Decarbonization and Montana—
Insights from the Northwest Deep Decarbonization Pathways Study

EVOLVED ENERGY RESEARCH

Prepared For:
Montana Climate Solutions Council

July 28, 2020

How to Use this Report and Information

- At the request of the Montana Department of Environmental Quality, the Clean Energy Transition Institute and Evolved Energy Research have provided this summary of analysis relevant to Montana from the Institute's June 2019 report: *Meeting the Challenge of Our Time: Pathways to a Clean Energy Future for the Northwest*, which describes the results of the Northwest Deep Decarbonization Pathways Study (NWDDP) conducted in the winter 2018.
- Data specific to Montana is shared here to help members of the public understand some of the emissions reductions pathways and tradeoffs facing Montana, as well as the ways in which Montana's energy system and unique assets may be able to serve regional needs in the future.
- Caution should be used in interpreting and applying the specific results presented here. As the Montana Climate Solutions Council report highlights, there is a need for a stakeholder process to support future study and investigation that tailors assumptions to Montana's specific state objectives and context, and more fully considers the implications of proposed projects, policies, and the timing of resource retirements.

Contents

Executive Summary -1-

- To meet future energy needs at least cost, the study finds that decarbonization can be achieved through a combination of five key strategies (energy efficiency, decarbonized electricity, decarbonized fuels, electrification, and carbon capture) along with the continued use of very limited natural gas resources to address peaking capacity needs.
- The study finds that Montana utilizes its geographic strengths on the supply side to meet these shifting demands across the NW region:
  - A large wind sector is established, supplying clean energy to Montana and surrounding regions
  - Carbon is sequestered in saline aquifers in the production of liquid fuels from biomass, offsetting emissions from other sources
  - Policy actions taken in the rest of the West could impact Montana's investments in significant ways, with opportunities to play a major export role in a decarbonized Western system
- The NWDDP assumptions drive decreased total energy demand as a result of efficiency gains, much of which comes from electrification in transportation and buildings. As a result, electricity demand grows by approximately 70%.

Executive Summary -2-

- Decarbonization costs are 1 to 1.5% of Montana GDP in the NWDDP using 2018 technology price forecasts, though likely a net benefit to the state when factoring in externalities.
  - Fossil fuel and electric vehicle price uncertainties have a major impact on total costs. Price declines in electric vehicle forecasts since 2018 may make decarbonization a net benefit to the state before factoring in externalities
- Stakeholder-driven, energy system planning specific to Montana can help further determine investments necessary to minimize total cost of achieving targets for different future scenarios and can inform subsequent policy analysis of how best to achieve those investments and allocate costs.
- Background on a modeling approach for the state is included to inform next steps.

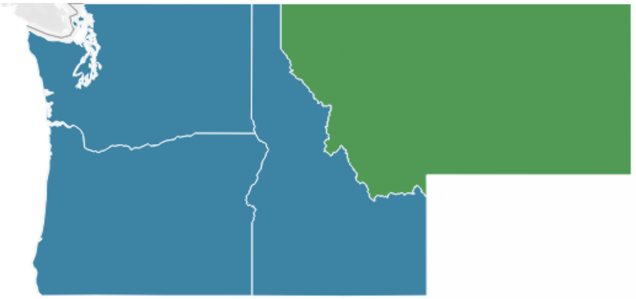
Background

Introduction

Supporting Montana: Summarizing Pathways Analysis for Future Decarbonization

- The following report shows Montana-specific results generated from analysis done for the Northwest Deep Decarbonization Pathways Study (NWDDP) released in June 2019
- Results include:
  - The demand side transformation – what types of investments were assumed across energy-consuming sectors of the economy over the next 30 years?
  - Supply side optimization – how best can we serve the energy needs of the economy while adhering to limits on total emissions?
  - Summary of high-level findings – what do they mean for Montana?
  - Caveats to the results – what has changed since this study took place?
- The report concludes with a high-level approach to studying Montana's specific decarbonization needs, incorporating the interests of stakeholders in the state

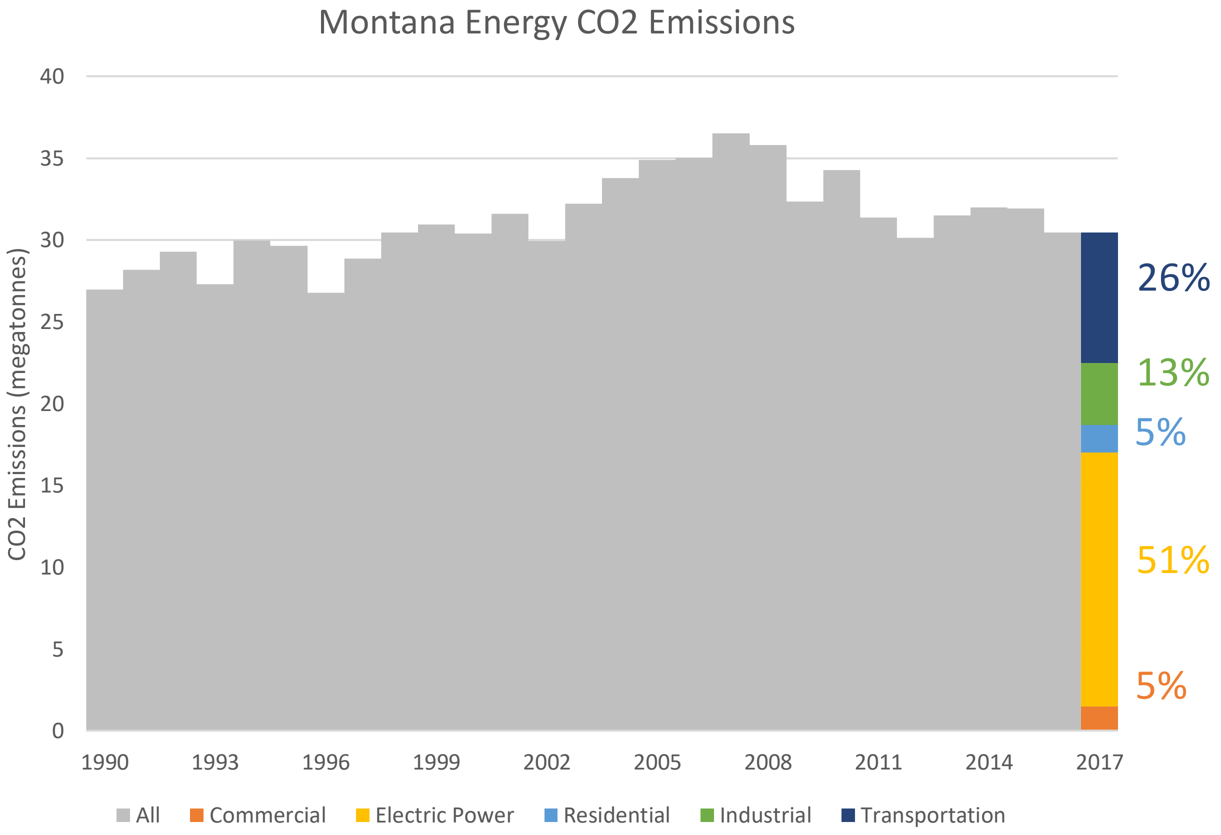
Analytical Context



- The Northwest Deep Decarbonization Pathways (NW DDP) analysis was conducted using state-level granularity to determine least-cost pathways
- The study released in June 2019 summarized results for the region, including Idaho, Montana, Oregon, and Washington
- This report presents results and insights specific to the state of Montana
  - The exception is the electricity sector, where operations and planning are already integrated regionally, and investments in resources benefit multiple states
  - We show resource decisions in Montana as part of the larger regional system
- Our analytical approach, assumptions and scenario design are not described in this document since they are extensively detailed in our technical report and do not vary by state

Historical Montana Energy-Related CO_2 Emissions

- Half of the emissions from within Montana's borders come from electric power
  - Montana's 2007 emissions inventory shows that ~50% of those emissions were from electricity exported to other states in 2005 (next slide)
  - Montana has remained a large net exporter of power through 2020
- The transportation sector accounts for a quarter of all energy-related CO_2 emissions, primarily due to liquid fossil fuel consumption:
  - Gasoline fuel in passenger transportation
  - Diesel fuel in freight transportation
  - Jet fuel in aviation



Sources: U.S. Energy Information Administration (EIA), State Energy Data System and EIA calculations made for this table. United States national-level total, EIA Monthly Energy Review, July 2019 Section 11.

Montana GHG Inventory

- Net emissions from exports to other states, Montana emitted 19.2 MMT CO2 from energy in 1990
- 12.9 MMT came from non-energy sources
- While there is a clear technological path to reducing energy-related emissions, measures for non-energy emissions reductions are less well developed

Table ES-1. Montana Historical and Reference Case GHG Emissions, Consumption-based, by Sector

	Historic			Projection	
Million Metric Tons CO2e	**1990**	**2000**	**2005**	**2010**	**2020**
Electric Sector	**8.9**	**9.5**	**10**	**10**	**11**
Coal	15.8	16.2	18.5	20.2	22.5
Natural Gas	0	0	0	0.4	0.4
Petroleum Coke	0	0.8	0.8	0.8	0.8
Net Exported Electricity	-7	-7.6	-9.4	-11.3	-12.8
Res/Comm/Non-Fossil Ind (RCI)	**4.5**	**4.5**	**4.8**	**5.2**	**5.3**
Coal	0.5	0.3	0.3	0.3	0.3
Natural Gas	2.1	3.1	2.9	3.2	3.3
Oil	1.9	1.1	1.6	1.7	1.7
Wood (CH4 and N2O)	0	0	0	0	0
Transportation	**5.9**	**7.3**	**8**	**8.8**	**10.4**
Motor Gasoline	3.8	4.4	4.4	4.8	5.7
Dieselb	1.7	2.5	3.1	3.4	3.9
Natural Gas, LPG, other	0.1	0.1	0.1	0.1	0.1
Jet Fuel, Aviation Gasoline	0.3	0.3	0.5	0.5	0.6
Fossil Fuel Industry	**3.5**	**4.1**	**5**	**5.2**	**5.3**
Natural Gas Industry	1.4	1.7	2	2.3	2.4
Oil Industry	2	2.2	2.7	2.8	2.8
Coal Mining (Methane)	0.2	0.2	0.2	0.2	0.2
Coal to Liquids					
Industrial Processes	**1.2**	**1**	**0.9**	**1.1**	**1.5**
ODS Substitutes	0	0.2	0.4	0.5	0.9
SF6 from Electric Utilities	0.1	0.1	0	0	0
Cement & Other Industry	0.4	0.4	0.5	0.5	0.5
Aluminum Industry	0.7	0.3	0.1	0.1	0.1
Waste Management	**0.2**	**0.2**	**0.3**	**0.3**	**0.4**
Solid Waste Management	0.1	0.2	0.2	0.2	0.2
Wastewater Management	0.1	0.1	0.1	0.1	0.1
Agriculture	**7.9**	**9.5**	**7.9**	**7.9**	**7.9**
Livestock Management	3.2	3.7	3.6	3.6	3.6
Ag. Soils and Residue Burning	4.7	5.8	4.2	4.2	4.2
Total Gross Emissions	**32.2**	**36.1**	**36.8**	**38.5**	**41.7**
Forestry and Land Use	**-23.1**	**-23.1**	**-23.1**	**-23.1**	**-23.1**
Agricultural Soils Sink	**-2.3**	**-2.3**	**-2.3**	**-2.3**	**-2.3**
Net Emissions (including sinks)	**6.8**	**10.7**	**11.4**	**13.1**	**16.3**
Energy-related CO2 emissions	19.2	21.2	22.8	24.1	26.5
Non-energy GHG emissions	12.9	14.9	14	14.5	15
Total Gross emissions	32.1	36.1	36.8	38.6	41.5

Source: Montana Greenhouse Gas Inventory and Reference Case Projections 1990-2020. Center for Climate Strategies. September 2007

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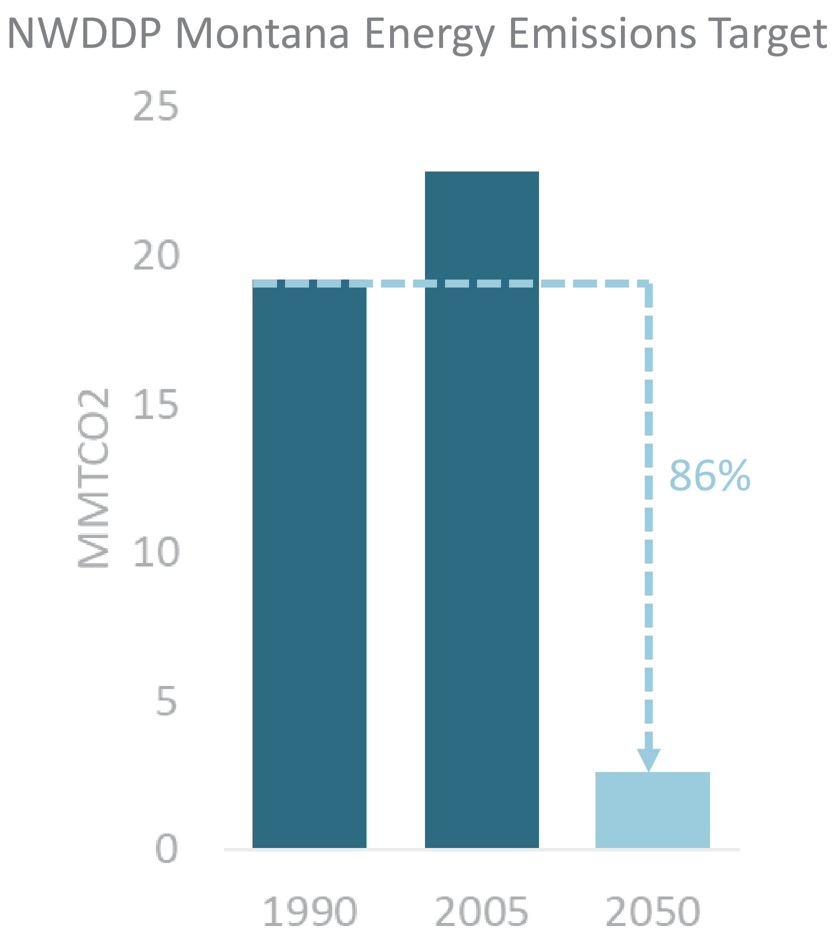
NWDDP Deep Decarbonization Target

- **Target**: 86 percent reduction in energy-related CO_2 emissions below 1990 levels by 2050
- Energy target is consistent with an economy-wide GHG reduction target of 80 percent below 1990 levels by 2050
  - Allows for reductions below 80 percent for non-energy CO_2 and non-CO_2 GHG emissions, where mitigation feasibility is less understood

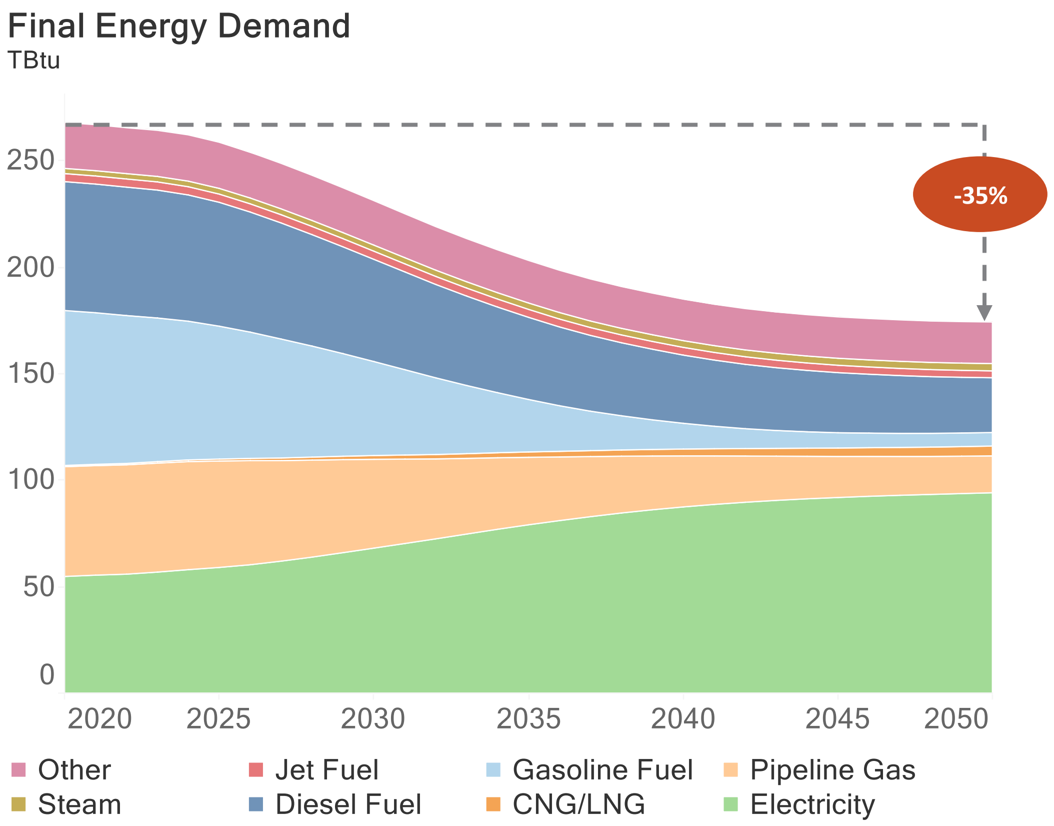


The Demand Side

How was Montana forecast to consume energy in the NWDDP?

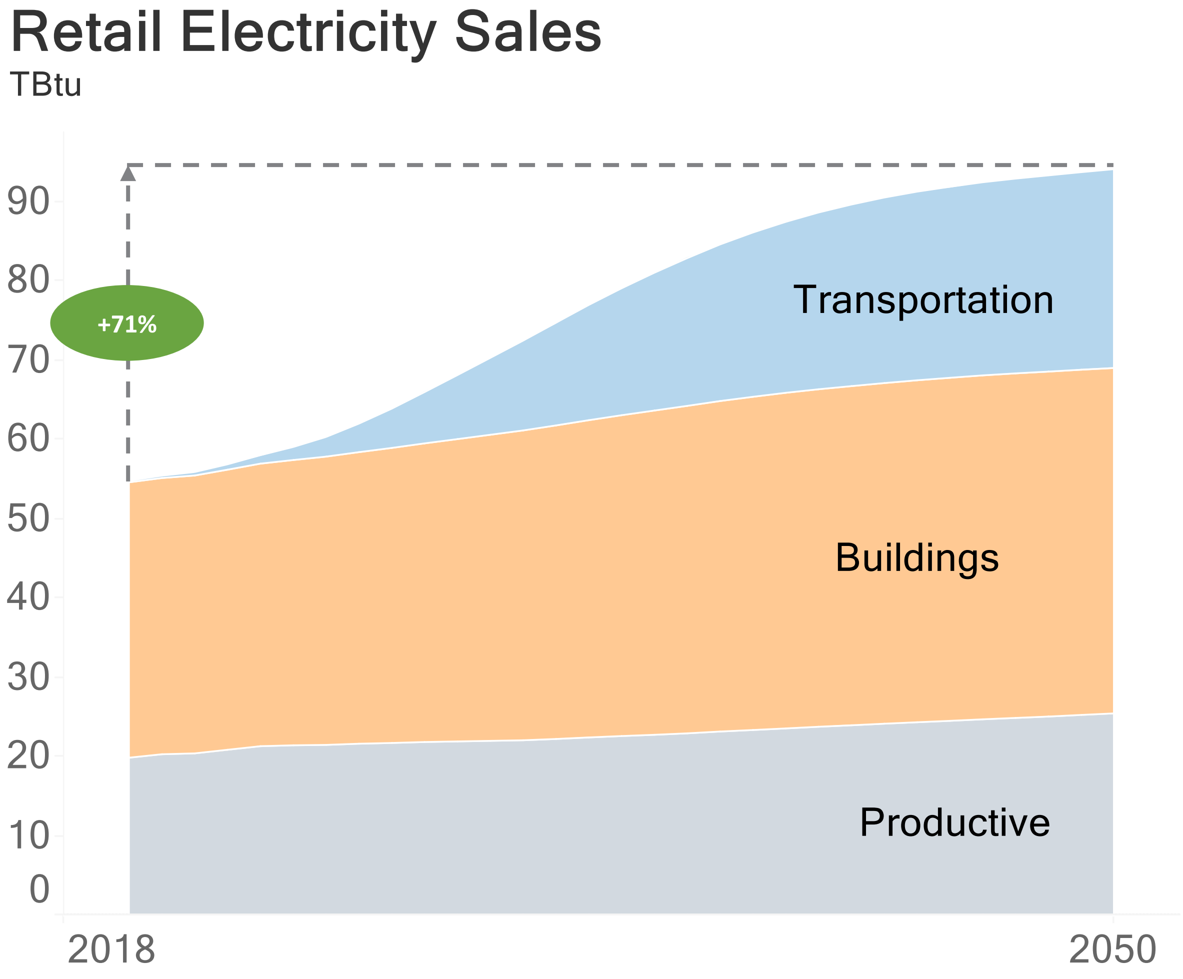
Montana Energy Demand: End-Use Consumption

- End-use consumption or final energy demand represents energy used in the delivery of services such as heating or transportation
  - Excludes energy consumed in converting to other forms of energy (e.g., pipeline gas consumed by power plants)
- Overall end-use demand in 2050 is one-third below today
  - Electricity consumption increases by more than 70% and comprises one-half of all end-use consumption by 2050
  - Gasoline and diesel decrease from one-half of demand today to one-fifth by 2050 as on-road vehicles transition to electricity



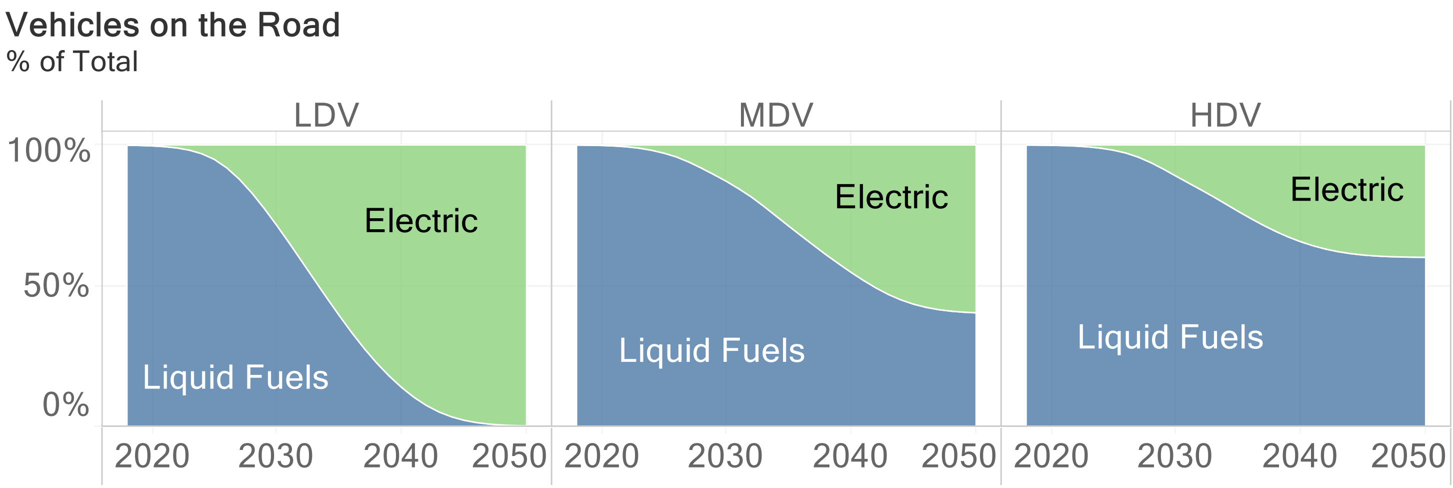
Montana Energy Demand: Retail Electricity Sales by End-Use

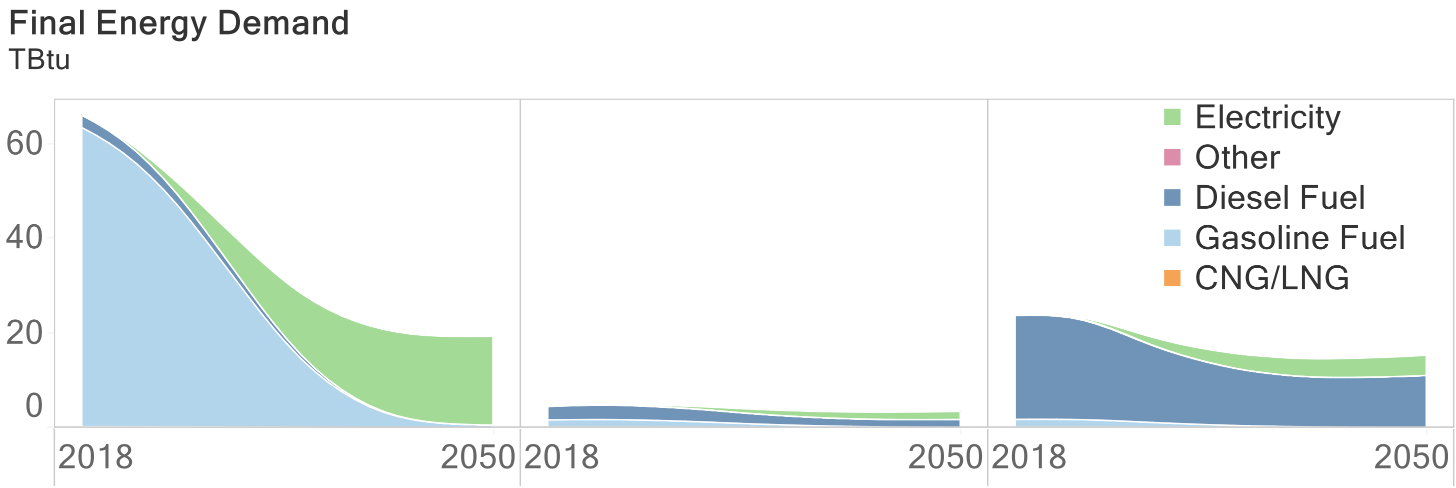
- Net increase in end-use electricity consumption is primarily related to electrifying passenger and freight transportation
- By 2050, all passenger vehicles on the road are electric, whereas about half of freight trucks are
  - Freight trucks that continue to use liquid fuels primarily consume renewable diesel in the 2050 timeframe



