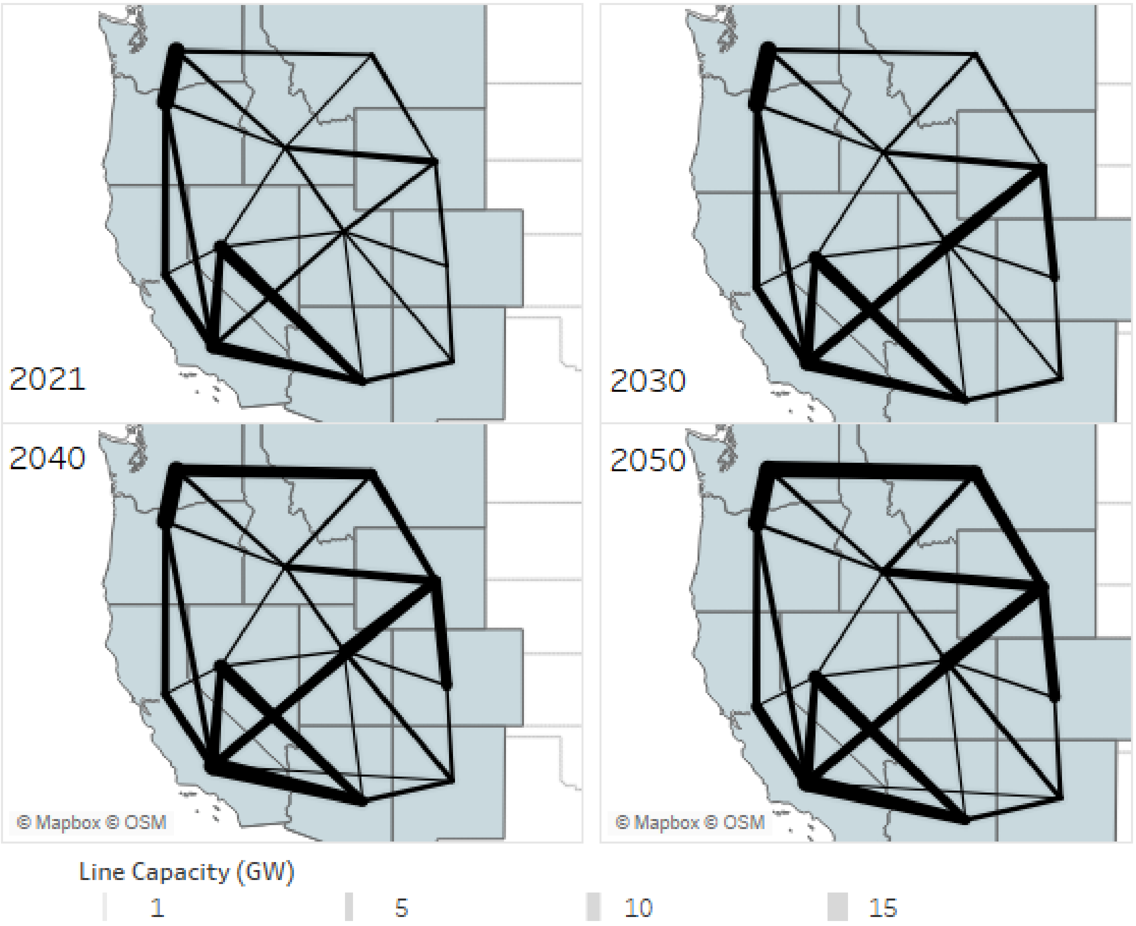
- Transmission expansion to Northwest states driven by expanding access to low-cost wind in Montana and Wyoming
- Key intertie expansion:
  - MT to WA, exporting low-cost wind to coastal Northwest
  - MT to WY, importing low-cost wind from WY into MT on net, supplying energy for coastal loads and expanded MT electrolysis and direct air capture
  - WY to CO and CA-S, exports south via HVDC and conventional options drive expansion of WY wind and expand markets for Northwest electricity exports
- Size of transmission expansion and timing driven by cost assumptions
  - Estimates are uncertain, and lower cost intertie expansion would drive earlier and greater expansion



Task 1: Core Case
Transmission Expansion Maps

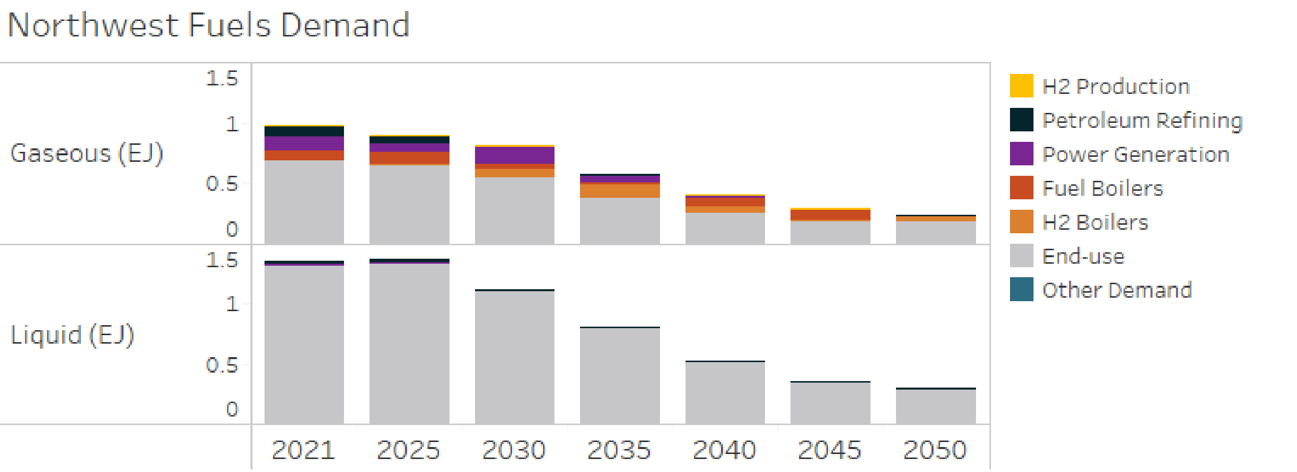
EVOLVED ENERGY RESEARCH

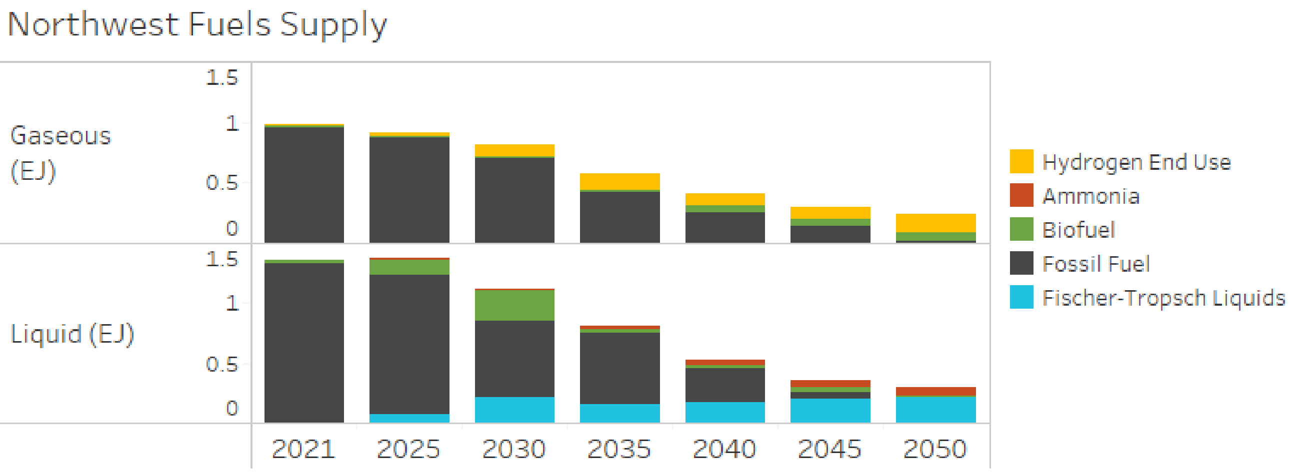
- Most new capacity is added to connect renewables in Montana and Wyoming to coastal load
- Buildout happens gradually from 2030 to 2050 in the model; timing in reality is uncertain



Task 1: Core Case Production of Fuels

- Demand for fuels in end uses and electricity shrinks over time
- By 2050 the supply of liquid fuels is fully decarbonized and remaining gas is partially decarbonized

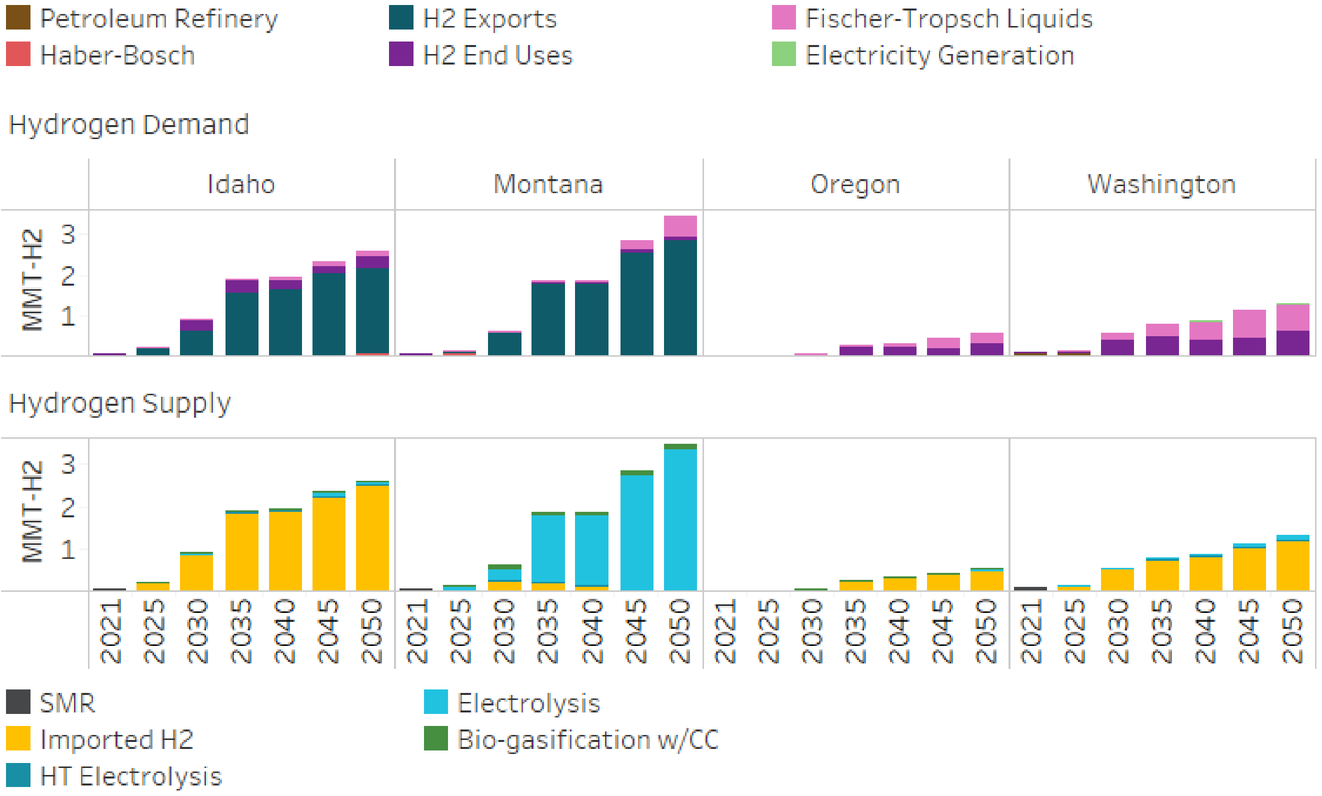




Task 1: Core Case Hydrogen

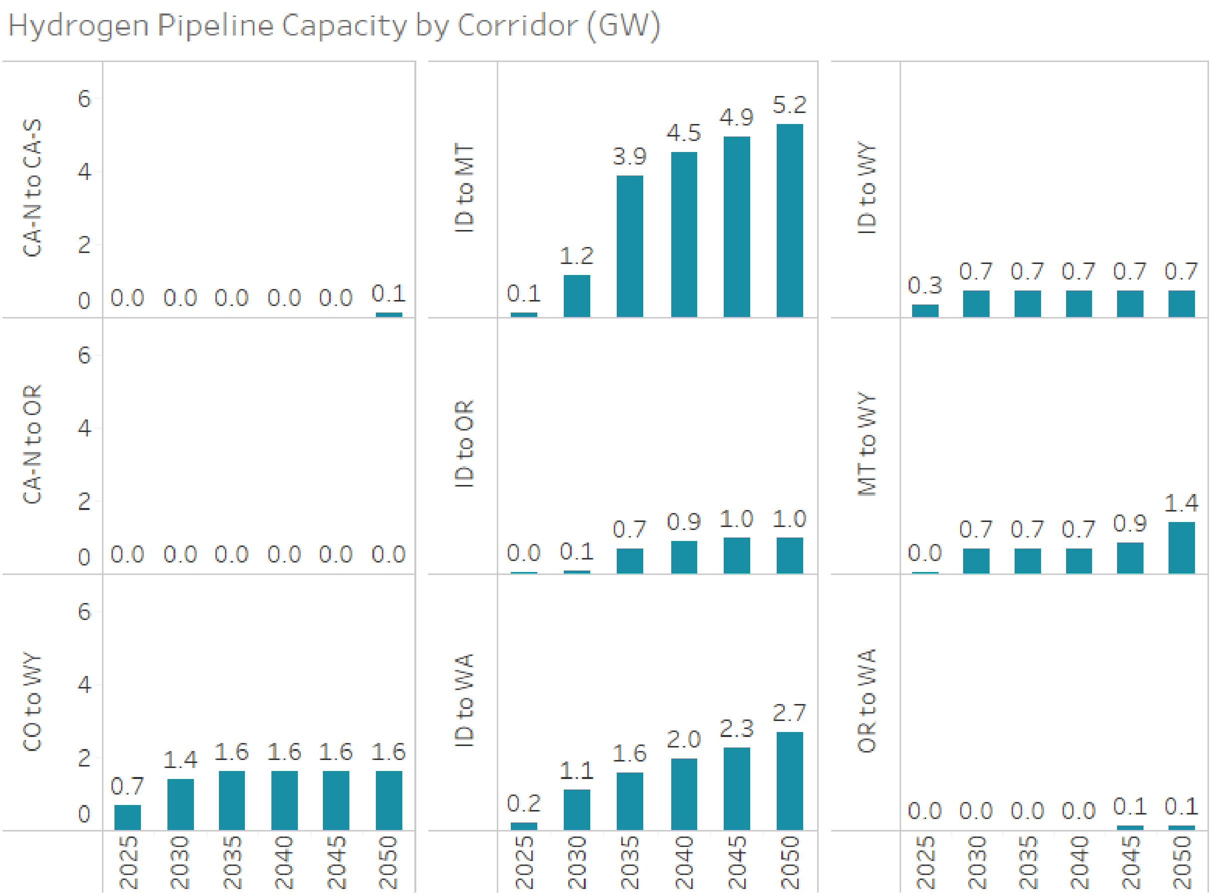
EVOLVED ENERGY RESEARCH

- Hydrogen in the Northwest produced in large quantities in Montana
  - Majority exported towards end uses in Washington, Oregon, and south to Wyoming
- Fischer-Tropsch liquids and ammonia production used to displace fossil fuels
  - Ammonia used in shipping
  - Drop-in synthetic hydrocarbons in vehicles and aviation



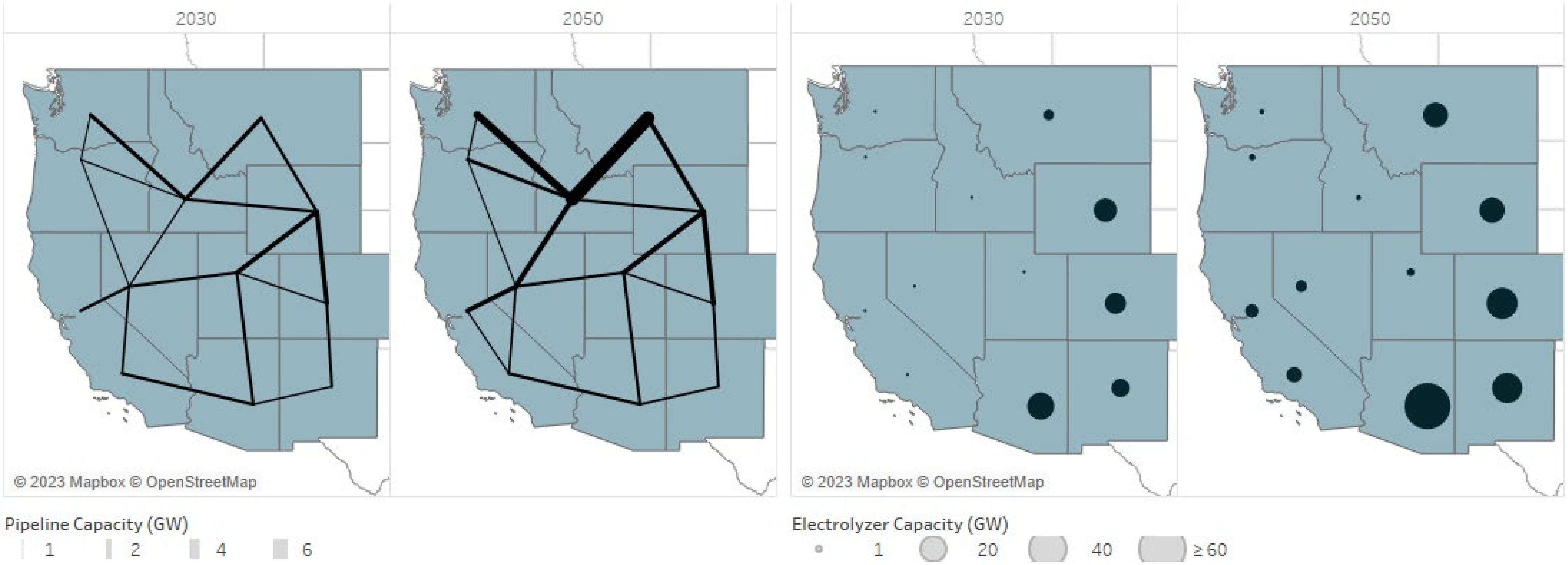
Task 1: Core Case
Hydrogen Pipeline Capacity

- Hydrogen can be consumed locally in end uses or in conversion to other fuels, or it can be exported elsewhere
- In the Northwest, Montana exports large amounts of hydrogen to Wyoming and Idaho



Task 1: Core Case
Hydrogen Pipeline And Electrolyzer Capacity Maps

EVOLVED ENERGY RESEARCH

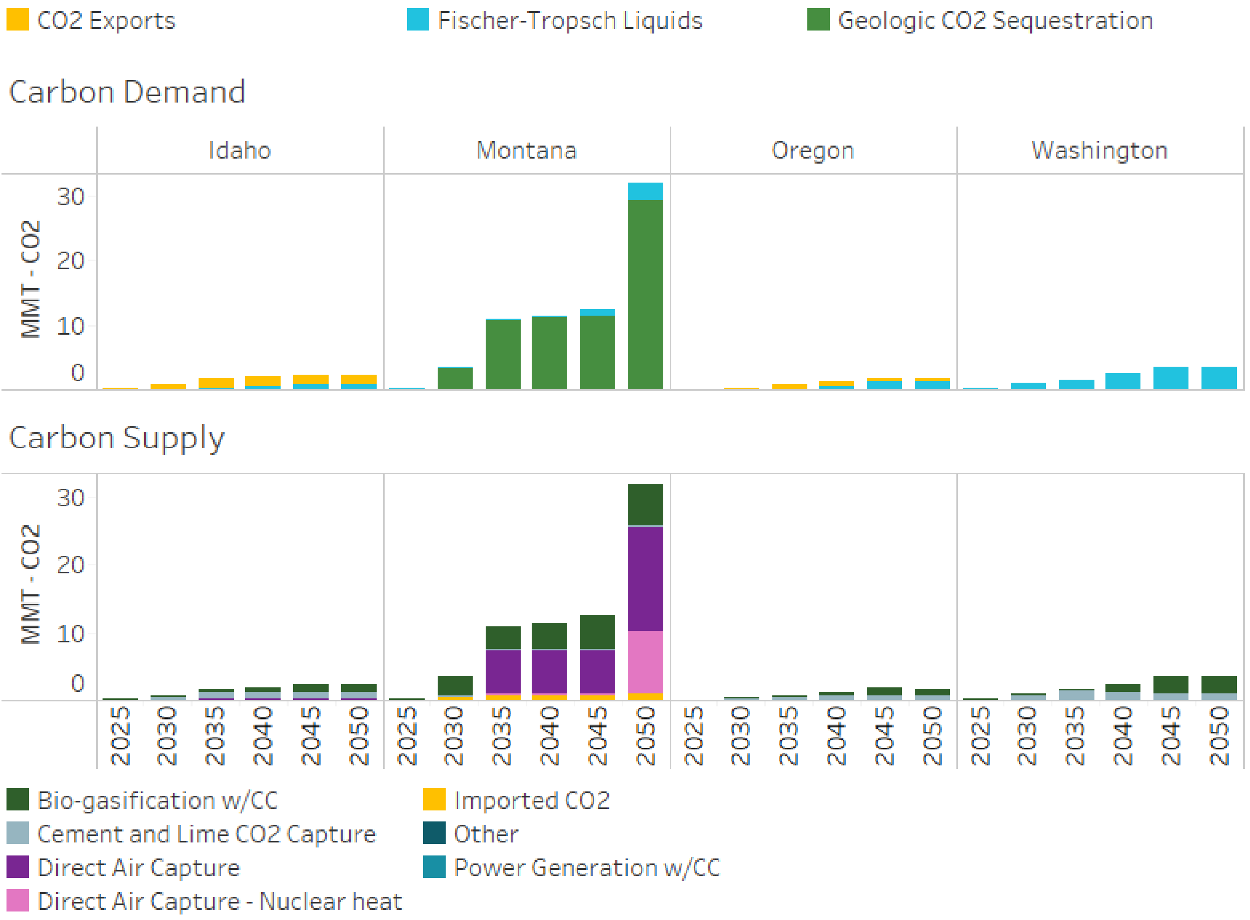


- Significant hydrogen production and delivery system is built out by 2030, in part due to IRA, with continued expansion through 2050
- Electrolyzer siting is driven by renewable resource quality and availability

Task 1: Core Case
Carbon Utilization and Sequestration

EVOLVED ENERGY RESEARCH

- Carbon dioxide captured from industry, power and fuels production, and direct air capture
- States without geologic storage opportunities utilize carbon dioxide for fuels production
  - What's not used is exported for sequestration elsewhere
- In the West, Montana sequesters 29 MMT annually by 2050
  - Large amounts come from direct air capture by 2035, driven by IRA incentives
  - Other states can pay for sequestration out of state
    - Avoids inefficient building of local CO_2 production and pipeline expansion
  - Dependent on feasibility of both sequestration opportunities and large investments in wind in Montana



Task 1: Core Case Emissions

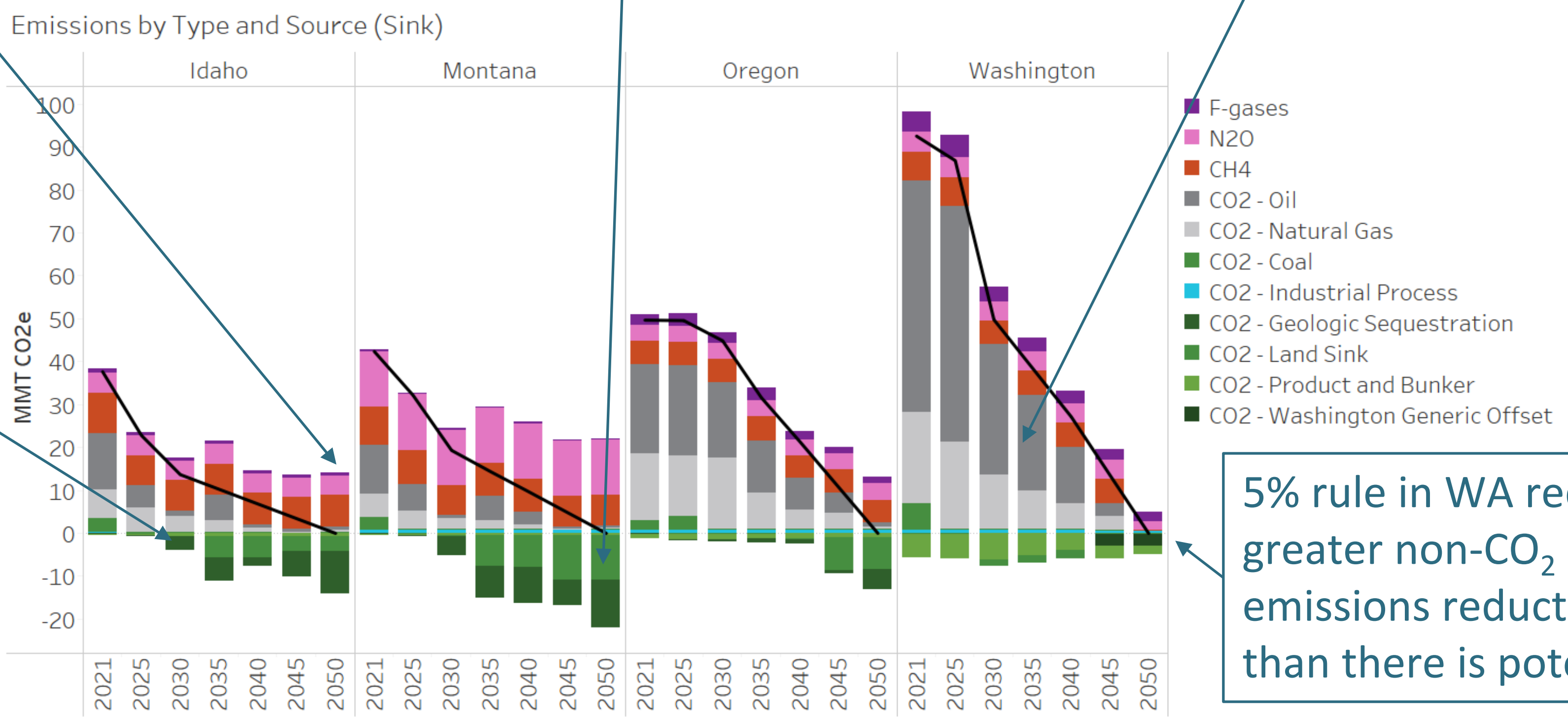
EVOLVED ENERGY RESEARCH

N_2O and CH_4 from agriculture difficult to decarbonize and remain in the economy

Remaining non-CO_2 emissions offset with land sink measures and geologic sequestration

Declines in emissions from oil and natural gas driven by efficiency, electrification, and substitution with clean fuels

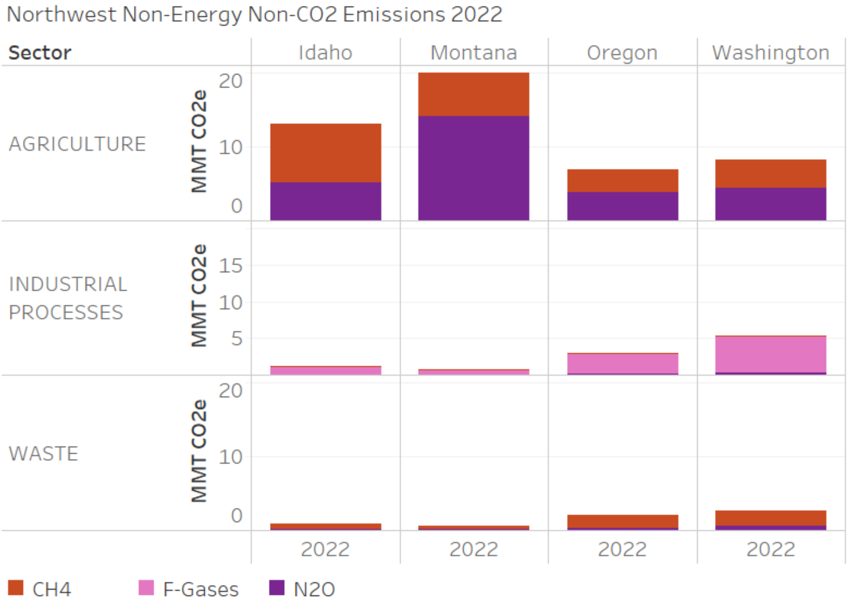
States with large agricultural sectors require carbon sequestration and clean fuels to achieve 40% by 2030 targets set in this study

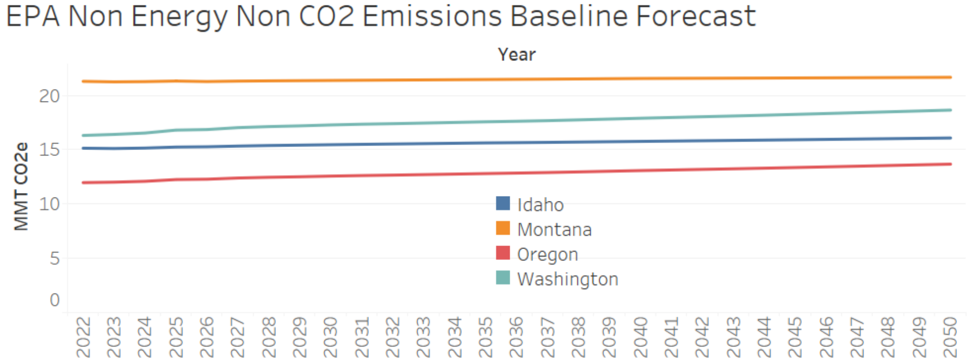


5% rule in WA requires greater non-CO_2 emissions reductions than there is potential

Task 1: Core Case
Non-CO_2 And Non-Energy Emissions

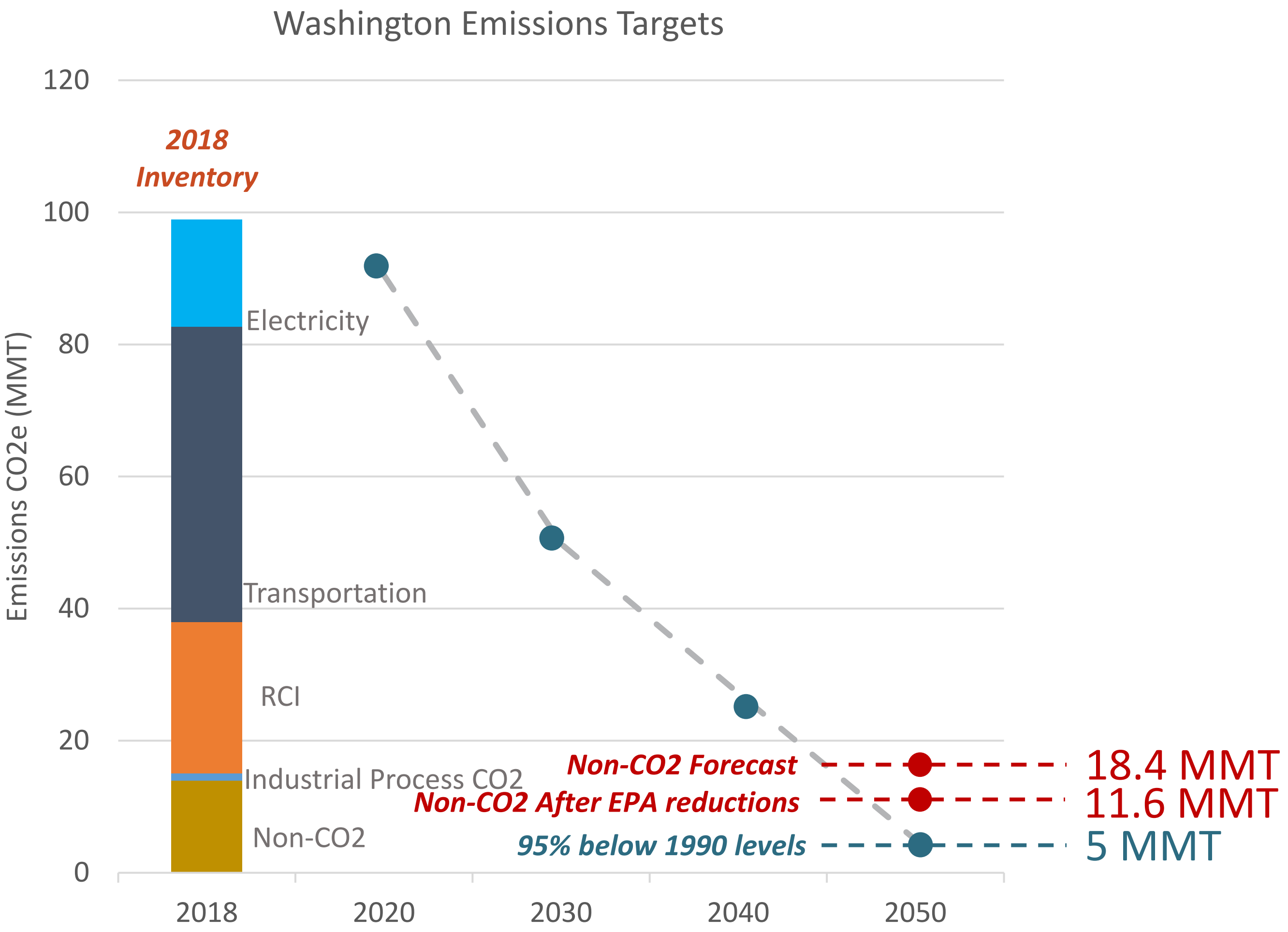
- Agricultural emissions particularly difficult to target with reduction measures
  - Where most of Montana's non-CO_2 emissions come from
- Max achievable reductions of non-energy non-CO_2 gases based on EPA supply curves of mitigation measures:
  - 28% in Idaho
  - 13% in Montana
  - 27% in Oregon
  - 37% in Washington
- Negative emissions technologies required in these sectors
  - Increasing land sink, geologic sequestration, and carbon capture including direct air capture





Task 1: Core Case
Washington Emissions – Meeting 95%

- EPA forecast of non-CO_2 emissions in WA is 18.4 MMT by 2050
- Need to reduce non-CO_2 and remaining CO_2 emissions to 5 MMT
  - Not possible with EPA non-CO_2 reduction potentials
  - 6.8 MMT of EPA identified potential reduction measures
- To model, we added generic non-CO_2 reduction measures at higher cost than EPA measures
  - Shows the gap that needs to be covered by new technologies or changes to economic activity or state policy



Task 1: Core Case
Montana and Idaho Emissions

EVOLVED ENERGY RESEARCH

- We assumed emissions targets for states without policy of 40% reductions below 1990 levels by 2030
  - In line with other targets in the region and around the United States
  - Investigates what it would take for these states to adopt a similar target: Is it reasonable policy to do so in Montana and Idaho?
- Achieving 40% reductions below 1990 levels by 2030 is difficult for Montana and Idaho
  - First, 1990 emissions are significantly lower than 2020 emissions levels. Emissions in electricity, transportation, and agriculture have grown in that time. Montana and Idaho start at a higher point relative to 1990 than states with targets based on this benchmark
  - Second, Montana and Idaho have higher proportions of non-CO_2 emissions than other states due to larger agricultural sectors, which are harder to reduce than energy sector emissions
  - Achieving 40% by 2030 with energy sector emissions reductions alone requires clean electricity and proportionally more decarbonized fuels than it does in Washington or Oregon
- Near-term targets to achieve clean energy in Montana and Idaho more achievable
  - Energy sector emissions reductions in line with the pace of Washington and Oregon would be more achievable policy
  - However, there is a window of opportunity for deeper reductions in clean fuels and through carbon sequestration by taking advantage of IRA

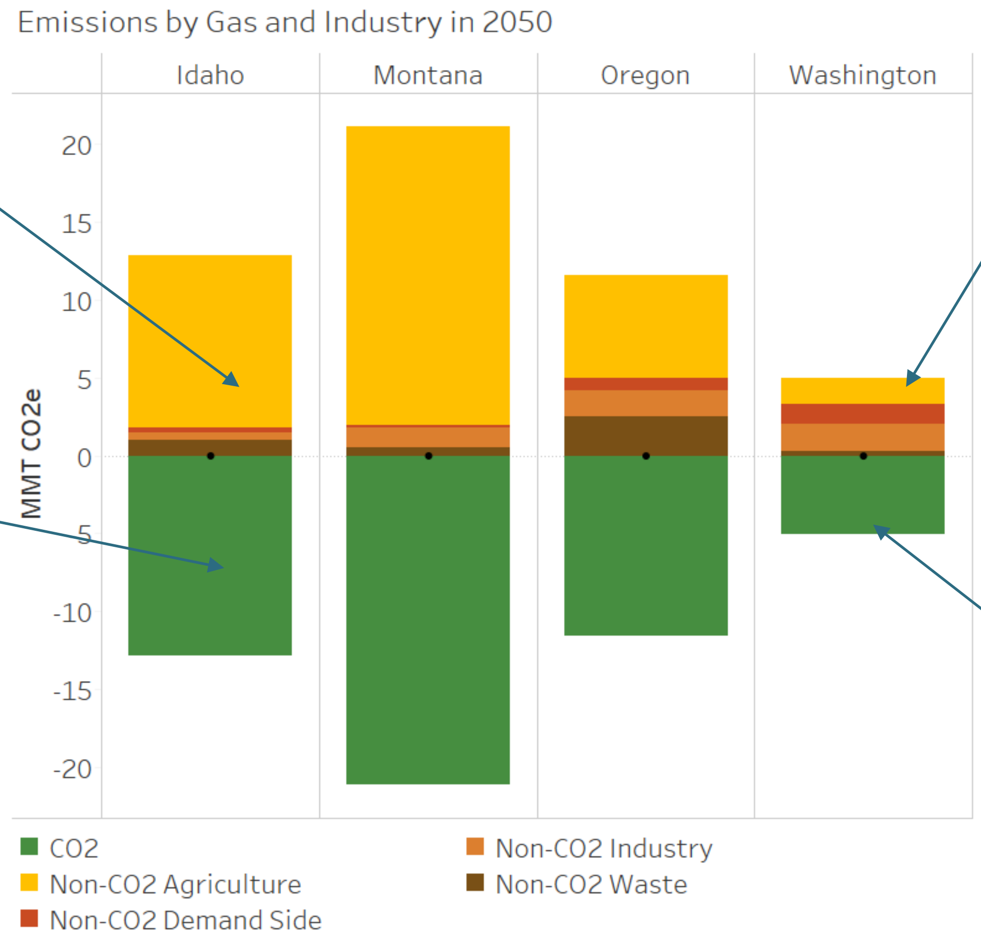
Task 1: Core Case
What do emissions look like in 2050?

EVOLVED ENERGY RESEARCH

Largest remaining emissions categories are CH4 and N2O in agriculture: limited options for reductions

Offset with geologic sequestration and incremental land sink from reforestation

Other incremental land sink opportunities could reduce sequestration



5% rule in Washington requires non-CO_2 and industrial process emissions to reach 5 MMT, beyond EPA potential for reductions

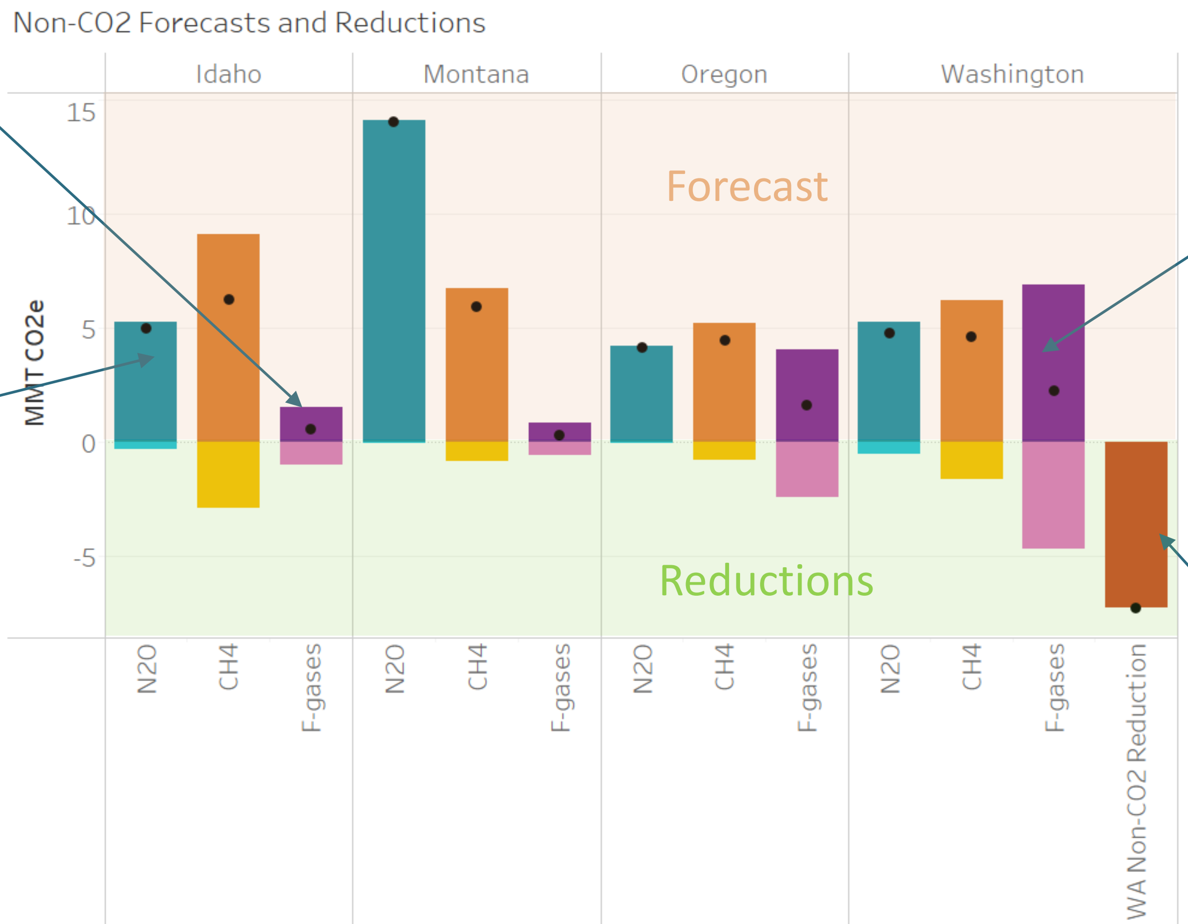
Washington generic offset could be CO_2 exports for sequestration or incremental land sink

Task 1: Core Case
Non-CO_2 Emissions Reductions in 2050

EVOLVED ENERGY RESEARCH

Largest potential for f-gas reductions in industry and customer products

Majority of N_2O and CH_4 emissions in agriculture and are difficult to avoid



Washington selects full EPA reduction potential across all non-CO_2 gases

7.3 MMT of additional reductions beyond EPA potential for these gases are needed to reach 5 MMT limit on gross emissions

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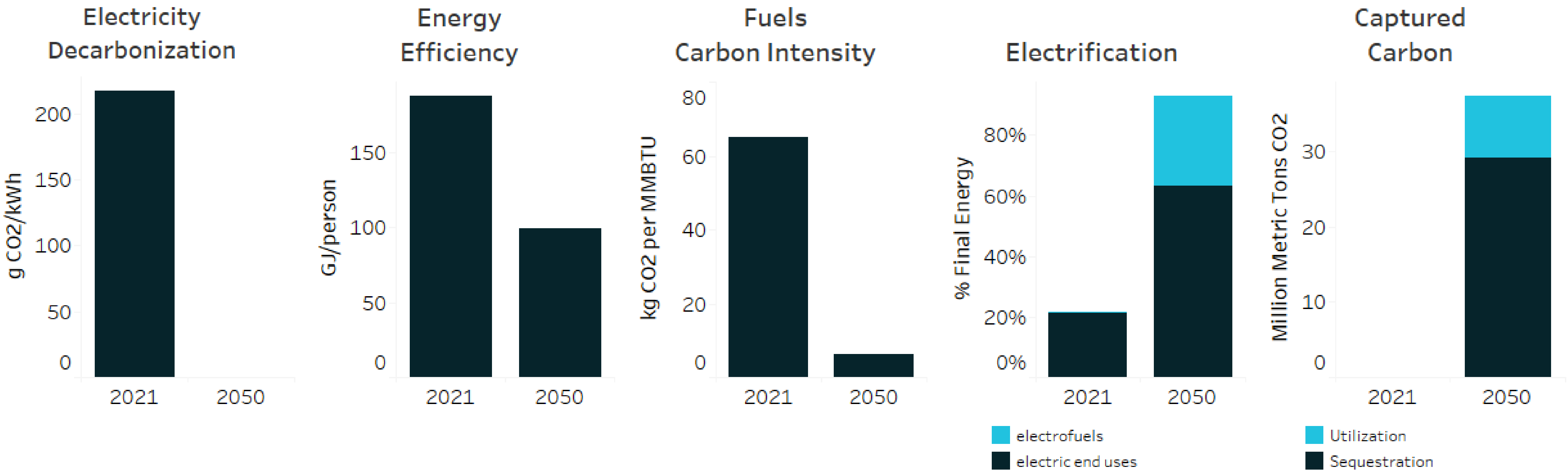
Task 1: Core Case

Key Findings

Task 1: Core Case Key Findings
Pillars Of Deep Decarbonization



- Decarbonization in the Northwest hinges on clean electricity, energy efficiency, clean fuels, electrification, and carbon capture

Task 1: Core Case Key Findings
Emissions

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- **The Northwest needs negative emissions technologies to reach net zero**
  - Not possible to reduce non-CO_2 emissions to zero without changing economic activity
  - Incremental land sink, geologic sequestration, and direct air capture offsetting remaining emissions in the economy
  - Gross CO_2 emissions from energy and industry close to zero by 2050
- **Achieving 40% below 1990 emissions by 2030 in states with large agriculture sectors requires carbon sequestration and clean fuels**
  - Regional emissions targets are more efficient – emissions reductions can come from lowest cost sources
  - Near-term energy sector only state targets in Montana and Idaho may be more appropriate given the difficulty of reducing or offsetting emissions from non-CO_2 sources in the near-term
- **Early investment in negative emissions technologies**
  - Incremental land sink – Uncertain, depends on changes to land use and climate impacts
  - Geologic sequestration – Need a carbon source, significant investment in direct air capture in Montana by 2035
- **Meeting 95% gross emissions levels in Washington will require new measures not currently identified**

Task 1: Core Case Key Findings Transmission

EVOLVED ENERGY RESEARCH

- **The transmission costs in the TNC Power of Place dataset limit new transmission build in the near-term but significant transmission expansion happens in the long-term**
  - Large-scale development of renewables occurs in all states in the Northwest, but as transmission expands post 2035, Washington and Oregon increase reliance on imported electricity
  - Energy in states with high quality renewables is used to produce clean fuels locally and export energy via pipelines and other fuels networks
- **How is this different from past studies?**
  - Transmission was less expensive using NREL datasets in previous Northwest studies, driving earlier expansion in transmission, imports, and exports
  - However, as Task 2 demonstrates, transmission expansion is relatively insensitive to cost when expanding lines to low-cost wind. By 2050 transmission between MT and WA grows by 9 GW
- **Alternative futures with different transmission costs and expansion potentials are explored in Task 2, giving more insight into the trends above**

Task 1: Core Case Key Findings
Nuclear Electricity

- **Idaho and Washington invest in 0.7 GW and 1.1 GW of new small modular reactors (SMRs), respectively**
  - Idaho invests in retrofitting retiring coal plants
  - Question of which coal generators are eligible for retrofits
- **West-wide, nuclear electricity capacity is 9.5 GW in 2040 and 8.4 GW in 2050**
  - The West retrofits 4 GW of retiring coal and gas with SMRs
  - Retrofits happen before 2035 to leverage IRA incentives
  - Total nuclear reactor capacity of 33.5 GW across the West by 2050 – the non-electric heat used in direct air capture
- **How is this different from past studies?**
  - Investment in new nuclear was not permitted in previous Northwest studies
  - IRA provides incentives for nuclear development, including increased incentives to retrofit retired plants
- **Role of nuclear is uncertain**
  - Nuclear development is a question of feasibility as much as economics
  - Nascent technology with an uncertain development path. Role in resource portfolio is subject to how project costs progress – larger opportunities economically if costs decline significantly

Task 1: Core Case Key Findings
Offshore Wind

- **California's offshore wind mandate of 25 GW by 2045 displaces economic offshore wind development in the Northwest**
  - Limits the market for additional offshore wind development – 1.2 GW in Oregon
  - Reduces the need for imported energy into California
- **How is this different from past studies?**
  - We have previously identified 20 GW of offshore wind development in Oregon prior to the California mandate
  - California development of HVDC lines to Wyoming in this study may also limit the export potential for the Northwest
- **Investigating an offshore wind development target for Oregon in a separate study**
  - An Oregon target for offshore wind may not increase costs significantly and could have in-state jobs growth and economic development benefits. Analyzing the impact of a potential Oregon mandates will give us a richer understanding of the trade-offs
  - Northern California offshore wind located in the same region as Oregon offshore wind with different interconnection point. What are the opportunities for Oregon in supporting regional offshore wind development?

Task 1: Core Case Key Findings
Inflation Reduction Act

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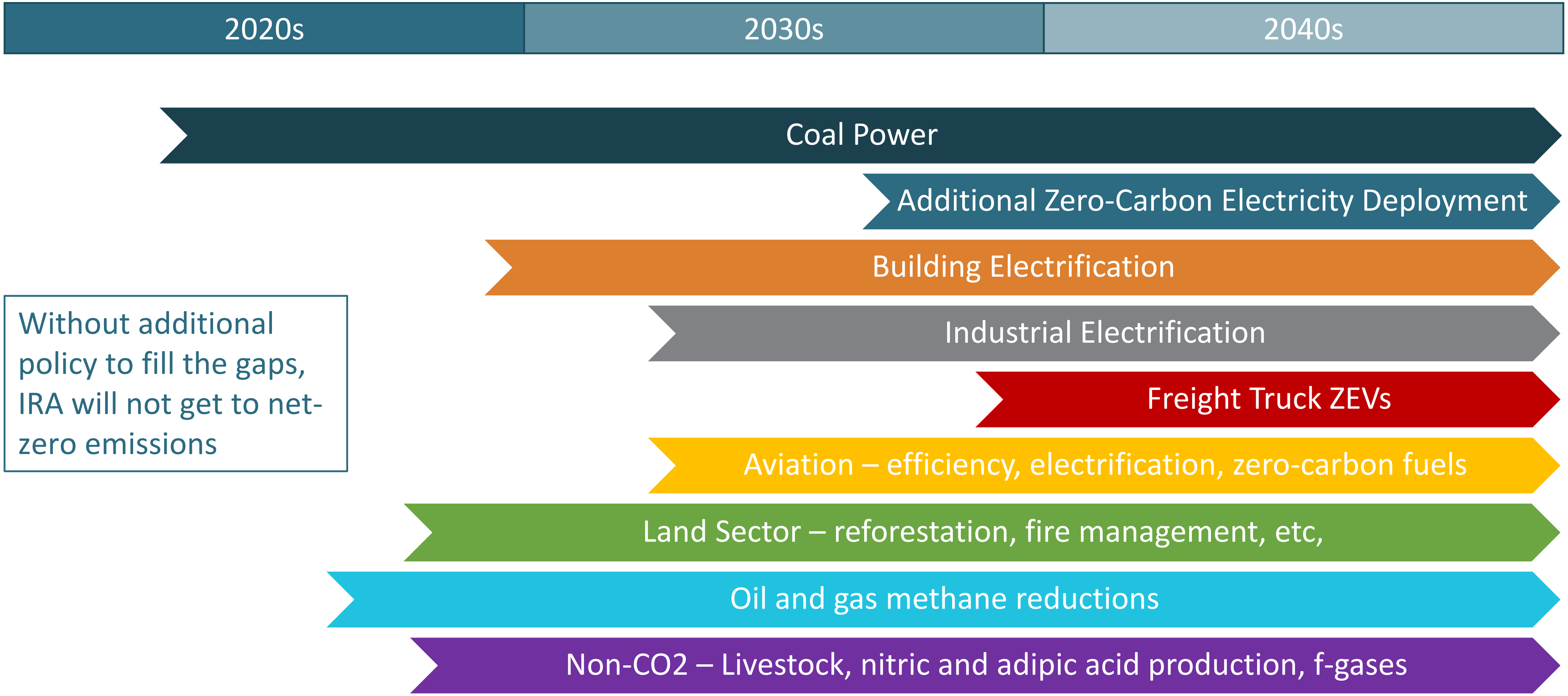
- **Technologies previously forecast for the 2040s shifted forward in time**
  - Incentive to build nuclear, electrolysis, and direct air capture in the early 2030s
- **EER national studies of IRA show that ITC and PTC incentives drive rapid adoption of renewables through 2035, in line with a pathway to net zero emissions**
  - Lowers costs in Western states with clean electricity policy, drives greater adoption in those without
- **Electrolysis to produce hydrogen is cost effective under IRA incentives**
  - Combined with lower cost renewables, states requiring near-term clean fuels to meet emissions targets will see significant economic benefits from IRA
- **Supplement to regional policy on a net zero pathway**
  - Positions states well in renewables, transportation, and in supporting nascent technologies that are key to reach net zero

Task 1: Core Case Key Findings
Where are the gaps in IRA support?



Task 1: Core Case
Questions posed in following tasks

- Comparison to Core Case – What are the consequences of different assumptions about uncertain future outcomes?
- Transmission
  - What if transmission were lower or higher cost?
  - What if transmission could not be expanded?
  - What if transmission expansion east to west in the Northwest were not possible?
- Clean Fuels Trade-Offs
  - What if electrolysis and electric fuels production were cheaper or more expensive than forecast?
    - Impact on competition with biofuels
  - What if local clean fuels production were required?
  - What if the market for hydrogen is not there to support production?

Task 1: Core Case
Questions posed in following tasks

- Pace of Transportation
  - What if electrification of the transportation sector happens more slowly than forecast?
  - Significant clean fuels production required in the Northwest. How much more expensive is it to increase fuels demand?
- Distributed Energy Resources
  - What is the impact on grid-scale investments if rooftop solar, distributed batteries, and demand response play more significant roles?
- Electricity versus Gas in Buildings
  - What are the impacts and uncertainties of a natural gas future in buildings versus electrification?
- Air Quality Impact on Health Metrics
  - How does decarbonizing the economy impact key health metrics including reduced mortality, morbidity, and economic impacts from lost workdays?

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Task 2: Transmission

Task 2: Transmission

- Key research questions:
  - Cost related: What if transmission were lower or higher cost?
  - Feasibility related: What if no transmission could be expanded? What if development of east to west transmission in the Northwest were not possible? What if only reconductoring were possible?
  - Technology related: What if transmission could increase rating through high-temperature low sag options?

Sensitivity	Question Asked	Description
1. No Tx Expansion	What if transmission cannot be expanded?	Bookend case to show how states in the Northwest could meet their goals in the absence of any transmission expansion. Comparing the cost of this sensitivity to the Core Case shows the additional cost of decarbonizing without transmission expansion and provides motivation for pursuing transmission planning.
2. Limited Wind	What if Montana and Wyoming are limited to 10 GW of onshore wind development?	56 GW of new onshore wind is built in MT by 2050 in the Core Case, driving transmission build. What if Montana and Wyoming see significant opposition to siting these resources?
3. No East-West Tx	What if expanding transmission from east-to-west in the Northwest is not possible?	In past studies, east-to-west transmission connections have driven investment patterns. How are local resource investments impacted if east-to-west expansion is not allowed?
4. Reconductor Only	Allow reconductoring only	Developing new transmission corridors will be difficult and is uncertain. This scenario explores the bookend case that no new transmission can be built, but existing lines can be reconductored.
5. Low Cost	What if transmission were lower cost (50%)?	Explores the opportunities for additional transmission expansion if costs were lower than the conservative assumptions used in the Core Case.
6. High Cost	What if transmission were higher cost (50%)?	Indicates the level of transmission expansion that is economic even if costs exceed conservative estimates.

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Task 2: Transmission

Core Case Results

Task 2: Transmission
Core Case Transmission Costs

- The Core Case uses transmission cost assumptions developed for the The Nature Conservancy Power of Place (PoP) West study
- PoP uses GIS modeling to determine least-cost interstate transmission routes between existing substation endpoints
- Cost assumptions and routes account for existing transmission capacity, reconductoring opportunities at different voltages, terrain, and sensitive land use areas
- PoP costs are higher than the NREL ReEDs transmission costs used in past Northwest analyses, resulting in later expansion of transmission in the Core Case

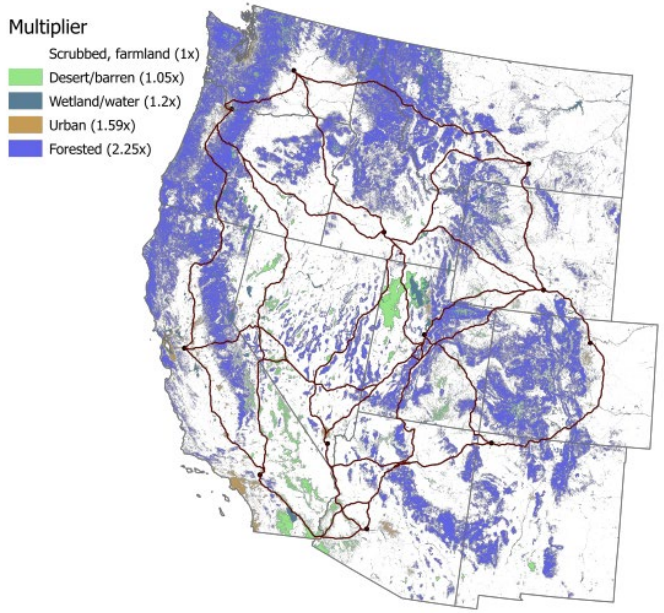

Fig. S7. Least cost path model results showing selected cost surface mutlipliers and new 500 kV transmission lines.

Source: Power of Place-West

Task 2: Transmission
Core Case Transmission Capacity

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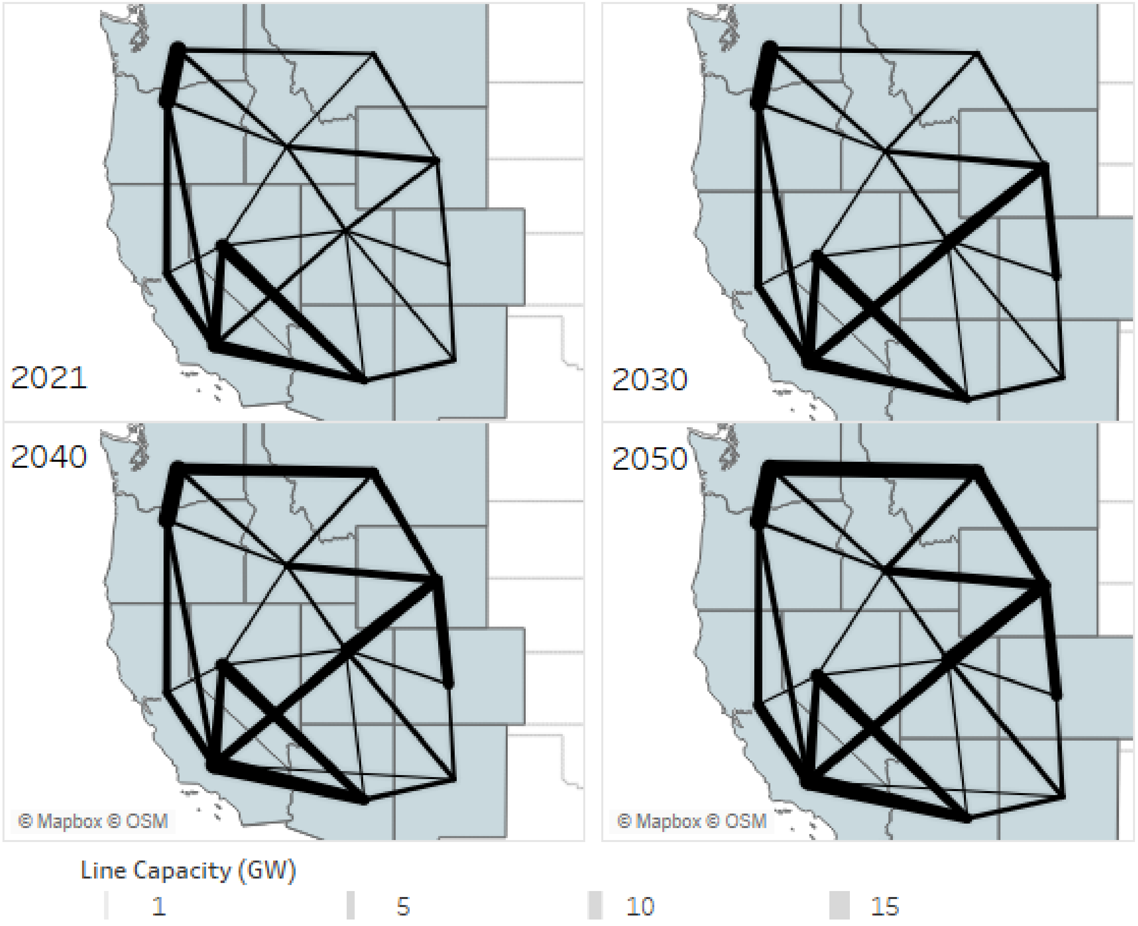
- Transmission expansion to Northwest states is driven by expanding access to low-cost wind in Montana and Wyoming
  - Key intertie expansion supports wind exports:
  - MT to WA expands to 11 GW by 2050
  - MT to WY expands to 6 GW
  - WY to CO expands to 7 GW and WY to CA-S to 6 GW
- Most dramatic expansion after 2035



Task 2: Transmission
Core Case Hydrogen

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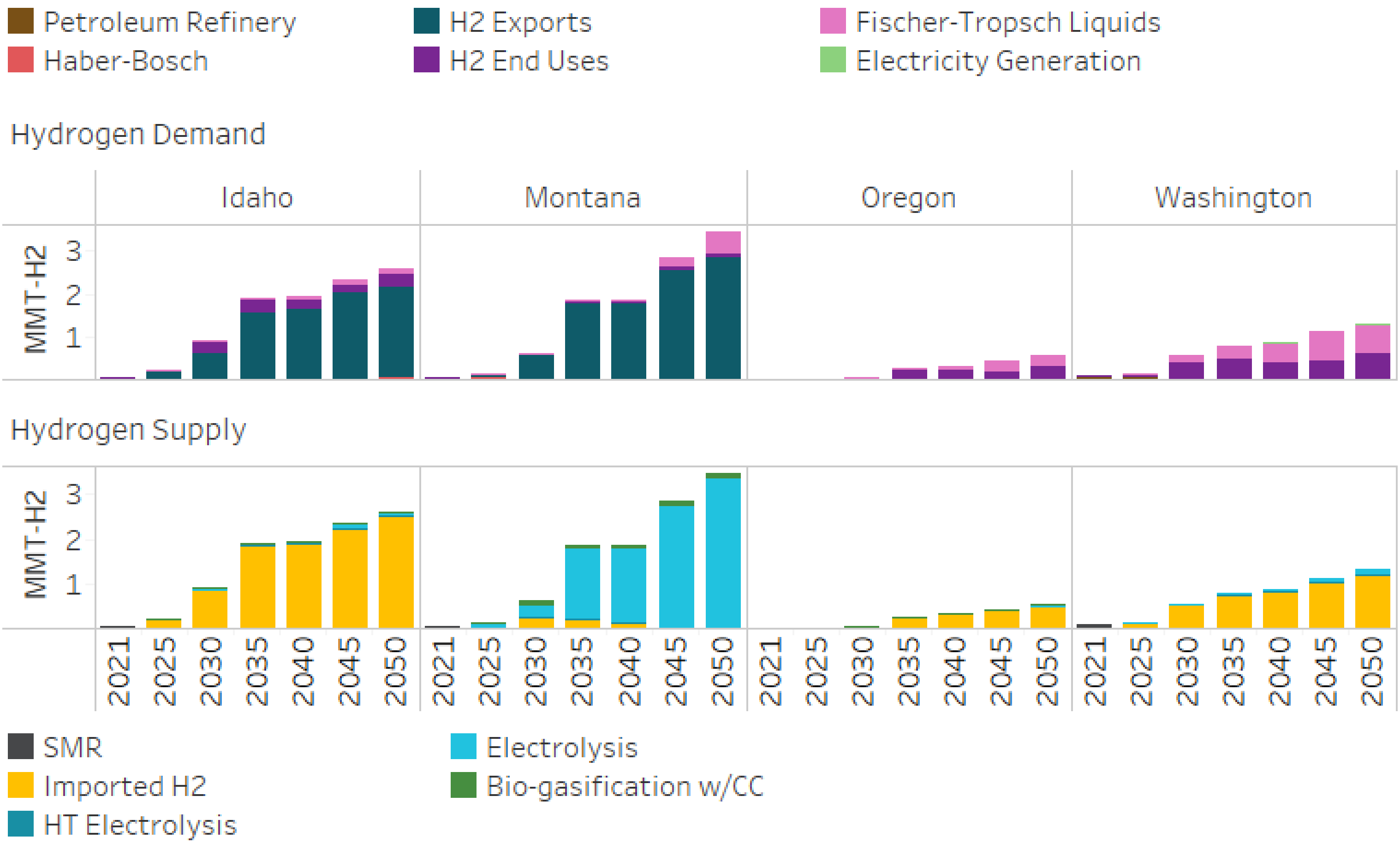
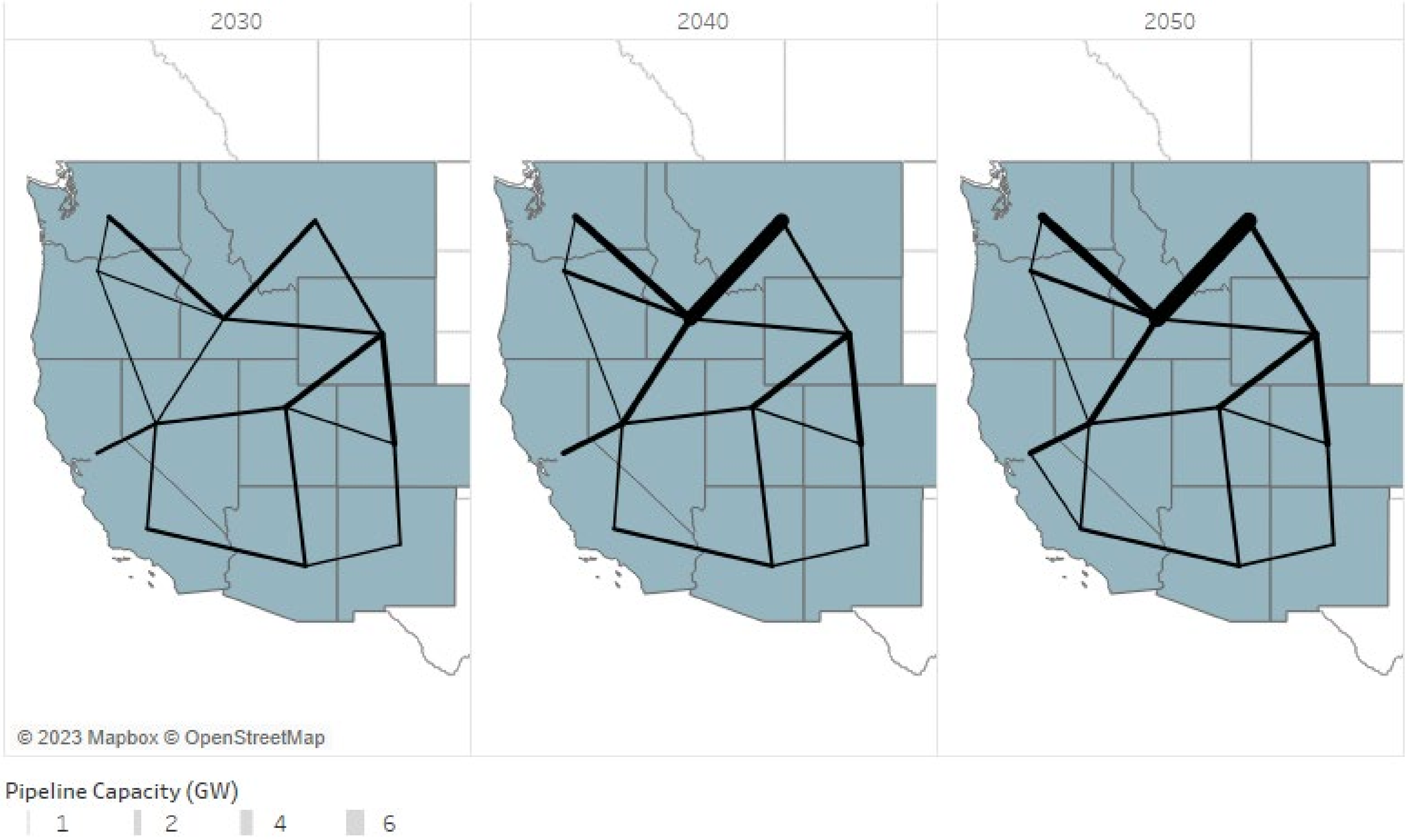
- Hydrogen electrolysis and pipelines are another means of transporting renewable energy to load centers alongside electricity transmission
- Hydrogen can be used directly in end uses, or it can be converted to ammonia (Haber-Bosch) or drop-in synthetic hydrocarbons (Fischer-Tropsch)
  - Ammonia is used in shipping, hydrocarbons are used in vehicles and aviation
- In the Northwest, hydrogen is produced in large quantities in Montana and exported to neighboring states via pipeline



Core Case: Hydrogen Pipeline Capacity

- Hydrogen produced in Montana is primarily exported to Wyoming and Idaho, driving new pipeline development beginning in 2030
- Hydrogen exported through Idaho to Washington and Oregon supplies end use demand and some clean fuels production
- Hydrogen exported south from Montana is used primarily for Fischer-Tropsch liquid fuels production in Wyoming and Colorado



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Task 2: Transmission

Transmission Feasibility And Cost Sensitivity Results

Task 2: Transmission Cost Sensitivities

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- Costs in the Core Case (from TNC PoP) can be disaggregated to a technology component and a terrain/land use component
  - Technology component is from Black & Veatch Transmission Capital Cost Tool
  - Terrain/land use component uses a multiplier approach
- For Sensitivities 5. Low Cost and 6. High Cost, we apply the cost adjustment to the terrain/land use multiplier (not to the technology cost)

Example: MT to WA Transmission Expansion Costs

Expansion Type	Capacity (MW)	Length (Miles)	Total PoP Cost ($/MW-mile)	B&V Technology Cost ($/MW-mile)	Terrain/Land Use Cost ($/MW-mile)	+50% ($/MW-mile)	-50% ($/MW-mile)
CO-LOCATE 500kVd	3000	726	2361	1093	1268	1902	634
NEW 500kV HVDC	3000	787	1851	1378	473	710	237
NEW 500kVd HVAC	3000	783	2386	1392	993	1490	497
RECONDUCTOR 230kVd	400	726	3070	1660	1410	2115	705
RECONDUCTOR 500kVd	1500	770	2755	1421	1334	2001	667

Task 2: Transmission Sensitivity Results-Capacity (1/2)

- CA-S to WY is built to maximum extent in the Core Case
  - Bypassing Northwestern Tx options to import into CA is favored economically if available
  - The model would build more if permitted
  - Lower cost transmission accelerates timing of transmission build, higher costs decelerates expansion
- If MT and WY are limited to 10 GW of wind potential each, then CA-S to WY expansion is not economic
  - Limited wind potential is delivered over alternative transmission pathways
- WY exports through CO are valuable for sending cheap wind energy south to predominantly solar states

Transmission Capacity (GW)

