

Meeting the Challenge of Our Time

Pathways to a Clean Energy

Future for the Northwest

An Economy Wide Deep Decarbonization Pathways Study • 2019

Agenda Montana Governor's Climate Solutions Council

- Clean Energy Transition Institute
- Evolved Energy Research
- Deep Decarbonization Pathways
- Key Findings
- Summary of Scenarios
- Discussion



Clean Energy Transition Institute

Independent, nonpartisan Northwest research and analysis nonprofit organization with a mission to accelerate the transition to a clean energy economy. Provide information and convene stakeholders.

- Identifying deep decarbonization strategies
- Analytics, data, best practices
- Nonpartisan information clearinghouse
- Convenings to facilitate solutions

**Clean Energy
Transition Institute** 

Evolved Energy Research

Energy consulting firm addresses key energy sector challenges accelerated by changing policy goals and new technology development. Developer of planning tools to explore economy-wide decarbonization and electricity system implications

- National and sub-national deep decarbonization studies
- 2016 study for State of Washington Office of the Governor
- 2018 study for Portland General Electric



EVOLVED
ENERGY
RESEARCH

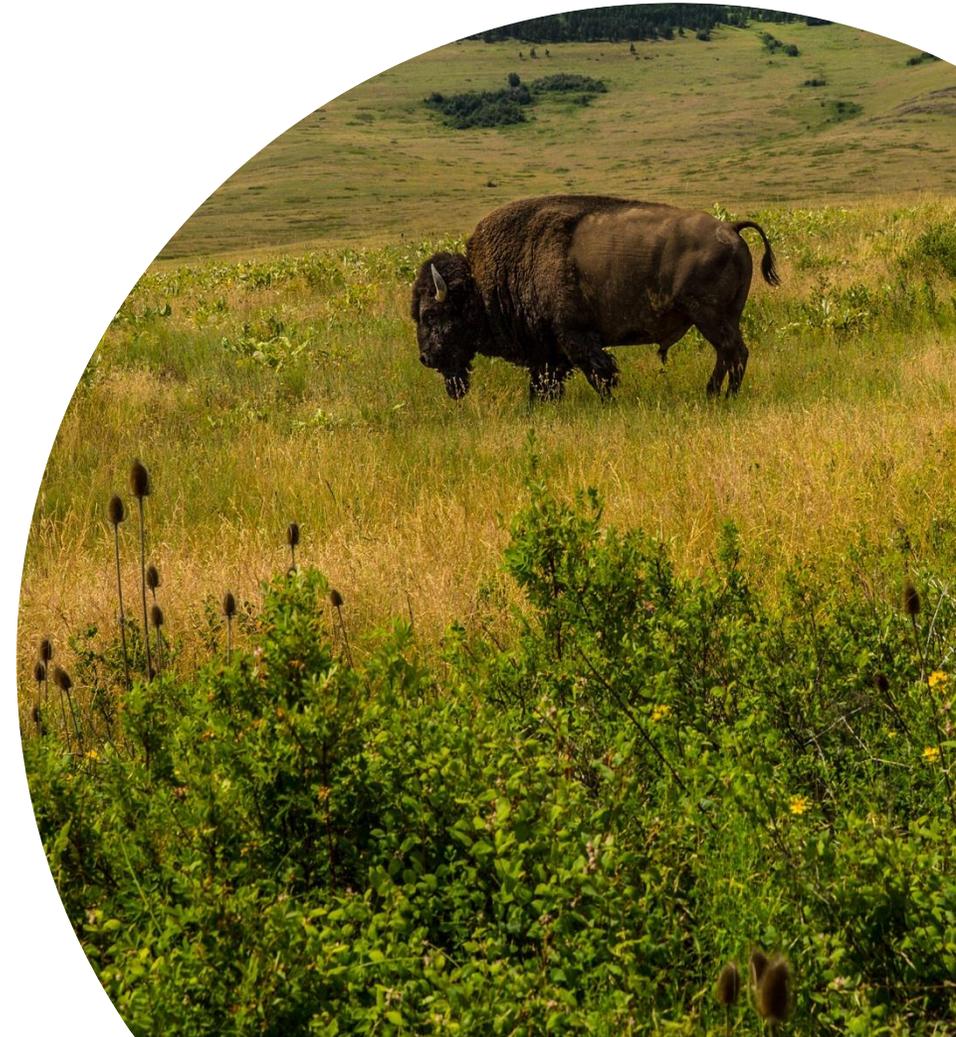
The Challenge: Meeting Science-Based Emissions Reduction Targets



Why a Northwest Deep Decarbonization Study?

Common set of assumptions to inform decisions about how the clean energy transition could unfold over the coming decades

- Unbiased, analytical baseline for the region
- Variety of pathways to lower carbon emissions
- Surface trade-offs, challenges, and practical implications of achieving mid-century targets
- Broaden conversations about actions needed



Key Study Questions Posed

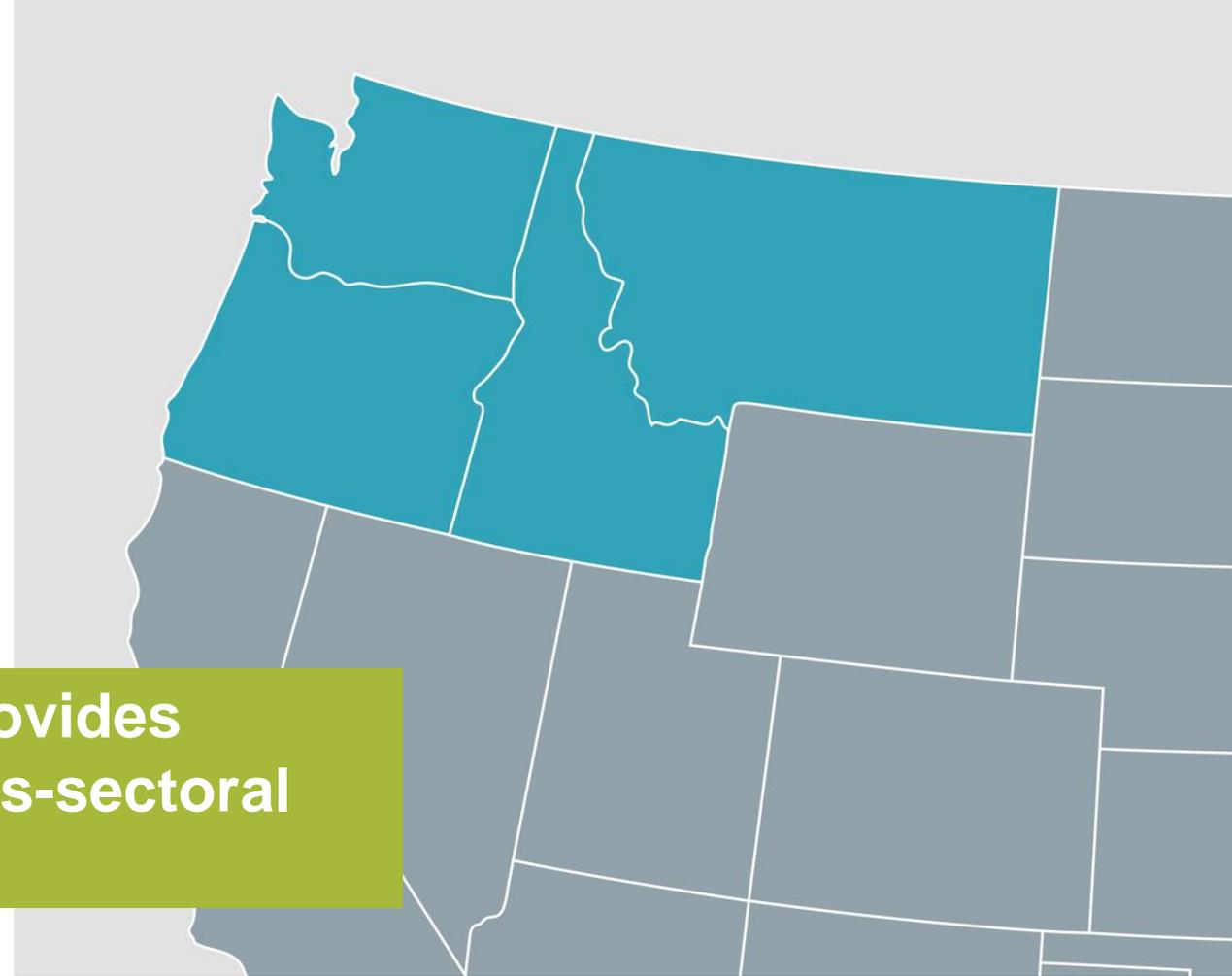
- **How does the energy sector need to transform** in the most technologically and economically efficient way?
- **How does electricity generation need to be decarbonized** to achieve economy-wide carbon reduction goals?
- **What if we can't** achieve high electrification rates?
- **What is the most cost-effective use** for biomass? What if biomass estimates are wrong?
- **What would increased electricity grid transmission** between the NW and CA yield?