Montana Transportation Electrification

- Vehicles on the road rapidly transition from liquid fuels to electric
  - Aggressive adoption over the next three decades is necessary
- This results in an overall decrease in final energy demand due to the efficiency of an electric powertrain relative to an internal combustion engine

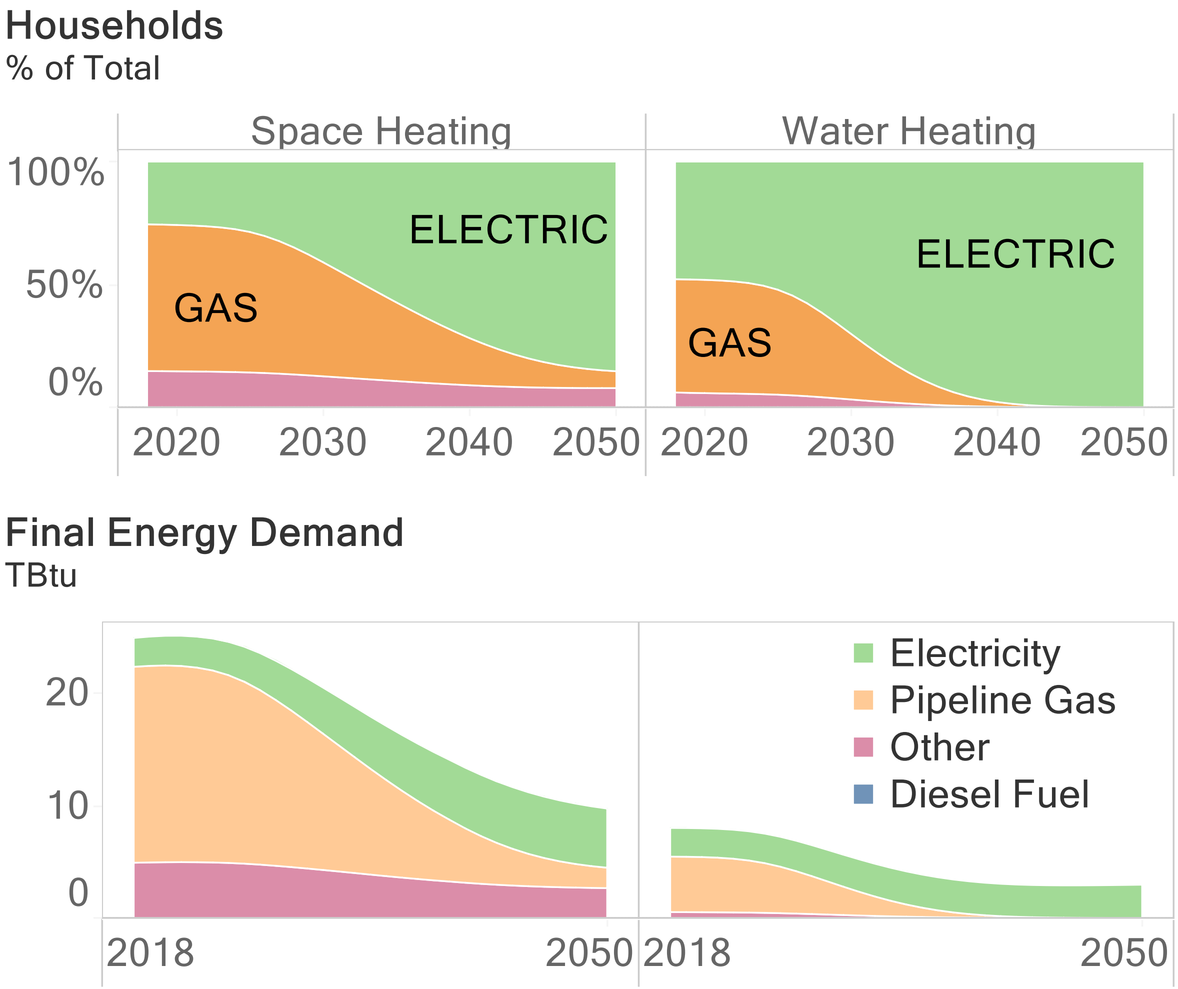




Montana Building Electrification

Example: Residential Buildings

- Energy consumption from buildings decreases significantly over time despite the growth of households and floorspace
- Electrification of space and water heating translates into deep energy use reductions due to the efficiency of heat pump technology relative to the best in-class combustion equipment
- This same trend is observed in commercial building stocks, as well as other end uses such as cooling and water heating



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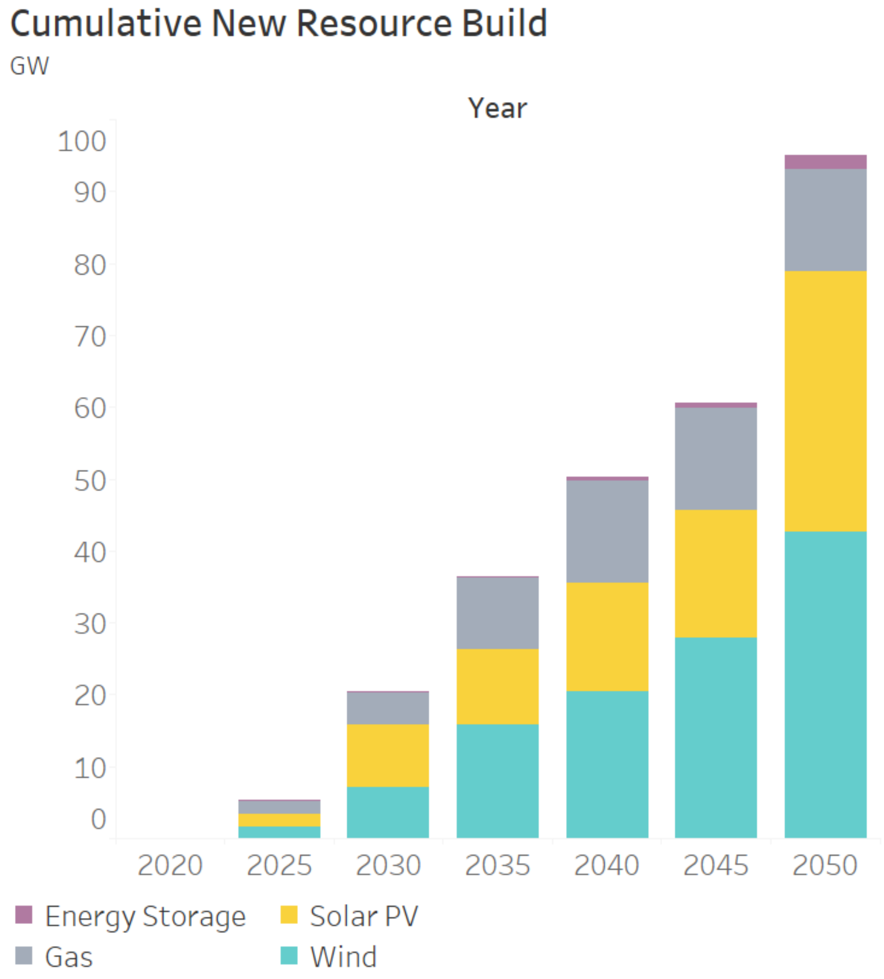
The Supply Side

Electricity Sector and Fuel Supply

Capacity Expansion

Northwest-Wide

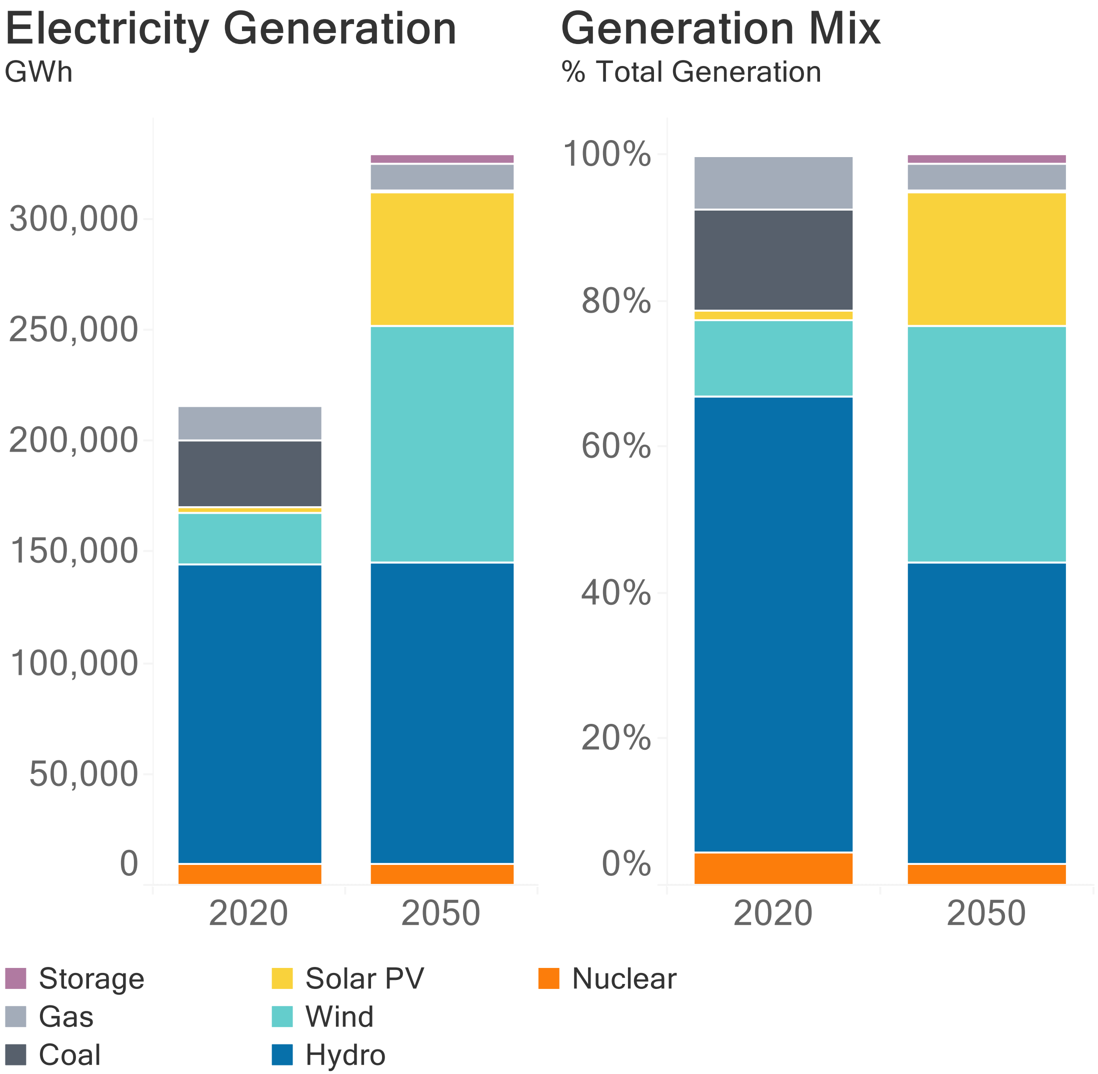
- Northwest electricity sector adds nearly 100 GW of new electricity supply resources by 2050
- Renewable resources dominate capacity additions, with more than 40 GW of new onshore wind developed and 35 GW of solar PV
- Gas and storage resources are added primarily to provide resource adequacy and balancing
  - The capacity factor (utilization) of the gas-fired fleet is below 10% in 2050



Electricity Generation

Northwest-Wide

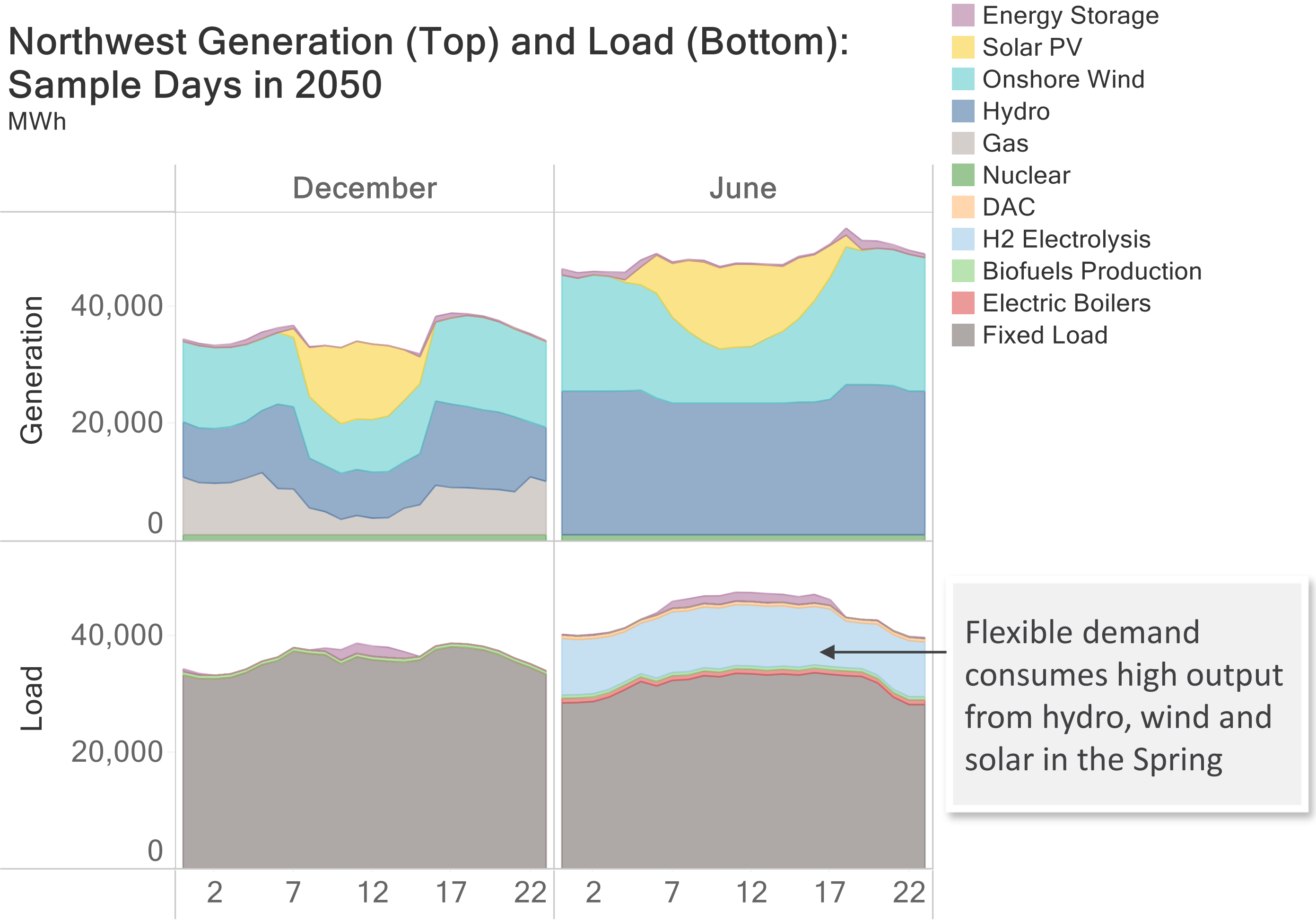
- Incremental wind and solar PV are the principal sources of supply to both decarbonize electricity generation and meet growing electricity consumption
  - Wind generation is nearly the same size as hydro generation by 2050
- Gas-fired generation share is 4% in 2050, while coal-fired generation is eliminated
- Columbia Generating Station is extended after 2043 and operates through the study horizon (2050)



Hourly Operations

Northwest-Wide

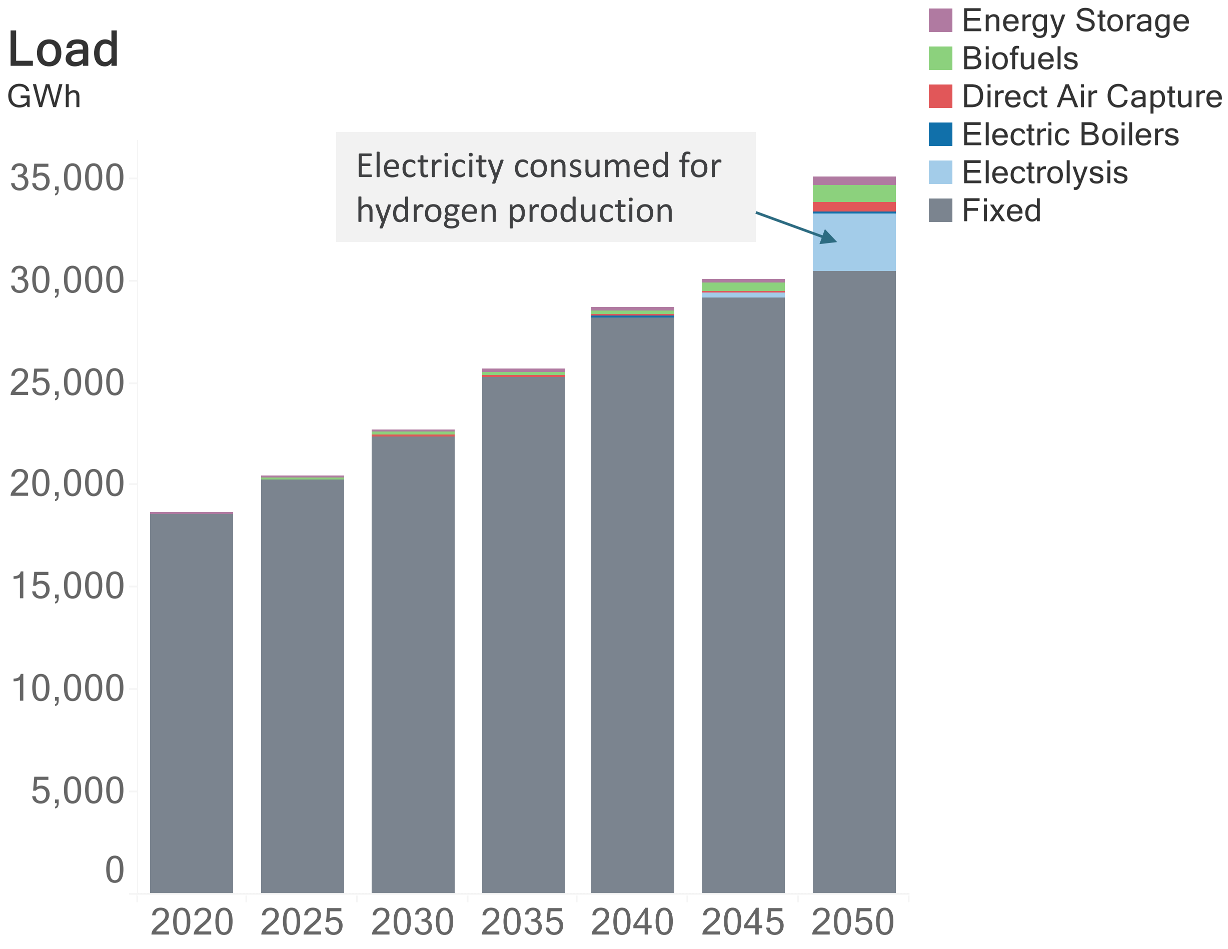
- Electricity balancing is one of the principal technical and economic challenges of a decarbonized energy system
- The energy systems in this study have a large percentage of non-dispatchable generation resources (e.g., wind and solar)
- In many studies of low-carbon electricity systems, balancing is limited to thermal and energy storage resources
- However, this is an incomplete toolkit, specifically when dealing with imbalances that can persist over days and weeks
- This study expands the portfolio of options available to address balancing challenges, employing solutions such as flexible electric fuel production (e.g., electrolysis) in addition to energy storage, thermal generation and transmission



Energy Demand: Transmission-Level Electric Load

Montana

- Transmission-level load increases by 90 percent between 2020 and 2050
- A large portion of the net increase is from higher “fixed” loads (e.g., end-use retail sales)
- However, another significant portion of load growth in the state is from electrolysis facilities, which produce hydrogen primarily for synthetic fuels

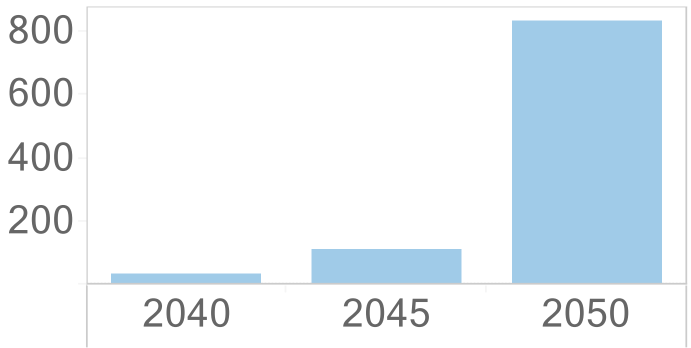


New Sources of Electric Load

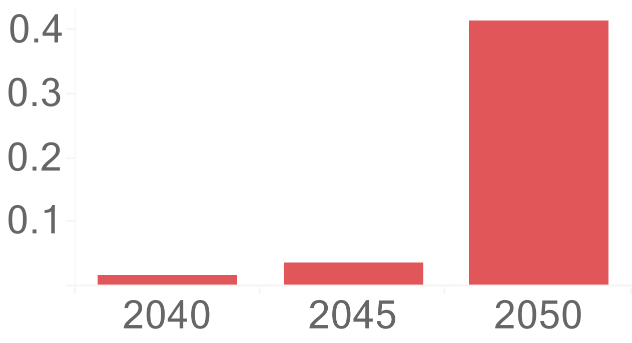
Montana

- Large, flexible sources of electric load help Montana manage electricity imbalances across the year
- Most of the new loads produce inputs for synthetic natural gas production, while electric boilers produce steam for commercial and industrial activity

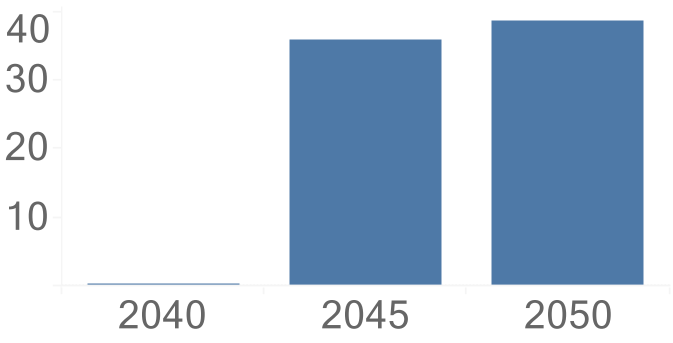
Electrolysis Capacity
MW



DAC Total Capture Capacity
MMT per year



Electric Boiler Capacity
MW



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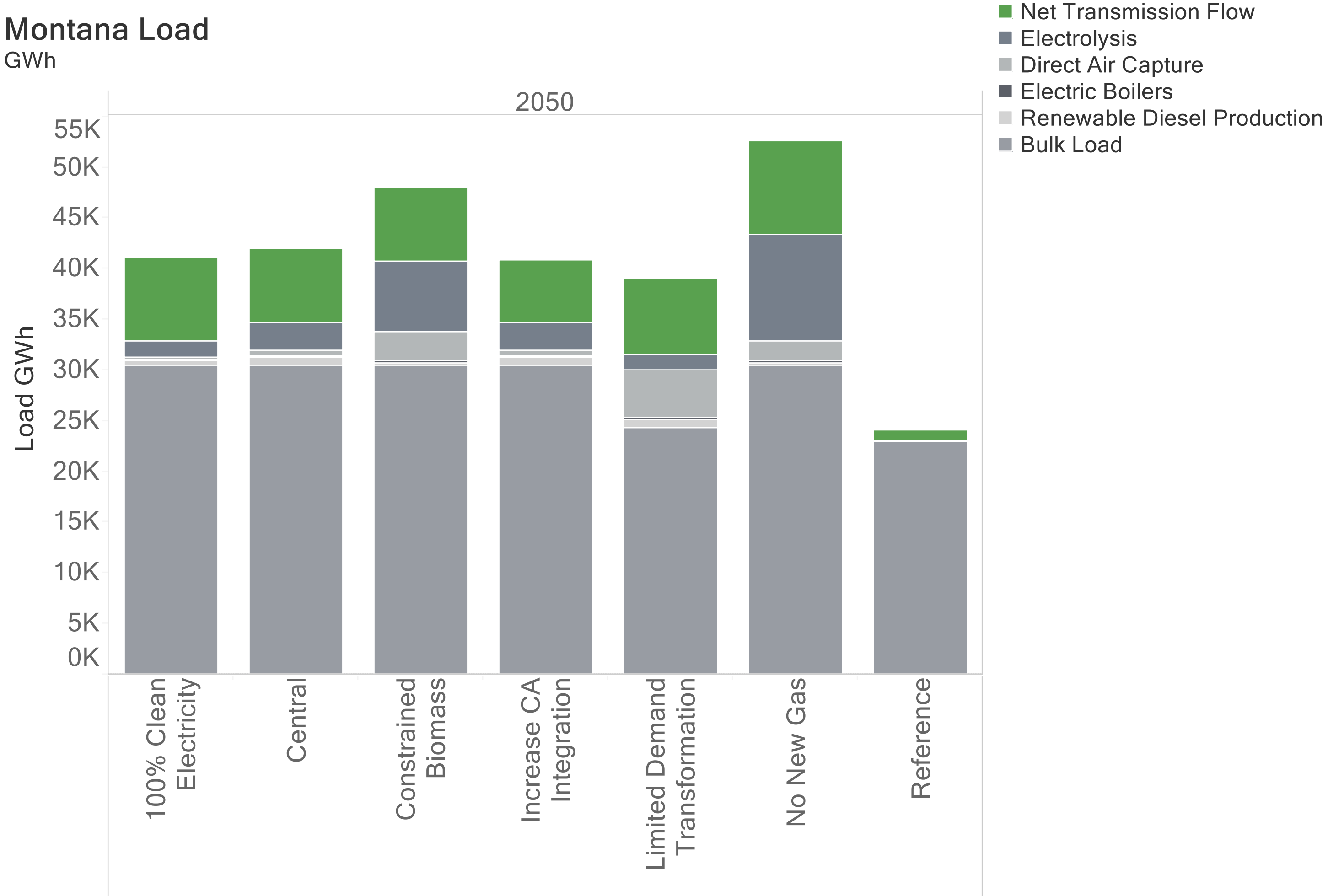
Montana's Electricity Export Market