		2021	2030	2040	2050
CA-N to CA-S	Core	5.4	5.4	5.4	7.6
	1. No Tx Expansion	5.4	5.4	5.4	5.4
	2. Limited Wind	5.4	5.4	5.4	7.7
	3. No East-West Tx	5.4	5.4	5.4	8.4
	4. Reconductor Only	5.4	5.4	5.4	5.4
	5. Low Cost	5.4	5.4	5.7	9.5
	6. High Cost	5.4	5.4	5.4	7.0
CA-S to WY	Core	0.0	6.0	6.0	6.0
	1. No Tx Expansion	0.0	0.0	0.0	0.0
	2. Limited Wind	0.0	0.2	0.2	0.2
	3. No East-West Tx	0.0	6.0	6.0	6.0
	4. Reconductor Only	0.0	0.0	0.0	0.0
	5. Low Cost	0.0	6.0	6.0	6.0
	6. High Cost	0.0	6.0	6.0	6.0
CO to WY	Core	1.4	5.1	7.0	7.0
	1. No Tx Expansion	1.4	1.4	1.4	1.4
	2. Limited Wind	1.4	4.3	4.4	7.3
	3. No East-West Tx	1.4	5.0	6.3	6.3
	4. Reconductor Only	1.4	4.0	4.1	4.1
	5. Low Cost	1.4	5.4	7.8	7.8
	6. High Cost	1.4	5.0	6.1	6.1

Task 2: Transmission Sensitivity Results-Capacity (2/2)

- MT to WA connection is also valuable by 2050, facilitating wind exports to load centers
  - Corridor is somewhat sensitive to cost changes: Sensitivity 5. Low Cost results in an additional 1.8 GW of expansion relative to Core
  - Reconductoring this intertie is expensive, yet is still selected if only reconductoring is available

Transmission Capacity (GW)

		2021	2030	2040	2050
MT to WA	Core	2.2	2.3	8.1	11.2
	1. No Tx Expansion	2.2	2.2	2.2	2.2
	2. Limited Wind	2.2	2.2	2.5	2.6
	3. No East-West Tx	2.2	2.2	2.2	2.2
	4. Reconductor Only	2.2	2.2	4.1	4.1
	5. Low Cost	2.2	2.4	8.4	12.1
	6. High Cost	2.2	2.2	6.5	9.6
MT to WY	Core	0.4	0.4	3.7	6.2
	1. No Tx Expansion	0.4	0.4	0.4	0.4
	2. Limited Wind	0.4	0.4	0.6	0.6
	3. No East-West Tx	0.4	0.4	3.9	7.8
	4. Reconductor Only	0.4	0.4	1.5	3.4
	5. Low Cost	0.4	0.4	4.3	7.3
	6. High Cost	0.4	0.4	2.9	4.8
ID to MT	Core	0.3	1.2	1.5	3.0
	1. No Tx Expansion	0.3	0.3	0.3	0.3
	2. Limited Wind	0.3	0.3	0.3	0.3
	3. No East-West Tx	0.3	0.3	0.3	0.3
	4. Reconductor Only	0.3	0.3	0.7	0.7
	5. Low Cost	0.3	1.9	1.9	3.3
	6. High Cost	0.3	1.0	2.5	3.3

Task 2: Transmission
Type of Transmission Expansion

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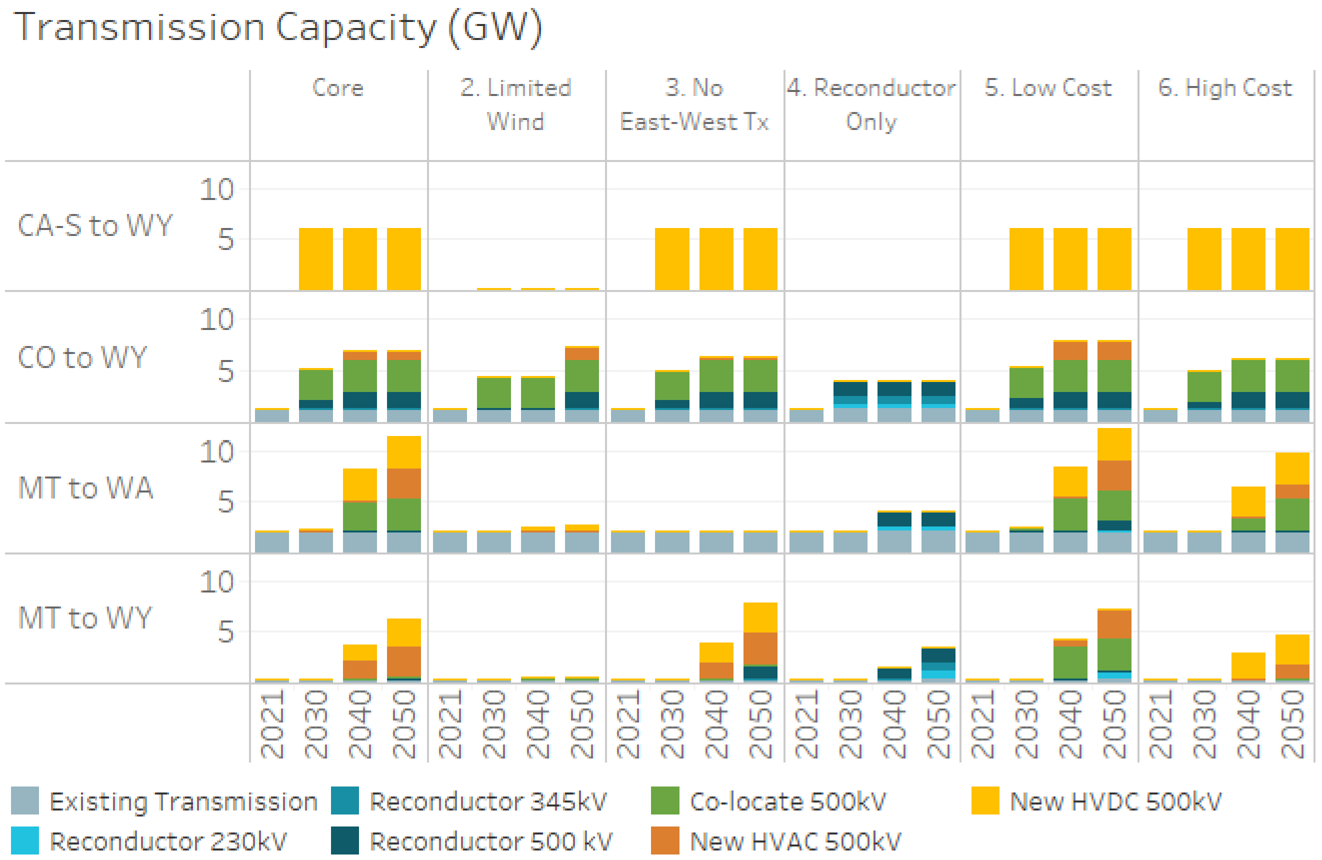
- Relative costs of AC, DC, and reconductoring options vary with line characteristics
  - Length, impact of terrain/land use multipliers
  - These relative costs have a high level of uncertainty—more line-specific and real-world data is needed
- CA-S to WY HVDC line is built to full 6 GW potential in all sensitivities where it's allowed and WY wind is available, demonstrating insensitivity to cost
- Reconductoring and co-location is cost-effective on CO to WY route
- MT to WA favors HVDC first due to long distance, but builds all available options based on the value of out of state wind
- A blend of options is economic from MT to WY unless wind development is constrained



This figure excludes Sensitivity 1, which allows no transmission expansion

Task 2: Transmission
Northwest Generation and Consumption in 2050

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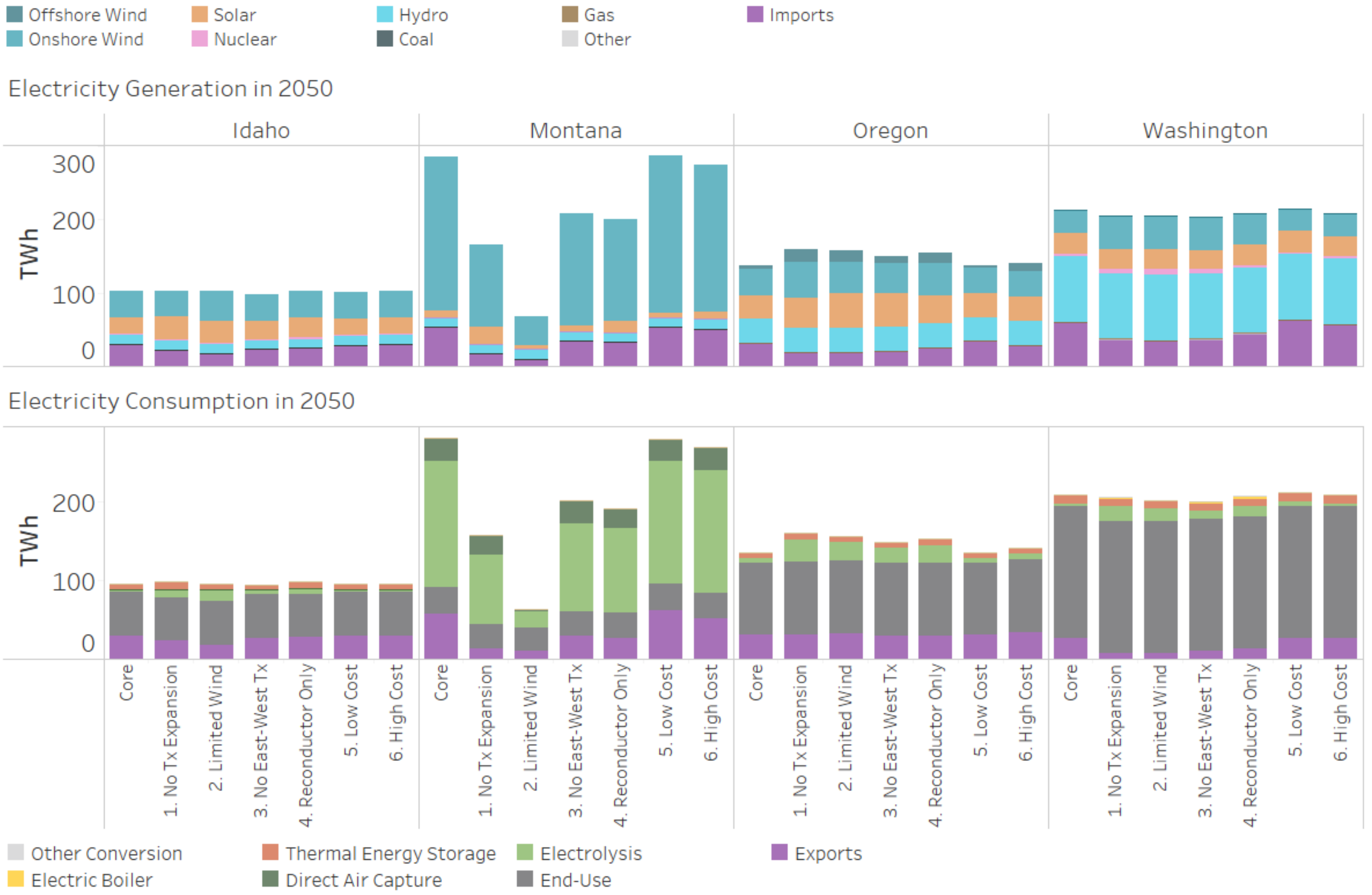
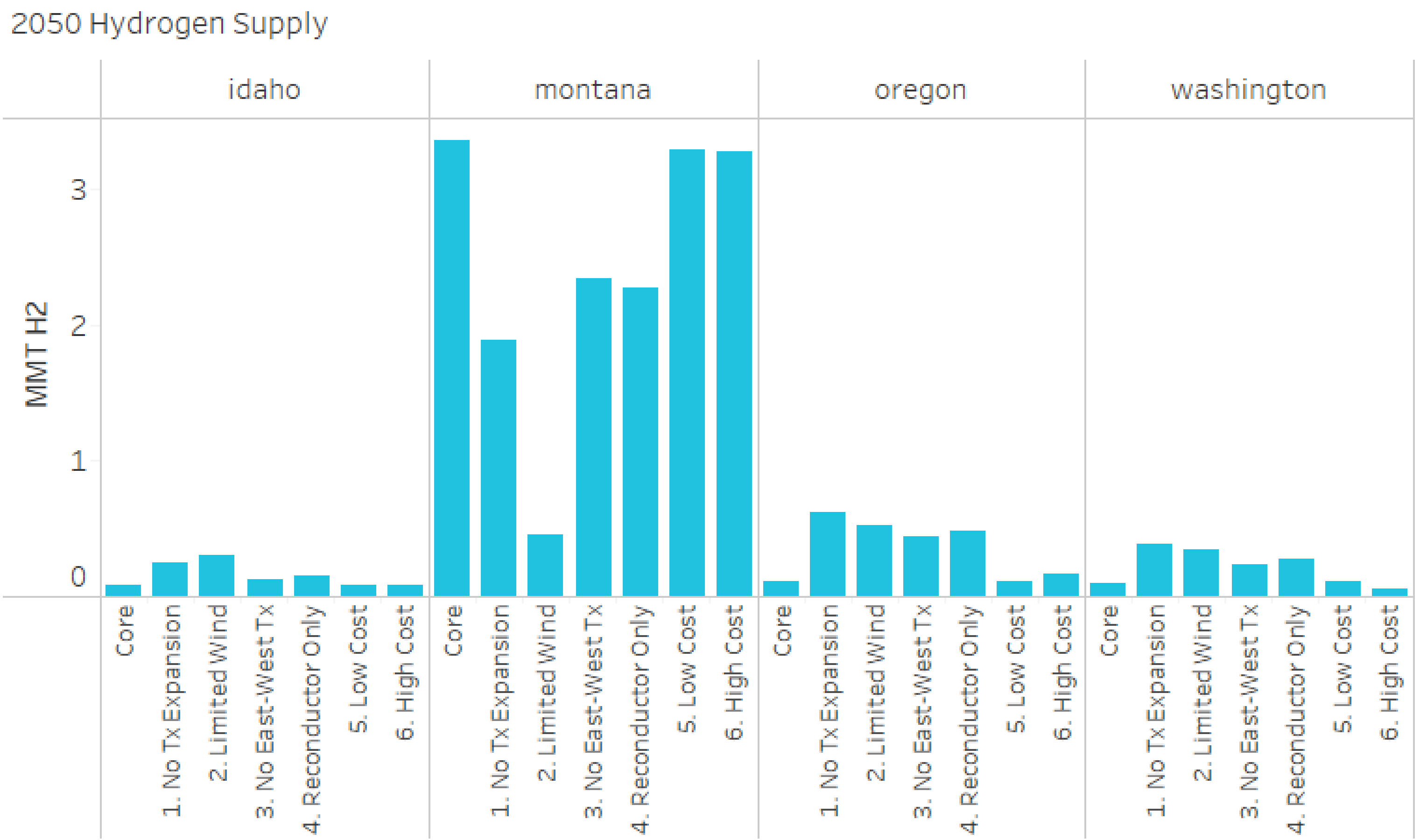
- Greater transmission connectivity increases wind investments, hydrogen production, and exports in MT
- Greater transmission connectivity reduces renewable energy investment and electrolysis in OR
- WA relies more on other markets when Tx is available
  - Imports from MT, reduced investments in local renewable energy
  - Exports to Oregon increase with greater access to other markets



Task 2: Transmission
Northwest Electrolytic Hydrogen Production

- Transmission constraints impact where hydrogen is produced in the Northwest, by limiting the economic buildout of wind power
- Greater transmission expansion drives more wind development in MT, which in turn drives more electrolysis siting
- When transmission expansion is limited or transmission costs increase, or when wind siting is limited, less hydrogen is produced in MT, and more electrolysis is sited in ID, OR and WA
- Lower transmission costs have the opposite effect: More hydrogen is produced in MT than in the Core Case



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Task 2: Transmission

High Temperature Low Sag Conductor Sensitivity Results

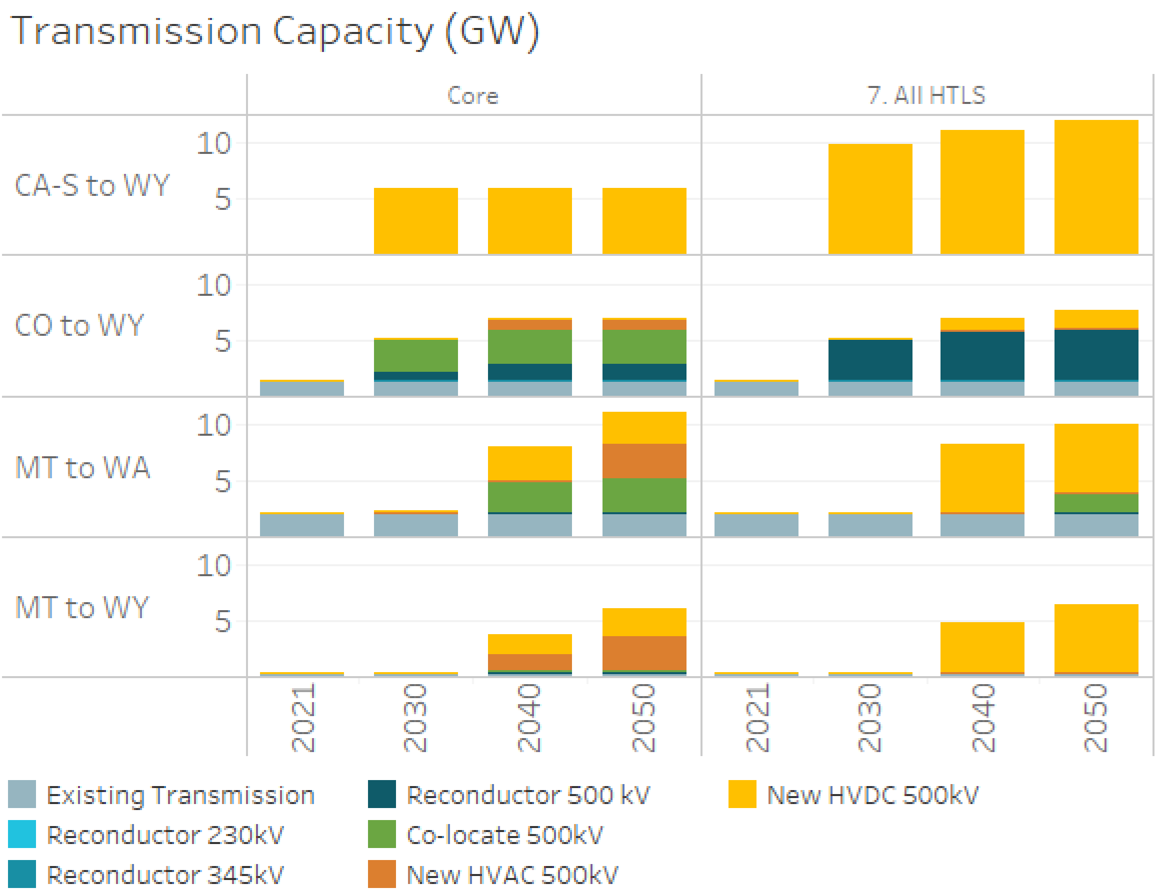
Task 2: Transmission
High Temperature Low Sag Conductors

- High temperature, low sag (HTLS) conductors with higher ampacity than regular ACSR conductors cost more, but increase the transmission expansion potential of reconductoring
  - We apply a 2.81 multiplier to ASCR costs, from MISO MTEP Transmission Cost Estimation Guide
- Each HTLS sensitivity can be compared to a previous scenario/sensitivity to investigate the impact of HTLS conductors on transmission builds and costs

Sensitivity	Question Asked	Description	Compare to Scenario:
7. All HTLS	What if all transmission expansion options use HTLS conductors?	This scenario investigates how transmission build decisions would be affected if both new and reconductored lines use HTLS conductors. It is the same as the Core scenario, but with HTLS conductors as the technology used in all transmission expansion options, instead of ACSR conductors.	Core
8. HTLS Reconductor	What if reconductored lines use HTLS conductors?	This scenario investigates how transmission build decisions would be affected if reconductored lines use HTLS conductors, but other line options still use ACSR. It is the same as the Core scenario, but with HTLS conductors as the reconductoring option.	Core
9. HTLS Reconductor Only	What if the Reconductoring Only scenario uses only HTLS conductors?	The Reconductoring Only scenario is limited in transmission expansion potential. By doubling the ampacity of reconductored lines, how does this impact total capacity build?	4. Reconductor Only

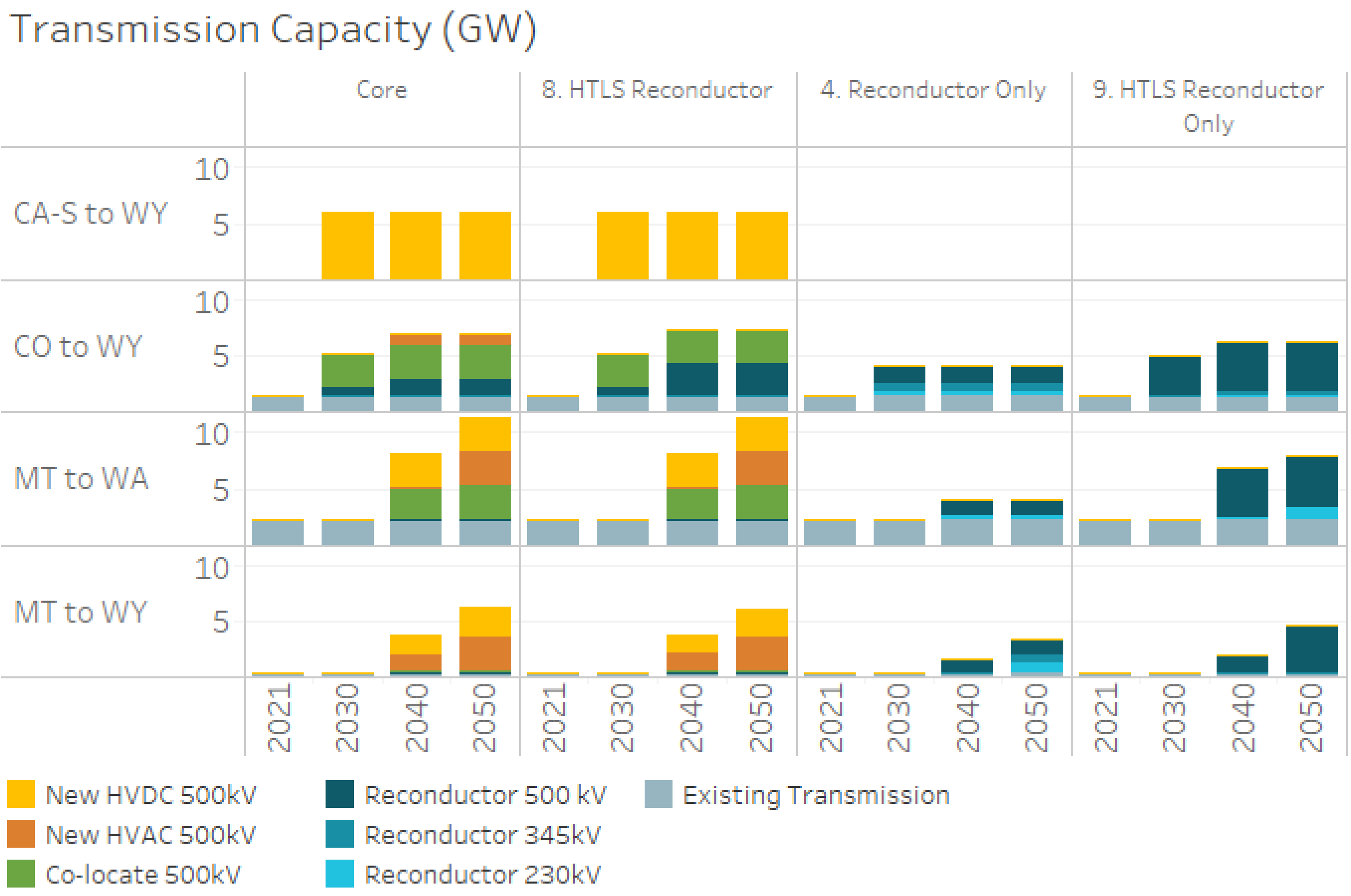
Task 2: Transmission
All HTLS Impacts

- When all line options use HTLS conductors, impacts are line-specific
  - Transmission capacity between CA-S to WY is doubled by 2050, showing the value of having additional expansion options to import wind into CA
  - Transmission capacity remains similar to the Core Case for other key interties, though the type of expansion is impacted
    - Reconductoring existing lines is favored in CO to WY versus the Core Case
    - The greater total potential for HVDC lines is utilized in MT to WA and MT to WY, favoring more HVDC line expansion



Task 2: Transmission
HTLS Reconductoring Impacts

- When reconductored lines use HTLS (Sensitivity 8), impacts are relatively small relative to Core Case
  - CO to WY favors slightly more reconductoring versus new HVAC
  - Other lines are unaffected
- Comparing Sensitivity 4. Reconductor Only to Sensitivity 9. HTLS Reconductor Only shows that increasing reconductoring potential by using HTLS conductor is valuable if new transmission cannot be constructed
  - CO to WY more than doubles the reconductored capacity
  - MT to WA capacity also significantly increases



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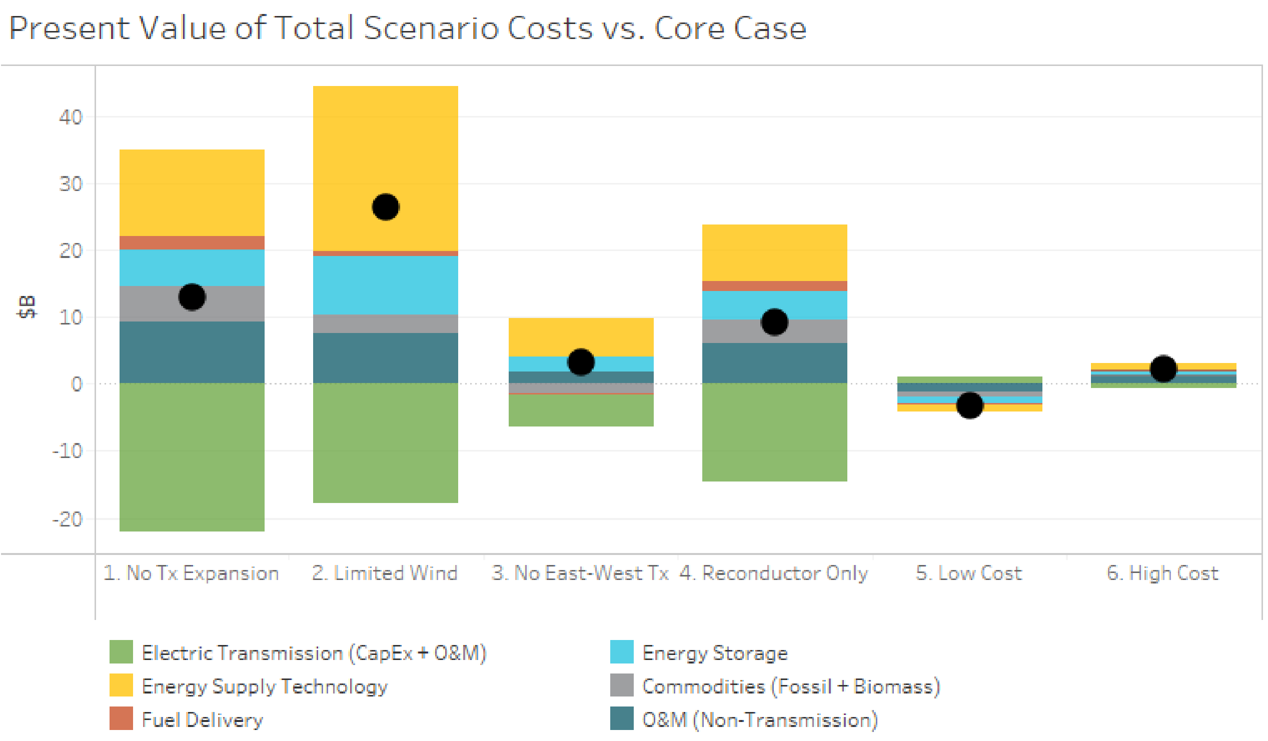
Task 2: Transmission

Cost Results

Task 2: Transmission
Cost Impacts: Feasibility and Cost Sensitivities

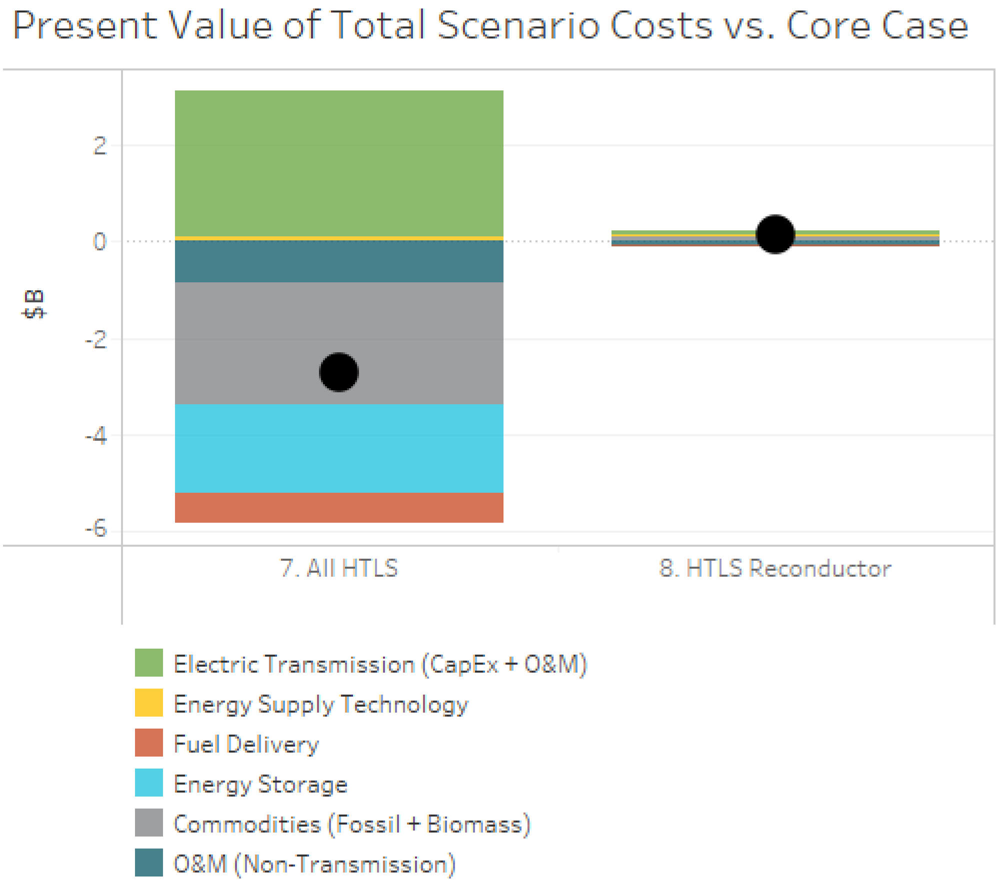
- Severely constraining transmission expansion increases total present value costs. e.g., in Sensitivities 1 and 4 present value costs through 2050 increase by $13B and $9B, respectively
  - Transmission constraints generally shift energy supply from wind to solar, which drives more investment in energy storage and clean fuels production
  - Increases in storage, PV, and hydrogen investment outweigh reduced transmission and fossil fuel costs
- Limited wind development (Sensitivity 2) dramatically increases total costs because it forces a wind-to-solar shift while also requiring more commodity use to meet energy demand
- Sensitivities 5 and 6, which explore variations in transmission cost, have lower impact on total costs. Cost differences shift investments between transmission and local resource development.
  - Lower cost transmission is built in greater quantities, increasing energy imports and exports from resources further afield
  - Higher cost transmission is built in lower quantities, driving investment in resources closer to load centers



Notes: 1. NPV calculations use a 3% discount rate. 2. Costs are shown for the entire US.

Task 2: Transmission
Cost Impacts of HTLS Conductors (1/2)

- Using HTLS conductors for all transmission expansion reduces total NPV costs through 2050 by $2.7B
  - HTLS is a question of feasibility rather than economics at the prices assumed in this study
- Using HTLS conductors for reconductoring only (all non-reconductoring transmission expansion uses ACSR) has a negligible impact on total costs
  - The benefit is in expanding transmission without new corridor development, potentially reducing permitting challenges for both transmission and renewable resources



Task 2: Transmission Cost Impacts of HTLS Conductors (2/2)

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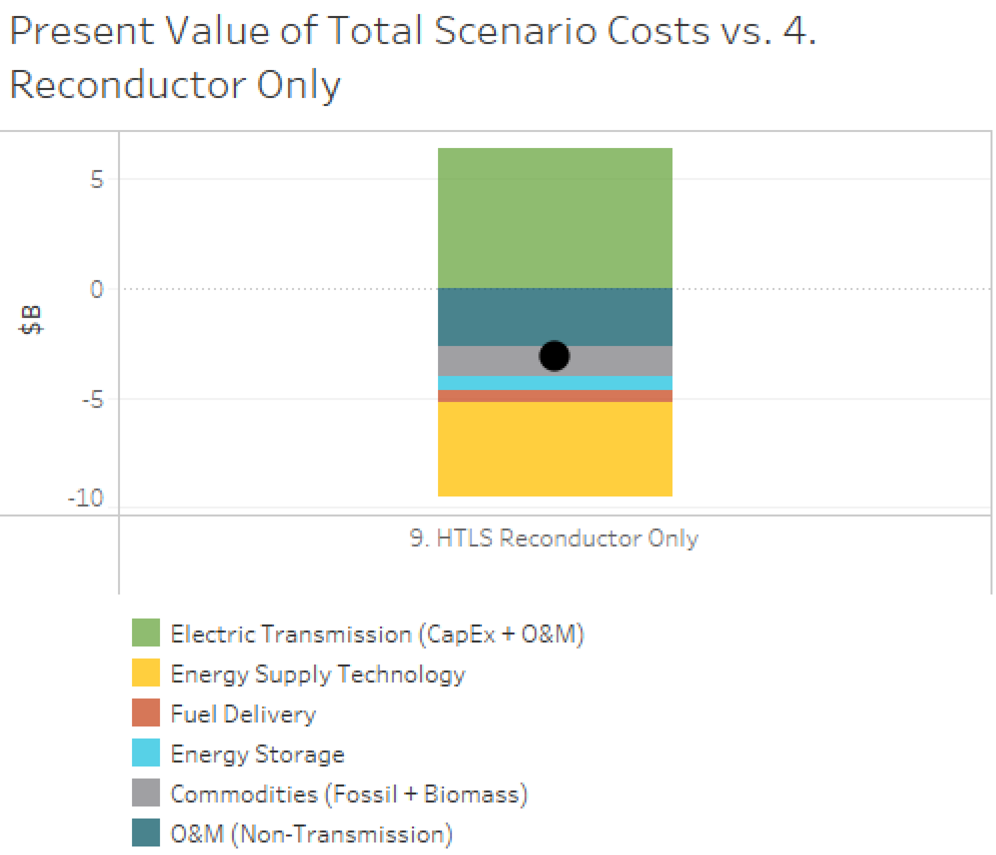
- If reconductoring is the only transmission expansion allowed, using HTLS conductors reduces total costs by $3.1B
- Transmission costs increase with the higher cost conductors, but the increased capacity facilitates greater interconnectivity and resource cost savings
  - Wind costs increase as resources in Montana and Wyoming are built out more extensively
  - Solar and energy storage costs decrease with improved access to wind resources



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Task 2: Transmission

Key Findings And Uncertainties

Task 2: Transmission Key Findings

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- Investment needed in the 2030s to ensure expanded transmission is available in 2040 and 2050
- Transmission is important in the 2040s to reach net zero economically
  - Large build out on key transmission lines facilitates wind exports from MT and WY (MT to WA, WY to CO, WY to CA-S)
  - If transmission costs are lower than forecast, cost effective transmission expansion is accelerated for key interties in the Northwest
- Costs for reconductoring relative to other options vary by line and are favored only on some interties
- Greater transmission expansion supports higher levels of electrolysis in Montana by improving the utilization and thus the economics of wind generation
- The option of HTLS conductors significantly impacts transmission expansion on particular lines
  - Capacity between CA-S to WY doubles, reaching the maximum potential in the model, when HTLS on HVDC lines is permitted
  - Reconductoring with HTLS significantly increases total transmission capacity relative to Sensitivity 4. Reconductoring Only, improving the economics of reaching net-zero goals in a future where building new transmission lines is infeasible

Task 2: Transmission Key Findings Uncertainty – Cost

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- Cost estimates for new transmission include a large amount of uncertainty
  - There has been little recent large-scale or interstate transmission development across the West that can help benchmark transmission costs over complex interregional corridors and difficult terrain and land use
  - 500kV lines that have been constructed recently have faced cost overruns in several cases
  - The TNC PoP dataset estimates cost impacts from multiple factors but detailed study of specific interties and realized costs from new development is needed to improve transmission cost estimates
  - Pipe flow representation of transmission in this model is high level and must be followed by detailed transmission modeling to refine infrastructure needs and cost estimates
- However, this analysis shows that transmission development is relatively insensitive to price over many interties, illustrating the value of interconnectedness in the West in a net-zero economy despite cost uncertainty

Task 2: Transmission Key Findings Uncertainty – Feasibility

EVOLVED ENERGY RESEARCH

- Multiple factors impact the feasibility of transmission expansion. Some of these include:
  - Physical factors, such as line length, terrain, land use, and fire risk
  - Whether the line is contained in a single planning area and/or state or whether it crosses multiple jurisdictions
  - Whether markets exist to make development of the line profitable
  - Whether market structures or policies mitigate risks to transmission developers
- The chicken and egg problem of requiring transmission access to develop new generation and requiring generation to justify investment in transmission is exacerbated when accessing remote resources across different planning jurisdictions, as well as relying on development of large amounts of renewables that themselves face uncertain siting and permitting processes

Task 2: Transmission Key Findings Uncertainty – Feasibility

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- By expanding transmission, more can go wrong along the path of reducing emissions before goals to reach net-zero by 2050 are threatened
  - Expands options available for clean energy
- Limiting transmission puts greater stress on siting and permitting local resources
  - One of the biggest challenges to achieving net-zero
  - Access to imports from other states, or exporting power in renewable rich regions allows renewables to be located where they are most desirable/feasible
- By comparing scenarios that vary the level of transmission development feasibility, this analysis demonstrates that more extensive transmission development lowers total decarbonization costs and increases optionality for meeting future net-zero goals—suggesting that policymakers should seek to address feasibility issues where possible

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Task 3: Gas in Buildings

Task 3: Gas in Buildings

EVOLVED ENERGY RESEARCH

- Key research questions:
  - What's the cost and feasibility of a high gas scenario in 2050 relative to the Core Case?
  - How much zero-carbon gas is required to meet demand if gas use in buildings continues at levels similar to today? What does the supply curve look like for that quantity of gas?
  - How does producing greater quantities of zero-carbon gas impact other infrastructure requirements? What are the implications of those infrastructure requirements in 2050, given expected infrastructure siting constraints?
  - Is a hybrid approach a viable option in some regions of the Northwest? What are the potential risks and benefits to hybrid heat?

Scenario	Description	Expected Results Relative to Core Case
1	Continued gas use in buildings where allowed by current policy. Electrification of new buildings in Washington but continued gas use in existing buildings not affected by existing policy.	The Northwest has the highest share of electric heating in the country. However, gas remains about 50% of energy use for heating. A continued gas use scenario will explore the consequences of facing large demands for gas while requiring net-zero emissions. We expect costs to be higher than the Core Case, but results related to feasibility are potentially more impactful—we will focus on the zero-carbon gas supply curve and the investment and land required to meet demand for zero-carbon gas, i.e., where would clean gas come from, what are the feasibility challenges of meeting clean gas demand, and how much would it cost relative to electrification?

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Task 3: Gas in Buildings

Demand-Side Results

Task 3: Gas in Buildings Demand Side Assumptions

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- The Gas in Buildings scenario represents the high end of the scale of continued gas use in residential and commercial buildings, creating a bookend scenario relative to the Core Case, which reflects an eventual transition to 100% electric appliance sales
  - Core Case – Rapid electrification of residential and commercial gas appliances, reaching 100% electric sales shares by 2035 in space heating, water heating, and cooking
  - Gas in Buildings – Today's share of gas appliances remains the same in the future. Gas appliances are replaced with high-efficiency options, reaching 100% sales by 2035. Appliance sales in buildings that already have electric appliances transition to higher-efficiency options at the same rate as in the Core Case.
- Demand side assumptions in other sectors are held constant across scenarios

Task 3: Gas in Buildings
Demand Side Evolution Final Energy

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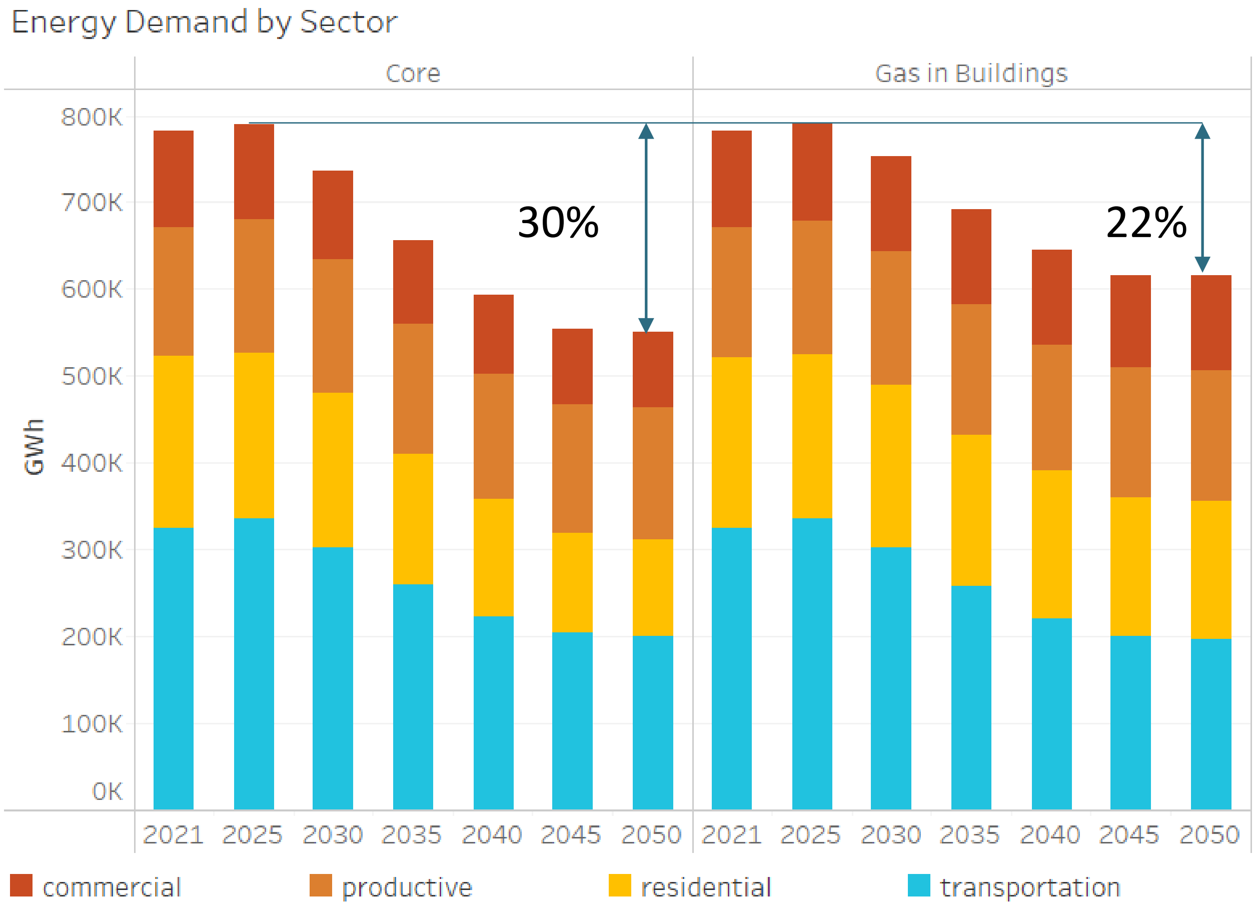
- The Core scenario has 30% less final energy demand in 2050 than in 2025
  - 100% sales of electrified appliances by 2035 in residential and commercial buildings
- Gas in Buildings preserves the 2021 share of gas appliances in residential and commercial buildings
  - Energy consumption in the transportation and industrial sectors remain the same as in the Core Case
  - Total energy use in the commercial and residential sectors is higher than in the Core Case, because gas appliances are less efficient than electric heat pumps



Task 3: Gas in Buildings
Demand Side Evolution Final Energy

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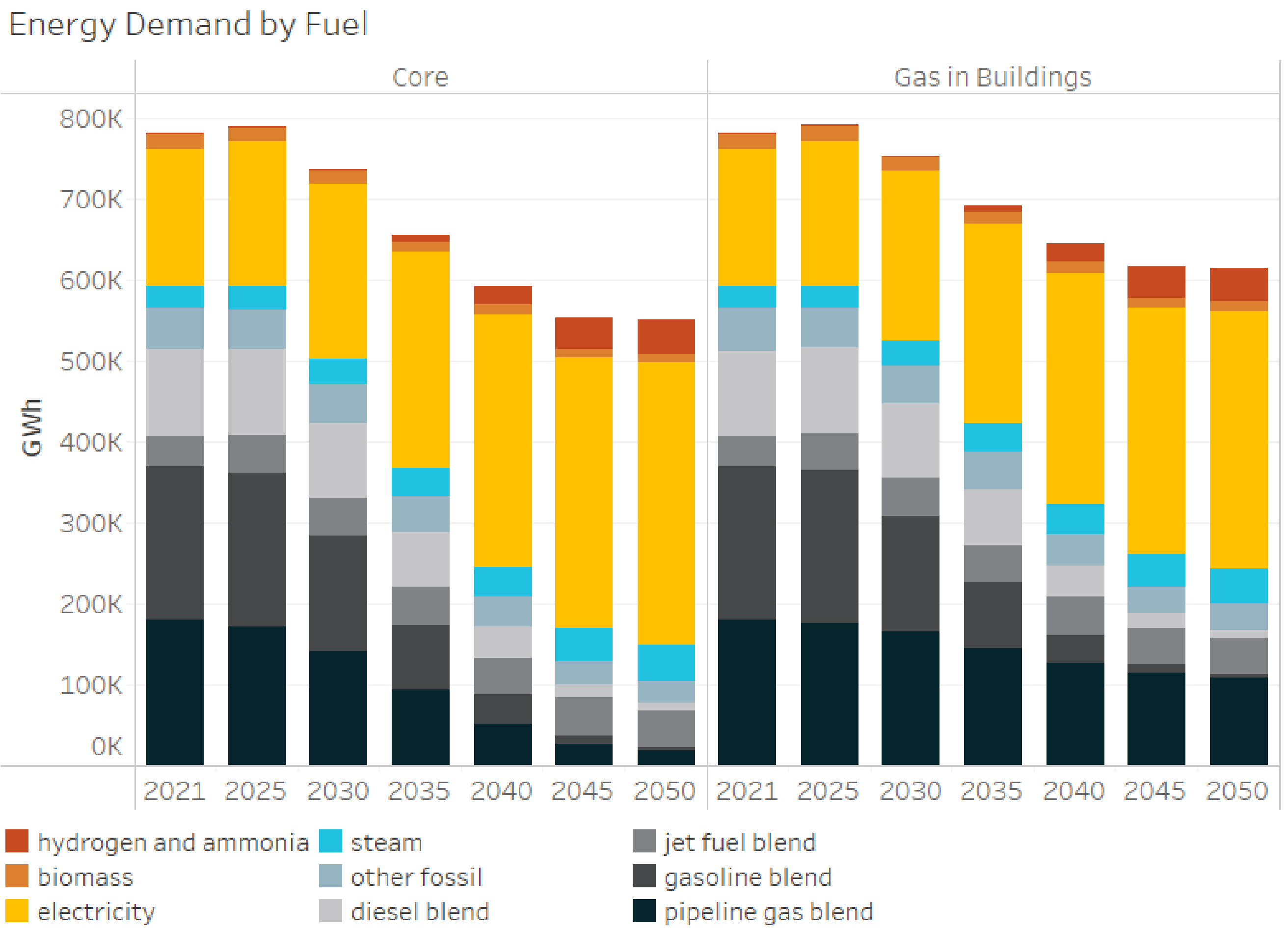
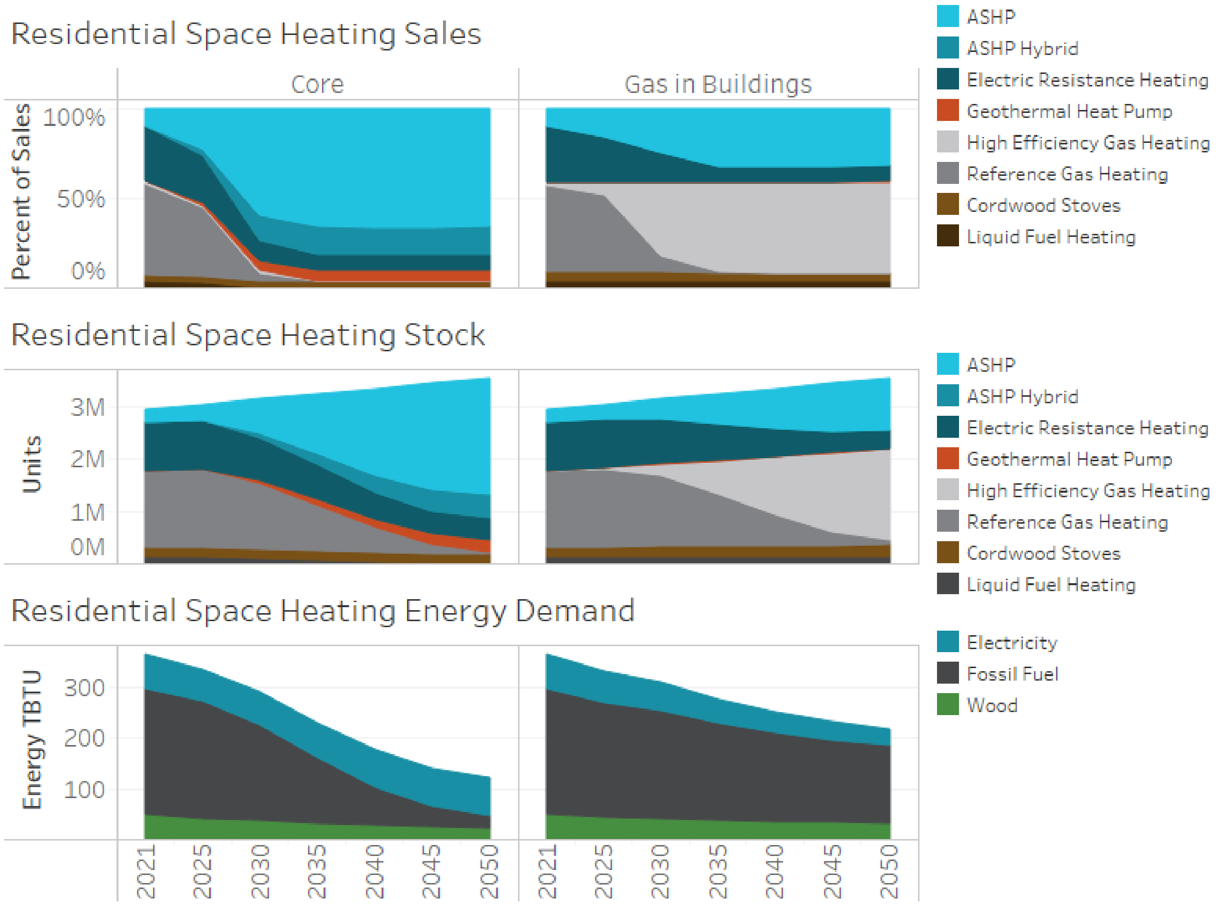
- Gas in Buildings shows reduced electricity growth and increased pipeline gas usage relative to the Core Case
  - Pipeline gas demand still declines relative to 2021, due to reductions industrial gas demand and greater efficiency of appliances in buildings
- Electricity demand in end uses grows from 2021 to 2050 by:
  - 105% increase in Core
  - 85% increase in Gas in Buildings
- Pipeline gas demand declines from 2021 to 2050 by:
  - 90% in Core
  - 39% in Gas in Buildings



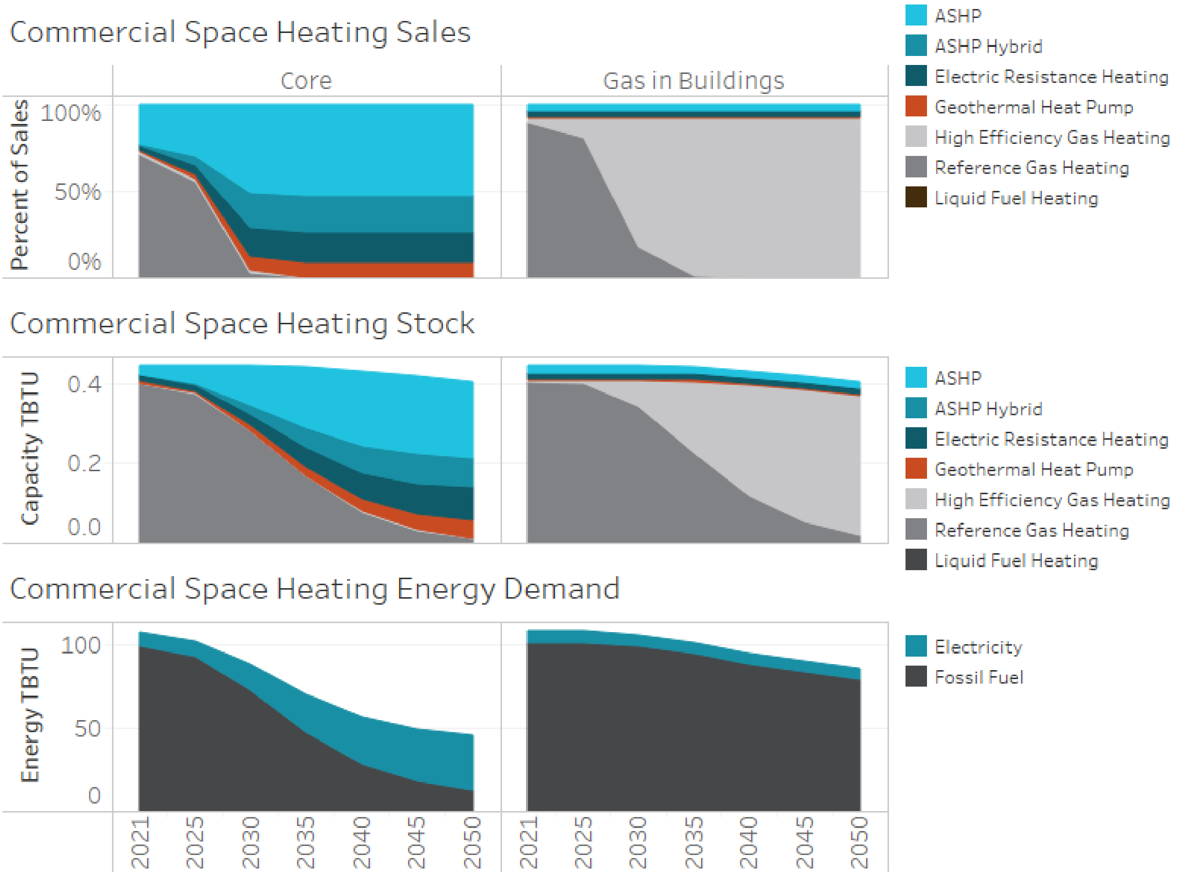
Task 3: Gas in Buildings
Residential Space Heating Sales, Stock, Energy

- Residential space heating sales reach 100% electric by 2035 in the Northwest in the Core Case
  - Majority of sales are air source heat pumps
  - Fraction of sales are hybrid air source heat pumps in cold temperature climate zones, using gas only on the coldest days of the year
  - Hybrid heat pumps are included to reflect the range of choices that consumers may make when selecting appliances
  - Hybrid technologies reduce electric peak loading on the electricity system during the coldest days
- Gas in Buildings preserves 2021 share of gas appliances through 2050
  - Reaches 100% high efficiency gas heating appliance sales by 2035
- Residential space heating energy demand is 80% higher in Gas in Buildings than in the Core Case by 2050



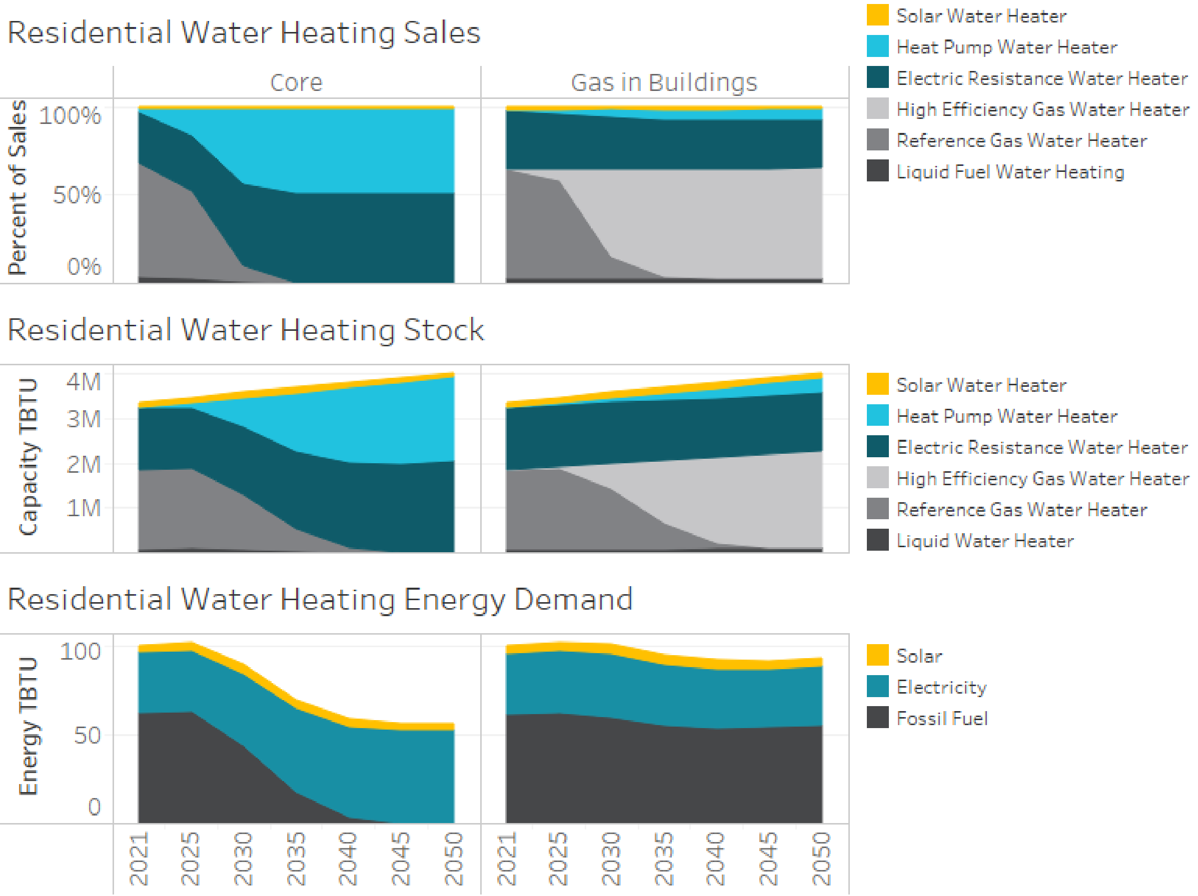
Task 3: Gas in Buildings
Commercial Space Heating Sales, Stock, Energy

- Commercial space heating sales reach 100% electric by 2035 in the Northwest in the Core Case
  - Majority air source heat pumps
  - As in the residential sector, some sales are assumed to be hybrid air source heat pumps
- Gas in Buildings preserves existing share of gas appliances
  - Reaches 100% high efficiency gas heating appliance sales by 2035
  - Exception is in Washington state where all new commercial buildings are assumed to use heat pump space heating
- Commercial space heating energy demand is 89% higher in Gas in Buildings than in the Core Case by 2050



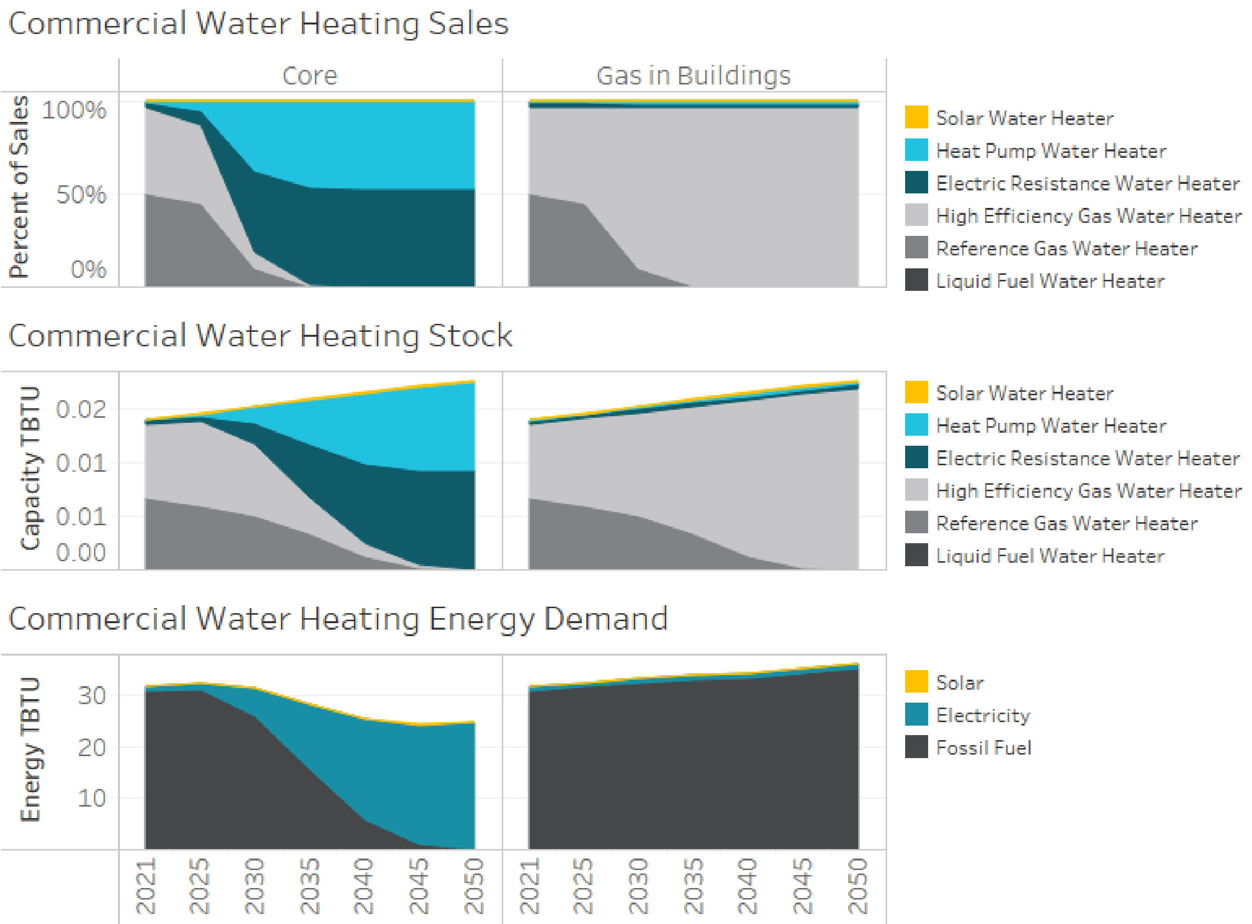
Task 3: Gas in Buildings
Residential Water Heating Sales, Stock, Energy

- Residential water heating sales reach 100% electric by 2035 in the Northwest in the Core Case
  - 50/50 split between heat pump and resistance water heating, reflecting space constraints to heat pump adoption
- Gas in Buildings preserves existing share of gas appliances through 2050
  - Reaches 100% high efficiency gas water heating appliance sales by 2035
- Residential water heating energy demand is 66% higher in Gas in Buildings than in the Core Case by 2050



Task 3: Gas in Buildings
Commercial Water Heating Sales, Stock, Energy

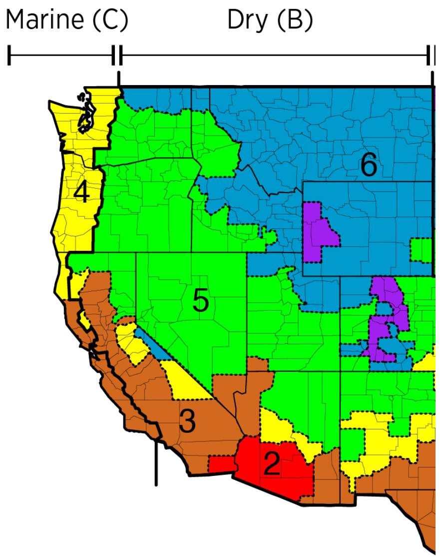
- Commercial water heating sales reach 100% electric by 2035 in the Northwest in the Core Case
  - 50/50 split between heat pump and resistance water heating
- Gas in Buildings preserves existing share of gas appliances
  - Reaches 100% high efficiency gas water heating appliance sales by 2035
- Commercial water heating energy demand is 44% higher in Gas in Buildings than in the Core Case by 2050



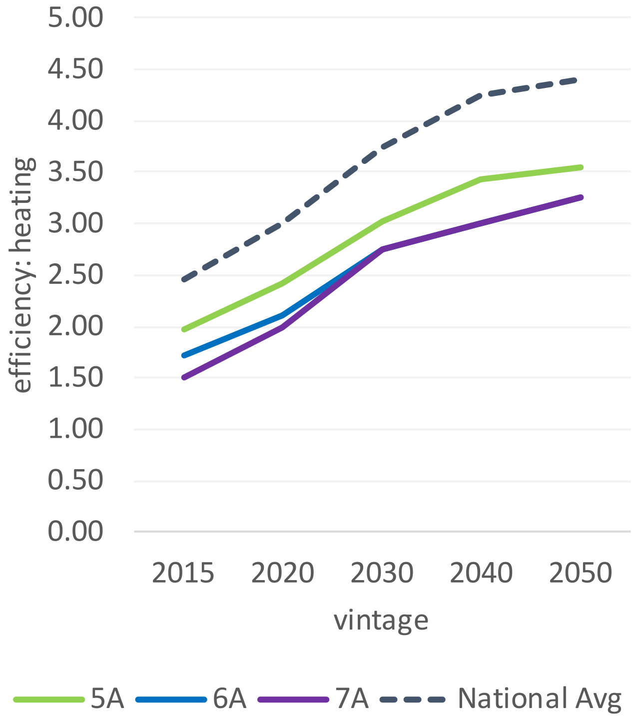
Task 3: Gas in Buildings
Heat Pump Performance

- The transition from natural gas to heat pump appliances will gradually increase electricity demand during the winter in the Northwest, causing a shift from a summer-peaking electric system towards a dual summer-and-winter peaking system
- The overall magnitude of winter peak impacts will depend on cold climate heat pump performance
  - Heat pumps perform at lower efficiencies in colder temperatures, but as technology advances, cold climate performance is expected to improve
- Space heating is the primary driver of heat pumps' grid impacts (relative to water heating, which uses less energy)

IECC Climate Zones

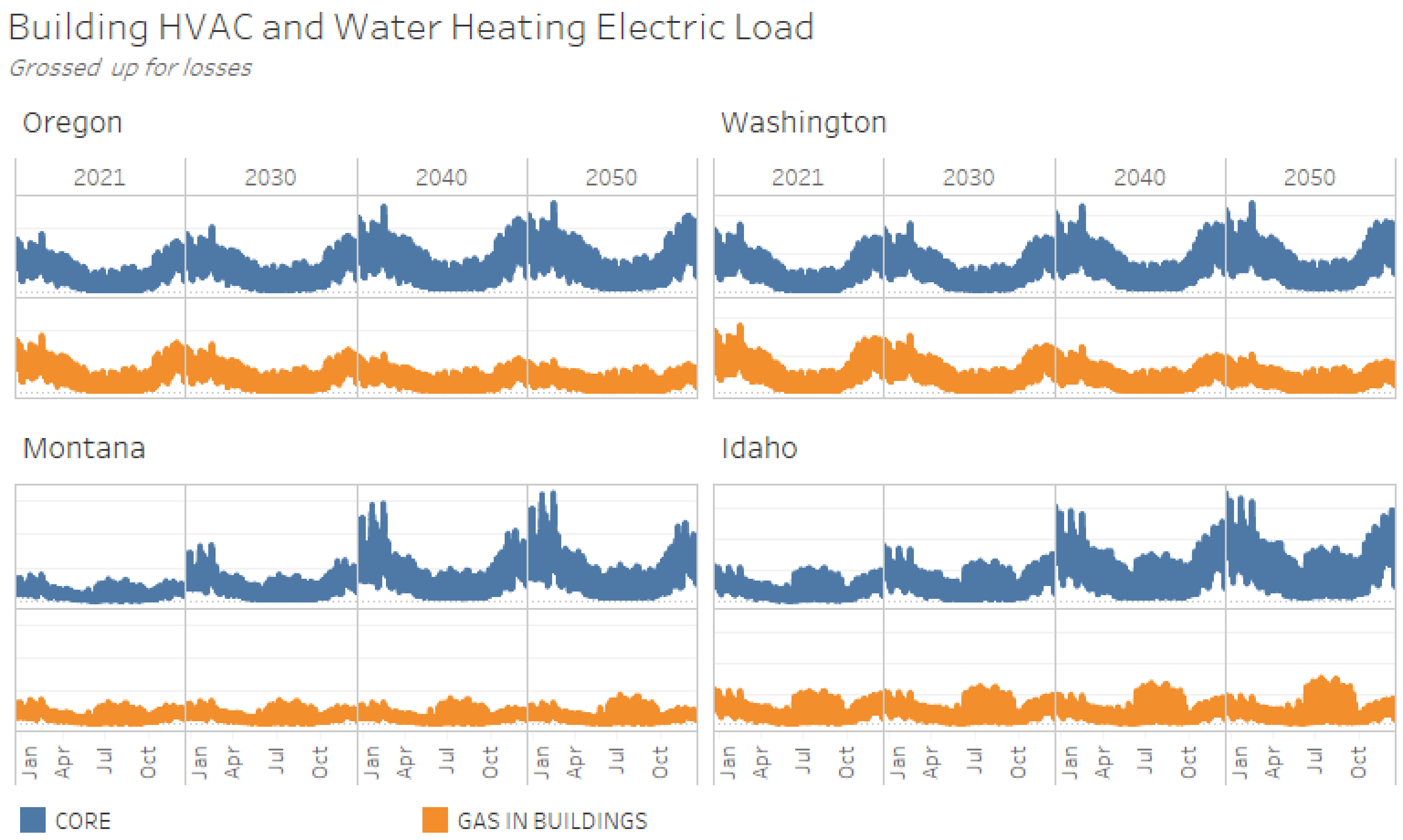


Residential ASHP



Task 3: Gas in Buildings
Building Load Profile Impacts

- In the Core Case, building HVAC and WH loads increase through 2050 in all Northwest states, and seasonal variation in load becomes more dramatic, with winter demand growing relative to summer demand
- In Gas in Buildings, electricity demand for HVAC and WH decreases and flattens in Oregon and Washington through 2050, driven by conversion from electric resistance heat to electric heat pumps
  - In Montana and Idaho, demand grows slightly, and profile remains the same through 2050