Scope: Northwest Regional Energy Sector

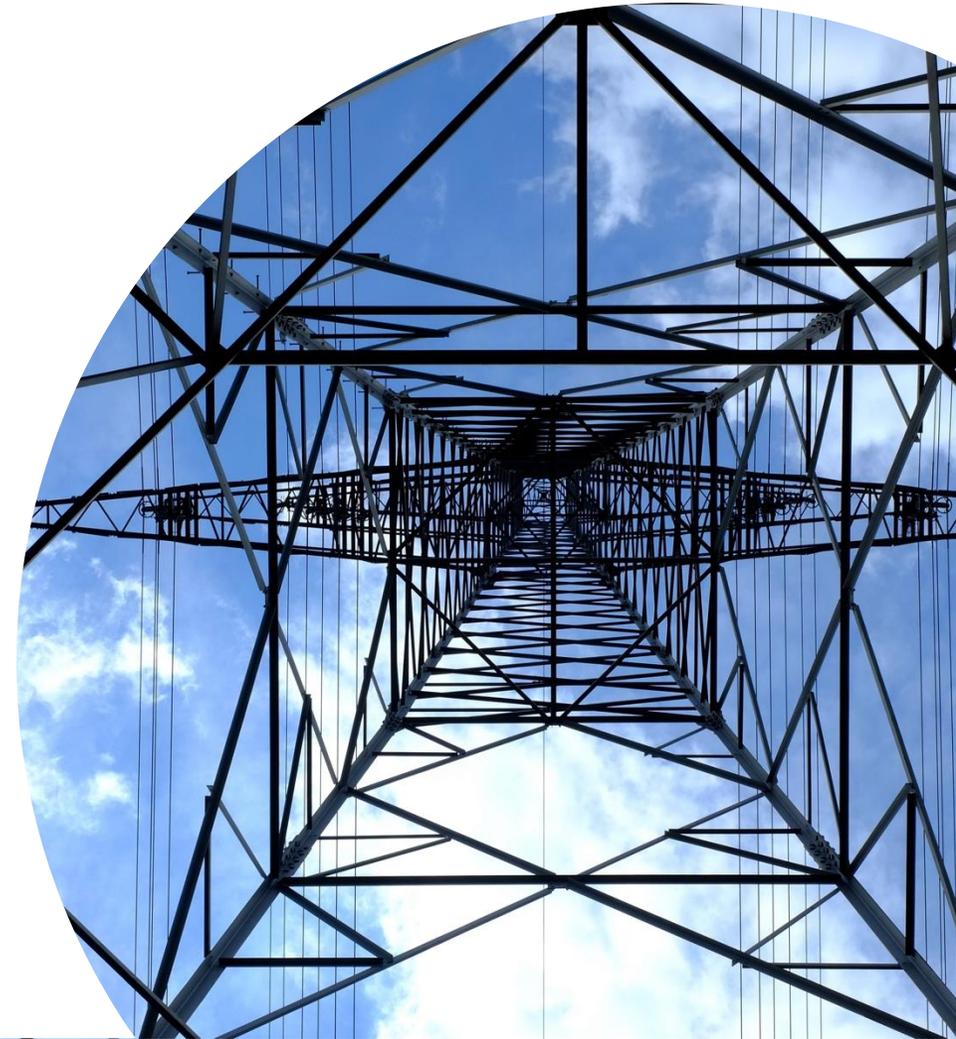
- **Scope:** WA, OR, ID, MT
- **All Energy Sectors Represented:**
 - Residential and commercial buildings
 - Industry
 - Transportation
 - Electricity generation

Evaluating holistically provides an understanding of cross-sectoral impacts and trade-offs



Approach to Decarbonizing Energy Supply

- Uses **conservative** assumptions about existing technology from public sources
- **Explores** how four NW states can achieve deep decarbonization in all energy sectors
- **Modeling determines optimal investment** in resources with least-cost
- **Decarbonizing energy supply**—electricity, pipeline gas, liquid fuels
- Accounts for **California systems** impact on the region



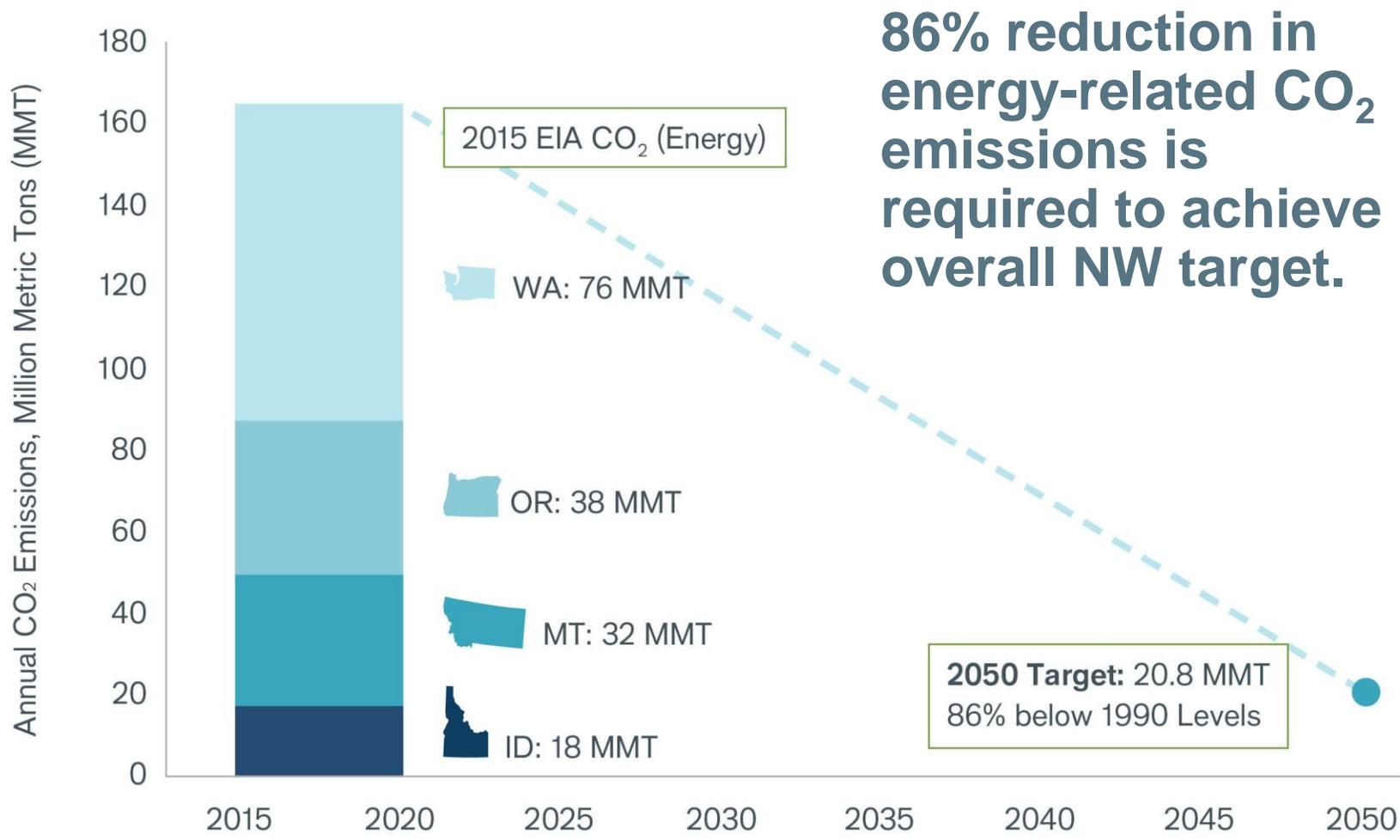
Study Emissions Target

86% reduction in energy-related CO₂ below 1990 levels by 2050

- Applied to each Northwest state independently instead of regionally
- Consistent with economy-wide reduction of 80% below 1990 levels by 2050
- Allows for reductions below 80 percent for non-energy CO₂ and non-CO₂ GHG emissions, where mitigation feasibility is less understood relative to energy



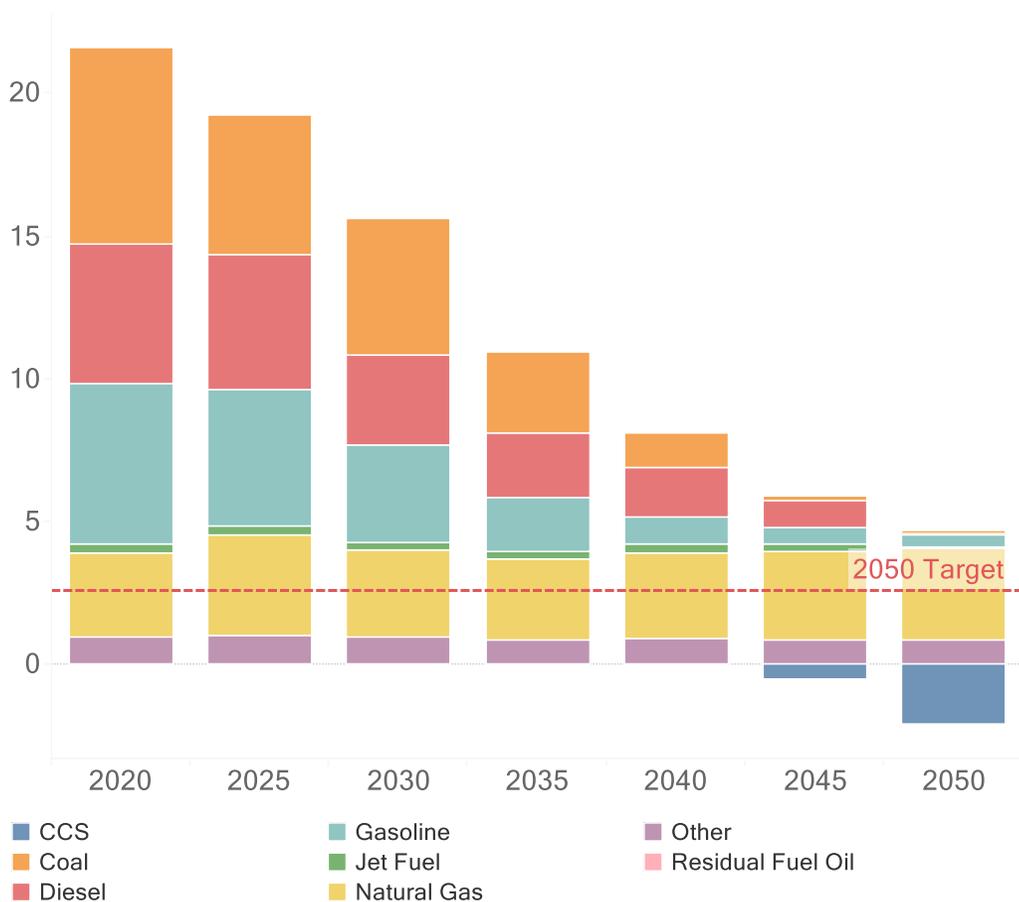
Northwest Deep Decarbonization Target



86% reduction in energy-related CO₂ emissions is required to achieve overall NW target.