Montana

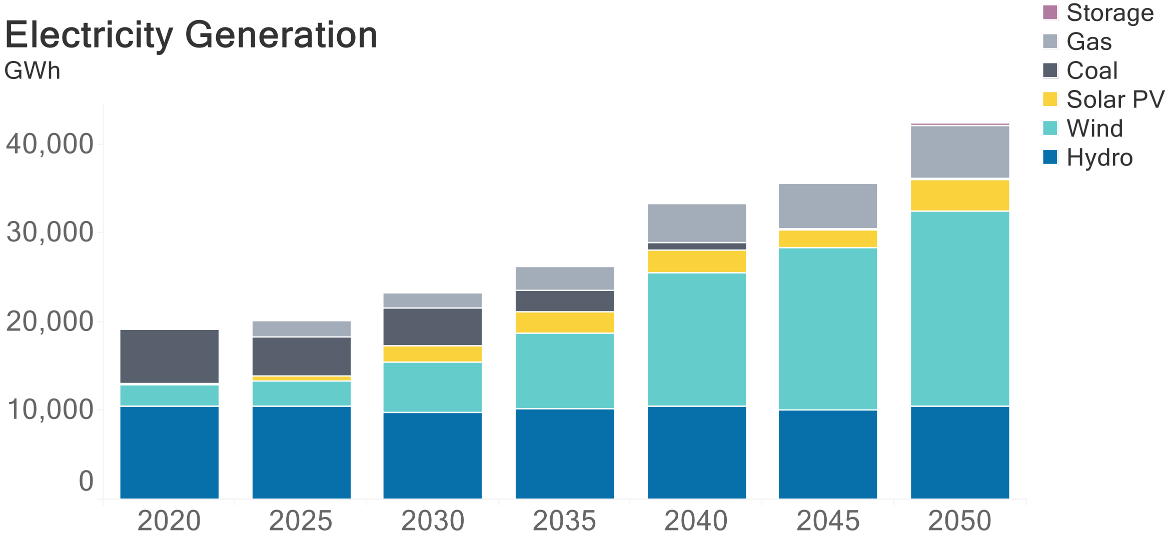
- In all cases, Montana is a significant net exporter of electricity to other states by 2050
- Total exports are limited by the available transmission
  - 2.2 GW to Washington
  - 0.34 GW to Idaho
  - 0.6 GW to the rest of the West
- Expanding transmission to surrounding regions would increase the export market potential for Montana
  - Key opportunity to investigate in future state planning efforts

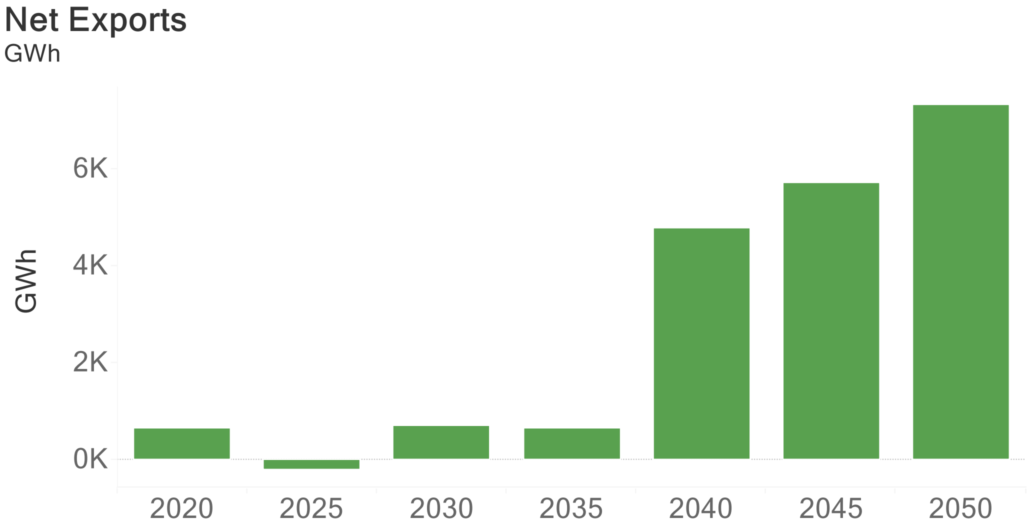


Exports Increase with Development of Montana Wind Sector

Montana Net Exports in the Central Case

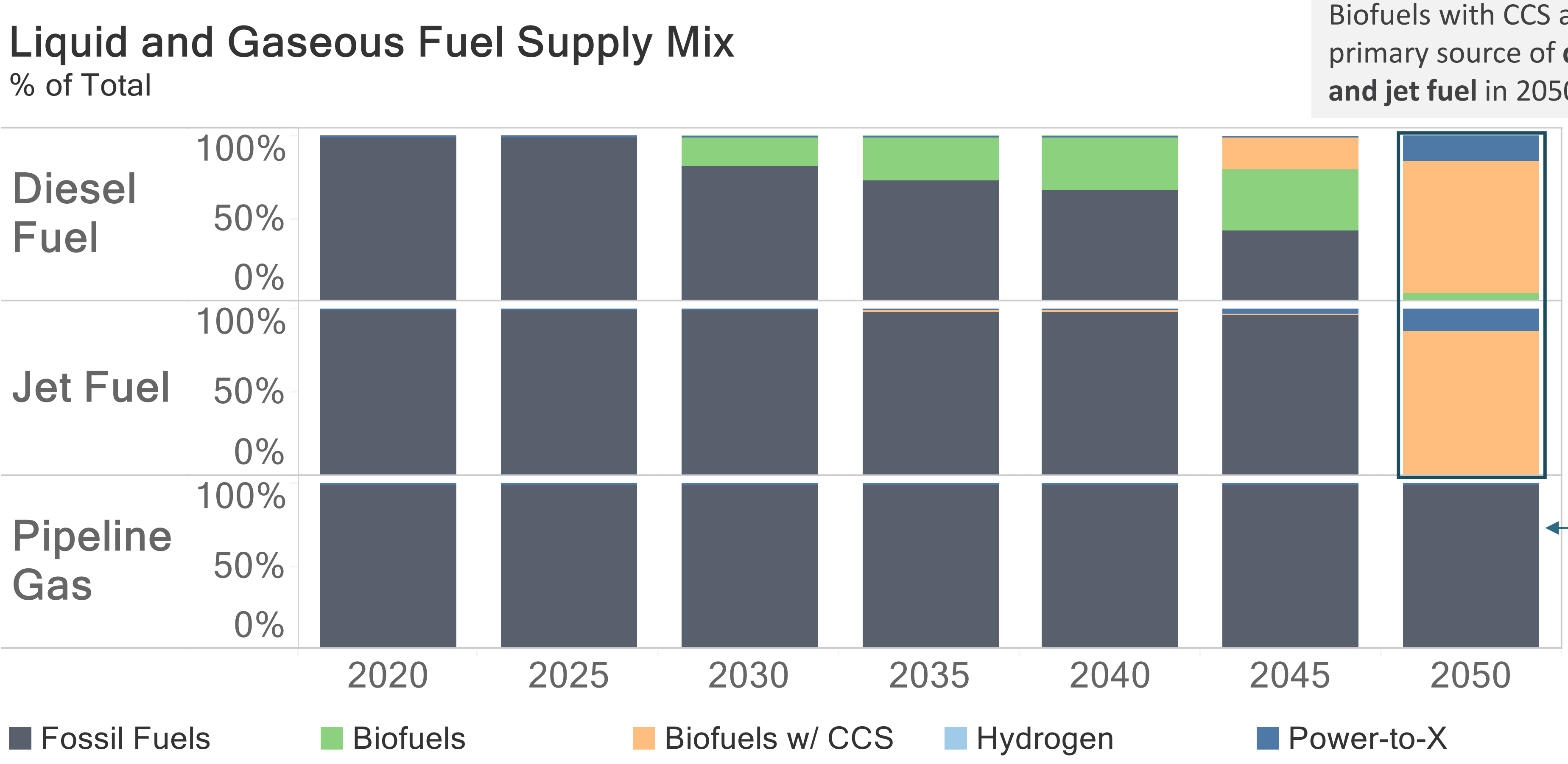
- A close to doubling of wind from 2035 to 2040 supplies out of state demand for clean energy
  - Washington State is the main export market, driven by larger transmission ties to the state
- Montana energy is majority wind by 2050
- New, tighter emissions targets proposed in Washington and other Western states since the NWDDP was conducted will drive further demand for low cost and clean Montana wind exports





Montana Energy Supply: Fuels

Biofuels with CCS are the primary source of **diesel and jet fuel** in 2050



While other states decarbonize a fraction of pipeline gas with synthetic electric fuels, Montana retains fossil gas, choosing instead to offset emissions with CCS

Caveats

Caveats

There are several ways in which the NWDDP analysis cannot be directly applied to Montana

- Scenario definitions and assumptions are not tailored to Montana interests or to represent the Montana policies and uncertainties most valuable to investigate to inform policy development
  - Tailored analysis supporting State and stakeholder driven questions will best serve State climate policy action
- Targets have since been proposed for Montana
  - Carbon neutral electricity by 2035 and net zero emissions by 2050
  - These will drive more clean energy investment in the state than in the NWDDP
- Targets have changed for other Western states
  - Since the NWDDP was conducted, Western states including Washington, Colorado, and Nevada have set more stringent emissions and clean energy standards
  - These will drive more clean energy investment, and potentially greater demand for Montana resources
- Prices are out of date
  - Forecasted prices have been lowered for many clean energy technologies, in some cases substantially, since the NWDDP analysis was conducted in 2018. This includes for electric vehicles – one of the largest drivers of decarbonization cost reductions
- Covid-19 has impacted demand and fuel prices
  - Short-term market price impacts, and longer term demand impacts and structural changes may revise the outlook for demand and prices over the coming years

Caveats

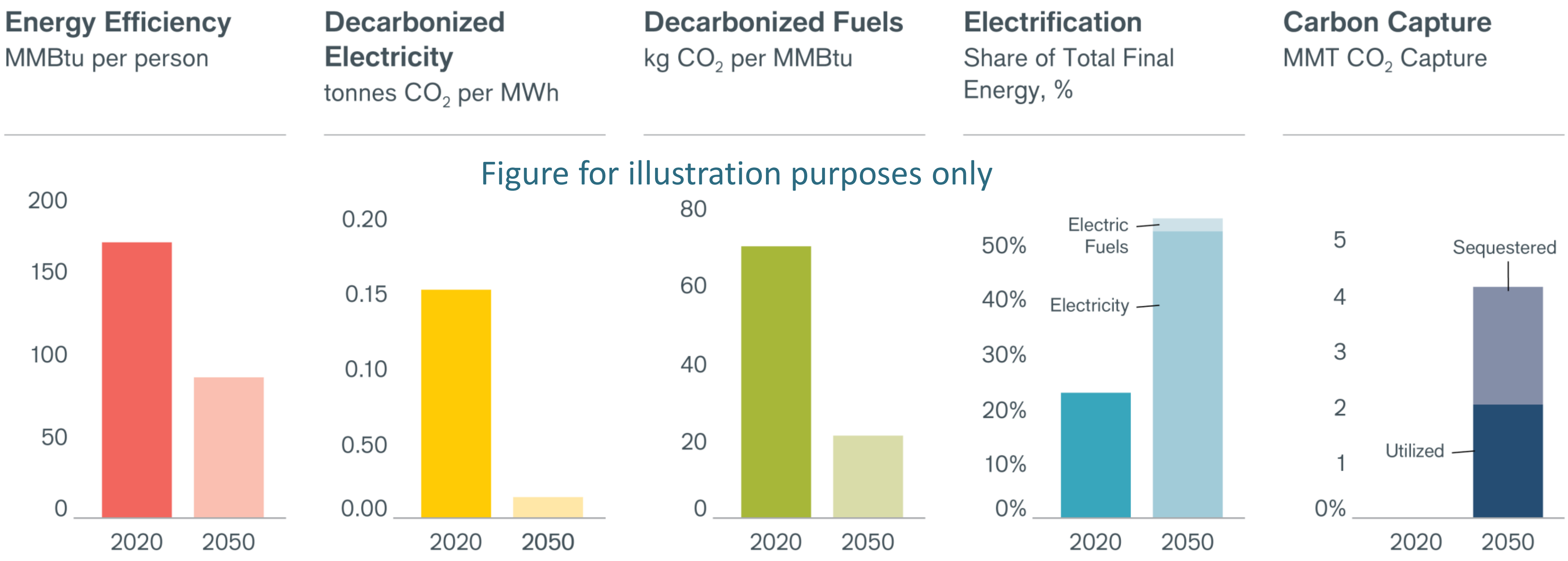
Continued

- No transmission expansion and limited interstate representation
  - The NWDDP did not simulate the opportunity of expanding transmission and thus expanding the market for Montana clean energy to other regions
  - Investigating this becomes more important with the move of other states towards stringent clean energy and emissions goals
- Lack of detailed consideration of Montana's coal generators
  - Policy options surrounding Montana's coal industry, including retirement schedules, were not investigated in the NWDDP
- Fuels trading limitations
  - The NWDDP did not allow states to trade clean fuels and build supply routes for clean fuel exports. This is an important pathway towards more realistic and lower cost regional decarbonization solutions
- Outdated assumptions about vehicle stock rollover
  - Assumed levels of electrification and remaining internal combustion energy stocks in the economy may not be appropriate for Montana
  - Options for trucking using fuel cells have become more viable since the NWDDP analysis was conducted. Fuel cells may play an important role in the future, particularly in long-distance trucking

Summary

What Are the Least Cost Strategies that Policy Should Target?

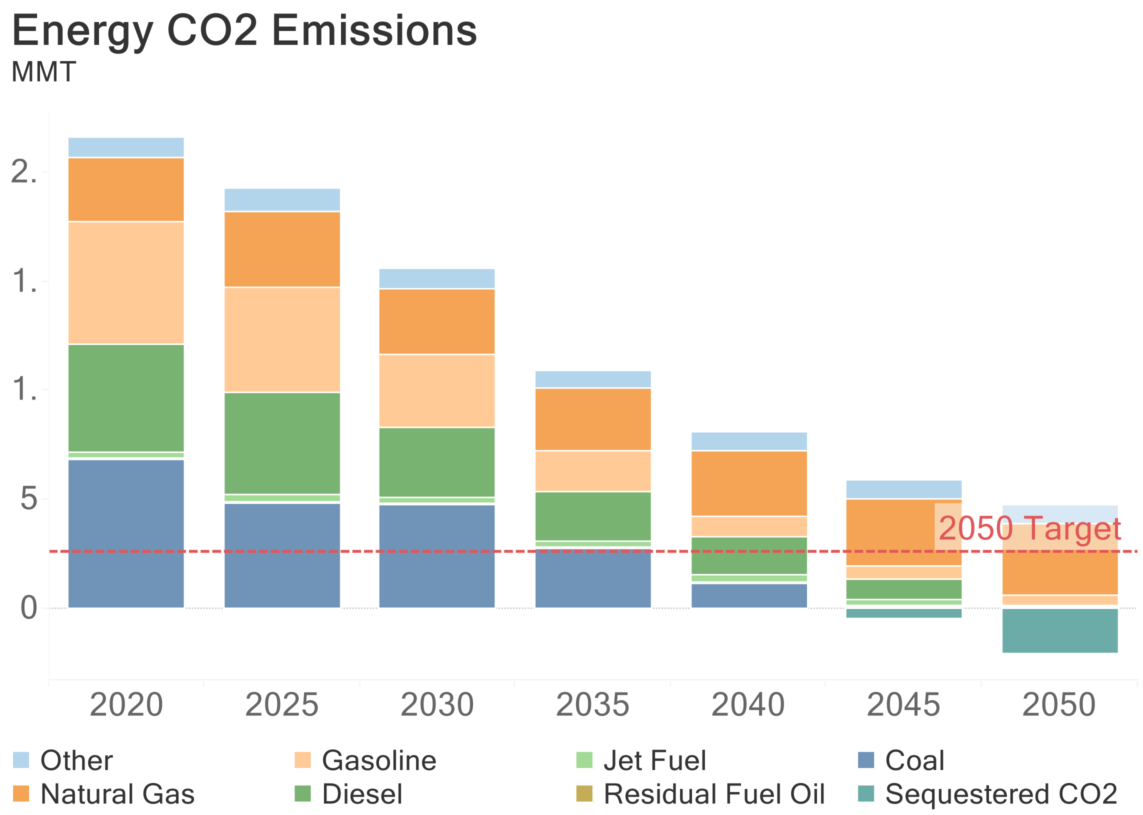
Northwest-wide



Source: Northwest Deep Decarbonization Pathways Study, June 2019, Evolved Energy Research

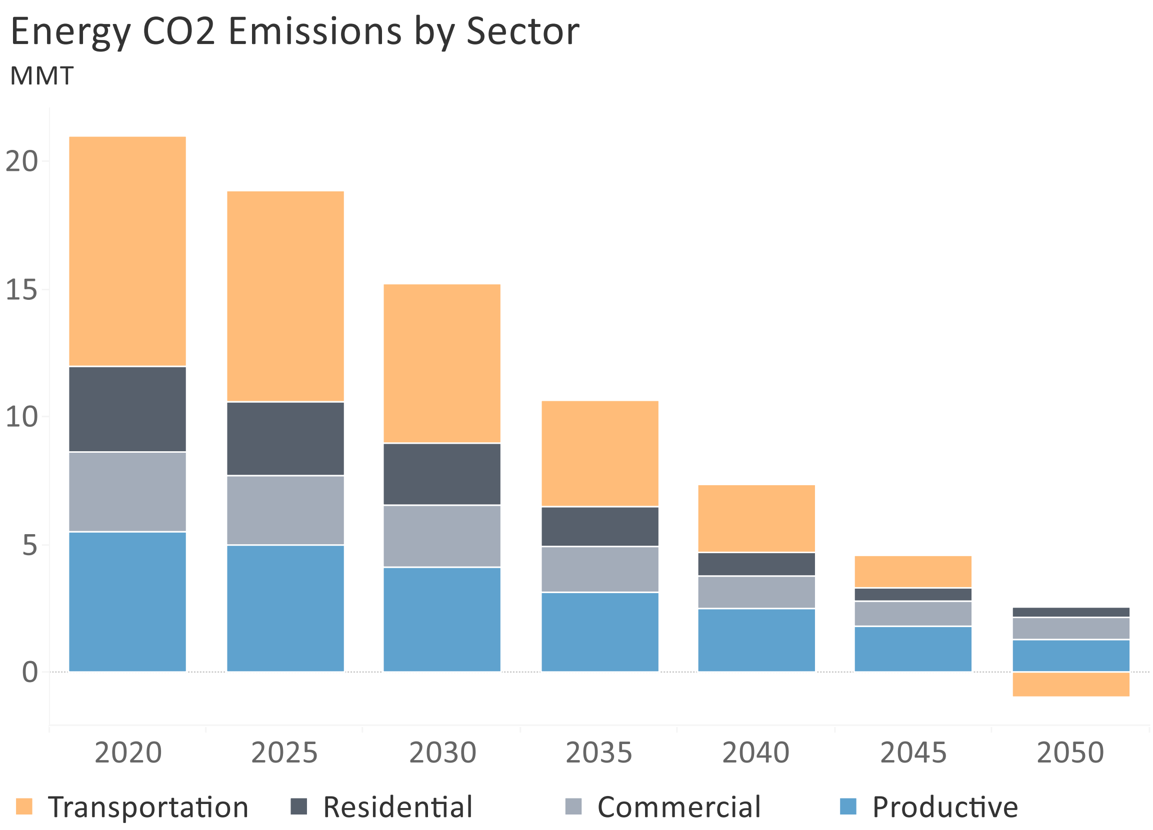
Montana Energy CO_2 Emissions By Fossil Fuel Type 2020-2050

- The five decarbonization strategies reduce Montana's emissions over the next three decades
- The largest remaining source of emissions is natural gas
  - Natural gas is the cheapest fossil fuel, therefore it is the last to be decarbonized
- Montana offsets remaining emissions with carbon sequestration in saline aquifers to reach the 2050 target



Montana Energy CO_2 Emissions By Sector

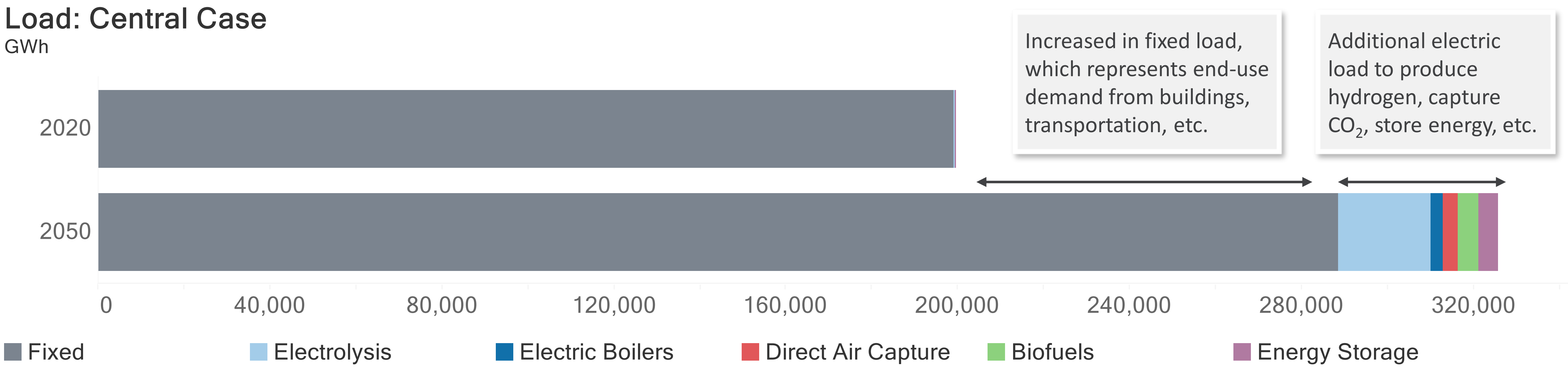
- Overall emissions decrease across all sectors of the state's economy
- Transportation emissions decline significantly with on-road (LDV, MDV, and HDV) significantly reduced
  - In 2050, biofuels with CCS are the dominant source of diesel and jet fuel, resulting in negative emissions
- Building emissions are reduced to ~1MMT by 2050 as heating services are electrified



Load

Northwest-Wide

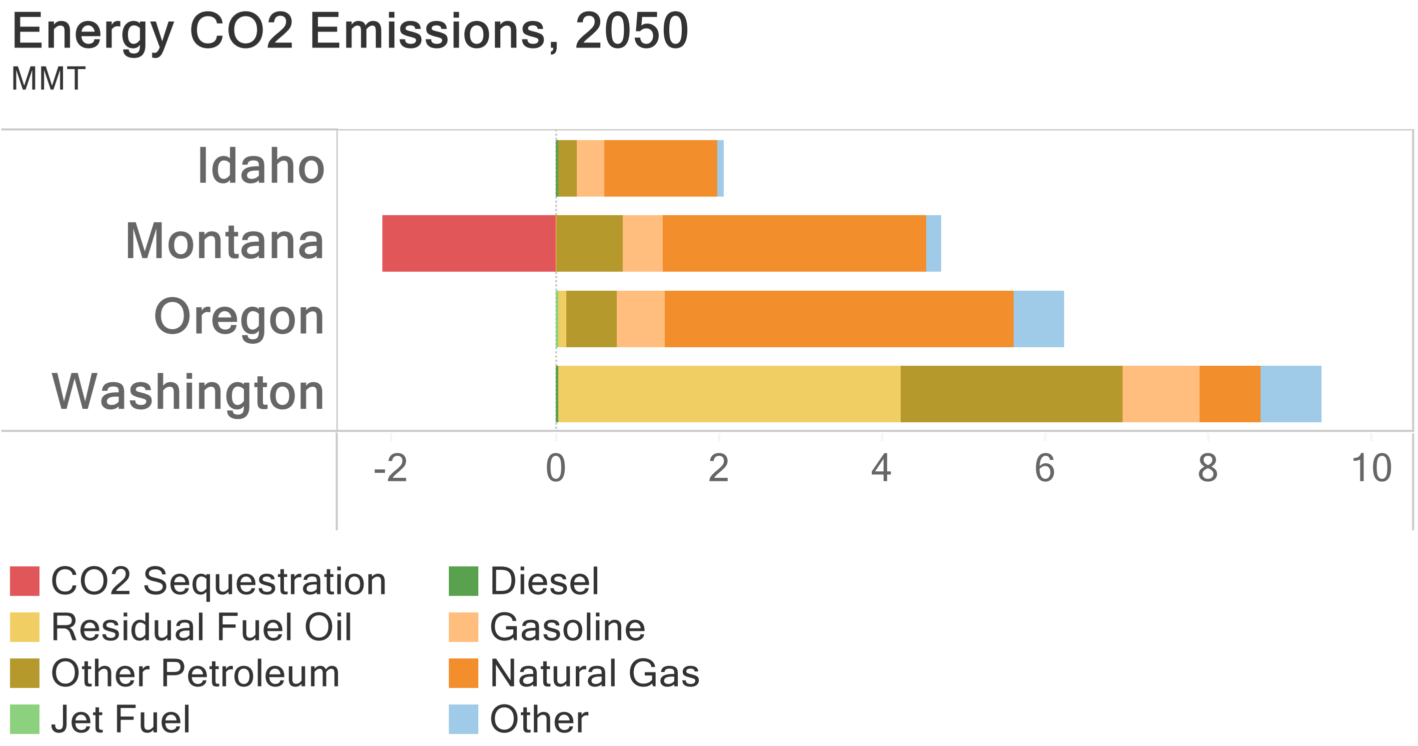
- Load increases by more than 60 percent between 2020 and 2050
- A large portion of the net increase is from higher "fixed" loads, such as transportation electrification
- However, a significant portion is from other demand sources, including the production of hydrogen, capturing CO_2 and using electric boilers to produce steam