Task 3: Gas in Buildings System Peak Impacts

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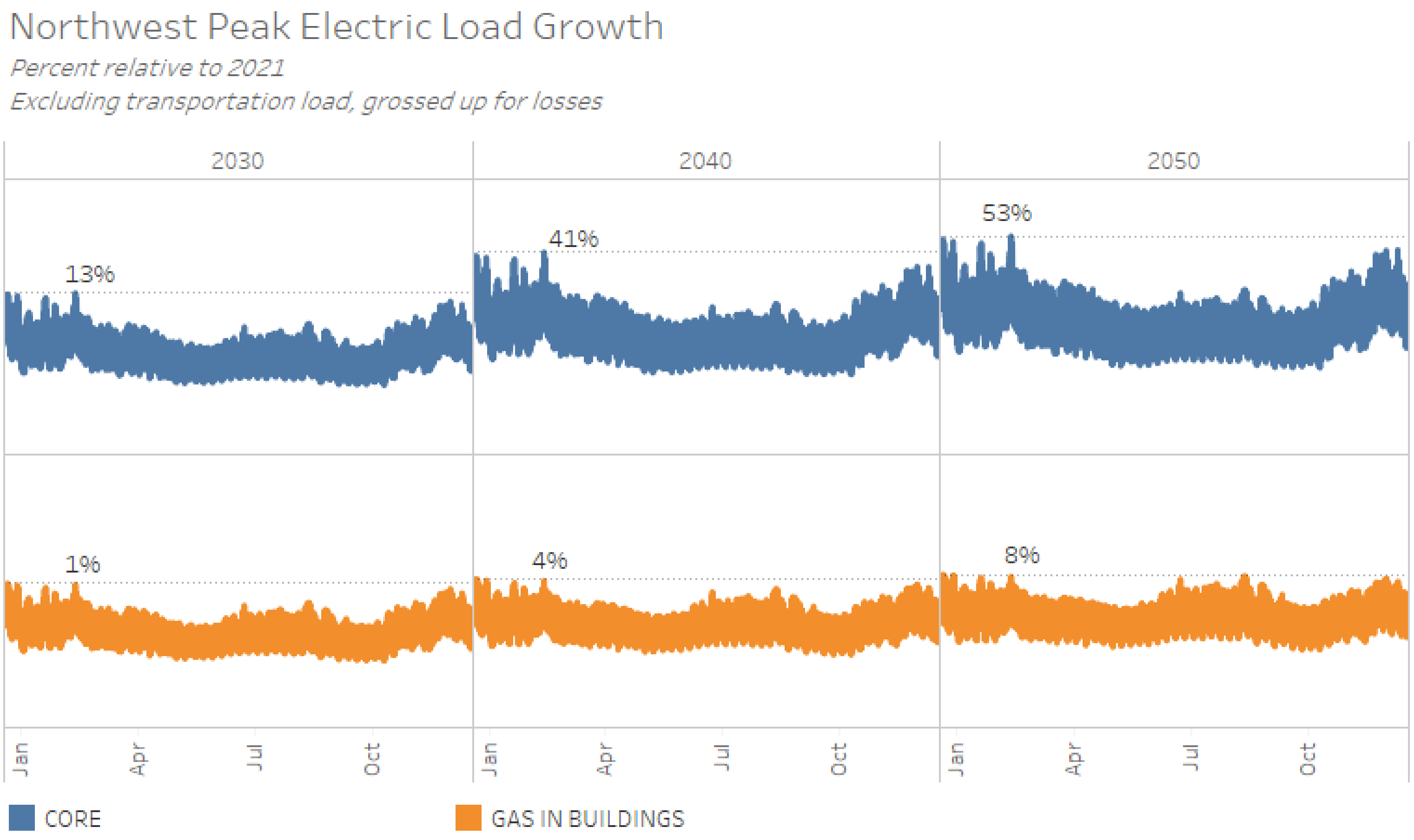
- Northwest peak load grows by over 50% in 2050 relative to 2021 in the Core Case (excluding transportation load)
- In Gas in Buildings, peak growth is only 8% from 2021 to 2050
- The Core Case profile shows much more seasonal variation than Gas in Buildings, driven by heat pump demand in the winter
- Though the Gas in Buildings profile has a higher utilization factor when transportation loads are excluded, the Core profile has greater complementarity with widespread vehicle electrification: flexible electric vehicle loads can increase utilization on the distribution system without impacting peak capacity requirements



Task 3: Gas in Buildings
Hybrid Heat Pumps

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- Hybrid heat pumps operate with electricity most of the time, but switch to a fuel-combustion backup system when temperatures drop below a defined setpoint
  - There are different options for backup fuels; we assume hybrid systems use pipeline gas in this analysis
- Because hybrid systems don't use electricity during the coldest hours of the year, they reduce electricity system and distribution peaks in the winter
- Hybrid heat pumps are most beneficial in colder climates: In the Northwest, Montana, Idaho, and northeast Washington are the regions most suited to hybrid space heating

Task 3: Gas in Buildings
Fuel Delivery Economics In Hybrid Systems

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- The primary challenge to continued natural gas use in buildings is related to the cost of delivery as pipeline gas throughput declines
  - Even in the Gas in Buildings case, which is designed to be a high-end estimate of future Northwest demand for pipeline gas, gas throughput declines ~40% in 2050 relative to 2021
  - Most gas pipeline and distribution costs are fixed, as opposed to variable, meaning that the cost of operating the gas system does not decline linearly as throughput declines
  - When gas throughput falls more quickly than the total cost of operating the system, the price per unit of delivered fuel increases—encouraging more consumers to switch from gas to electric appliances, and worsening the problem of declining throughput
- This relationship between cost and throughput also applies to hybrid heating systems
  - If most appliances are electrified, but hybrid heat pumps become the preferred hybrid space heating technology, the gas transmission and distribution network must be maintained in order to supply gas to a large number of buildings in a small number of hours every year—creating the risk that the delivered cost of that fuel could be extremely high

Task 3: Gas in Buildings
Evaluating Hybrid Systems

- Hybrid space heating is an economic alternative to electrification if the cost savings from avoided electric system and distribution peak impacts are larger than the cost of continuing to operate gas transmission and distribution assets that could otherwise be retired
- Performing this cost-benefit analysis requires access to geographically granular data typically owned by electric and gas utilities:
  - Electric distribution data at the feeder-level: available capacity, hourly load profile, capacity upgrade cost
  - Long-term gas system investment requirements by asset, and the potential to avoid specific investments by decommissioning assets
- Hybrid heat pumps are most valuable in very cold climates where gas assets require minimal future investment and electric distribution systems are highly constrained during the winter peak
- Identifying specific communities or regions in the Northwest that meet those criteria is an important area for future study

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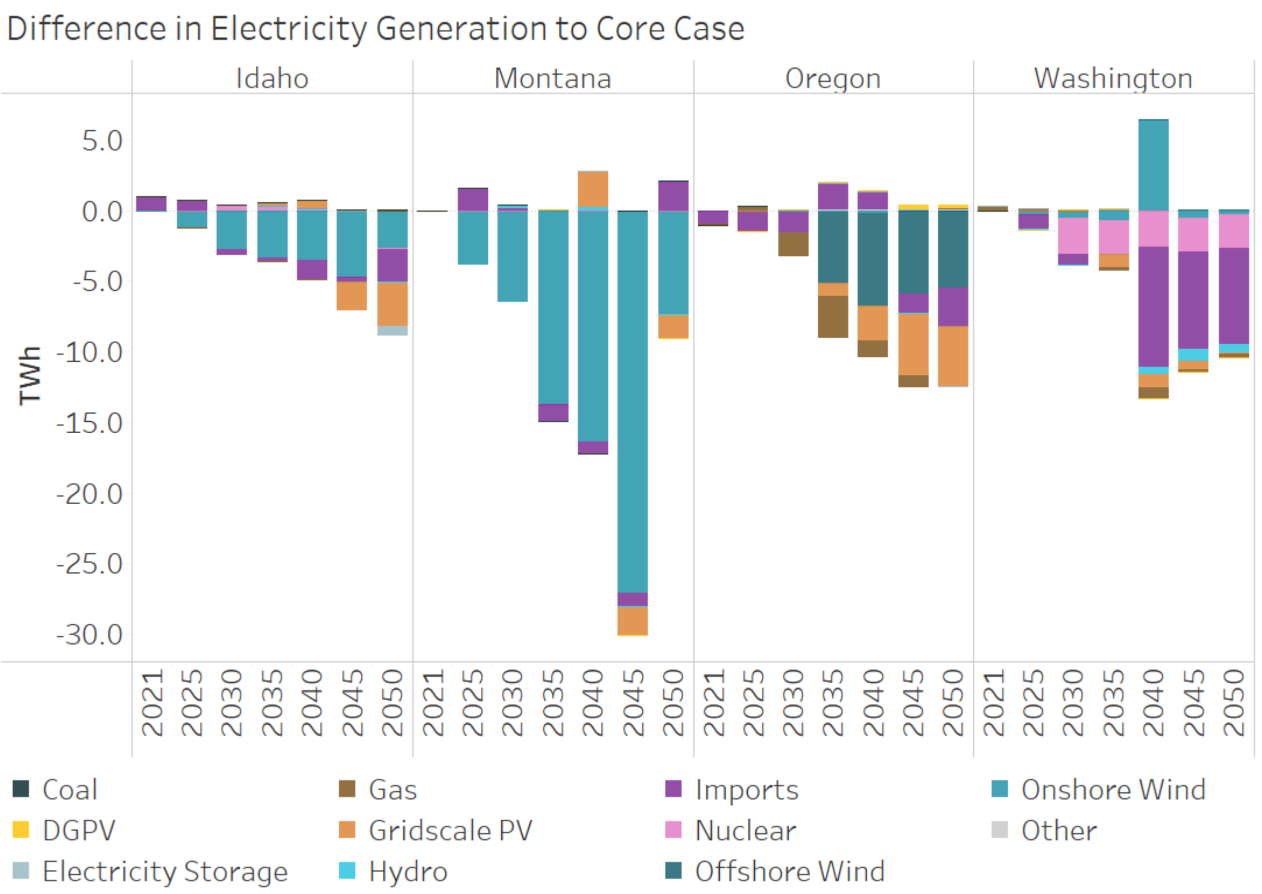
Task 3: Gas in Buildings

Supply-Side Results

Task 3: Gas in Buildings
Electricity Generation-Core vs. Gas In Buildings

- Electricity generation in the Northwest is reduced in all states in the Gas in Buildings scenario relative to the Core Case
- Energy from biomass to produce clean gas replaces the energy supplied by electricity in the Core Case for building heat



Task 3: Gas in Buildings
Electricity Capacity In The Northwest

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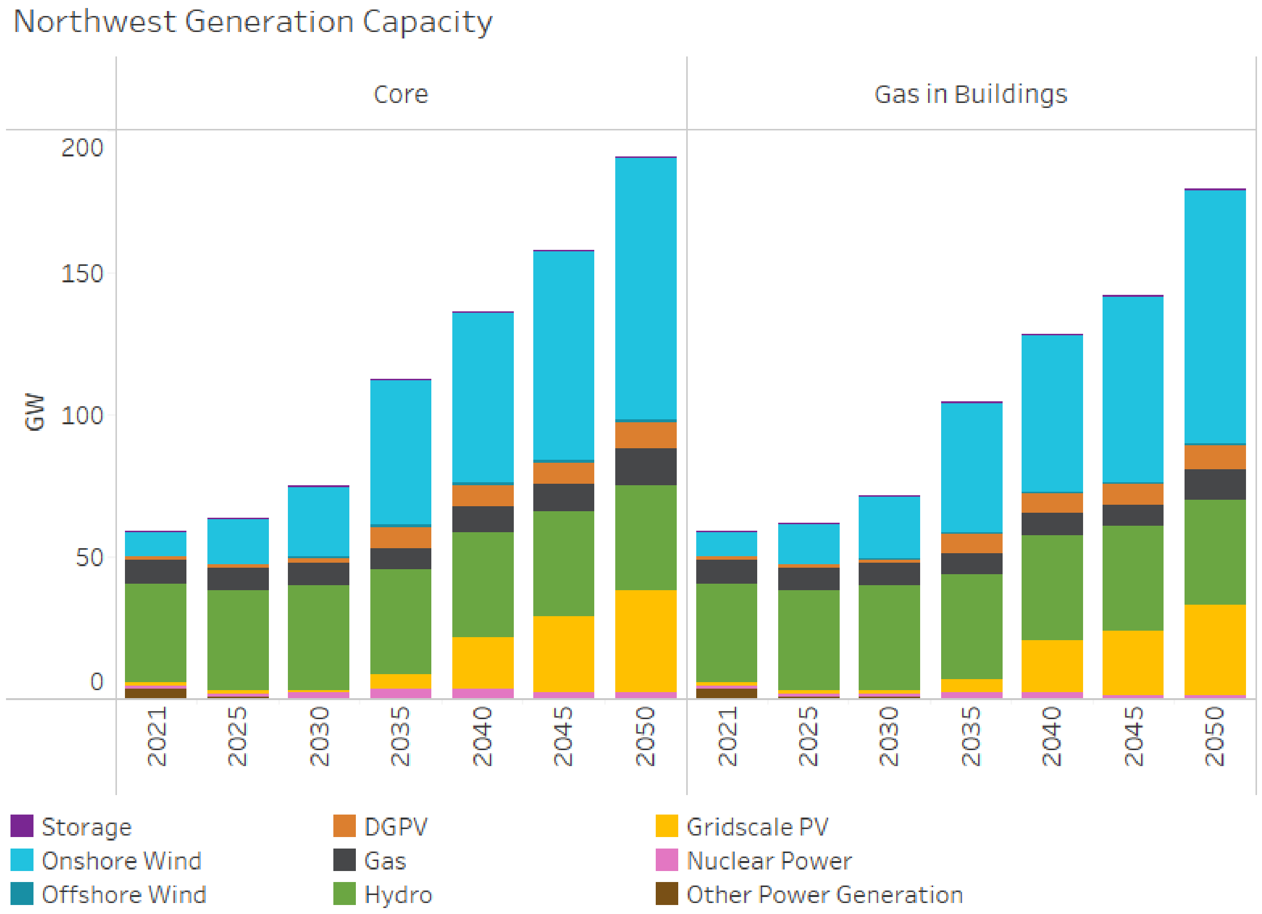
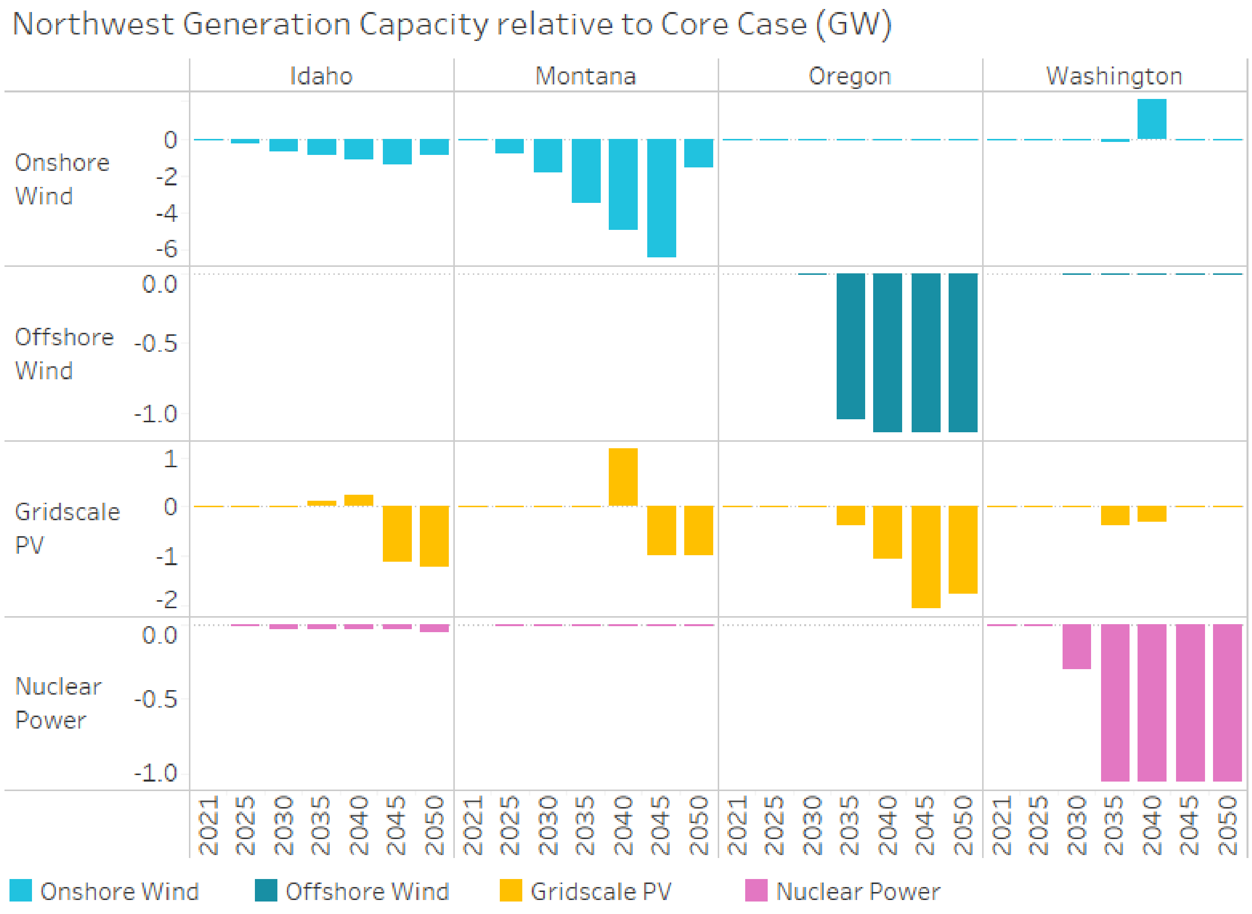
- Because Gas in Buildings uses less electricity overall than the Core Case, electric capacity needs are lower
- The impact on capacity investments by 2030 in Gas in Buildings includes:
  - 11% reduction in wind capacity
  - 19% reduction in nuclear
- The impact on capacity investments by 2050 includes:
  - 3% reduction in wind capacity
  - 11% reduction in solar capacity
  - 61% reduction in nuclear



Task 3: Gas in Buildings
Electricity Capacity By State Core vs. Gas in Buildings

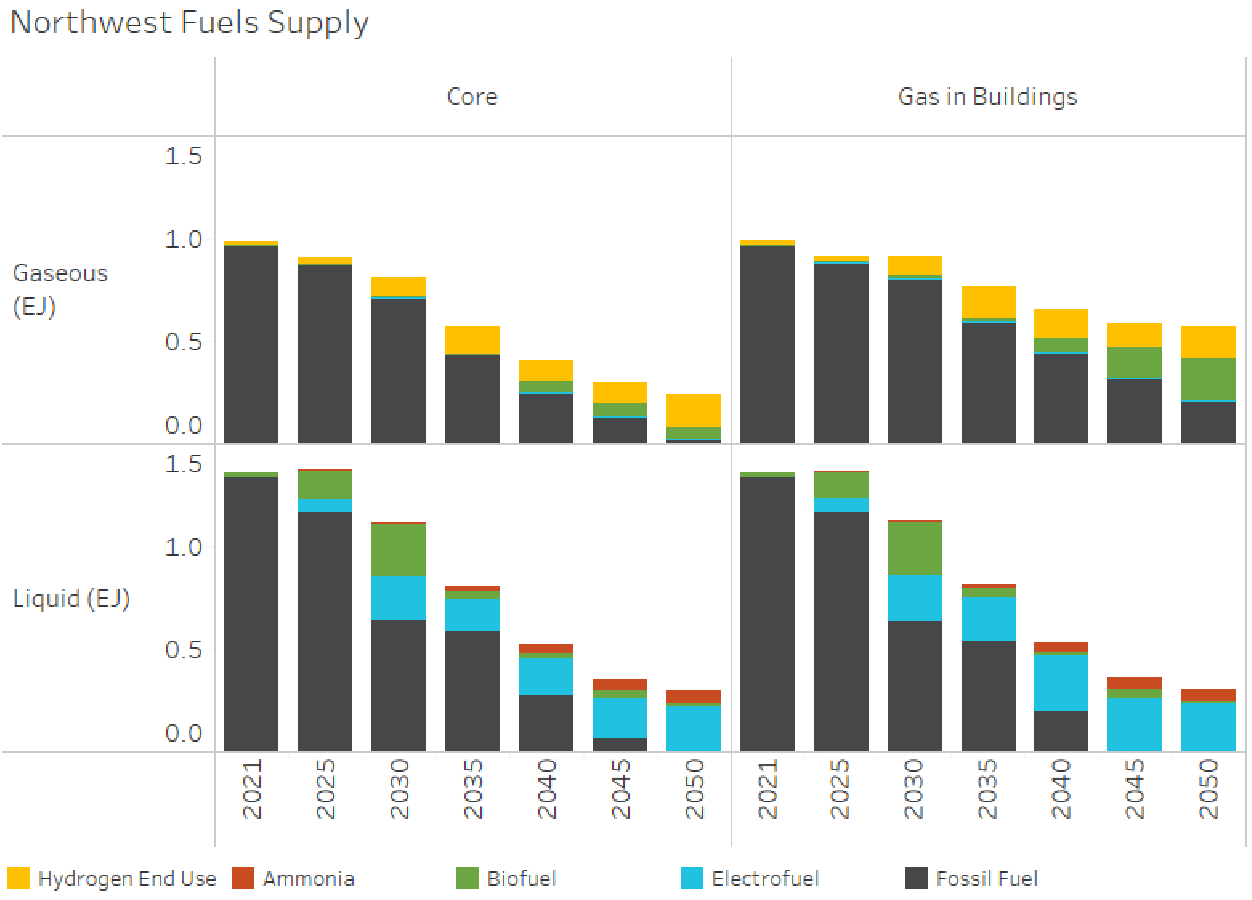
EVOLVED ENERGY RESEARCH

- Electric capacity reductions in Gas in Building relative to the Core Case vary by state, primarily driven by the available resources in each region
- Onshore wind capacity declines in Idaho and Montana, offshore wind installation declines in Oregon, and nuclear capacity build declines in Washington
- Reductions in solar capacity are spread across all Northwest states, but concentrated in Oregon



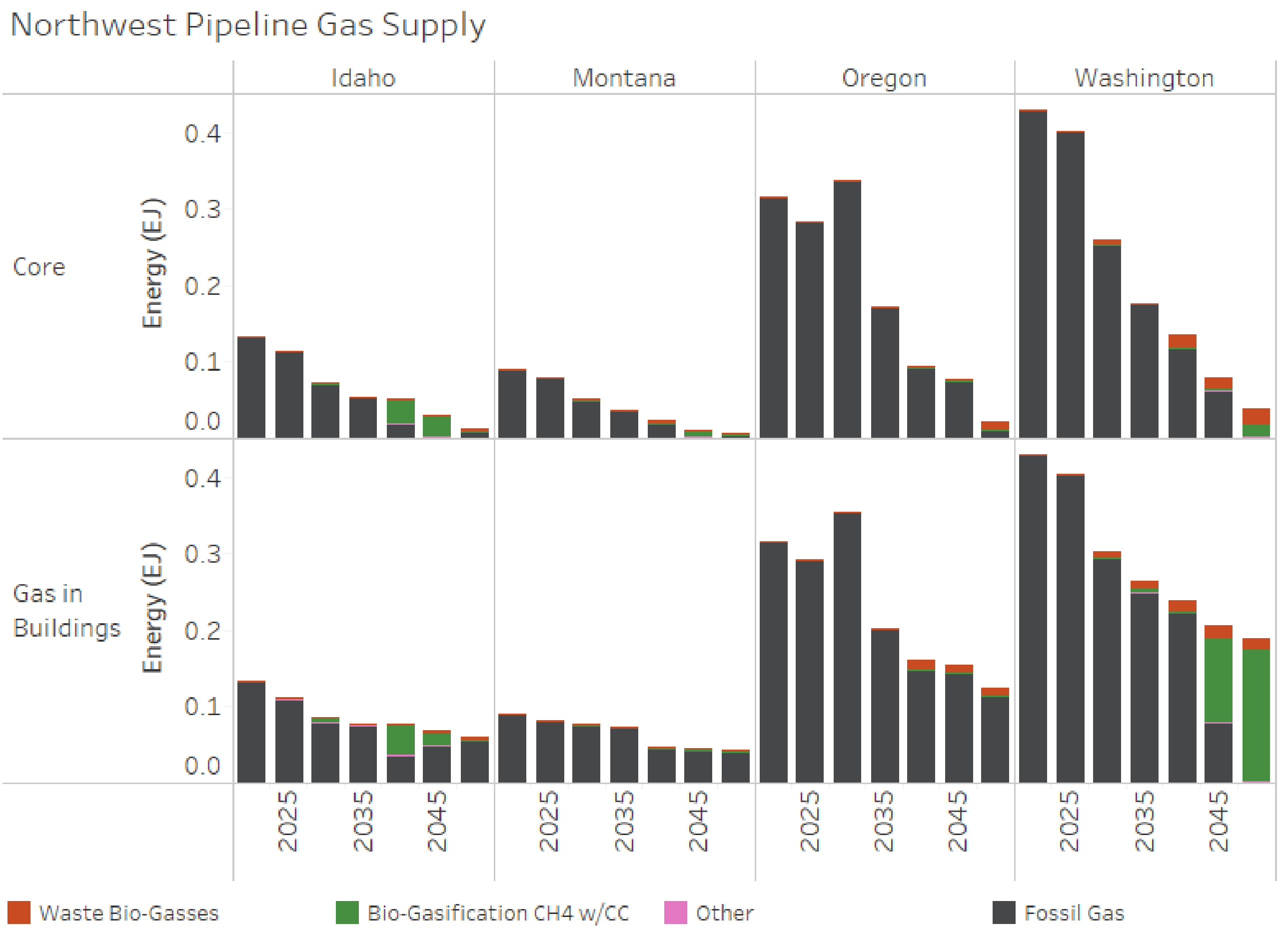
Task 3: Gas in Buildings
Northwest Fuels Supply

- Gas in Buildings is subject to the same emissions constraints as the Core Case, meaning that increased gas demand must either be met with decarbonized fuels or offset by emissions reductions elsewhere in the economy
- In Gas in Buildings, increased gas demand impacts fuel supply:
  - Increased usage of fossil gas through 2050
  - Increased usage of fossil gas and biogas from 2040 to 2050
- Increased fossil gas usage is offset by earlier use of clean fuels in liquids
  - Electrofuels are produced in greater volumes from 2030 through 2045
- Fossil gas use is further offset by increased carbon sequestration in Gas in Buildings



Task 3: Gas in Buildings
Northwest Pipeline Gas Supply

- Pipeline gas supply remains largely fossil across the Northwest
    - Lower cost to continue to use fossil gas and offset emissions with carbon sequestration than to replace it with clean alternatives
- Washington's rule to limit gross emissions to 5% drives 100% clean pipeline gas by 2050 in both Core and Gas in Buildings
- Waste bio-gas from anaerobic digestion is the lowest cost clean gas option, though its quantity is limited
- Remaining clean gas supply is met with bio-gasification methane (CH_4) with carbon capture



Task 3: Gas in Buildings
Decarbonized Gas Supply

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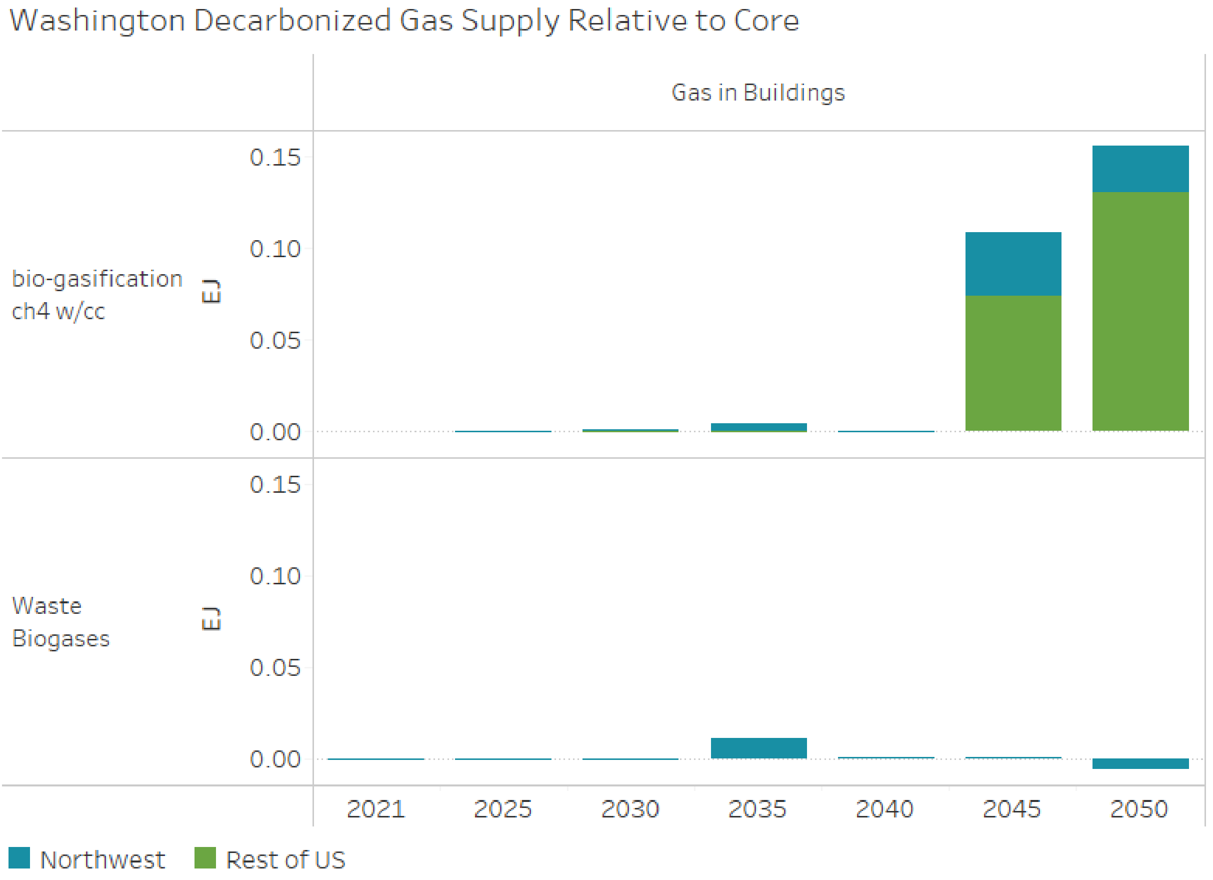
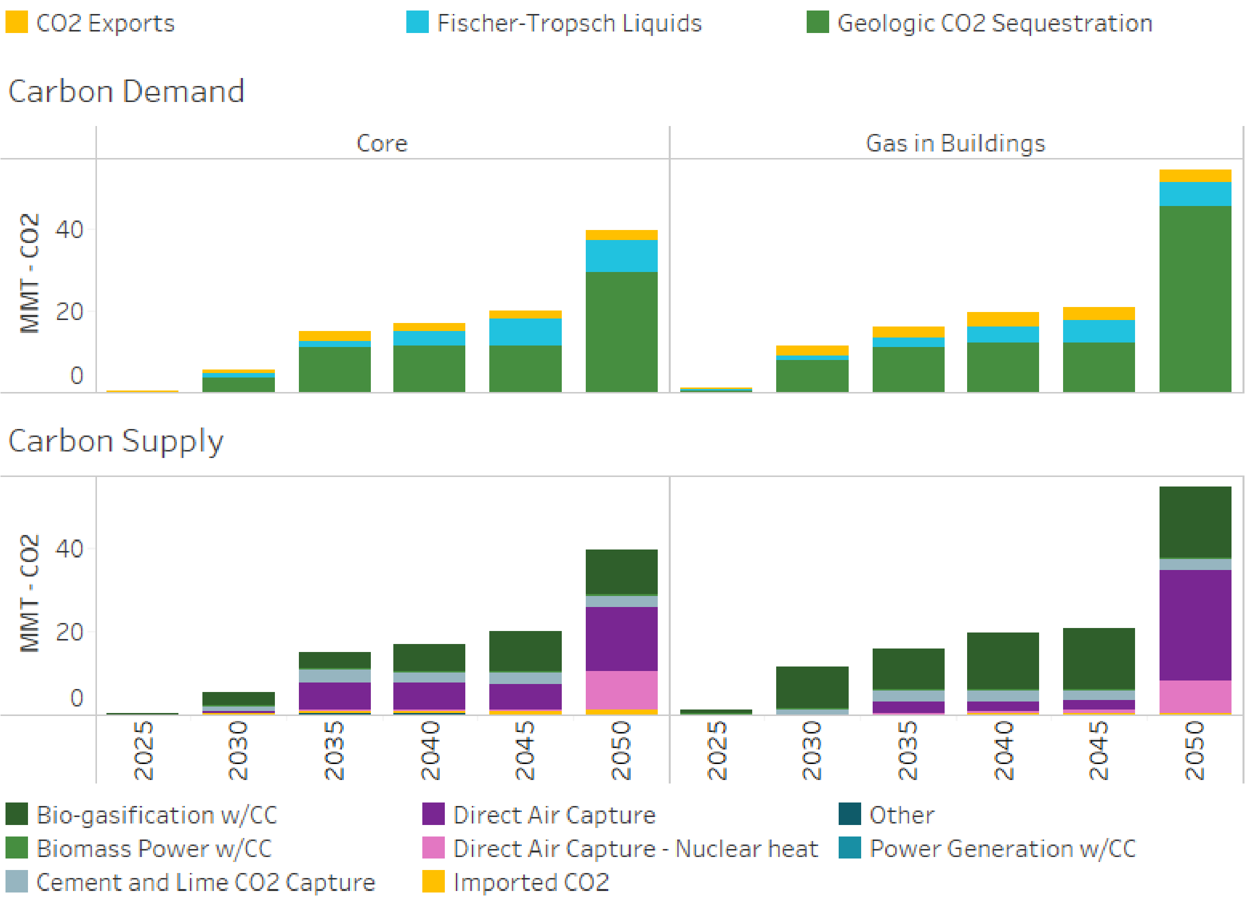
- To meet Washington's higher demand for decarbonized gas, Gas in Buildings requires a substantial increase in bio-gasification methane production in states outside of the Western US
    - The target of 5 MMT gross emissions in Washington restricts the use of carbon capture to offset fossil gas use, requiring higher decarbonized gas volumes than other states with no such target
- Waste biogas quantities are similar between the two scenarios and are sourced within the Northwest
- Limited decarbonized gas supply in the Northwest increases Washington's reliance on zero-carbon gas imports, creating implementation risk



Task 3: Gas in Buildings
Northwest Carbon Demand And Supply

- Geologic sequestration of CO_2 increases significantly by 2050 in Gas in Buildings relative to Core; more sequestration is required to offset emissions from increased fossil gas use
  - Fischer-Tropsch liquids production decreases in the Northwest in Gas in Buildings, but more is imported from other regions to decarbonize liquid fuels
- Because the Gas in Buildings case requires more geologic sequestration in early years, it drives more investment in bio-gasification with carbon capture instead of DAC—because industrial-scale direct air capture (DAC) is a less mature technology
  - This shift towards bio-gasification delays the Northwest's investment in DAC relative to the Core Case—the 2050 quantity of DAC is larger in Gas in Buildings, but the investment ramps up more slowly



Task 3: Gas in Buildings Northwest Emissions

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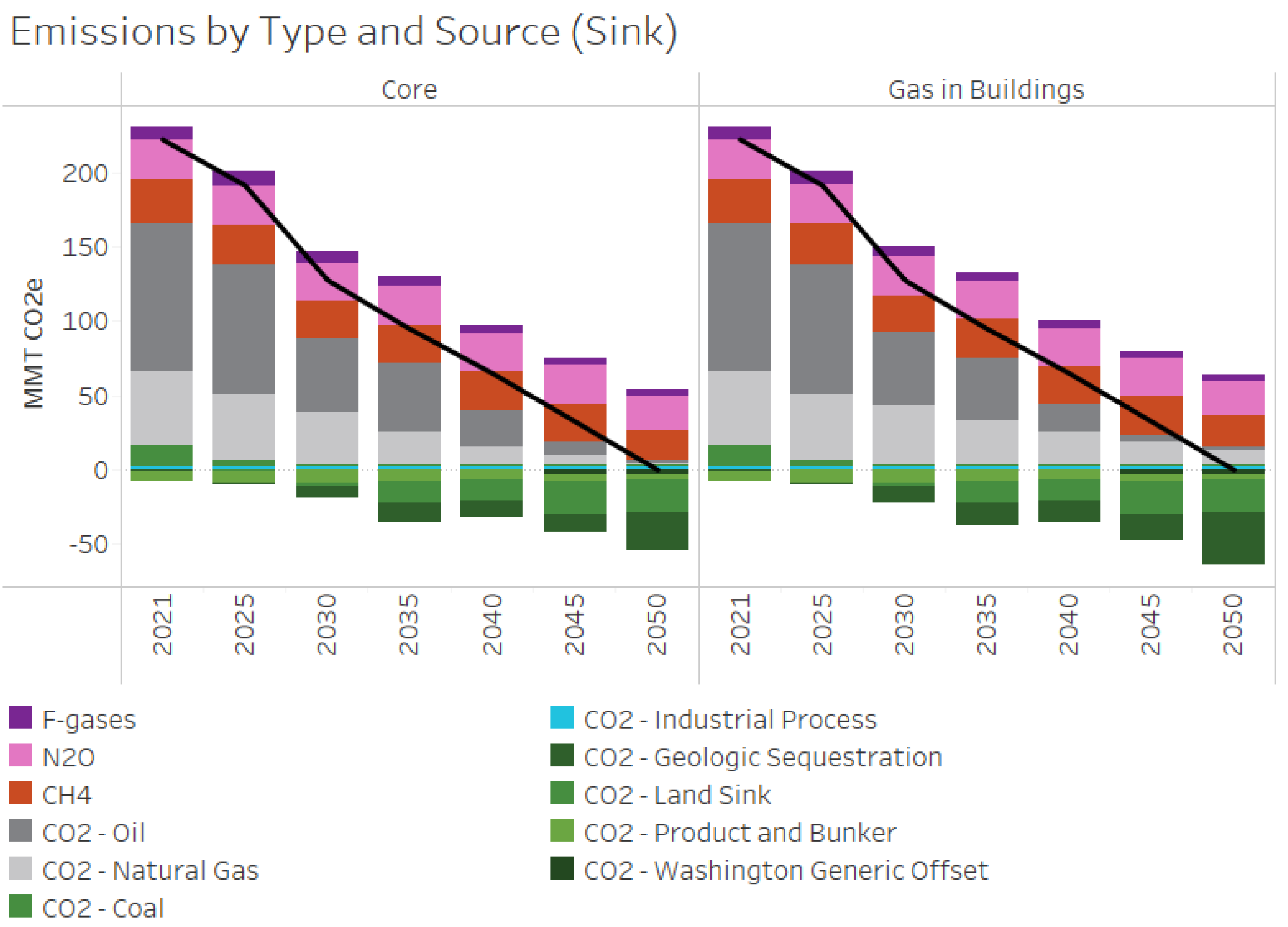
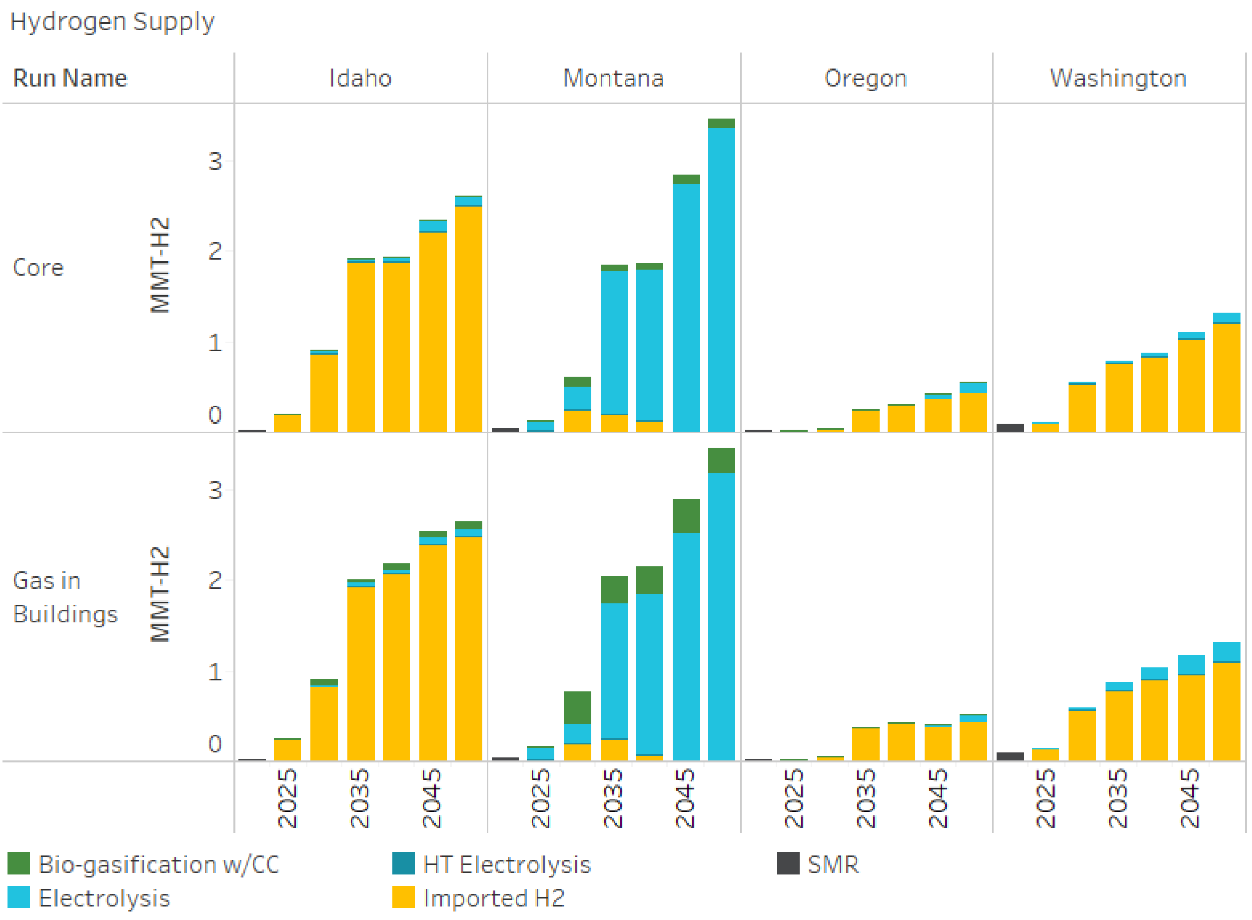
- Gas in Buildings retains more emissions from fossil natural gas that are offset by increased amounts of geologic carbon sequestration



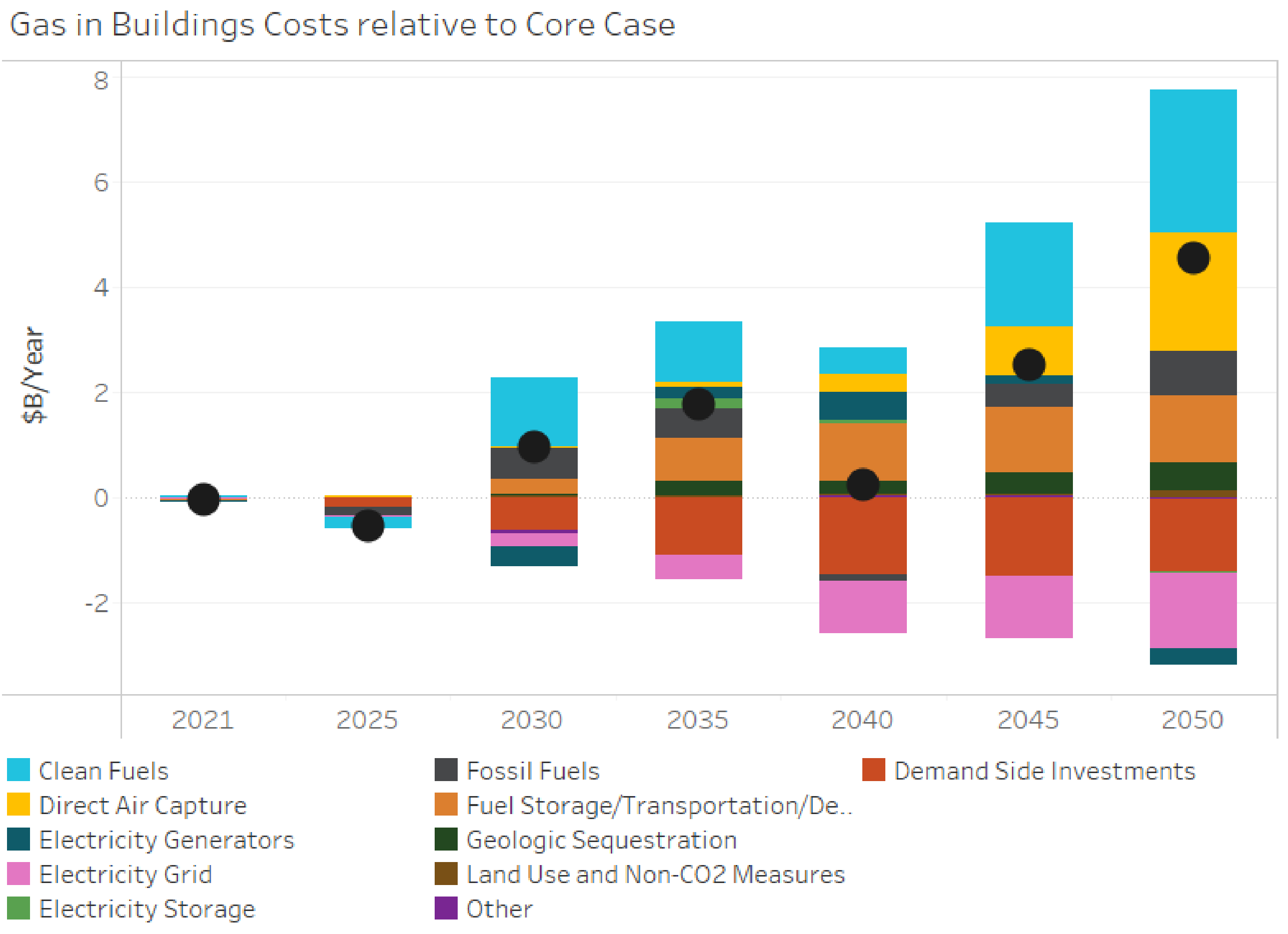
Task 3: Gas in Buildings
Northwest Hydrogen Supply

- Gas in Buildings has minimal impact on hydrogen supply relative to Core
- Montana produces more hydrogen from bio-gasification w/carbon capture in Gas in Buildings versus Core from 2030-2050
  - Higher investment in bio-gasification with carbon capture is driven by the earlier need for carbon sequestration in Gas in Buildings
  - Bio-gasification capacity is installed for carbon supply purposes but also produces hydrogen, reducing the need for electrolysis
- While hydrogen production in the Northwest remains similar, more clean fuels are imported from elsewhere to meet higher clean fuel demand in Gas in Buildings



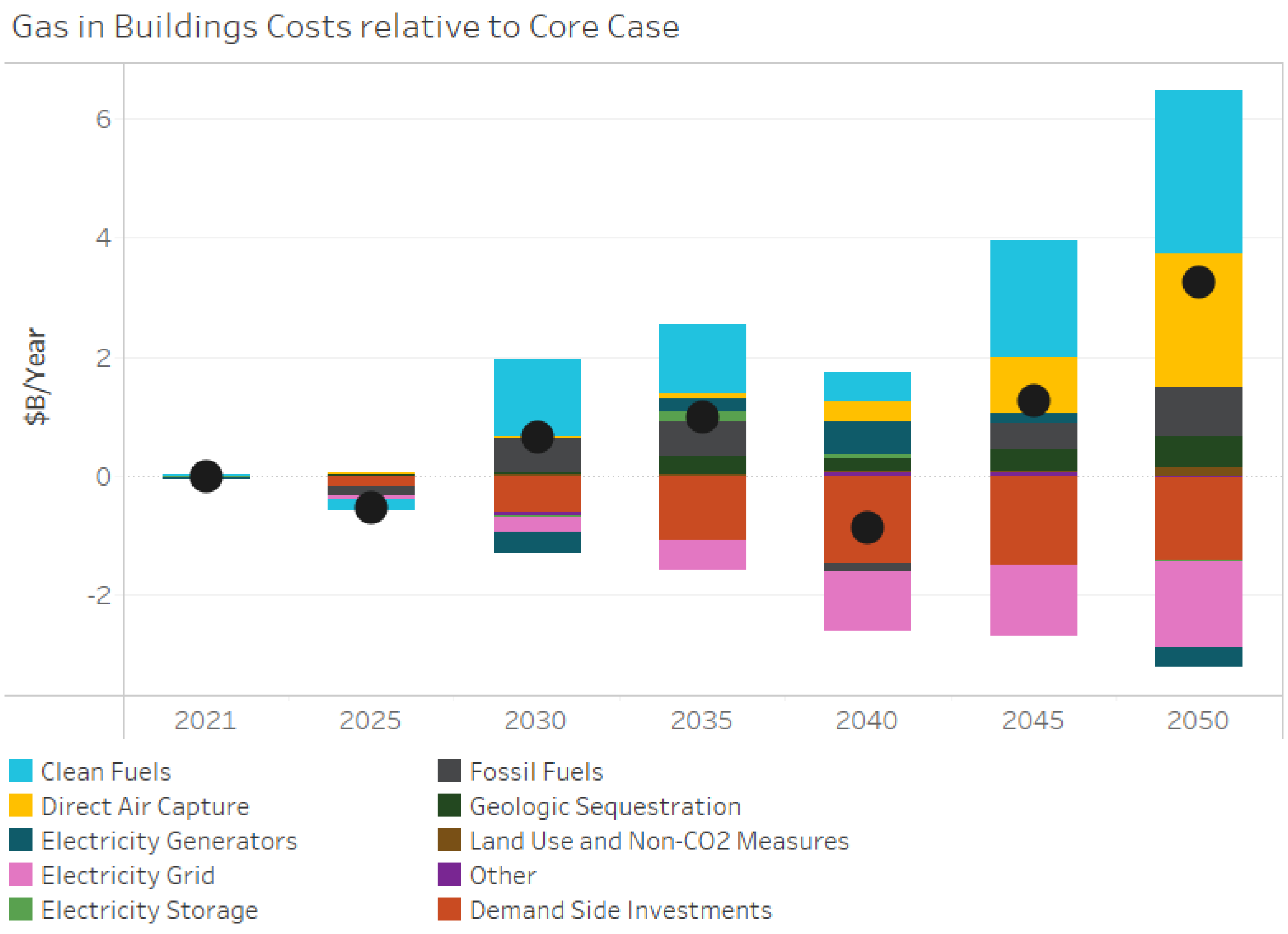
Task 3: Gas in Buildings Costs

- Increased costs include:
  - Clean fuels production, including electrofuels and biofuels,
  - Increased fossil fuel costs, and fuel transportation and delivery costs, including gas pipeline costs,
  - Increased direct air capture costs,
  - And increased geologic sequestration costs
- Decreased costs include:
  - Reduced electricity grid investments due to lower levels of electrification in buildings
  - Demand side equipment costs are reduced due to the lower cost of gas appliances versus their heat pump counterparts
- In total, Gas in Buildings cost $4.6B/year more than the Core Case by 2050
- Costs in Gas in Buildings in 2050 are reflective of increased costs continuing post-2050 as higher cost clean gas is needed in larger volumes as long as the demand remains
- To avoid high gas demands in 2050, electrification needs to start early to achieve sufficient stock rollover by 2050



Task 3: Gas in Buildings
What if no savings on gas pipeline infrastructure?

- The Core Case assumes that as building electrification drives down pipeline gas demand, the cost of operating the gas pipeline network will decline
- This is a highly uncertain assumption: it's possible that even as pipeline gas throughput declines, gas system costs will remain relatively flat
  - Gas system cost savings depend on the ability to avoid future investment and maintenance costs, or to decommission pipeline assets entirely
  - Further study is required to understand whether those cost savings can be realized
- To conservatively illustrate the benefits of the Core Case over Gas in Buildings, on this slide we have assumed costs for pipeline replacement, expansion, and maintenance are identical between the two scenarios (i.e., that greater electrification in the Core Case does not translate to reduced gas pipeline costs)
- Even under this conservative assumption, the Gas in Buildings case costs \$3.3B/year more than the Core Case in 2050, driven by increased clean fuels and carbon capture and sequestration costs
  - Electricity grid costs are lower in Gas in Buildings than in the Core, reflected the decreased need to expand electric distribution capacity—but these savings are outweighed by other costs in our analysis



Task 3: Gas in Buildings
What if heat pump costs were higher or lower?

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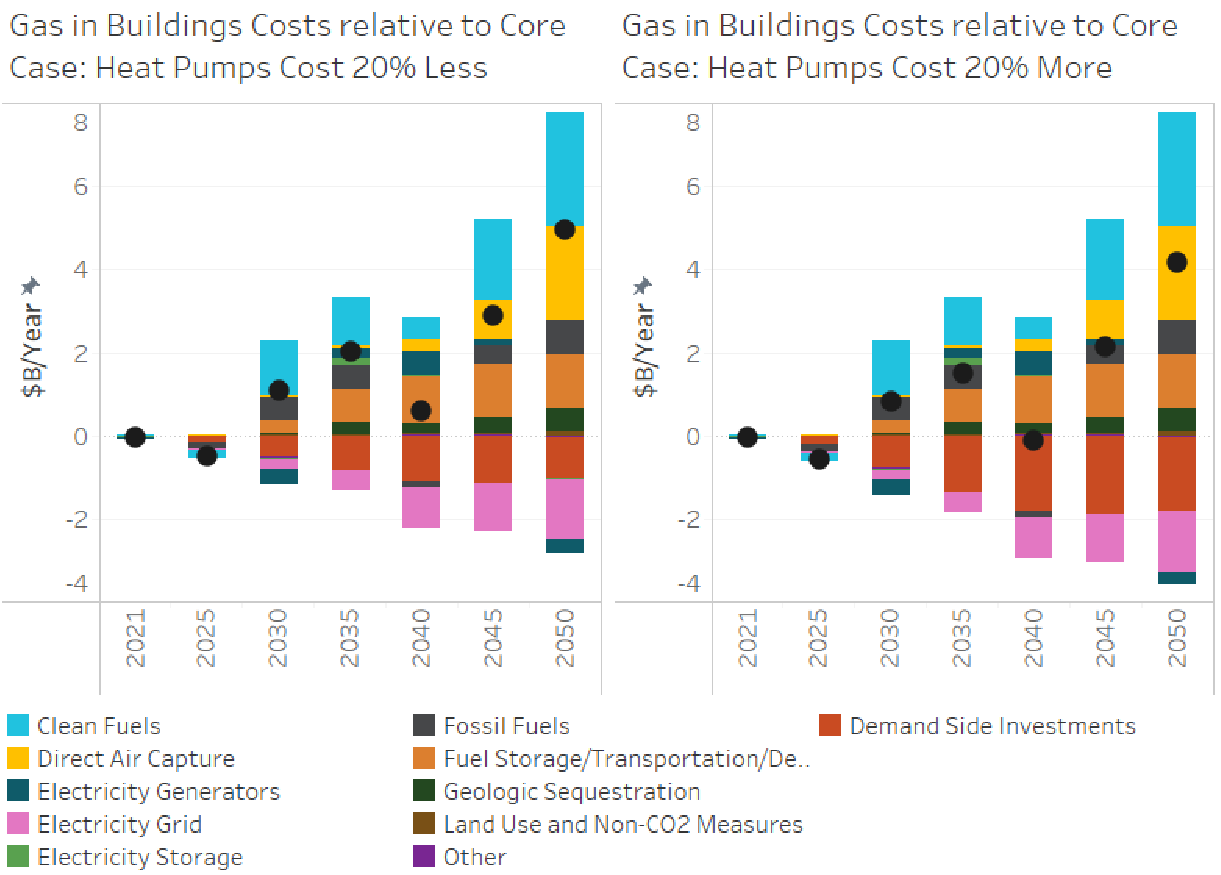
- The cost of heat pumps in the future is uncertain
  - We use EIA's estimates for installed costs[1]
  - What if heat pumps were 20% higher or lower in cost? How does that impact the economics of gas versus electrification?
- The economics are relatively insensitive to heat pump cost
  - Clean fuel and carbon capture costs drive higher costs in most years
  - By 2050, costs are $4.2B/yr higher when heat pumps cost 20% more, setting up higher costs post-2050
    - Costs are $2.9B/yr higher by 2050 even if no savings on gas pipeline infrastructure



1. "Updated Buildings Sector Appliance and Equipment Costs and Efficiencies" (U.S. Energy Information Administration, 2018; https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf).

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Task 3: Gas in Buildings

Key Study Findings

Task 3: Gas in Buildings Key Findings

EVOLVED ENERGY RESEARCH

- Final energy demand is 11% higher by 2050 in Gas in Buildings than in the Core Case, requiring more energy resources across the economy
  - Greater efficiency of electric heat pumps lowers overall energy demand in Core Case
- Gas in Buildings mitigates electric peak impacts relative to the Core Case: in the Core, Northwest system peak (not including transport loads) grows by >50% from 2021 to 2050, vs. 8% in Gas in Buildings
- Emissions from increased pipeline gas demand are offset with either carbon sequestration, additional clean fuels in liquids or, in the case of Washington, decarbonized with biogas
  - It's more economic to decarbonize liquid fuels than pipeline gas due to the higher price of fossil liquid fuels
  - Washington requires 100% clean fuels by 2050 to meet gross emissions targets
- Waste biogas potential meets only a small portion of total demand for clean pipeline gas; the remainder is met with bio-gasification methane w/CC
  - Clean gas supply chains require costly investments to produce the volumes required to decarbonize pipeline gas

Task 3: Gas in Buildings Key Findings

EVOLVED ENERGY RESEARCH

- Gas in Buildings drives up decarbonization costs by requiring more investment in clean fuels production, carbon capture, fossil fuels, and pipeline infrastructure
  - Gas in Buildings avoids investment in distribution infrastructure, but not enough to offset cost increases in other areas
- Costs for investment in gas pipeline infrastructure or decommissioning are uncertain
  - A conservative cost comparison assuming no savings in pipeline infrastructure costs in the Core Case relative to the Gas in Buildings scenario still show significant benefits to electrification in the Northwest
- Demand side costs are uncertain
  - Scenarios investigating heat pump costs 20% higher or lower than assumed in the Core and Gas in Buildings scenarios showed that the cost effectiveness of electrification as a decarbonization strategy is relatively insensitive to heat pump cost
    - Even when heat pumps are 20% more costly, costs are $4.2b/yr higher in Gas in Buildings than in the Core Case. Increase costs would persist post-2050
- Hybrid space heating technologies are most suited to areas with cold climates, constrained electric distribution infrastructure, and minimal opportunities to retire gas assets or otherwise avoid gas infrastructure investment
  - Detailed gas and electric distribution studies, likely with utility participation, are required to identify such areas in the Northwest
  - In areas where these conditions are not met, hybrid space heating is unlikely to be economically sustainable

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Task 4: Distributed Energy Resources (DER)

Task 4: DER
Distributed Energy Resources (DERS)

EVOLVED ENERGY RESEARCH

- Key research questions:
  - What's the potential for Distributed Energy Resources (DERs) to avoid grid-scale infrastructure investment?
  - What system value can demand response provide?
  - How can reduced service demand ease the path to net zero?

Scenario	Description	Assumptions
1	Accelerated rooftop PV and distributed battery deployment. 50% of all rooftop PV technical potential is realized (adding 11 GW of rooftop solar in WA by 2050). Equal deployment of 1.5-hour duration distributed battery storage. Distributed battery deployment that can participate in system operations	Some reduction in grid-scale PV and battery build; reduction in distribution peak load (and corresponding distribution capacity expansion cost). Note: we will assume that batteries are dispatch to respond to system conditions, not to minimize customer utility bills, making this a high estimate of the system value of distributed batteries.
2	What if no demand response participation instead of the Core case forecast?	Higher total costs of electric distribution, generation and transmission will demonstrate the system value of demand response. Note: a "low DR" scenario is more useful for demonstrating this value than a "high DR" scenario due to diminishing returns.
3	What if high demand response participation? Increase vehicle participation to allow vehicle to grid. Increase heating and cooling participation to 50% and water heating to 75% by 2050	Lower total costs of electric distribution, displaces supply side resource procurement. Diminishing returns of greater demand response. May show relatively little cost difference to core case

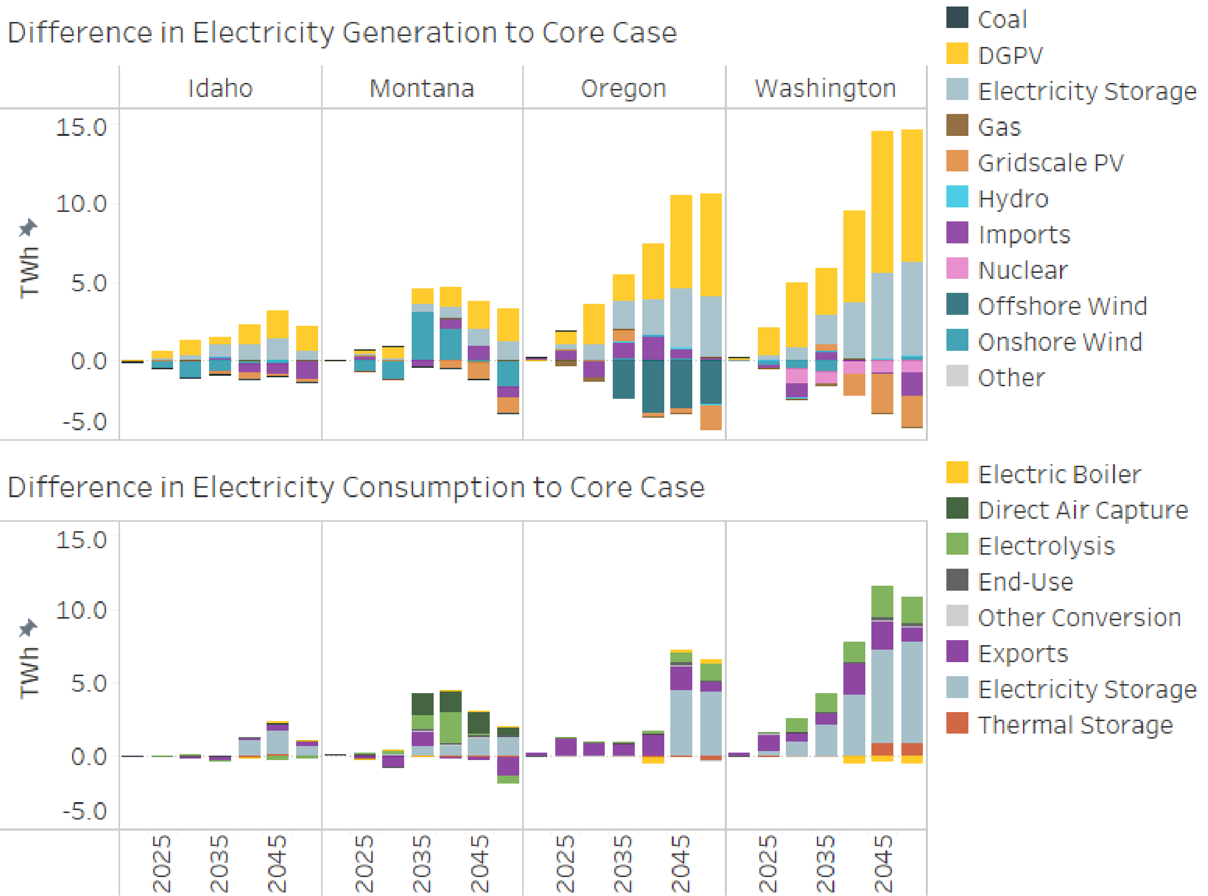
Task 4: DER
High DER

- High DER increases adoption of rooftop solar in the Core Case to reach 50% of technical potential by 2050
- An equal number of GWs of 1.5-hour duration distributed storage systems are also added to the system

State	Core Case DGPV by 2050 (GW)	High DER DGPV by 2050 (GW)	Core Case Distributed Storage by 2050	High DER Distributed Storage by 2050
Oregon	3.0	7.3	0	7.3
Washington	4.9	11.7	0	11.7
Idaho	1.3	2.4	0	2.4
Montana	0.2	1.6	0	1.6

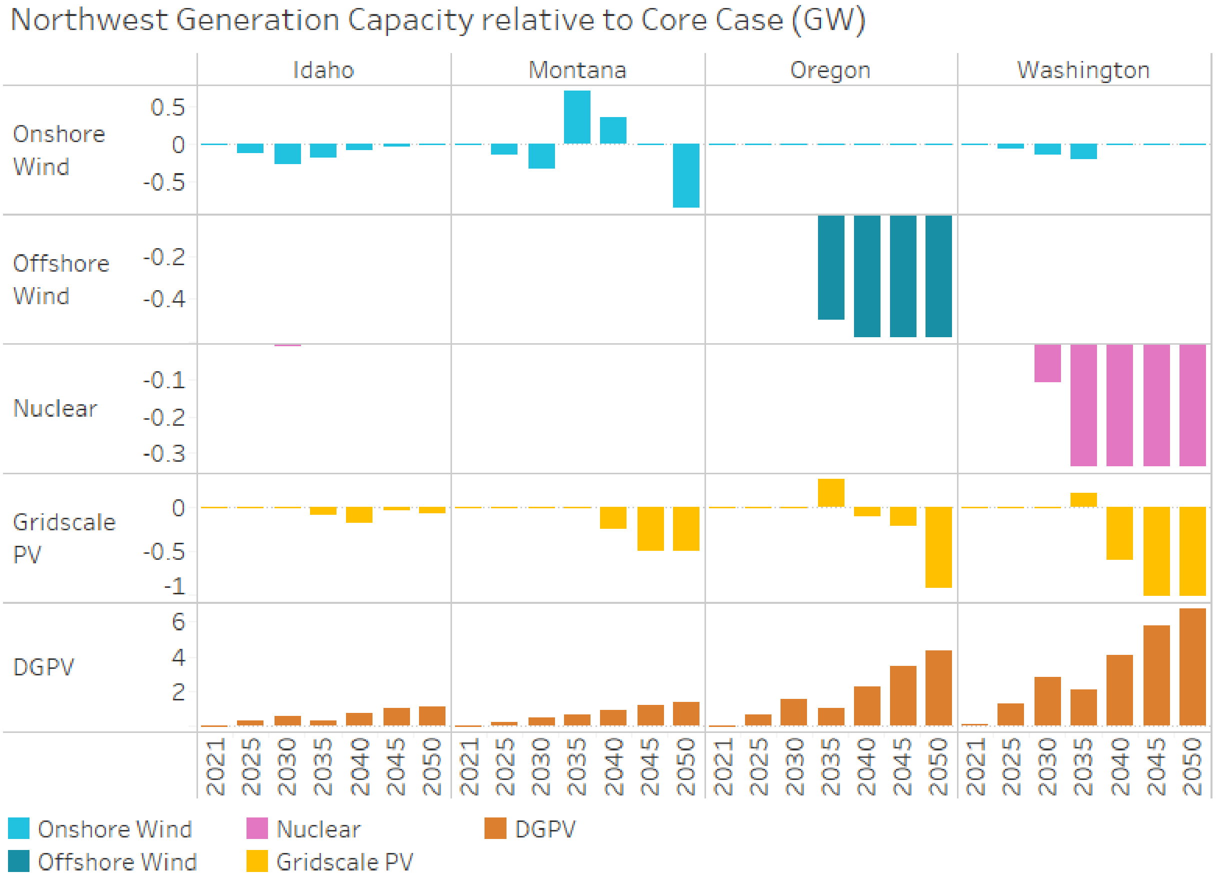
Task 4: DER
High DER – Generation And Consumption

- The impact of this policy varies by state
  - Idaho reduces onshore wind construction in early years and imports of electricity in later years
  - Montana increases electrolysis and direct air capture, while also displacing grid-scale PV build in later years
  - Oregon backs off offshore wind construction and grid-scale PV in later years
  - Washington backs down construction of nuclear and grid-scale PV, while also increasing electrolysis and exports
- In general, High DER increases loads on a similar scale to decreasing grid-scale electricity production with additional generation from DER



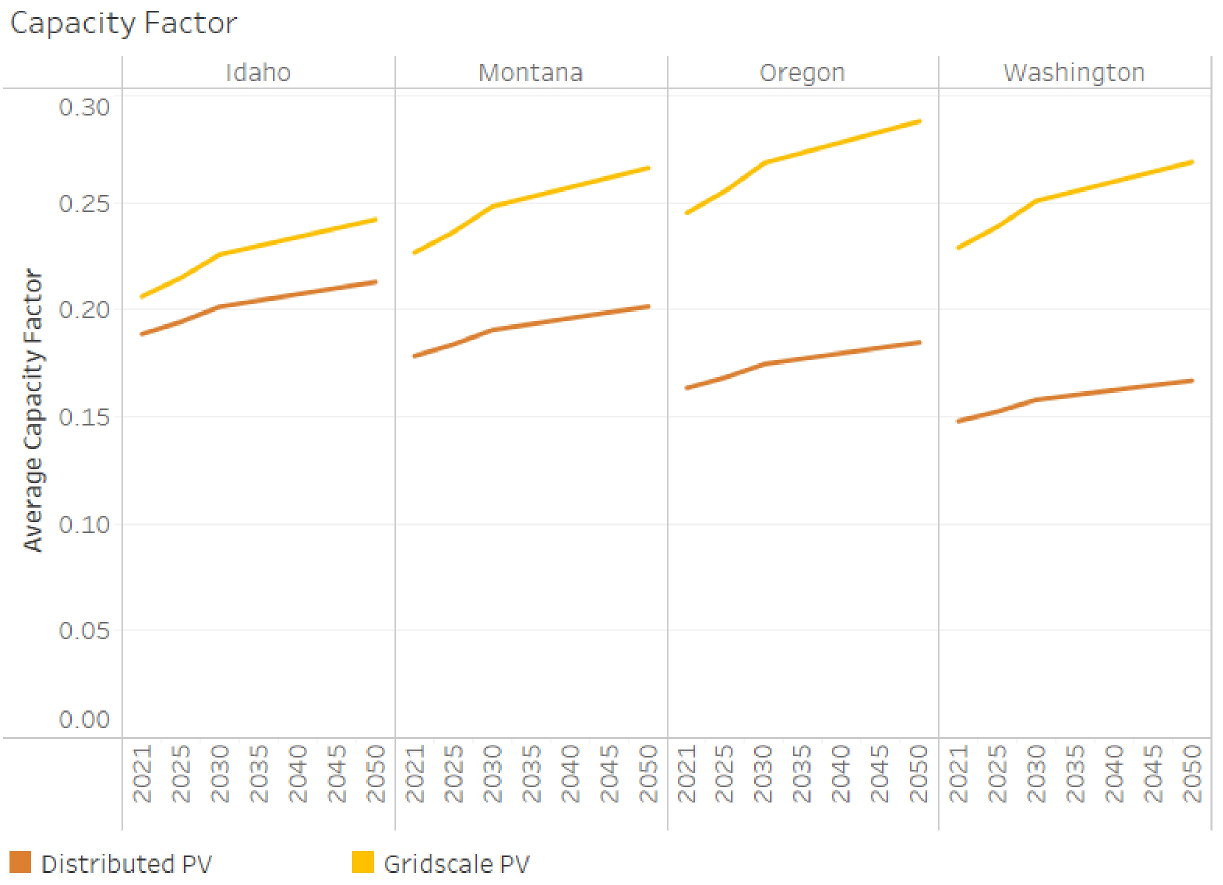
Task 4: DER
High DER – Capacity

- Additional DGPV drives reductions in capacity of other renewable resources
- By 2050:
  - Grid-scale PV is reduced by ~1GW in Oregon and Washington
  - Offshore wind in Oregon is reduced by 0.6 GW
  - Nuclear in Washington decreases by 0.3 GW
- Investment in a unit of capacity of DGPV does not displace a unit of renewable production for two reasons:
  - Loads grow to take advantage of additional energy in local fuels production
  - Capacity factors of rooftop are not as high as grid-scale alternatives



Task 4: DER Capacity Factors

- Additional MWs of DGPV are required to replace the energy of grid-scale resources
- Comparing capacity factors for DGPV and grid-scale PV, the difference depends on the state
  - More variation in weather patterns in Oregon and Washington between locations for grid-scale resources versus population centers where distributed resources would be located