Montana Emissions Reductions

Energy CO2 Emissions
MMT



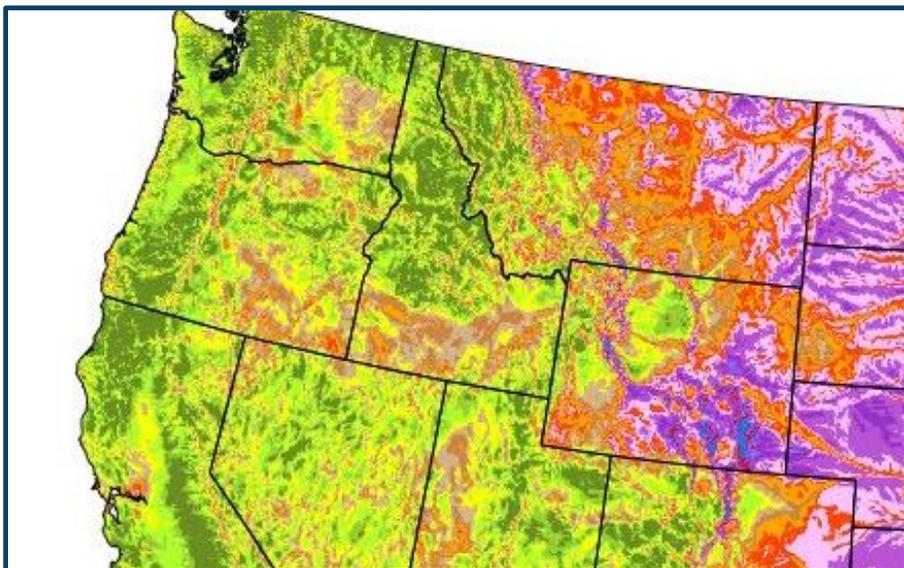
Emissions today from coal, gasoline, diesel, and natural gas

Declining emissions in Montana from:

- Decarbonizing electricity
- Electrifying vehicles
- Improving energy efficiency
- Decarbonizing fuels
- Capturing Carbon

Montana 2035 Carbon Neutrality will drive faster electricity emissions reductions

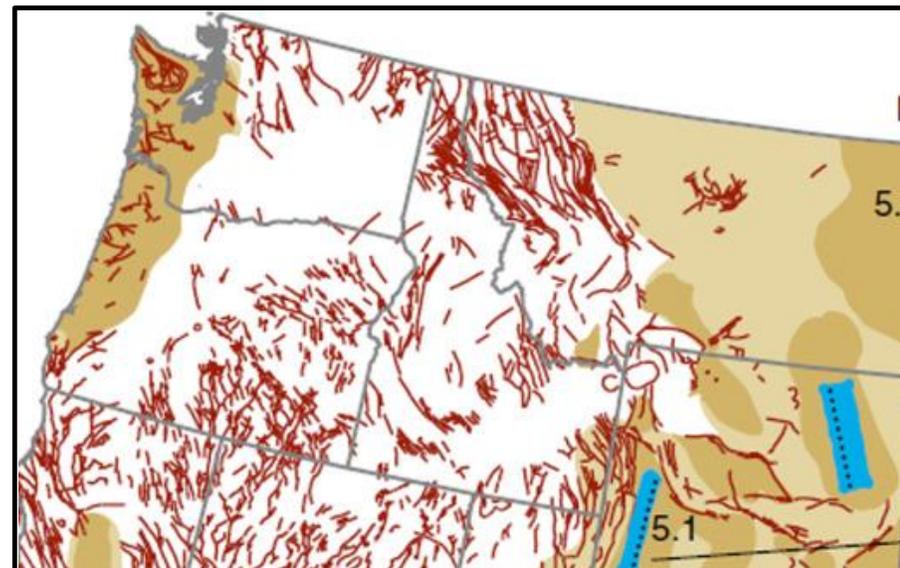
Montana's Clean Energy Assets



NREL 80m Wind Speed Map

Excellent wind resource

Complimentary to solar production in California and the South West



CO2 saline aquifer storage potential, Szulczewski et al. , 2012

Sedimentary rock and basin formations suitable for CCS

Opportunities for saline aquifer carbon sequestration



Key Findings

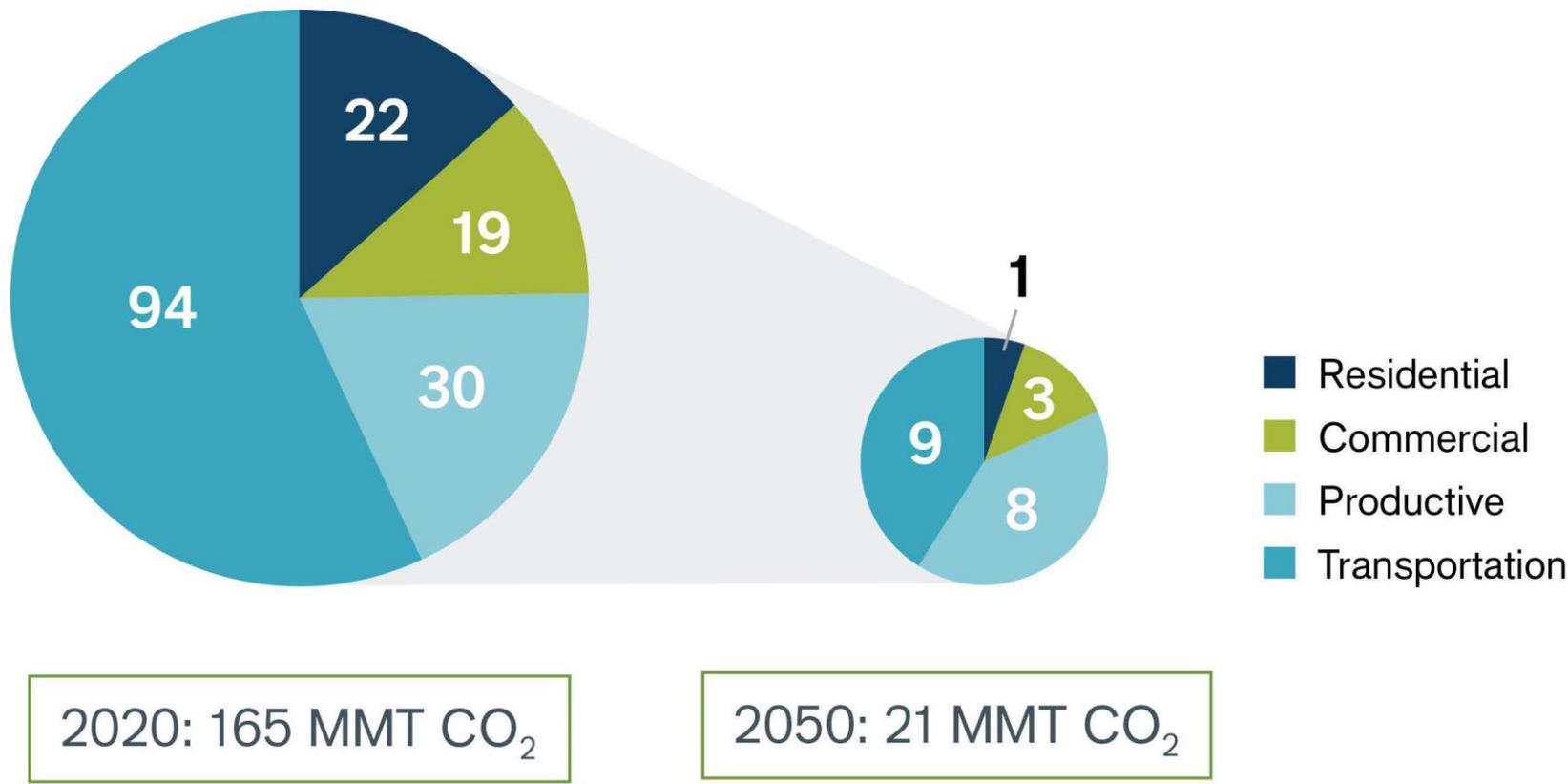
Deep Decarbonization Achievable

- **Electricity** generation must be **~96% clean**
- **A highly efficient built environment** powered by clean electricity
- **Aggressive vehicle electrification** powered largely by clean electricity
- **Thermal generation (natural gas) important for reliability** but operates at low capacity factor in 2050
- **Significant cost savings** if the Northwest and California **grids are better integrated**
- **Biomass** allocated to replace jet and diesel fuel
- **Electric fuels** and **emerging technologies** play an important role