State-level Energy CO_2 Emissions in 2050

Northwest Wide

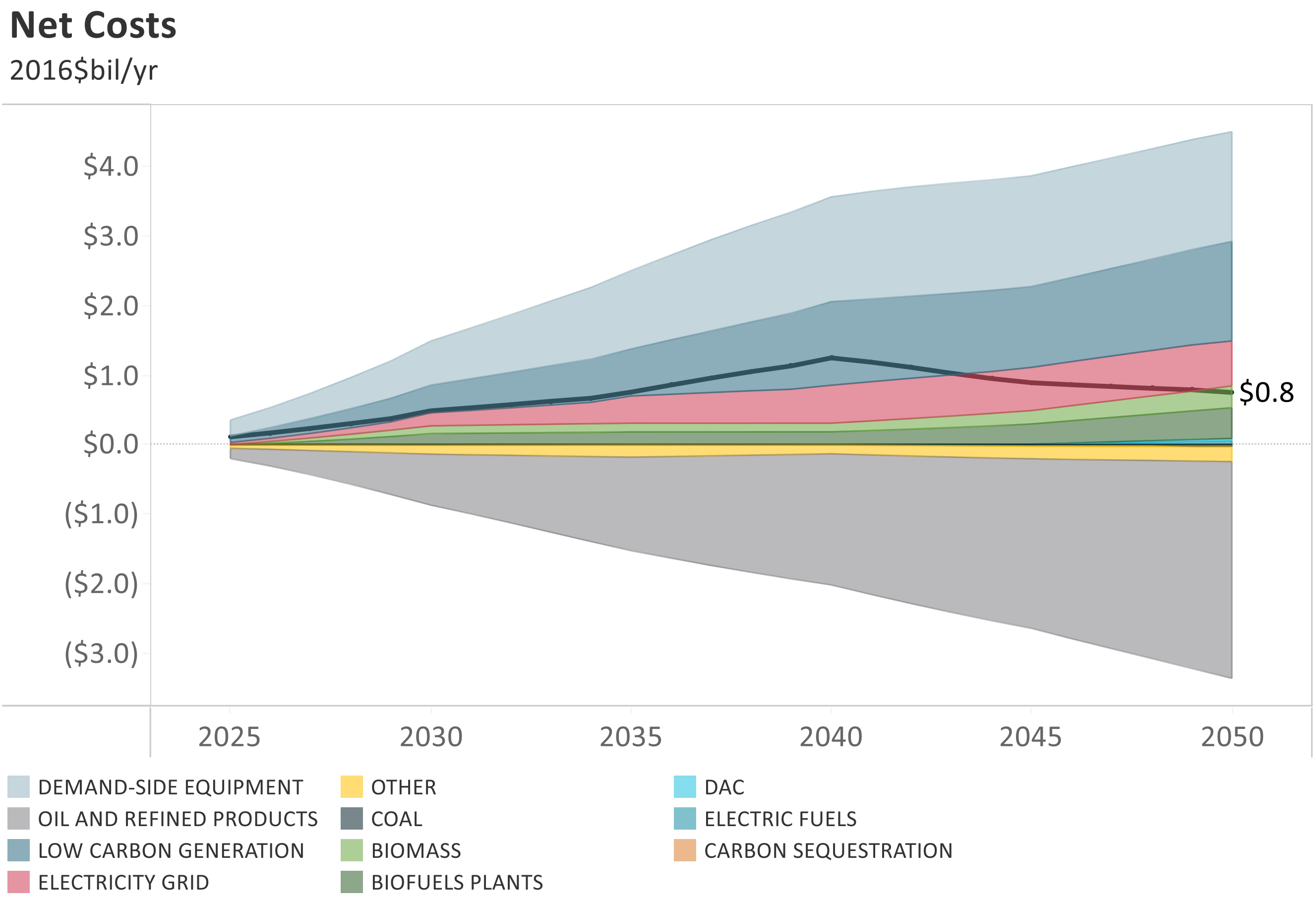
- In most states, the majority of remaining emissions are from natural gas combustion
- The exception is Washington State, where residual fuel oil used in shipping is the largest remaining source of emissions
  - The NWDDP did not include options for decarbonizing this sector. Future studies will, impacting regional investments
- Montana has geological CO_2 sequestration potential, which allows for the capture of CO_2 and storage in saline aquifers



Montana Net Costs

Estimated as the difference between the Central Case and Reference Case

- Net costs for the state primarily represent incremental:
  - Biofuel feedstocks and infrastructure;
  - Demand-side electrification and efficiency investments; and
  - Renewable power plants and supporting electricity infrastructure
- These incremental costs are mitigated by savings from avoided fossil fuel expenditures
- Net costs peak around 2040 as costs of key decarbonization technologies are still declining and the alternative cost of fossil fuels continues an upward trajectory



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Net Costs Relative to Montana's Economy

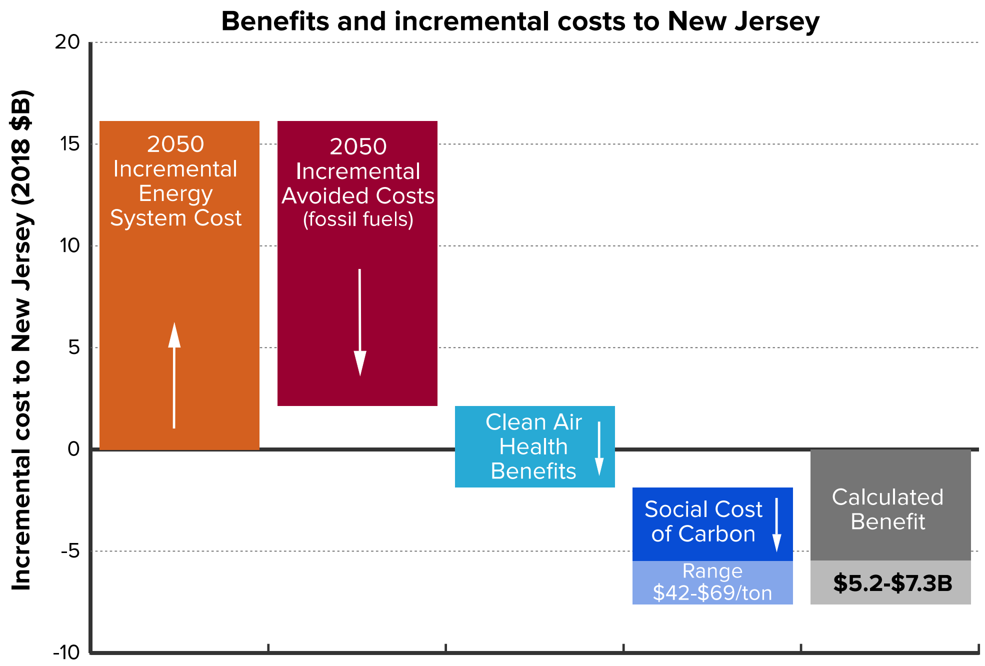
Share of GDP

- Magnitude of net costs are small relative to the size of the state's economy
  - Montana's gross domestic product in 2019 was $52.2 billion
- Between 2030 and 2050, incremental net costs of the Central Case are between 1% and 1.5% of today's economy for Montana
- Since this study was conducted, the forecasts for renewables and electric vehicle prices have dropped so decarbonization costs are lower
- These costs would be even smaller if future economic growth and benefits from avoided climate change and pollution were considered
  - Factoring in carbon and health externalities in other studies resulted in a net benefit from decarbonization
  - An example of these net benefits are shown on the next slide from the New Jersey Energy Master Plan

Example: New Jersey Energy Master Plan

Costs and benefits of decarbonizing in 2050

- New Jersey targeted an 80% emissions reduction and 100% clean electricity by 2050
- The chart opposite shows annual costs and benefits in 2050 of achieving that target relative to a reference case
- While decarbonization is a net cost when considering incremental costs and avoided costs, factoring in externalities would drive New Jersey to net benefits
- A future decarbonization study for Montana may find that net costs are close to zero, or a net benefit, while considering only incremental energy and avoided costs given price declines since the NWDDP
  - Adding additional accounting for externalities including health and climate change impacts is highly likely to result in a net benefit to the state

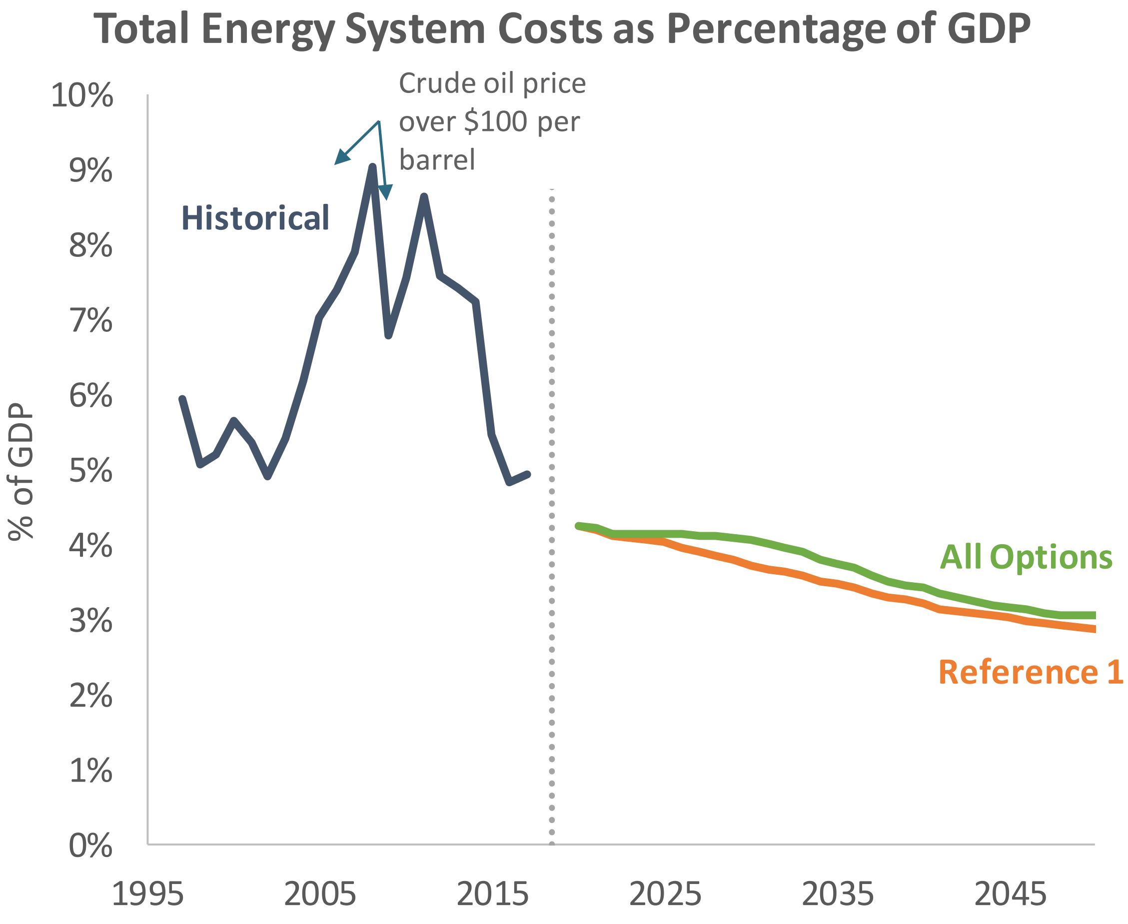


Source: New Jersey Energy Master Plan, analysis conducted by Evolved Energy Research and Rocky Mountain Institute

Total Spending on the Energy System as Share of GDP

New Jersey Example

- While Montana's incremental spending to decarbonize the economy is 1 to 1.5% of today's economy in the NWDDP, this is worth thinking about in context
- Energy spending in general across the US is set to decrease as economic growth is further decoupled from energy consumption
- Contextualizing spending in a future study of Montana decarbonization is likely to show the decreasing percentage spending in GDP terms, and lower spending compared to historical precedent

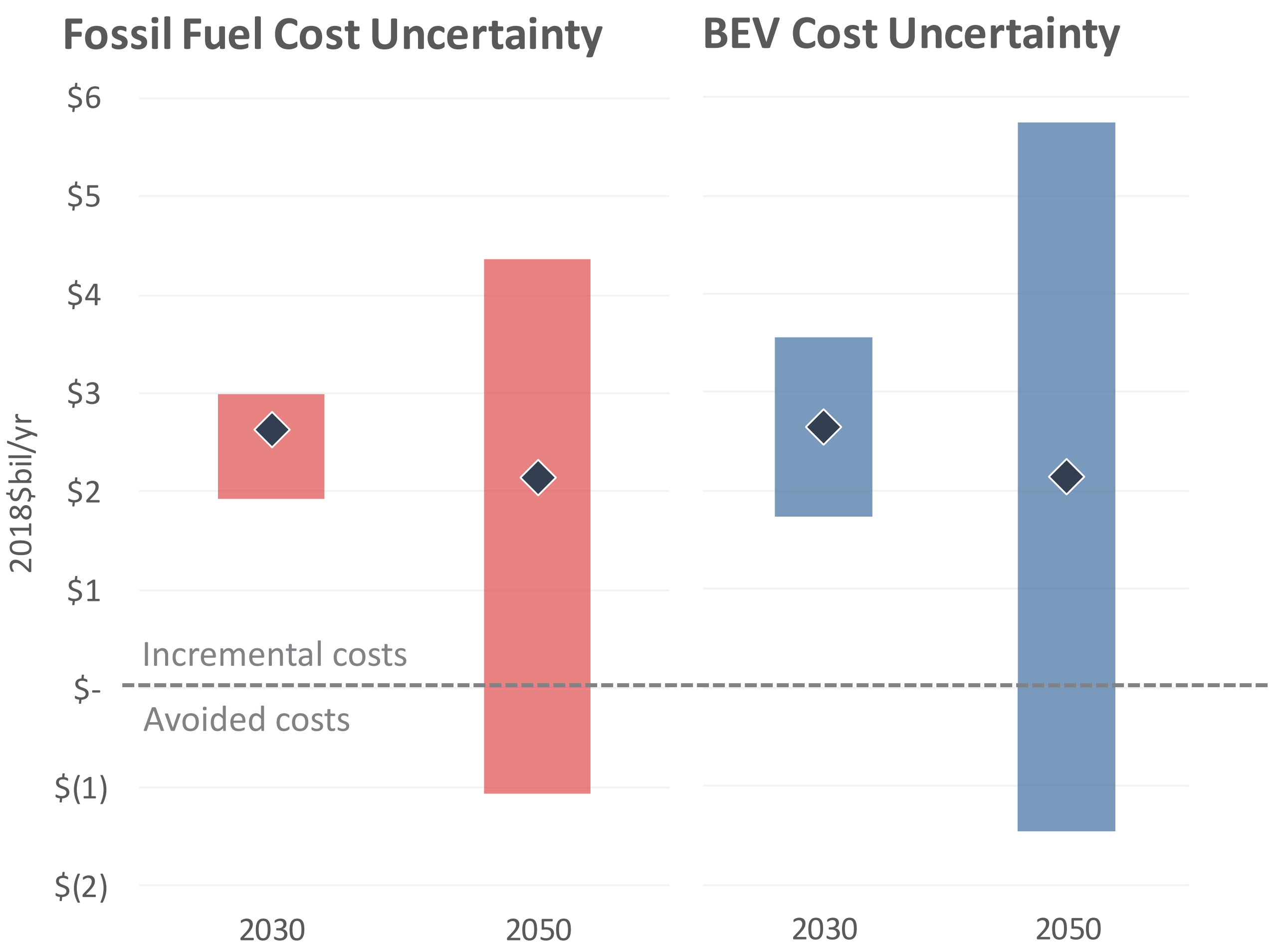


Sources and notes: New Jersey, Energy Master Plan. Historical state GDP from the U.S. Bureau of Economy Analysis; historical energy spending from U.S. Energy Information Administration.

Uncertainty in Cost Inputs

New Jersey Example: Sensitivity to fuel prices in 2050

- Decarbonization costs are uncertain, and this uncertainty increases with time
- Uncertainty is illustrated through ranges in net cost for the New Jersey example, with alternative fossil fuel prices and battery electric vehicle costs
  - Range of fossil fuel price projections are from EIA's *AEO 2019*
    - *Oil price ~+/-10% in 2050*
    - *Gas price +70%/-30% in 2050*
  - Range of BEV cost projections is +/-10% of the baseline assumption
- Deep decarbonization will reduce Montana's exposure to uncertain and volatile fossil fuel prices
  - Hedge against fuel prices dictated by international markets, increasing energy security
- Electric vehicle price forecasts have been trending downwards. They are an important driver of total decarbonization costs, with a 10% decrease in forecasted prices resulting in net benefits of decarbonization for New Jersey



Key Takeaways

- The NWDDP assumptions drive final energy demand to fall by 35% through greater efficiency, much of which comes from a transition to electrified transportation and electrified end uses in buildings
  - As a result electricity demand rises 71%. Whether this result is best for Montana was not investigated in the NWDDP, and any future decarbonization study should include weighing the costs and benefits of electrification policy with assumptions tailored to Montana
- Montana utilizes its geographic strengths on the supply side in the NWDDP
  - A large wind sector is established, supplying clean energy to Montana and surrounding regions
  - Carbon is sequestered in saline aquifers in the production of liquid fuels from biomass, offsetting emissions from other sources
- Policy actions taken in the rest of the West could impact Montana's investments in significant ways, with opportunities to play a major export role in a decarbonized Western system
  - Low cost and complementary wind resource
    - Coastal states have a relatively poor wind resource and import significant quantities of wind from Montana and Wyoming. Transmission between Montana and Washington was fully utilized to export clean energy in the NWDDP
  - Transmission expansion
    - The NWDDP did not allow transmission expansion between Montana and neighbors. However, transmission expansion is likely cost effective and would open up greater opportunity for exports for Montana. This would be a valuable avenue of investigation for a future decarbonization study
  - Decarbonized fuels
    - Decarbonized fuels from biomass and hydrogen play a major role in Montana's transportation sector by 2050. Other Western states also rely on decarbonized fuels to reach their own targets. Montana has low cost resources to produce fuels and could export fuels to other states – another opportunity to investigate
    - Fuels export can also take the pressure off expansion of transmission lines, by exporting clean energy through pipelines or other forms of transport instead
- Decarbonization costs are 1 to 1.5% of Montana GDP in the NWDDP. This estimate will have decreased with falling price forecasts for clean energy technology
  - Decarbonization is likely to be a net benefit to the state when factoring in externalities
  - Fossil fuel and electric vehicle price uncertainties have a major impact on total costs. Further price forecast declines in electric vehicles could result in net benefits for Montana

Planning Framework for Decarbonization

Designing a state-driven process to achieve climate goals most effectively

What is Success when Planning State Climate Policy?

- Policy and near-term action development that:
  - Achieve “best” balance of state objectives – what outcomes would best satisfy Montana’s many, sometimes competing, objectives?
  - Are actually implemented through collective action across state agencies, utilities, and other participants
- Multiple objectives including reaching climate targets, but also labor, productivity, equity, environmental, environmental justice, etc.
- Effective planning includes:
  - Representative stakeholder participation for all interests in the state
  - Providing as much information to policymakers as possible, economic and otherwise, to weigh the options

Tailored Analytical Approach

- Least-cost energy system planning, and policy/action design complement one another
  - Process to determine Montana's best path forward
  - Least cost energy system planning determines investments necessary to minimize total cost of achieving targets for different future scenarios
  - Policy and action design determine how best to achieve those investments and allocate those costs
- The best path is a balance of different, often competing objectives
  - Not all objectives can be quantified in economic terms
  - Analysis provides more information to allow decisionmakers to weigh one option against another
- Stakeholder input essential to define the options and evaluate policies and actions

Three Framing Questions

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

Where Are We Now?

- Present day
  - What do Montana's energy technologies/systems and consumption patterns look like on the demand and supply side?
    - e.g., what types of appliances are homes and businesses currently using? What are transportation energy consumption patterns? How does the state generate electricity? What do imports and exports look like? What are industrial process emissions?
  - What policies presently drive investments and behavior?
  - What behaviors are markets incentivizing?
  - What do technologies and fuels presently cost?
- Building the full picture of what Montana's energy consumption and emissions profile looks like today

Where Do We Want to Go?

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

Investigating policies

100% Clean Electricity Grid

Limited New Thermal Plant Development

Examples for illustration only

Evaluating uncertainties

Limited Electrification & Efficiency

Limited Biomass for Liquid Fuels

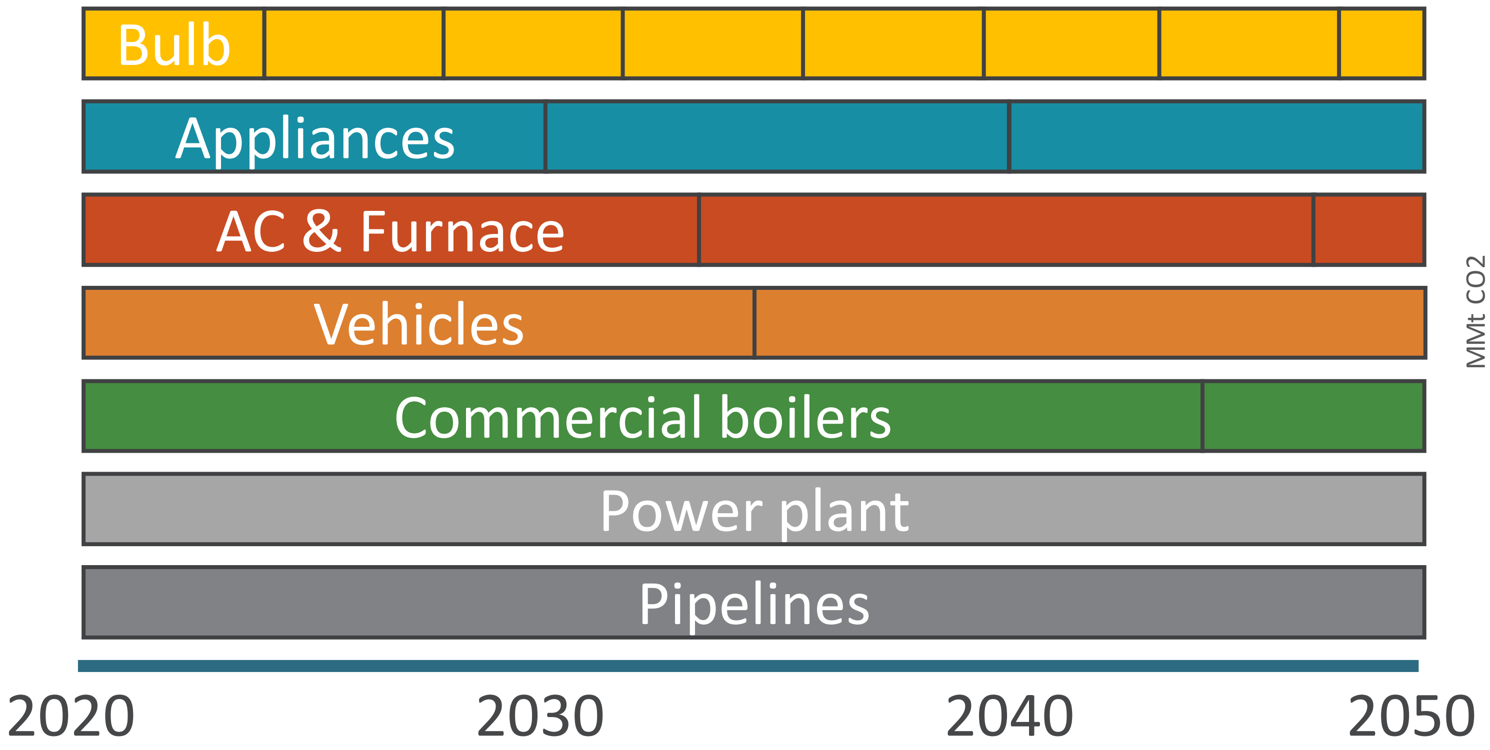
How Should We Get There?