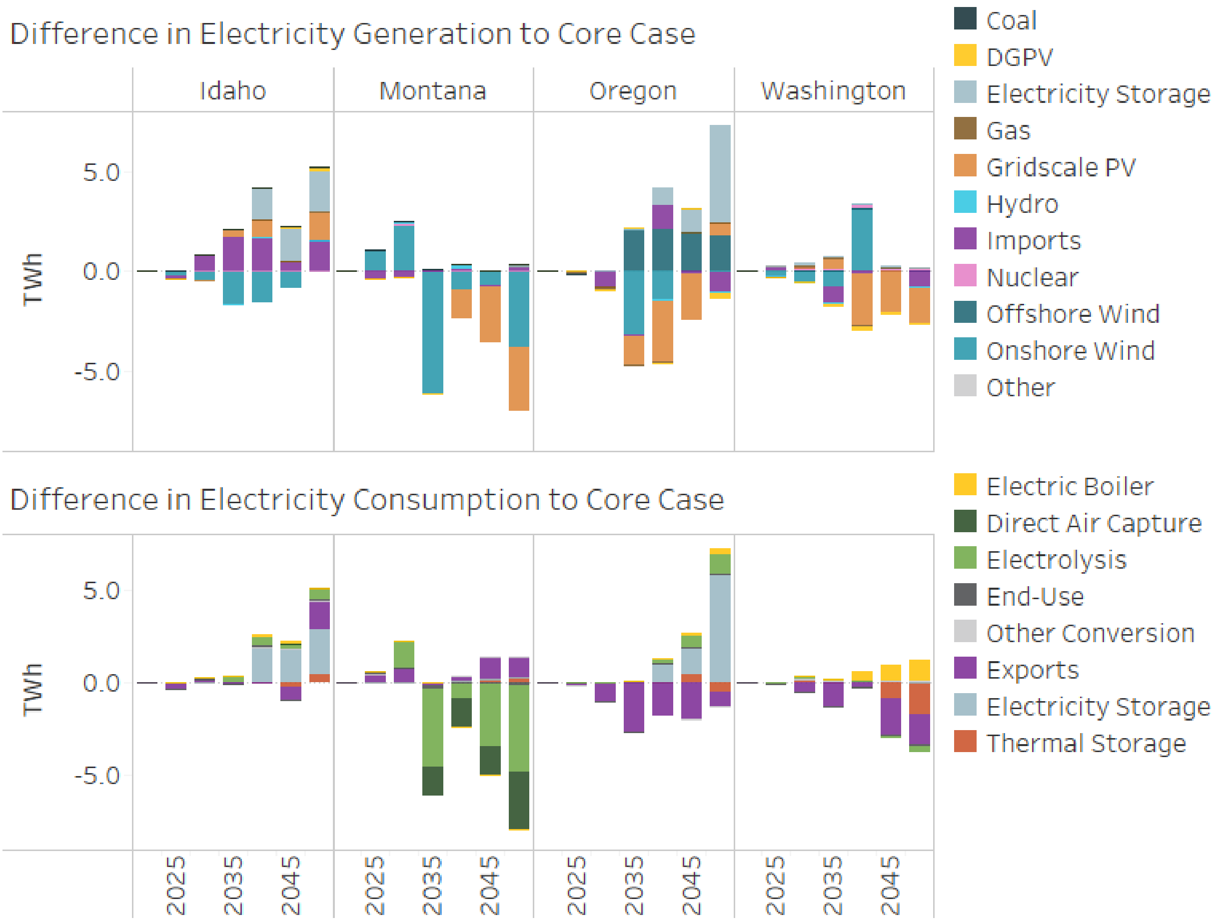
Task 4: DER
No Flex Load

- No Flex Load removes participation of electric loads in providing flexibility, including vehicles, heating, and cooling
- Participating flexible resources can shift their energy use from their normal hourly consumption pattern forward or back in time to varying degrees depending on the technology

Participating Load	Hours that load can be delayed	Hours that load can be advanced	% of load participating in Core Case by 2050	% of load participating in No Flex Load by 2050
Res/Com AC	1	1	10%	0%
Res/Com Water Heating	2	2	10%	0%
Res/Com Space Heating	1	1	10%	0%
LDVs	8	0	75% (charging only)	0%

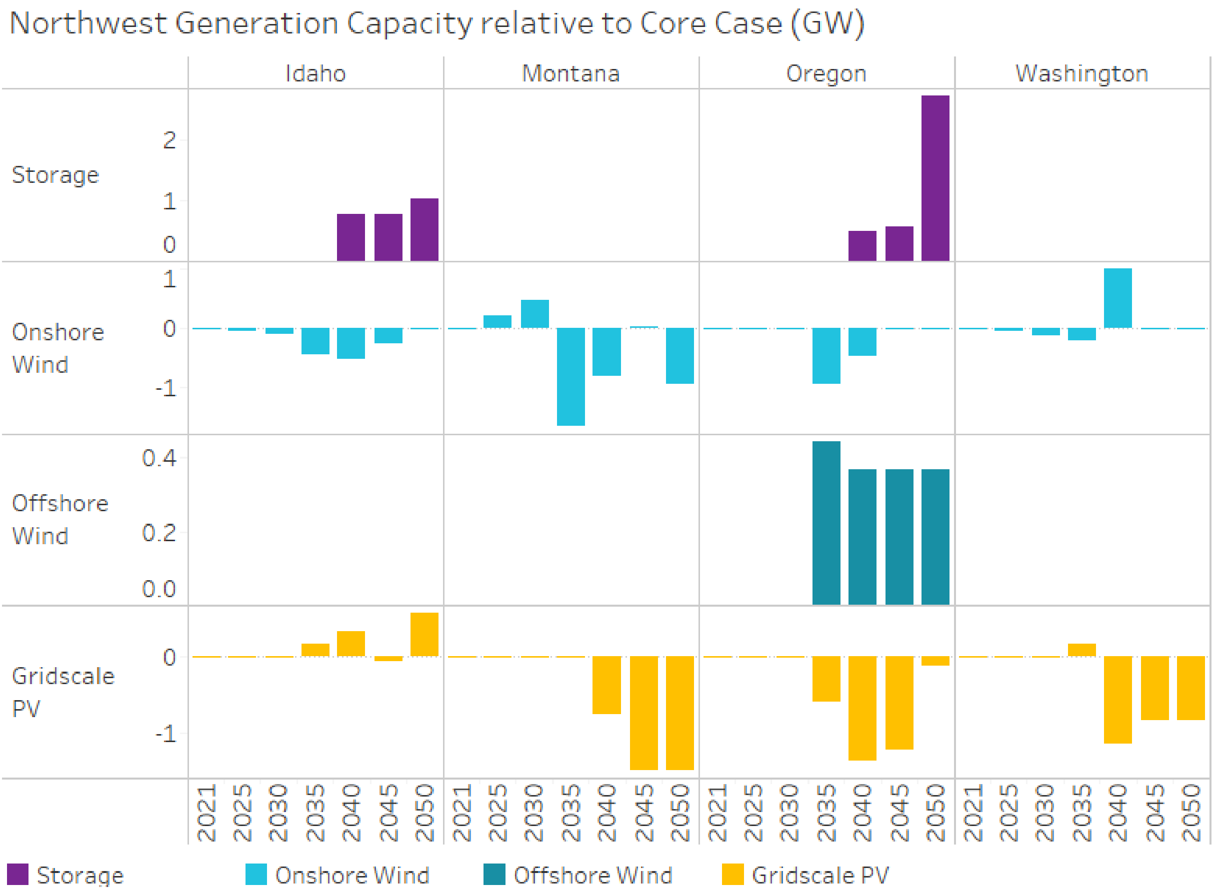
Task 4: DER
No Flex Load – Generation And Consumption

- No Flex Load has the effect of rebalancing the renewable mix on the supply side
  - Less solar generation in Oregon and Washington
  - Increased offshore wind in Oregon
  - Increased investment in storage to balance the grid, rather than relying on flexible loads
  - Reduced generation in Montana with decreased loads
- On the demand side, it redistributes valuable flexible industrial loads across the West
  - Reduces electrolysis and direct air capture in Montana and increases it in solar states where balancing from these resources is more valuable



Task 4: DER
No Flex Load - Capacity

- Decreased capacity of grid-scale solar PV across the Northwest as balancing the grid becomes more expensive without flexible loads
- Increased storage capacity in Idaho and Oregon to replace lost balancing capability
- Reduced overall generating capacity in Montana as electrolysis and direct air capture loads partially move to other states in the West



Task 4: DER
High Flex Load

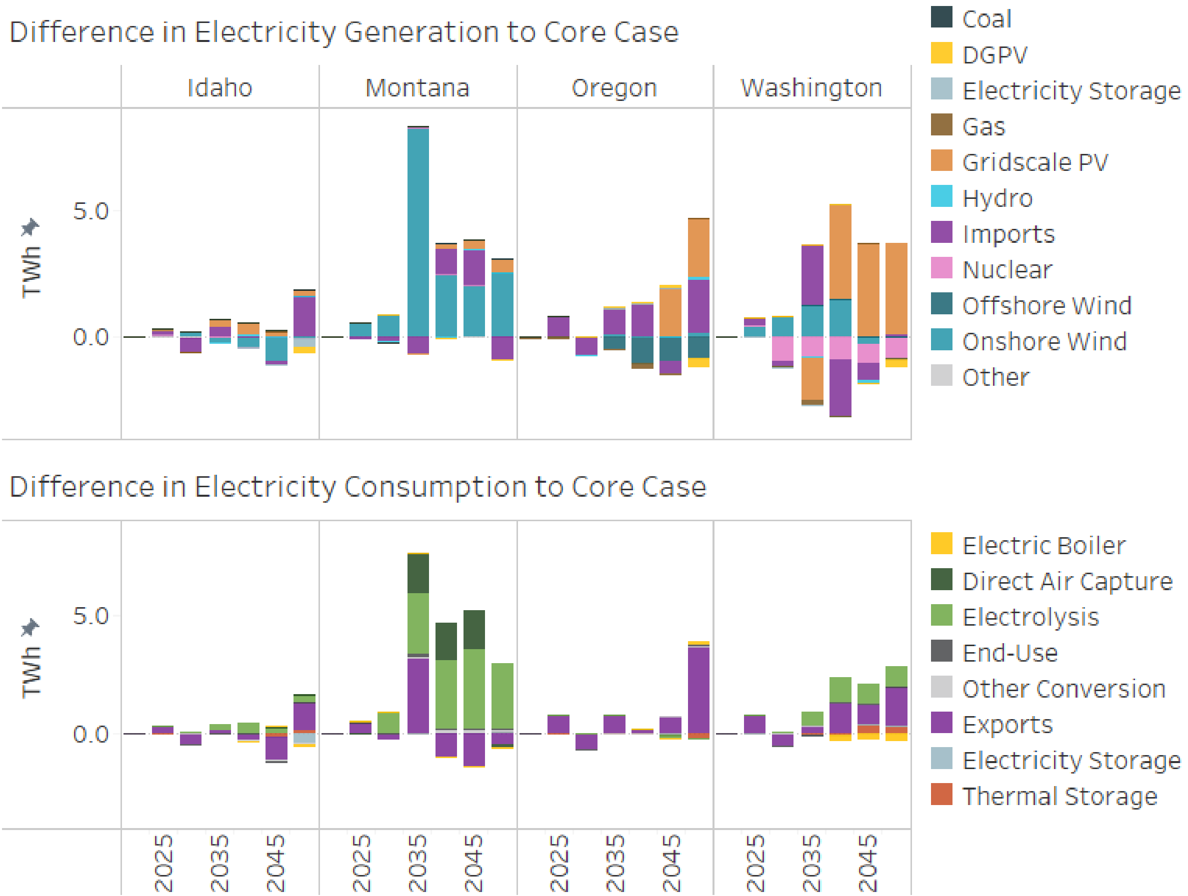
- High Flex Load increases the participation of electric loads in providing flexibility, including vehicles, heating, and cooling
- Participating flexible resources can shift their energy use from their normal hourly consumption pattern forward or back in time to varying degrees depending on the technology

State	Hours that load can be delayed	Hours that load can be advanced	% of load participating in Core Case by 2050	% of load participating in High Flex Load by 2050
Res/Com AC	1	1	10%	50%
Res/Com Water Heating	2	2	10%	75%
Res/Com Space Heating	1	1	10%	50%
LDVs	8	0	75% (charging only)	75% (Vehicle to Grid)

Task 4: DER
High Flex Load – Generation And Consumption

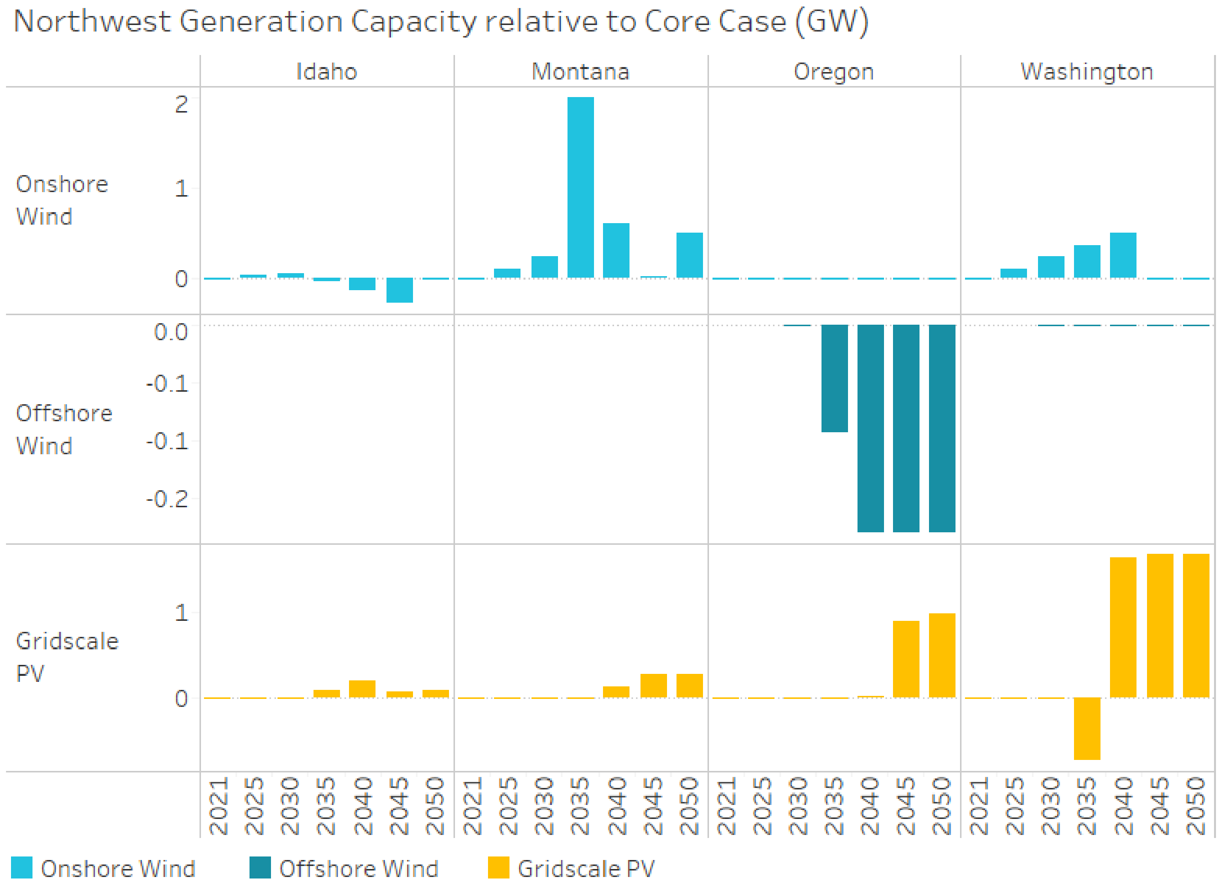
EVOLVED ENERGY RESEARCH

- High Flex Load has the opposite impact of No Flex Load
  - Increased generation and electrolysis and DAC loads in Montana as the rest of the West gains greater balancing capabilities from loads
  - Increased solar generation in Washington and Oregon
  - Reduced nuclear generation in Washington
  - Greater imports and exports, using flexible loads across the West to balance renewable resource generation
- Scale of these changes is relatively small compared to generation of 740 TWh across the Northwest in 2050



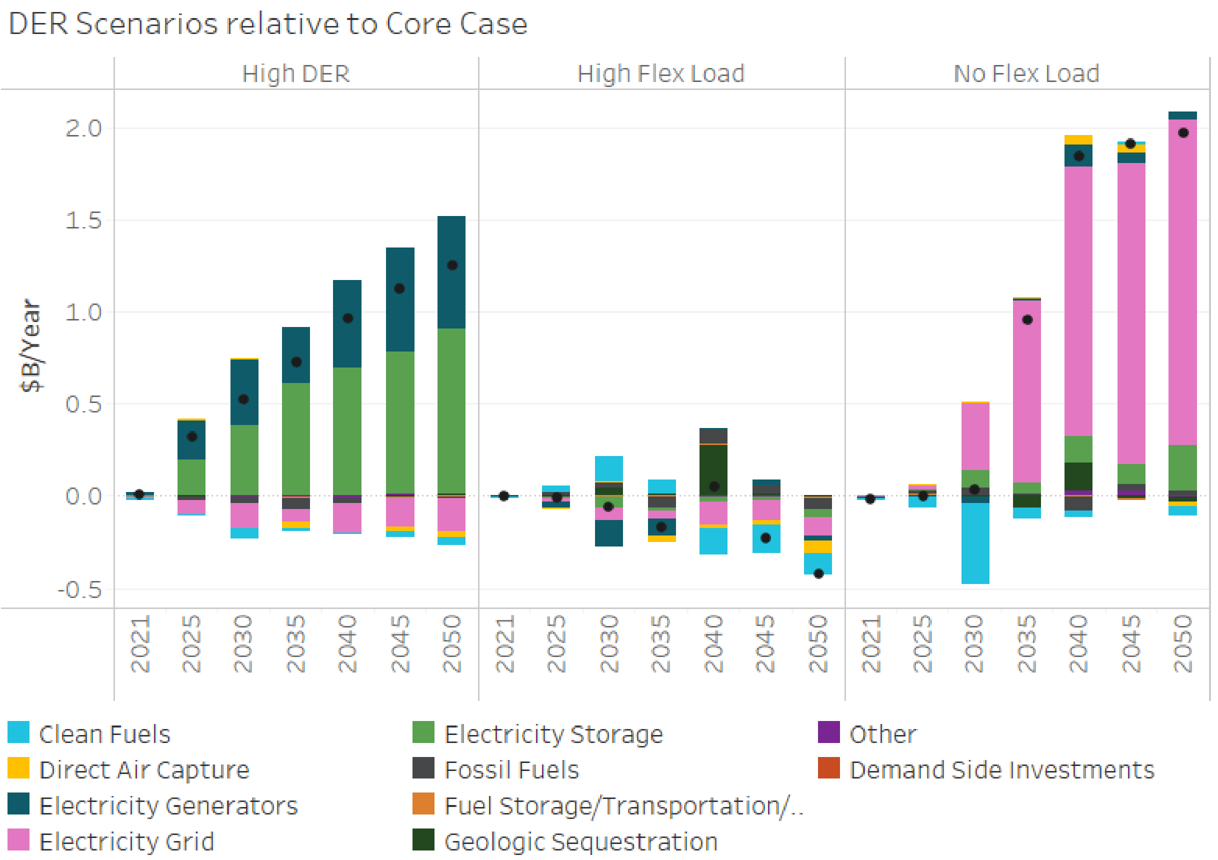
Task 4: DER
High Flex Load - Capacity

- The trends described on the previous slide translate to:
  - Increases in solar capacity across the Northwest
  - Increased overall generation in Montana with commensurate increases in electrolysis and direct air capture loads



Task 4: DER
Cost Impacts – DER Scenarios

- No Flex Load is most impactful on costs relative to the Core Case, reaching $2B/yr more by 2050
  - These costs are largely due to increased distribution system costs. Flexible loads reduce peak loads on the distribution system and without them more investment in distribution infrastructure is needed
- High DER drives costs higher with investment in electricity generators and electricity storage. These costs are offset by decreases in distribution infrastructure due to peak load mitigation
  - The Northwest has lower storage demand than other regions because of flexible hydro fleet and investments in electrolysis over time. Distributed storage investments therefore do not displace investments in balancing resources
- High Flex Load decreases overall costs, but only marginally. The incremental benefits over No Flex Load include:
  - Reduced investment in distribution system infrastructure
  - Reduced investment in hydrogen electrolysis (contained in the Clean Fuels cost category)



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Task 4: Distributed Energy Resources (DER)

Key Study Findings

Task 4: DER Key Findings
Flexible Loads

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- **Flexible loads play an important role in containing decarbonization costs**
  - Electrification of the demand side adds many GWs of new loads
  - Operating these loads flexibly best utilizes distribution infrastructure and mitigates costs associated with peak load growth
  - Flexible load in the Core Case, which is largely from electric vehicles in 2050, saves $2B/yr in avoided distribution infrastructure and storage costs when compared to No Flex Load
- **Increasing levels of flexibility in loads beyond Core Case levels have diminishing returns**
  - Savings over the Core Case by 2050 are $0.4B/yr in the High Flex Load scenario with significantly higher levels of flexibility
  - Are the costs of achieving this level of deployment higher than the savings?
- **The levels of flexible loads impact where and how much electrolysis and direct air capture are built**
  - Reduced flex loads across the west redeploy some electrolysis and DAC to high solar states where balancing need is higher value

Task 4: DER Key Findings
Distributed Energy Resources

EVOLVED ENERGY RESEARCH

- **Increased DER reduces energy demand from grid-scale resources**
  - The High DER scenario shows decreased investment in grid-scale resources and increased local investment in fuels production
  - Takes some of the strain, and potentially alleviates rate constraints of permitting processes for grid-scale resources across the Northwest
- **Increased DER increases investment in local hydrogen production**
  - Distributed PV does not fully displace local grid-scale resources but augments production from the state's best resources
  - Reduces the need for imported hydrogen and clean fuels from other states
- **Distributed storage is of higher cost than the investments it avoids in the Northwest**
  - The Northwest has little economic investment in battery storage in the Core Case due to the large hydro system, electrolysis in later years, and in contrast to solar dominant systems with large storage investments, the balance between solar and wind resources
  - The addition of many GWs of distributed storage costs more than the avoided investment of grid-scale assets
  - However, customers may want to install distributed storage for economic or other benefits not included in the model, such as back up during outages. Participating grid-scale storage avoided costs include distribution system, hydrogen electrolysis, and DAC

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Task 5: Pace of Transportation

Task 5: Pace of Transportation Transformation

EVOLVED ENERGY RESEARCH

- Key research questions:
  - The Core Case assumes 100% light duty ZEV sales by 2035. How would accelerating or decelerating that transition impact the Northwest's optimal decarbonization pathway?
    - Modeling accelerated ZEV adoption is aligned with SB 5974 passed in Washington last year to achieve 100% EV sales in the light duty sector. This could be of particular benefit to Washington whose emissions policy drives the need for clean fuel deployment in transportation in 2030. Is it worthwhile for the Northwest to adopt similarly aggressive ZEV sales mandates, despite their potential political risk?
    - Decelerated ZEV adoption after 2035 demonstrates the impact of failing to meet full ZEV penetration. This failure could be due to lack of policy support, or incomplete charging infrastructure buildout and resulting customer backlash. How costly is it to achieve lower levels of vehicle electrification by 2050?

Scenario	Description	Expected Results Relative to Core Case
1	Accelerated vehicle electrification: 100% electric sales by 2030 in the light duty segment	Reduced cost of producing clean fuels for transportation, higher vehicle costs due to adoption further up the cost curve, larger electricity sector earlier depending on where clean fuels are sourced from
2	Decelerated vehicle electrification: stalled policy reaches only 50% sales of EVs	Incomplete penetration of ZEVs will require more production of clean drop-in fuels, increasing overall scenario costs and infrastructure needs.

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Task 5: Pace of Transportation

Demand-Side Results

TASK 5: Pace of Transportation
Pace Of Transportation Demand Side Scenarios

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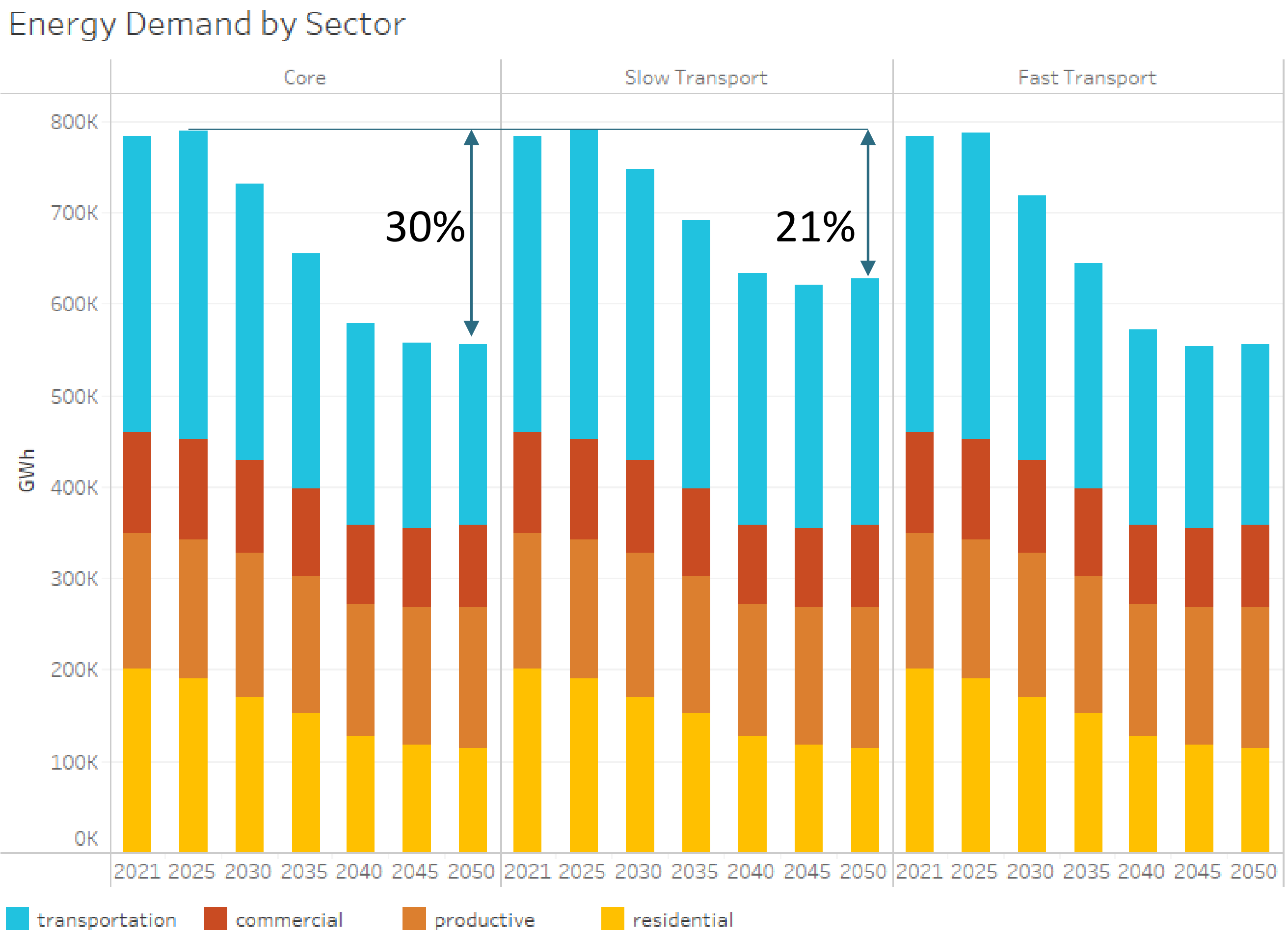
- Differences between scenarios on the demand side are designed to investigate differences in transportation policy or uncertainty in vehicle adoptions over time
  - Three unique demand side scenarios
    - Slow Transportation Scenario – threats to adoption of electric vehicles such as congestion of charging infrastructure, supply chain disruptions, or customer rejection for other reasons cause failure to reach full penetration of EVs
    - Core Case – Rapid electrification of vehicle fleets, reaching 100% sales shares of zero emission vehicles (ZEVs) by 2035 in light duty vehicles
    - Fast Transportation Scenario – Sales shares in light duty vehicles reach 100% by 2030, reflecting even more rapid, policy driven adoption
- Demand side assumptions in other sectors are held constant across scenarios

Task 5: Pace of Transportation Demand Side Evolution – Final Energy

EVOLVED ENERGY RESEARCH

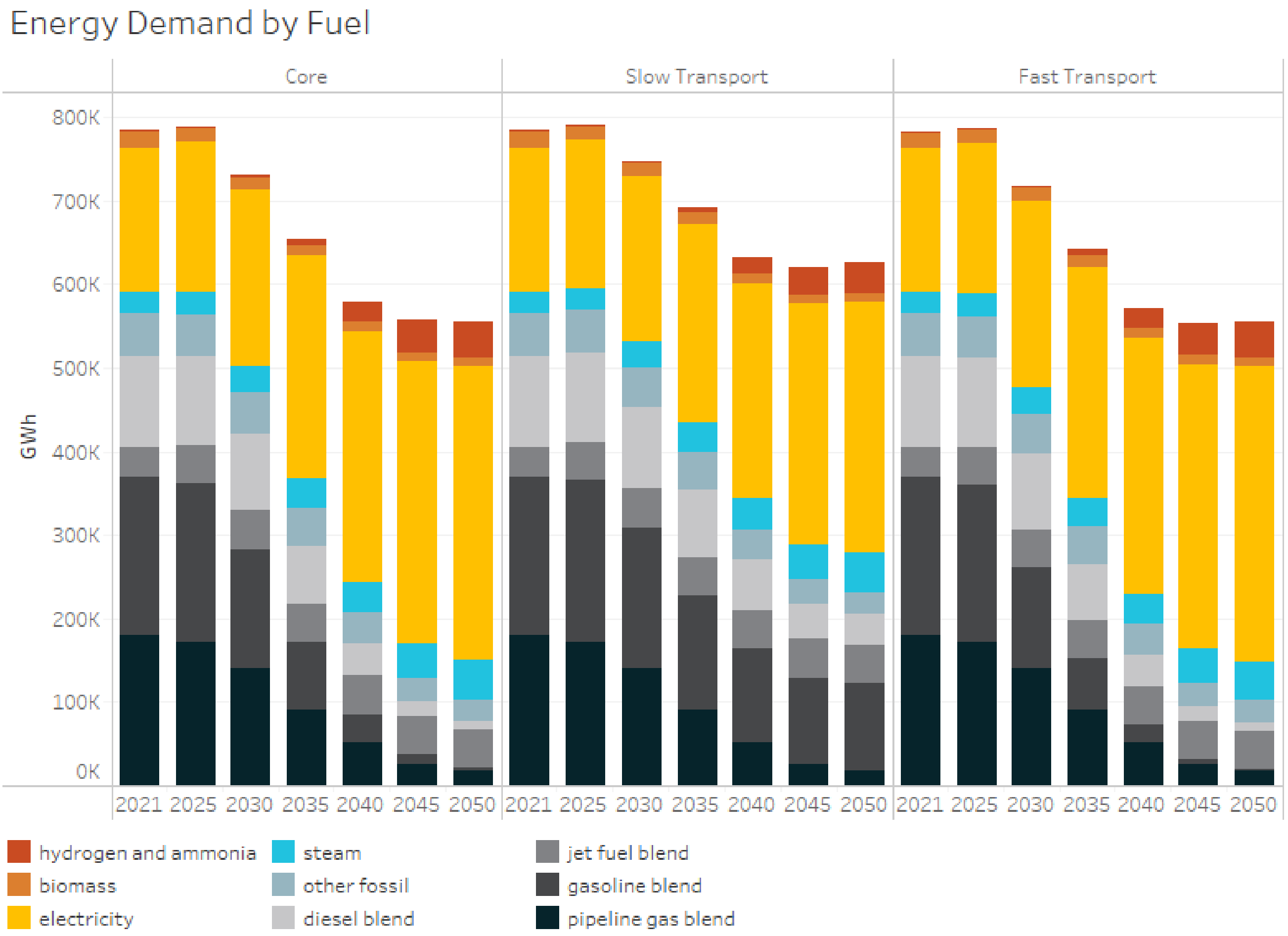
- The Core Case has 30% less final energy demand in 2050
  - Increase in electrification but decrease in overall energy requirement
  - 30% reduction from peak final energy demand in 2025
- Slow Transport reaches 21% reduction by 2050 with significantly higher energy use in interim years
- Fast Transport reaches similar numbers of electric vehicles by 2050, but faster adoption lowers energy demand in 2030, 2035, and 2040



Task 5: Pace of Transportation Demand Side Evolution – Final Energy

EVOLVED ENERGY RESEARCH

- Electricity growth displacing primary fuel use in the economy
  - Greater efficiency of electric vehicles and appliances
- Differences in rate and volume of displacement between cases
- Evolution of pipeline gas and non-transport fuel demand constant between cases
- Electricity growth in end uses by 2050 over 2021 levels by scenario:
  - 105% in Core
  - 75% in Slow Transport
  - 105% in Fast Transport



Task 5: Pace of Transportation
Varying Transportation Sector Assumptions

- Demand side scenarios vary by transportation sector sales share assumption, as detailed in the previous section
- These sales share assumptions are inputs to a stock rollover model that represents the stocks of demand side equipment across the economy, including light, medium, and heavy-duty vehicles
  - Vehicles have assumed lifetimes based on the literature and are replaced when they come to the end of their useful life
  - The stock of light duty vehicles, for example, becomes almost fully electric 15 years after a policy of 100% EV sales is adopted based on a 15-year lifetime assumption
  - Cost and efficiency varies by vehicle vintage based on forecasted improvements in technology
- **The following slides show the evolution of vehicle sales share, stocks, and energy demand over time in each scenario**

Task 5: Pace of Transportation
Light Duty Vehicle Sales, Stock, Energy

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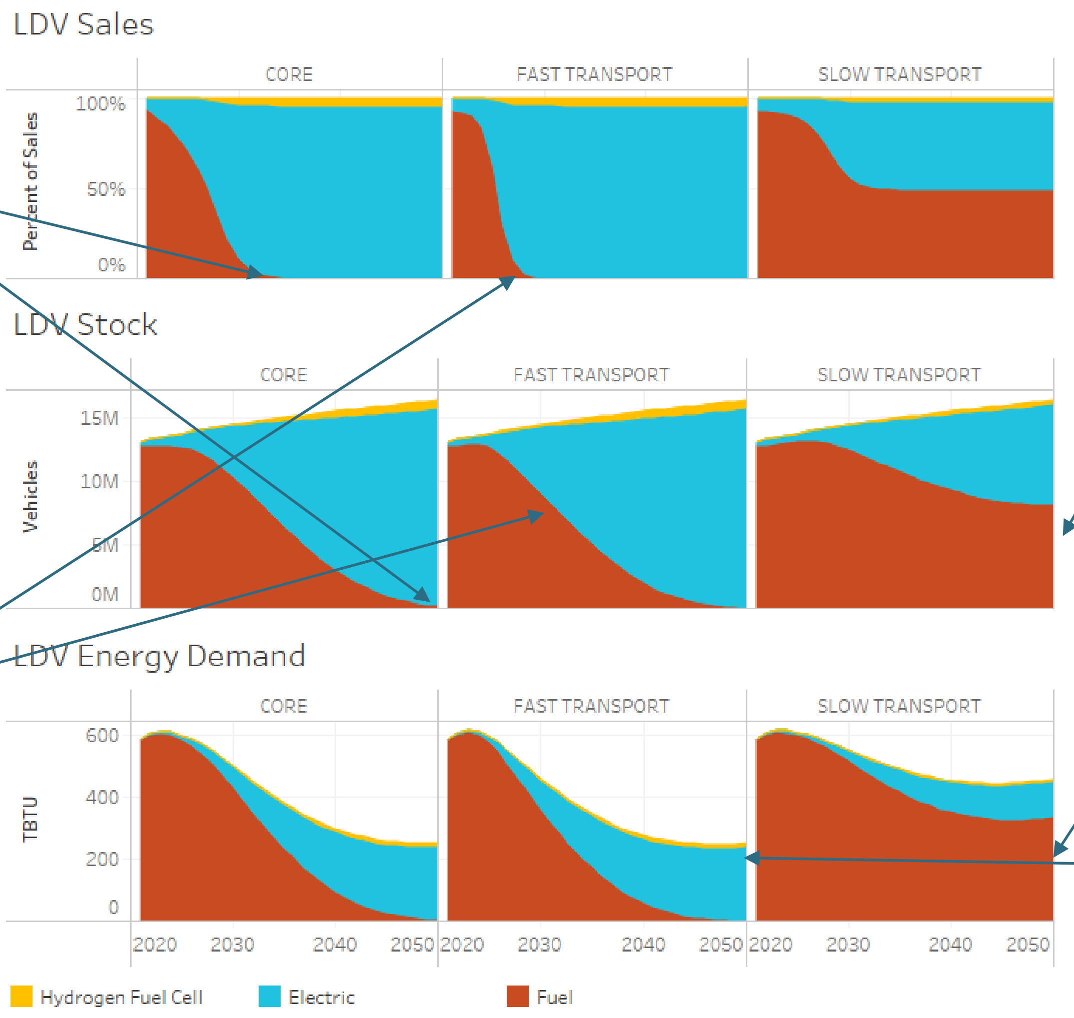
Sales target of 100% clean vehicles by 2035 results in ~100% clean vehicle stocks by 2050

Fast Transport accelerates light and medium duty vehicle sales targets to 2030, reaching the same point in 2050, but following a steeper transition of stocks



50% of vehicle stocks remain ICEs in Slow Transport by 2050, representing a failure of infrastructure investment to support large EV penetrations

73% of energy demand is liquid fuel in 2050

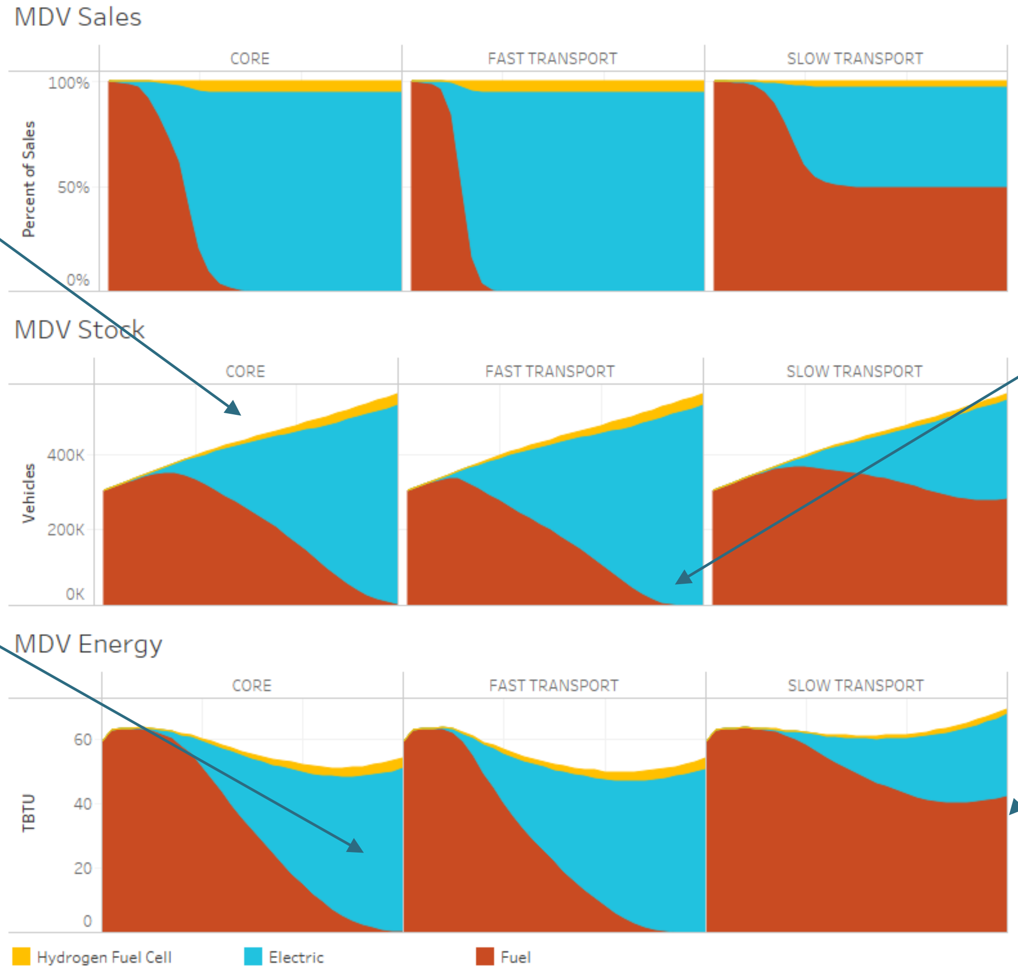
Core and Fast Transport reach 54% of Slow Transport energy demand in 2050

Task 5: Pace of Transportation
Medium Duty Vehicle Sales, Stock, Energy

EVOLVED ENERGY RESEARCH

Rapid growth of the medium duty vehicle sector in AEO forecast

100% stock of EVs in Core and Fast Transport by 2050 results in 22% reduction in energy use over No Transportation Action



Fast Transport achieves earlier full electrification of the fleet, but both Core and Fast Transport are ~100% clean by 2050

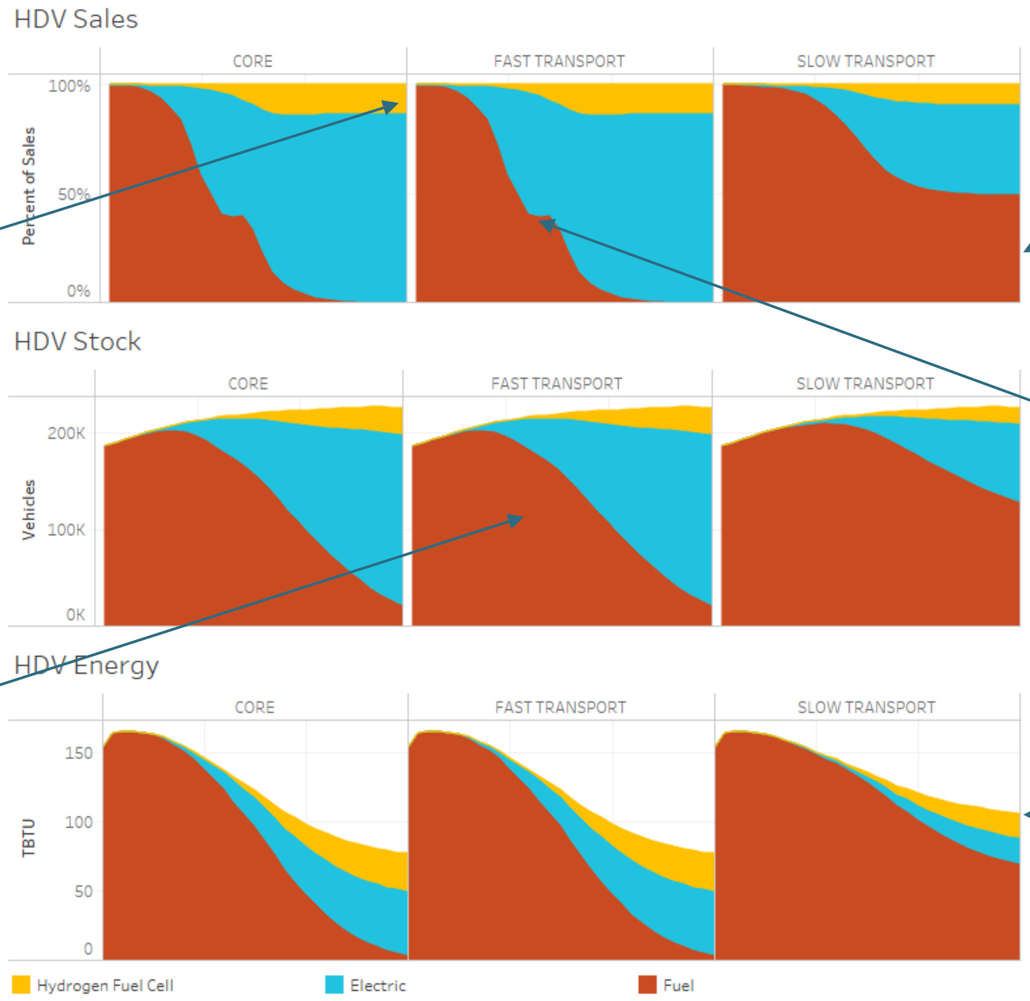
Liquid fuels are 60% of energy demand in Slow Transport by 2050

Task 5: Pace of Transportation
Heavy Duty Vehicle Sales, Stock, Energy

EVOLVED ENERGY RESEARCH

60/40 split in sales between EVs and hydrogen for long-haul trucking. EVs are assumed more competitive for short-haul, resulting in 13% hydrogen sales by 2050 across the sector

Fast Transport the same as Core for HDVs, assuming interstate vehicle fleets will be impacted less by local policy changes



Slow Transport assumes 50% of sales remain internal combustion

Assume EV sales plateau post IRA incentives

Slow Transport has a 38% higher energy demand by 2050 than the Core

Task 5: Pace of Transportation Demand Side Discussion

EVOLVED ENERGY RESEARCH

- **Action taken in the transportation sector significantly impacts economy-wide energy demand**
  - The Core Case reduces energy demand from peak by 30% versus 21% in the Slow Transport Scenario
  - This difference reduces supply side investments necessary to serve that demand
- **Adoption of EVs and FCVs results in significant growth in electricity demand over 2021 levels**
  - 105% in the Core Case versus only 75% in Slow Transport
  - While electricity demand increases, total economy-wide energy demands drop due to the greater efficiency of EVs
- **While energy demand is reduced overall, electrification will drive significant changes in the way energy is produced and consumed**
  - New opportunities and challenges in shifting modes of energy consumption across economic sectors
  - Risks to electrifying too quickly as well as too slowly

Task 5: Pace of Transportation Vehicle Charger Assumptions

EVOLVED ENERGY RESEARCH

- Numbers of vehicle chargers installed are based on assumptions from the NREL Electrification Futures Study about the ratios of different types of chargers per million vehicles
  - Total transportation costs include the cost of installing these chargers
- Light duty vehicle chargers installed per million vehicles are from (Melaina et al. 2016):

Charger Type	DC Fast Charger	Community Level 2	Community Level 1	Work Level 2	Work Level 1	Home Level 2	Home Level 1
Chargers per million vehicles (thousands)	0.47	11.11	0.43	166	166	328	559

- Medium and heavy-duty truck DC fast charger installations are based on assumptions on how many vehicles can be charged everyday by a charging complex
  - Calculated using coincident peak power output over 10-hour daily operations/vehicle battery size assuming 80% depth of discharge
  - Assumes 350kW for heavy duty and 50kW for medium duty

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Task 5: Pace of Transportation

Supply-Side Results

Task 5: Pace Of Transportation Northwest Fuel Supply

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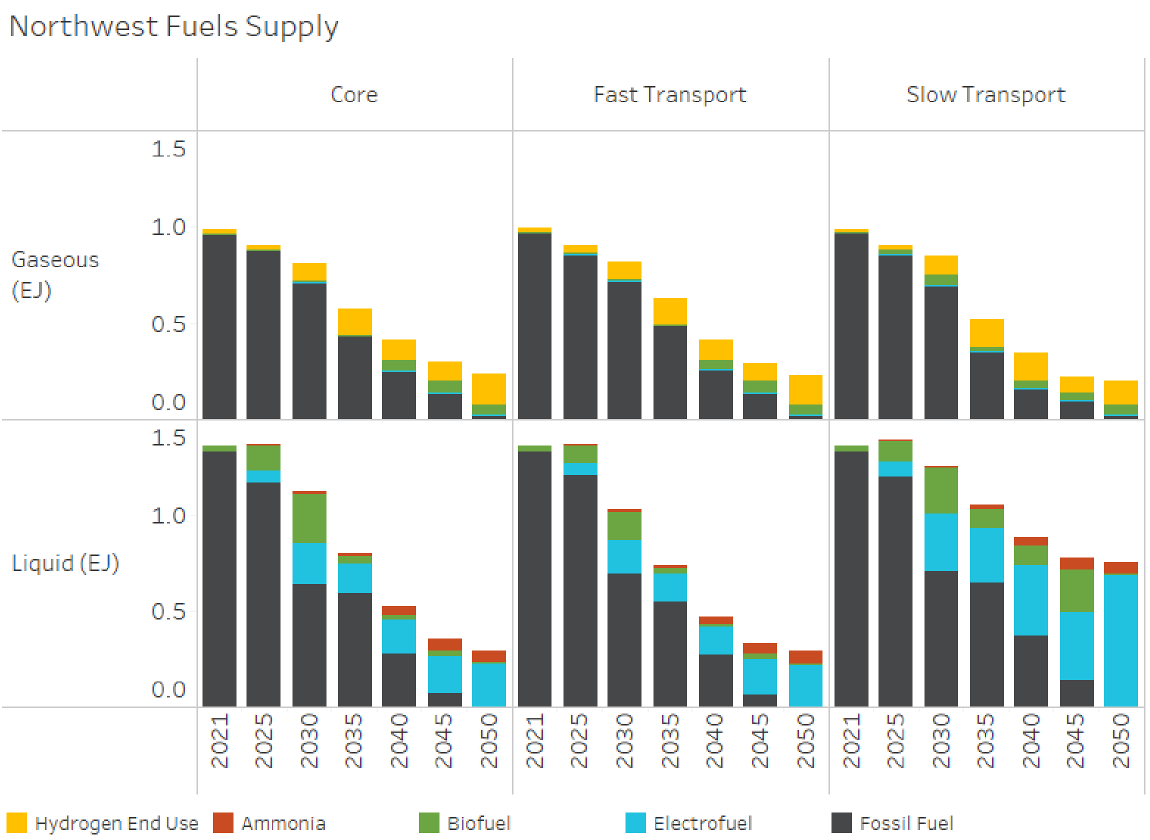
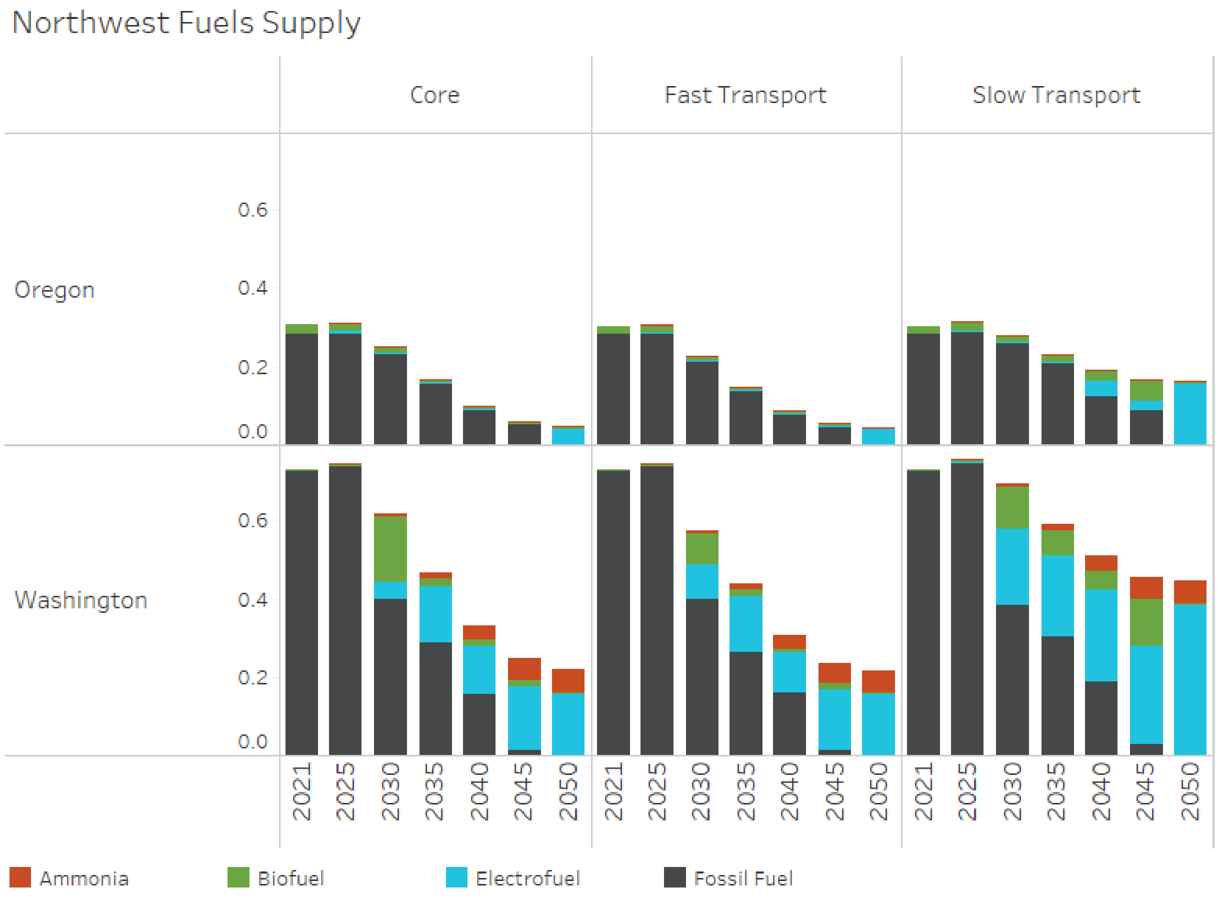
- Liquid fuel demand significantly impacted versus the Core Case
  - Fast Transport accelerates adoption of electric vehicles in the near-term, lowering regional liquid clean fuels demand in 2030 by 29%
    - Meeting 40% emissions reductions by 2030 in MT and ID drive significant decarbonization of their fuel sectors. As noted elsewhere in the findings of Net Zero Northwest, this indicates the difficultly of matching emissions policy with other states in the West
  - Slow Transport increases clean fuel demand in 2030 and all following years
- Impact on gas demand from Slow Transport
  - Lower volumes of fossil fuels, reducing emissions in other parts of the economy to accommodate greater liquid fuels demand



Task 5: Pace of Transportation Impact On States With Emissions Targets

EVOLVED ENERGY RESEARCH

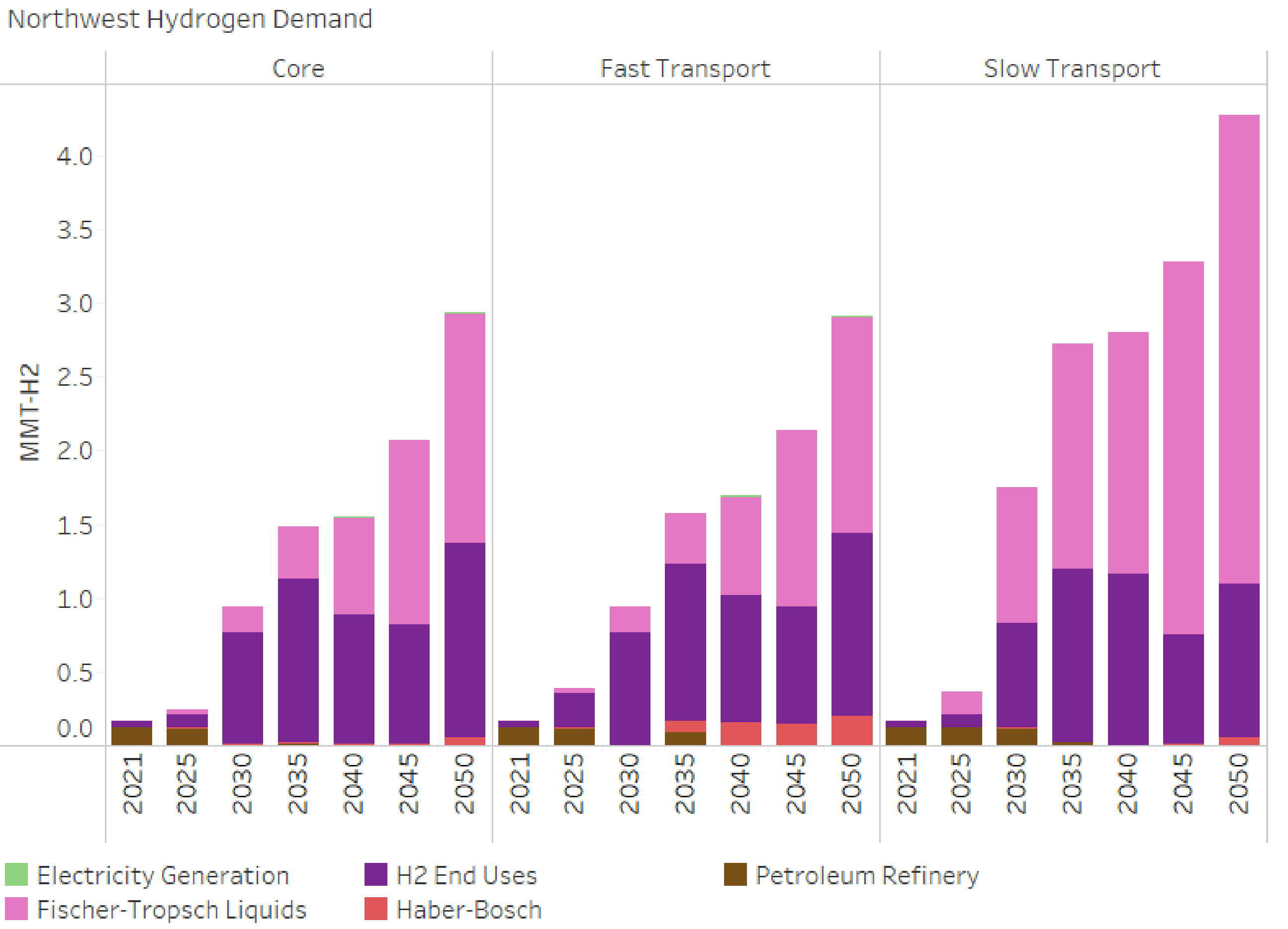
- Oregon and Washington have very different paths towards their emissions targets
  - Oregon emissions reductions from coal retirements mean that clean fuels are not needed beyond CFP requirements
  - Washington starts from a relatively clean electricity sector and thus some emissions reductions relative to the 1990 baseline must come from reducing fossil fuel in end uses by 2030
- Washington:
  - Accelerating electrification in Fast Transport reduces volumes of clean fuels required by 20% in 2030
  - Slow Transport increases volumes by 40% in 2030
- In Oregon, faster or slower electrification has no impact on clean fuel demands in 2030



Task 5: Pace of Transportation Northwest Hydrogen Demand

EVOLVED ENERGY RESEARCH

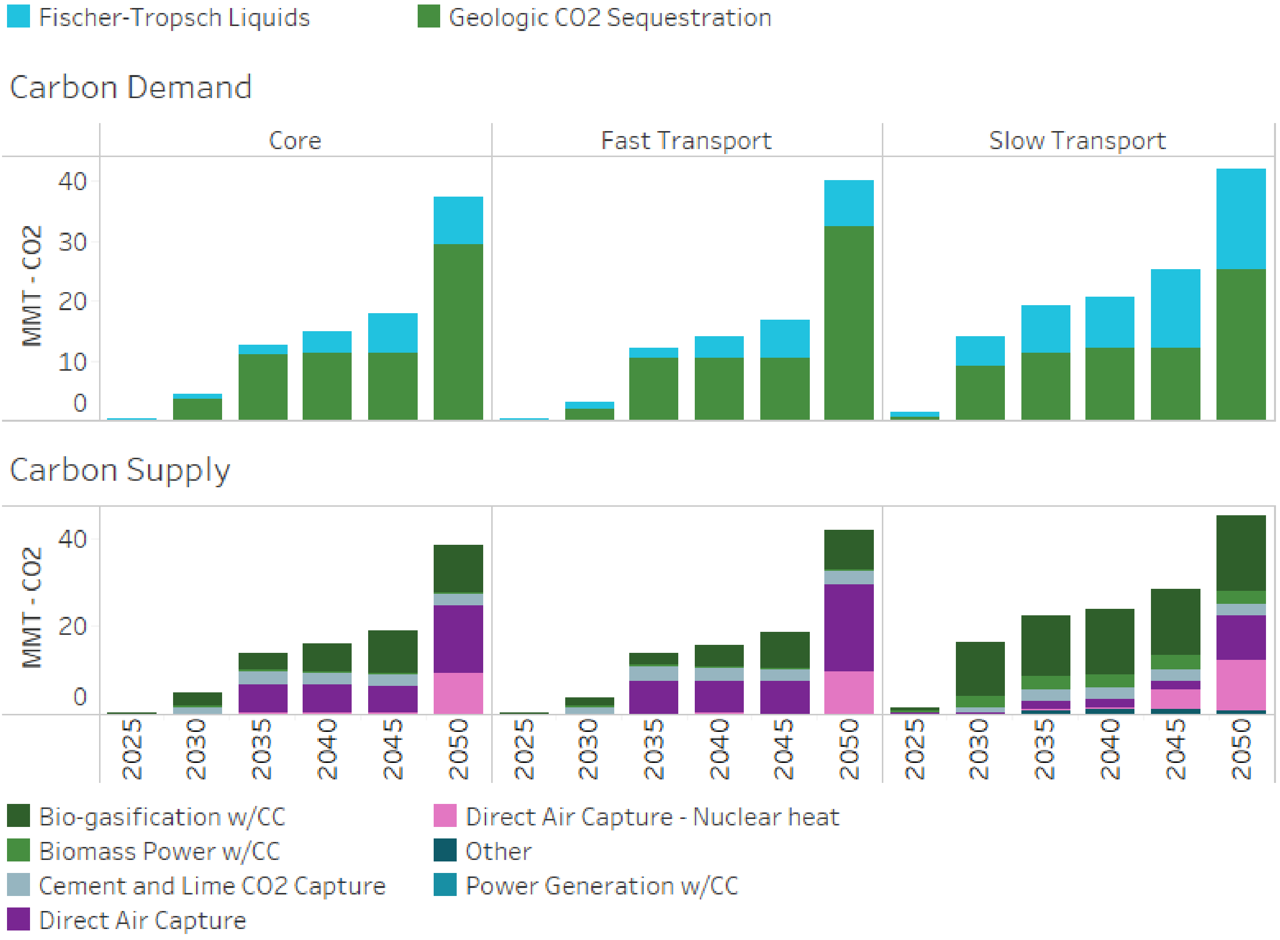
- As expected, Slow Transport increases hydrogen demand in the Northwest
  - End use demands decrease as fewer hydrogen vehicles are adopted
  - However, fuels production increases to contribute towards decarbonizing liquid fuel supplies
  - Total Northwest hydrogen demand is 46% higher in Slow Transport than in the Core Case
- Fast Transport has similar levels of hydrogen demand to the Core Case
  - Demands for clean fuels are dropping in the near-term
  - However, clean fuels imports from other regions are reduced rather than Northwest production



Task 5: Pace of Transportation
Northwest Carbon Demand & Supply

EVOLVED ENERGY RESEARCH

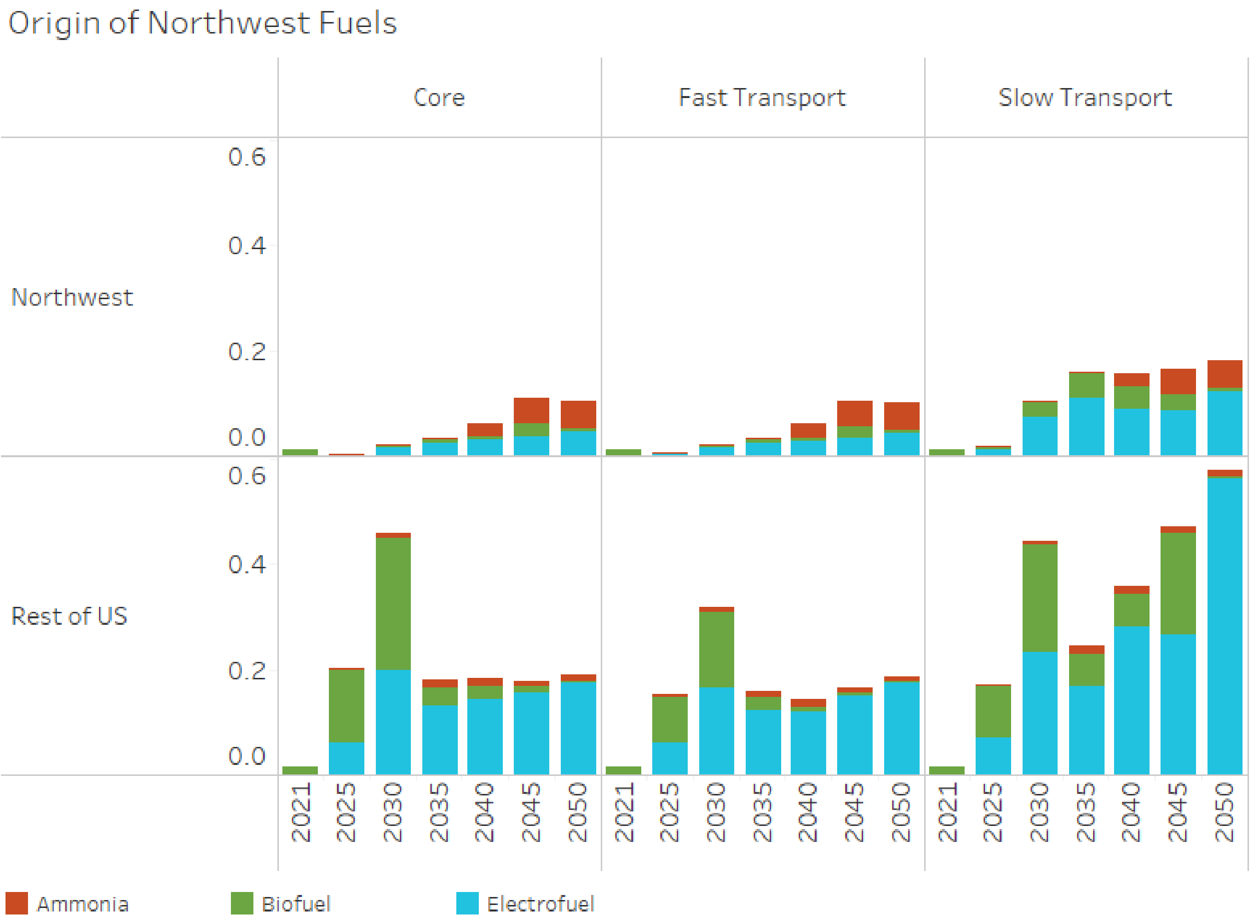
- Drop-in hydrocarbon electrofuels require carbon in the production process
- The majority of carbon captured is sequestered in the ground
- However, the quantity of carbon used in fuels production is impacted by the transportation scenario
- Slow Transport requires significantly more CO_2 in the near-term
  - Biogasification with carbon capture scaled up
- Fast Transport covers majority of carbon demand in 2030 with cement and lime CO_2 capture
- IRA incentives drive early direct air capture adoption
  - Exception is in Slow Transportation where CO_2 is needed earlier and a bio-gasification w/CC industry is developed instead



Task 5: Pace of Transportation
Sources of Supply of Northwest Clean Fuels

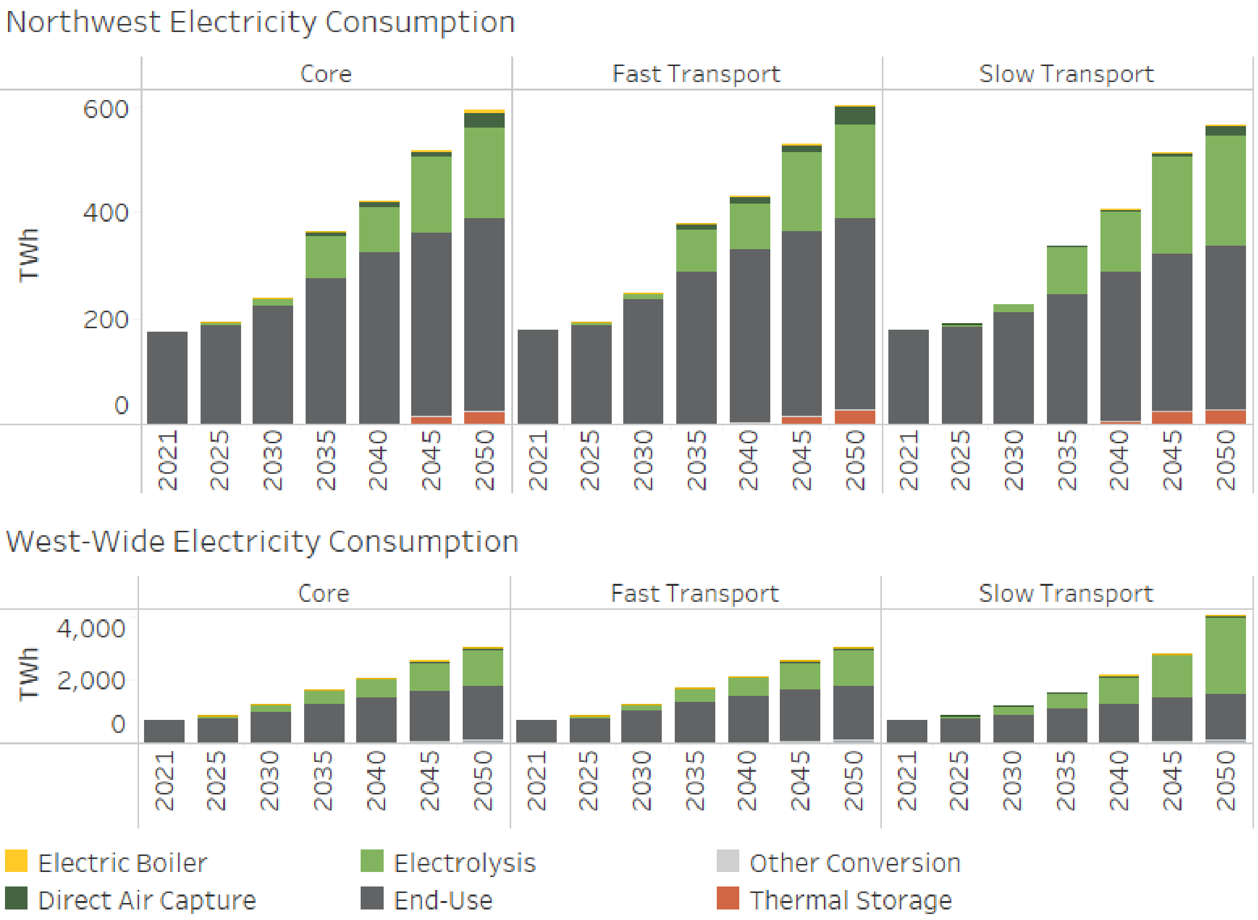
EVOLVED ENERGY RESEARCH

- Clean fuels production in the rest of the U.S. is the source of most of the clean fuel consumed in the Northwest
  - Biofuels from low-cost biomass from elsewhere
  - Electrofuels from states with abundant renewables resources, particularly the Southwest
- Meeting 2030 emissions targets is particularly difficult in the Northwest
  - Transportation stocks and other parts of the economy have not had enough time to significantly electrify, leaving high volumes of end use fuel consumption
  - This near-term bottleneck is met with biofuels and electrofuels before electrofuel takes over as the dominant source of clean fuel
  - Note: clean fuel consumption in the Northwest is also driven by assumed 40% emission reduction targets in Montana and Idaho by 2030, targets that are unlikely to be in place. The impact of this would be to lower biofuel demands
- Fast Transport: 30% decrease in imported clean fuels in 2030
- Slow Transport: 200% increase in imported fuels and 70% increase in Northwest supply by 2050