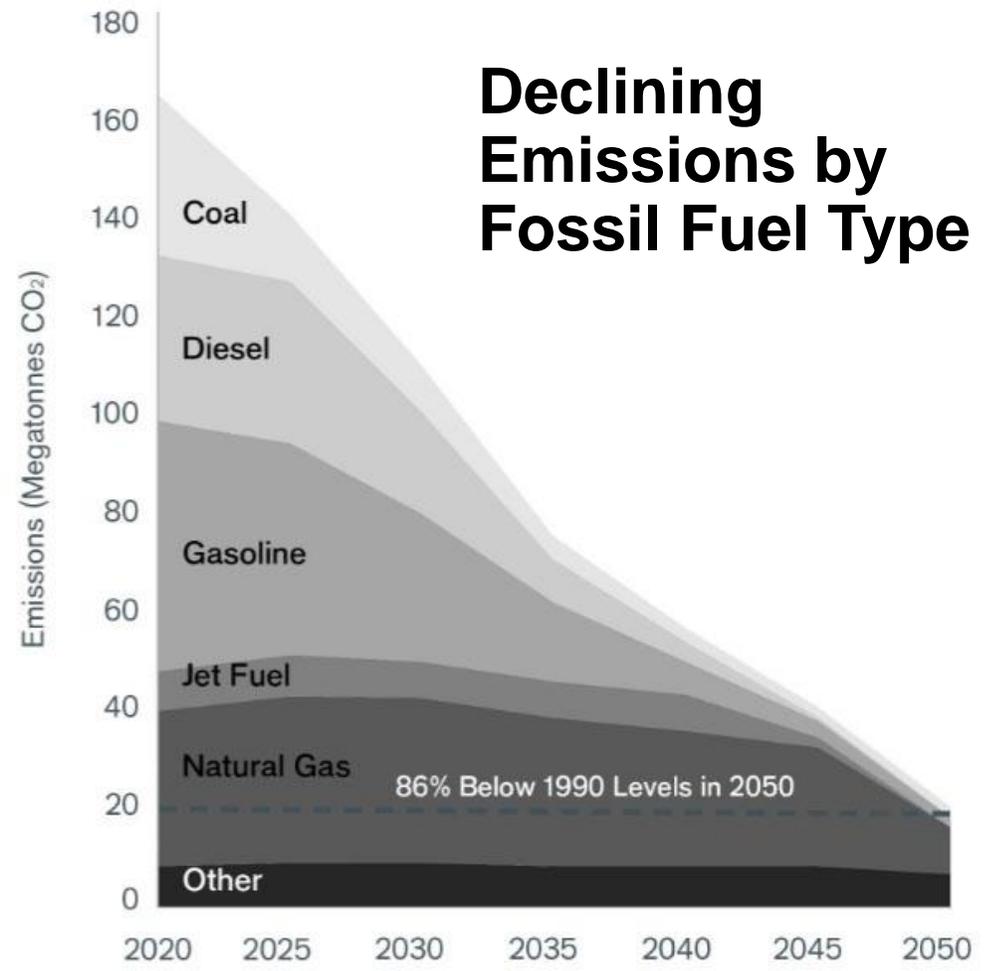
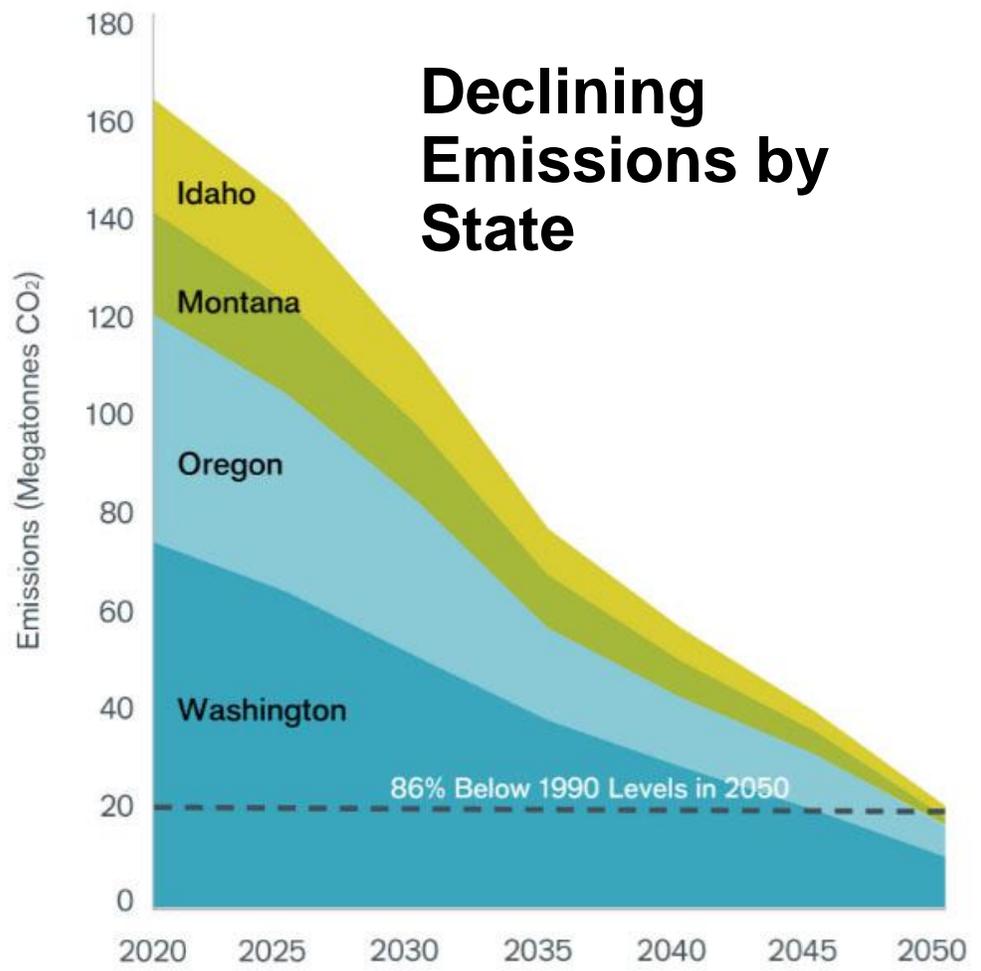


NW CO₂ Emissions Decrease by Sector

All sectors contribute to reduction in Northwest CO₂ emissions, with decreases ranging from 95 to 73%.



CO₂ Emissions Decrease by State & Fossil Fuel Type



Modeling Approach

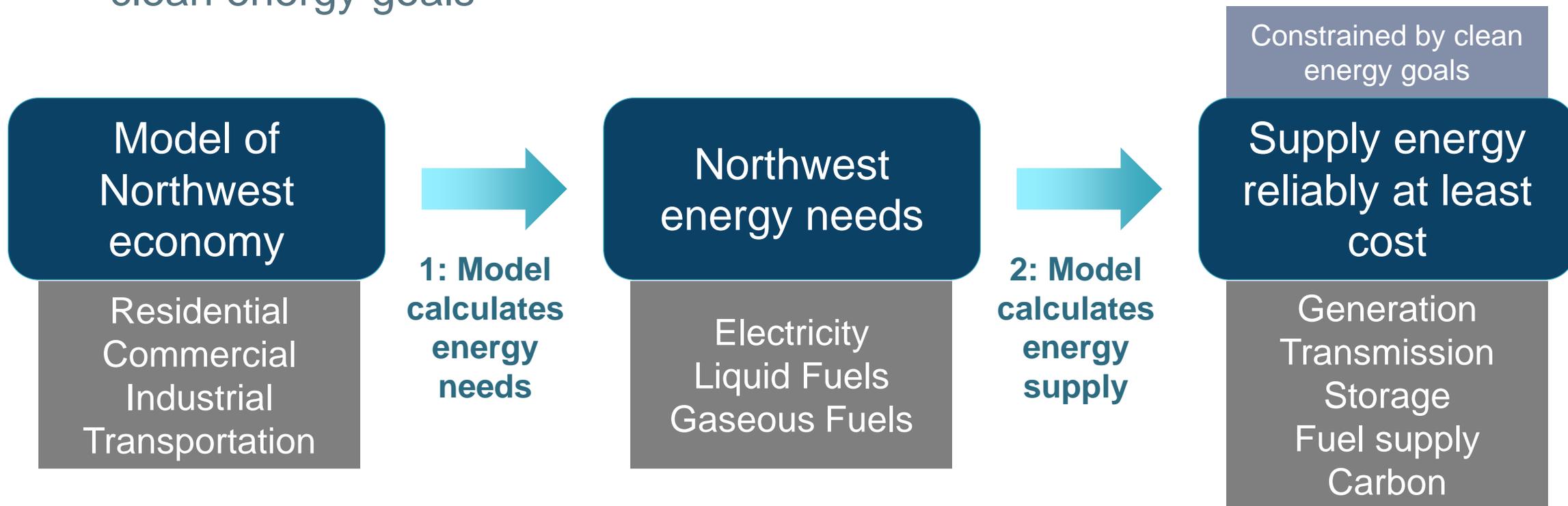
Proven Tool: Energy System Scenario Analysis Evolution