- By targeting favorable future pathways we can **develop and prioritize near-term policies and actions**
- Targets are not prescriptive, but provide the best guidance given current information and uncertainties
  - Common elements deployed 2020-2030: “no regrets”
  - Replace or avoid long-lived resources
  - Early action on long lead-time or hard to achieve energy transformations
- Policy development that favors Montana’s goals
  - Balance competing objectives in the state
  - Detailed sectoral analysis to evaluate distributional/equity/workforce etc. impacts and develop targeted policy guided by integrated economy wide planning efforts

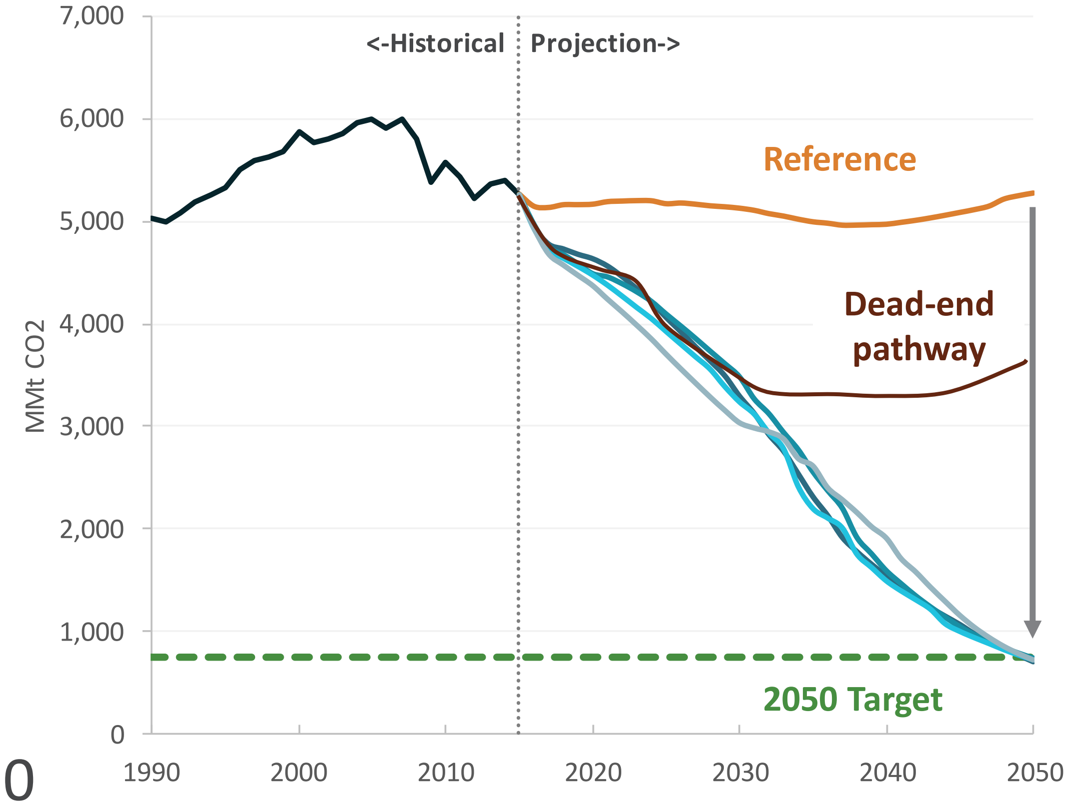
Near-Term Focus on Long-Lived Assets

Early action needed to avoid carbon lock-in or stranded assets

Stock replacement count before mid-century



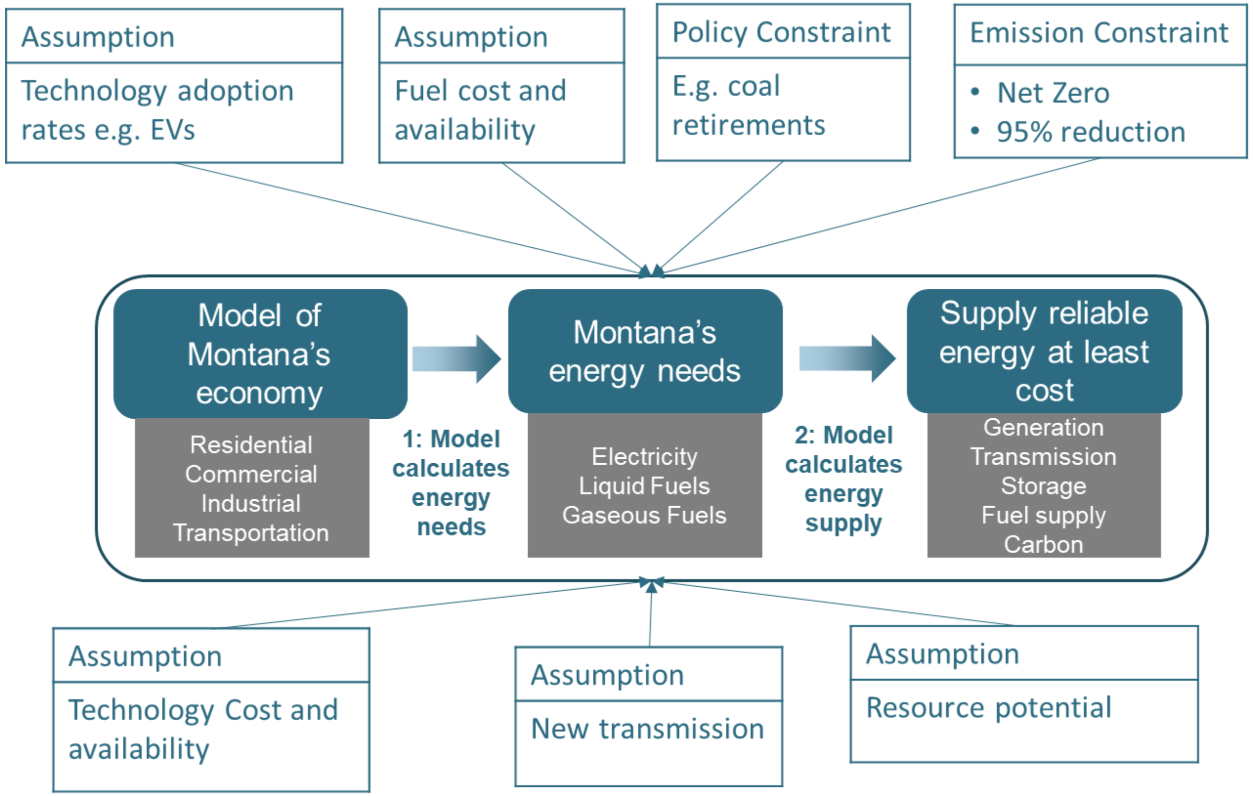
U.S. Energy-related CO_2 Emissions



Planning Process

Steps followed through stakeholder process

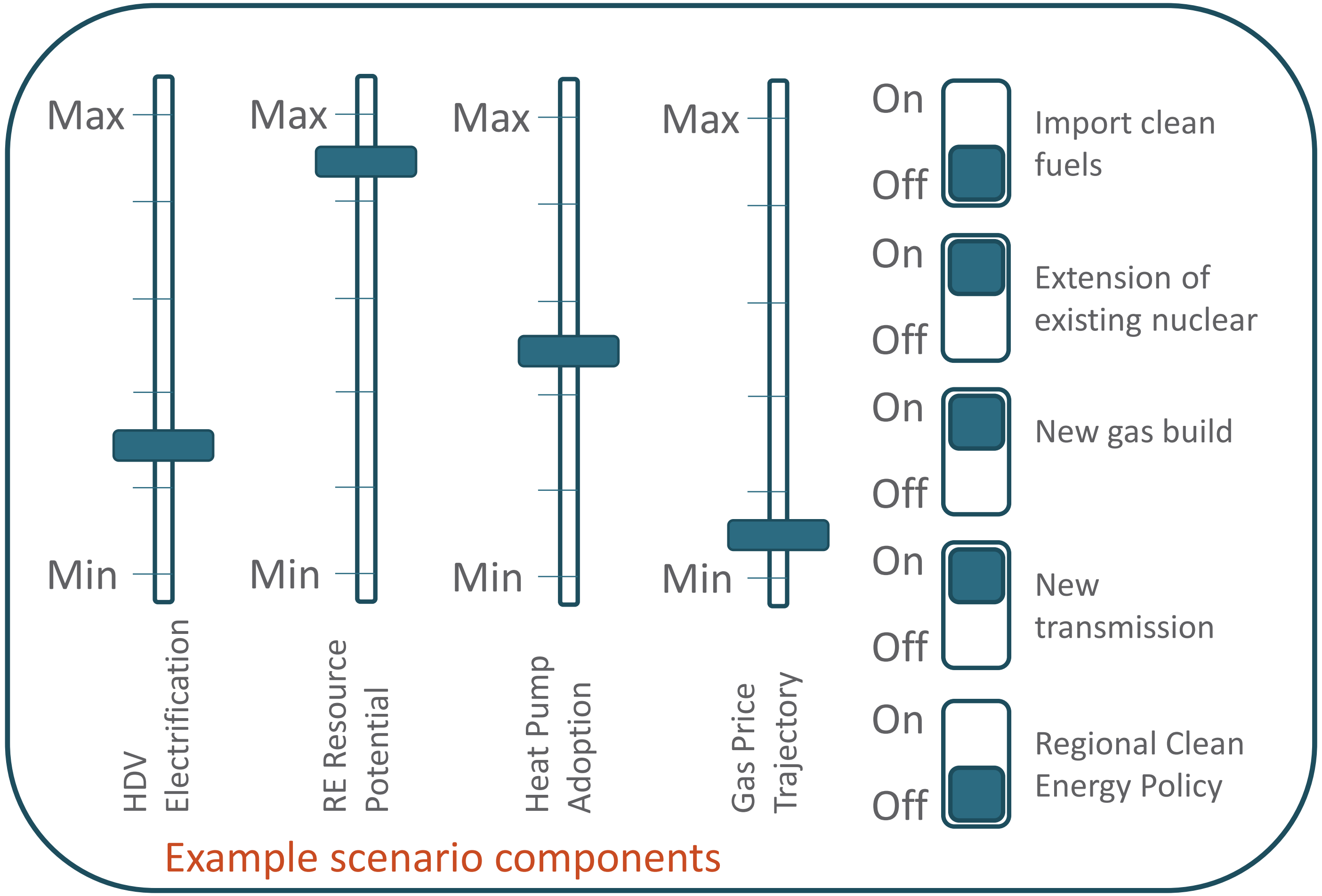
Scenario Development: Investigate State Objectives



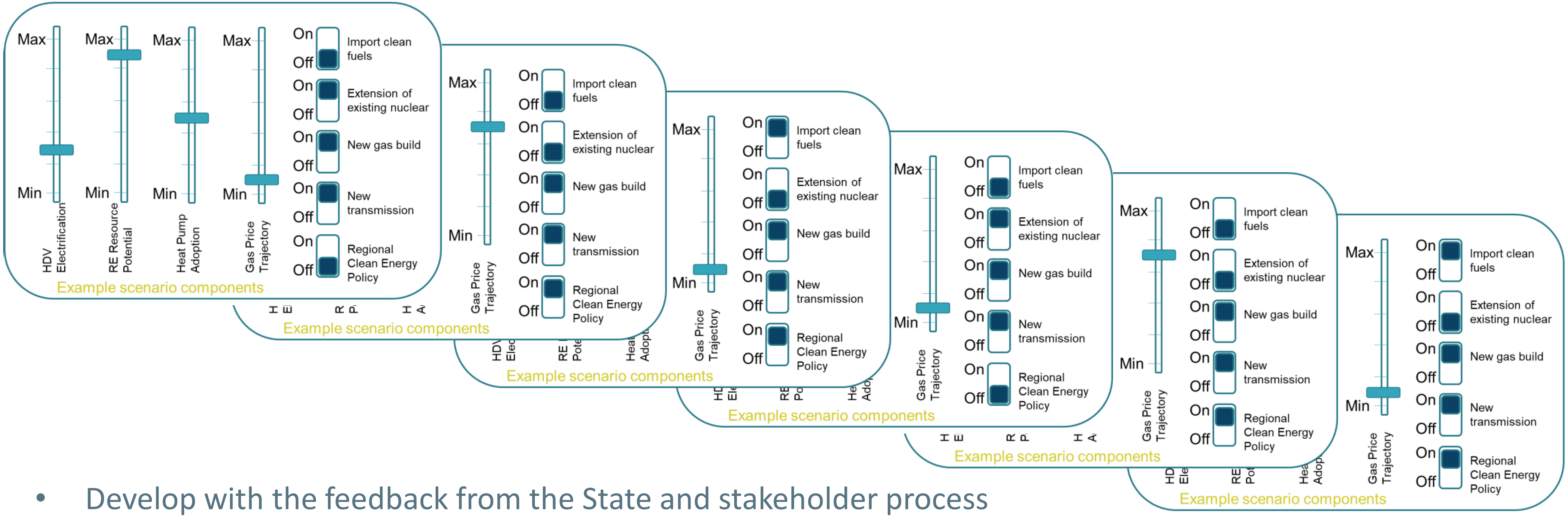
- Translate State objectives and potential policy pathways into constrained scenarios
  - What are state and stakeholder policy goals?
  - How hard should the state prioritize particular actions or strategies?
- Understanding the tradeoffs
  - How much does one pathway cost versus another?
    - Counterpoint for policymakers and stakeholders
  - Provides a target for near-term policy and action design to hit
- Understanding the uncertainties
  - How does an uncertain future impact State decisions?

Components of a Scenario

- Many assumptions go into projecting a decarbonization pathway
- Sets the parameters for the world within which the planning model optimizes decisions
  - Assumptions on how uncertainties now manifest in the future
  - Assumptions on how policies/actions/ customer behavior manifest in driving energy needs and how they can be served



Connect Scenarios to Important Outcomes for the State



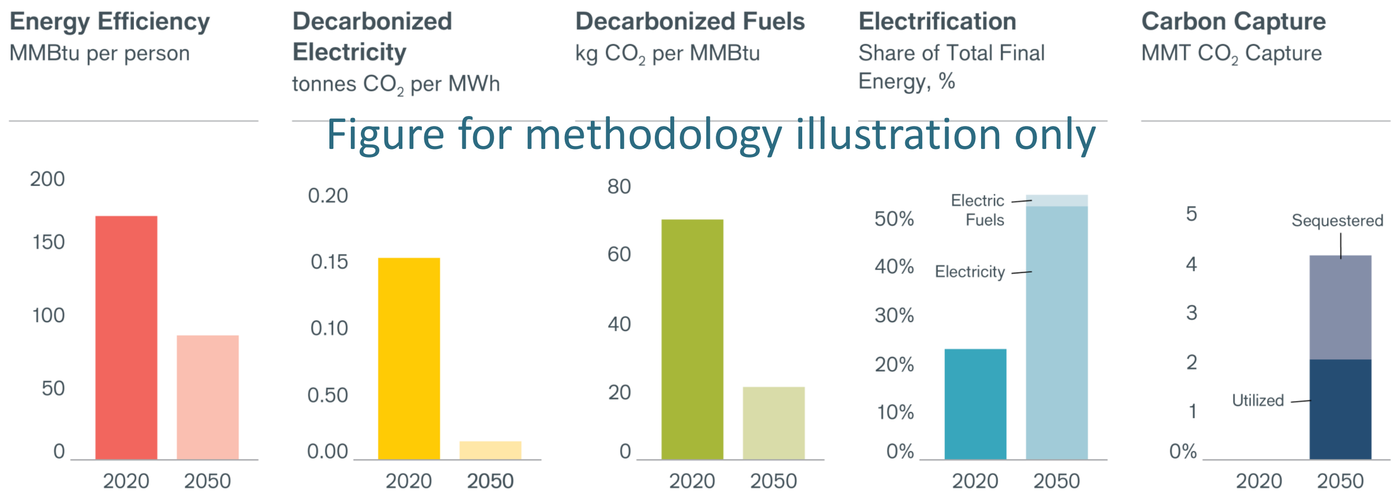
- Develop with the feedback from the State and stakeholder process
- Provides valuable information for the policy development process
  - What outcomes should be targeted through near-term policy and action development?

What Happens after Scenario Development?

Least Regrets Strategies

Where do we want to go?

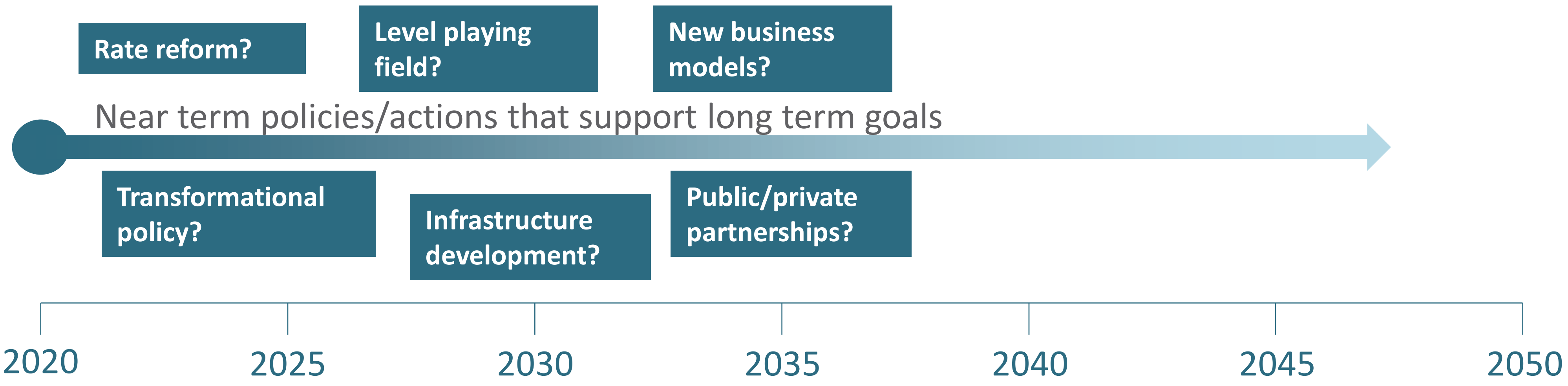
Cost effective outcomes from modeling to inform policy



Policy Development

How should we get there?

Creation of a state policy and action implementation plan



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Appendix A

Deep Decarbonization Scenario Definitions from Northwest Deep Decarbonization Pathways Study

Summary of Alternative Deep Decarbonization Pathways

Case	Description
Limited Demand Transformation	• Increased fuel demand from lower electrification requires significant volumes of synthetic fuel production • Raises net costs by $15 billion in 2050
Constrained Biomass	• Similar impacts as the "Limited Demand Transformation", where additional synthetic fuels are needed to meet the carbon constraint • Raises net costs by $3 billion in 2050
Increased Gas in Transportation	• Biofuels are primarily allocated to pipeline gas rather than liquid fuels
100% Clean Electricity	• State can achieve a 100% clean electricity standard with a small increase in synthetic natural gas production for gas-fired power plants
No New Gas Plants	• Additional energy storage and renewables are required across the region for balancing • This incentivizes additional synthetic fuels and avoids some biofuels consumption
Increased NW-CA Transmission	• Northwest avoids developing low-quality solar and increases wind development • California avoids procurement of remote wind generation from other Western states (NM and WY) and develops additional high-quality solar which is exported to the Northwest

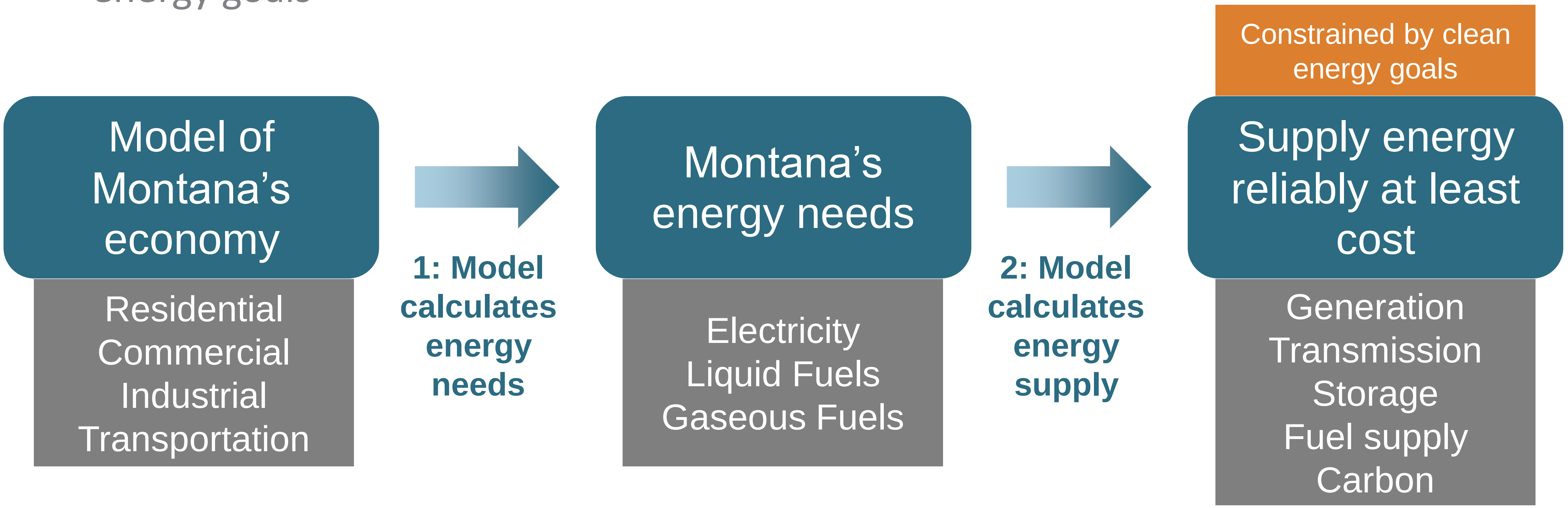
Appendix B

Evolved Energy Research Modeling Overview

Model Overview
High level description of our approach

High-Level Description of Modeling Approach

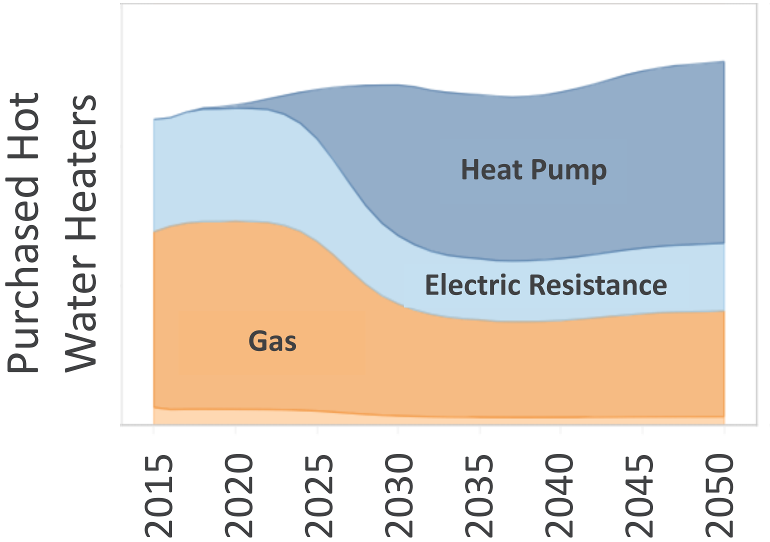
- Model calculates the energy needed to power the Montana economy, and the least-cost way to provide that energy under clean energy goals



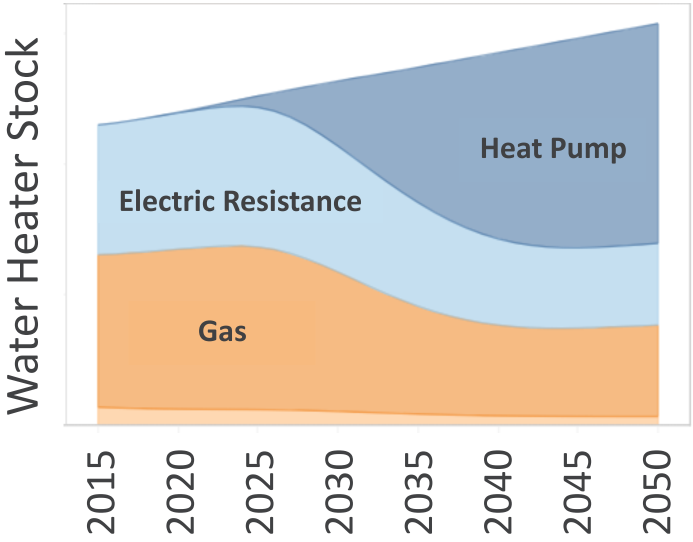
1. The model calculates energy demand by assuming population growth, economic growth, and adoption of new technologies

Example: Water heaters

Model estimates how many water heaters of each type are purchased each year



Model calculates the changing stock of hot water heaters by year



Model calculates the gas and electricity required for water heaters

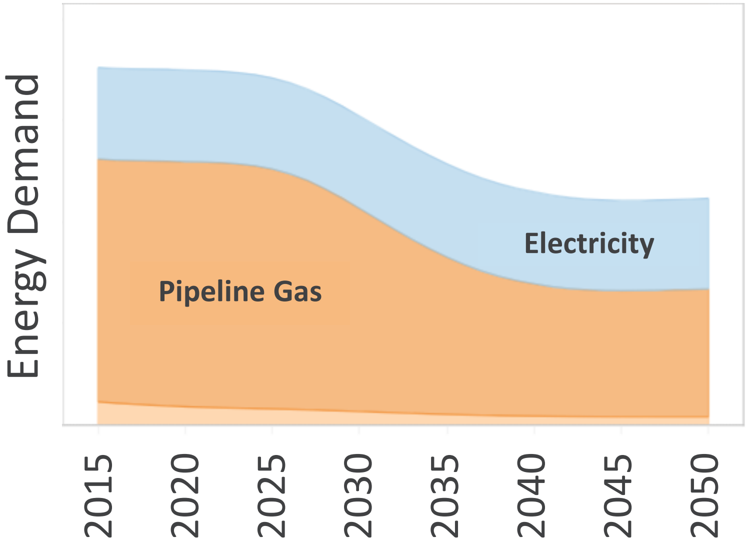


Figure for methodology illustration only

This 'stock rollover' analysis is repeated for ~30 end-uses across the economy

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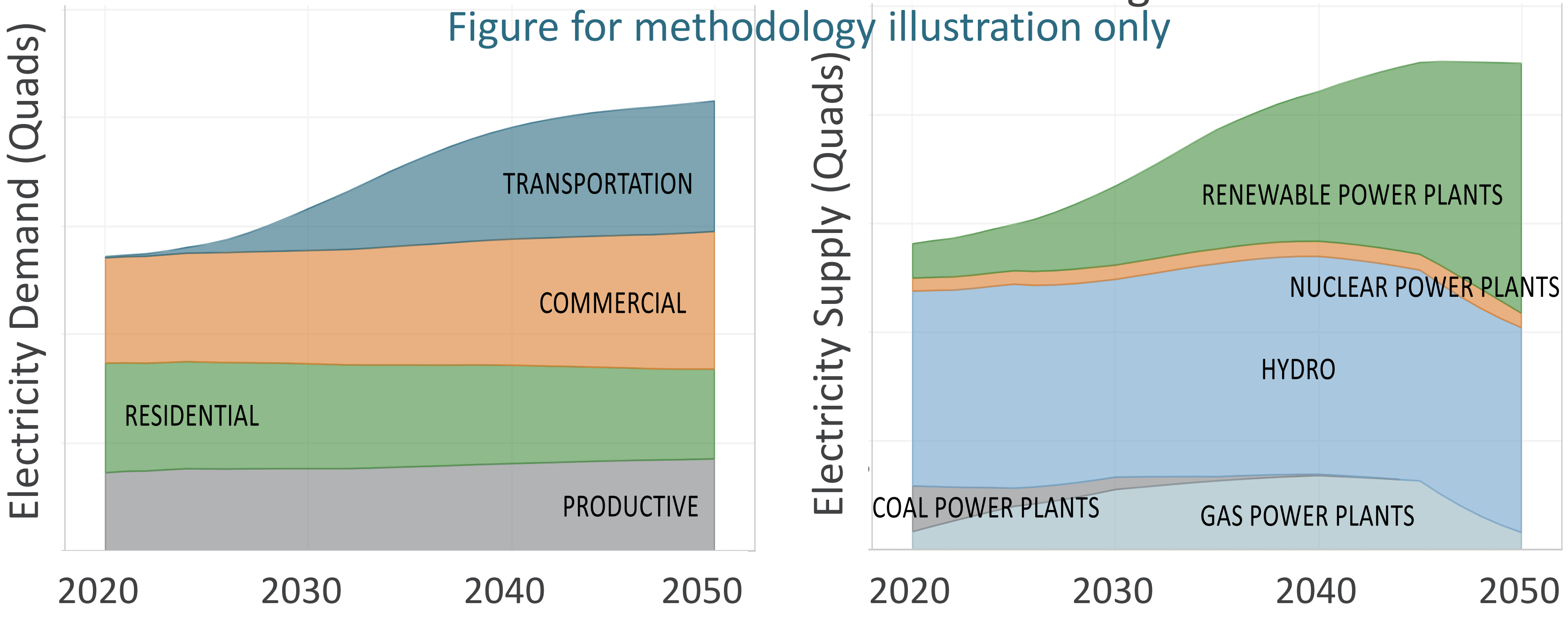
2. The model optimizes investments in energy infrastructure to meet energy demands and satisfy emissions constraints