Task 5: Pace of Transportation Impact on Electric Loads

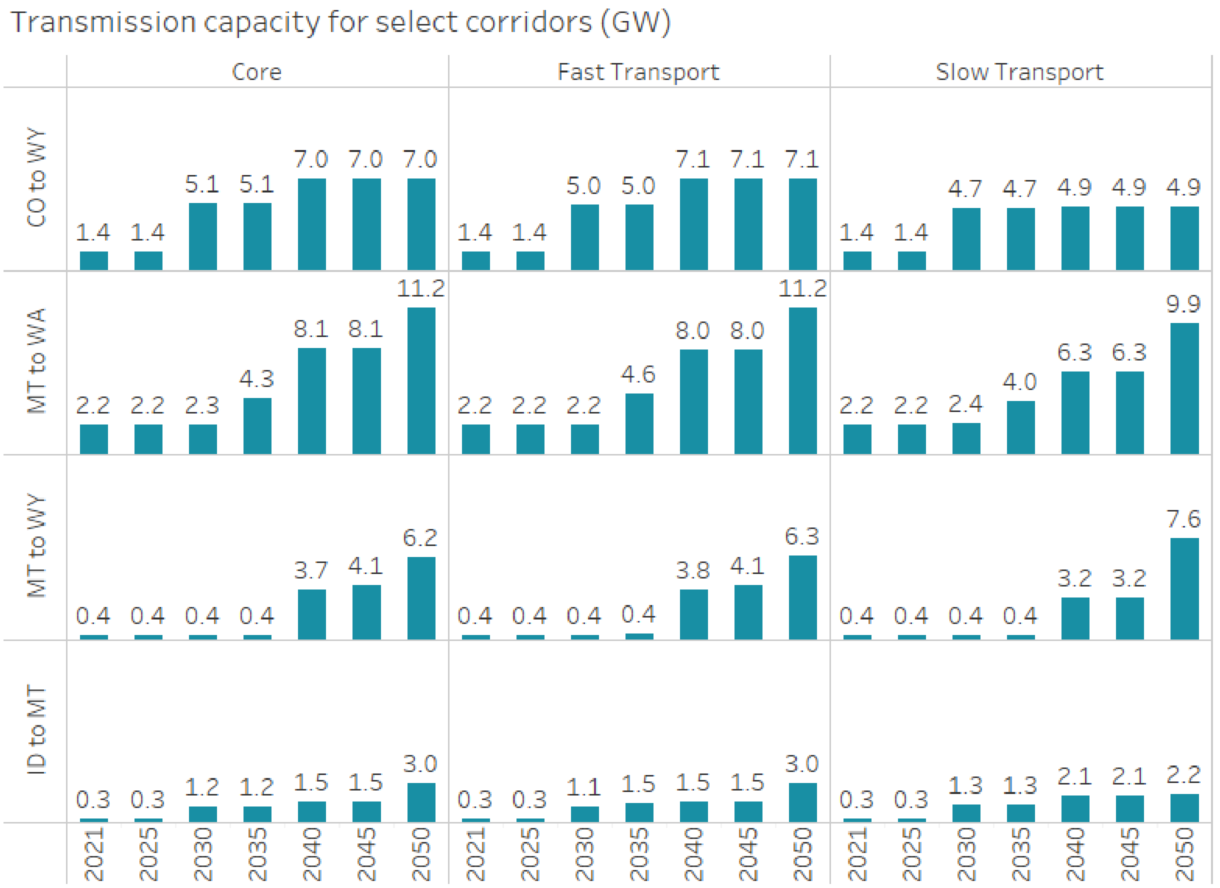
- Electric loads in the Northwest are similar in the Fast Transport scenario to the Core and decrease by 5% by 2050 in the Slow Transport scenario
  - The decreased demand from reduced electrification in transportation is larger than the growth in electrolysis loads
- However, across the West, Slow Transport increases electric loads by 35%
  - Regions with excellent renewable resources are tapped for energy to produce clean fuels
  - Electrolysis becomes majority of electric loads by 2050
  - Much larger West-wide electricity sector needed
- Fast Transport and Core are similar because higher demands in the Core in 2030 come from increased biomass consumption



Task 5: Pace of Transportation Transmission

EVOLVED ENERGY RESEARCH

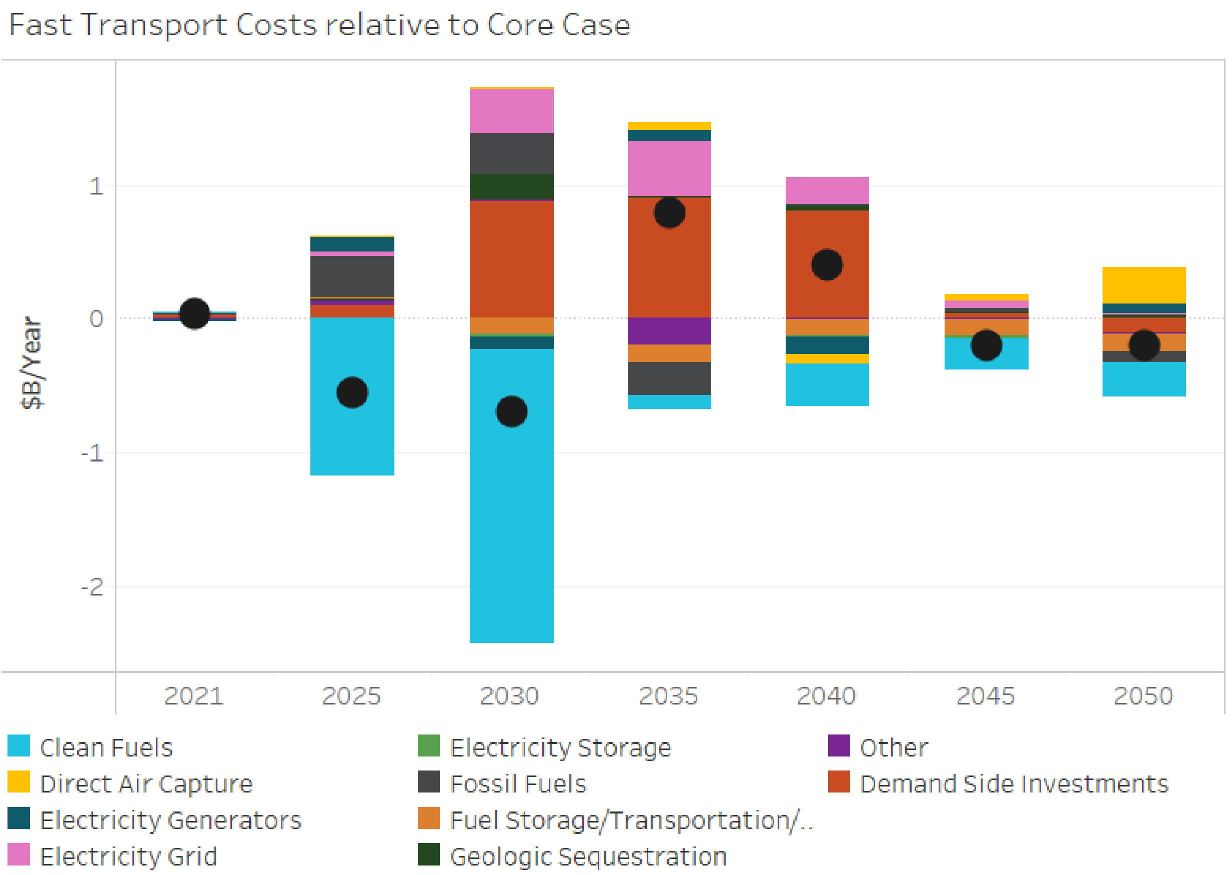
- The decrease in electric loads in the Northwest reduce transmission expansion in the Slow Transport scenario
  - Decreased flows between east and west reduce expansion of the MT to WA and MT to ID corridors by 2050 relative to the Core Case
- Slow Transport clean fuels demand is met with increased loads for fuels production further south and in Montana relative to the Core Case
  - Reflected in transmission expansion impacts in the north-south direction between Montana and Colorado



Task 5: Pace of Transportation Cost Impacts – Fast Transport

EVOLVED ENERGY RESEARCH

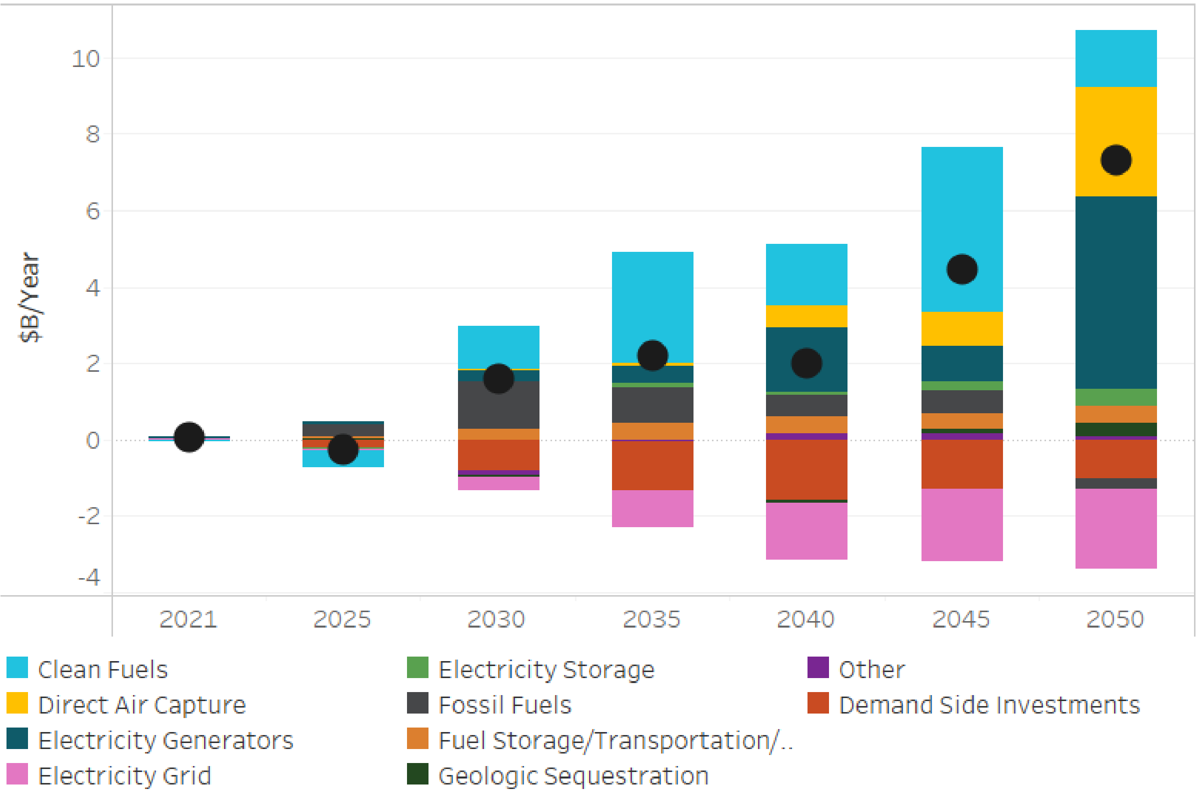
- Fast Transport reduces the costs associated with clean fuels production in 2030 vs the Core Case
  - Reduced clean fuels investment: Less fuel demand due to more electric vehicles
  - Greater demand side and distribution system investment: Accelerated electric vehicle adoption and growth in customer loads
  - Greater fossil fuel purchases: Shifts economic balance in emissions accounting towards sequestration
- 2035 and 2040 reductions in clean fuel costs offset increased vehicle and distribution costs
- IRA will reduce demand side costs: cost differences relative to the Core Case shown here reflect the full capital cost of the vehicle
  - Tax incentives for vehicle purchases reduce costs for the region (see page163)



Task 5: Pace of Transportation Cost Impacts – Slow Transport

- Slow Transport impacts are relatively small through 2030 versus the Core Case
  - Differences in vehicle sales result in additional costs from clean fuels offset by avoided vehicle and distribution system investments
  - IRA hydrogen incentives control 2030 clean fuels costs
- As adoption stalls post 2030, clean fuels costs rise and savings in vehicle costs and distribution system investments are not enough to control rising cost impacts
- By 2050, clean fuel volumes are significant at ~50% of today's volumes of fossil liquid fuels
  - Cost of producing it raises costs by $7.3B/year by 2050
- Electrification of the vehicle fleet is necessary for cost containment when achieving net-zero emissions

Slow Transport Costs relative to Core Case



Task 5: Pace Of Transportation Impact of IRA

EVOLVED ENERGY RESEARCH

- The complexity of vehicle tax credits under IRA, including income brackets, vehicle classifications under IRS tax code, and domestic content provisions, including who qualifies among vehicle manufacturers and suppliers of constituent parts, make predicting total tax credits over the next decade very difficult
- We have chosen to be conservative and not reflect these tax credits in the costs presented on previous slides
- However, adoption rates of electric vehicles will be impacted by IRA
  - We have used the sales predictions under IRA made by the Princeton REPEAT study that analyzed IRA's impacts
  - Where our own targets become more stringent, in getting to 100% ZEV by 2035 in light duty vehicles for example, our higher rates of adoption are used in place of the Princeton REPEAT forecast
- Factoring in the benefits of IRA would improve the economics of the Fast Transport scenario through 2030 and worsen the economics of the Slow Transport scenario
  - In Fast Transport, accelerating vehicle adoption through 2030 already improves the economics for states that have clean fuel requirements by 2030. Whether faster electric vehicle adoption is pursued is not an economic question from a societal cost perspective, but a feasibility and distributional impacts question: Can supporting infrastructure be developed? Can faster adoption be achieved without impacts to equity?
  - In Slow Transport, less vehicle adoption increases costs over time and EV credits would make this impact more pronounced in 2025 and 2030

Task 5: Pace of Transportation Supply Side Discussion

EVOLVED ENERGY RESEARCH

- **Pace of transportation electrification directly impacts clean fuels demand**
  - Washington requires large amounts of clean fuels to meet 2030 emissions targets. Replacing an ICE with an EV substitutes clean fuel demand on the margin with clean electricity under the emissions cap
  - If Montana and Idaho were to achieve 40% emissions reductions by 2030, an EV would directly reduce the clean fuels demand of an ICE like in Washington
  - Oregon, on the other hand, does not need clean fuels in 2030 to meet the emissions target
- **Impacts of slower transition to clean vehicles include:**
  - Reliance on larger amounts of clean fuel in 2030 and beyond
  - Larger investments in electrolysis and Fischer Tropsch drive larger loads and bulk electricity sector investment
  - Savings on investment in vehicles and distribution
- **Impact of accelerated transition to clean vehicles include:**
  - Reliance on less clean fuel, in 2030 in particular
  - A smaller overall electricity sector producing less hydrogen and lower clean fuels production
  - Increased near-term investment in vehicles and distribution

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Task 5: Pace of Transportation

Key Study Findings

Task 5: Pace of Transportation Key Findings Transportation Sector (1/2)

- **Moving away from ICE vehicles is imperative to lowering energy costs during the transition to Net Zero**
  - Stalled transition to EVs and FCVs in the Slow Transport scenario is $8.2b/yr in 2050 more expensive than when vehicle stocks transition fully to EVs and FCVs by 2050 in the Core Case
- **Rapid action to promote vehicle electrification is key to cost containment**
- **Even more rapid vehicle adoption has economic benefits of $0.7B/yr by 2030, but several potential risks and challenges exist**
  - It will require more aggressive policy: Potential challenges with equity between customer groups and limited policy options when meeting a 2030 100% EV sales target
  - Accelerating infrastructure requirements to establish charging networks to support larger EV stocks may not be feasible and a bad customer experience risks derailing adoption goals

Task 5: Pace of Transportation Key Findings Transportation Sector (2/2)

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- **Balance economic benefits and feasibility/achievability**
  - Electric light duty vehicle sales of 100% by 2035, and 100% clean vehicle sales in heavy duty vehicles by 2045 is a cost effective and achievable middle ground with relatively similar costs to moving faster for the Northwest
  - Longer runway to establish charging infrastructure
  - Lower vehicle prices in future years may require lighter policy interventions to achieve target sales outcomes
  - Exception is WA, who has already passed SB 5974 requiring 100% EV sales by 2030. WA stands to benefit most economically from such a policy because 2030 emissions policy in the state drives the need for decarbonized fuels and accelerating vehicle adoption targets from 2035 to 2030 avoid 20% of the clean fuels demand
- **Delaying action has economic repercussions**
  - Delaying sales in light duty EVs past 2035 results in greater 2050 transport fuel demands because of the assumed 15-year lifetime of a vehicle. Remaining transport fuels in 2050 under a net-zero emissions policy drives costs higher
  - If policy stalls and sales of ICEs remain at 50% by 2050, national costs increase by $37b/yr in 2050 over the Core Case, showing the imperative for successful electric vehicle policymaking and infrastructure development

Task 5: Pace of Transportation Key Findings
How does transport policy impact supply side investments?

EVOLVED ENERGY RESEARCH

- Supply side investment/operational differences across transportation scenarios depend on energy demands for electricity and energy demands for clean fuels
  - Washington’s emissions policy requires clean fuels from 2030 onwards in the Core Case. Retaining more fossil fuel demand in vehicles increases that demand in all years through 2050
  - ICEs are less efficient than EVs: Reduced electrification drives larger total energy demands in the economy, requiring a larger energy supply side to serve it
- Slow Transport results in a smaller electricity sector in the Northwest but increases loads across the West by 35%, driving many more infrastructure investments than in the Core Case
  - The majority of the clean fuel consumed in the Northwest is supplied by regions outside of the Northwest with high quality renewable resources or low-cost biomass
  - Stalled electrification of the vehicle fleet in Slow Transport increases reliance in the Northwest on clean fuel purchases from out of state
- Fast Transport reduces reliance on biofuels in the short-term versus the Core Case and reduces costs
  - Feasibility challenges to implementing this policy may make it less attractive than the Core Case vehicle transition, particularly in states whose current policy does not require clean fuels to meet emissions targets in 2030

Task 5: Pace of Transportation Key Findings
What needs to happen by 2030?

EVOLVED ENERGY RESEARCH

- **Rapid growth in electric vehicles sales: Drives lower decarbonization costs**
  - Lower energy consumption from cleaner vehicle fleets have benefits in all years going forward
  - **Tight emissions constraints with no potential for emissions reductions in electricity from 2030 and beyond drive expensive alternatives in futures with higher numbers of ICE vehicles**
    - Post-2030 marginal emissions reductions come from decarbonizing end use fossil fuels and offsetting emissions with DAC/CCS
    - Higher remaining fossil fuel demands increase demand for clean fuels from hydrogen and biofuels
  - **Determine level of policy support required to reach targets**
    - IRA incentives expected to drive significant adoption of EVs. What policy support may be needed to reach 100% ZEV sales targets?
    - Accelerating EV targets to before 2035 comes with economic benefits, however not if feasibility challenges derail adoption goals
- **Investments in charging infrastructure: Key to supporting a rapid shift to electric vehicles and needs to ramp up early**
  - Stock rollover of vehicles and construction of charging networks/distribution system investments take time
  - Delay too long, and the Northwest could run out of runway to avoid high decarbonization costs in the future
  - Strong networks will build customer confidence in EVs

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Task 6: Clean Fuels

Task 6: Clean Fuels

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- Key research questions:
  - What happens if biofuels are less available than anticipated?
  - How would policies that require local production of clean fuels impact decarbonization pathways and costs in the Northwest?
  - How do fossil fuel prices impact clean fuel economics?
  - What happens if hydrogen is more expensive than anticipated, or if hydrogen end use markets do not develop as quickly as anticipated?

Scenario	Description	Expected Results Relative to Core Case
1	Biofuels can be produced only from waste products, not from energy crops	Reduced supply of biofuels will necessitate more synthetic fuel use and emissions reductions from other end uses.
2	All clean fuels must be produced locally (not imported from other regions)	Increase in electricity generation and transmission requirements in the Northwest, as local production displaces imports from regions with low-cost renewables.
3	Decelerated hydrogen market development	International shipping in the core scenario begins to use hydrogen-based ammonia in 2030 and 2035 and hydrogen replaces gas in industrial boilers. Preventing that use of hydrogen until 2040 indicates what size hydrogen market can be supported by alternate end uses in the near-term.
4	Low fossil fuel price	Clean fuels less competitive
5	High fossil price	Clean fuels more competitive
6	High H2 electrolysis price	Core Case assumes electrolysis prices drop substantially through 2050. Higher electrolysis price assumption will make hydrogen relatively more expensive than in the Core Case. The magnitude of the impact to overall hydrogen production indicates how robust IRA subsidies are.

Task 6-Clean Fuels Overview

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- The following slides present comparisons to the Core Case across the following categories:
  - Hydrogen demand: How do the different clean fuels scenarios impact hydrogen demand?
  - Fuel supply: How are liquid and gaseous fuel demands met?
  - Carbon supply: Where does carbon for clean fuels and sequestration come from?
  - Costs: What does the Northwest spend more on and what does it spend less on?
- The scenarios presented are divided into two categories:
  - Policy scenarios: Delayed H2 Market, Local Clean Fuels, Limited Biomass
    - These represent either policy decisions on qualifying resources to meet emissions goals, development of markets or supply based on policy decisions, or uncertainties that drive the same outcomes
  - Price sensitivities: High Fossil Price, Low Fossil Price, High H2 Cost
    - Testing changes to projections of uncertain future prices to examine their impact on resource decisions and decarbonization costs
- For overall scale of the differences, each of the results categories above are presented not as a difference but overall supply or demand in the appendix to this report

Task 6: Clean Fuels Scenario Assumptions

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Scenario	Description	Fossil Fuel Price Forecast	Biomass Potential	Hydrogen Demand	Electrolyzer Capital Cost	Clean Fuel Transportation
--	Core	AEO Reference	Derived from 2016 Billion Ton Study (BTS)	Shipping fuel eligible for conversion to ammonia in 2030; industrial boilers begin to convert to direct hydrogen in 2025	Hydrogen electrolyzer capital cost forecast from IRENA(1), reflects an 80% capital cost decline from 2020-2050	Clean fuels can be imported to the Northwest from other US regions via new or existing pipelines, or existing liquid fuel trucking networks
1	Limited Biomass	Same as Core	Purpose-grown biomass feedstocks are eliminated from BTS, meaning only waste and residual feedstocks are available	Same as Core	Same as Core	Same as Core
2	Local Clean Fuels	Same as Core	Same as Core	Same as Core	Same as Core	All electrofuels and biofuels consumed in the Northwest must be produced in-state, no interstate/interregional transport of clean fuels is allowed
3	Delayed H2 Market	Same as Core	Same as Core	Shipping fuel conversion to ammonia and industrial boiler conversion to hydrogen are delayed until 2040	Same as Core	Same as Core
4	Low Fossil Price	EIA High Supply	Same as Core	Same as Core	Same as Core	Same as Core
5	High Fossil Price	EIA Low Supply	Same as Core	Same as Core	Same as Core	Same as Core
6	High H2 Price	Same as Core	Same as Core	Same as Core	Electrolyzer capital cost declines only 50% from 2020-2050	Same as Core

(1) https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

Task 6: Clean Fuels
Fuel Price Forecasts

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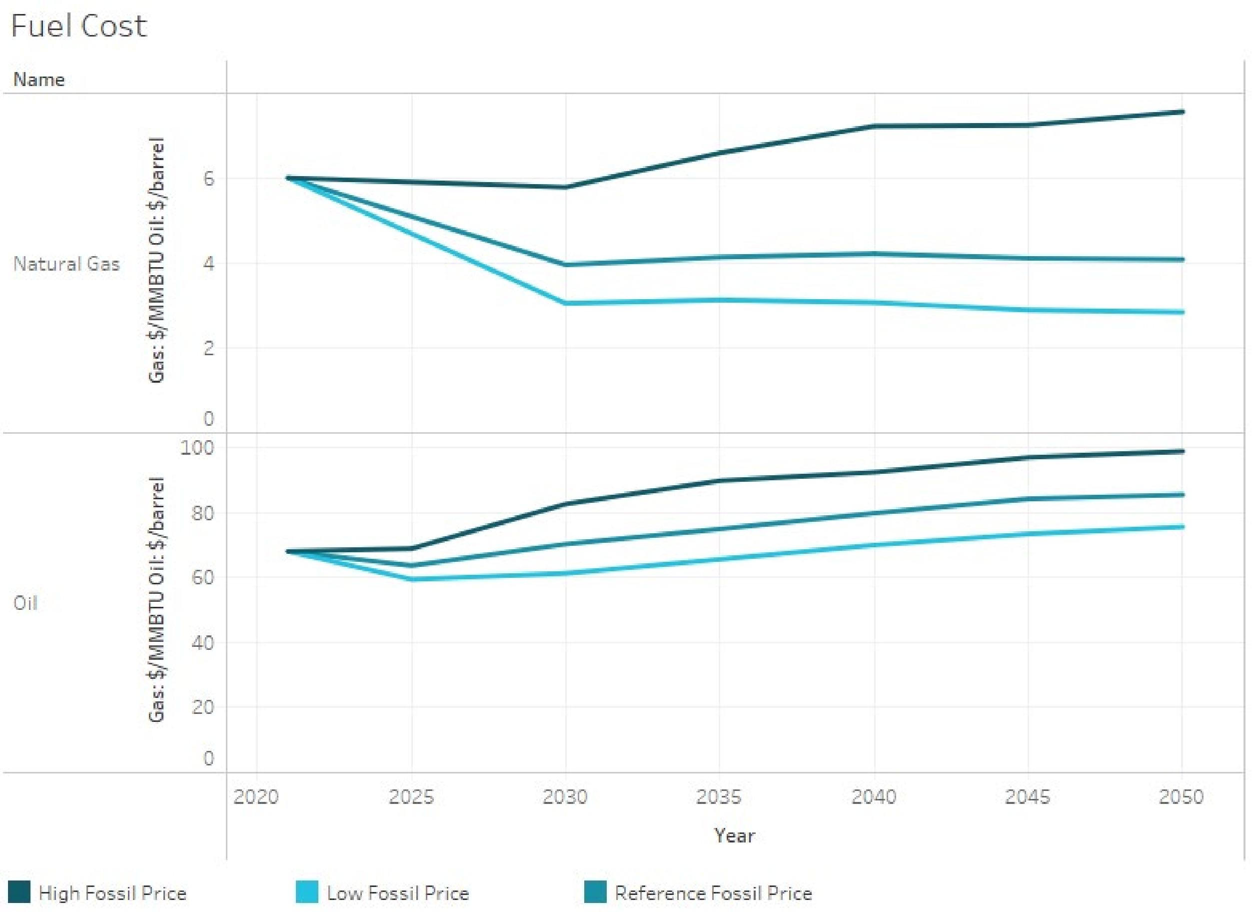
- Fuel price forecasts from EIA 2022 Annual Energy Outlook
  - Reference
  - High Fossil Price (EIA low supply scenario)
  - Low Fossil Price (EIA high supply scenario)
- Near-term gas pricing from recent gas market data
  - Linear interpolation to 2030 EIA forecast
- Forecasts are lower than recent price spikes due to geopolitical events
  - Potential for higher prices than forecast
  - However, scenario differences illustrate the impact on decarbonization costs of changing fossil fuel prices



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Task 6: Clean Fuels

Hydrogen, Carbon, and Fuels Totals By Scenario

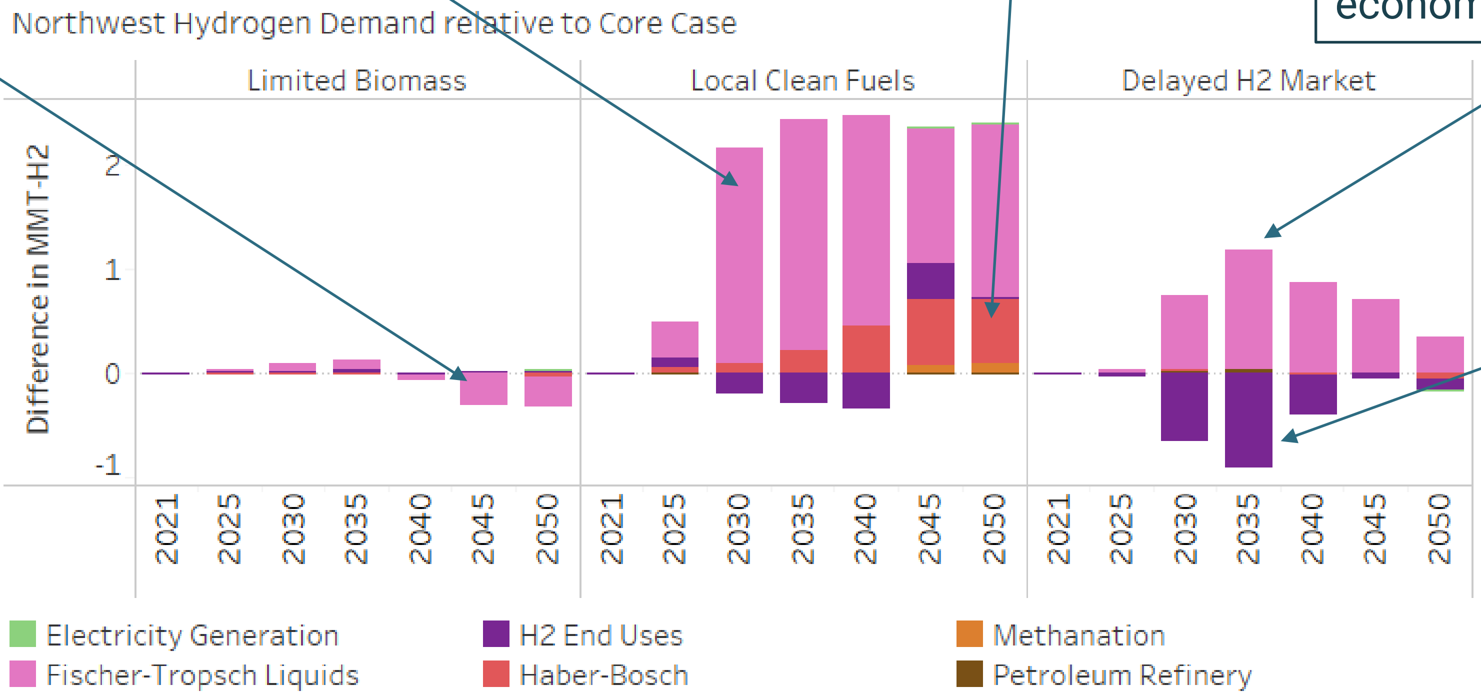
Task 6: Clean Fuels
NW Hydrogen Demand – Policy Scenarios

Limited Biomass decreases FT due to reduced carbon capture from biomass conversion in later years

Local Clean Fuels drives FT production of fuels that were previously imported from outside the Northwest

Ammonia production also brought into the Northwest for shipping demand in Oregon and Washington

Delayed H2 Market does not decrease hydrogen volumes but shifts it into production of drop-in fuels via FT. Driven by the economics of IRA



Delayed H2 Market delays demand growth in shipping and industrial H2 boilers

Task 6: Clean Fuels
Hydrogen Demand – Price Sensitivities

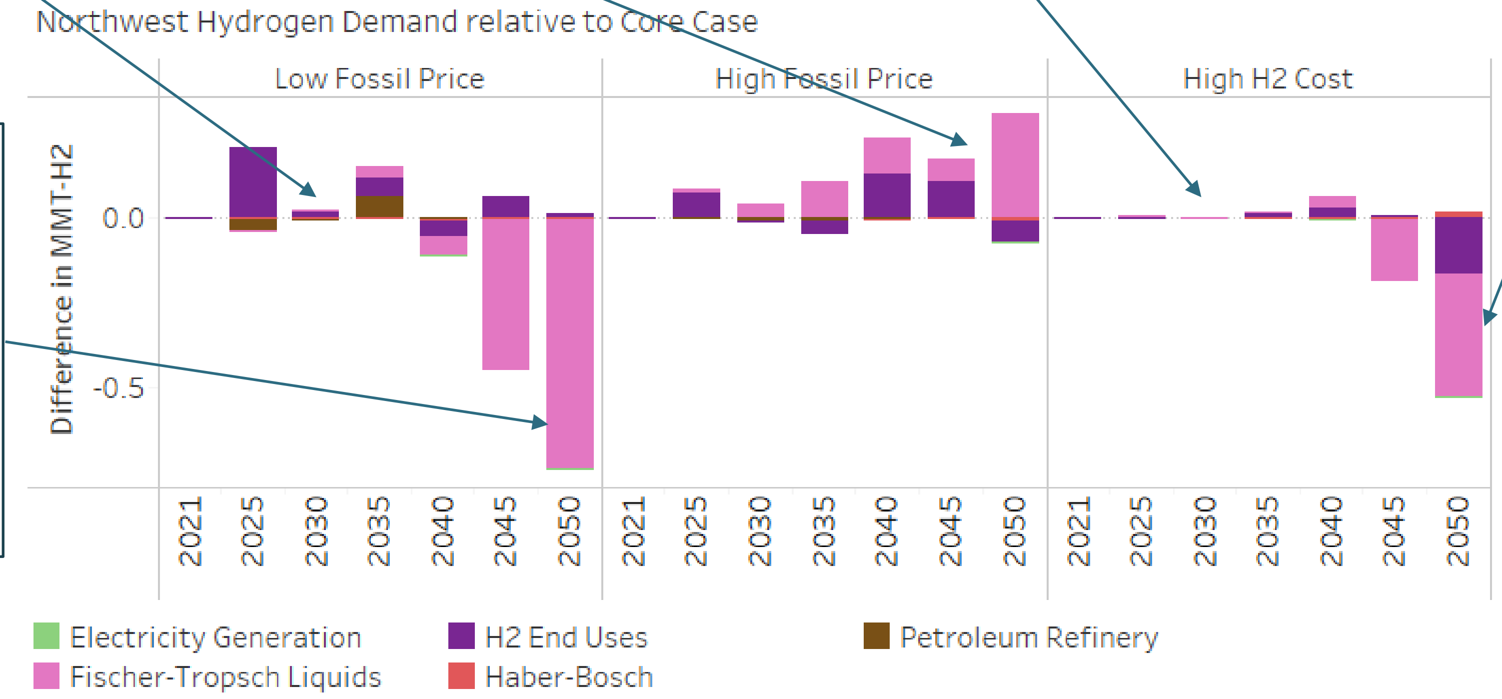
Little impact of lower fossil prices in the near-term

High Fossil Price drives greater production of clean fuels via FT to displace fossil fuel use

Higher electrolyzer costs have little impact in 2030 when clean fuel demand is driven by emissions targets and IRA H2 incentives

High H2 Cost has reduced H2 use in later years. Increased biofuel use and CO2 sequestration

Reduced hydrogen demand as some fossil fuels remain in the economy in 2050, offset by increased carbon sequestration

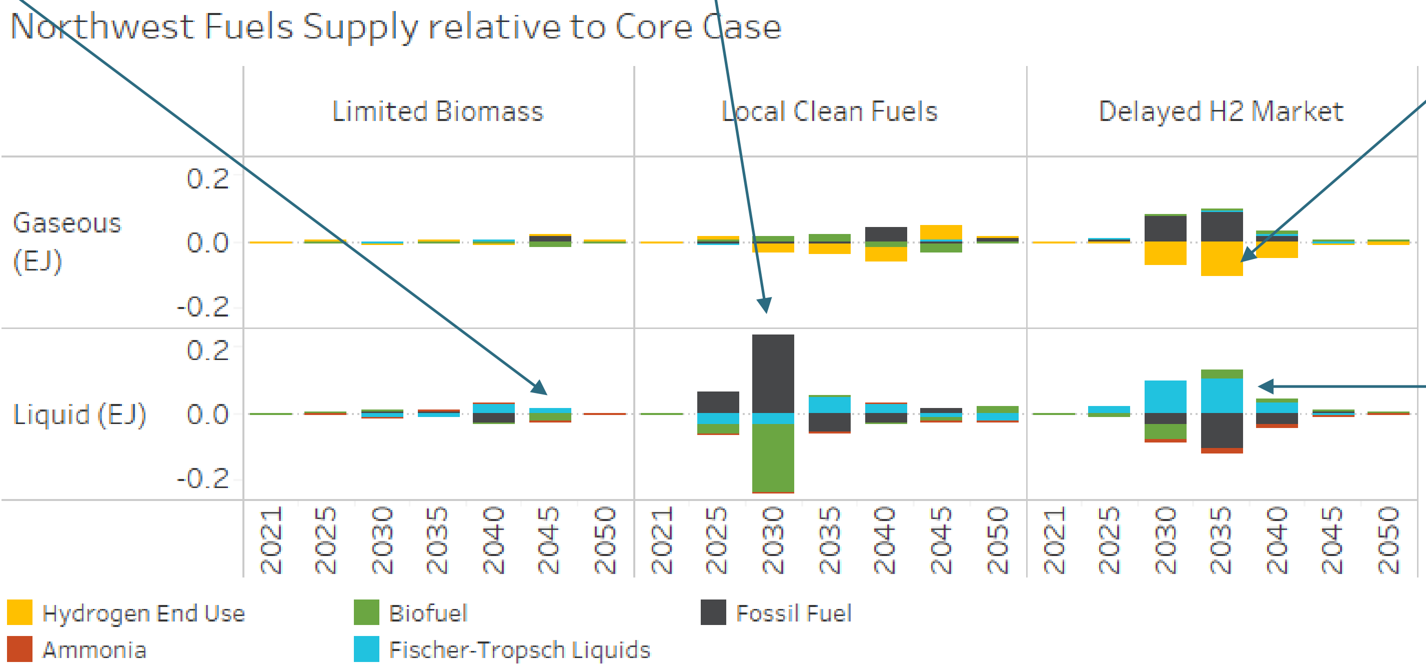


Task 6: Clean Fuels
Fuel Supply – Policy Scenarios

Low amounts of biomass displacement with fossil and clean fuels

Local clean fuels reduces biomass usage in 2030, offsetting greater fossil fuel consumption with land use measures/CCS. These may be infeasible given the short timeline, suggesting a larger clean fuels market is necessary

Delayed H2 market reduces gas usage in H2 boilers prior to 2040, driving more fossil consumption



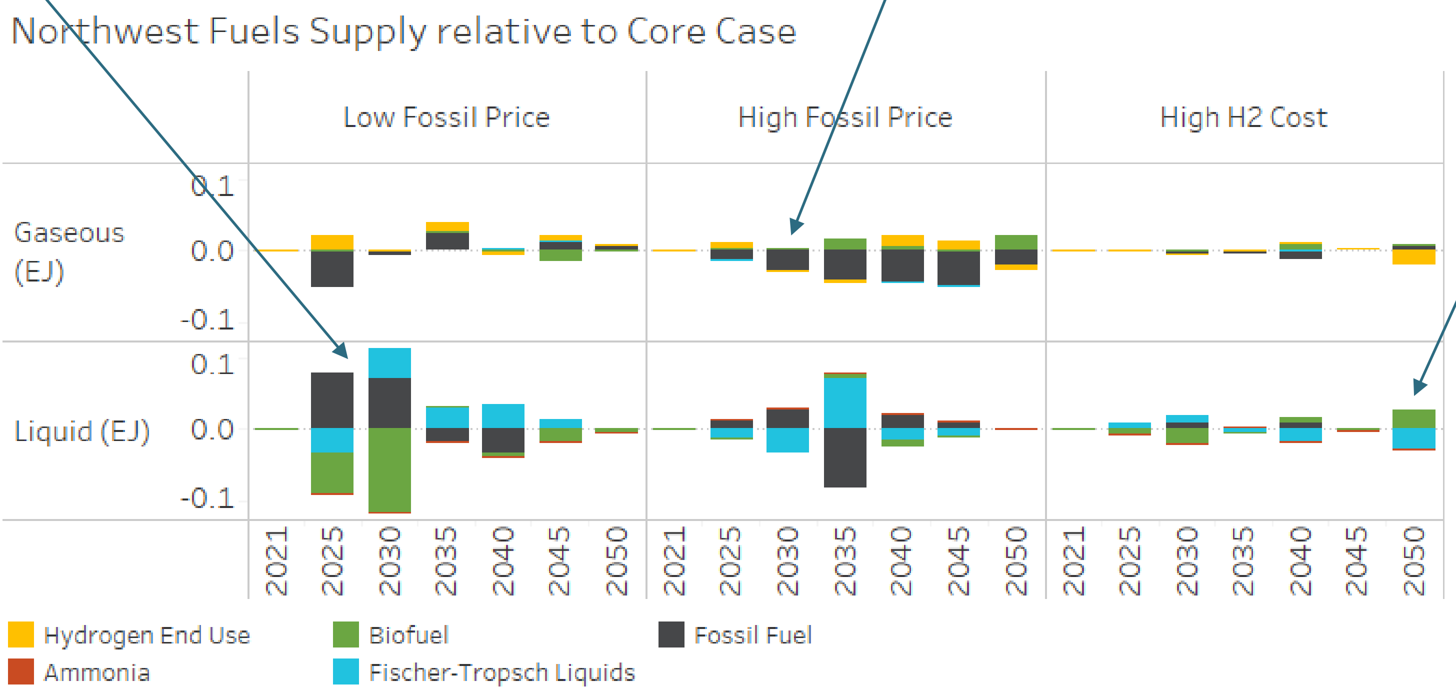
Delayed H2 market reduces emissions introduced in gaseous fuels with increased Fischer-Tropsch liquids

Task 6: Clean Fuels
Fuel Supply – Price Sensitivities

Low Fossil Price increases fossil fuel use nationally, driving more carbon sequestration to offset it. In the Northwest, the trend is more convoluted, a result of being only a piece of a national fuels market.

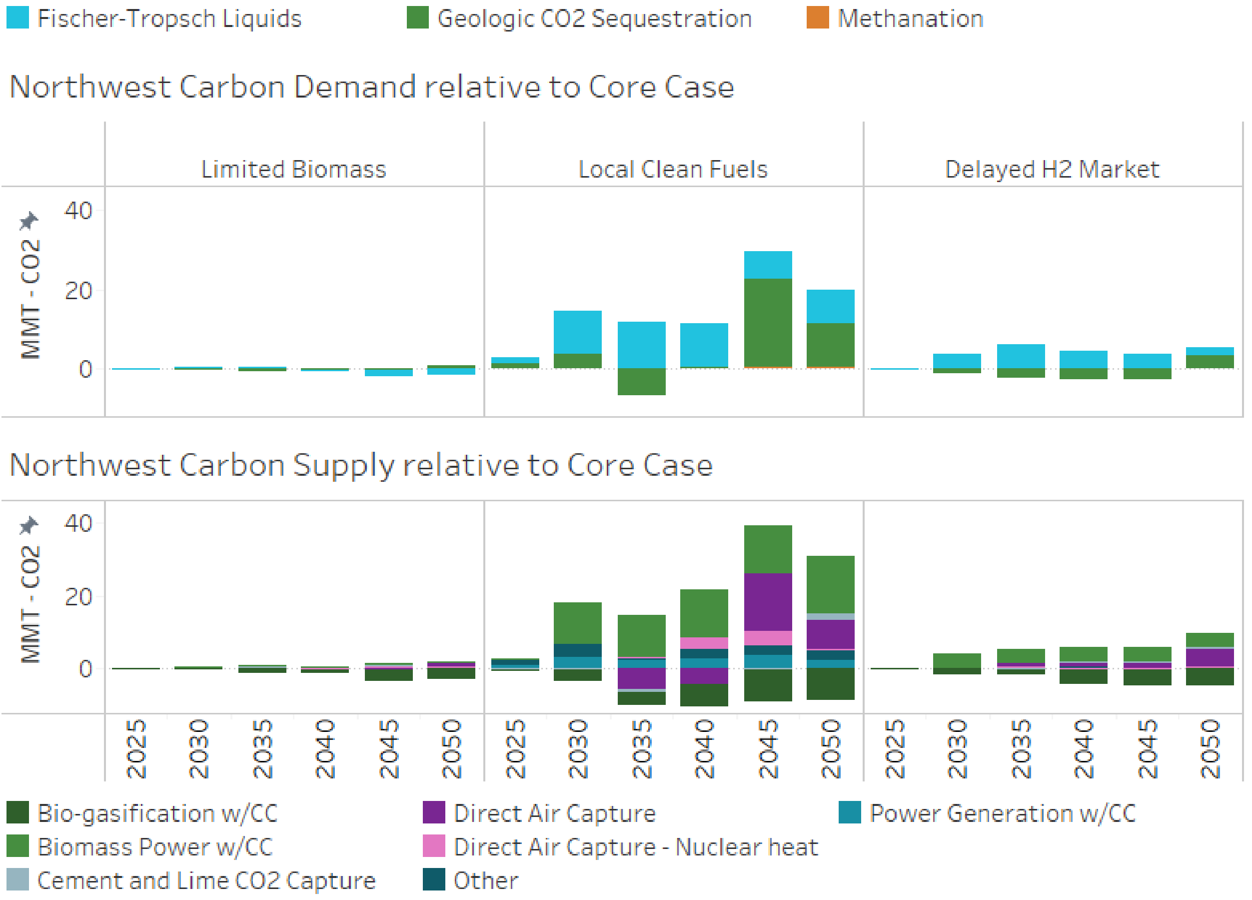
Higher Fossil Fuel prices drive reductions in fossil fuel use, but as with Low Fossil Price, this is convoluted in the Northwest.

High H2 Cost has minimal impact. Some substitution of biofuels for hydrogen and Fischer-Tropsch in 2050.



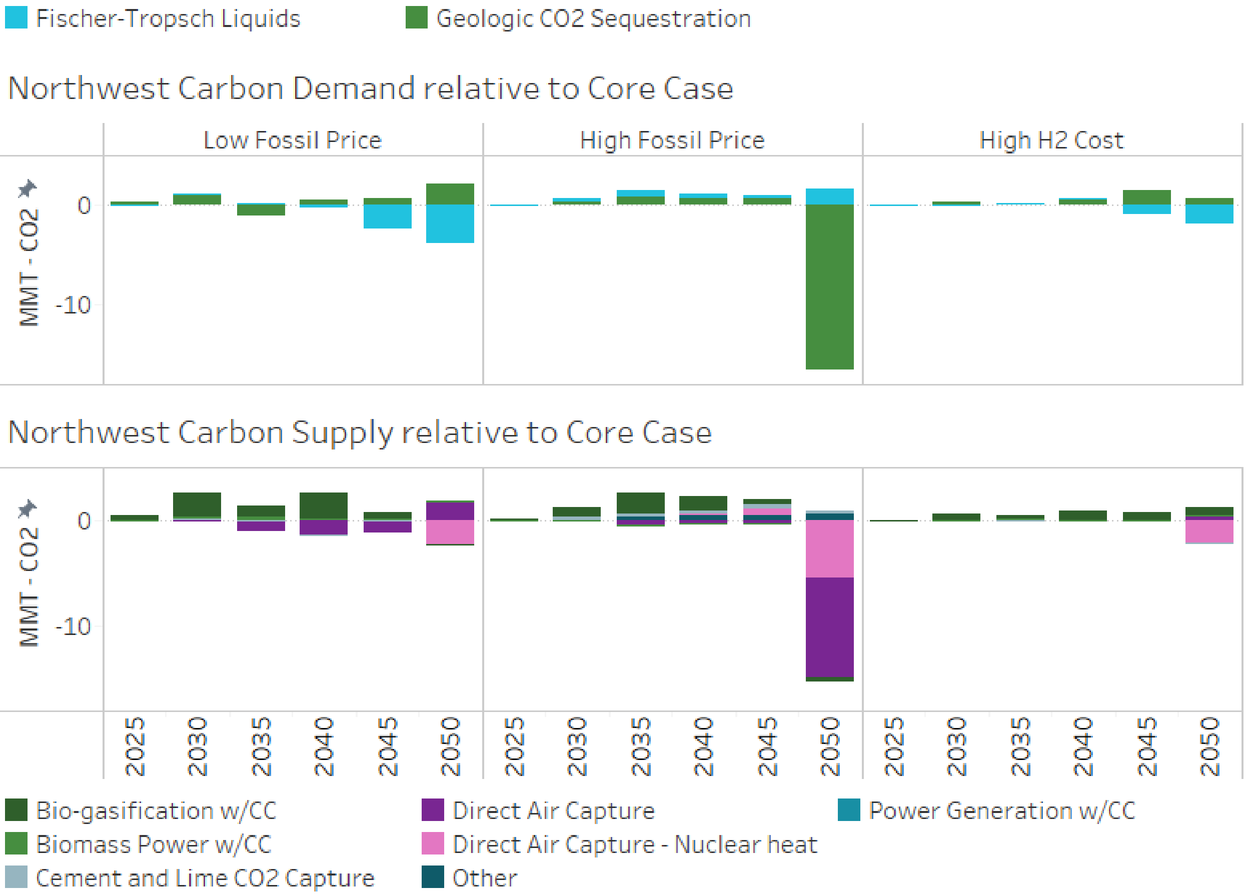
Task 6: Clean Fuels
Carbon Supply – Policy Scenarios

- Delayed H2 Market diverts hydrogen production from end uses into fuels production, requiring additional carbon earlier
  - Invests in power generation with carbon capture to support increased hydrogen demands from Fischer-Tropsch
- Limited Biomass has minimal impact on carbon. Small reductions in final years from reduced bio-gasification with carbon capture
  - Even when reducing biomass potential by 68%, the economics of hydrogen from electrolysis helped by IRA means that biofuel does not have a large role to play
- Local clean fuels drives a significantly different economy, requiring local Fischer-Tropsch and local carbon supply
  - Power generation with CC as well as increased direct air capture provide the additional carbon



Task 6: Clean Fuels
Carbon Supply – Price Sensitivities

- High Fossil Price makes the economics of continuing to use fossil in 2050 worse than in the Core Case
  - Reduced carbon capture from DAC and reduced sequestration
- High H2 Cost reduces electrofuel production and therefore reduces DAC
- Low Fossil Price increases carbon sequestration by 2050 to offset increased use of the lower cost fossil fuels
  - Additional carbon demand met with power generation with carbon capture and DAC



Task 6: Clean Fuels
Local Clean Fuels – Generation & Consumption

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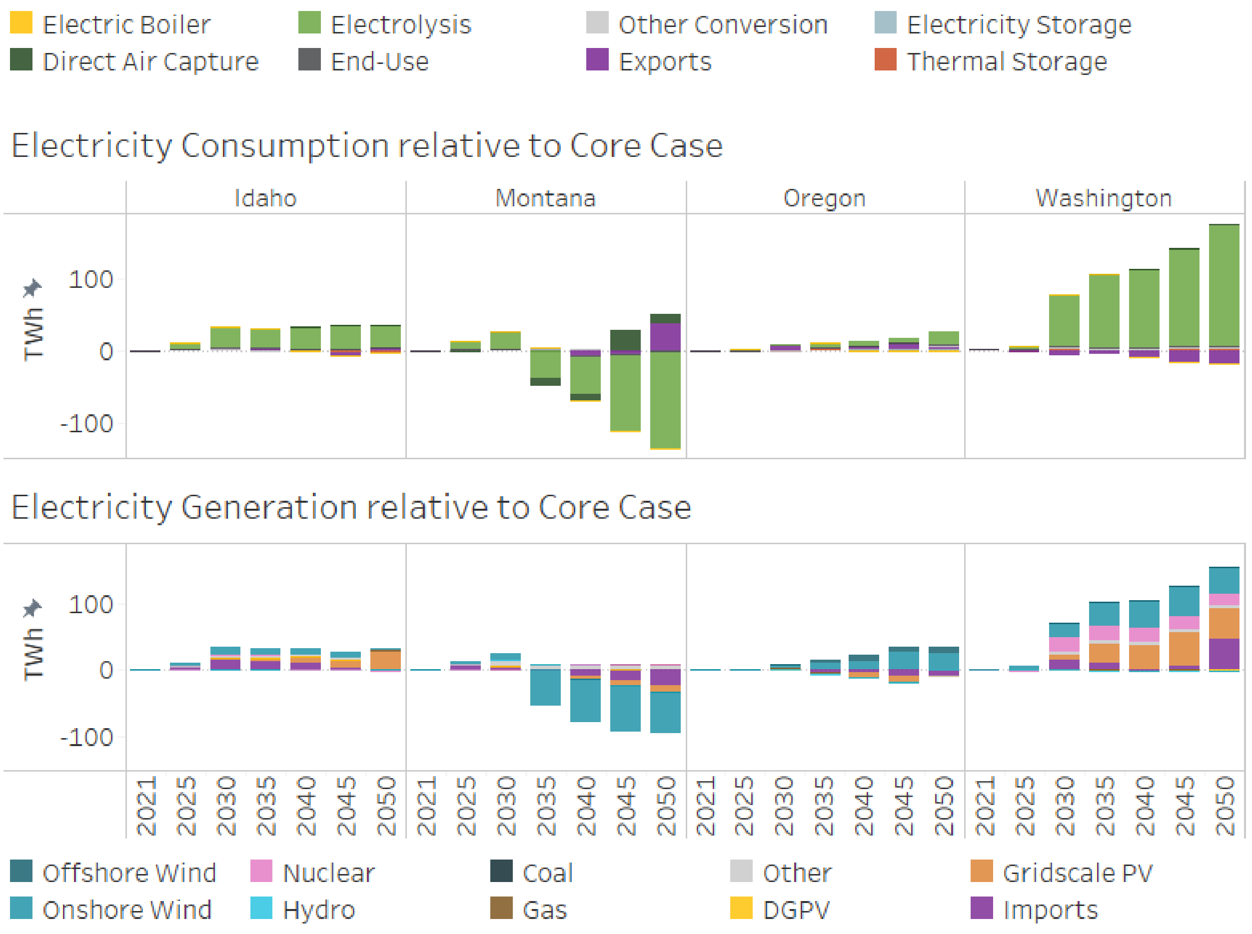
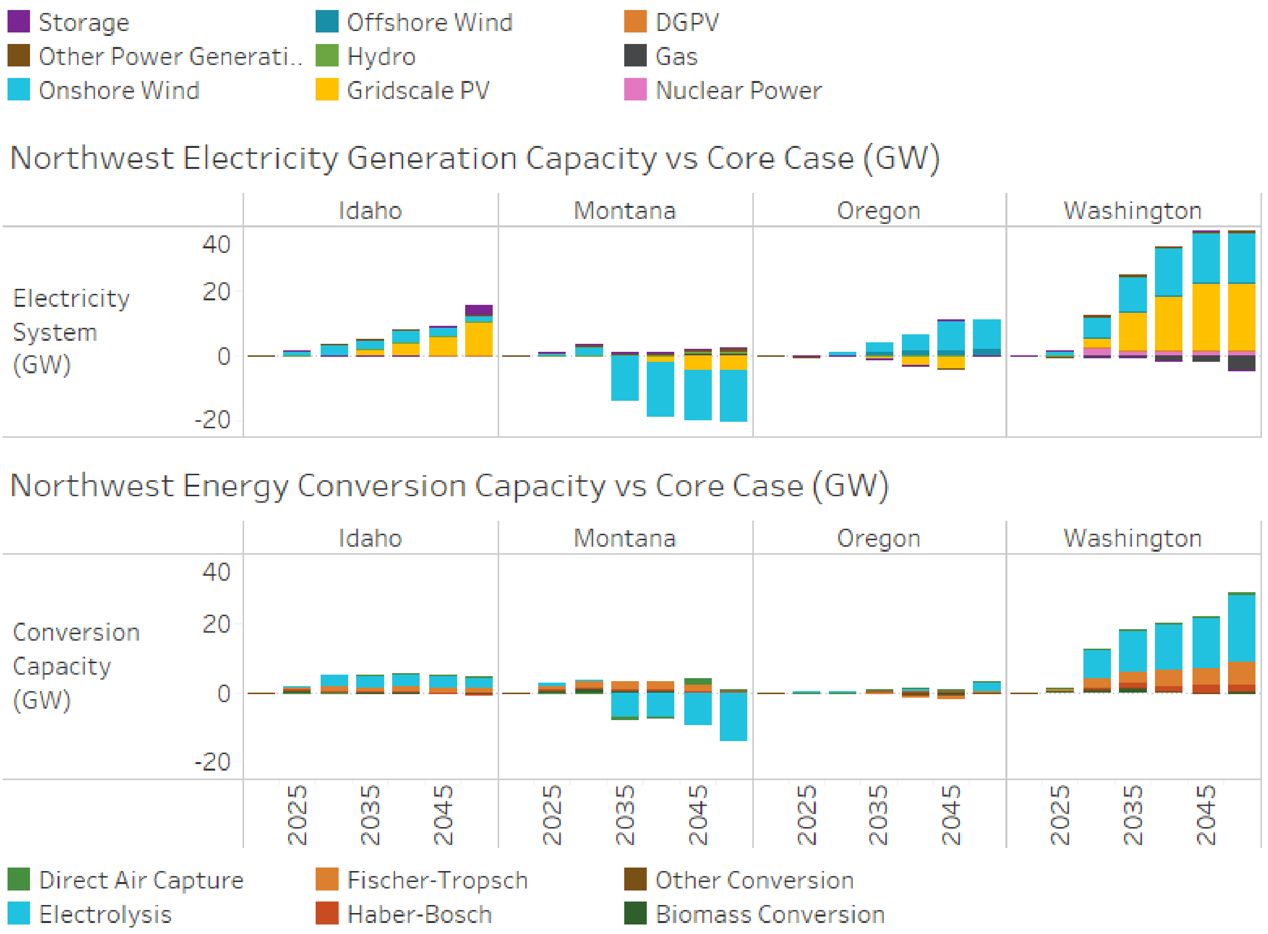
- Requiring clean fuels to be produced locally drives a significantly different electricity system
  - Growth in electrolysis, particularly in Washington to serve fuel demands in local load centers
  - Decrease in electrolysis in Montana as exports are no longer permitted
- Additional energy demands met with growth in imports, solar, wind, and nuclear



Task 6: Clean Fuels
Local Clean Fuels – Generation Capacity

- Significant increases in conversion capacity to meet hydrogen and fuel demands starting in 2030 in Washington
  - An additional 8.5 GW of electrolyzers by 2030 and an additional 19 GW by 2050
- Capacity additions over Core Case reaching 40 GW in Washington by 2050
- Reductions in gas capacity as flexibility of large electrolysis fleet provides additional balancing
- Decrease in both conversion capacity and electricity system in Montana, reducing onshore wind capacity by 16 GW by 2050

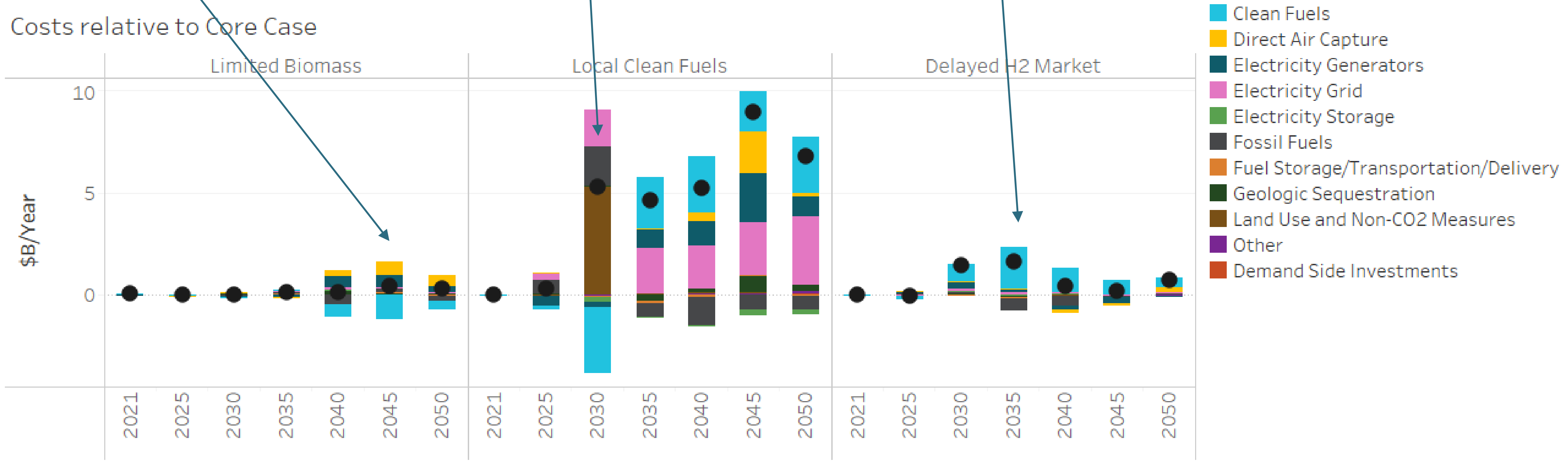


Task 6: Clean Fuels Costs – Policy Scenarios

Low-cost impact from Limited Biomass due to the relatively low levels of biomass usage in the Core Case

Local Clean Fuels drives additional local electricity system costs, clean fuels costs, and, in 2030, carbon offset costs

Delayed H2 Market redirects hydrogen into clean fuels production, raising the clean fuels costs

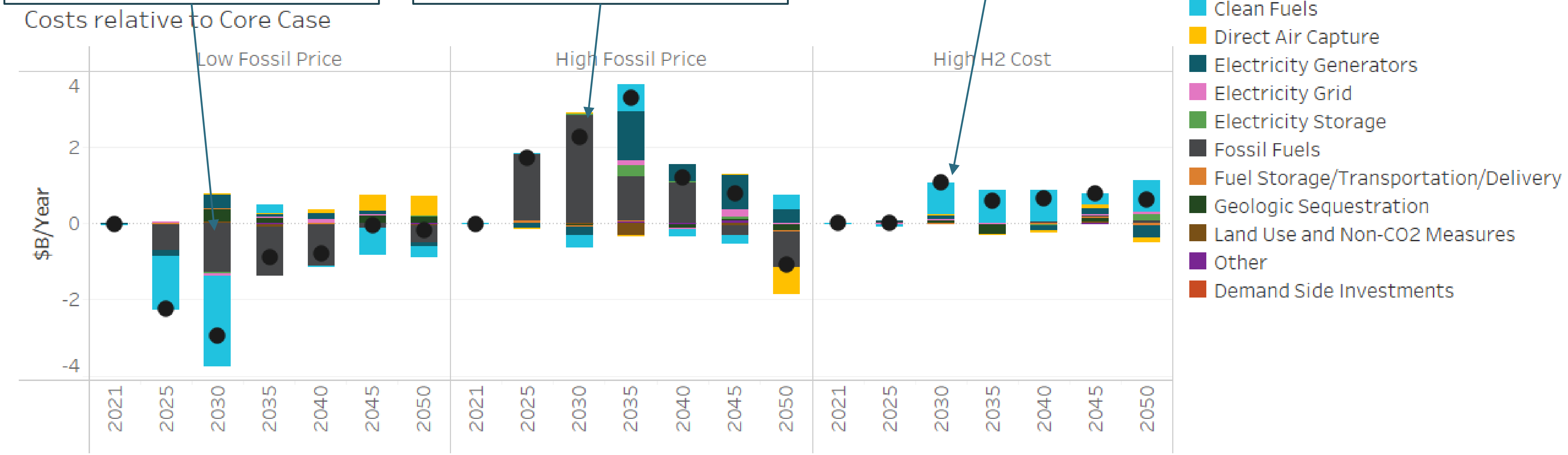


Task 6: Clean Fuels Costs – Price Sensitivities

Decrease in fuel costs in Low Fossil Price, as well as decreased clean fuels costs. More fossil fuels burned with increased carbon sequestration

Increased fuel costs in High Fossil Price, as well as increased electricity and clean fuels costs from additional displacement of fossil use

High H2 Costs drives up the cost of clean fuels



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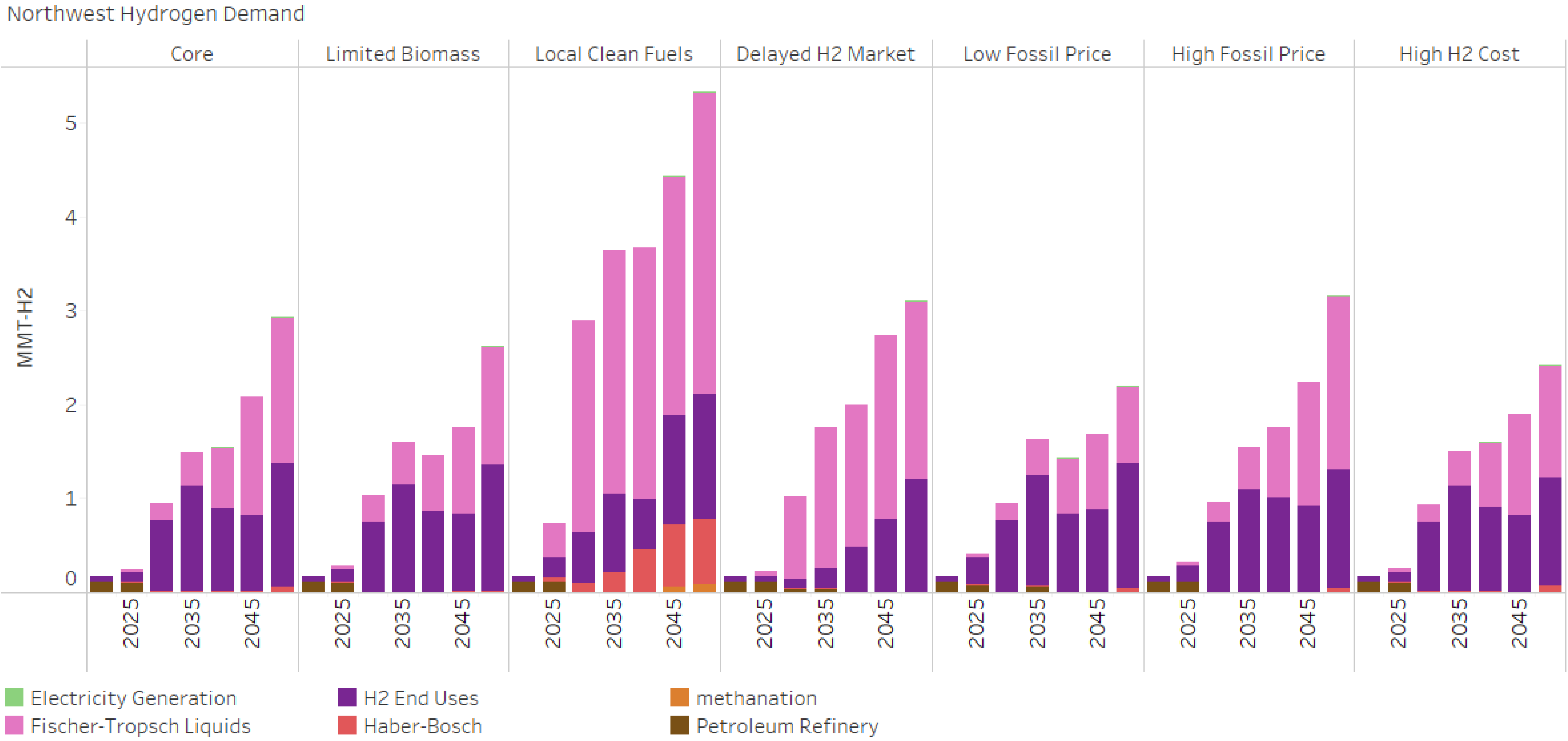
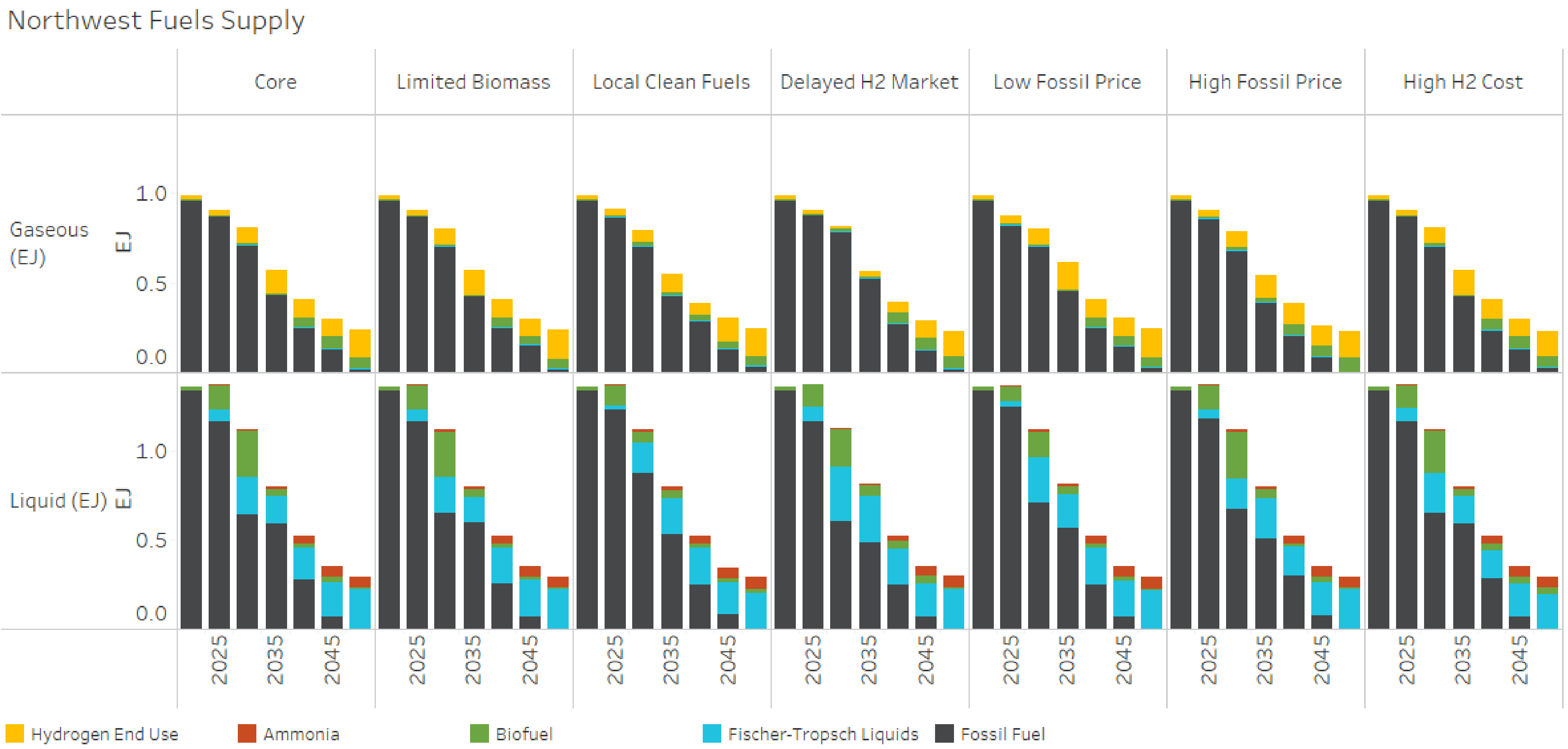
Task 6: Clean Fuels

Results

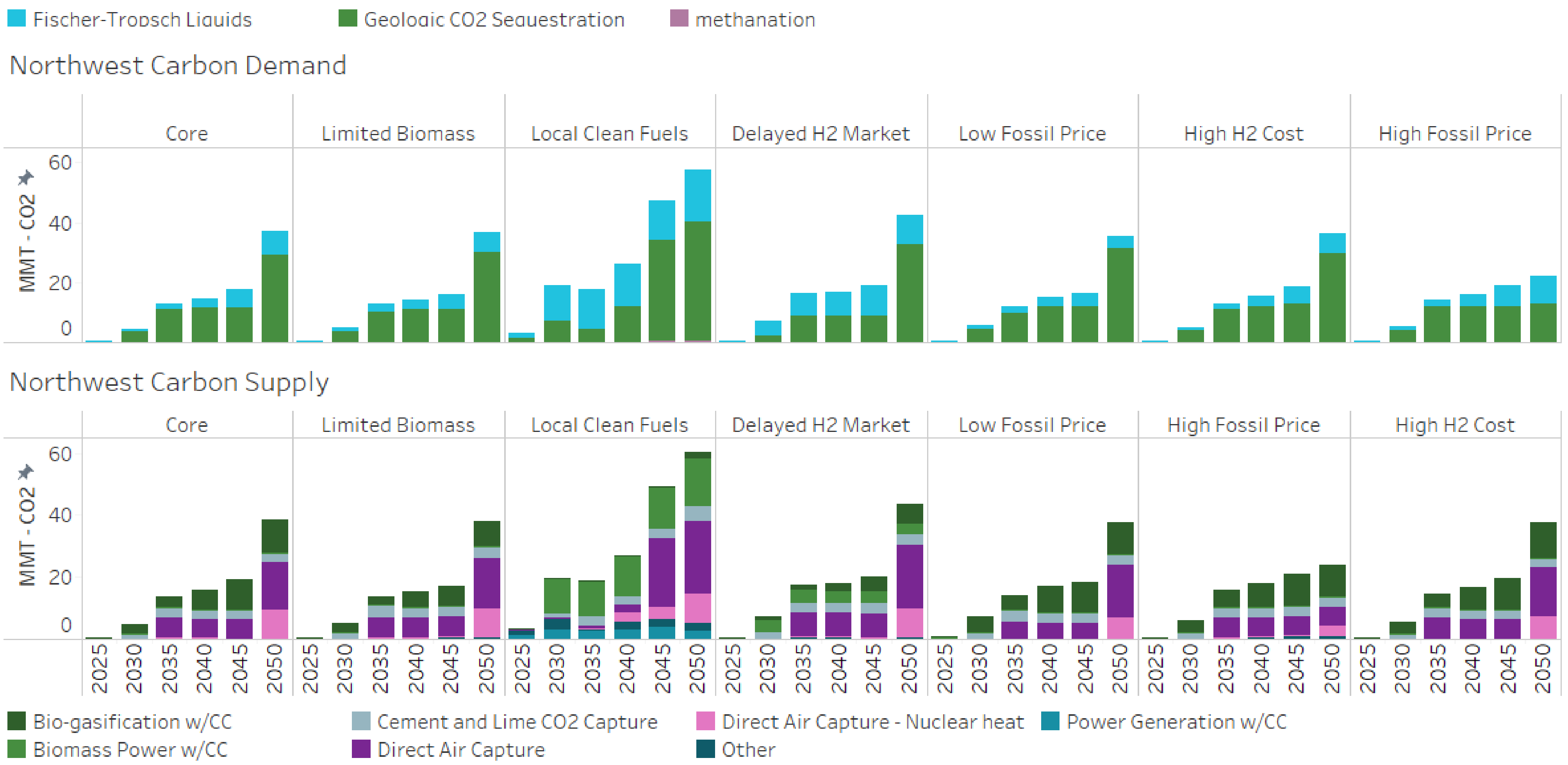
Task 6: Clean Fuels Hydrogen Demand



Task 6: Clean Fuels
Fuel Supply



Task 6: Clean Fuels
Carbon Demand And Supply



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Task 6: Clean Fuels

Key Study Findings

Task 6: Clean Fuels Key Findings
What If Biofuels Are Less Available?