- ▶ Track record includes many regional, US wide, and international decarbonization studies
- ▶ Proven toolkit for clean energy policy analysis and energy system planning



High-Level Description of Modeling Approach

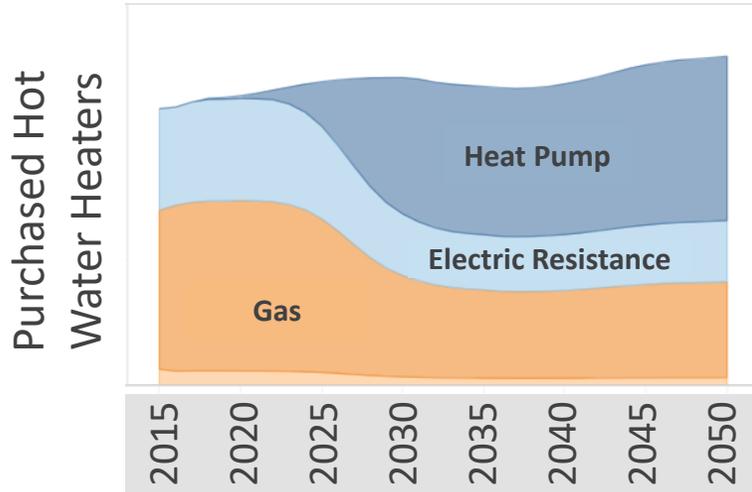
- Model calculates the energy needed to power the Northwest economy, and the least-cost way to provide that energy under clean energy goals



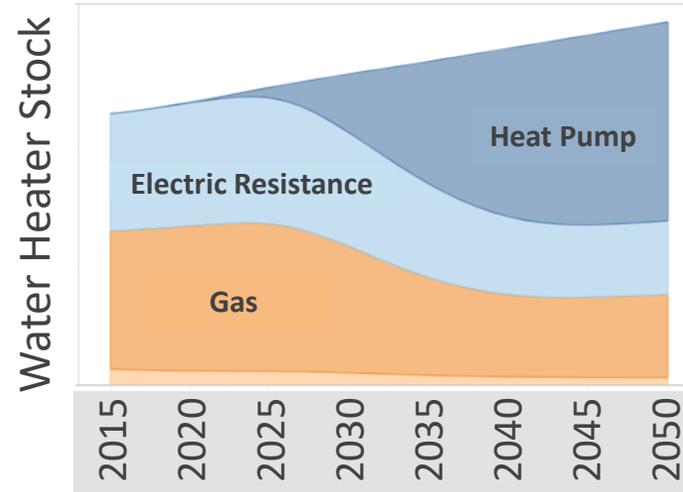
1. Energy Demand: Assumes Population Growth, Economic Growth, and New Technologies Adoption

Example: Residential Water Heaters

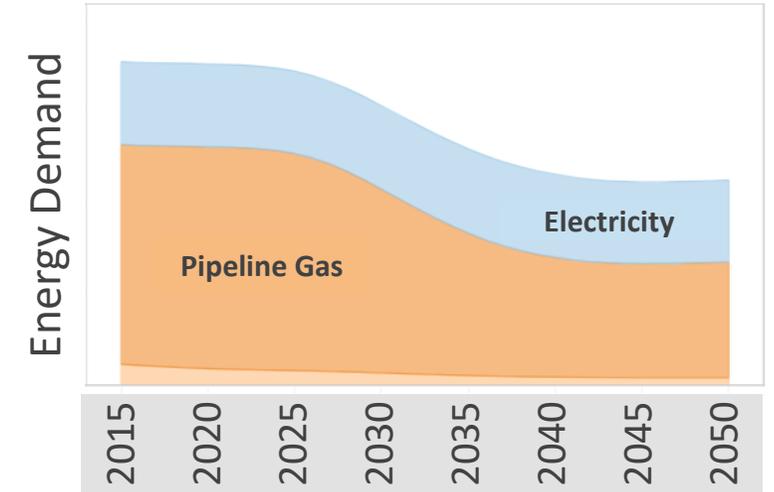
Sales shares: how many water heaters of each type are purchased each year



Model calculates the changing stock of hot water heaters by year



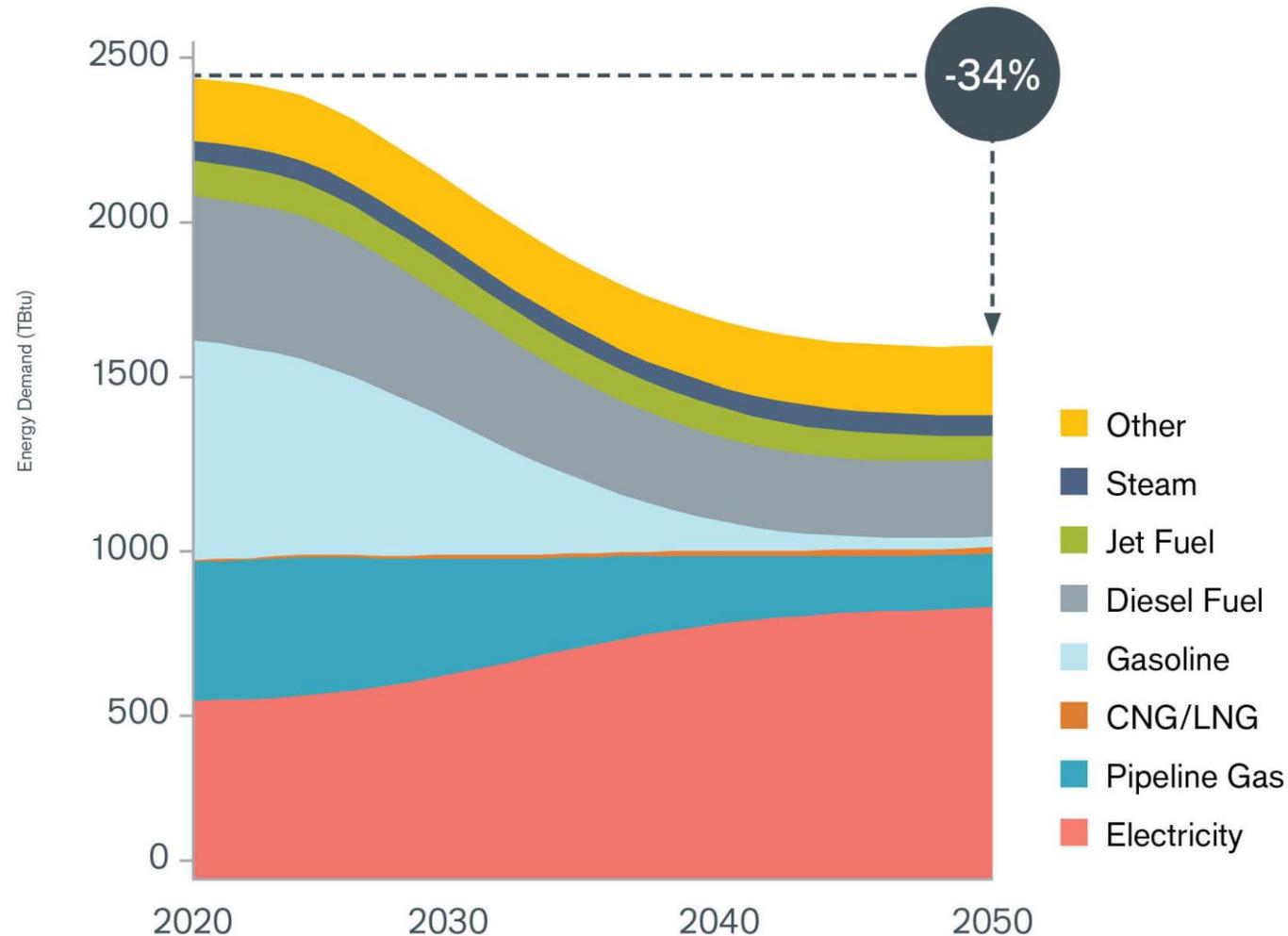
Model calculates the gas and electricity required for water heaters



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

2. Aggregate Energy Demand by Fuel Type across Economy

- Combining energy demand from stock rollover logic provides final energy demand by fuel type in each year
- Final energy demand is an input to the supply side model
 - How to meet these demands at least cost?