Example: Electricity

Electricity includes all economic sectors

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



- **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

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

New Electric Sector Resource Options

- Model invests across a range of thermal, renewable and energy storage technologies to satisfy energy, capacity, balancing, and environmental needs

Thermal	Renewable	Energy Storage
Gas Combustion Turbine (CT)	Onshore/Offshore Wind	Pumped Hydro
Gas Combined Cycle (CC)	Solar PV	Lithium-ion
Gas CC with Carbon Capture and Sequestration (CC w/ CCS)	Geothermal	Vanadium Flow

Supply-Side Fuel Options

Diesel Fuel
- Power-to-Diesel
- FT Diesel
- FT Diesel with CCS
- FT Diesel with CCU

Jet Fuel
- Power-to-Jet Fuel
- FT Jet Fuel
- FT Jet Fuel with CCS
- FT Jet Fuel with CCU

Pipeline Gas
- Power-to-Gas
- Hydrogen
- Biomass Gasification
- Biomass Gasification with CCS
- Biomass Gasification with CCU
- Landfill Gas

Liquid Hydrogen
- Electrolysis
- Natural Gas Reformation
- Natural Gas Reformation with CCS
- Natural Gas Reformation with CCU

Direct Air Capture
- DAC with CCS
- DAC with CCU

Gasoline Fuel
- Corn Ethanol
- Cellulosic Ethanol

Steam
- Fuel Boilers
- CHP
- Electric Boilers

Acronyms
CHP: combined heat and power
CCS: carbon capture and sequestration
CCU: carbon capture and utilization
DAC: direct air capture
FT: Fischer-Tropsch

Model Structure and Operations

EnergyPATHWAYS 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

RIO & EP Data and Methods have Improved across many Past Studies

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

RIO Decisions Variables and Outputs

Hours

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

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

Days

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

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

Years

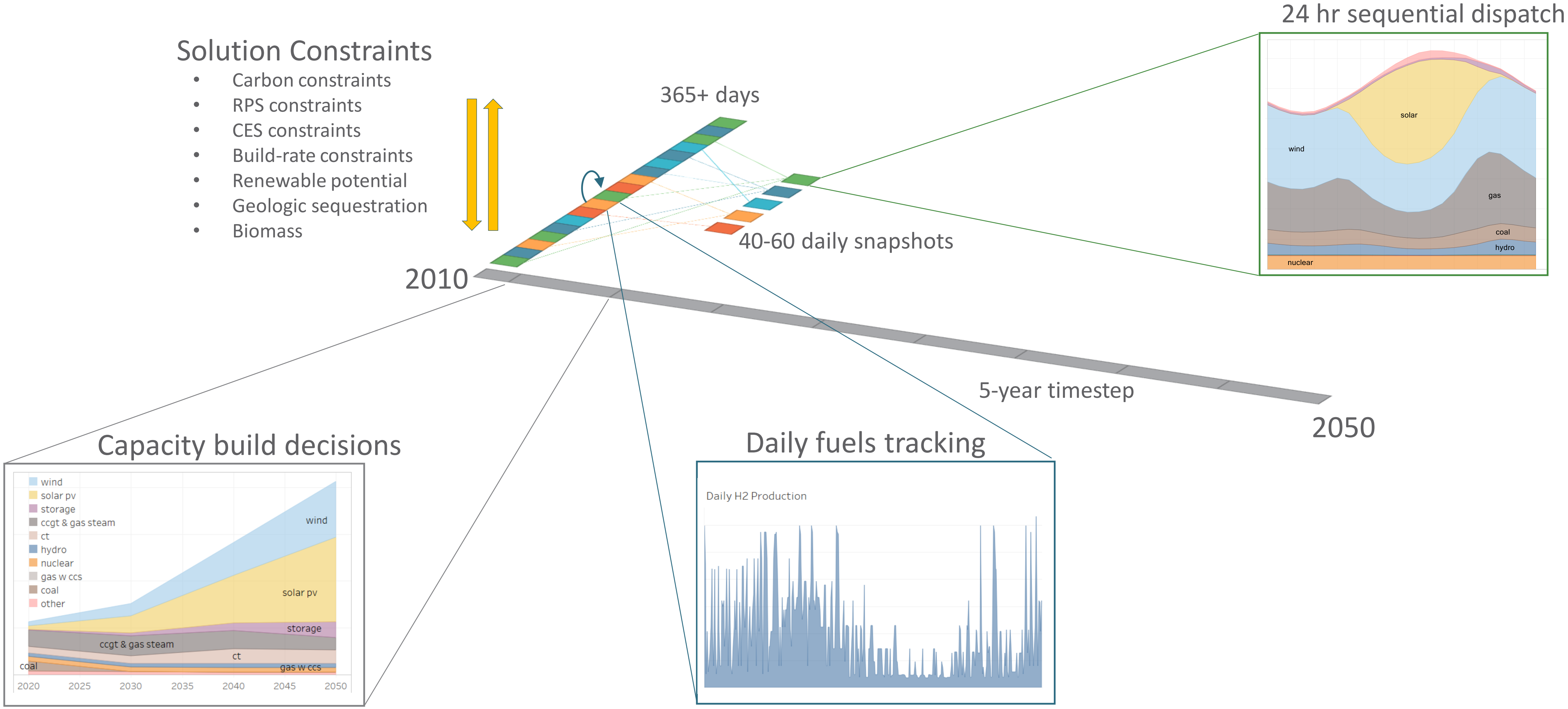
30 yr study / 2 – 5 yr timestep
= 6 – 15 years

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

RIO Optimizes across Time-Scales

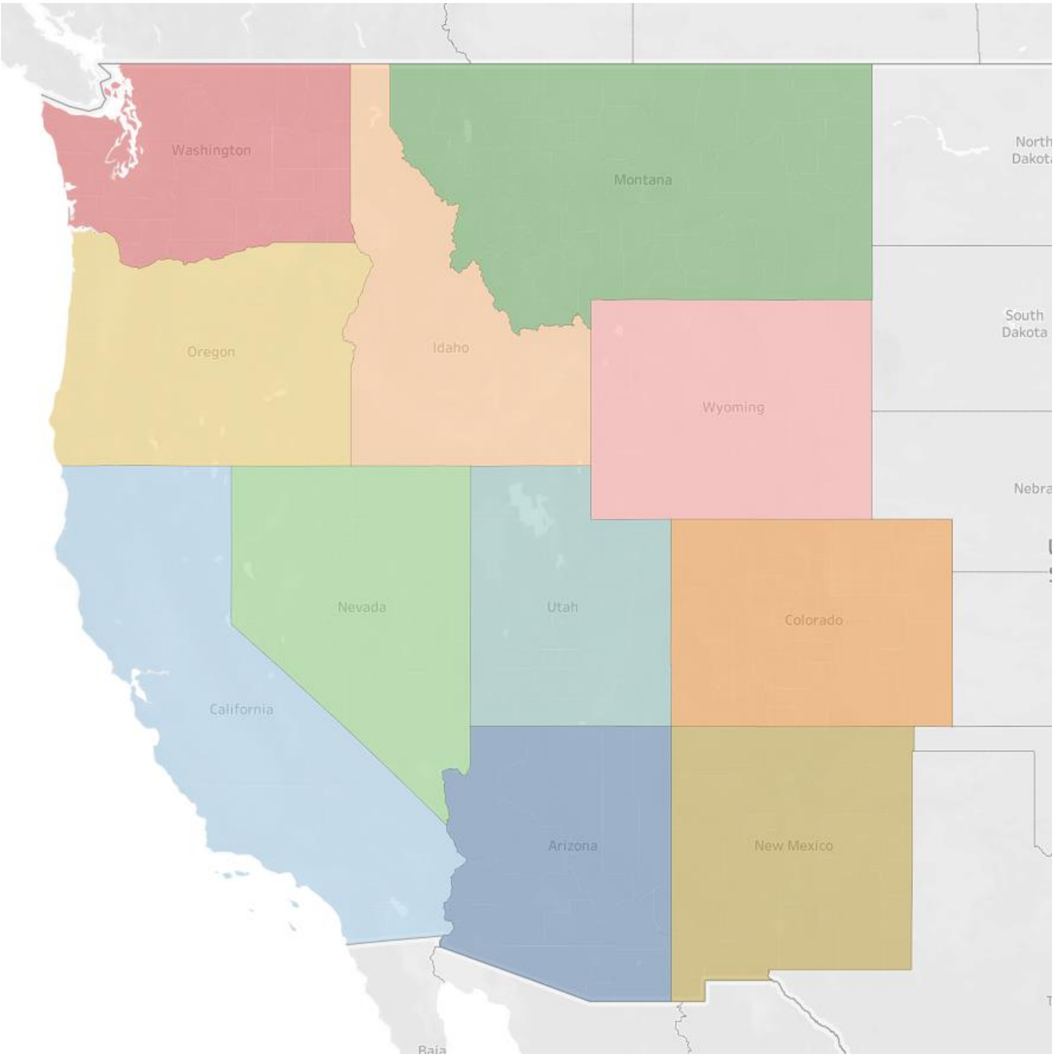
Solution Constraints

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



RIO optimizes across Geographic Constraints

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



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Flexible Load Operations

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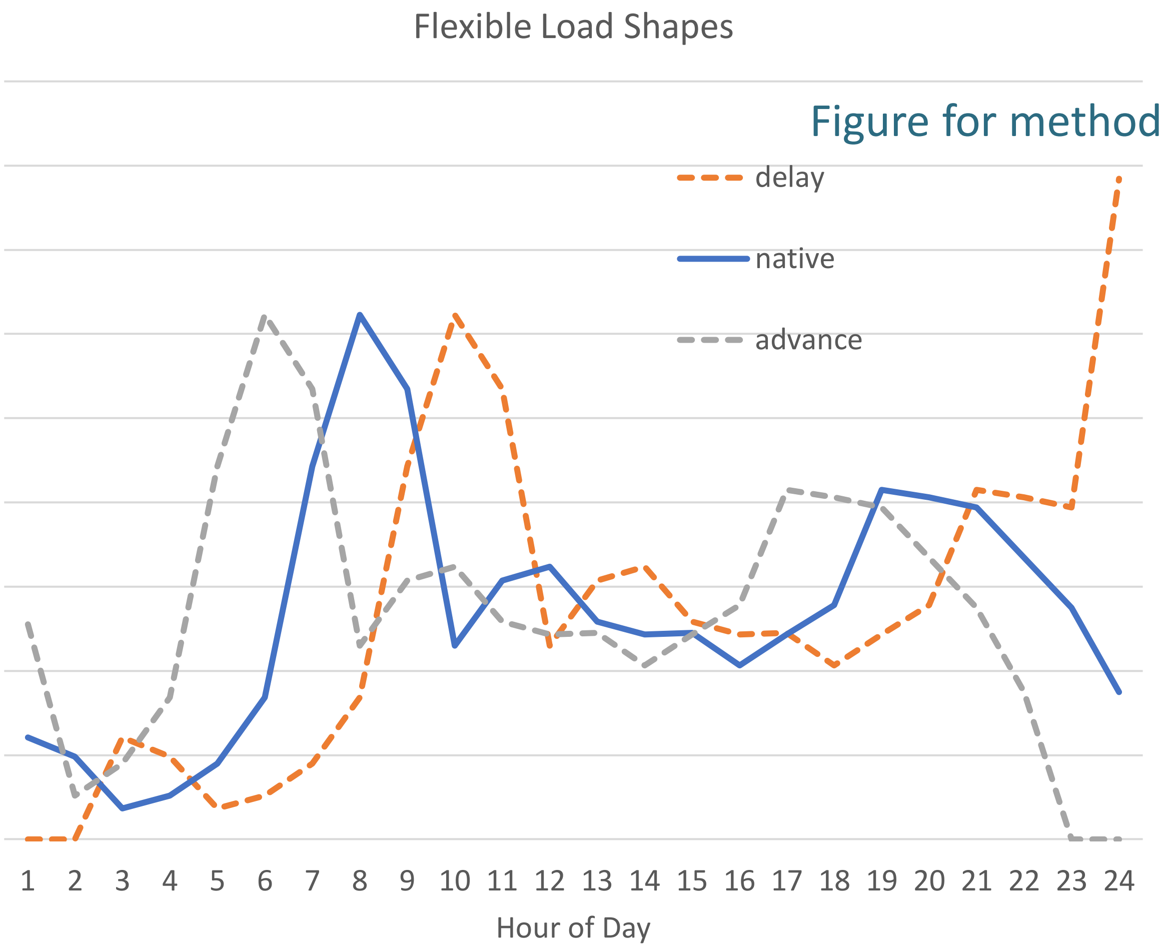
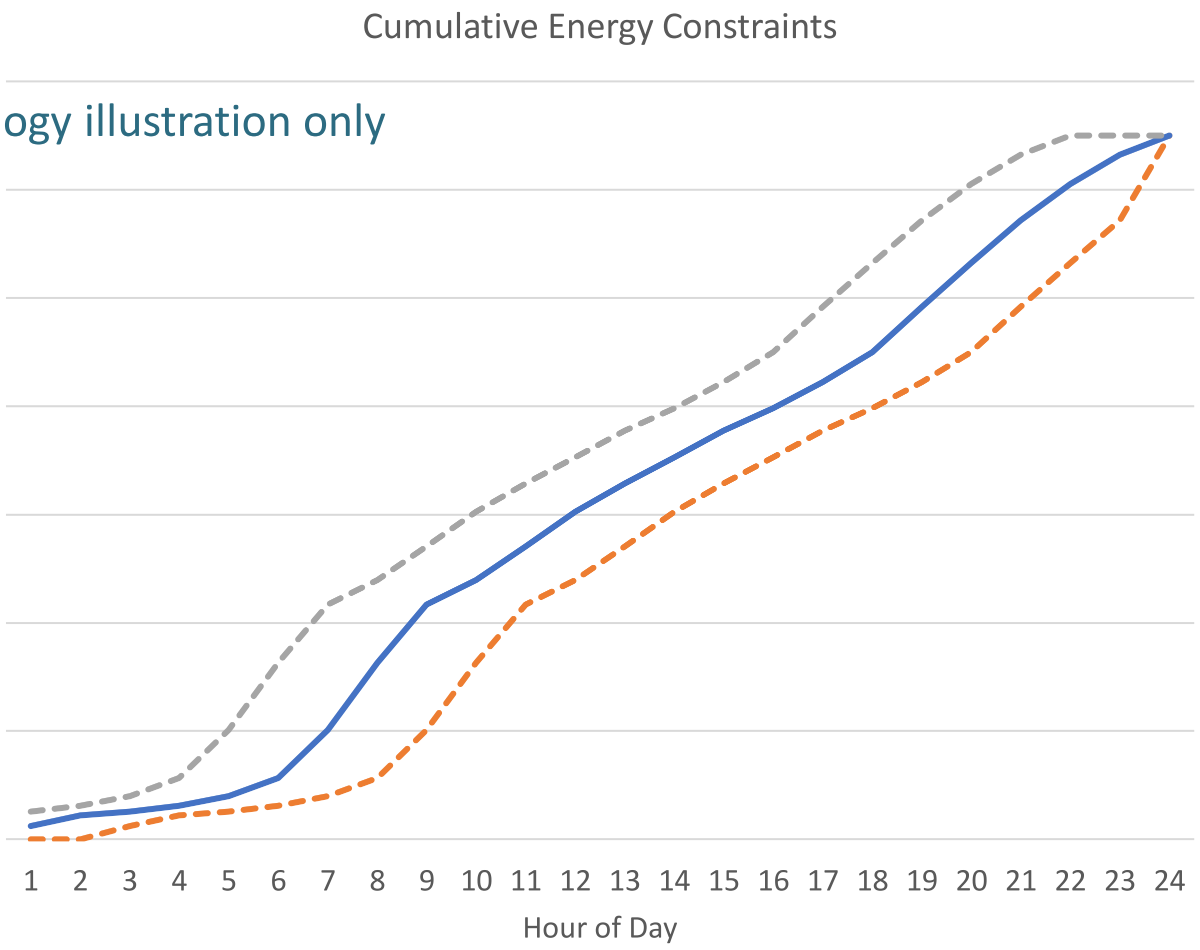
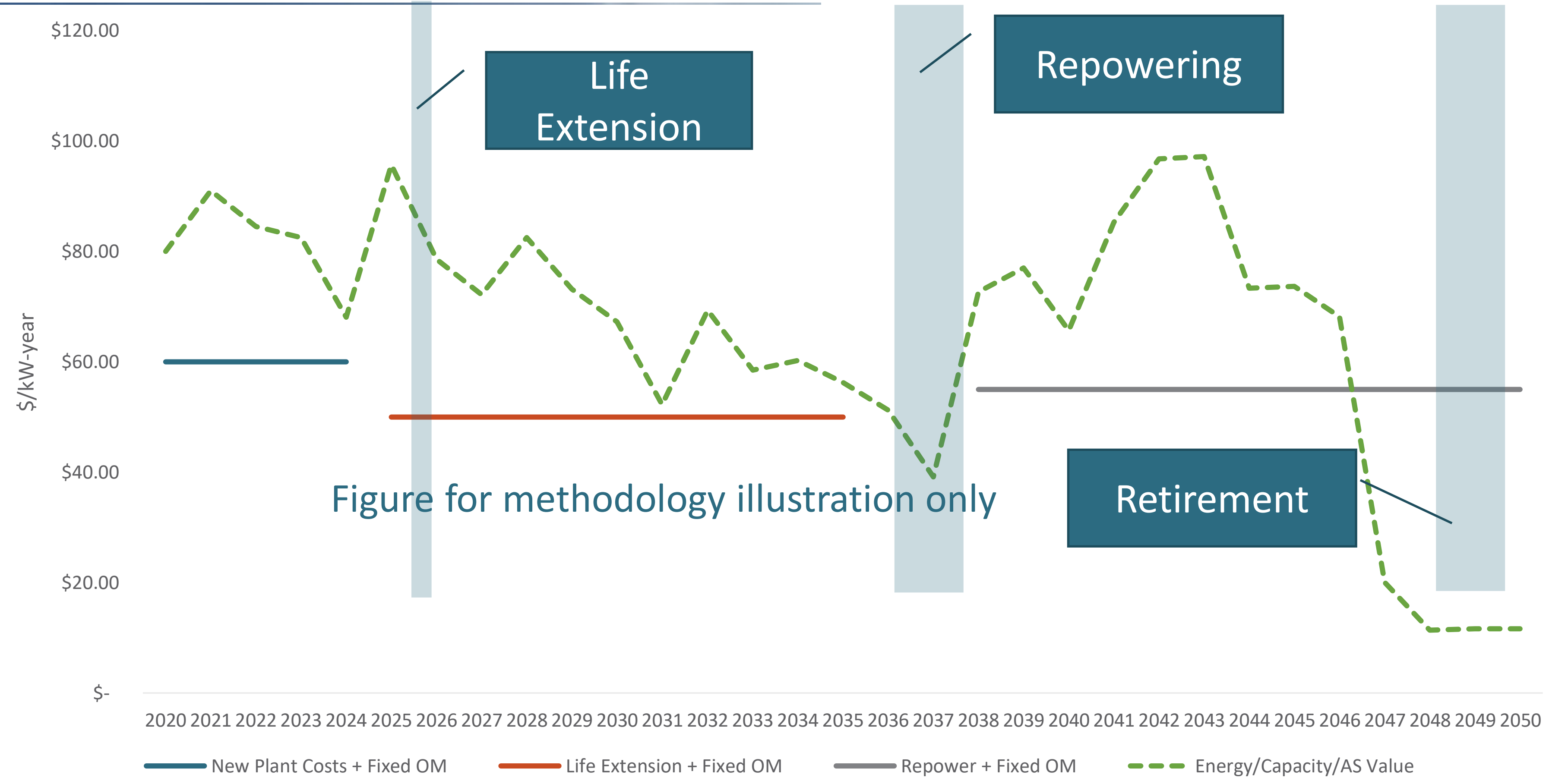




Economic Generator Lifecycles

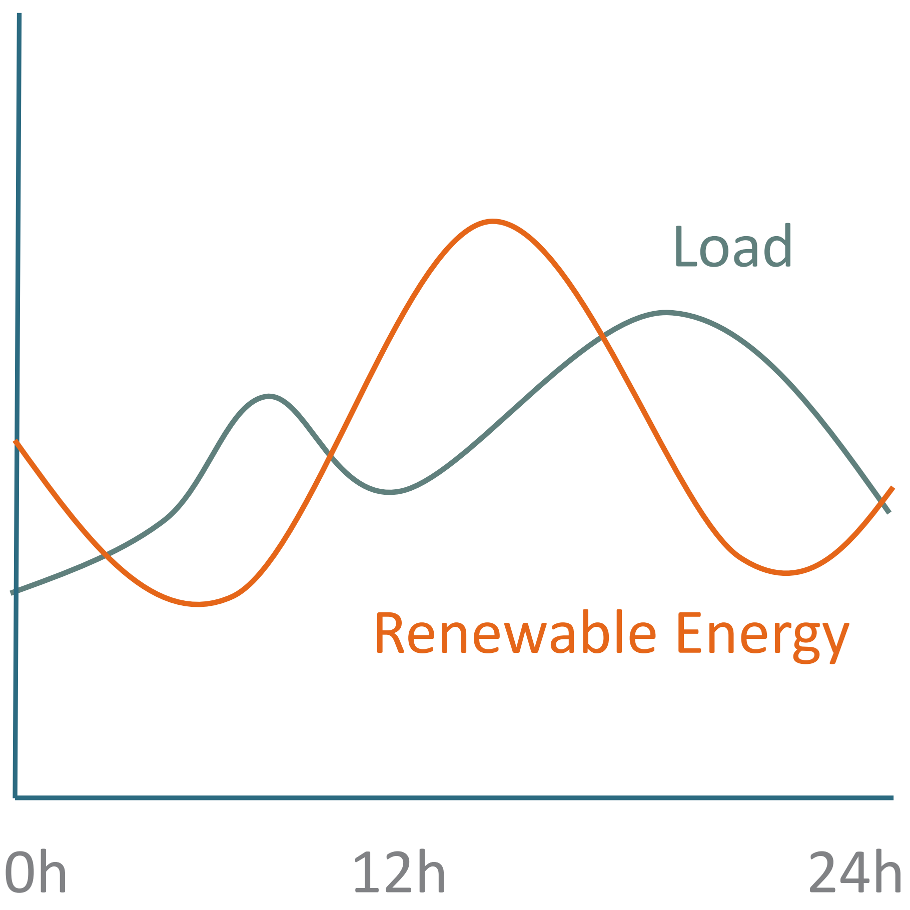
RIO optimizes plant investment decisions including life extensions, repowering, and retirements based on system value and ongoing costs



Electricity and Fuels Sector Integration

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

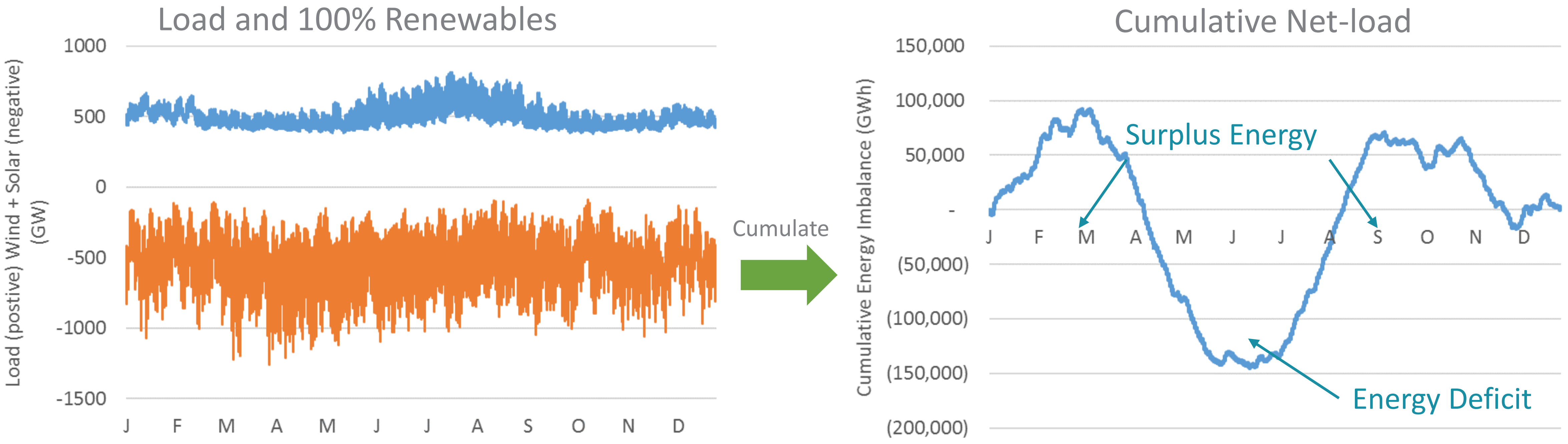
Daily Energy Imbalances



- Renewable energy produced when the sun shines and the wind blows
- Inconvenient because it does not match production exactly with load
- Already happening in regions with significant renewable penetration
- Need to disconnect instantaneous load and supply
  - Overgeneration conditions
  - Diurnal energy storage opportunities