- Limited Biomass restricts biomass availability to only biomass waste and no purpose-grown energy crops
  - Reduces available biomass by 68%
- Relatively little impact on decarbonization pathway and costs
  - Small amounts of displacement of biofuels with fossil and electrofuels
  - Biomass potential not close to full utilization in the Core Case, though biomass plays an important role in providing carbon for sequestration and electrofuels production
- These findings are based on competition between biofuels and electrofuels
  - IRA incentives for hydrogen and direct air capture and costs of electricity and conversion processes mean that purpose-grown energy crops not necessary for decarbonization cost containment
- Large amounts of uncertainty
  - Dependent on both uncertain prices and policy

Task 6: Clean Fuels Key Findings
What If Local Production Of Fuels Required?

- Local Clean Fuels requires that fuels production occurs in the state the fuel is consumed
  - States must rely on local biomass or produce hydrogen and clean fuels in-state to serve local loads
  - Restrictive for states that have lower quality renewable resources or limited biomass
- 2030 bottleneck – where to source clean fuels prior to hydrogen industry ramping up?
  - Washington requires large amounts of clean fuels in 2030. Biomass is limited and hydrogen and clean fuels production cannot ramp up fast enough, so Washington requires some form of CO2 offset to reach the 2030 target
  - Shows that achieving 2030 targets with local clean fuels faces feasibility challenges
- Requiring local production of all clean fuels dramatically shifts electricity supply expansion in the Northwest, requiring 40 GW of additional electric capacity in Washington by 2050 relative to the Core Case
  - Growth in grid-scale PV, wind, nuclear, and imports in the state to meet demands for electrolysis
- Costs are $5B/yr-$10B/yr higher than the Core Case from 2030 to 2050
- Feasibility issues make this a pathway where everything must go right
  - If states cannot meet their own clean fuel demands, they will not reach net-zero targets

Task 6: Clean Fuels Key Findings
What If A Market For Hydrogen Is Delayed?

EVOLVED ENERGY RESEARCH

- Delayed H2 Market restricts ammonia use in shipping and hydrogen use in industrial boilers until 2040 and after
  - Represents a world where technology and acceptance moves more slowly
- Hydrogen production does not decrease
  - Shifted hydrogen usage away from shipping and end use boilers and into fuels production
  - Hydrogen incentives under IRA are valuable and the model must capture them early to use them
  - Emissions reductions previously in shipping and industrial boilers now captured from increased clean fuels
- Diversion of hydrogen from direct use into electrofuels also diverts carbon away from sequestration and into fuels production
- Delayed H2 Market increases costs, particularly in 2030 and 2035

Task 6: Clean Fuels Key Findings
What If Hydrogen Infrastructure Is More Expensive?

EVOLVED ENERGY RESEARCH

- Impact of increased hydrogen infrastructure costs is small on both costs and fuels production pathways
- Higher electrolyzer costs reduce overall hydrogen consumption, in favor of greater biofuel use and fossil fuel use with carbon sequestration
- Most of the reduction in hydrogen consumption comes from a decrease in production of drop-in electrofuels
  - This decrease in electrofuels production also causes a reduction in direct air capture investment, as less carbon is demanded for fuel synthesis
- Demand for direct hydrogen in industrial boilers also declines, replaced with greater electricity and pipeline gas consumption in boilers

Task 6: Clean Fuels Key Findings
How Do Fossil Fuel Prices Impact Costs?

EVOLVED ENERGY RESEARCH

- Higher and lower fossil fuel prices show how price volatility could impact energy costs in the future
  - Derived from EIA High and Low Oil and Gas Supply scenarios
  - Relatively conservative – geopolitical events have driven far higher spikes in oil and gas prices than reflected in this study
  - High Fossil Price scenario indicative of price risk of exposure to international fuel markets
- High Fossil Price increases annual costs by up to $3B/yr
  - However, it actually decreases costs in 2050 where investment decisions driven by the higher costs displace more fossil fuel
- Low Fossil Price decreases annual costs by up to $3B/yr
  - Favors greater fossil combustion and sequestration and reduced electrofuels production
- The Northwest will have little control over the cost of fossil fuels. EIA fuel price forecasts are relatively low compared to today's costs

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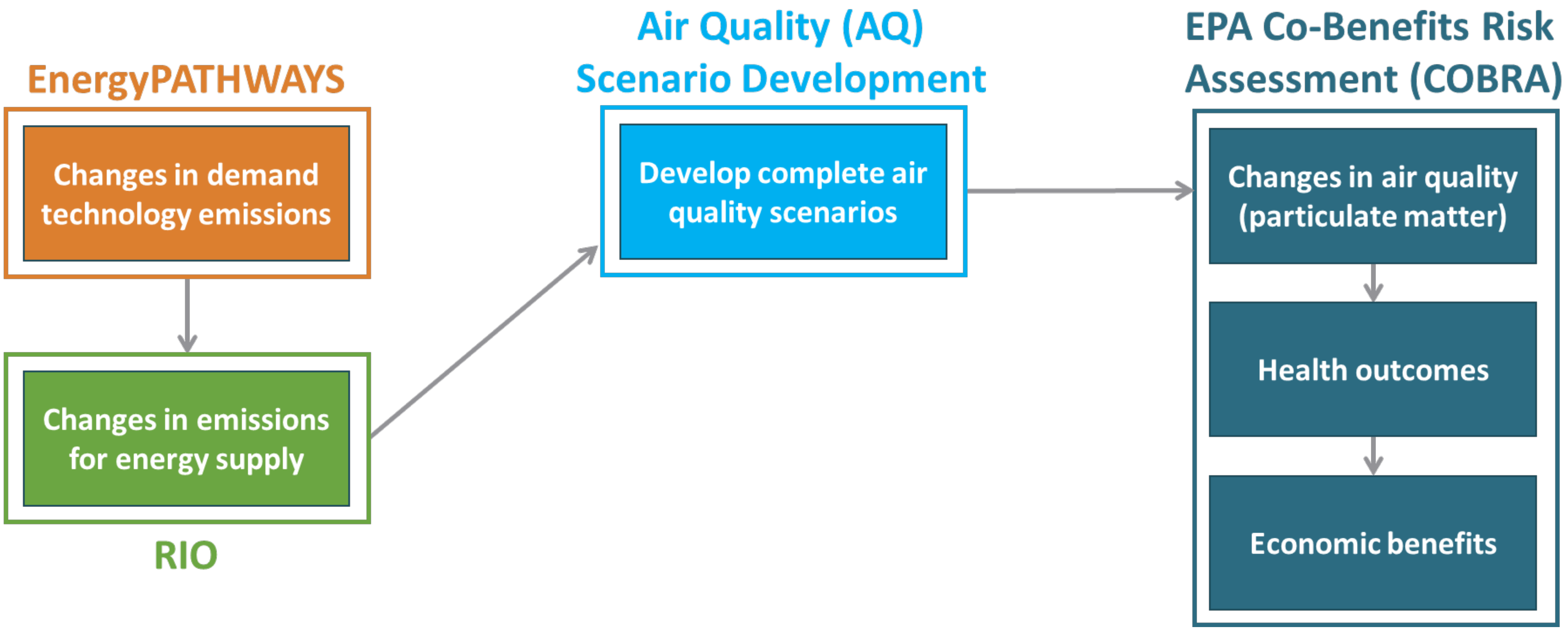
Task 7: Pollutant Emissions

Task 7: Pollutant Emissions
Overview of Cobra Modeling



Task 7: Pollutant Emissions Data Development in EnergyPATHWAYS and RIO

EVOLVED ENERGY RESEARCH

EnergyPATHWAYS

Demand technology emission changes

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

RIO

Energy supply emission changes

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

Task 7: Pollutant Emissions
Flow Chart of Cobra Analysis

EVOLVED ENERGY RESEARCH

RIO

Changes in Emissions (PM2.5, SO2, NOx, NH3, VOCs) →

- Database of emissions factors by existing plant and by new build generator
  - Taken from EPA Avoided Emissions and Generation Tool (AVERT) and eGRID 2019
- RIO calculates emissions based on least cost dispatch

COBRA

Changes in Air Quality (particulate matter) → **Health Outcomes** → **Economic Benefits**

Changes in Air Quality (particulate matter)

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

Health Outcomes

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

Economic Benefits

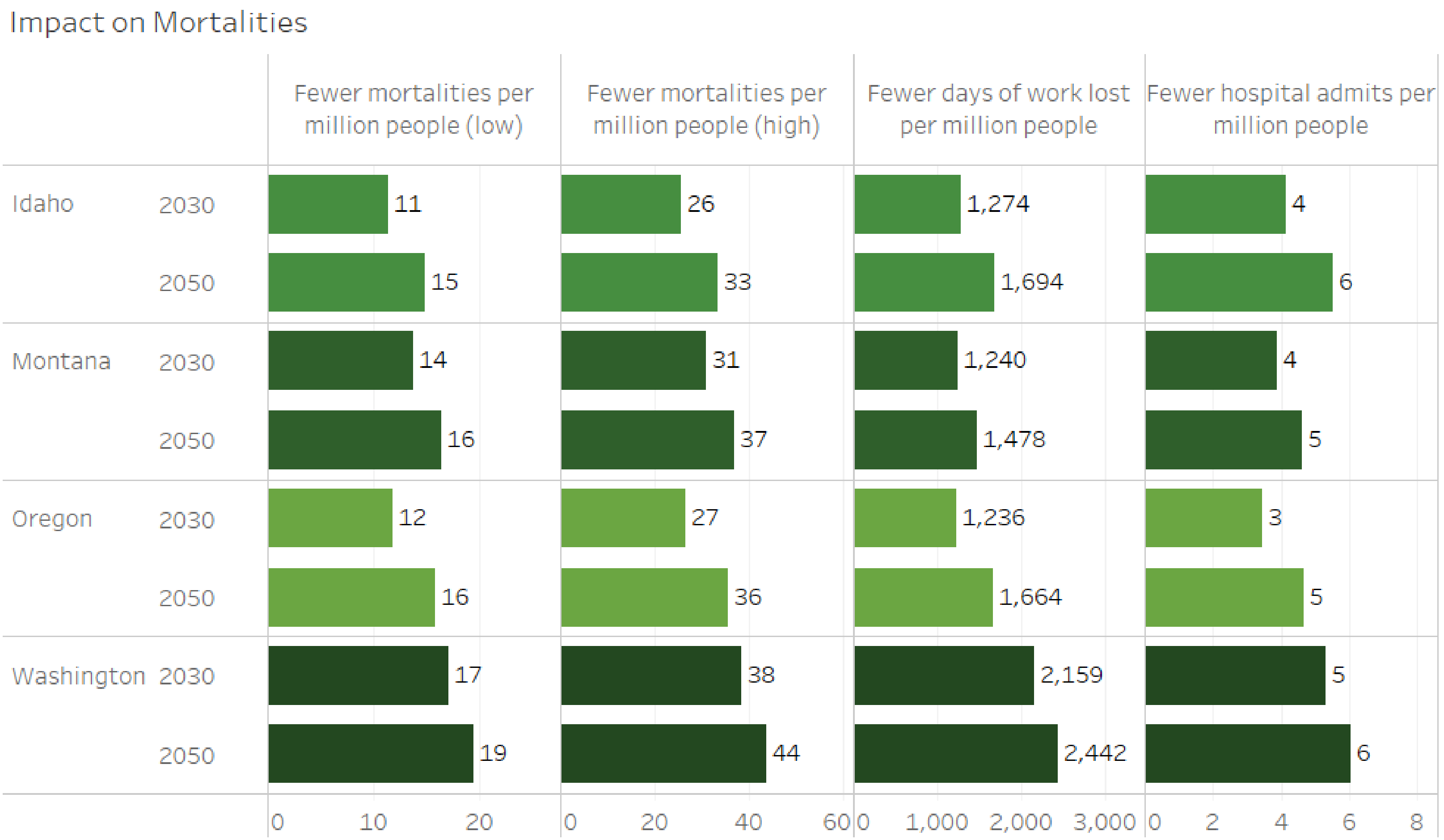
- Economic costs of health impacts
  - Value of statistical life (VSL)
  - Cost of illness
  - Hospital charges
  - Willingness to pay
    - Symptoms of illness
    - Restricted activity
    - Lost workdays

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

Task 7: Pollutant Emissions Cobra Methodology

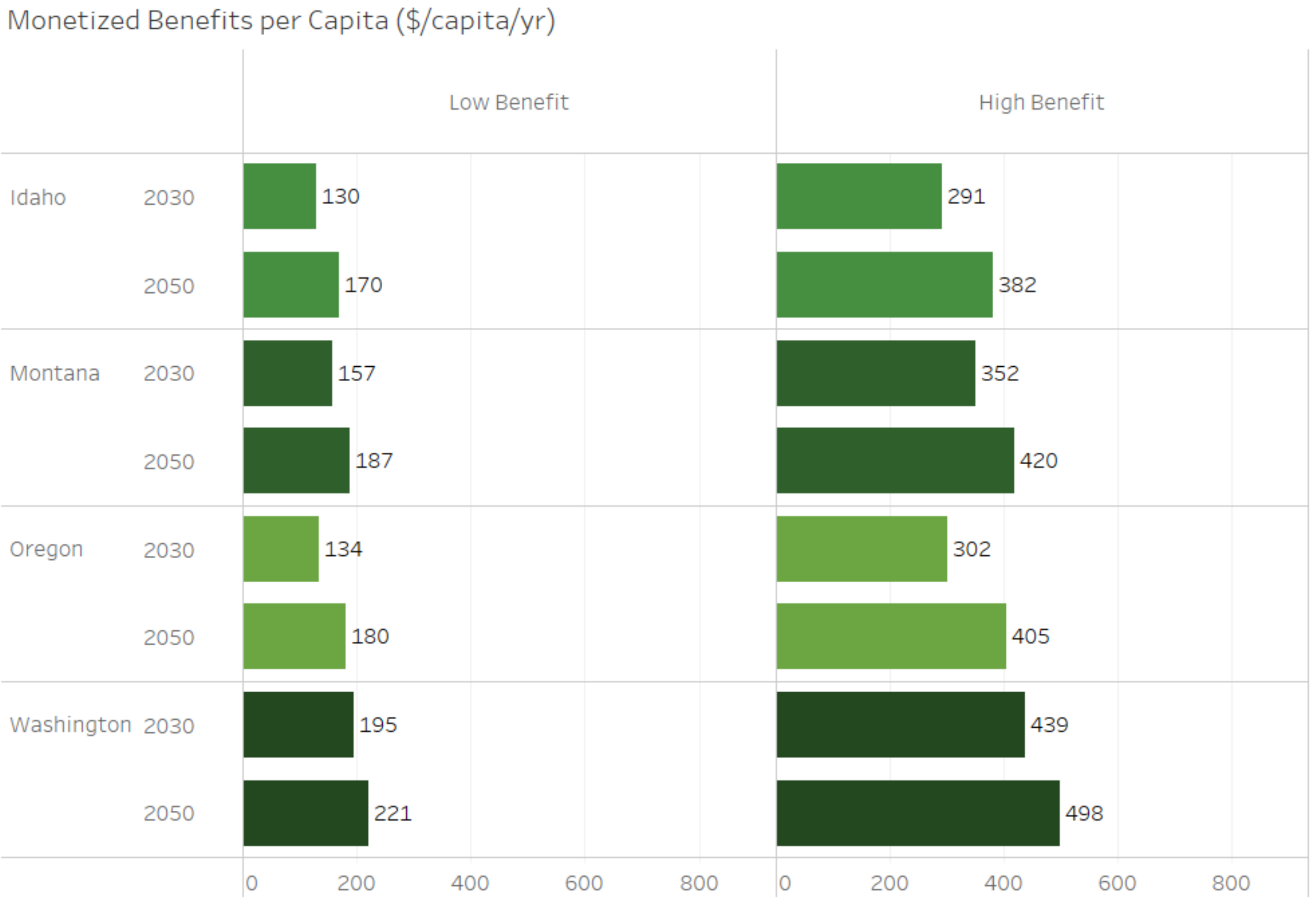
- Reports the benefits attributed to emissions reductions in a single year versus emissions in 2021
  - Reporting 2030 and 2050
  - Benefits are attributed to the emissions reductions over 2021 experienced by the population in 2030 and 2050
- Fewer hospital visits, lost workdays, incidences of illness are determined for the year in which the emissions reductions are experienced
- Mortalities attributed to the emissions in a particular year are assumed to occur over the following 20 years
  - Benefits of emissions reductions are the present value of reduced mortalities over that time period
  - All attributed to the emissions reductions experienced within a single year
- COBRA analysis accounts for $PM_{2.5}$ exposure, but not ozone which also causes health damage

Task 7: Pollutant Emissions Impact On Health Metrics



Task 7: Pollutant Emissions Per Capita Benefits

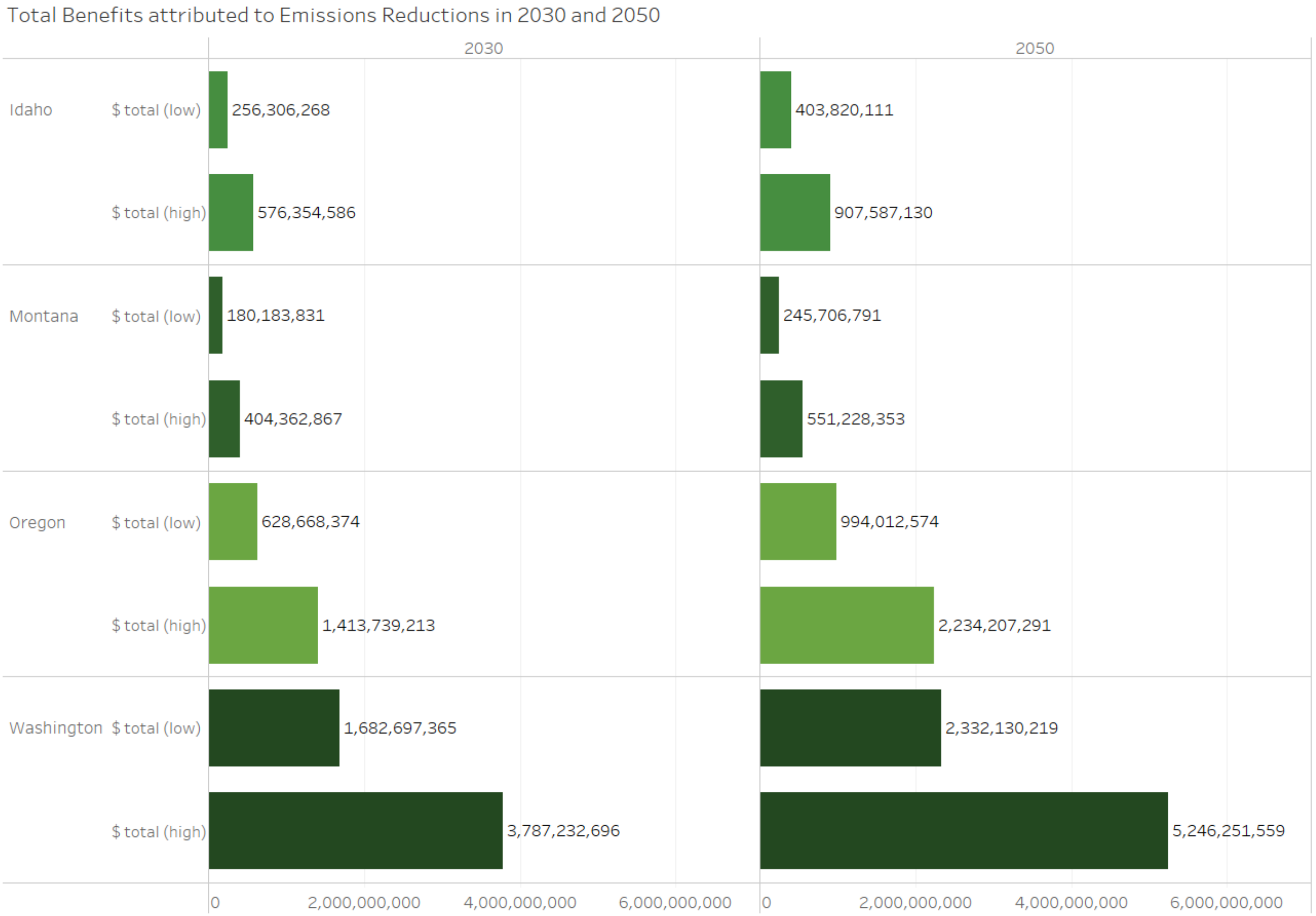
- Largest $PM_{2.5}$ improvements from removing coal from the economy between 2020 and 2030
  - NOx and SOx contributions to particulate matter
- Improvements from 2030 to 2050 are harder to come by
  - Major sources of pollutants remaining in 2050
    - NH_3: Livestock, fertilizer
    - NO_2: Background biogenic sources
    - $PM_{2.5}$: Wildfires, road dust, agriculture
    - VOCs: Background biogenic sources



Task 7: Pollutant Emissions
Benefits Attributed to Annual Pollutant Reductions

EVOLVED ENERGY RESEARCH

- Pollution reductions from economy-wide decarbonization drive significant annual benefits
- Biogenic and wildfire sources of pollutants will remain
  - Wildfire frequency may increase with climate change
- However, other anthropogenic sources of pollutants remaining in 2050 should be areas of ongoing policy focus
  - Furthermore, the high value of improving health outcomes may add to the benefits of GHG emissions reductions from hard to reduce sources such as in agriculture



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Task 8: Oregon Offshore Wind

Task 8: Oregon Offshore Wind Scenario Definition

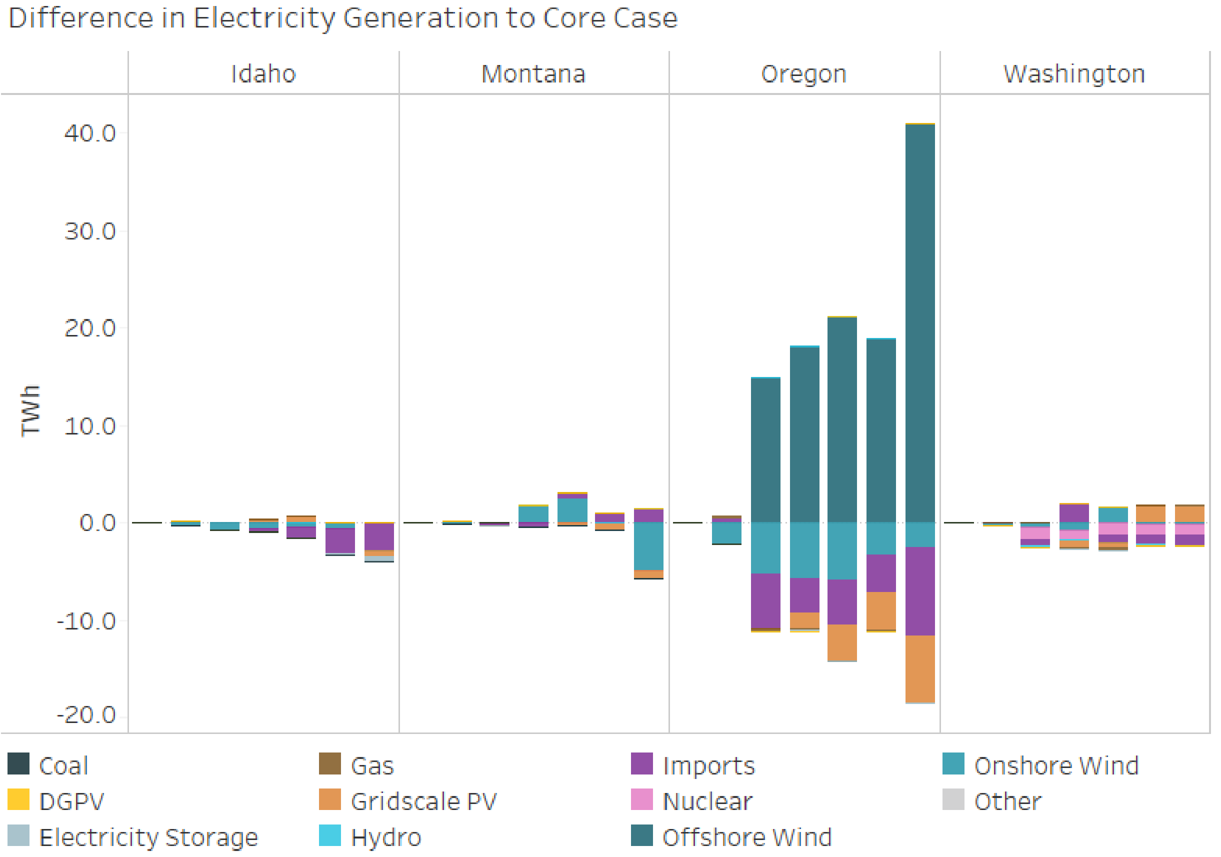
EVOLVED ENERGY RESEARCH

- Key research question: How do investments in the Northwest and Oregon energy resources change with an Oregon offshore wind target?
- In past studies, we have found more economic offshore wind build in Oregon than identified in Net-Zero Northwest
  - 1.2 GW in Net-Zero Northwest versus 20 GW in the Oregon Clean Energy Pathways Study
- The reason for this is the California offshore wind planning goal of 5 GW by 2030 and 25 GW by 2045, which we have included in this study
  - California offshore wind constructed in the same region as Oregon offshore wind potential reduces the economic need for Oregon offshore wind
- For comparison, in this task we tested the following Oregon offshore wind target:
  - 2030: 3 GW of offshore wind
  - 2035: 5 GW of offshore wind
  - 2050: 10 GW of offshore wind
- Together with the Core Case, the results were used by BW Research for jobs impact modeling in Oregon

Task 8: Oregon Offshore Wind Impact on Electricity Generation vs Core Case

EVOLVED ENERGY RESEARCH

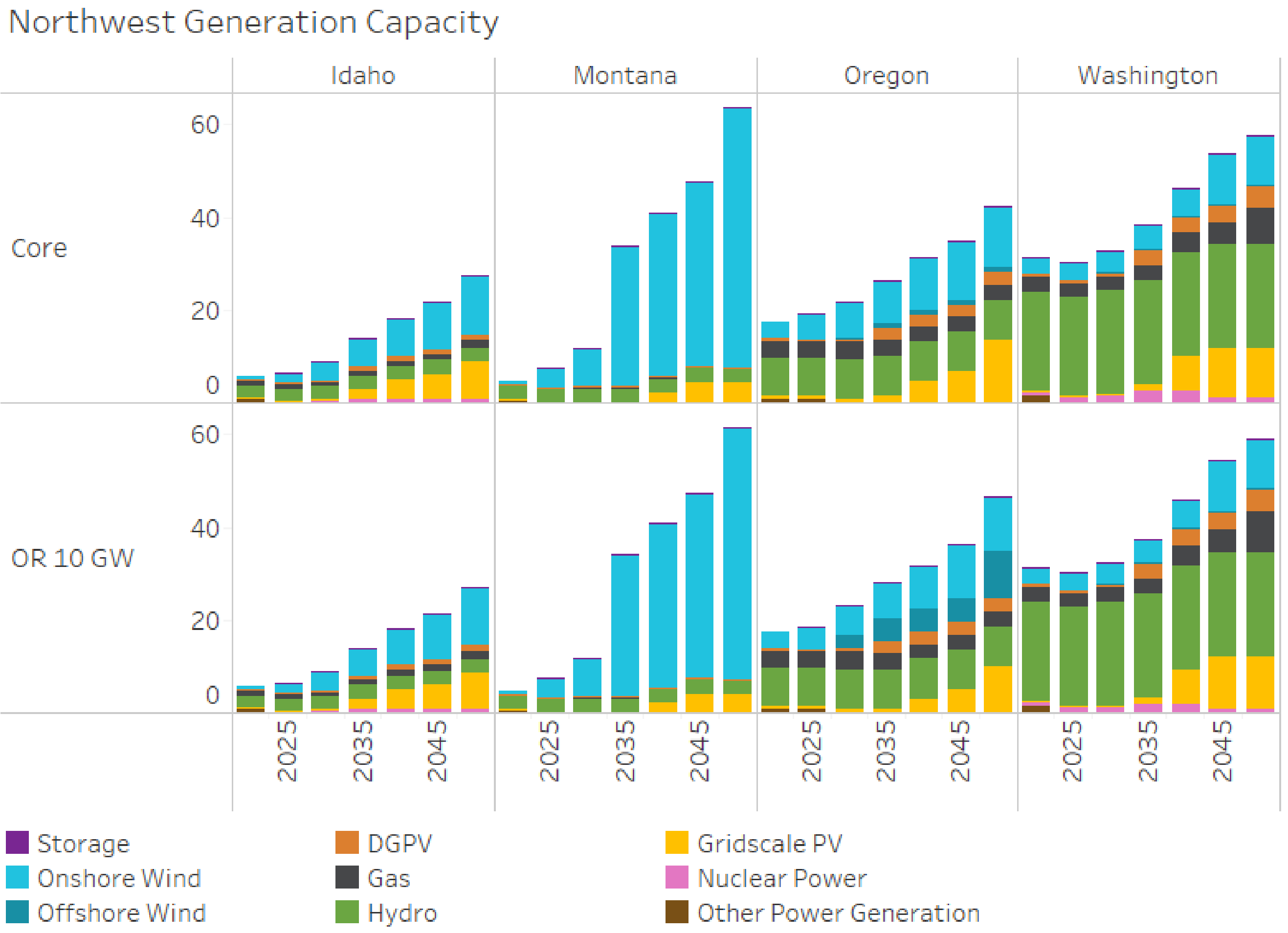
- Relatively minor impacts to generation outside of Oregon
  - Small reduction in offshore wind generation by 2050 in Montana
  - Reduced energy flow between Montana and Oregon
- Substitution of imported generation and onshore wind and solar for offshore wind in Oregon
  - Largest impact is the displacement of onshore renewables in Oregon and less reliance on imported energy from other states
- Overall increase in generation in Oregon is exported as well as supplies increased electrolysis loads



Task 8: Oregon Offshore Wind Generation Capacity in the Northwest

EVOLVED ENERGY RESEARCH

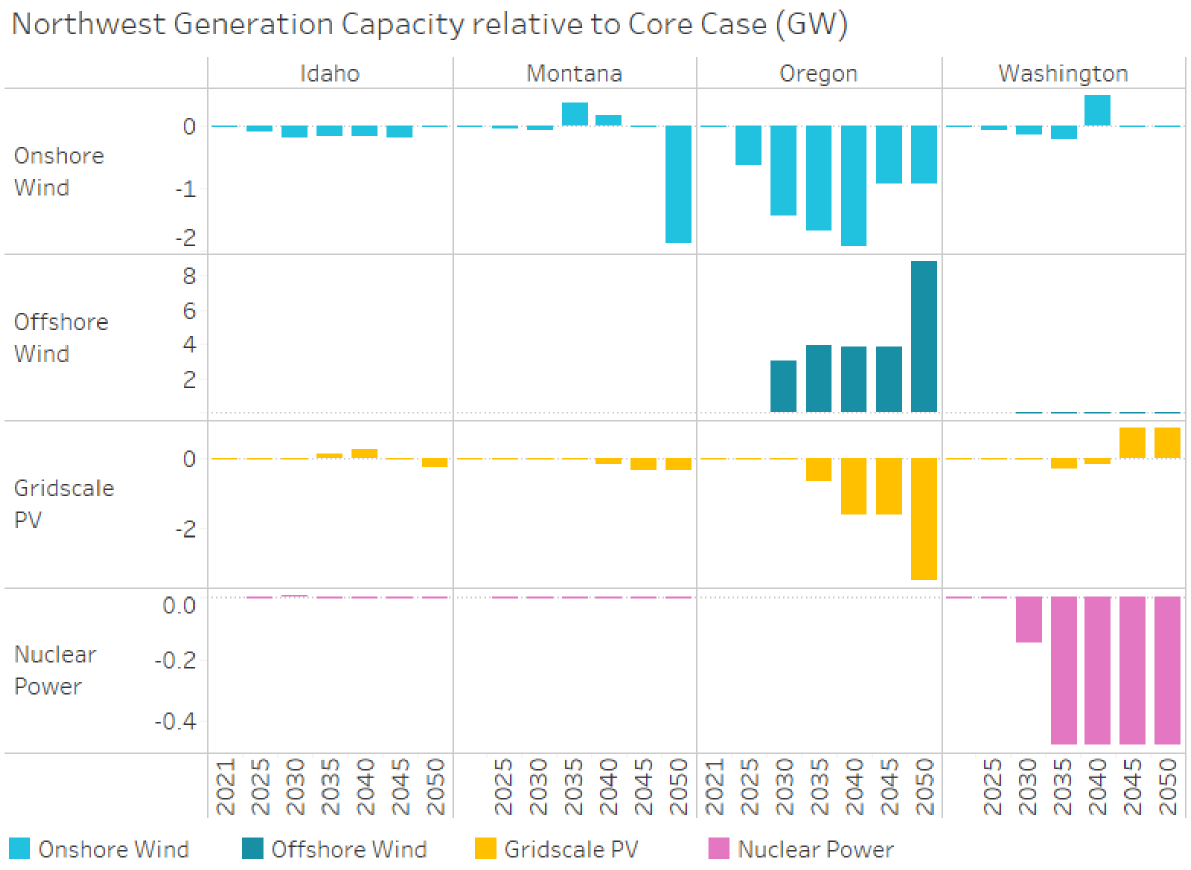
- Capacity impacts are relatively limited other than in Oregon where 3 GW by 2030, 5 GW by 2035, and 10 GW by 2050 of offshore wind displaces other renewable capacity including solar and wind
- Montana wind and Washington nuclear builds reduced on a limited scale



Task 8: Oregon Offshore Wind Generation Capacity versus the Core Case

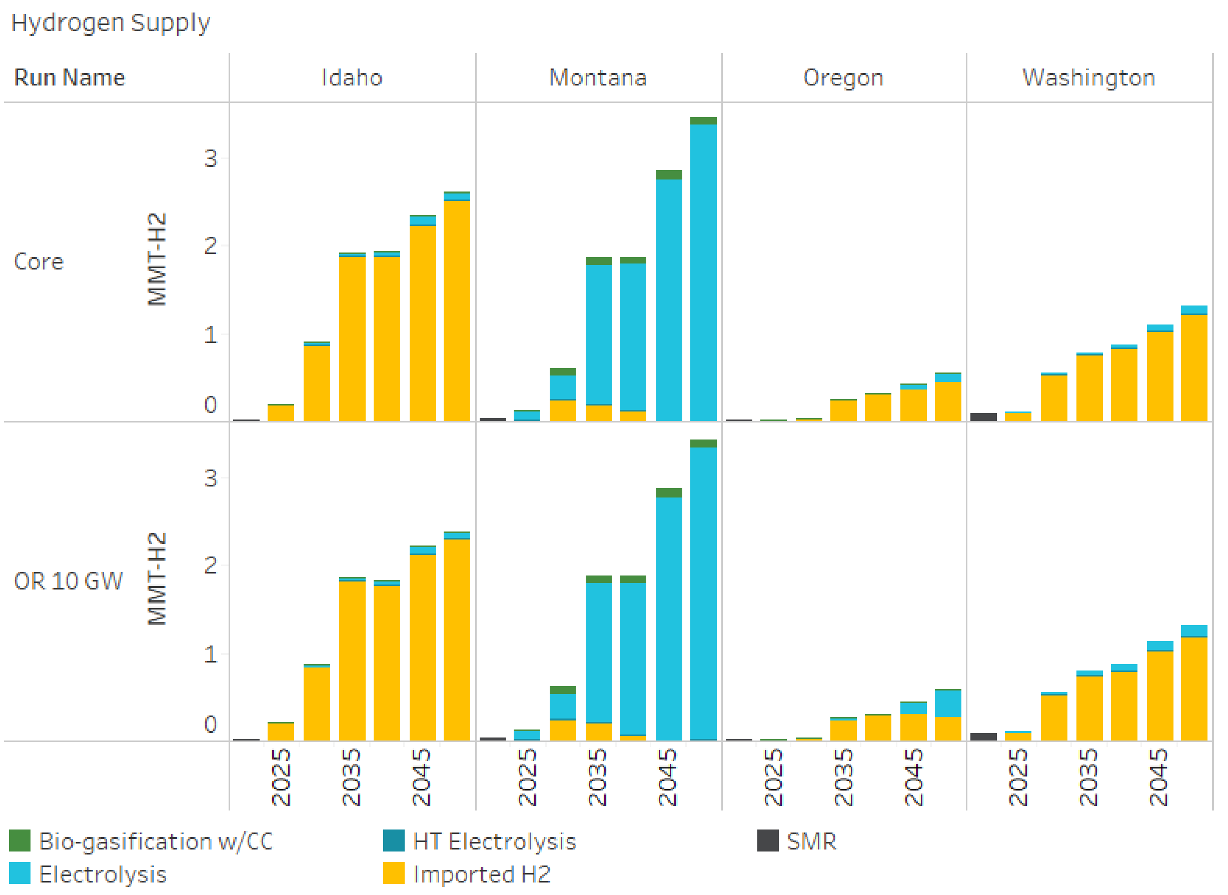
EVOLVED ENERGY RESEARCH

- Relative capacity investments show the difference in impact within Oregon versus surrounding states
  - Offshore wind build in Oregon has relatively little impact on resource investment outside the state



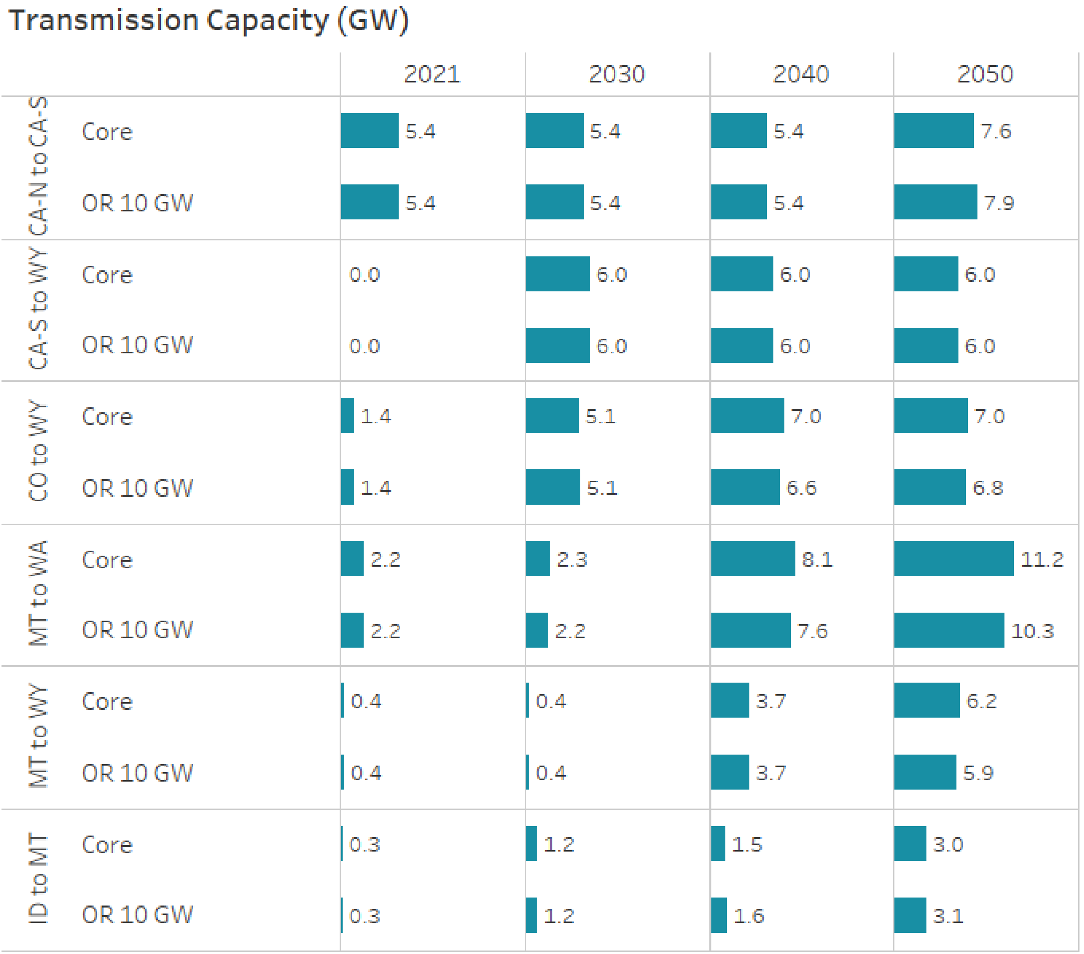
Task 8: Oregon Offshore Wind Impact on Hydrogen Supply

- Hydrogen production ramps up in Oregon displacing previously imported hydrogen by 2050
- The scale of the increase is small relative to hydrogen production in Montana and outside of the Northwest



Task 8: Oregon Offshore Wind Impact on Transmission Capacity

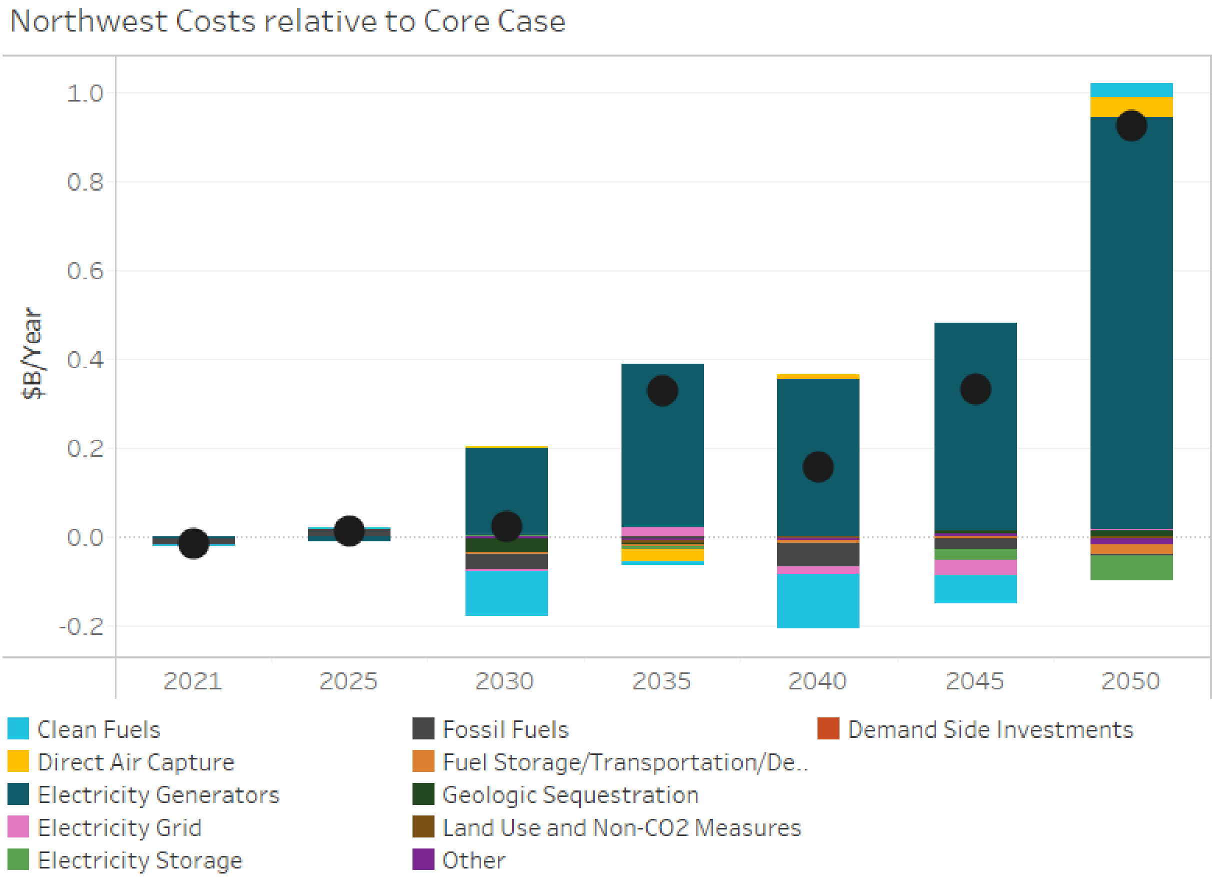
- 10 GW of offshore wind in Oregon in 2050 has minimal impact on transmission
- Offshore wind in Oregon decreases imports and increases exports
- The effect of this is to reduce transmission build from MT to WA by ~1 GW by 2050 due to increased generation closer to load centers



Task 8: Oregon Offshore Wind Impact on Overall Decarbonization Costs

EVOLVED ENERGY RESEARCH

- Adding additional offshore wind to the 25 GW of offshore wind built under the California goal in the model has cost impacts of $0.92B/yr in the Northwest by 2050
  - These costs come from net increases in overall renewable resource costs
- These costs do not account for other benefits that Oregon could experience in jobs and productivity growth



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Task 8: Oregon Offshore Wind

Key Study Findings

Task 8: Oregon Offshore Wind Key Findings

EVOLVED ENERGY RESEARCH

- Requiring 3 GW by 2030, 5 GW by 2035, and 10 GW by 2050 of offshore wind in Oregon has the following impacts on investments:
  - Oregon substitutes onshore wind and solar build for offshore wind, however the substitution is incomplete, and Oregon experiences a net gain in generation
  - The additional generation in Oregon over the Core Case is exported and used to produce more hydrogen locally
  - The impact of offshore wind in Oregon on other Northwest states is minimal
    - Transmission investments are slightly reduced, as are exports from Montana
  - Costs increase by $0.9B/yr by 2050, however this does not reflect increased jobs and economic development in Oregon
- This case was run to produce inputs to jobs and economic modeling done by BW Research in a separate study done for Renewable Northwest investigating the economic impacts in Oregon of offshore wind development

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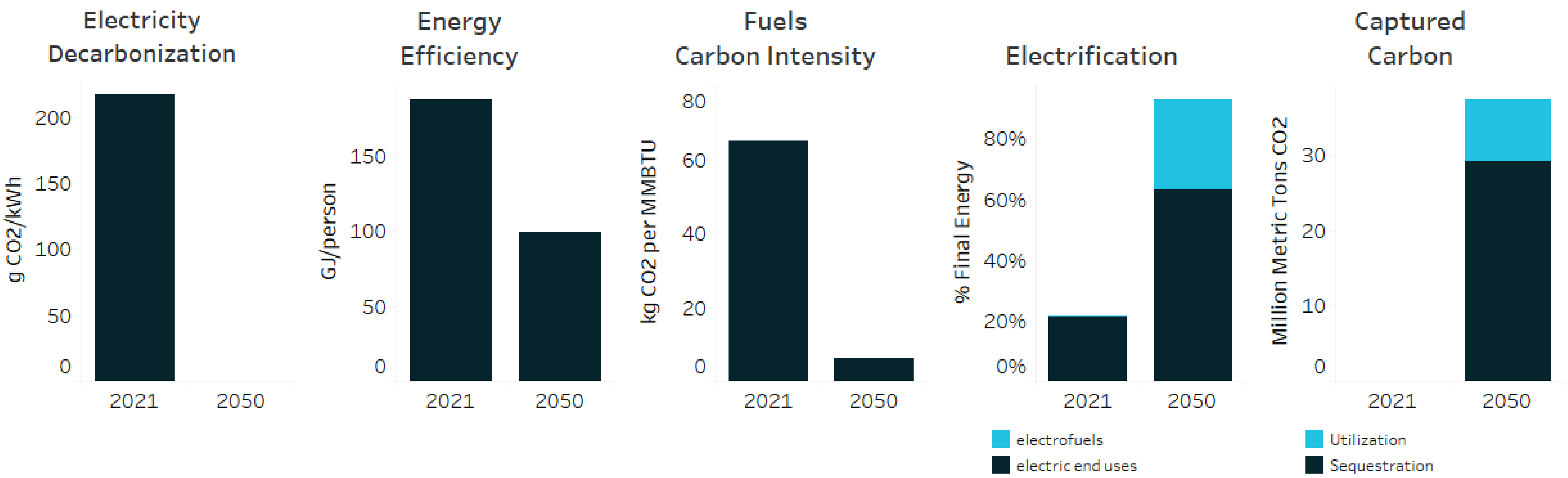
Themes in Northwest Energy Transition

Five Pillars

Themes: Five Pillars
Pillars of Deep Decarbonization

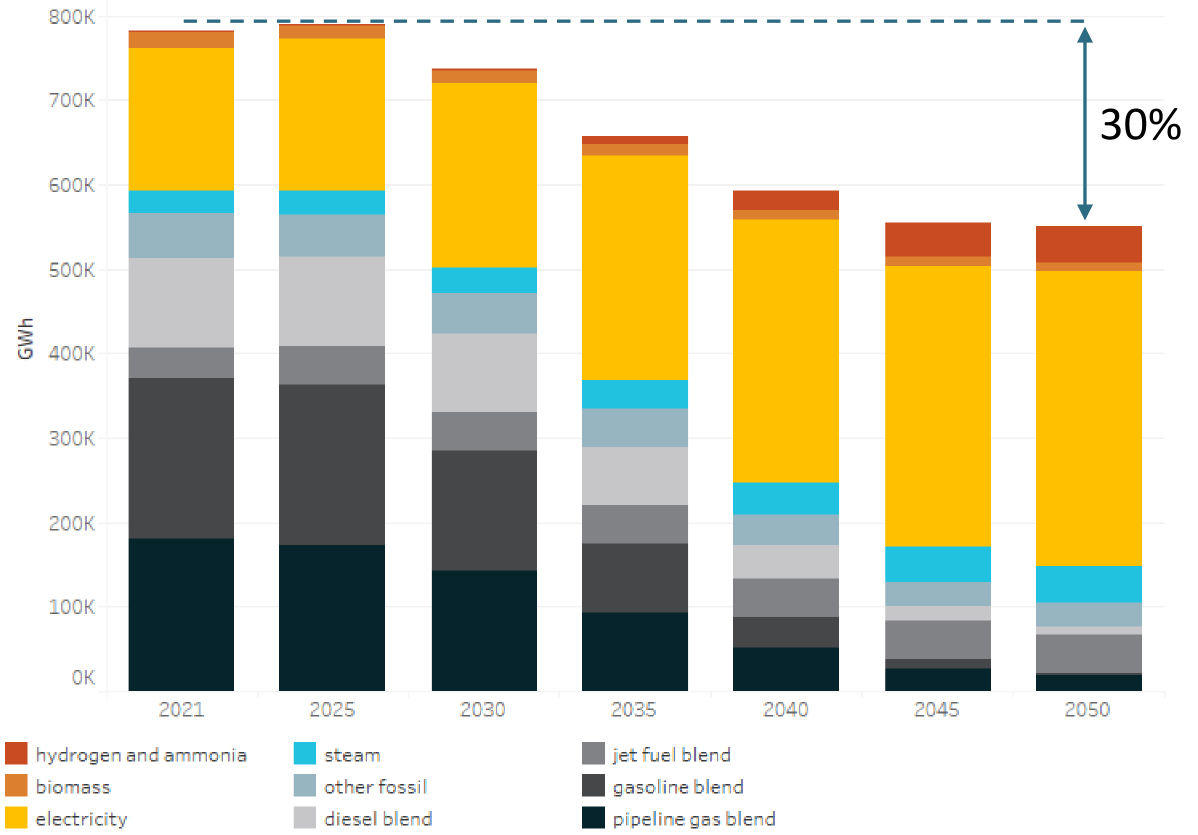


- Decarbonization in the Northwest hinges on clean electricity, energy efficiency, clean fuels, electrification, and carbon capture

Themes: Five Pillars
Efficiency: Overall Energy Demand Decreases

- Overall decrease in energy demand is driven by efficiency gains, mostly from fuel switching to electricity
- End use demand for electricity grows by 105% while economy-wide energy demand drops by 30%

Energy Demand by Fuel

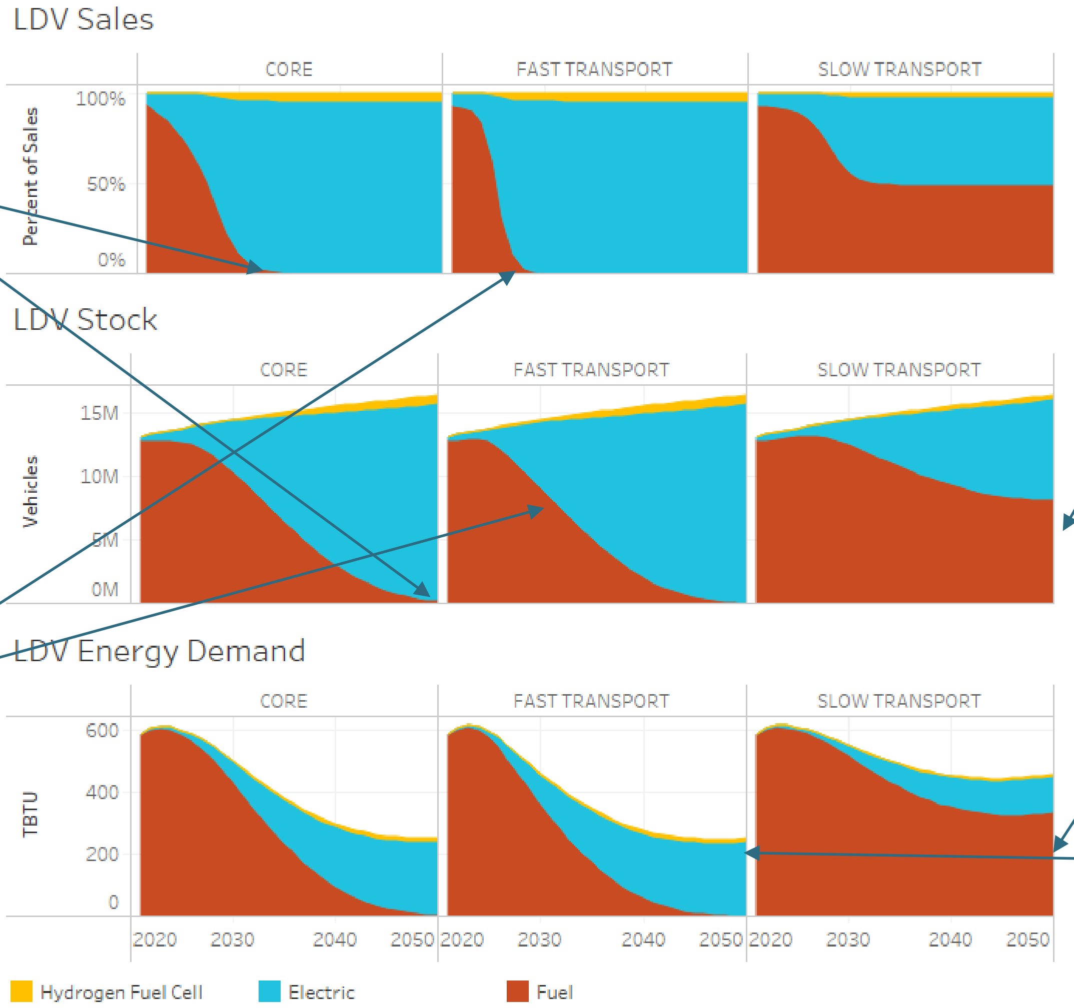


Note: “other fossil” includes fuel oil, lpg, oil, coal, and petroleum coke.

Themes: Five Pillars
Electrification: Light Duty Vehicle Example

Sales target of 100% clean vehicles by 2035 results in ~100% clean vehicle stocks by 2050

Fast Transport accelerates light and medium duty vehicle sales targets to 2030, reaching the same point in 2050, but following a steeper transition of stocks



50% of vehicle stocks remain ICEs in Slow Transport by 2050, representing a failure of infrastructure investment to support large EV penetrations

73% of energy demand is liquid fuel in 2050

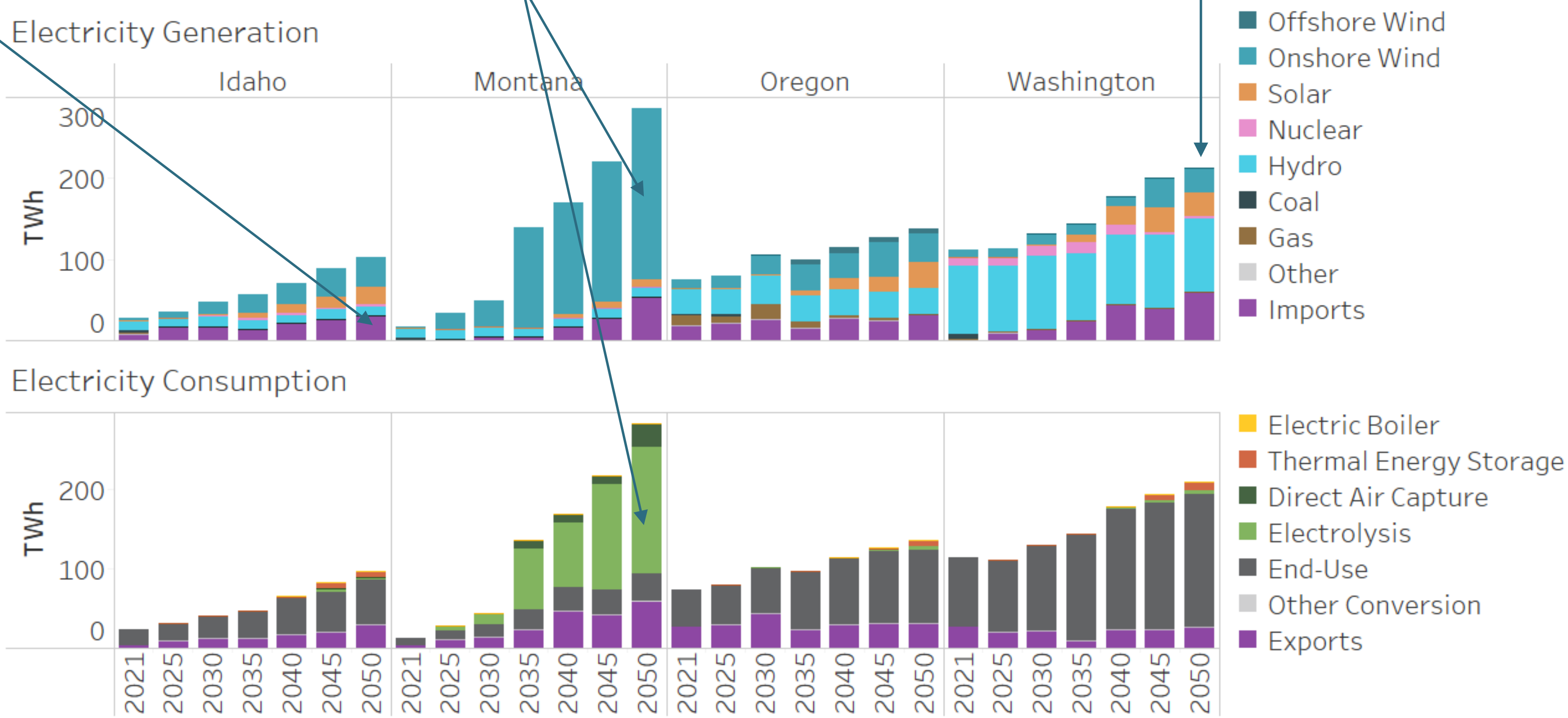
Core and Fast Transport reach 54% of Slow Transport energy demand in 2050

Themes: Five Pillars
Electricity Decarbonization: Growth of Renewables

Imported energy from other states most prevalent in Idaho and Washington

Montana becomes a major hydrogen producer and electricity exporter

Greater reliance on in-state resources results from higher Tx prices than used in previous studies

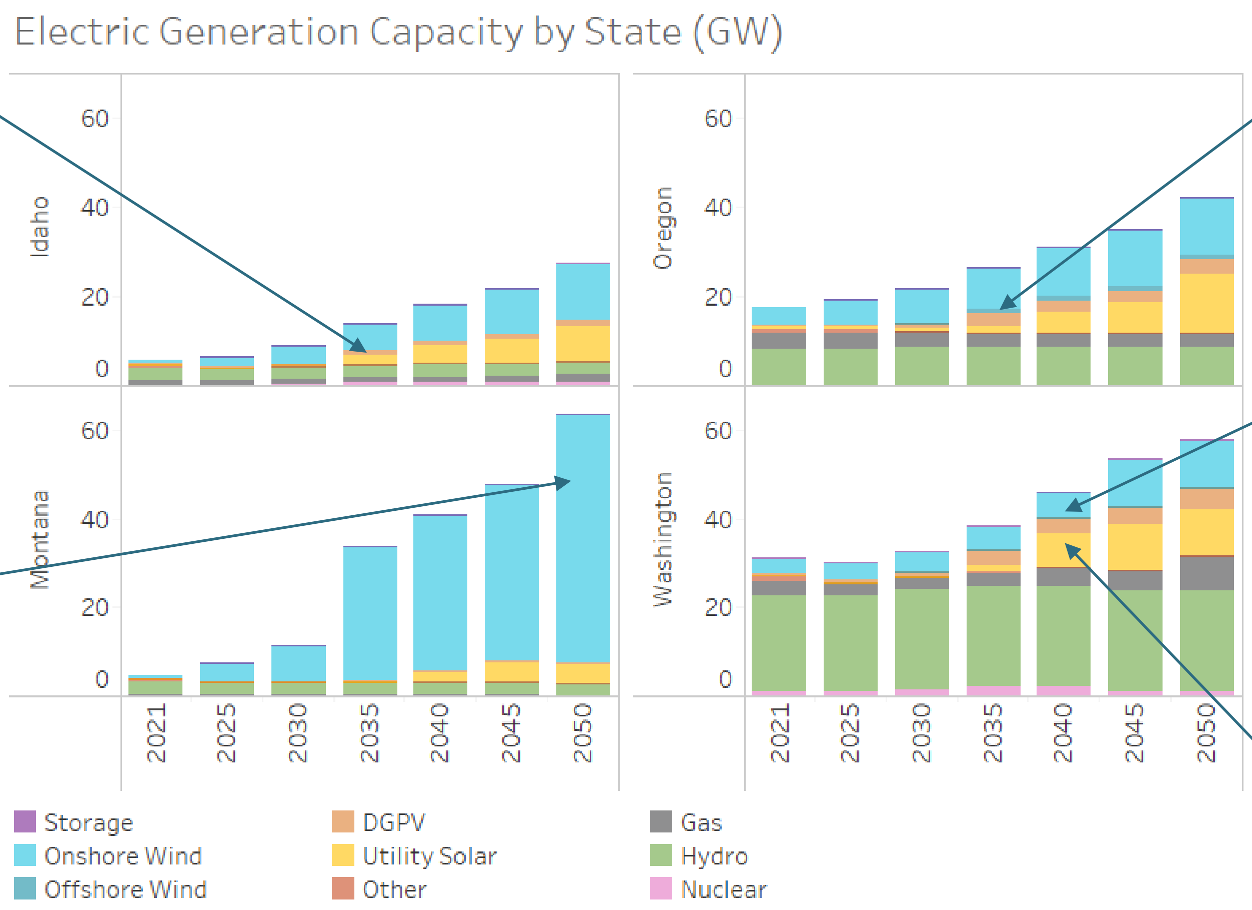


Themes: Five Pillars

New capacity built where the best resources are but depends on siting/permitting

Retrofits of retiring coal and gas in Idaho with nuclear SMRs

56 GW of onshore wind in Montana for hydrogen production and electricity export market. Feasibility may drive alternative resource decisions



1.2 GW of offshore wind in Oregon by 2035 CA Wind Mandate reduces need for OR wind versus previous studies*

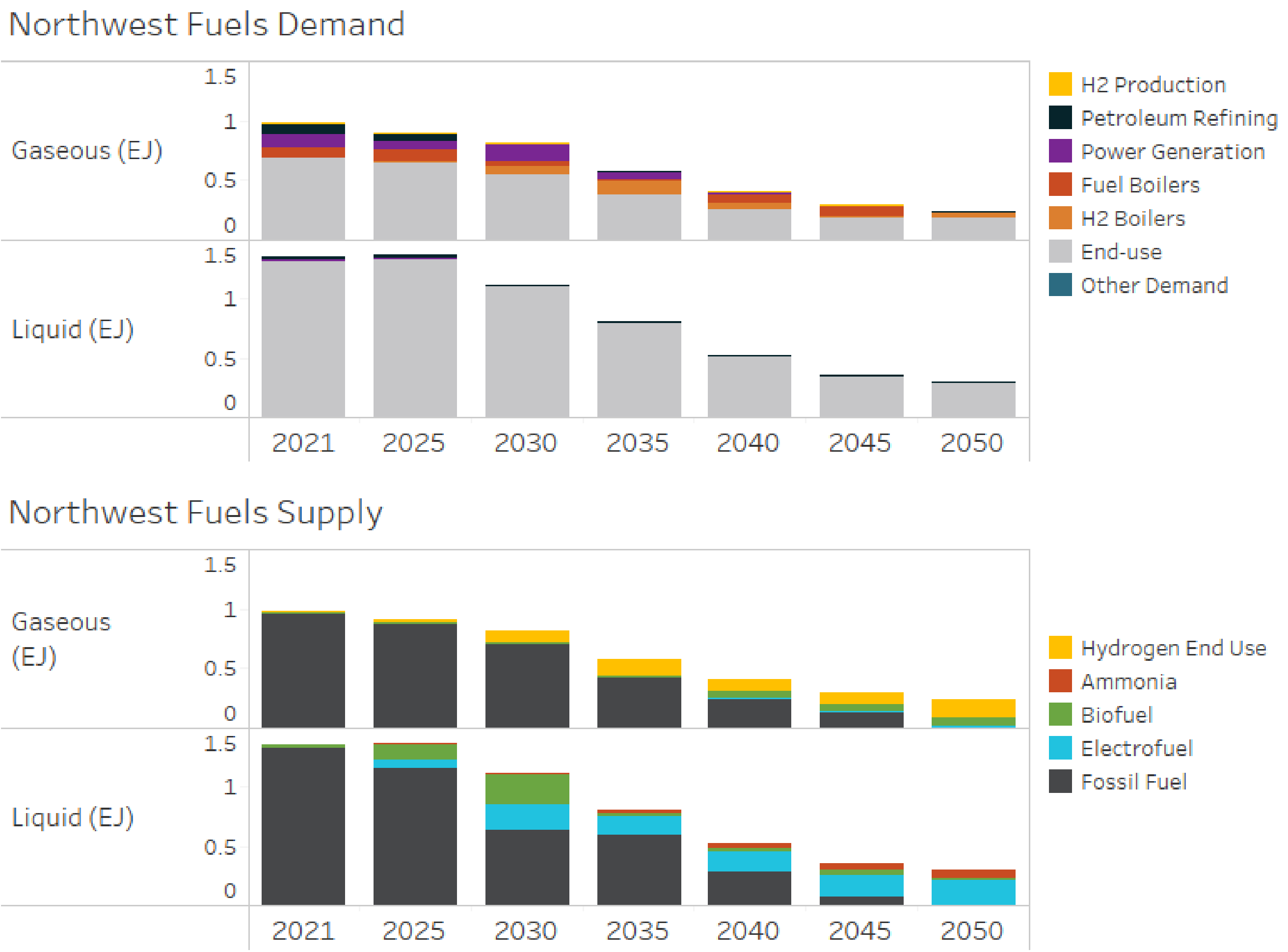
Greater internal resource development in WA than past studies because of increased Tx costs

Washington renewables develop after 2035 due to national build rate constraint: best national resources built out first under IRA

*An OR Wind Mandate is investigated in a separate scenario exploring 10 GW of offshore wind added in OR

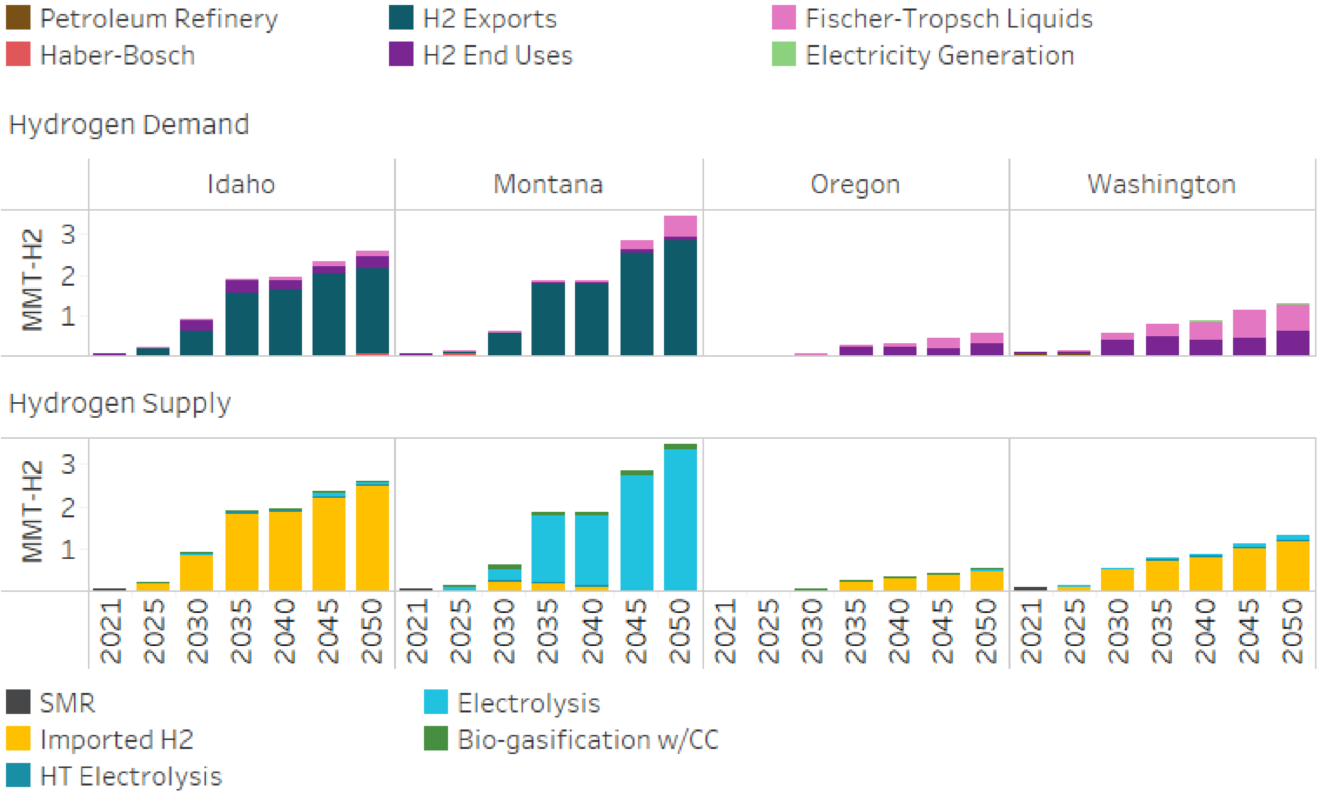
Themes: Five Pillars
Decarbonized Fuels: Transitioning to Hydrogen