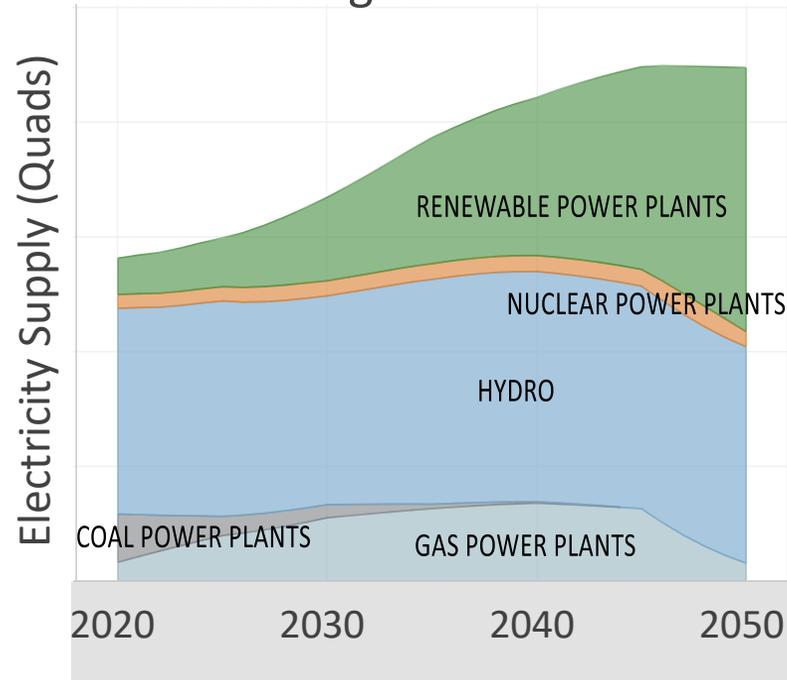
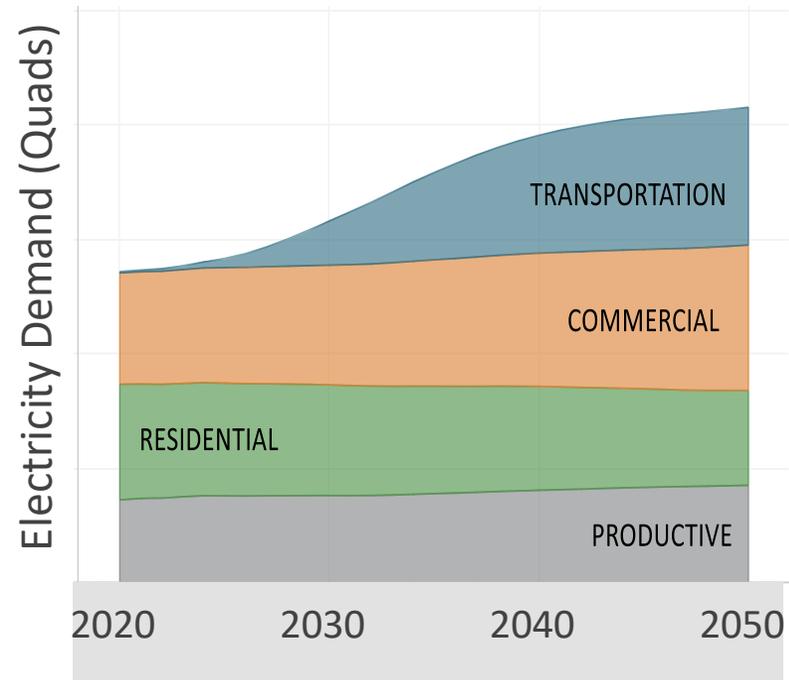
3. Model Optimizes Energy Infrastructure Investments for Northwest Energy Demands and Emissions Constraints

Example: Electricity

Electricity includes all economic sectors



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

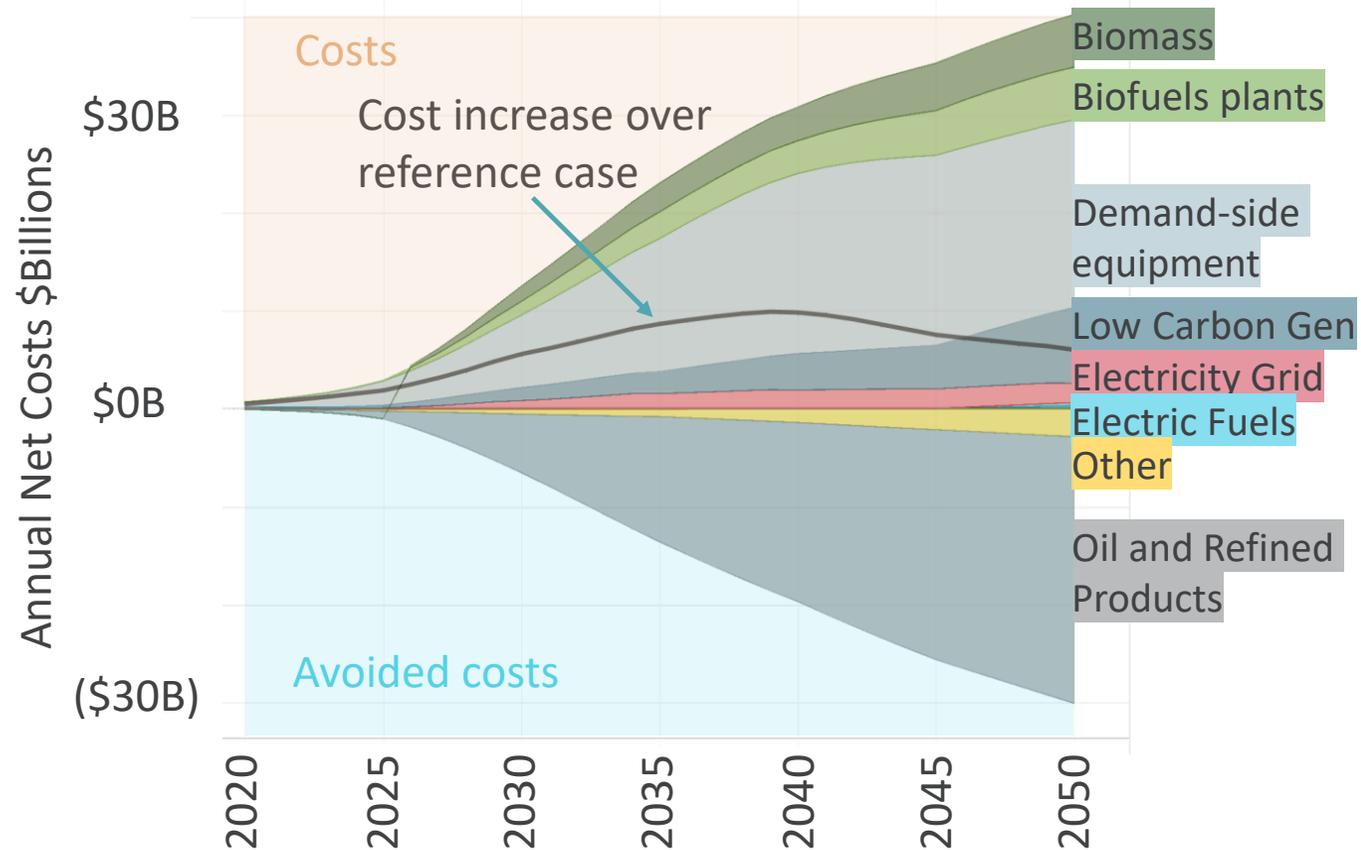


- **Reliability:** Model requires supply is met during rare, severe weather events, while maintaining reserve margin
- Fuel and electricity supply are optimized together
- Model uses best available public data

Outputs: Least-Cost Fuels and Infrastructure Investments that Reliably Meet Demand and Emission Goals

- Costs compared to business-as usual (BAU)
- The reference (BAU) 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 avoided costs, not social cost of carbon
- Annual costs compare clean energy policy versus the alternative