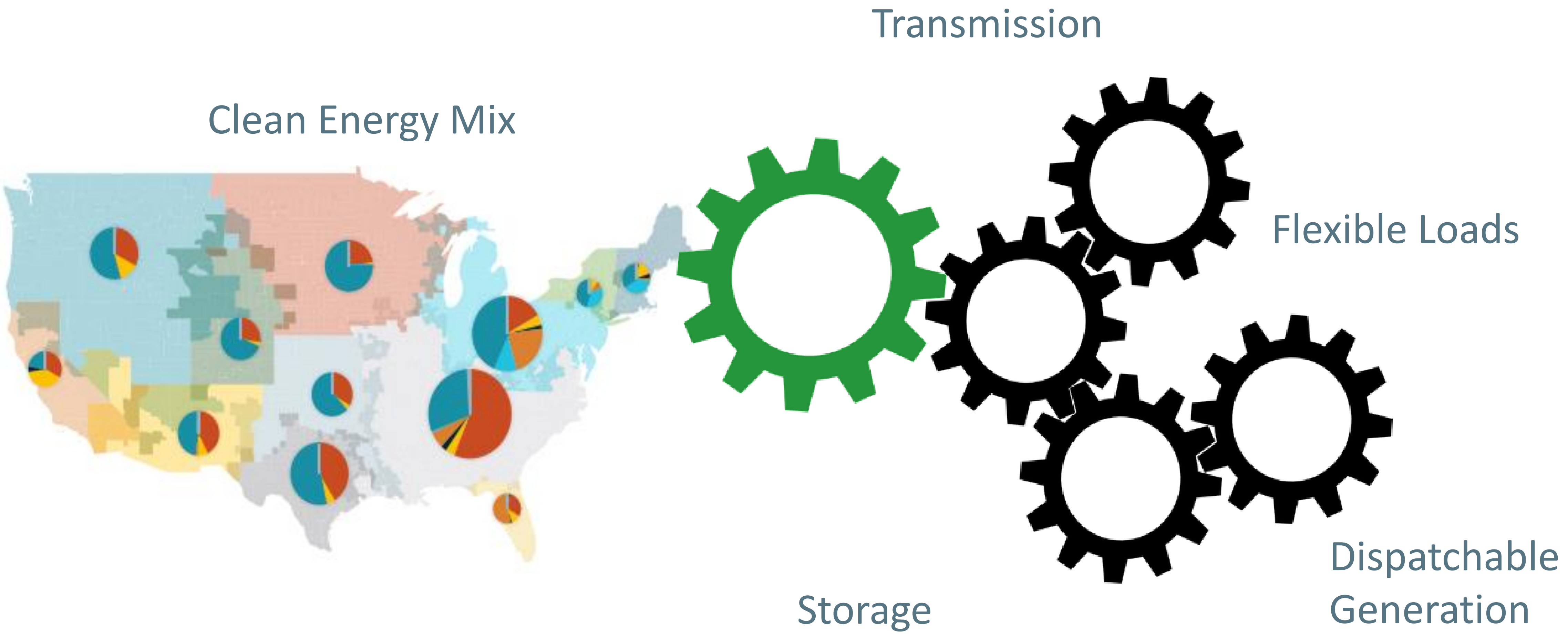
Energy Imbalances beyond a Day to Seasonal to Annual

- Storms or other weather events will cause multi-day energy deficits
- Seasonal energy imbalances become the dominant challenge for achieving deep decarbonization in electricity in many climates

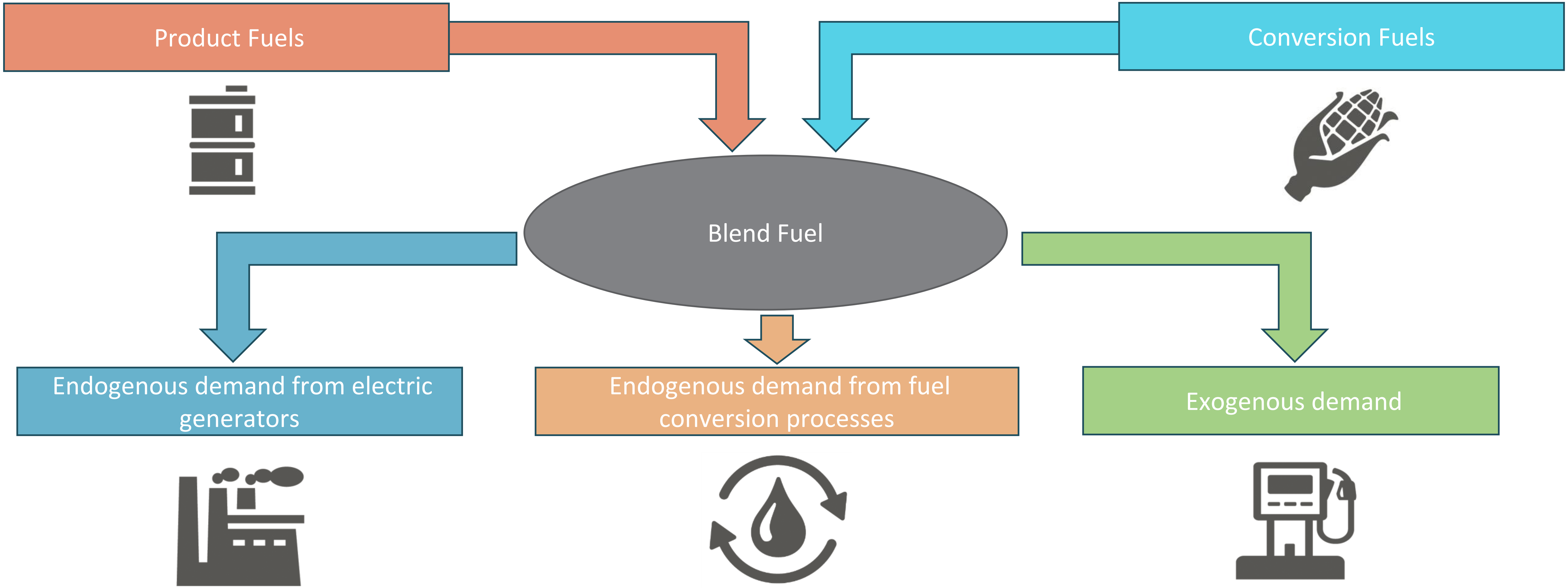


U.S. Eastern Interconnect 2015 Load with simulated 40% Solar & 60% Onshore Wind by Energy

Balancing Load and Supply in a Decarbonized System?

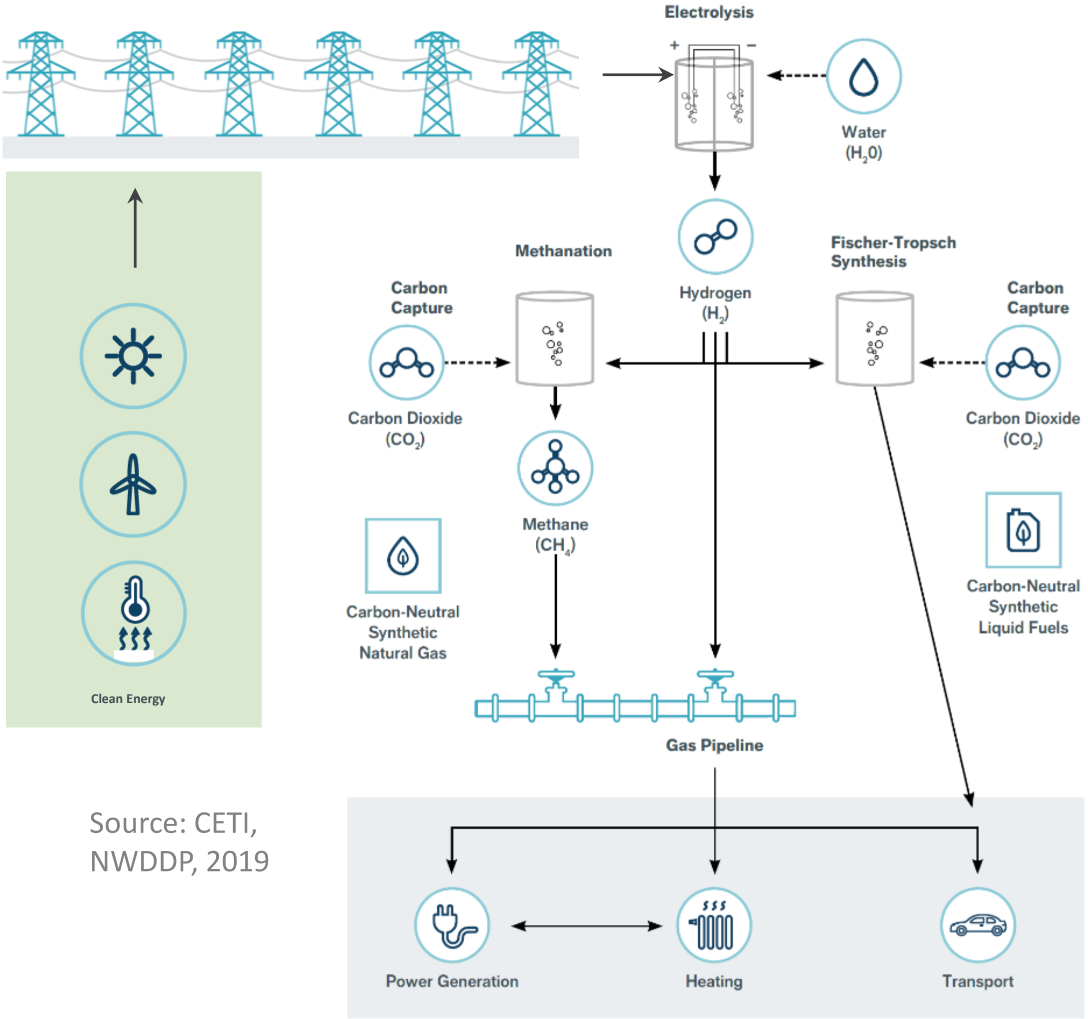


RIO Fuels Structure



Integrated Supply Side: Electricity and Fuels

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



Source: CETI, NWDDP, 2019

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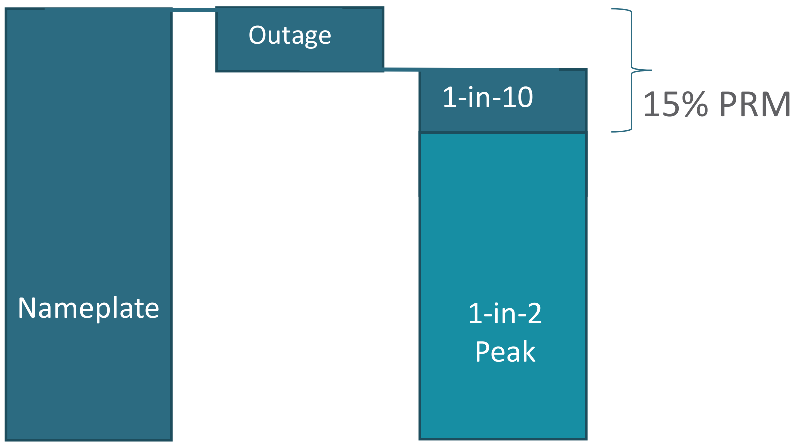
Reliability
Reliable operations in a rapidly changing electricity system

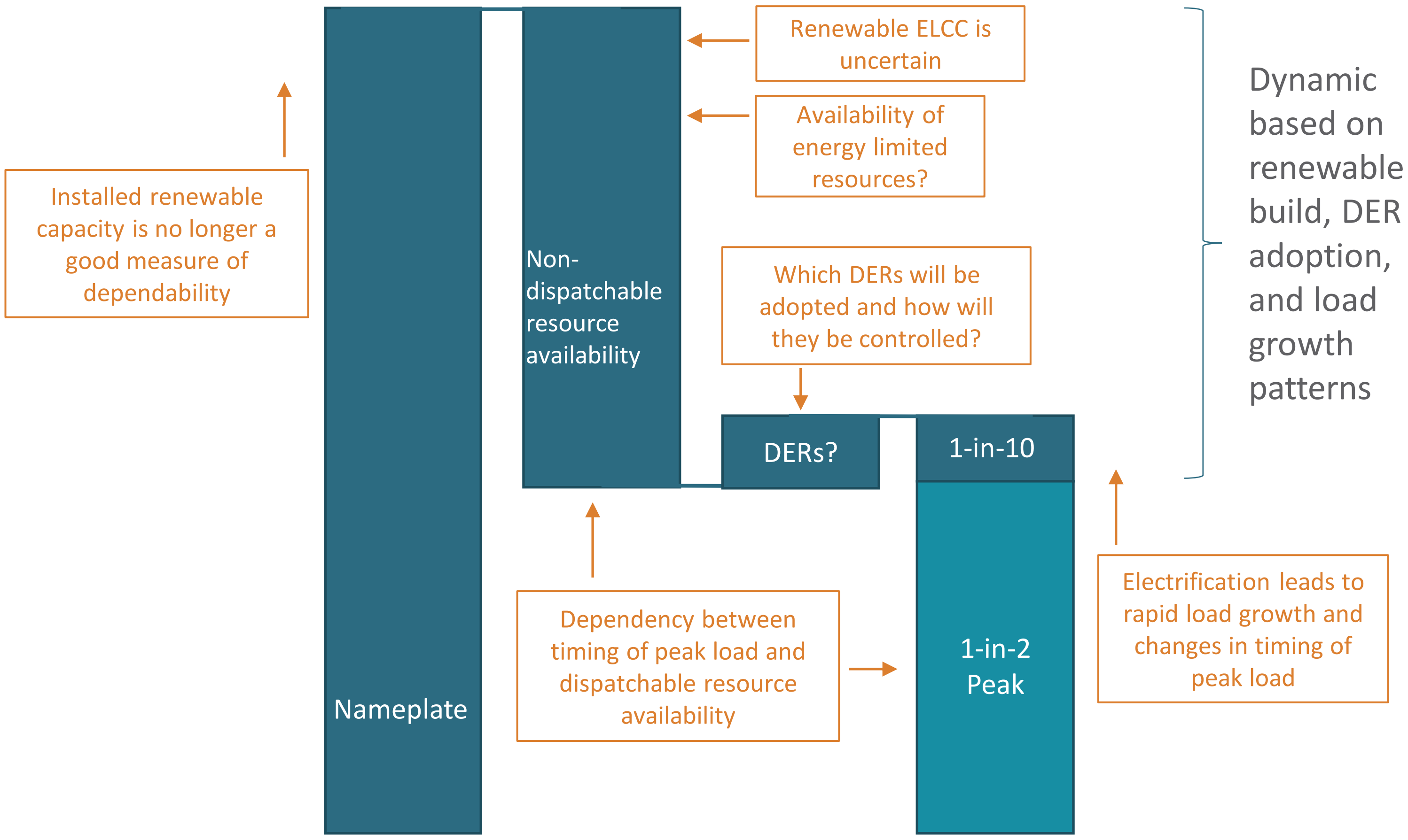
Hourly Reserve Margin Constraints by Zone

Assessing Reliability Becomes Challenging in Low-Carbon Electricity Systems

Traditional Reserve Margin



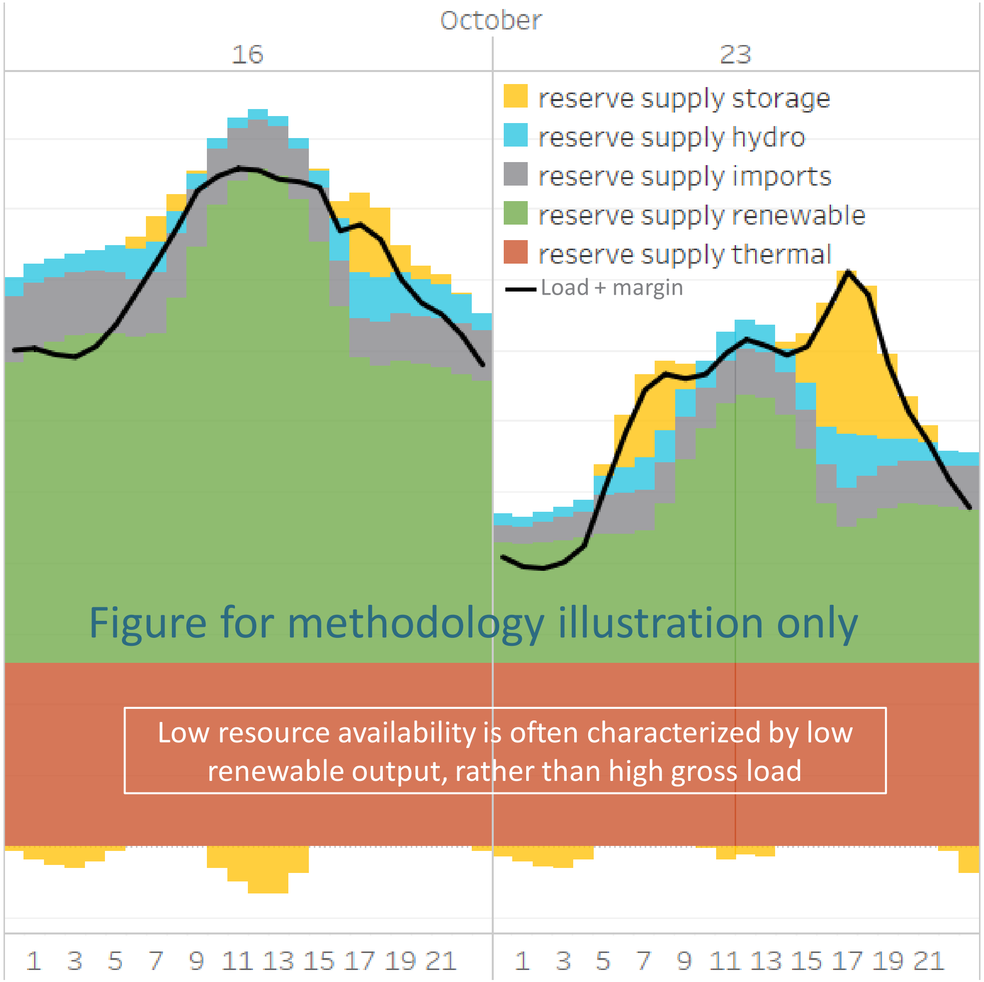
Future System Reliability Assessment



How Does RIO Approach Reliability?

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

Hourly Reliability Snapshot



Example Derates for Resources

Load/Resource	Reliability contribution	Description
Loads	106%	Represents weather related risk of load exceeding that sampled
Thermal resources	80-95%	Derated by generator forced outage rates
Renewable resources	70-90% of hourly production	Additional 10-30% derate from hourly profiles comes from weather related risk and is informed by statistical analysis of multiple weather years
Hydro	95% of hourly production	For energy limited resources, hourly production is used to ensure sustained peaking capability
Energy storage	95% of hourly production	Similar to hydro, energy storage must demonstrate reliability through dispatch
Imports/Exports	0-100% of hourly interchange	Depends on contractual arrangements and N-1 contingencies. By dispatching neighboring regions we ensure external resources will be available and still maintain reliability regionally.

Sourcing the data

Demand-subsectors

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

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

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

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

Load Shape Sources

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

Load Shape Sources, Continued

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

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

Supply-Side Data

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

Supply-Side Data Continued

Data Category	Data Description	Supply Node	Source
Technology Cost and Performance	Renewable and conventional electric technology installed cost projections	Nuclear Power Plants; Onshore Wind Power Plants; Offshore Wind Power Plants; Transmission – Sited Solar PV Power Plants; Distribution – Sited Solar PV Power Plants; Rooftop PV Solar Power Plants; Combined – Cycle Gas Turbines; Coal Power Plants; Combined – Cycle Gas Power Plants with CCS; Coal Power Plants with CCS; Gas Combustion Turbines	(National Renewable Energy Laboratory 2020)
Technology Cost and Performance	Electric fuel cost projections including electrolysis and fuel synthesis facilities	Central Hydrogen Grid Electrolysis; Power – To – Diesel; Power – To – Jet Fuel; Power – To – Gas Production Facilities	(Capros et al. 2018)
Technology Cost and Performance	Hydrogen Gas Reformation costs with and without carbon capture	H2 Natural Gas Reformation; H2 Natural Gas Reformation w/CCS	(International Energy Agency GHG Programme 2017)
Technology Cost and Performance	Nth plant Direct air capture costs for sequestration and utilization	Direct Air Capture with Sequestration; Direct Air Capture with Utilization	(Keith et al. 2018)
Technology Cost and Performance	Gasification cost and efficiency of conversion including gas upgrading.	Biomass Gasification; Biomass Gasification with CCS	(G. del Alamo et al. 2015)
Technology Cost and Performance	Cost and efficiency of renewable Fischer-Tropsch diesel production.	Renewable Diesel; Renewable Diesel with CCS	(G. del Alamo et al. 2015)
Technology Cost and Performance	Cost and efficiency of industrial boilers	Electric Boilers; Other Boilers	(Capros et al. 2018)
Technology Cost and Performance	Cost and efficiency of other, existing power plant types	Fossil Steam Turbines; Coal Power Plants	(Johnson et al. 2006)

Impact of Covid-19

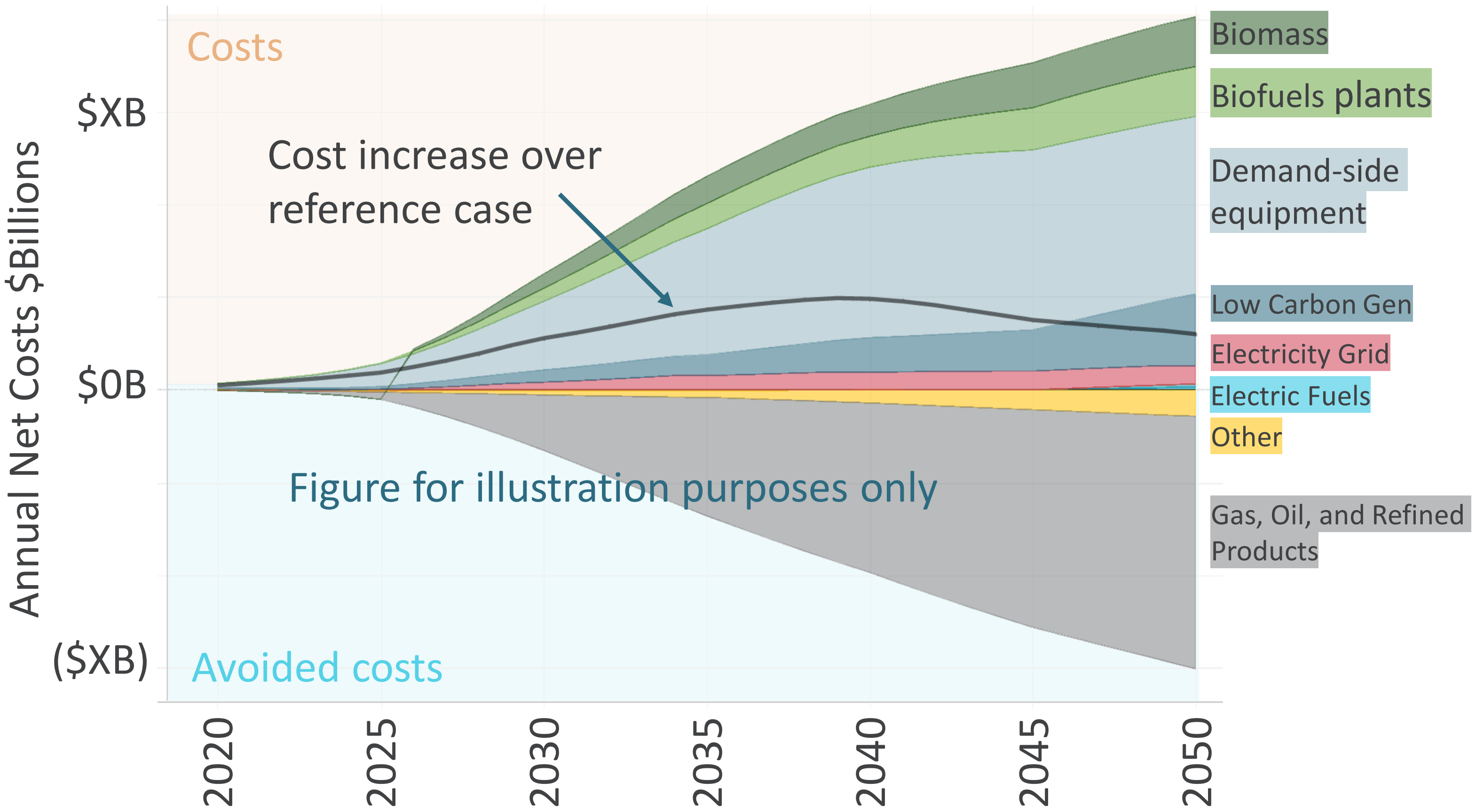
- None of the long-term forecasts include Covid impacts
- Long-term versus short-term
- Changes to near-term adoption rates of new technologies
  - Impacts on consumer spending for new appliances, vehicles etc.?
  - Accelerated action later? Delayed electrification?
  - Opportunity for economic development in post-Covid environment?
- Impact on fuel prices
  - Supply and demand imbalance

Key Results

Examples of how results are presented

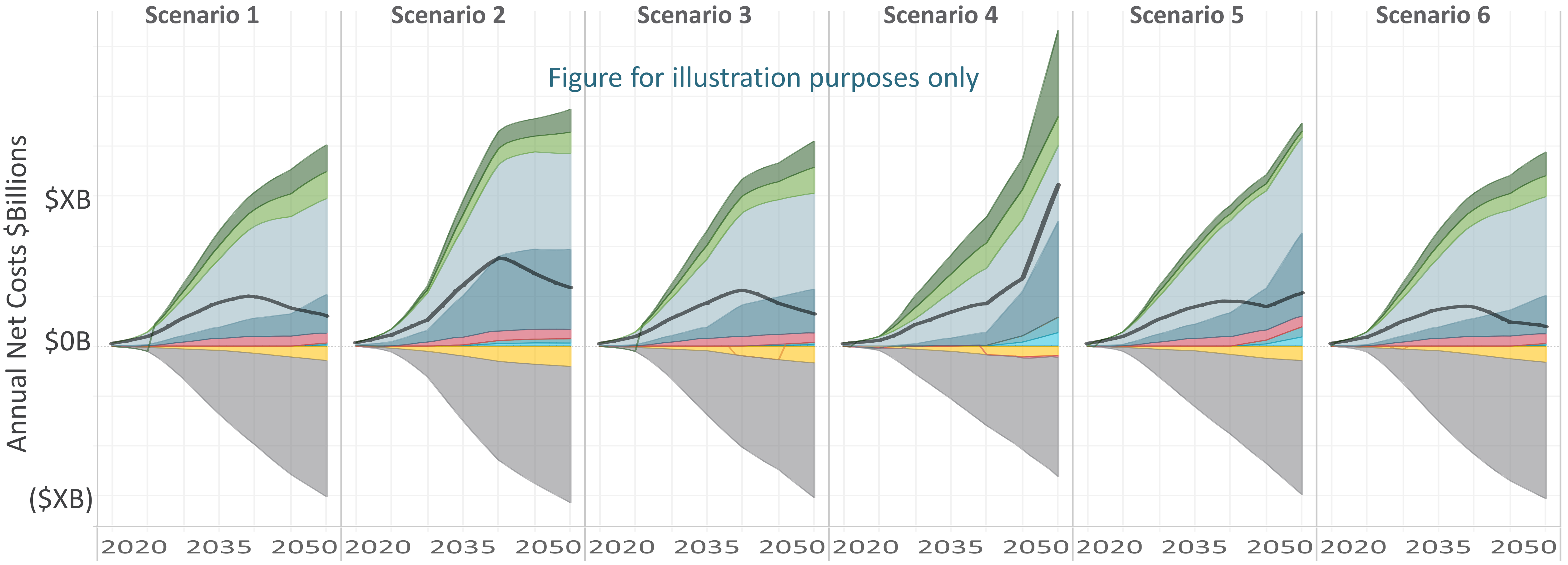
Fuels and Infrastructure Investment vs. Business and Usual