- Demand for fuels in end uses and electricity shrinks over time
- By 2050 the supply of liquid fuels is fully decarbonized and remaining gas is partially decarbonized



Themes: Five Pillars
Hydrogen production next to the best resources

- Hydrogen in the Northwest produced in large quantities in Montana
  - Majority exported towards end uses in Washington, Oregon, and south to Wyoming
- Fischer-Tropsch liquids and ammonia production used to displace fossil fuels
  - Ammonia used in shipping
  - Drop-in synthetic hydrocarbons in vehicles and aviation



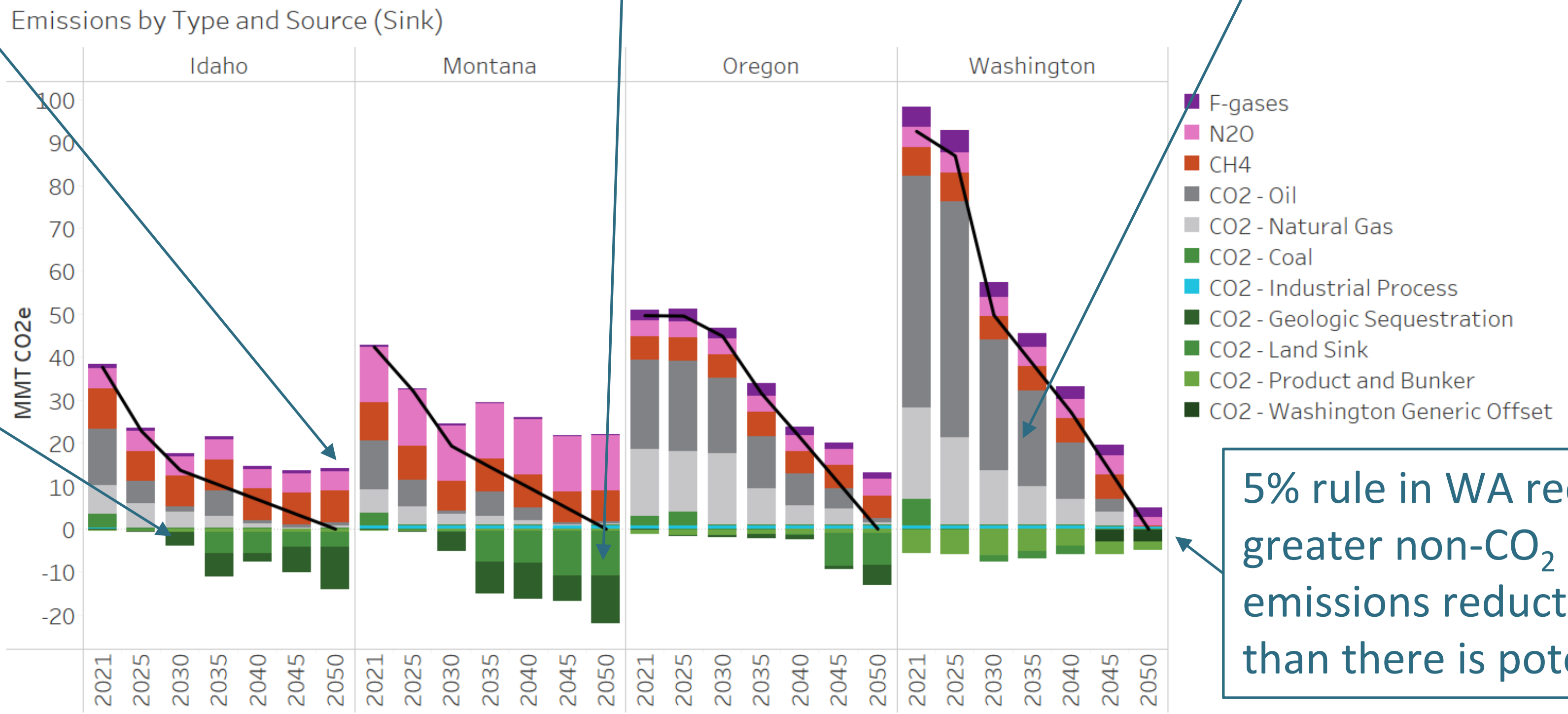
Themes: Five Pillars
Captured Carbon: Emissions targets require NETs

N_2O and CH_4 from agriculture difficult to decarbonize and remain in the economy

Remaining non-CO_2 emissions offset with land sink measures and geologic sequestration

Declines in emissions from oil and natural gas driven by efficiency, electrification, and substitution with clean fuels

States with large agricultural sectors require carbon sequestration and clean fuels to achieve 40% by 2030 targets set in this study



5% rule in WA requires greater non-CO_2 emissions reductions than there is potential

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Themes in Northwest Energy Transition

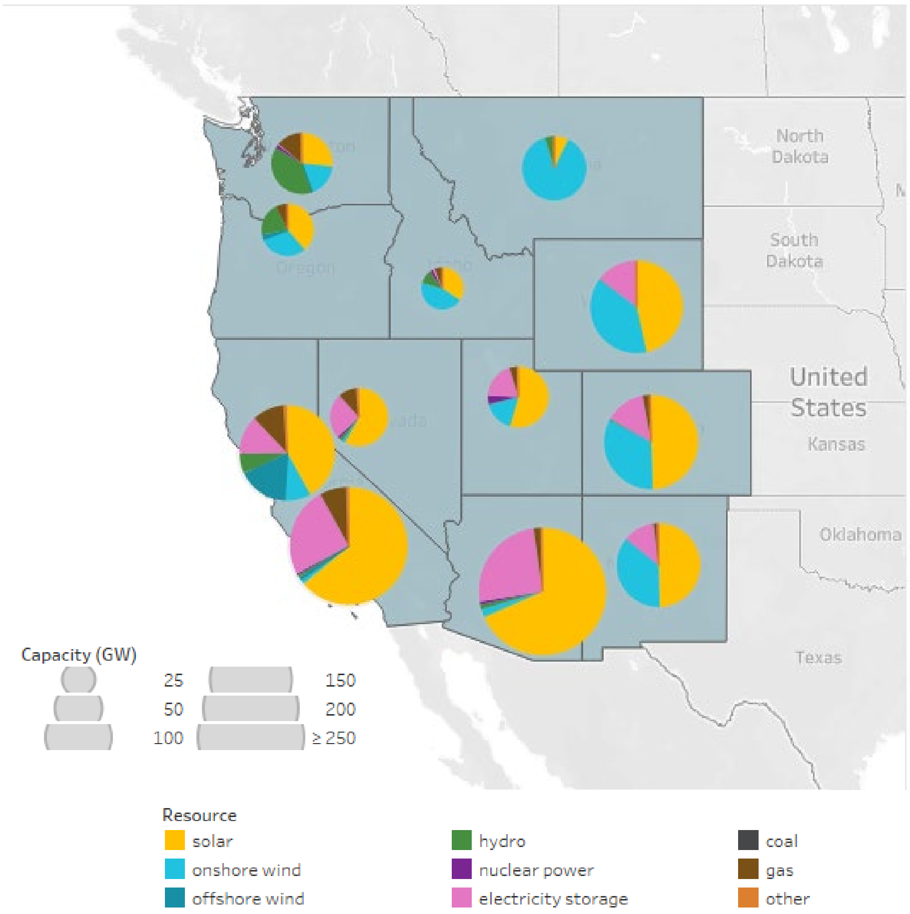
Siting and Permitting

Themes: Siting/Permitting
Siting/permitting will drive the new energy map

EVOLVED ENERGY RESEARCH

- **Regional transmission's role at the simplest level is for geographic and resource diversity in the West**
  - Move high quality Southwest solar to loads
  - Move high quality Northeast wind to loads
- **But rapid growth of the renewable energy sector will face challenges siting wind and solar plants, and expanded transmission**
  - What if renewables in particular regions not developed at the pace expected?
  - What if long-distance transmission or pipeline development faces obstacles?
- **Coordinated planning across the region will provide more options for success**
  - Profitable development of renewables and fuels production depends on access to markets
  - Transmission/pipeline development depends on development of renewables and fuels production

2050 Electricity Capacity



Themes: Siting/Permitting
Renewable Siting

EVOLVED ENERGY RESEARCH

- **Renewable builds in the Northwest total 138 GW by 2050**
  - New loads from electrification and fuels production while decarbonizing the electricity system drive large new investments including 92 GW of wind and 46 GW of solar
- **Electricity and fuels supply in the Northwest will be shaped by what renewable and transmission projects can be permitted**
  - When all options in the model are available, 56 GW of high-quality wind resources in Montana are used for both electricity exports and clean fuels production
  - Scenarios that limit renewables in Montana and Wyoming or restrict transmission build all simulate difficulty with permitting and shift more electricity production closer to loads and more clean fuels production to outside of the Northwest

Themes: Siting/Permitting
Renewable Siting

EVOLVED ENERGY RESEARCH

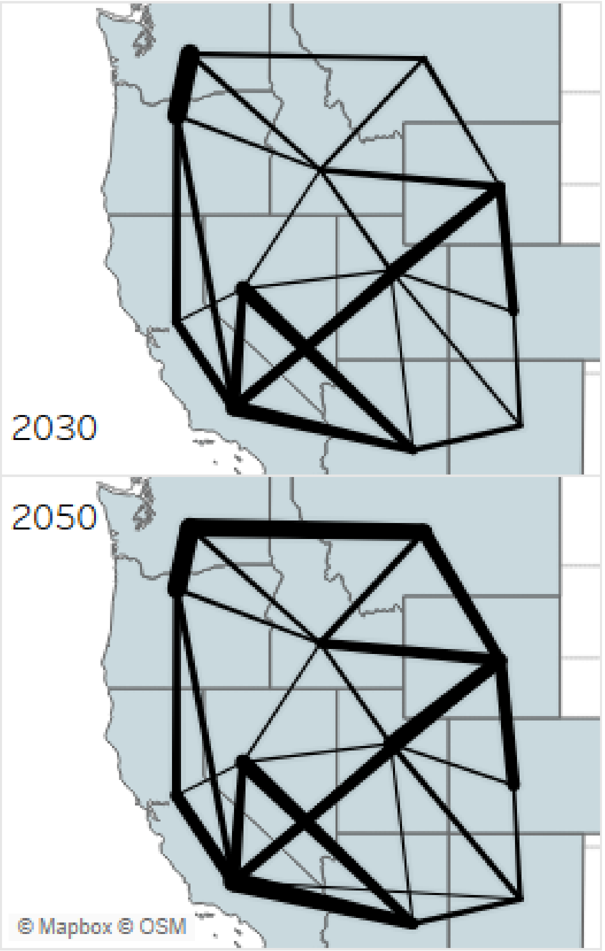
- **High adoption of rooftop solar reduces some of the pressure on siting grid scale renewables and moves hydrogen and fuels production closer to loads**
  - Overall resource costs increase by $0.6b/yr, but with the benefit of increasing the number of options to achieve net zero should siting grid scale resources be more challenging
- **Siting renewables and other clean energy economy resources has local economic opportunities**
  - Development of these projects come with environmental downsides. However, they do not come with the local health impacts of fossil facilities. Regions with high quality renewable resources hold natural renewable resources that will become more valuable as emissions caps tighten, presenting economic development and jobs growth opportunities
  - Montana, for example, sees large scale investment in renewables, hydrogen and fuels supply chain infrastructure, and nuclear by 2050

Themes: Siting/Permitting

Transmission is long lead time, long lifetime so planning needs to start now

EVOLVED ENERGY RESEARCH

- Transmission assets built in the next decade will spend much of their lives in a net-zero economy
  - We know where we are going so plan proactively rather than reactively
    - Plan for integrated energy systems across geographies
    - Plan for sector coupling between electricity and fuels
- Transmission takes time to build – planning needs to start now
  - Planning transmission is time consuming and highly uncertain, both cost-wise and feasibility-wise
  - IRA accelerates the need for transmission to deliver low-cost renewable energy
  - Pursuing multiple pathways to net-zero will give us more ways of failing before achieving net-zero is jeopardized



Themes: Siting/Permitting Transmission Challenges

- **Chicken and egg problem:** Transmission required to develop new generation; generation required to justify investment in transmission
  - Exacerbated when accessing remote resources across different planning jurisdictions that also face uncertain siting and permitting processes
  - Forward looking and coordinated planning needed to support interties for renewable access
- **Whack-a-mole problem:** Expanding transmission will be difficult but, without it, feasibility challenges are shifted to permitting more local resources
  - Doing less in one area of the energy system requires more from other areas. Less interstate transmission will mean more local resources, local interconnections, and potentially greater pipeline expansion
  - Expanded interties lower decarbonization costs and increases the options available to meet state emissions targets – more can go wrong before emissions targets are not met

Themes: Siting/Permitting Transmission and Renewables: Uncertainty

EVOLVED ENERGY RESEARCH

- **Siting/permitting challenges, and by extension transmission expansion and RE development, one of the largest uncertainties in both the rate of clean energy adoption and the pathway taken to net zero**
- **Costs**
  - Little recent large-scale or interstate transmission development to benchmark costs against
  - Frequent cost overruns in past projects
  - However, our analysis shows that economic expansion of transmission is relatively insensitive to cost. Access to diverse and high-quality resources is so valuable
- **Feasibility**
  - Many complex factors including physical and regulatory may be obstacles
  - Limiting transmission puts greater stress on local siting and permitting in regions with potentially lower quality or unbalanced renewables
  - Pursuing transmission and high-quality renewables despite the uncertainty is valuable both economically and in providing optionality when achieving net zero goals

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Themes in Northwest Energy Transition

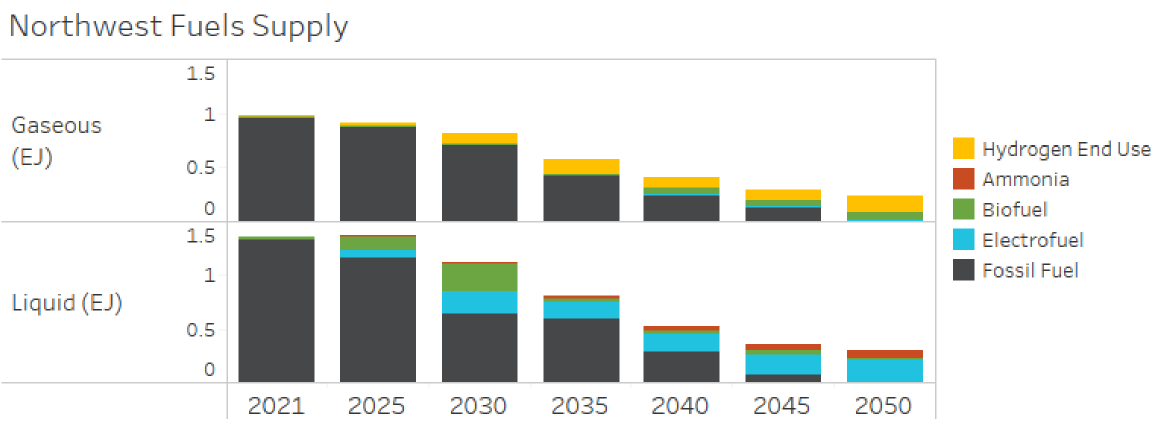
Clean Fuels Industry

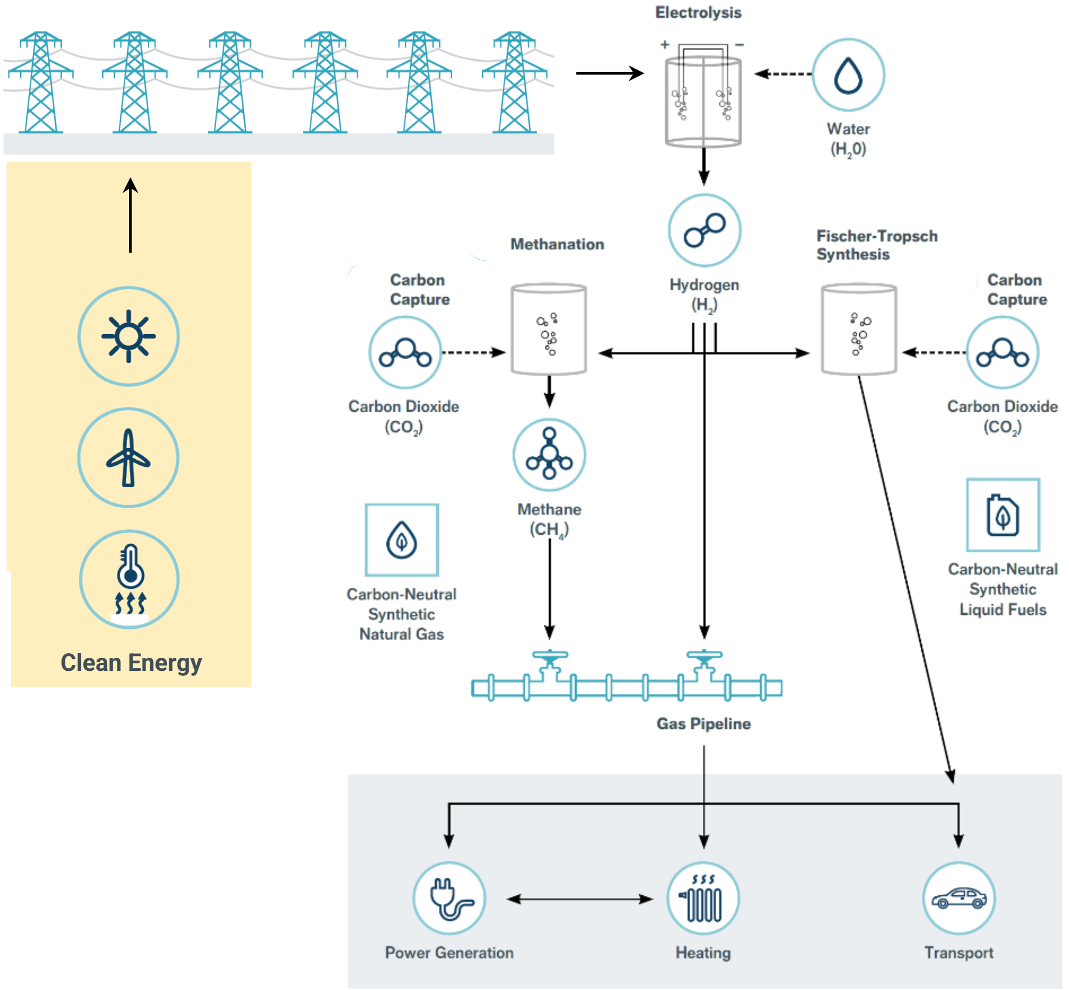
Themes: Clean Fuels Industry

Development of a Northwest Clean Fuels Industry in the 2020s to meet Emissions Targets

EVOLVED ENERGY RESEARCH

- **2030 emissions targets require reductions from sectors beyond electricity**
  - Relatively clean electricity sector already – less opportunity for emissions reductions
  - Limited reductions in fuel demand – electrification takes time
- **Biofuel and synthetic fuel demand by 2030**





Source: CETI, NWDDP, 2019

Themes: Clean Fuels Industry
Fuels Sector Development

EVOLVED ENERGY RESEARCH

- **The ability to import clean fuels from other states lowers costs by taking advantage of higher quality resources and increases the feasibility of reaching emissions goals**
  - Requiring all clean fuels demand to be served by local production means significant investment in Washington to meet 2030 emissions targets, not only in biomass and clean fuels infrastructure, but also in carbon sequestration
  - Local clean fuels production requirements increase renewable investment significantly in Washington and Oregon, including an additional 40 GW of electricity capacity in Washington, with significant cost increases versus sourcing clean fuels from out-of-state
  - Additional siting challenges for local renewables, transmission, and other clean energy infrastructure means that pursuing local clean fuels may be infeasible as well as $5-10b/yr more expensive from 2030 to 2050

Themes: Clean Fuels Industry Fuels Sector Development

EVOLVED ENERGY RESEARCH

- **IRA incentives for renewables, hydrogen production, and carbon utilization mean that H2 production is economic**
  - Even if the market for end use hydrogen does not keep pace, hydrogen not used in end uses is diverted into drop-in fuels for the economy
  - Hydrogen production is insensitive to the cost of electrolyzers – IRA incentives put production in the money
  - Hydrogen electrolyzer growth rate limited in the model to simulate constraints on scaling the industry. If unconstrained, hydrogen volumes would be higher
  - The economics of hydrogen reduce the amount of biomass use in the economy versus studies prior to IRA. Restricting biomass supply to waste biomass only, a 68% reduction in potential, has little impact on investments or overall costs
- **Clean fuel use in gasoline, diesel, and fuel oil depends on the rate of electrification of gas appliances in buildings**
  - Liquid fuels are preferentially decarbonized ahead of natural gas because of the economics of the replaced fuel
  - Lower rates of building electrification drive higher emissions in the residential and commercial sectors. This shifts greater emissions reductions into liquid fuels where more is replaced with clean alternatives

Themes: Clean Fuels Industry
Competition for Transfer of Clean Energy: Wires versus Pipes

- **Diverse resources of varying quality across the West**
  - High quality renewables are often far from largest energy demands
- **Clean energy is useful as electricity and fuels, both are needed long-term to decarbonize the economy – what is the best way to transport it?**
  - Depends on relative **costs** and **feasibility** of transporting electrons, gases, and liquids
- **New potential opportunities:**
  - New long-distance transmission including HVDC
  - Reconductoring/new build with high ampacity conductors
  - Hydrogen/liquid fuels production local to high quality resources for export in pipelines
  - Direct air capture co-located with high quality renewables and sequestration sites

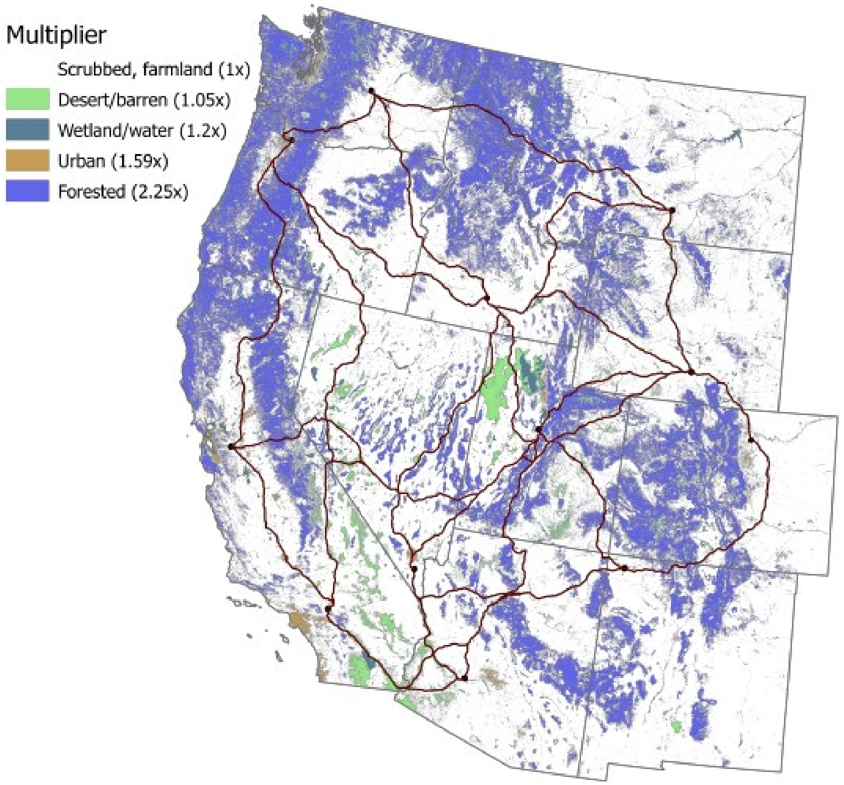


Fig. S7. Least cost path model results showing selected cost surface mutlipliers and new 500 kV transmission lines.

Source: The Nature Conservancy Power of Place – West

Themes: Clean Fuels Industry
Carbon Management

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- **Carbon becomes a valuable commodity in a decarbonized energy system**
  - Emissions-neutral or net-negative carbon supplies carbon molecules for production of clean drop-in fuels for parts of the economy that are difficult or expensive to electrify or switch to alternative carbon free fuels
  - Reducing gross anthropogenic emissions to zero is not possible and carbon sequestration can offset those emissions to reach net-zero
- **Carbon demand increases in scenarios where fuels play a larger role, either because electrification is delayed or incomplete, or fossil fuel costs are low**
  - Higher fuel demand, especially liquid fuel, creates more demand for captured carbon for use in electrofuels production
  - Higher fossil fuel use creates more demand for carbon sequestration, offsetting emissions
- **There are cost advantages to delaying carbon management investments by achieving emissions reductions through electrification**
  - Scenarios that require Carbon Dioxide Removal (CDR) earlier (Gas in Buildings, Slow Transportation) rely on bio-gasification with carbon capture in 2030, because of the relative economics of industrial scale direct air capture. After 2030, direct air capture plays a prominent role in carbon supply
  - Bio-gasification facilities constructed through 2030 persist through 2050, becoming a lasting part of the Northwest's energy transition
  - Achieving greater emissions reductions through CDR and clean fuels production in Gas in Buildings and Slow Transportation increases costs relative to scenarios with greater electrification of loads

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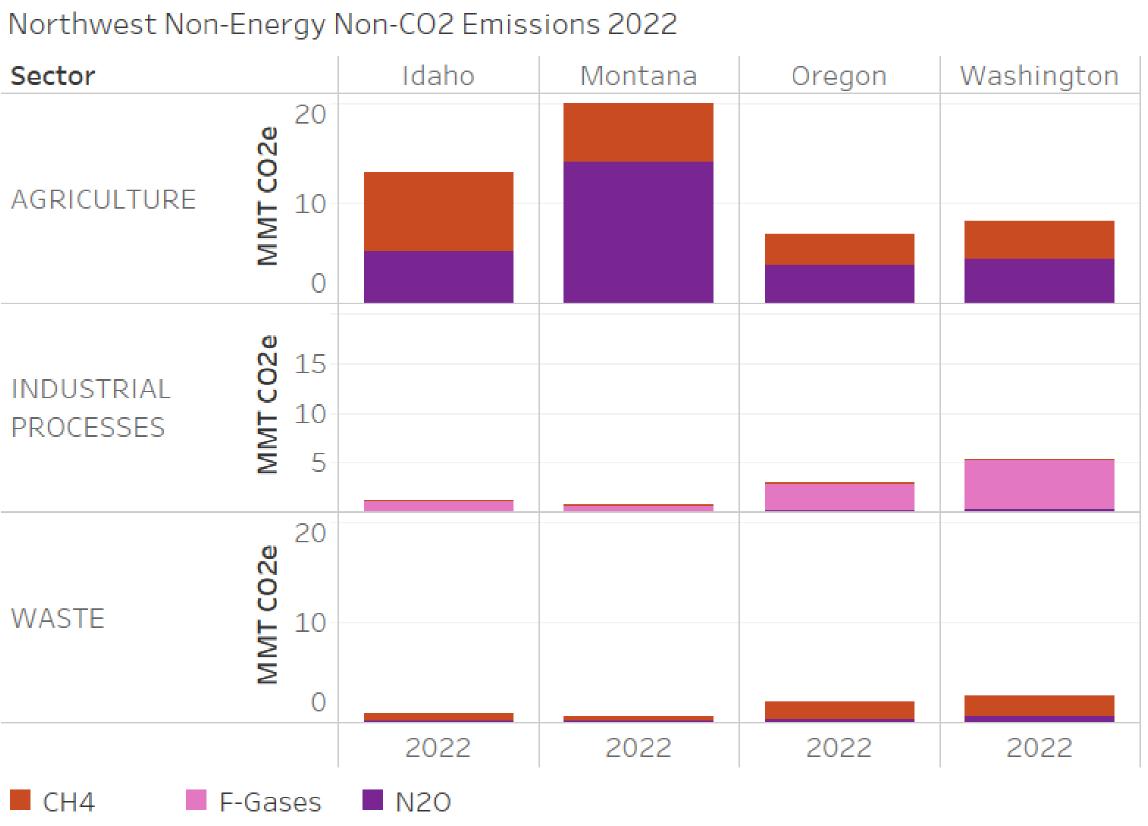
Themes in Northwest Energy Transition

Emissions and Pollution

Themes: Emissions and Pollution

Negative Emissions Technology Adoption driven by Non-CO_2 Emissions

- **Agricultural emissions particularly difficult to target with reduction measures**
  - One of the largest sources of emissions in some states
- Maximum achievable reductions of non-energy non-CO_2 gases according to EPA:
  - 28% in Idaho
  - 13% in Montana
  - 27% in Oregon
  - 37% in Washington
- **Negative emissions technologies required in these sectors**
  - Increasing land sink, geologic sequestration, and carbon capture including direct air capture



Themes: Emissions and Pollution

Emissions targets require decarbonized fuels near-term and negative emissions technologies long-term

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- **The Northwest needs negative emissions technologies to reach net-zero**
  - Not possible to reduce non-CO_2 emissions to zero without changing economic activity
  - Incremental land sink, geologic sequestration, and direct air capture offsetting remaining emissions in the economy
  - Gross CO_2 emissions from energy and industry close to zero by 2050
- **Achieving 40% below 1990 emissions by 2030 in states with large agriculture sectors requires carbon sequestration and clean fuels**
  - Regional emissions targets are more efficient – emissions reductions can come from lowest cost sources
- **Early investment in negative emissions technologies**
  - Incremental land sink – Uncertain, depends on changes to land use and climate impacts
  - Geologic sequestration – Need a carbon source, significant investment in direct air capture in Montana by 2035
- **Meeting 95% gross emissions levels in Washington will require new measures not currently identified**

Themes: Emissions and Pollution
Pollutant Emissions

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- **Benefits attributed to annual pollutant reductions range from:**
  - **\$2.8b/yr to \$6.2b/yr in 2030** relative to emissions remaining at 2021 levels
  - **\$4.0b/yr to \$8.9b/yr in 2050** relative to emissions remaining at 2021 levels
- **Pollutant reductions come from fossil fuel plant retirements and vehicle tailpipe emission reductions as the economy decarbonizes, but sources of pollutants remain in 2050:**
  - NH_3: Livestock, fertilizer
  - NO_2: Background biogenic sources
  - $PM_{2.5}$: Wildfires, road dust, agriculture
  - VOCs: Background biogenic sources
- **Biogenic and wildfire sources of pollutants will remain and may increase with climate change**

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Themes in Northwest Energy Transition

Nascent Technologies and Inflation Reduction Act

Themes: Nascent Technologies and IRA

IRA brings forward adoption of nascent techs and electric load growth

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- **Technologies previously forecast for the 2040s shifted forward in time**
  - Incentive to build nuclear, electrolysis, and direct air capture in the early 2030s
- **EER national studies of IRA show that ITC and PTC incentives drive rapid adoption of renewables through 2035, in line with a pathway to net zero emissions**
  - Lowers costs in Western states with clean electricity policy, drives greater adoption in those without
- **Electrolysis to produce hydrogen is cost effective under IRA incentives**
  - Combined with lower cost renewables, states requiring near-term clean fuels to meet emissions targets will see significant economic benefits from IRA
- **IRA accelerates electrification, primarily through vehicle incentives**
- **What does this mean for transmission?**
  - Earlier growth of electric loads for end uses and fuels production coupled with greater renewables adoption require transmission expansion

Themes: Nascent Technologies and IRA
Nuclear opportunities if feasible

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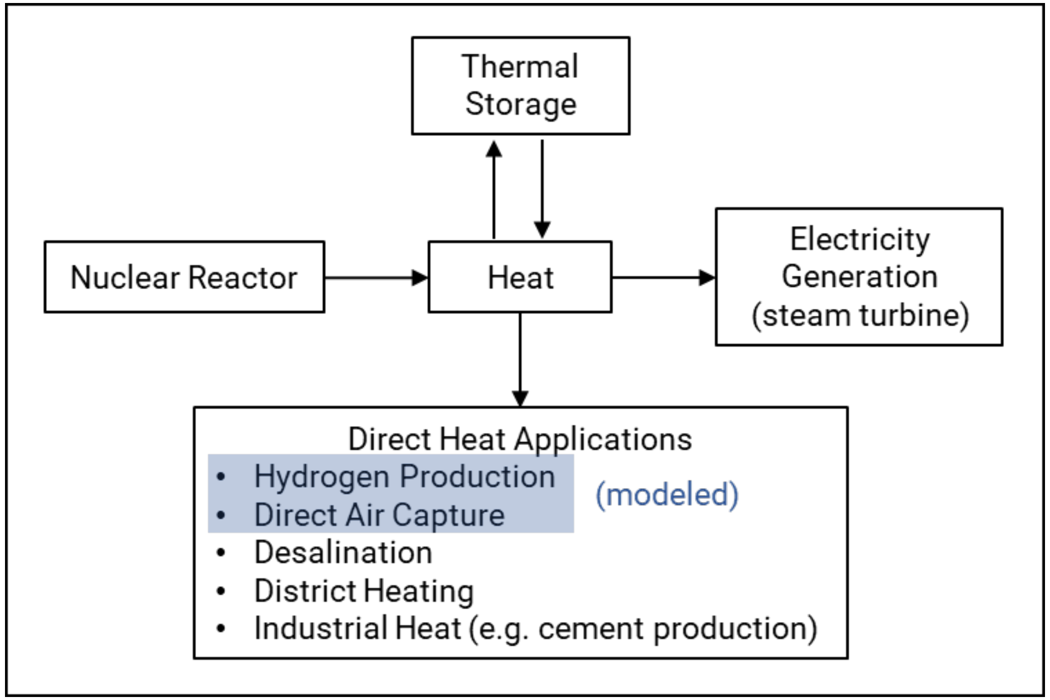
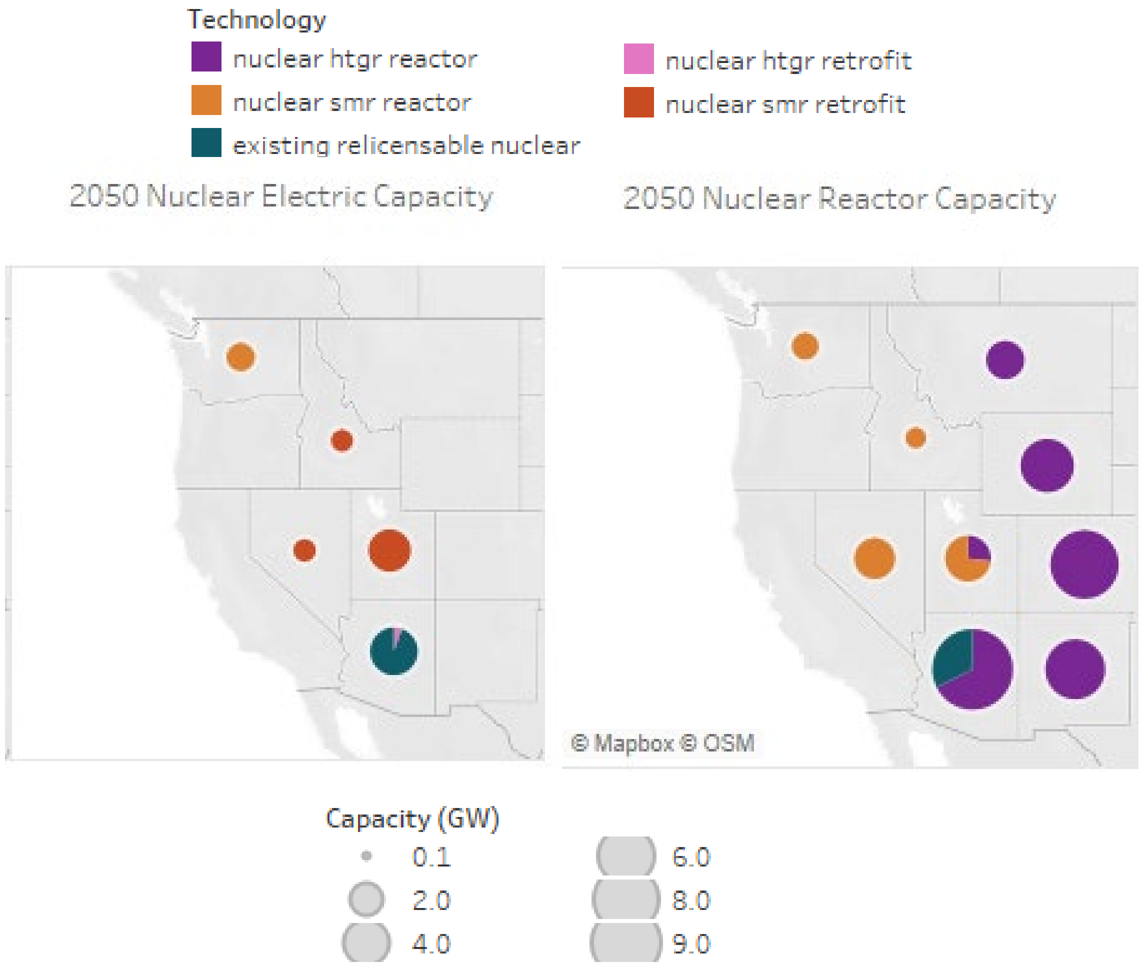
IRA incentives for nuclear, including additional incentive for retrofits of coal and gas plants

- Model can make separate capacity build and operational decisions for reactor technologies; heat storage; and electricity generation technologies (i.e., steam turbine)
  - Small Modular Reactors (SMRs) produce heat for electricity generation or thermal energy storage
  - High Temperature Gas Reactors (HTGRs) can produce heat for direct air capture and hydrogen
- Nuclear heat can be used in electricity generation or in other industrial applications
- Representation of non-electric sectors and sector coupling opportunities key to nuclear economics



Themes: Nascent Technologies and IRA Nuclear Investments by 2050

- **Idaho and Washington invest in 0.7 GW and 1.1 GW of new SMRs, respectively**
  - Idaho invests in retrofitting retiring coal plants
- **West-wide, nuclear electricity capacity is 9.5 GW in 2040 and 8.4 GW in 2050**
  - The West retrofits 4 GW of retiring coal and gas with small modular reactors before 2035 to leverage IRA incentives
- **Nuclear thermal heat used for more than electricity production**
  - Total nuclear reactor thermal capacity of 33.5 GW across the West
  - Non-electric heat used in direct air capture of carbon
- **Role of nuclear is uncertain**
  - Nuclear is a question of feasibility as much as economics
  - Nascent technology with an uncertain development path. Role in resource portfolio is subject to how project costs progress – larger opportunities economically if costs decline significantly



Themes: Nascent Technologies and IRA
Fill the gaps in IRA support with state/regional policy

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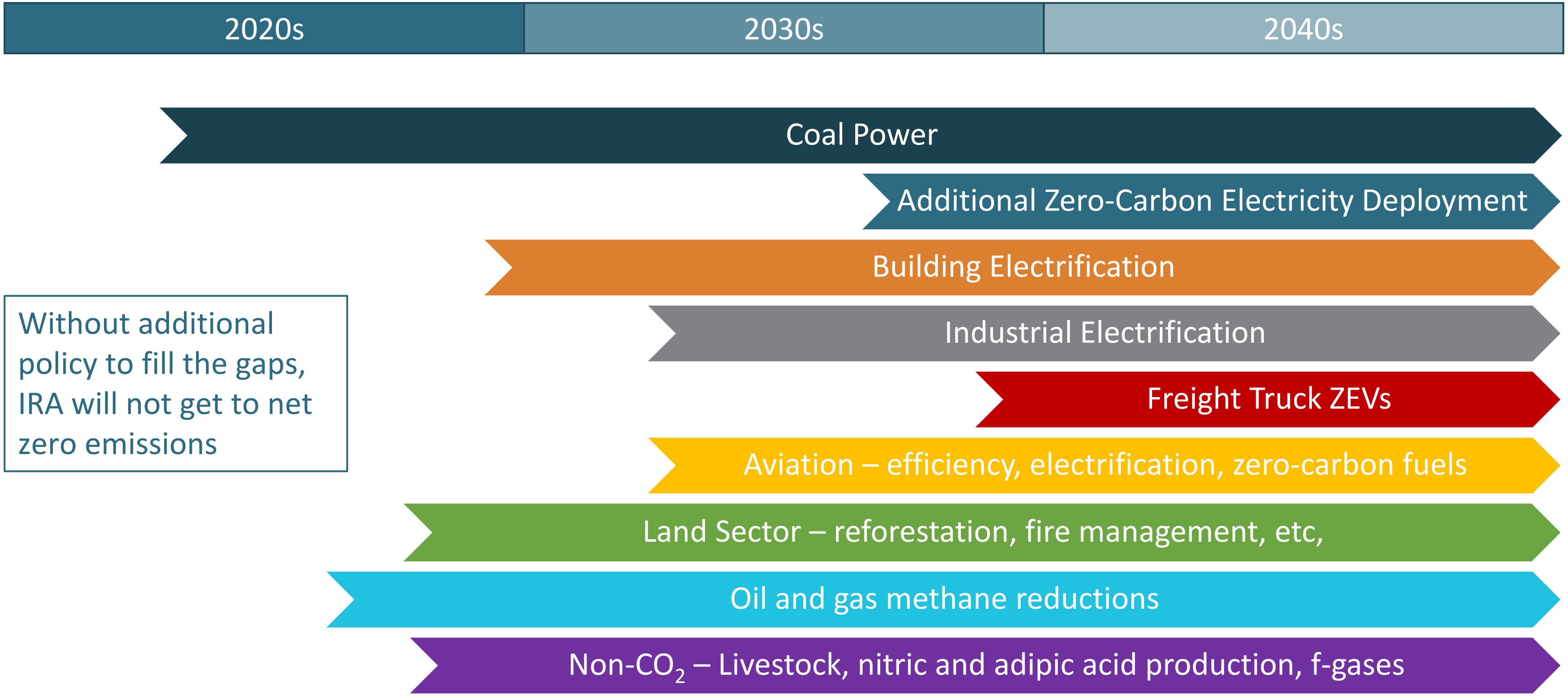

Without additional policy to fill the gaps, IRA will not get to net zero emissions

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Appendix

Study Methodology

Appendix: Study Methodology
Key Questions

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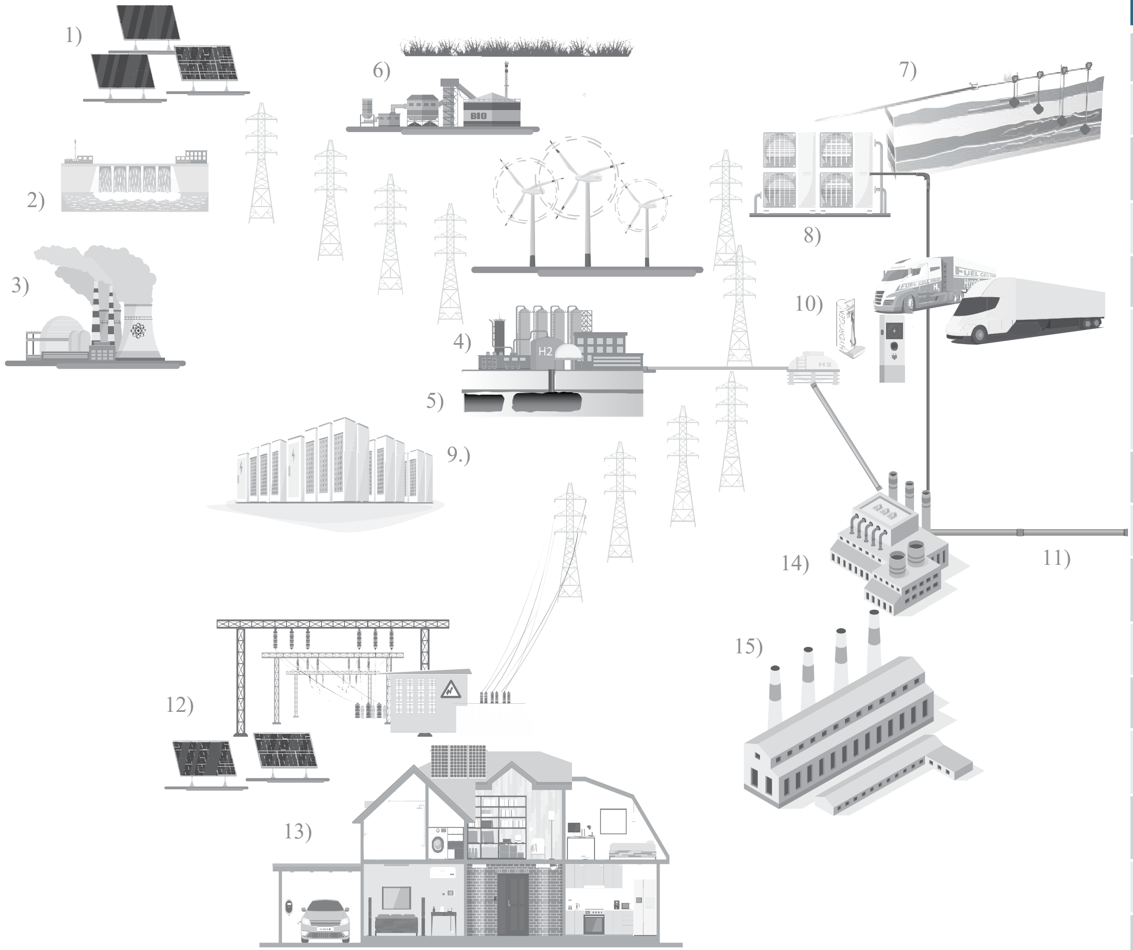
- What resources must be built to meet clean energy demand for different energy sectors in the Northwest by 2030 and 2050?
- What is the impact of accelerated or constrained transmission expansion across the Western grid?
- How does decarbonizing gas compare with electrification as a decarbonization strategy in buildings?
- What role can distributed energy resources (DERs) play in a decarbonization strategy?
- What are the tradeoffs between clean fuels, including biofuels and synthetic fuels/hydrogen?
- What is the impact of the pace of transportation electrification on the overall cost of decarbonization for the Northwest?
- What is the impact on health metrics in the Northwest if decarbonization reduces criteria pollutants?

Appendix: Study Methodology
Optimization Scope

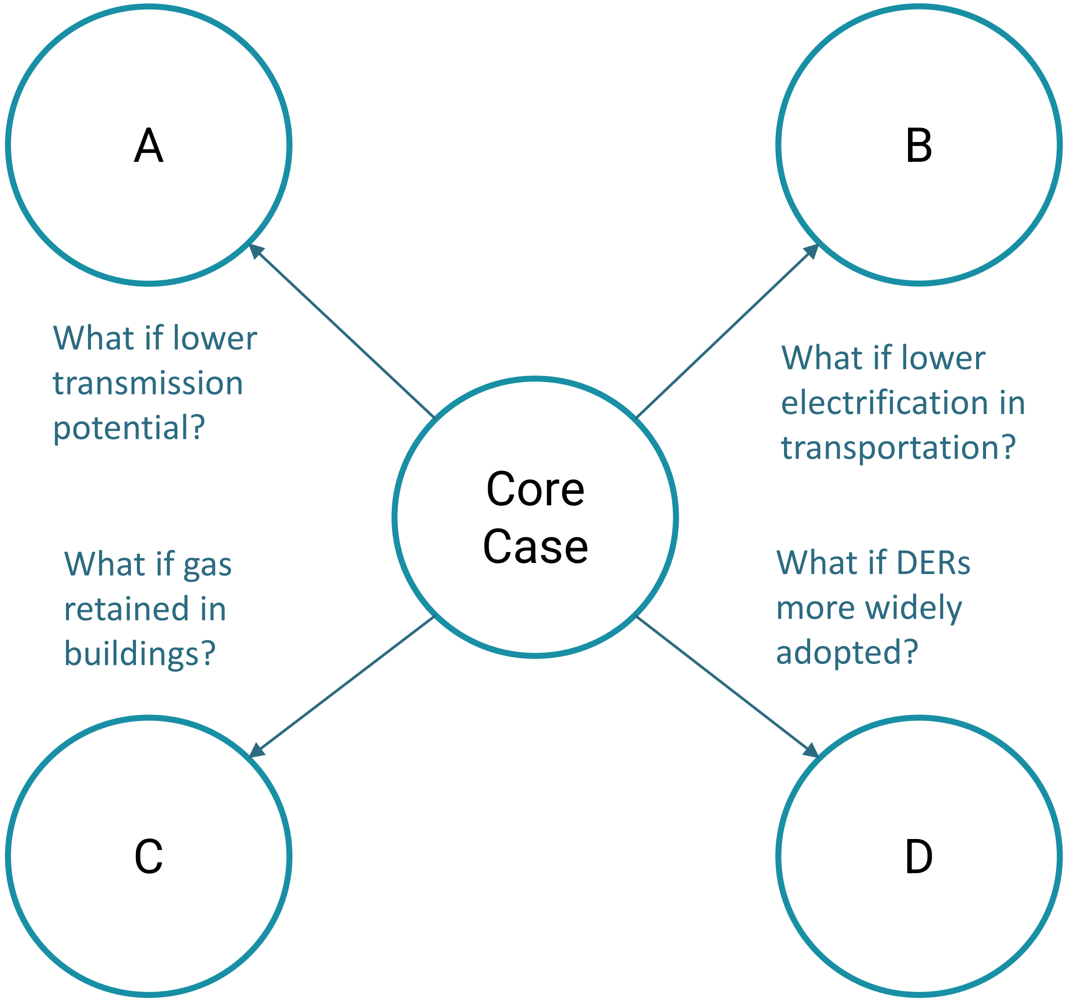
EVOLVED ENERGY RESEARCH



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

Appendix: Study Methodology
Scenario Analysis: Common Set of Assumptions

- Core Case that all other cases are compared to
- Relatively unconstrained technology availability in-state and out of state
  - Aside from technical potentials, infrastructure investments can be freely located according to lowest cost for the West
- Aggressive electrification and efficiency
- No measures taken to reduce service demands
  - Conservative, can we decarbonize even without behavior changes?
- Other scenarios change something about the Core Case
  - “What if?”
  - Unlikely that everything in the Core Case is achievable given siting and permitting, regional coordination, and other factors. How do things change if options are more constrained?



Appendix: Study Methodology
Common (Core) Principles between Scenarios

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- Aggressive on efficiency and electrification
- Regional clean energy policy:
  - Net-zero emissions by 2050, 40% emissions reduction below 1990 by 2030 in states without emissions targets
  - State-by-state clean electricity policy
- States can utilize out-of-state resources to count towards clean energy requirements in-state
- Service demands remain business as usual through 2050
- All resource options permitted for electricity and fuels production
- Fuels trading between states, including pipeline construction
- DOE Billion Ton Study Update for biomass availability updated with NW-specific data
- Waste gases and renewable fuels from waste oils
- Transmission expansion between states permitted – TNC supply curves
- Load management through dispatch of new flexible load technologies

Appendix: Study Methodology
Policy and Supply-side Assumptions

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Assumption Type	Core Case Assumptions
Clean Electricity Policy	State-by-state clean electricity policy. Oregon: 100% clean electricity by 2040; Washington: Clean Energy Transformation Act (CETA), 100% clean by 2045, coal retirements by 2025
Economy-Wide GHG Policy	State targets by 2030 (or 40% below 1990 for those without them); net zero by 2050
Clean Resource Qualification	Renewables and 100% clean fuels, nuclear, fossil gas with carbon capture
Inflation Reduction Act Incentives	Supply-side incentives included for hydrogen production, renewable electricity generation, battery storage, carbon sequestration, clean fuels, and nuclear
Resource Availability	NREL resource potential; TNC new transmission supply curves; 4th generation and SMR nuclear not permitted in Oregon or California. New gas build not permitted in Oregon
Fuels	AEO Reference fuel prices; sequestration potential across the West where geologic formations exist; clean fuels have zero emissions associated with them, so sequestration credit is left in state of origin. Oregon and Washington clean fuel standards incorporated
Land sink	Supply curve of land sink measures
Non-energy emissions	Non-energy emissions abatement curve

Appendix: Study Methodology Demand-side Assumptions

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Assumption Type	Core Case Assumptions
Energy Service Demand	Annual Energy Outlook (AEO) 2022
Buildings: Electrification	Fully electrified appliance sales by 2035
Buildings: Tech Energy Efficiency	Sales of high efficiency technology: 100% in 2035 High efficiency building shell sales: 100% by 2035
Transportation: Light-Duty Vehicles	100% ZEV sales by 2035
Transportation: Medium and Heavy-Duty Vehicles	HDV long-haul: 50% hydrogen, 50% electric sales by 2045. HDV short-haul: 100% electric sales by 2045. MDV: 100% electric sales by 2035
Industry	Generic efficiency improvements over AEO of 1% a year; fuel switching measures; 1.5% a year efficiency improvement in aviation. Process heat storage opportunities
DER Schedule	State-by-state rooftop solar schedule, 75% of light duty vehicle load and 10% of heating and cooling load is flexible by 2050

Appendix: Study Methodology
Summary of Scenarios: “What If?” Questions

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SECTION	SUMMARY	KEY QUESTIONS INVESTIGATED
Task 1: Core Case	**Assumes all states hit net-zero target by 2050; 2030 emission targets in states where they exist & 40% in states where not**	What resources must be built to meet clean energy demand for different energy sectors in the Northwest by 2030 and 2050?
Task 2: Accelerated/ Constrained Transmission	**Varies transmission expansion potential in six scenarios**	What is the impact of accelerated or constrained transmission expansion across the Western grid?
Task 3: Gas vs. Electrification in Buildings	**Examines the relative costs of preserving or eliminating gas infrastructure over time**	How does decarbonizing gas compare with electrification as a decarbonization strategy in buildings?
Task 4: Role of Distributed Energy Resources	**Four scenarios varying levels of DERs (rooftop solar and customer appliance flexible load)**	What role can distributed energy resources (DERs) play in a decarbonization strategy?
Task 5: Pace of Transportation Electrification	**Two scenarios that vary the pace of transportation electrification**	What is the impact of the pace of transportation electrification on the overall cost of decarbonization for the Northwest?
Task 6: Clean Fuels Tradeoffs	**Explores the impact of technology pricing options for biofuels, synthetic fuels, and hydrogen**	What are the tradeoffs between clean fuels, including biofuels and synthetic fuels/hydrogen?
Task 7: Emissions Impacts on Health Metrics	**Determines changes in criteria pollutants and their impact on health metrics**	What is the impact on health metrics in the Northwest if criteria pollutants are reduced as a result of decarbonization?
Task 8: Oregon Offshore Wind Targets	**Investigates the impact on investment decisions if Oregon were to target offshore wind builds of 3 GW by 2030, 5 GW by 2035, and 10 GW by 2050**	How does Oregon offshore wind targets impact decarbonization costs and strategy? Used as an input to a Renewable Northwest study on jobs and economic impacts of offshore wind development in OR

Appendix: Study Methodology
Models Used in the Analysis

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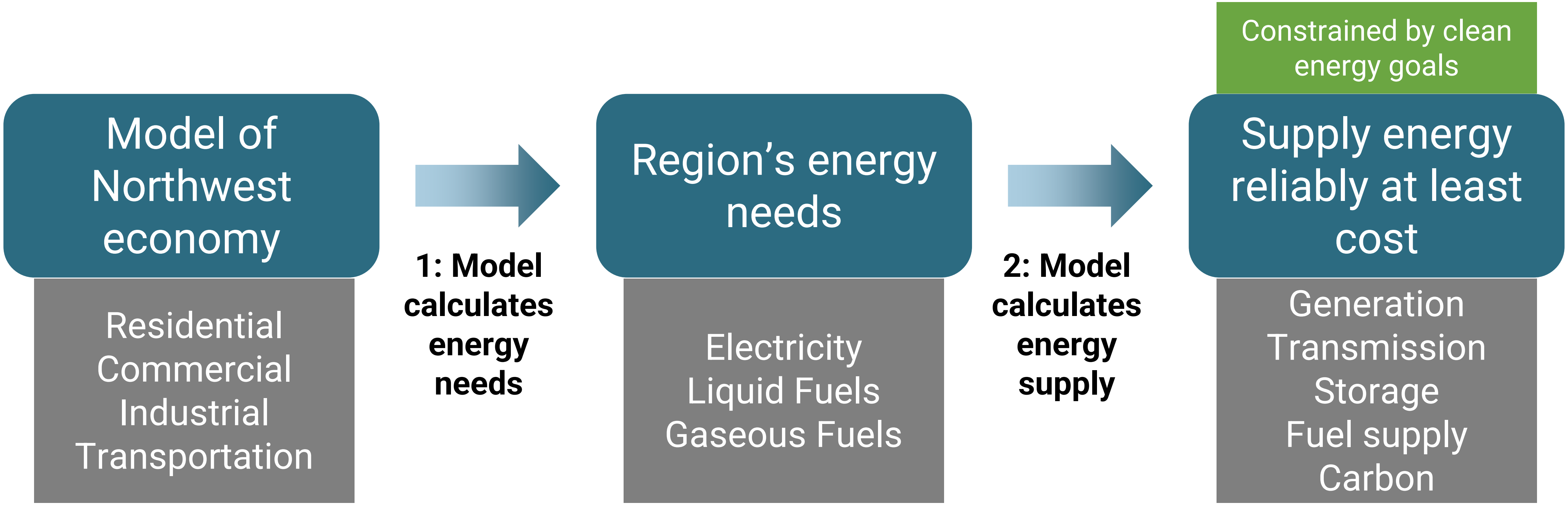
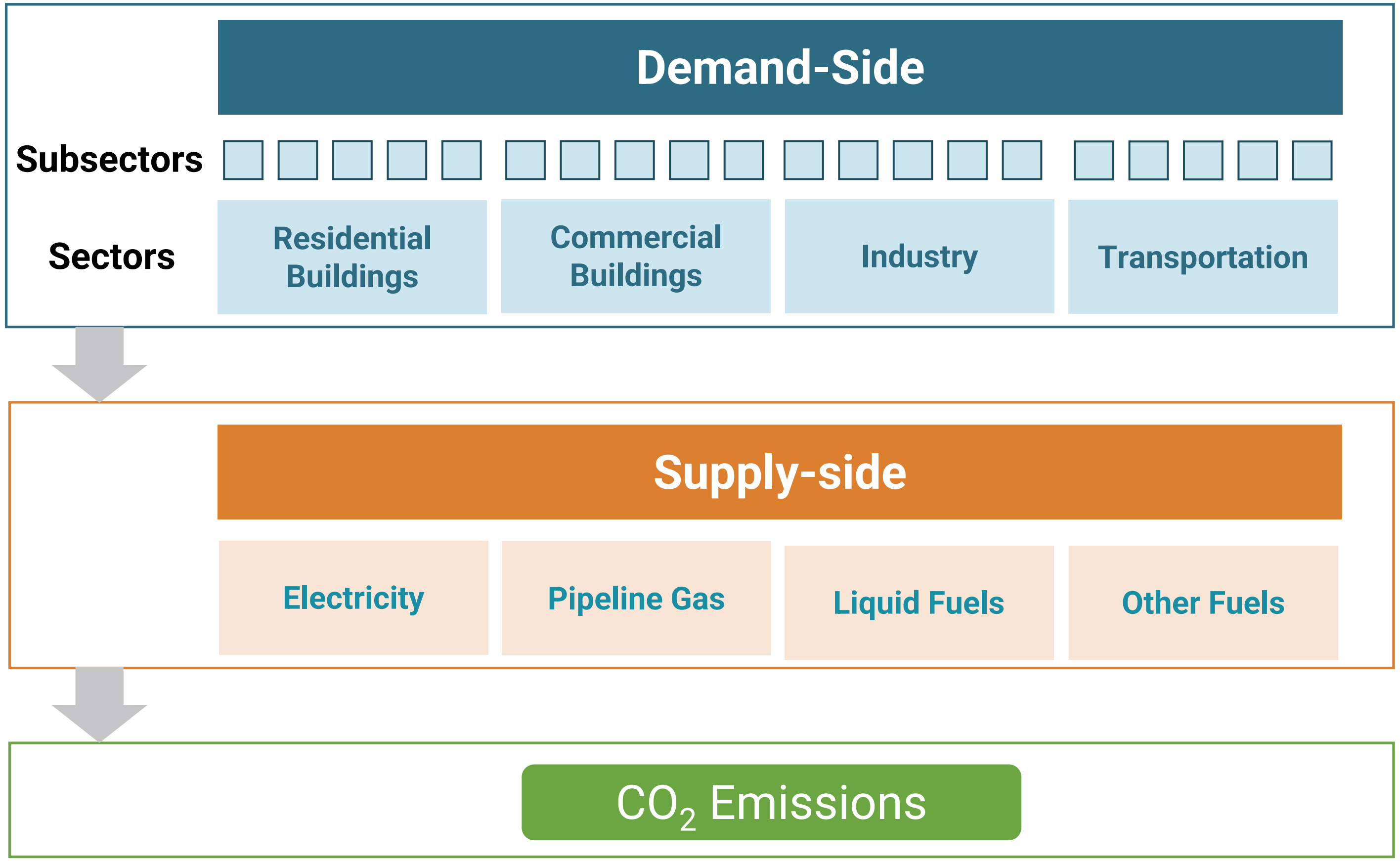
- The Evolved models used in this analysis are updated every year with new features and technologies to best represent the current understanding of future decarbonization options
- For comprehensive descriptions of the EnergyPATHWAYS and RIO models, please see our Annual Decarbonization Perspective (ADP) 2022 that showcases the version of the model used in this analysis
- These can be found at:
  - ADP 2022
  - ADP 2022 Supporting Documentation
- The following slides give an introduction to the EnergyPATHWAYS and RIO models

Appendix: Study Methodology
High Level Description of Modeling Approach

- Model calculates the energy needed to power the Northwest economy, and the least-cost way to provide that energy under clean electricity and emissions goals



Appendix: Study Methodology
Analysis Covers Entire Northwest Energy System



- **EnergyPATHWAYS** model used to develop demand-side cases
- Applied electrification and energy efficiency 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)

Appendix: Study Methodology
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

Appendix: Study Methodology
Demand-side Modeling

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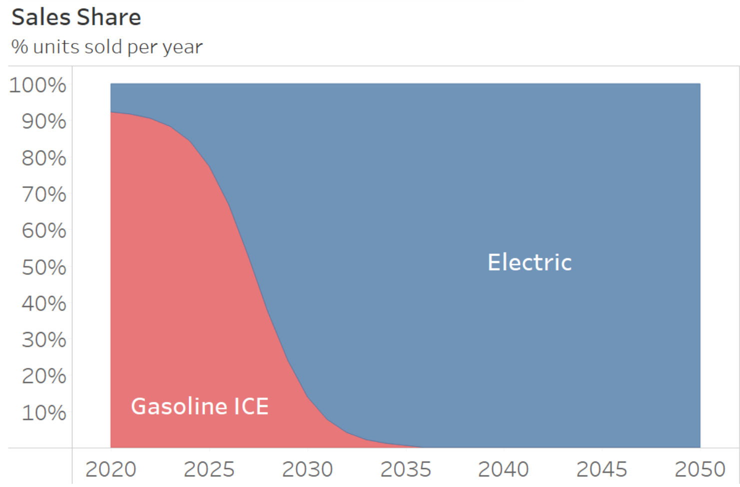
- Scenario-based, bottom-up energy model (not optimization-based)
- Characterizes rollover of stock over time
- Simulates the change in total energy demand and load shape for every end use

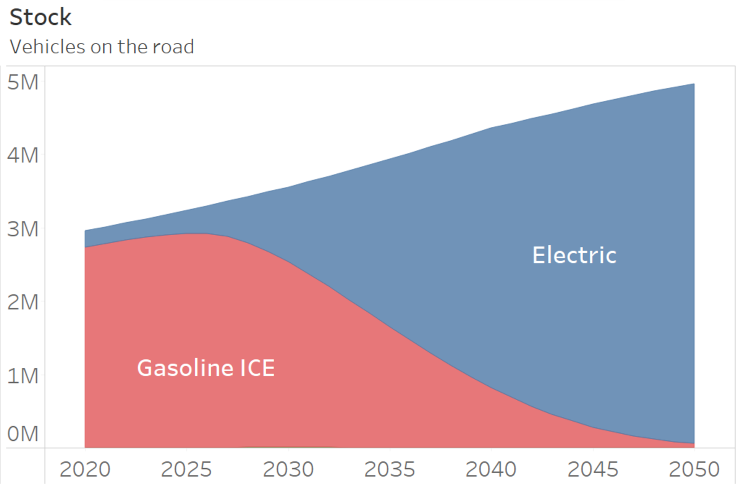
Illustration of model inputs and outputs for light-duty vehicles

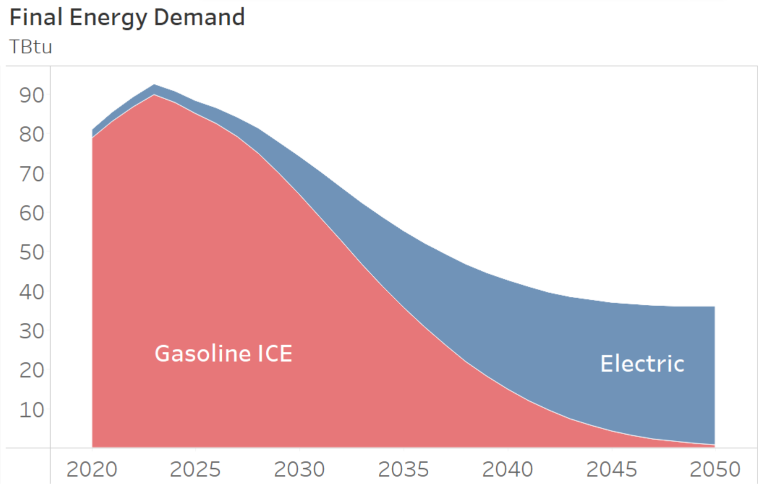
Input: Consumer Adoption
EV sales are 100% of consumer adoption by 2035 and thereafter

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







Appendix: Study Methodology
End-use Sectors Modeled

- Approximately 70 demand sub-sectors represented
- The major energy consuming sub-sectors are listed below:

Key energy-consuming subsectors:

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

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

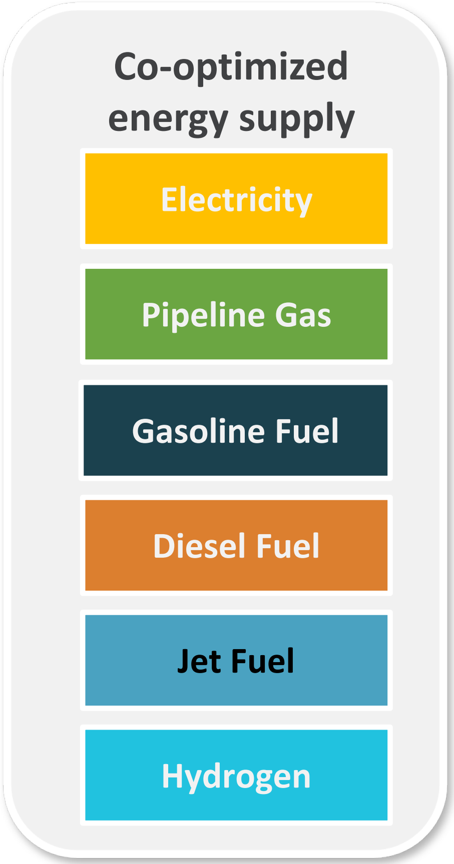
Industrial Sector
- Boilers
- Process heat
- Space heating
- Curing
- Drying
- Machine drives
- Additional subsectors (e.g., machinery, cement)

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

Source: CETI, NWDDP, 2019

Appendix: Study Methodology
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



Appendix: Study Methodology

Supply-side Modeling: Optimized investments in energy infrastructure

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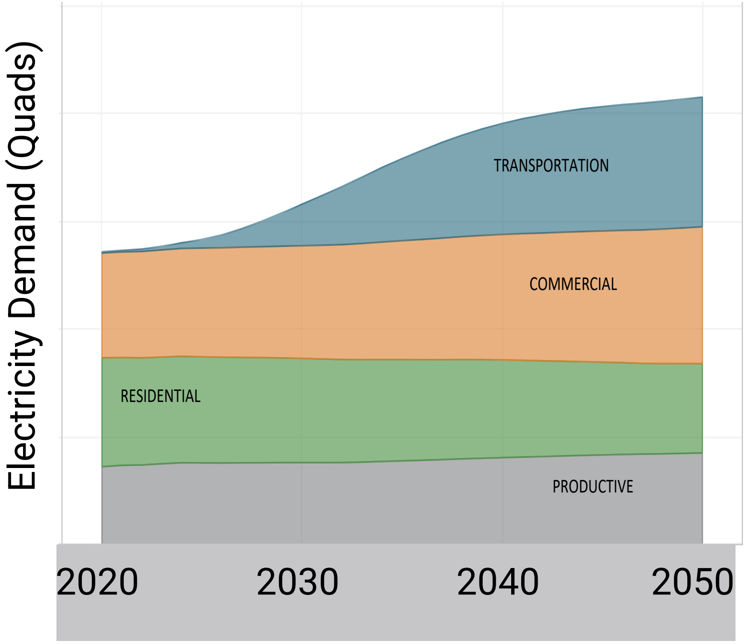
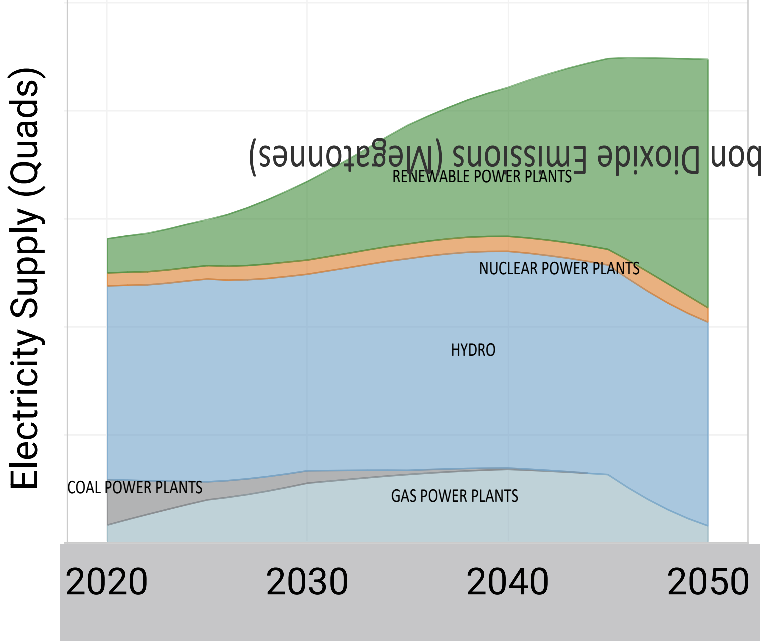
Example: Electricity

Electricity includes all economic sectors



Model optimizes investments to meet demand, reliability, and emission targets



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- **Reliability**: Model requires supply is met during rare, severe weather events, while maintaining reserve margin
- Fuel and electricity supply are optimized together
- Model uses best available public data