Annual Net Energy Costs: Central Case



Pathway Scenarios Examined



Business as Usual



Central Case



100% Clean Electricity Grid



Limited Electrification & Efficiency



No New Gas Plants for Electricity



Increased NW-CA Transmission

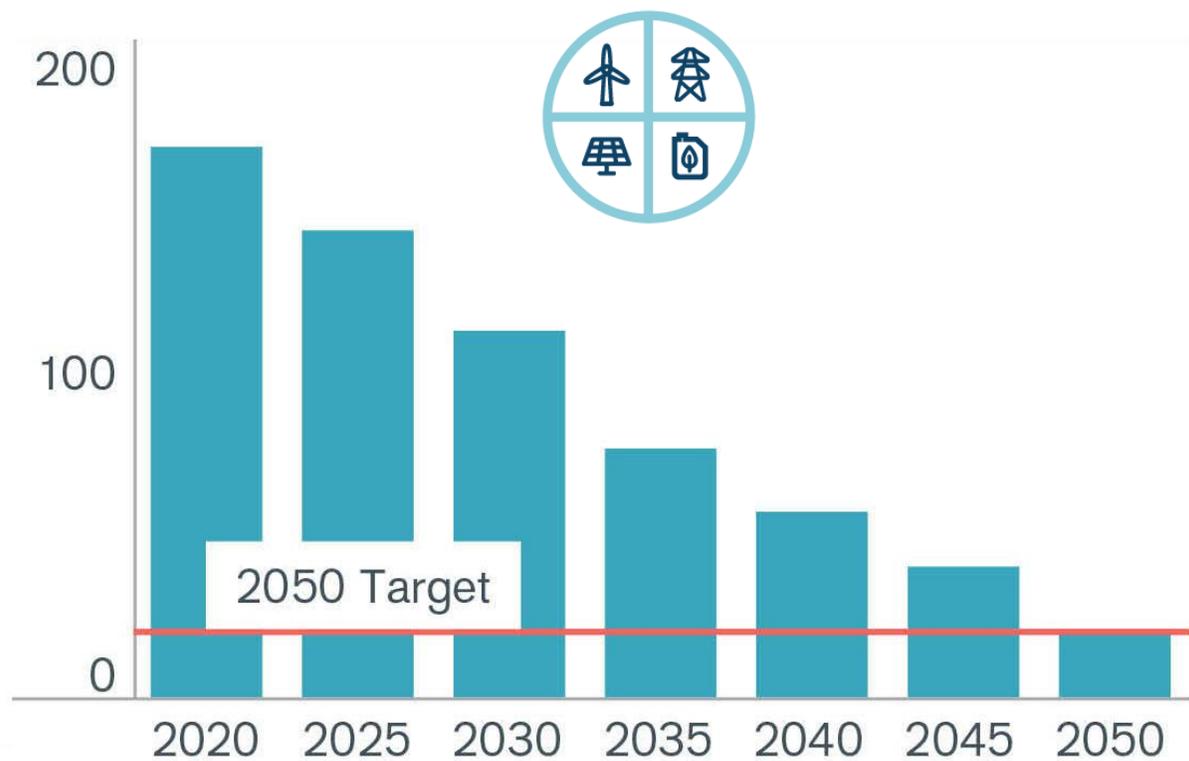
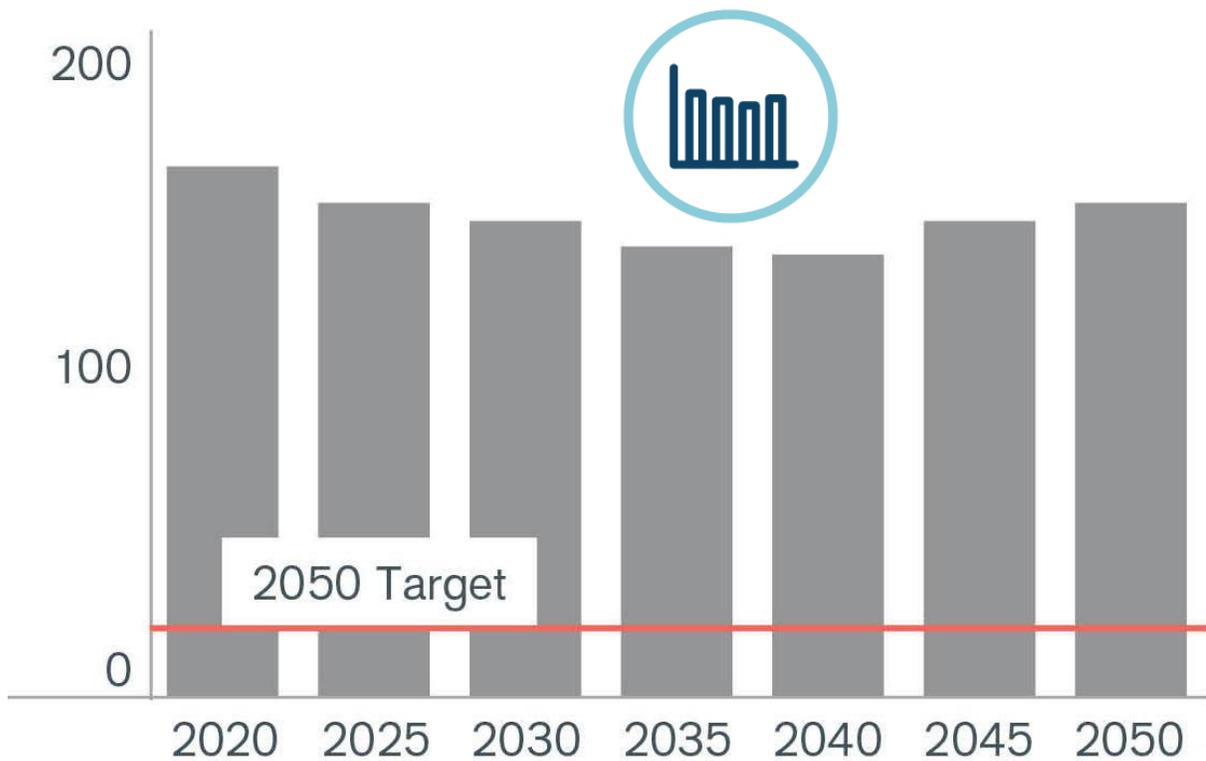


Limited Biomass for Liquid Fuels

Overview of Central Case

Business as Usual vs. Central Case

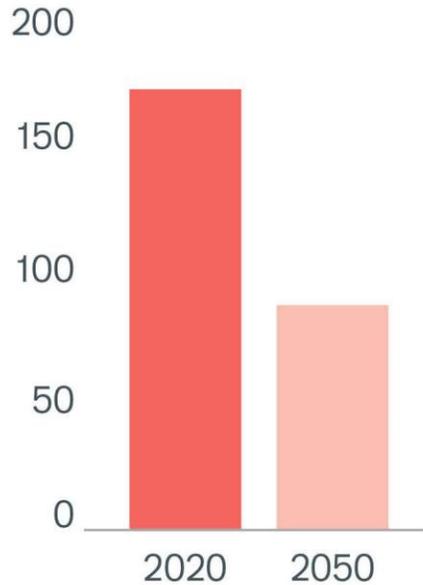
In the Business as Usual Case emissions trajectory falls far short of the 2050 reduction goal, while the Central Case meets the mid-century energy CO₂ emission target of 86% below 1990 levels.



Five Decarbonization Strategies Deployed

Efficiency

Per capita decreases 50%



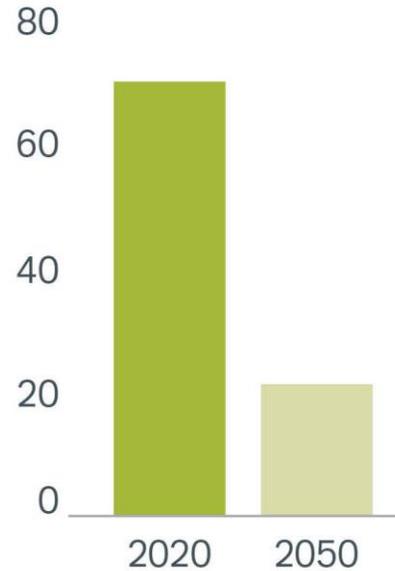
Clean Electricity

96% Clean by 2050



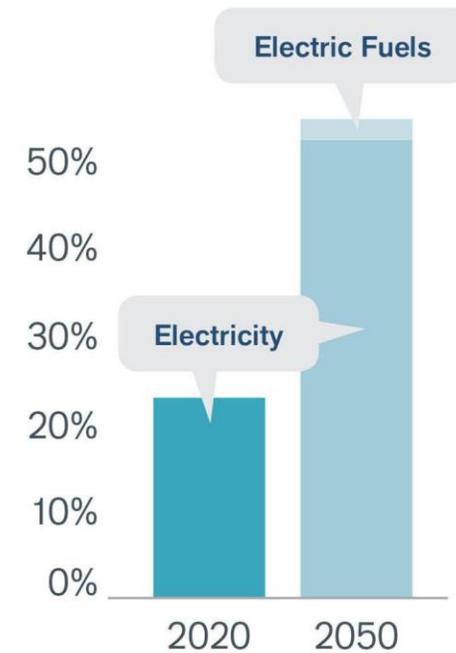
Clean Fuels

70% decrease



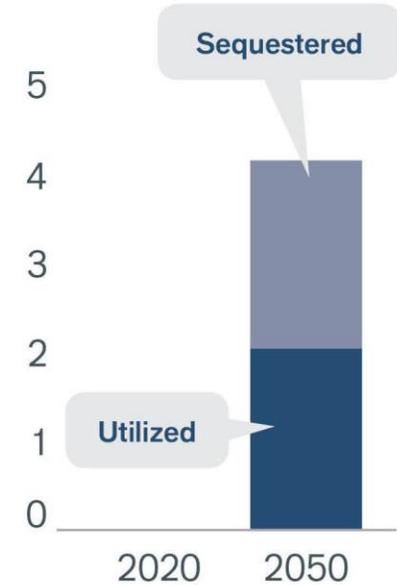
Electrification

Doubles from 23% to 55%



Carbon Capture

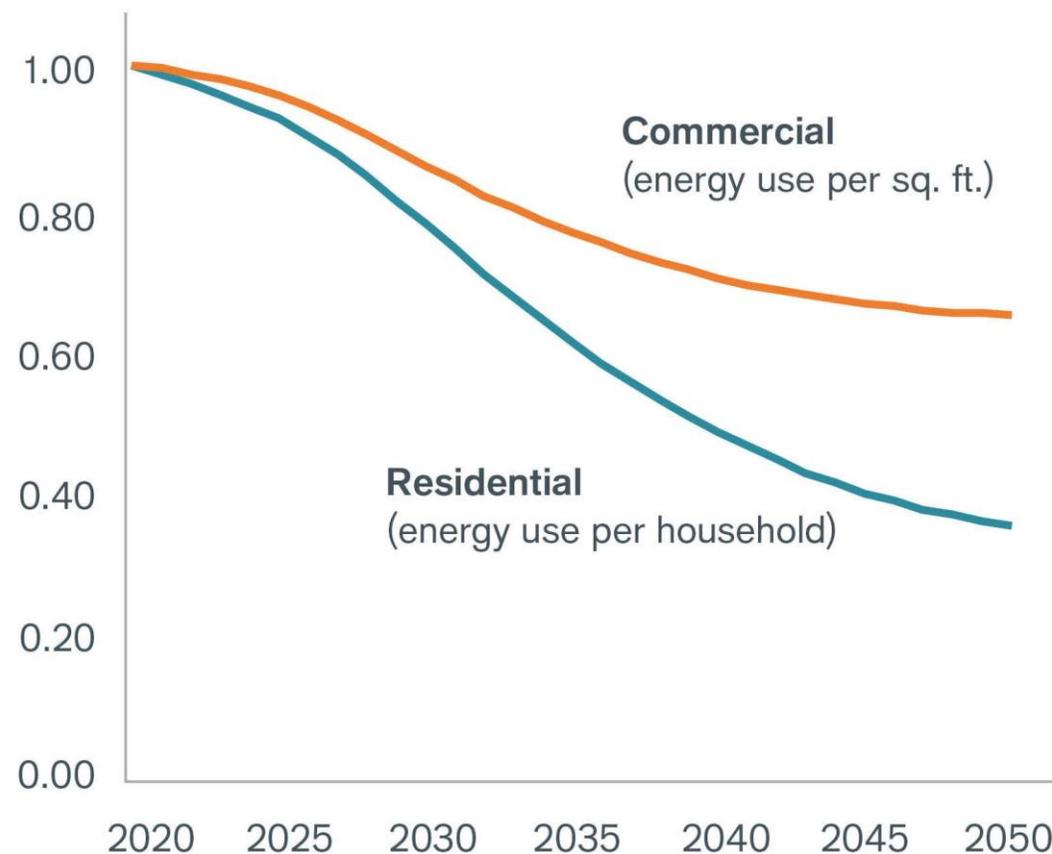
1/2 fuel; 1/2 sequestered



Buildings: Deep Efficiency & Electrification

- ▶ Building energy intensity declines by 30% for commercial and 60% for residential sector from 2020 to 2050.