Annual Net Energy Costs: Example Clean Energy Scenario



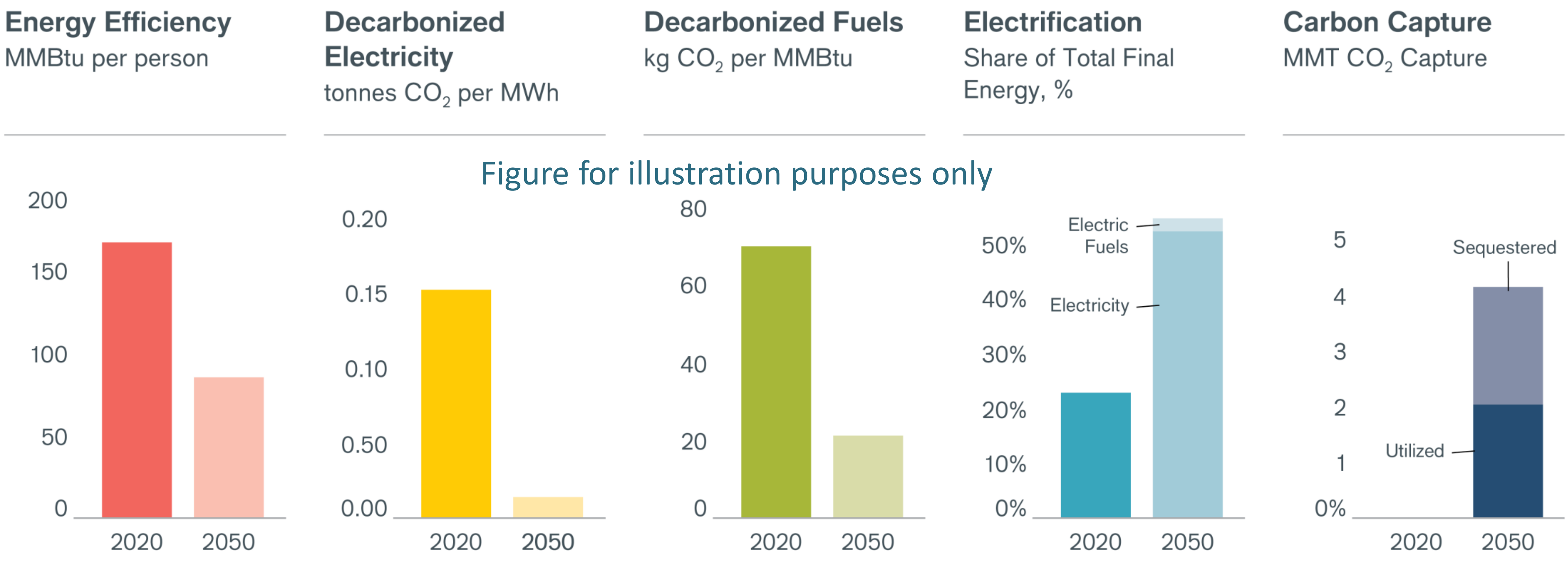
- A reference scenario is needed because business-as-usual is not zero-cost.
- Total cost to meet clean energy goals are offset by avoided BAU costs such as fossil fuels
  - Actual Montana avoided costs, not social cost of carbon
- Annual costs compare clean energy policy versus the alternative

Net Energy System Costs by Scenario



Source: Northwest Deep Decarbonization Pathways Study, June 2019, Evolved Energy Research

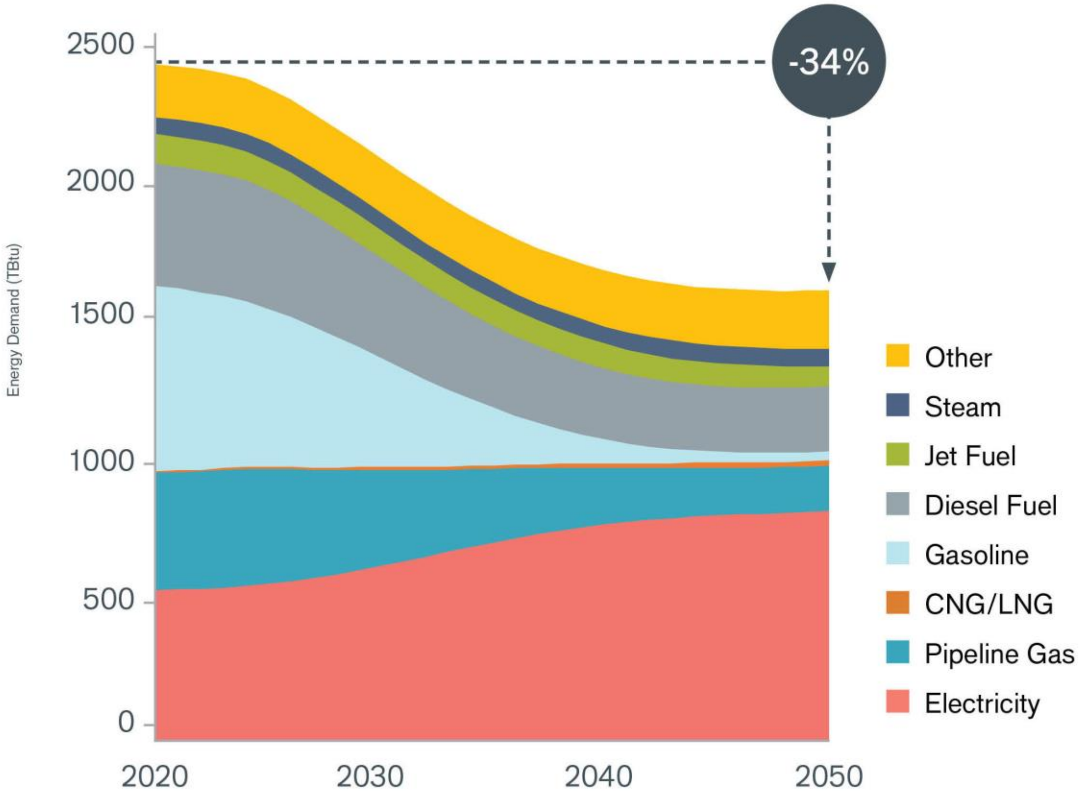
What Are the Least Cost Strategies that Policy Should Target?

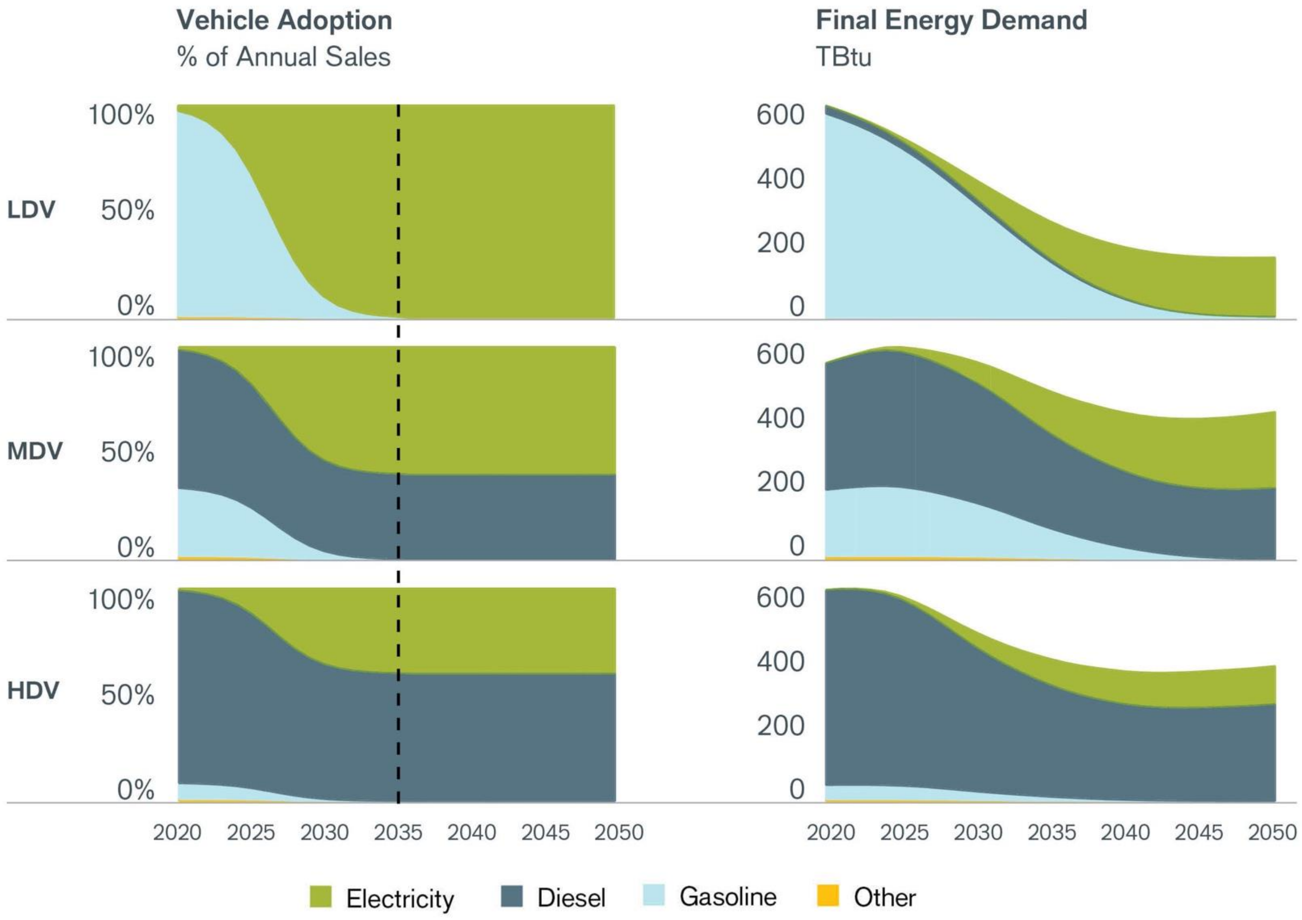


Source: Northwest Deep Decarbonization Pathways Study, June 2019, Evolved Energy Research

Final Energy Demand

Figure for illustration purposes only





Source: Northwest Deep Decarbonization Pathways Study, June 2019

Energy Supply: Electricity Generation

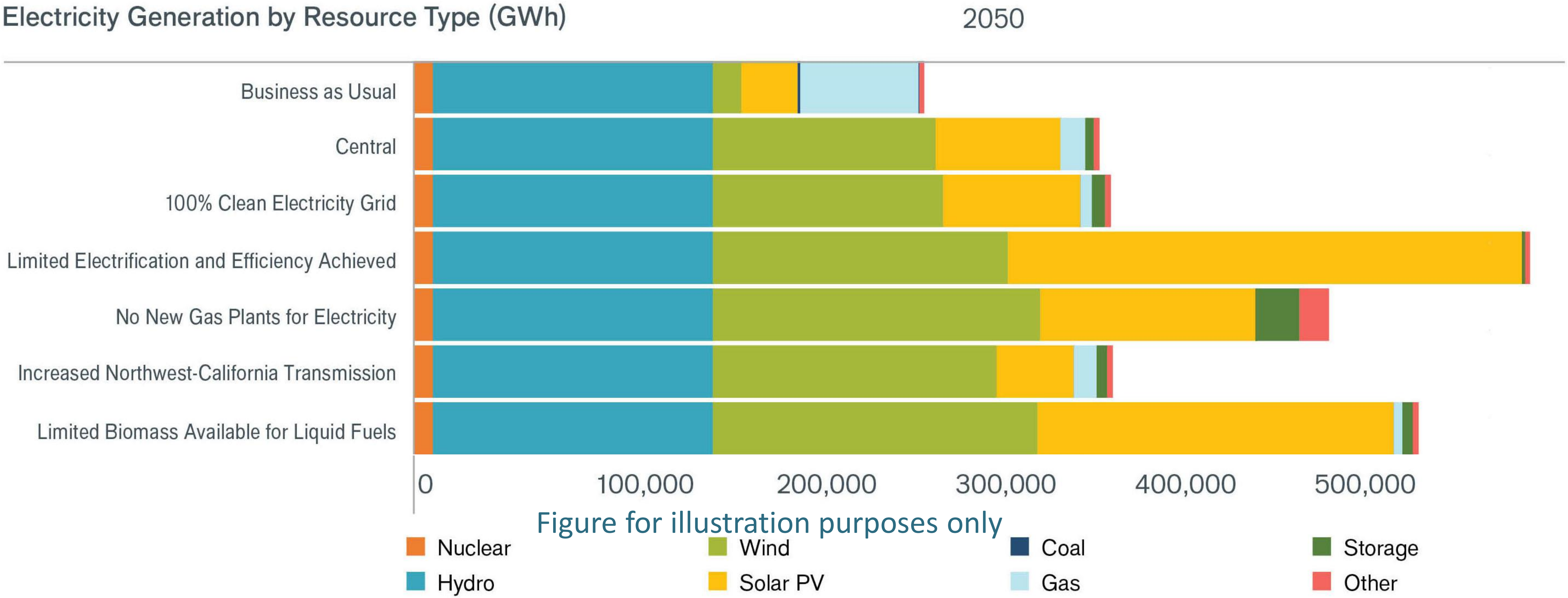


Figure for illustration purposes only

Source: Northwest Deep Decarbonization Pathways Study, June 2019

Energy Supply: Liquid and Gaseous Fuel Composition Over Time

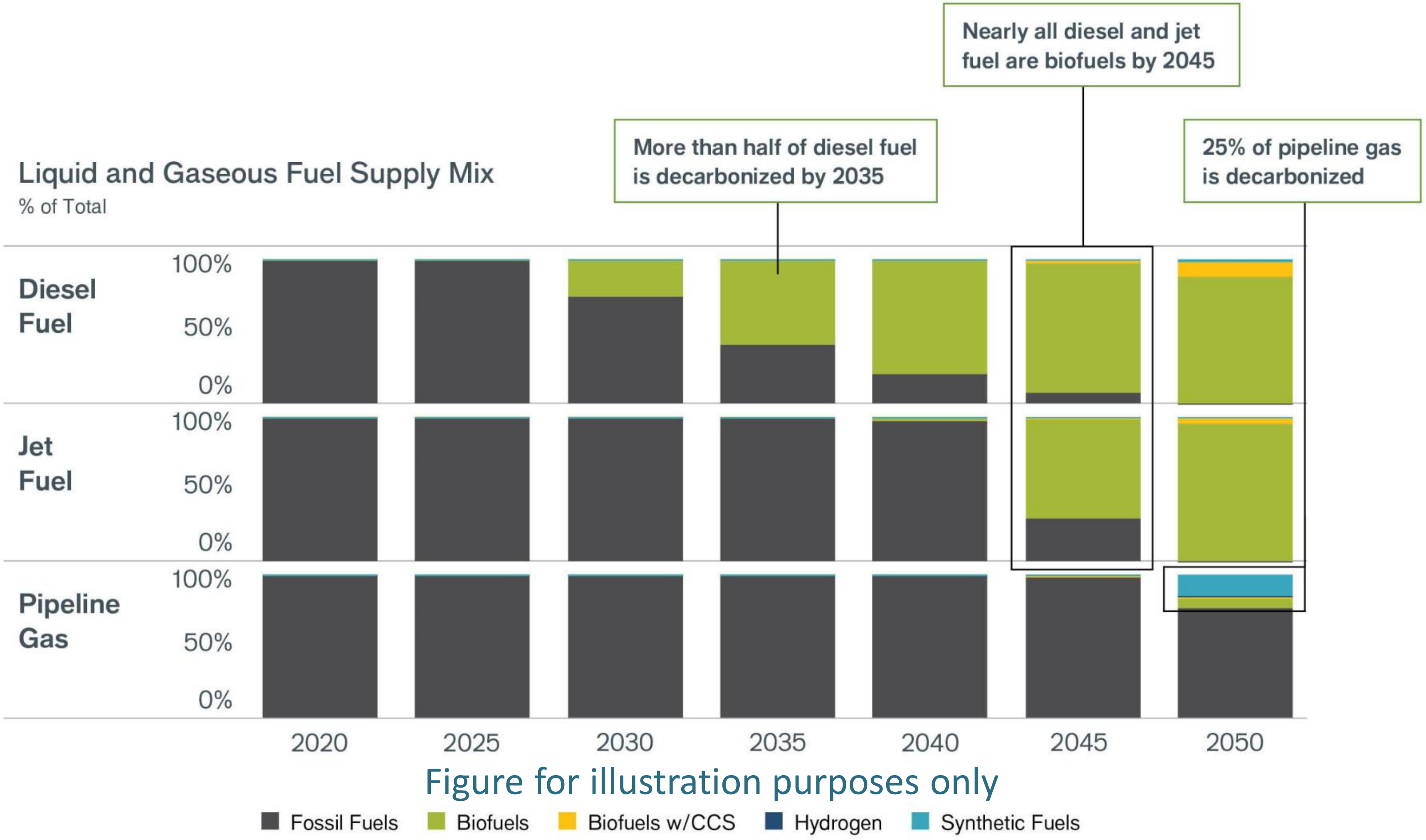


Figure for illustration purposes only

Source: Northwest Deep Decarbonization Pathways Study, June 2019

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Emissions Reductions from Liquid/Gaseous Fuels, and Electricity

Liquid, Gas, and Electricity Demand by Sector and Supply by Fuel Type

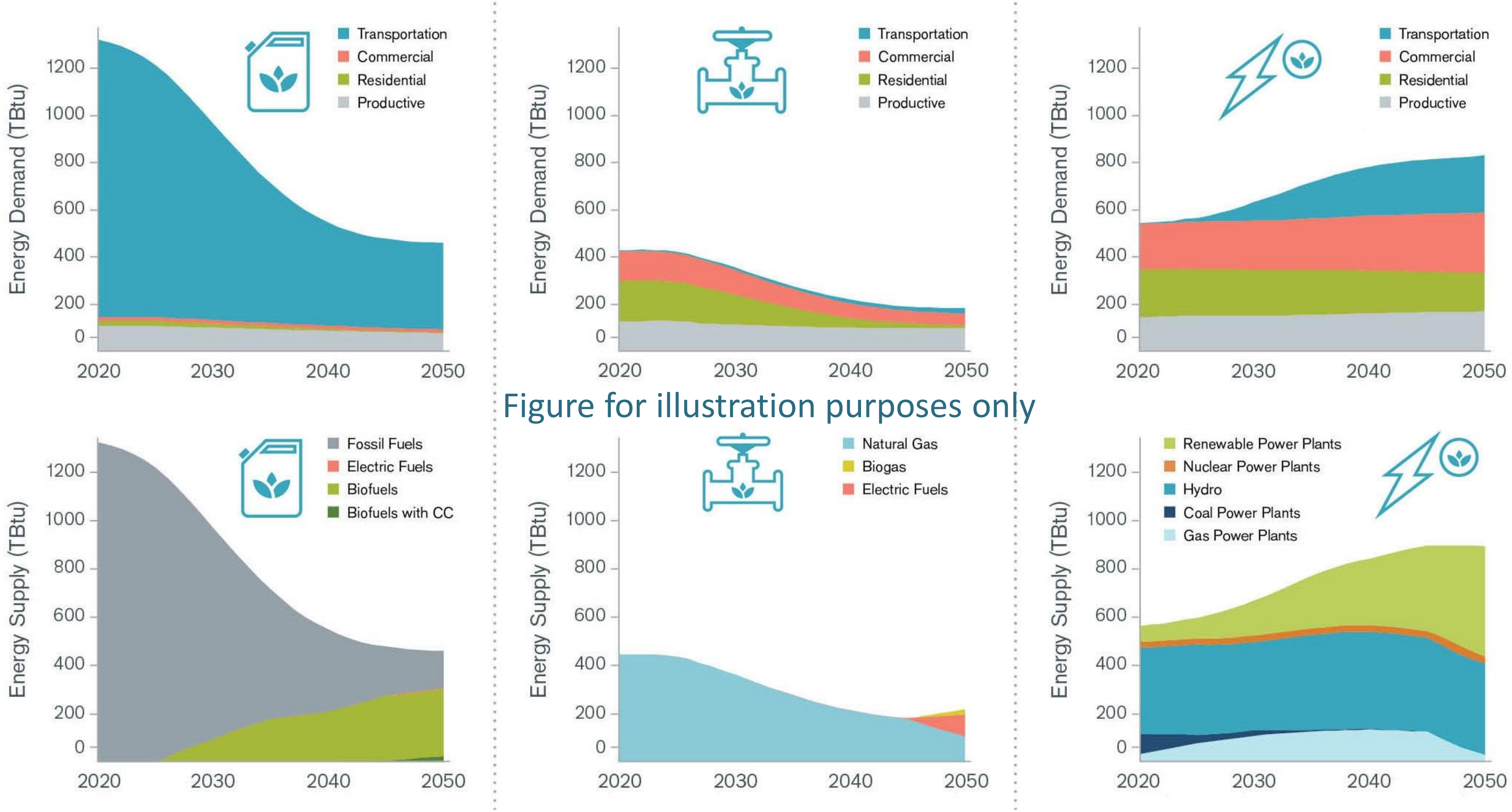
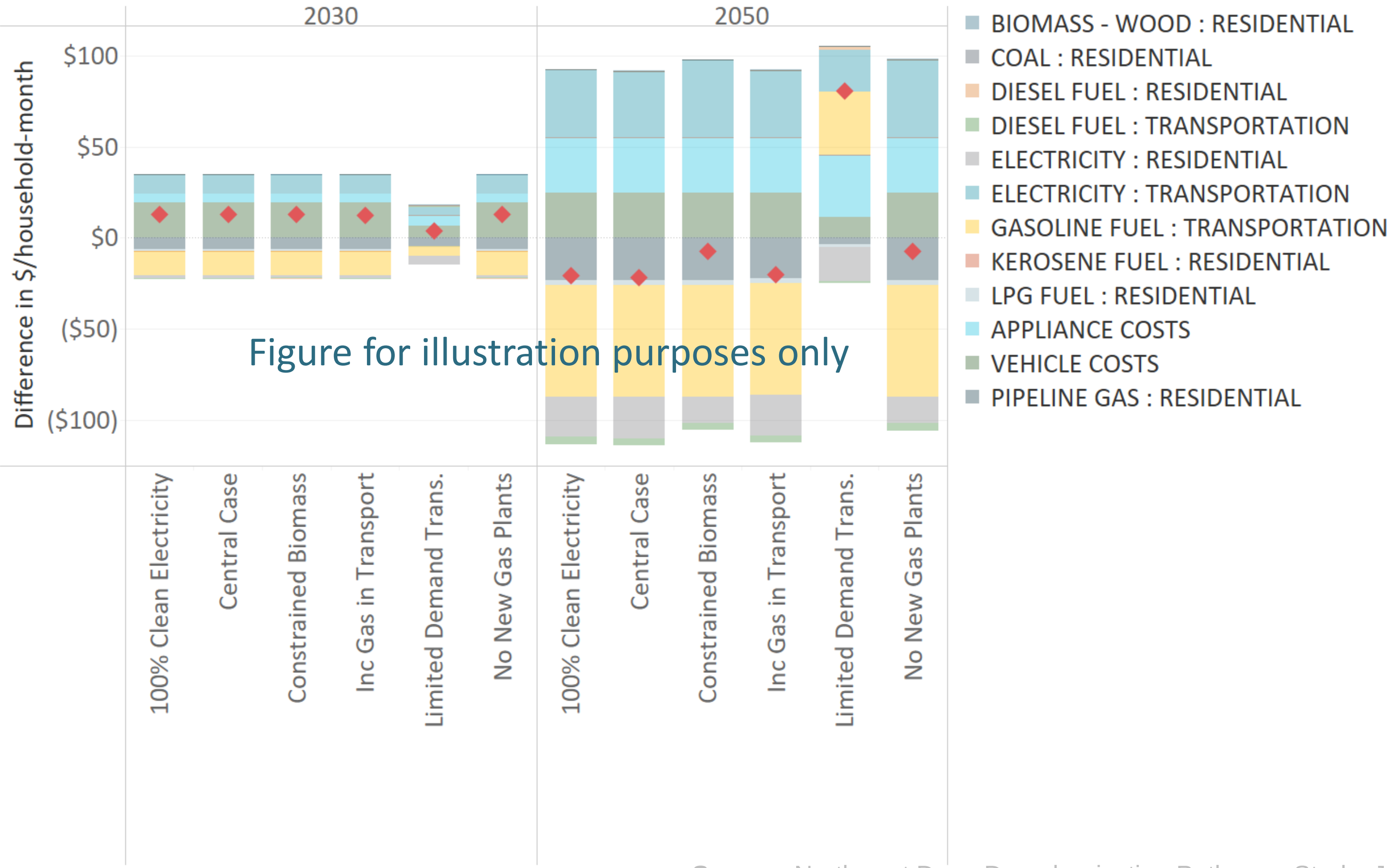


Figure for illustration purposes only

Source: Northwest Deep Decarbonization Pathways Study, June 2019, Evolved Energy Research

Cost Impacts by Sector



Source: Northwest Deep Decarbonization Pathways Study, June 2019