Appendix: Study Methodology
Integrated Supply Side: Electricity and Fuels

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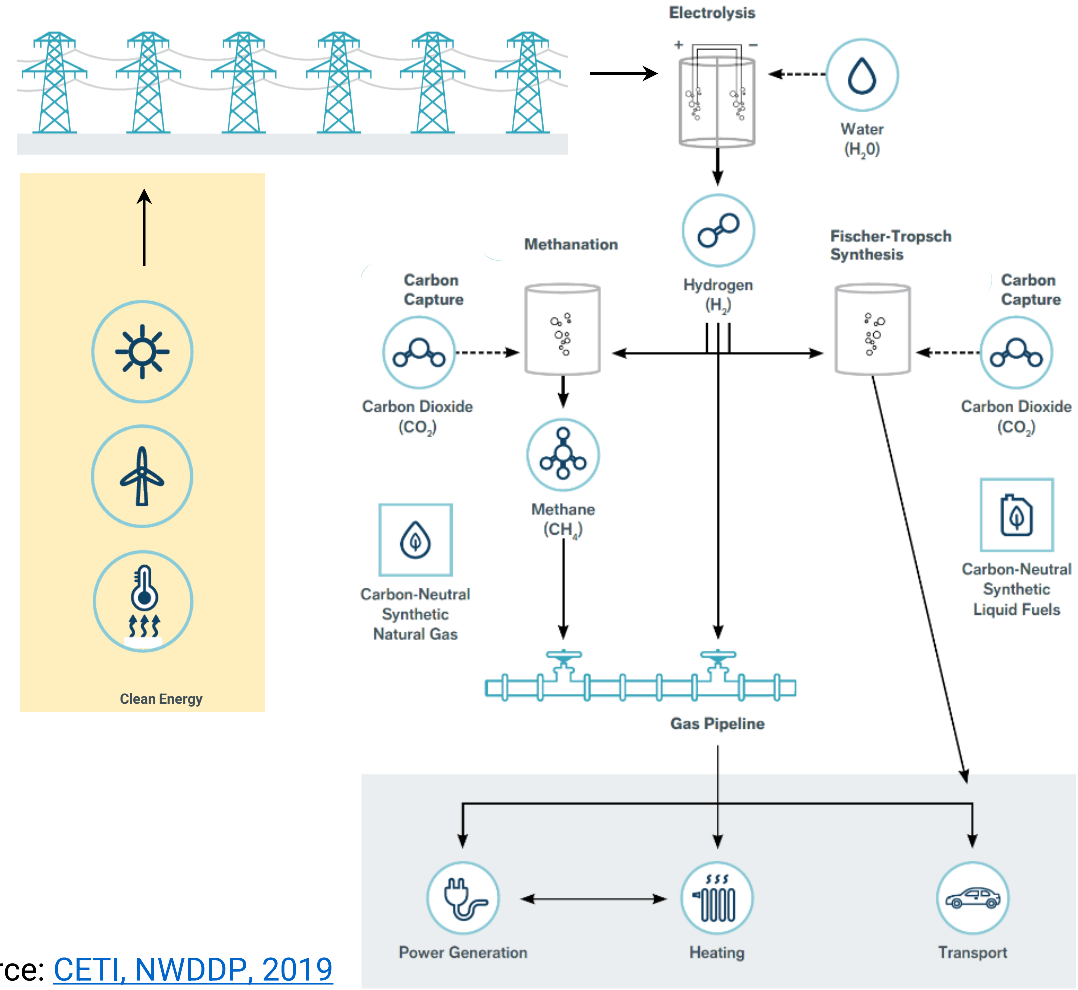
- Conventional means of "balancing" may not be the most economic or meet clean energy goals
- New opportunities: Storage and flexible loads
- Fuels are another form of energy storage
- Large flexible loads from producing decarbonized fuels:
  - Electrolysis, synthetic fuels production

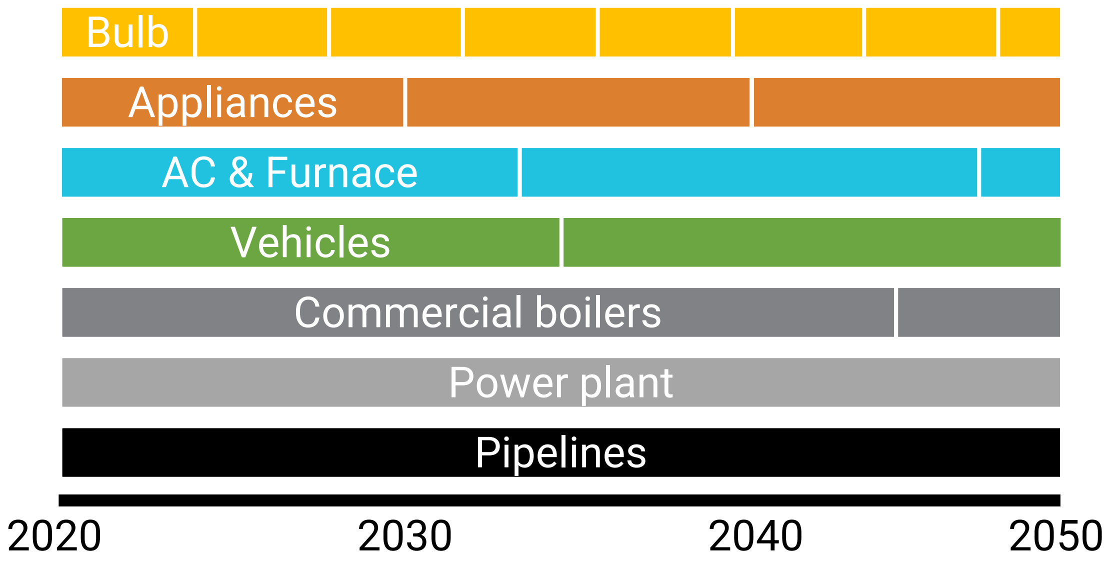


Source: CETI, NWDDP, 2019

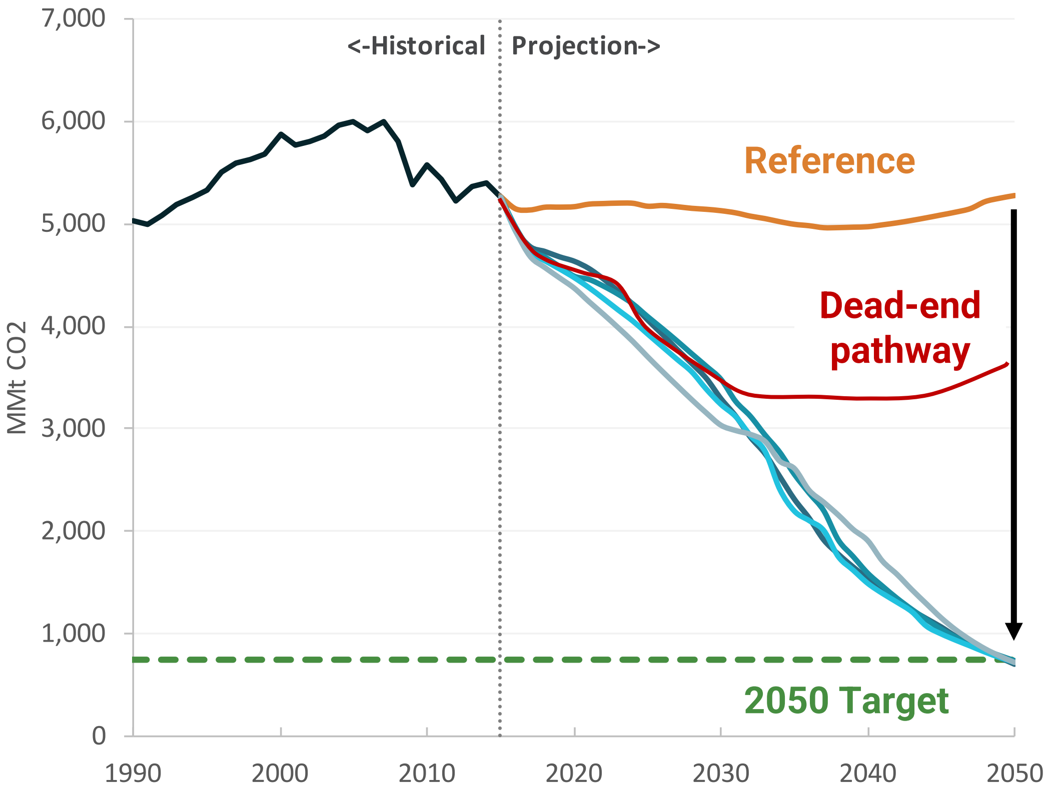
Appendix: Study Methodology
Near-term Focus On Long-lived Assets

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



Appendix: Study Methodology
Demand and Supply-side Modeling Framework

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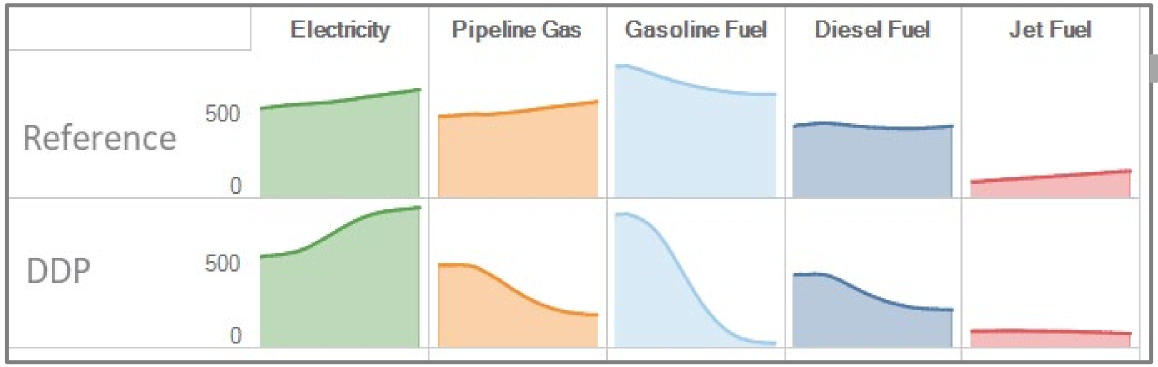
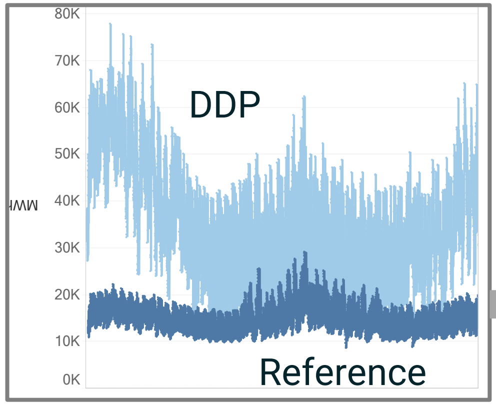
EnergyPATHWAYS (EP)

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: Study Methodology
RIO Decisions Variables and Outputs

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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 study 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

Appendix: Study Methodology
Rio Optimizes across Time-scales

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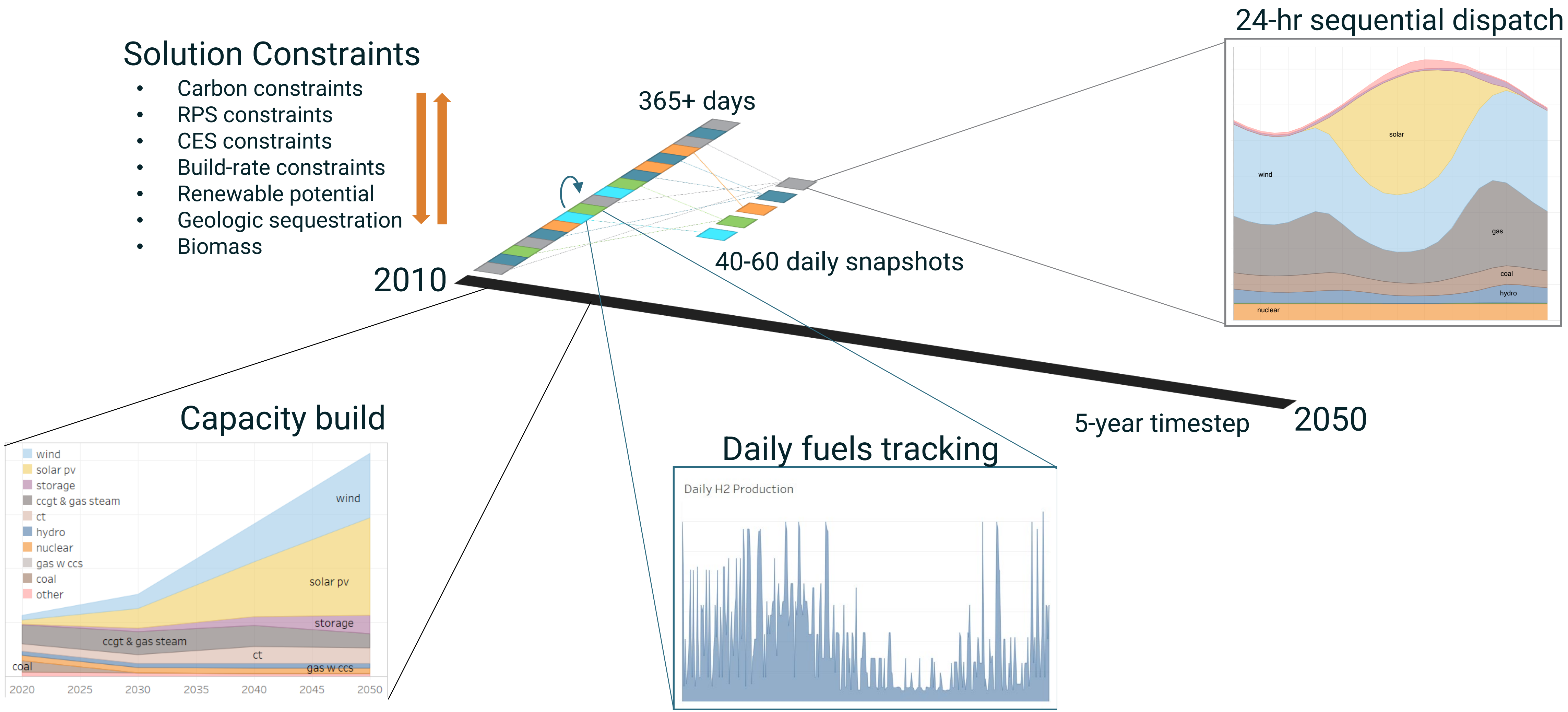

Appendix: Study Methodology
Flexible Load Operations

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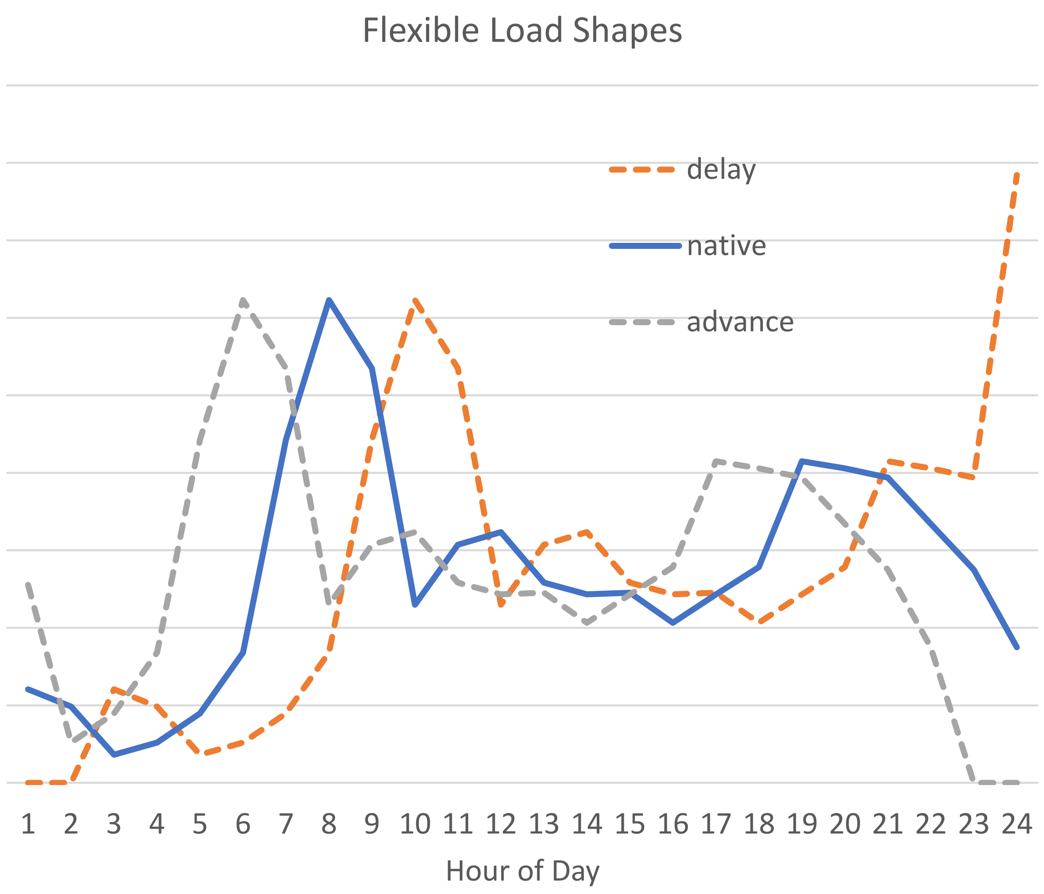
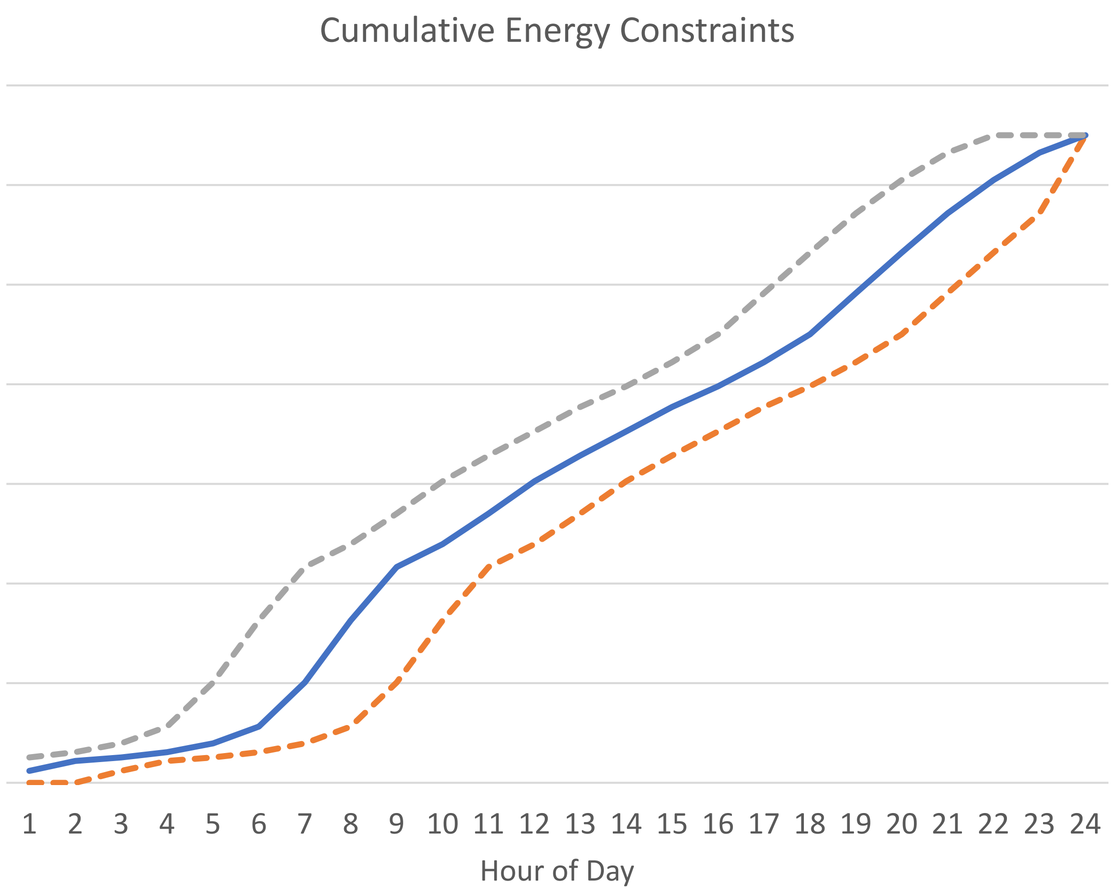
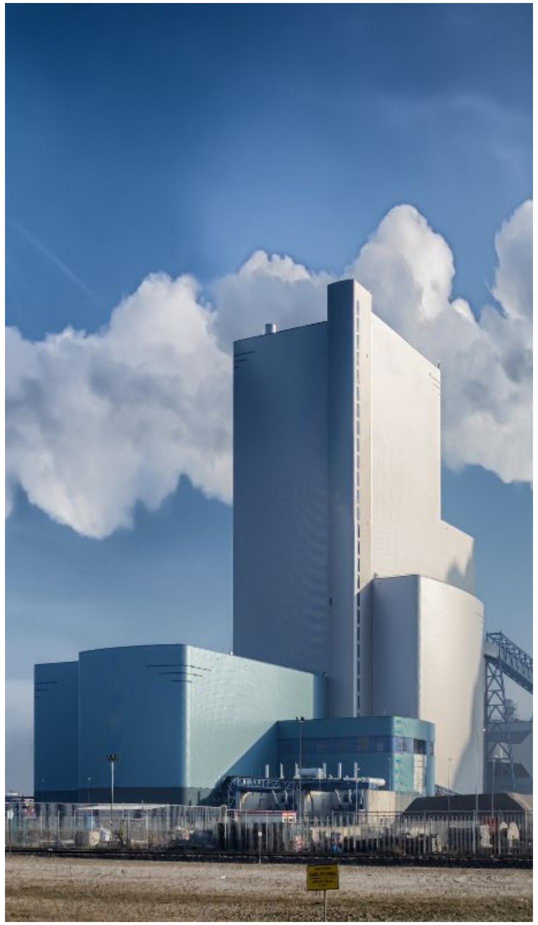
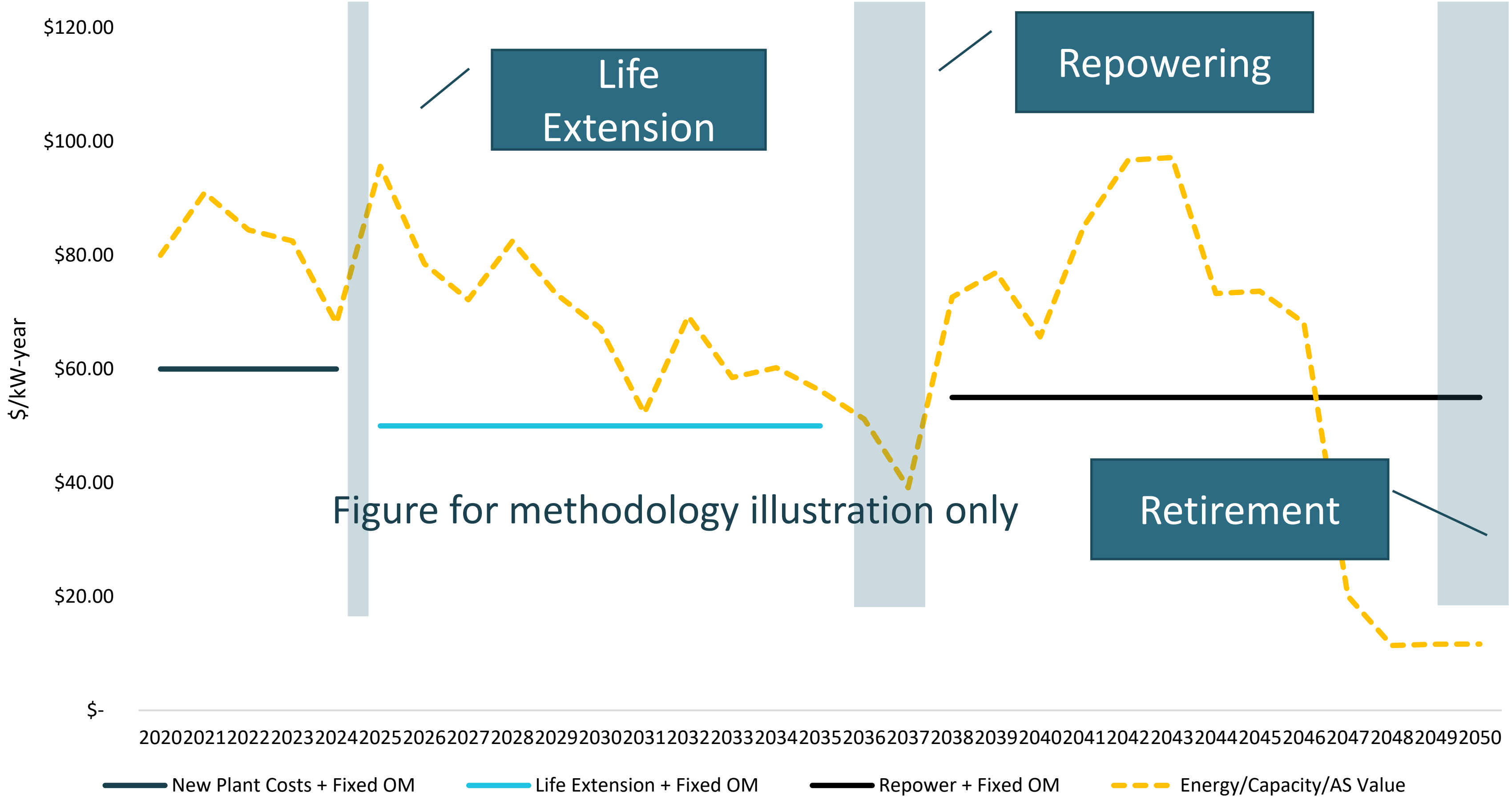




Appendix: Study Methodology
Economic Generator Lifecycles

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





Appendix: Study Methodology
RIO Commodities Module Definitions

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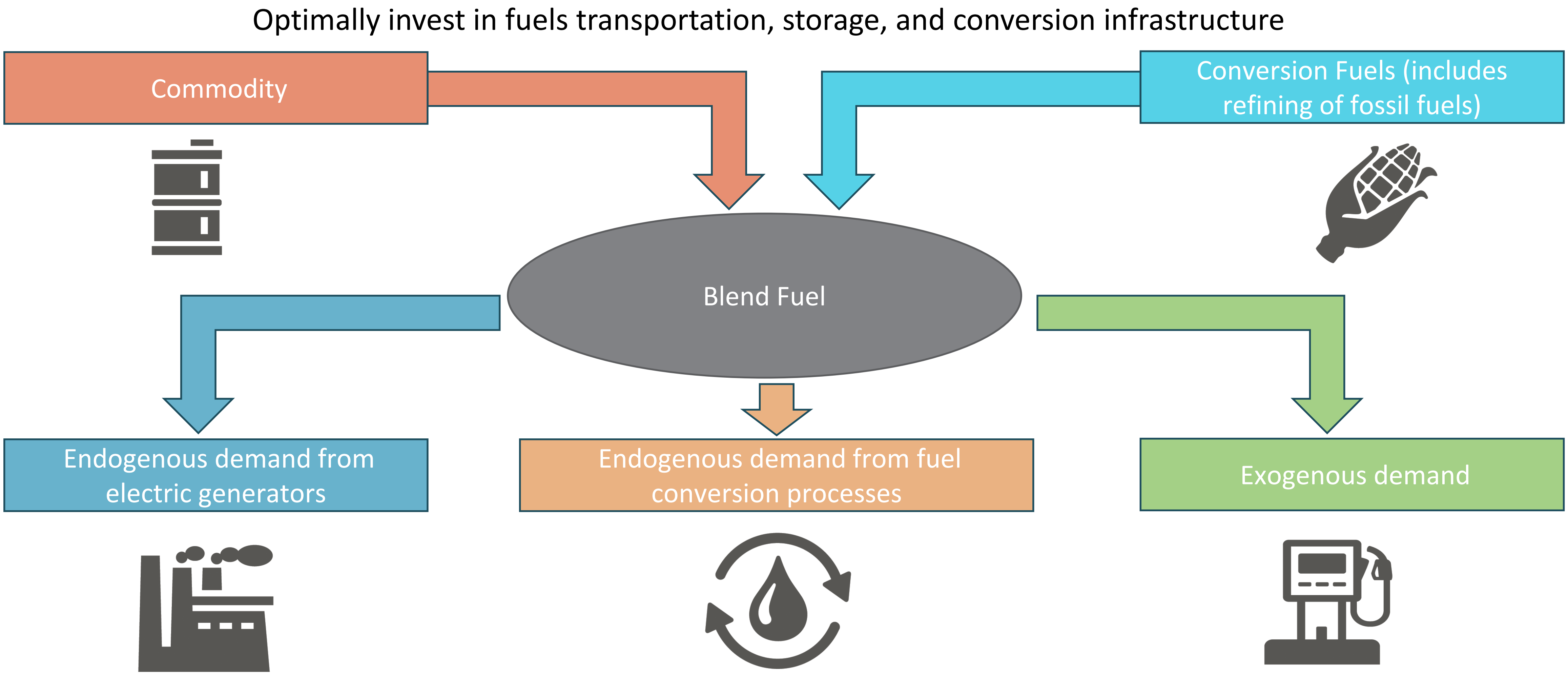
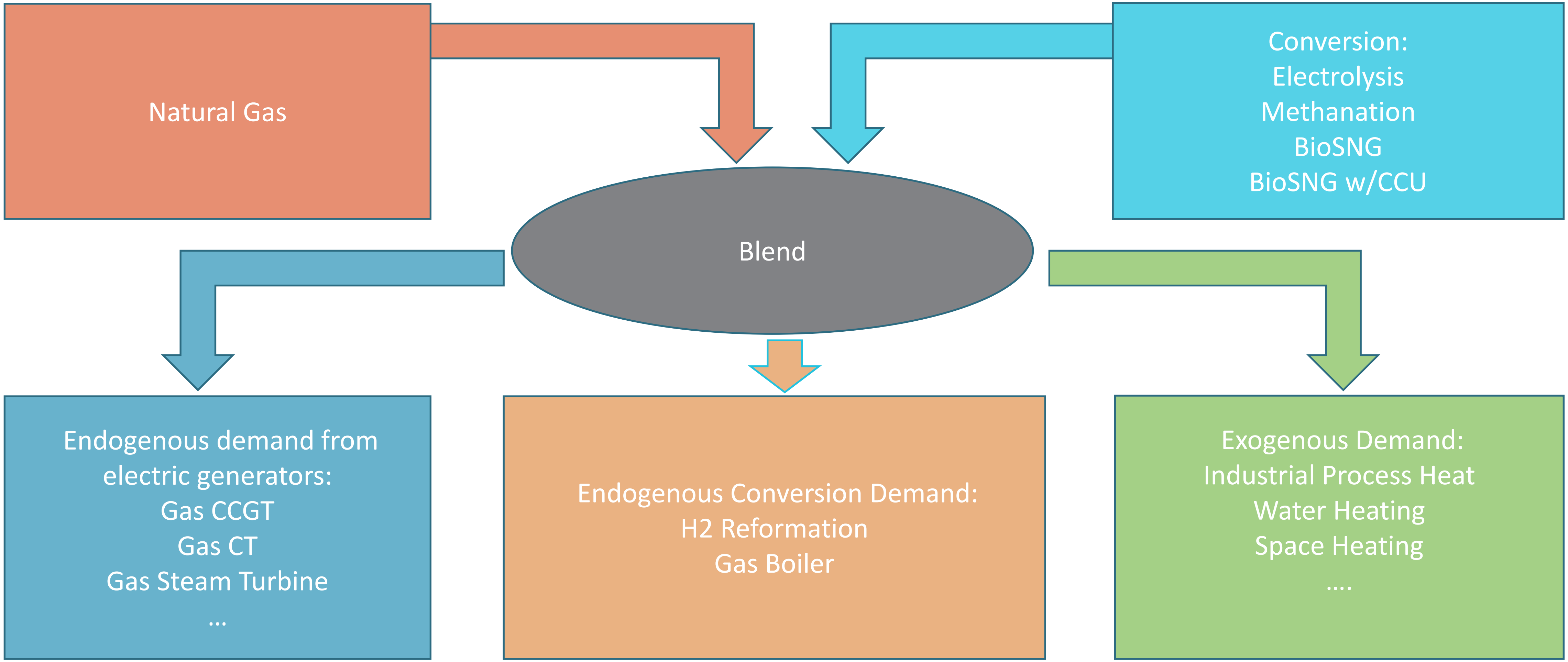
Category	Definition	Examples
Commodity	Exogenously specified commodity type defined with price supply curve, emissions rates, and available volumes	Natural Gas; Oil; Coal; Biomass
Conversion	Capital investment defined with cost of production capacity and efficiency of production (blend x -> blend y and/or electricity->blend y)	Biomass SNG; Power-to-Gas; Direct Air Capture
Blend	Aggregation point for product and conversion commodities. All inputs (conversion and products) are drop-ins for an individual blend.	Pipeline Gas; Diesel Fuel; Hydrogen; Captured CO2

Appendix: Study Methodology
RIO Fuels Structure

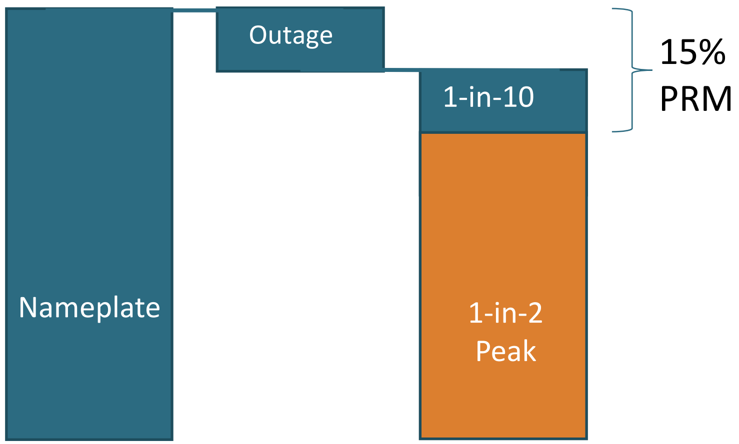


Appendix: Study Methodology
RIO Commodities Structure: Pipeline Gas Blend Example

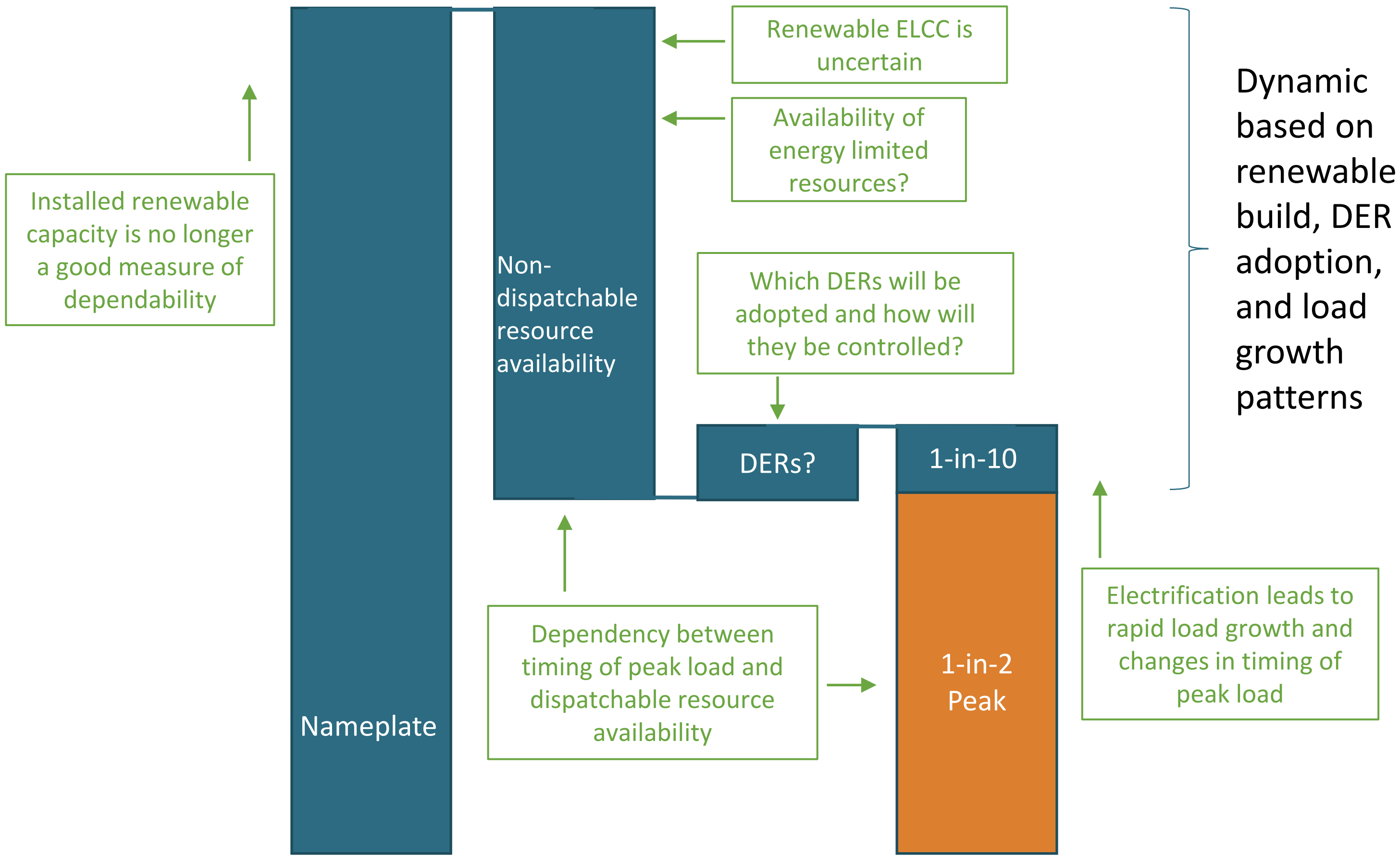


Appendix: Study Methodology
Hourly Reserve Margin Constraints by Zone

Traditional Reserve Margin



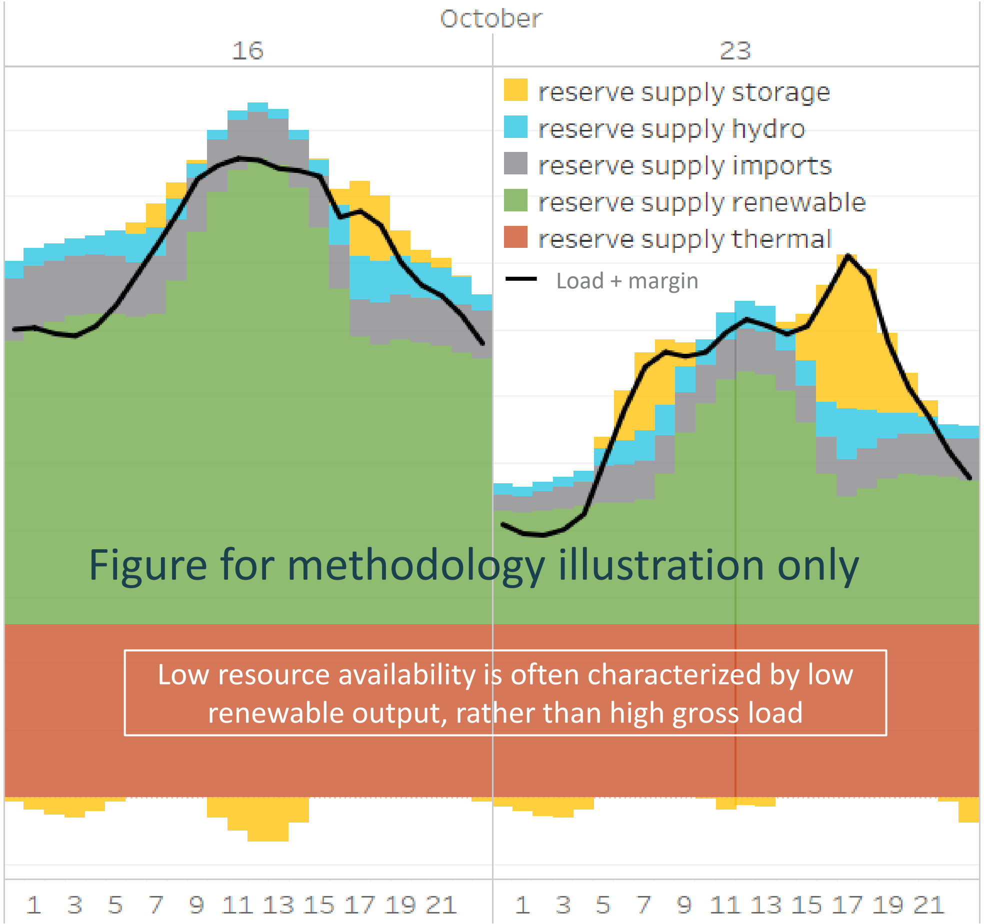
Future System Reliability Assessment



Appendix: Study Methodology
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



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Appendix

Study Assumptions

Appendix: Study Assumptions Options to Reduce Emissions

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- Changing the way customers consume energy
  - Demand-side measures to electrify and install high efficiency equipment
- Reducing emissions intensity of energy supply
  - Least cost supply-side optimization of investments and operations in the supply chains of all forms of energy
- Measures to reduce non-CO_2 emissions
  - EPA supply curve of measures to reduce non-CO_2 emissions
- Incremental land sink/carbon capture
  - Offset emissions by capturing more carbon in the land, such as through reforestation, or through sequestration of carbon

Appendix: Study Assumptions
Model Geography

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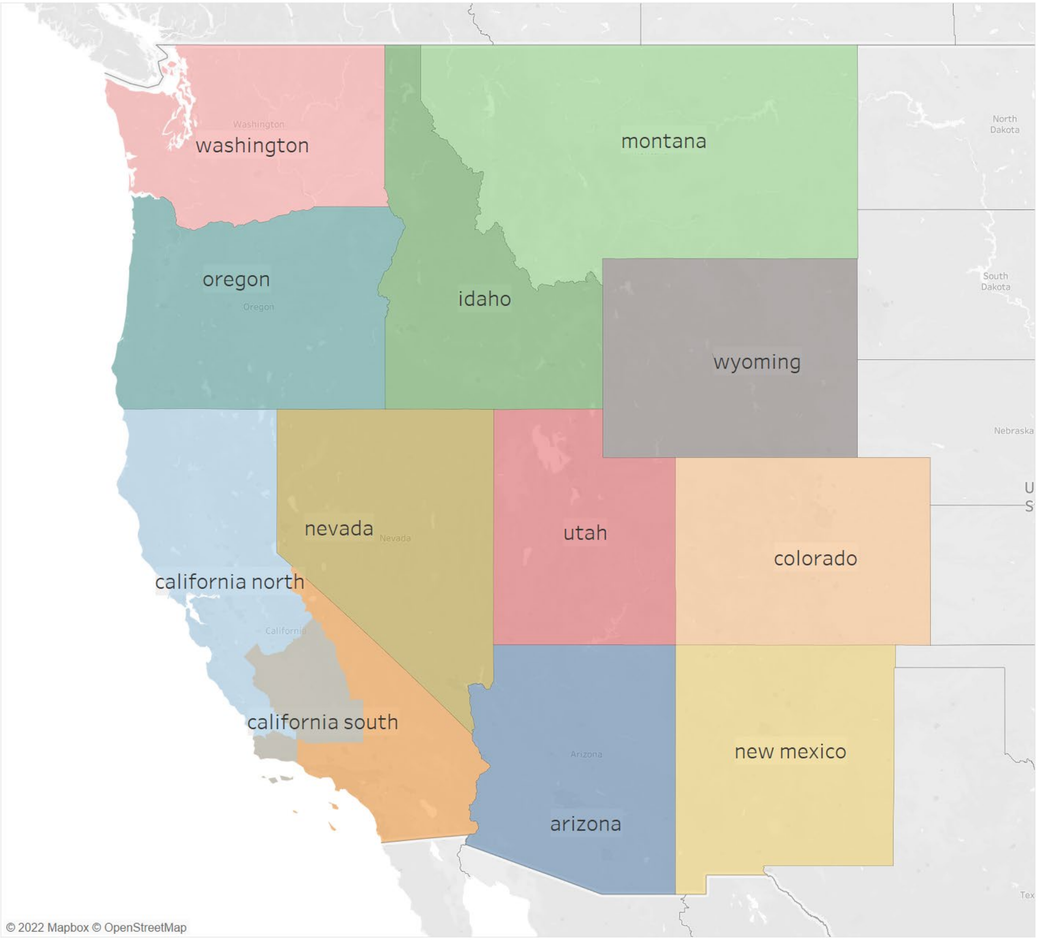
- We model the states in the Western United States with California represented as 2 zones and the rest of the US as a single zone
- Contextualizes the decisions made in Northwest operating as part of a larger energy system
  - Competition for fuels including biomass, renewables, and hydrogen derived from renewables
  - Balances the electricity system over a large and diverse region – assumes single balancing authority
  - Captures transmission line and pipeline flow and build constraints
  - Resource, load, and temporal diversity contribute to economy and region-wide least cost strategy to reach net zero



Appendix: Study Assumptions
Economy-wide GHG Policy

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Assumption Type	Strawman Core Case Assumptions
Economy-Wide GHG Policy	State targets by 2030 (or 40% below 1990 for those without them), net zero by 2050

Existing state GHG policy targets:

(MMT)	2025	2030	2035	2040	2045	2050	Benchmark Year	Notes
Arizona	None							
California		40%			Net-zero		1990	Executive target
Colorado	26%	50%				90%	2005	Statutory target
Idaho	None							
Montana						Net-zero	N/A	Executive target
Nevada	28%	45%				Zero or near-zero	2005	Statutory target
New Mexico		45%					2005	Executive target
Oregon			45%			80%	1990	Executive target
Utah	None							
Washington		45%		70%		95%/ net-zero	1990	Statutory target
Wyoming	None							

Appendix: Study Assumptions
Where do we start from in the Northwest?

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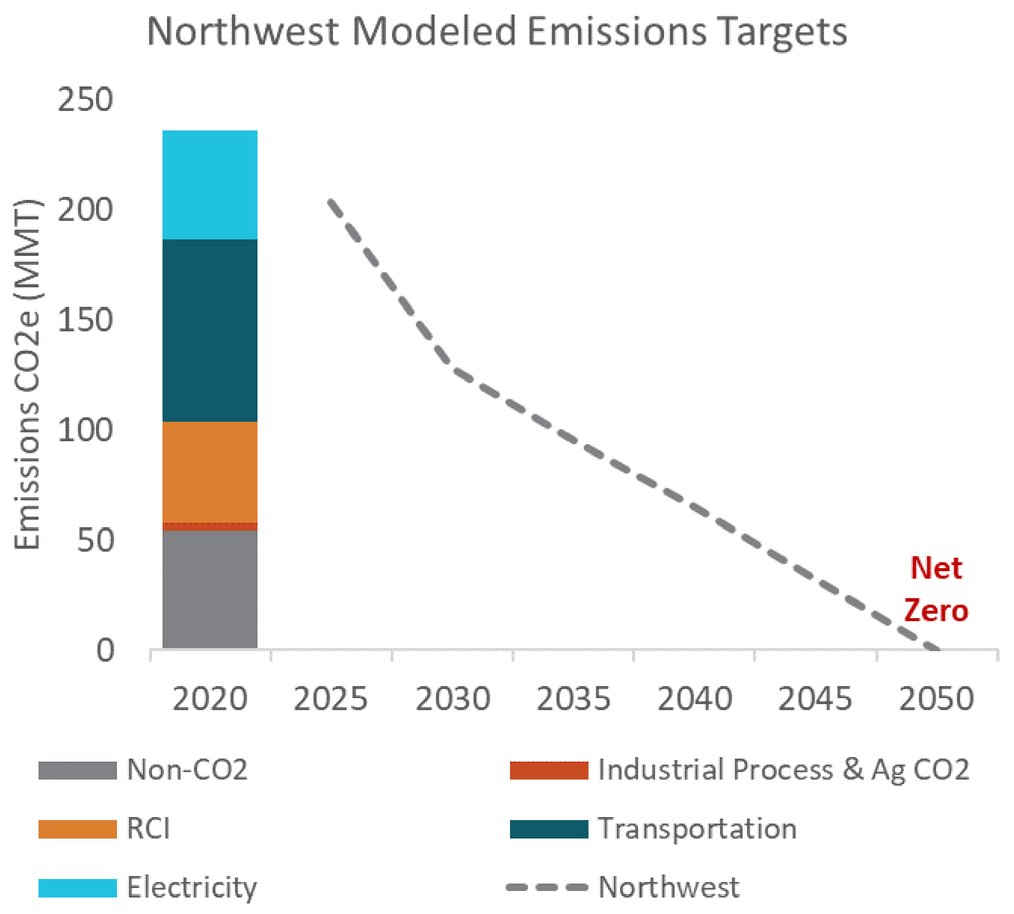
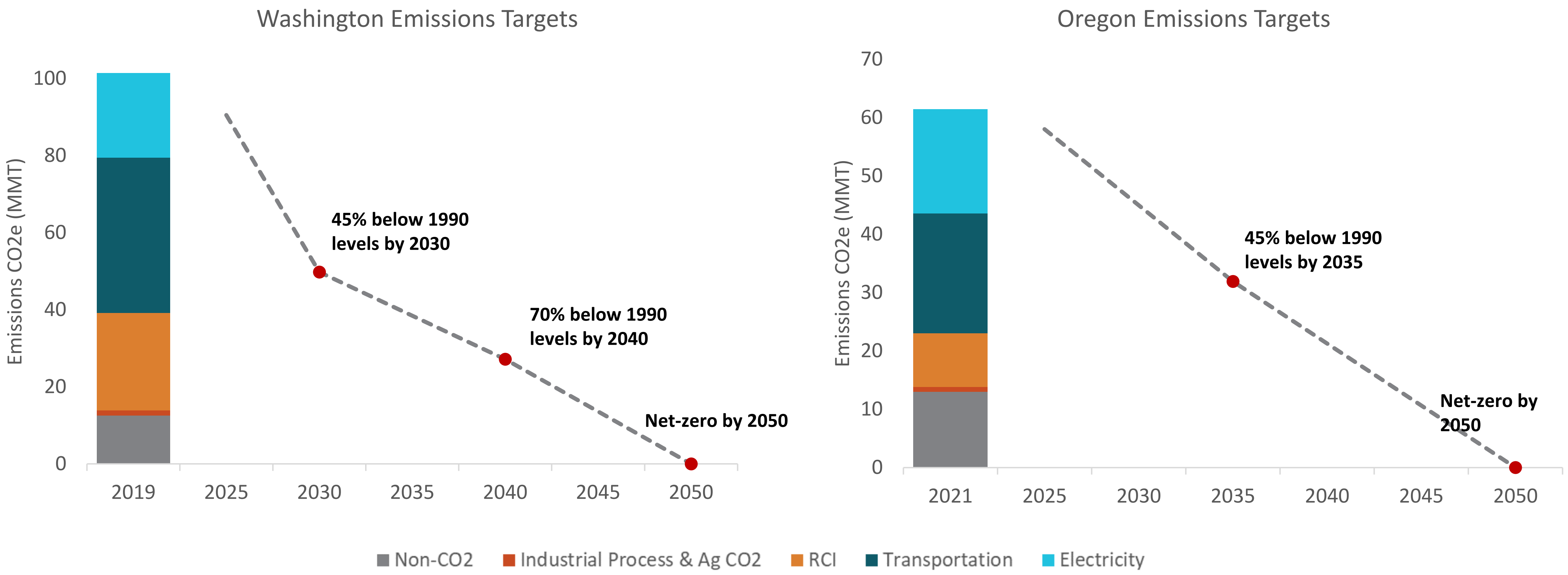
- We use 1990 as the reference year for all Northwest states, drawing from each state's emissions inventory
  - All emissions targets in the model are set using the 1990 baseline
- Our emissions modeling includes CO_2 and non-CO_2 emissions
- Total 2021 emissions for Oregon, Washington, Montana and Idaho estimated at nearly 236 MMT, with over 20% coming from non-CO_2 emissions based on emissions inventories
  - Emissions inventory data has been published for prior years, including 2020 in WA for electricity, 2019 in WA for all other categories, 2021 in OR, and forecast for 2020 in MT and ID. We use the values for these various reporting years in 2021 to get an estimate for the region

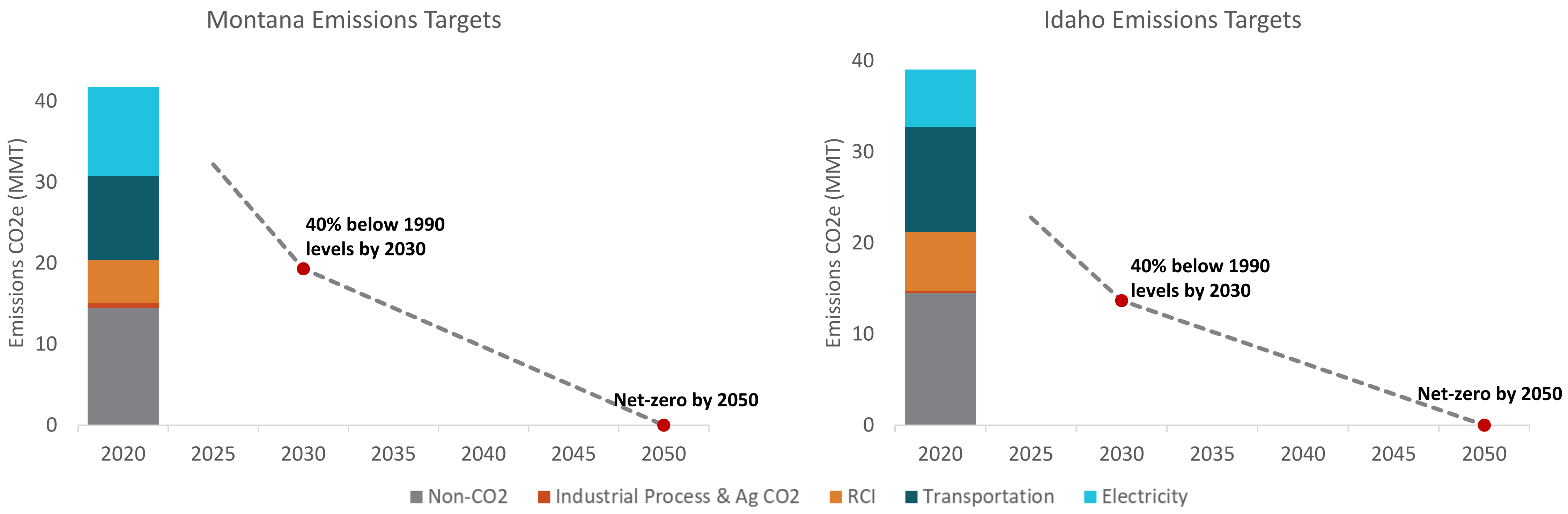


Appendix: Study Assumptions
Modeled Emissions Targets by State



Emissions targets were set using the 1990 baseline from the 2021 Ecology Emissions Inventory because the 2022 publication was not available when the project began. State targets reached then straight-line interpolation to net zero by 2050 in Oregon.

Appendix: Study Assumptions
Modeled Emissions Targets by State



In the absence of state policy targets, we restrict Montana and Idaho emissions to 40% below 1990 levels in 2030 and net-zero in 2050. Projected emissions from Montana's and Idaho's emissions inventories are from 2007 and 2010, respectively, produced by Center for Climate Strategies. These predictions match well with Evolved's bottom-up modeling of emissions in these states, found to be 42 MMT in Montana and 38 MMT in Idaho in 2021.

Appendix: Study Assumptions
Clean Electricity Policy

Assumption Type	Strawman Core Case Assumptions
Clean Electricity Policy	2030: state-by-state clean electricity policy targets. 2050: 100% clean in all states.

Existing state clean electricity policy targets:

State	Targets							Notes
	2020	2025	2030	2035	2040	2045	2050	
Arizona	6%	15%						Arizona Public Service targeting 100% carbon free by 2050
California	33%		60%			100%		
Colorado	30%		30%		100%			
Idaho	None							Idaho Power targeting 100% clean by 2045
Montana	15%							
Nevada	22%		50%				100%	
New Mexico	20%		50%		80%	100%		
Oregon	20%		80%	90%	100%			Reductions relative to 2010 baseline
Utah		20%						
Washington	12%		80%			100%		
Wyoming	None							

States with existing 100% targets make up ~75% of total 2020 WECC load

Appendix: Study Assumptions
Summary of IRA Provisions

EVOLVED ENERGY RESEARCH

Provision	Modeling Assumptions	
Renewable energy PTC	\$26/MWh credit for PV, onshore wind, geothermal, and certain offshore wind resource classes and zones	
Renewable energy ITC	30% for batteries, fuel cells, and certain offshore wind resource classes and zones	
Carbon sequestration tax credit (45Q)	\$85/ton CO2 stored for ethanol with CCS, BECCS hydrogen with CCS, power with CCS and cement with CCS. \$180/ton CO2 stored from DAC.	
Clean fuel PTCs	2022-2024: \$1/gallon biodiesel \$1.01/gallon cellulosic ethanol \$1.25/gallon sustainable aviation fuels (bio-fischer-tropsch (FT)) \$1.75/gallon bio-FT with CCS	2025-2027: \$1/gallon for all zero or negative emissions transportation fuels \$0.82/gallon for cellulosic ethanol w/o CCS \$1.75/gallon zero-emissions (FT) aviation fuels
Clean hydrogen PTC	\$3/kg for hydrogen produced via electrolysis, 2023-2032	
Transmission project loans	\$2B in direct loans for transmission projects through 2030, modeled as \$6B intertie capacity addition (assuming loans are leveraged 3x by private sector). Capacity added between WECC, ERCOT and Eastern Interconnection and PNW to Southern CA and Desert SW, must be online by 2028.	
Nuclear ITC and PTC	30% ITC for nuclear that commences construction after 2025 and is online by 2035 10% additional ITC for sites in energy communities, which we assume to be only coal power plant repowering \$35/MWh PTC assumed to prevent economic retirements of nuclear through 2032	
Solar in low-income communities	1.8 GW incremental DG solar US-wide annually from 2023-2032 (assumes program is fully subscribed)	Solar in low-income communities

Appendix: Study Assumptions
Summary of IRA Provisions

EVOLVED ENERGY RESEARCH

Provision	Modeling Assumptions
Electric vehicle incentives and funding	Accelerated adoption of light duty EVs after 2024 (assuming that sales are supply constrained through 2024). A maximum of $7,500 tax credit in light duty vehicle segment, depending on customer, supplier, and vehicle qualifications 30% reduction in cost for medium and heavy EV and FCV, capped at $40,000 per vehicle 30% reduction in charger and fueling costs for non-commercial LDVs and all MDV and HDV EVs and FCVs $1,000 additional reduction in charger costs for LDVs in certain geographies (all outside the West / Northwest) $1B allocated to incremental cost of HD EVs and FCVs (clean heavy duty vehicles provision) $3B allocated to MD EV incremental cost (postal service provision) $1.5B allocated to MD/HD ZEV incremental cost (EJ Block Grants)
Energy efficiency funding	Accelerated adoption of heat pump water and space heaters, residential and commercial energy efficiency measures, and residential rooftop solar through 2032. $1.72B allocated to agricultural energy efficiency (Rural Energy for America) $1B allocated to multifamily residential energy efficiency (Affordable Housing) $4.3B allocated to residential building shell and heat pump HVAC costs (Home Energy Performance-Based Rebates) $4.5B allocated to residential heat pump space and water heating (High-Efficiency Electric Home Rebates) $5.8B allocated to industrial efficiency improvements (Advanced Industrial Facilities) $0.25B allocated to commercial building shell and HVAC improvements (federal buildings provision) $1.5B allocated to residential building shell incremental costs in disadvantaged communities (EJ Block Grants)
Green banks funding	Incremental 7 GW DG solar capacity (assumptions: $7B loans are levered 3x for $21B total investment. Incremental to low-income solar ITC bonus). $20B allocated to building shell and heat pump HVAC incremental costs in single family and multifamily residential buildings (assumption: $20B grants leveraged 3x, but only 1/3 contributes to incremental costs of efficient improvements; remainder goes to base costs).

Appendix: Study Assumptions Demand Subsectors

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- EnergyPATHWAYS database includes 67 subsectors
  - Primary data-sources include:
    - Annual Energy Outlook 2022 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

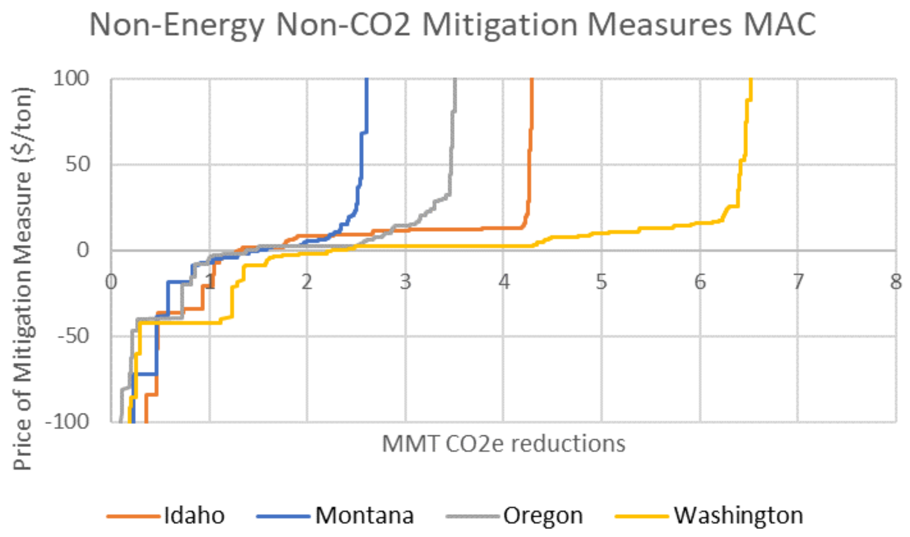
Appendix: Study Assumptions Database Used in the Analysis

EVOLVED ENERGY RESEARCH

- The Evolved databases are updated every year with the latest inputs defining the energy economy, sources of emissions, and technology options to produce or consume energy in different ways or reduce/capture carbon dioxide and other global warming gases
- These are developed as part of Evolved's Annual Decarbonization Perspective (ADP) and the database used in this analysis is a version of the ADP 2022 database modified for the Northwest
- Comprehensive description of the ADP 2022 database as well as sources for the data used can be found at the following locations:
  - ADP 2022
  - ADP 2022 Supporting Documentation
- The following slides summarize changes made to the ADP 2022 database for Net Zero Northwest
  - These refer to the underlying data and not to the assumptions defining each scenario developed for Net Zero Northwest

Appendix: Study Assumptions Non-CO_2 and Land Use

- **Non-CO_2**
- EPA Non-CO_2 Emissions and Mitigation Measures
  - Supply curve of mitigation measures for non-CO_2 reductions starts negative
    - Some measures taken have economic benefits. Examples include gas recovery, better maintenance practices, leak reduction
  - Majority of non-energy non-CO_2 measures are achievable at less than $25/ton
- **Land use**
  - Using TNC-developed potentials for reforestation by state across the West
  - Including reforestation costs from national land use measure potential studies



Appendix: Study Assumptions Transmission Costs

EVOLVED ENERGY RESEARCH

- The study uses transmission cost assumptions developed for The Nature Conservancy Power of Place (PoP) West study
- PoP uses GIS modeling to determine least-cost interstate transmission routes between existing substation endpoints
- Cost assumptions and routes account for existing transmission capacity, reconductoring opportunities at different voltages, terrain, and sensitive land use areas
- PoP costs are higher than the NREL ReEDs transmission costs used in past Northwest analyses, resulting in more limited (though still substantial) transmission expansion in the Core Case

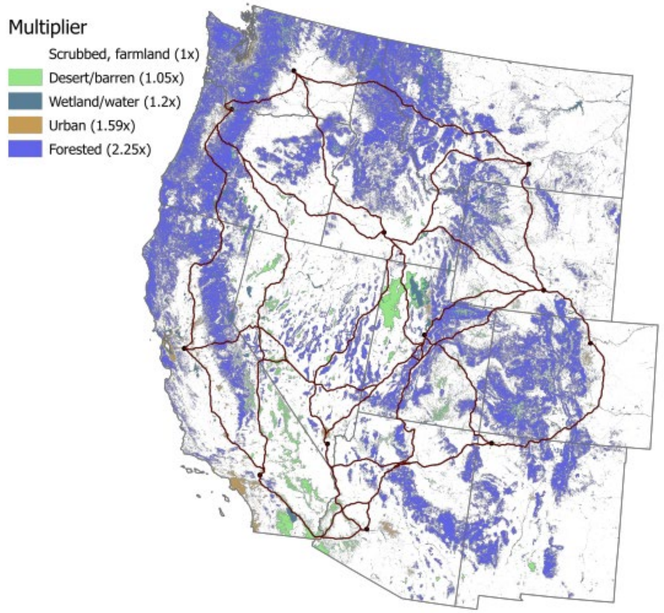


Fig. S7. Least cost path model results showing selected cost surface mutlipliers and new 500 kV transmission lines.

Source: Power of Place-West

Appendix: Study Assumptions
Western States Transmission Cost Benchmarking

EVOLVED ENERGY RESEARCH

- Recently completed and proposed western transmission projects demonstrate the high degree of variation in transmission costs

Line	Description	Cost/MW-Mile	ReEDs Benchmark $/MW-Mile	PoP Benchmark $/MW-Mile
West of Devers	220 kV reconductor in Southern California, completed 2021	$7,000 (actual)	$2,333	$2,500
Boardman to Hemingway	Approved but not constructed 500 kV Idaho to Oregon	$4,100 (proposed)	$1,347	$7,700
TransWest	Permitted 500 kV Wyoming to Nevada, both DC and AC segments	$2,700 (proposed)	$1,347	$6,000 - $6,700
Tehachapi	500 kV line in Southern California, completed 2016	$3,500 (actual)	$1,347	$6,700

Appendix: Study Assumptions
Renewable Resource Quality and Potentials

EVOLVED ENERGY RESEARCH

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

Appendix: Study Assumptions
Rooftop Solar

EVOLVED ENERGY RESEARCH

- Core Case rooftop solar adoption from NWPCC 2021 Northwest Power Plan
- In addition, the model can select solar as part of the optimization
- Though bulk system solar is cheaper than rooftop and will be selected ahead, we do not preclude rooftop solar as part of a future resource portfolio
  - Model does not pick up all of the benefits of rooftop solar because the RIO distribution model represents average benefits of deferring distribution infrastructure and not the full distribution
  - Rooftop may be desirable for other reasons such as promoting jobs within state, or avoiding land use challenges siting bulk system level solar
- Technical potential for rooftop solar used in the High DER scenario from NREL

Appendix: Study Assumptions
Columbia Generating Station (CGS) Extension

EVOLVED ENERGY RESEARCH

- We assume that the CGS could be extended for an additional 20 years of life at 1,210 MW gross output from a retirement date of 2043 to a retirement date of 2063
- Extending CGS:
  - Cost assumptions taken from the Washington 2021 State Energy Strategy, developed by Energy Northwest and consistent with NWPCC 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
- However, the model chooses to build SMRs in Washington earlier with ITC funding

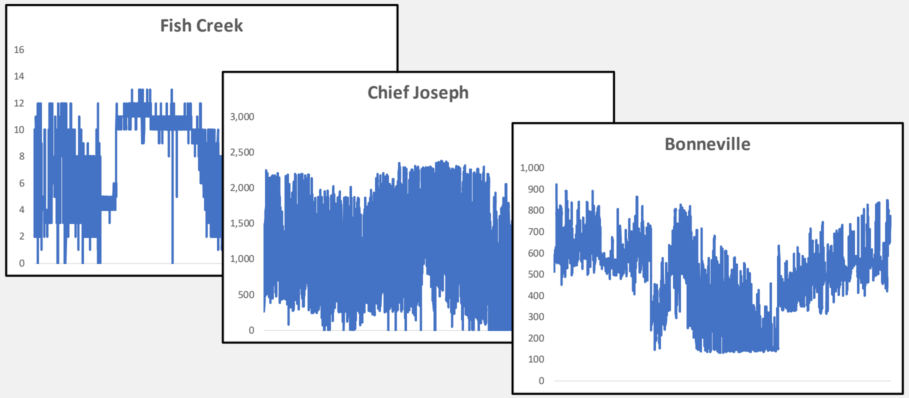
Appendix: Study Assumptions
Climate Impacts on Load and Hydro

- 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

Appendix: Study Assumptions 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)

Historical Generation Data by Plant



Operating Constraints for Regional Fleets

- Energy Budget
- Maximum Capability
- Ramp Rate
- Minimum Capability

Appendix: Study Assumptions
Industrial Sector Targets

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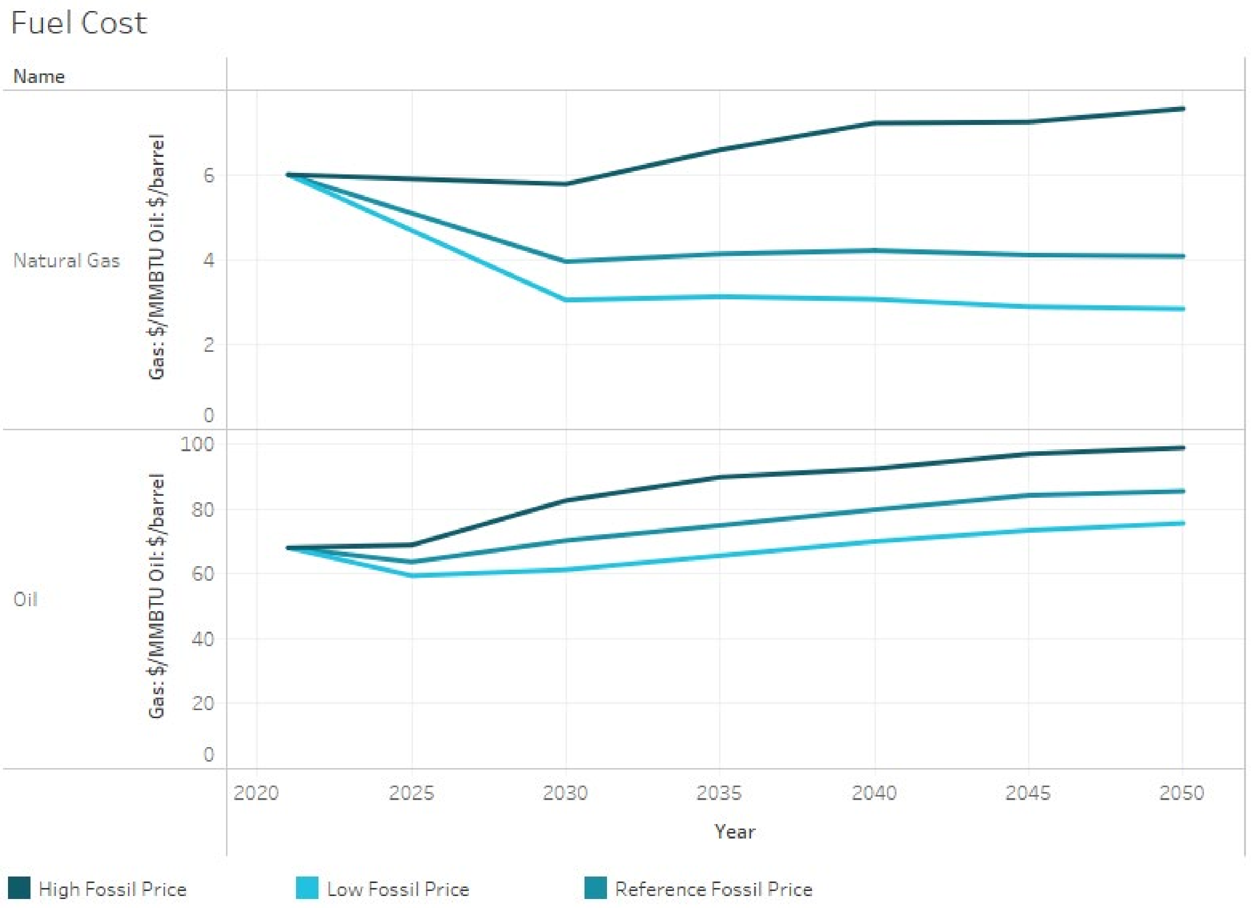
- Great deal of uncertainty about industrial opportunities
  - Not a lot of information
  - Specific to industry/company/geography
  - Tied to competitiveness/labor force considerations
- Using "keep it simple" approach
  - 1% per year improvement in energy intensity across industrial subsectors
  - 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 drops endogenously in the model as demand for refined petroleum products decreases across Washington, the Northwest, and the US

Appendix: Study Assumptions
Fuel Price Forecasts

- Fuel price forecasts from EIA 2022 Annual Energy Outlook
  - Reference
  - High Fossil Price (EIA low supply scenario)
  - Low Fossil Price (EIA high supply scenario)
- Near-term gas pricing from recent gas market data
  - Linear interpolation to 2030 EIA forecast
- Forecasts are lower than recent price spikes due to geopolitical events
  - Potential for higher prices than forecast
  - However, scenario differences illustrate the impact on decarbonization costs of changing fossil fuel prices



Appendix: Study Assumptions

Biomass Feedstocks: Updated Estimates for Woody Biomass using LURA Model

EVOLVED ENERGY RESEARCH

- 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 Washington Department of Commerce during the Washington 2021 State Energy Strategy: 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 for Net Zero Northwest

Appendix: Study Assumptions
Understanding Modeled Costs

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