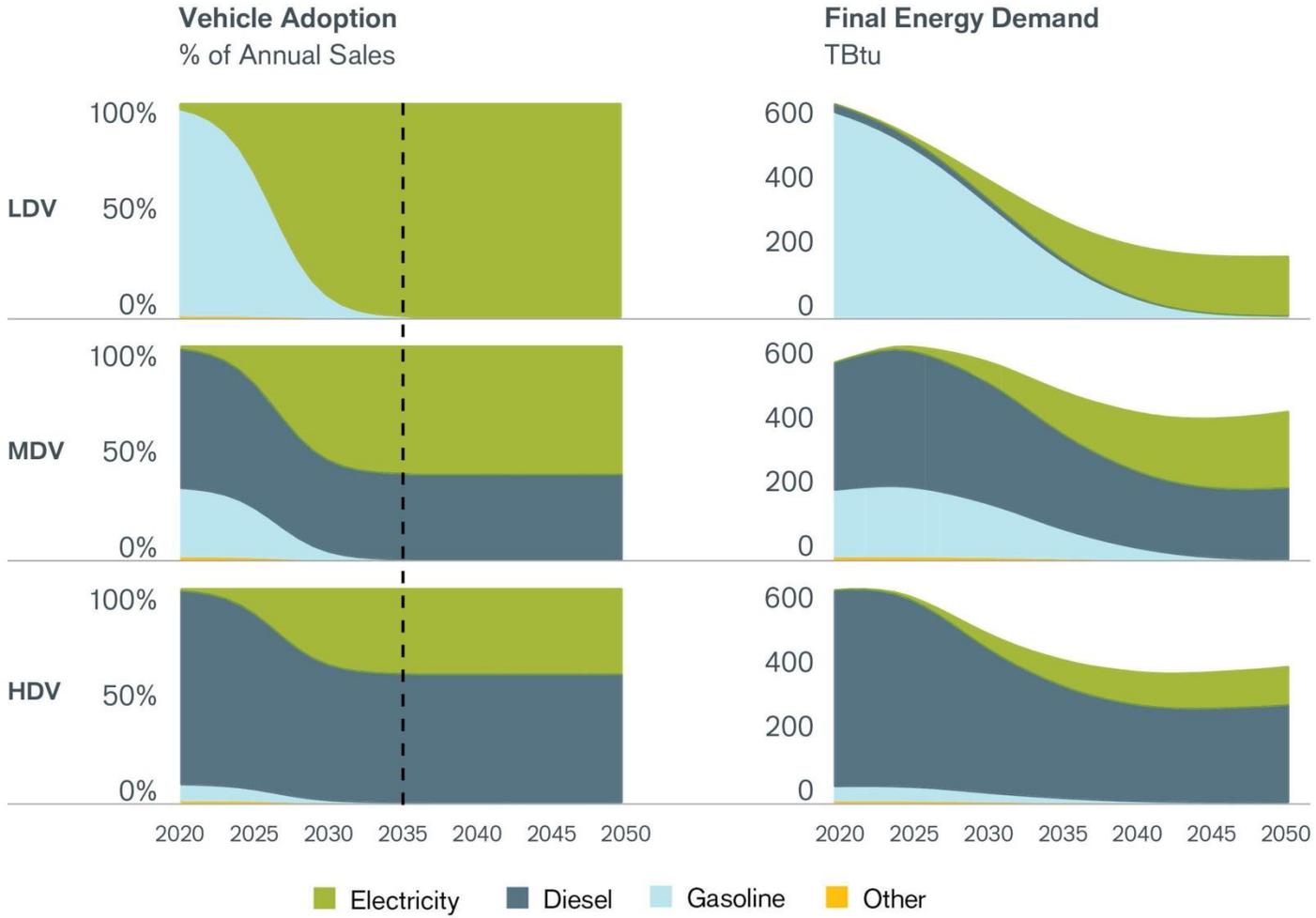
Building Energy Intensity (2020=1.0)



Transportation: Massive Shift to Electric Vehicles

By 2050:

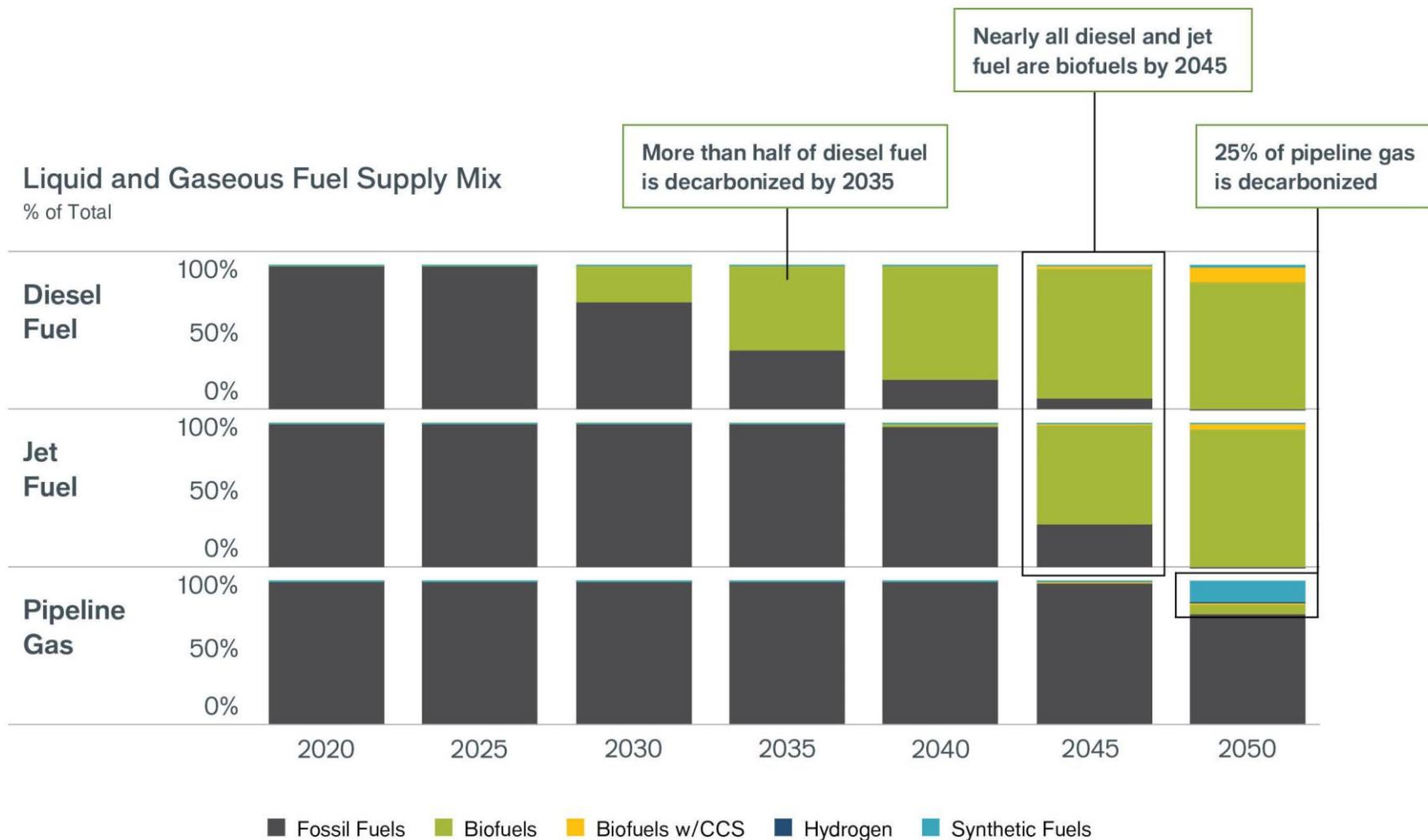
- Cars, SUVs, and light trucks fully electrified
- Medium and heavy-duty trucks partially electrified
- Results in a 60% reduction in final transportation sector energy demand from light, medium, and heavy-duty vehicles



Fuels: Decarbonized Diesel, Jet, and Pipeline Gas

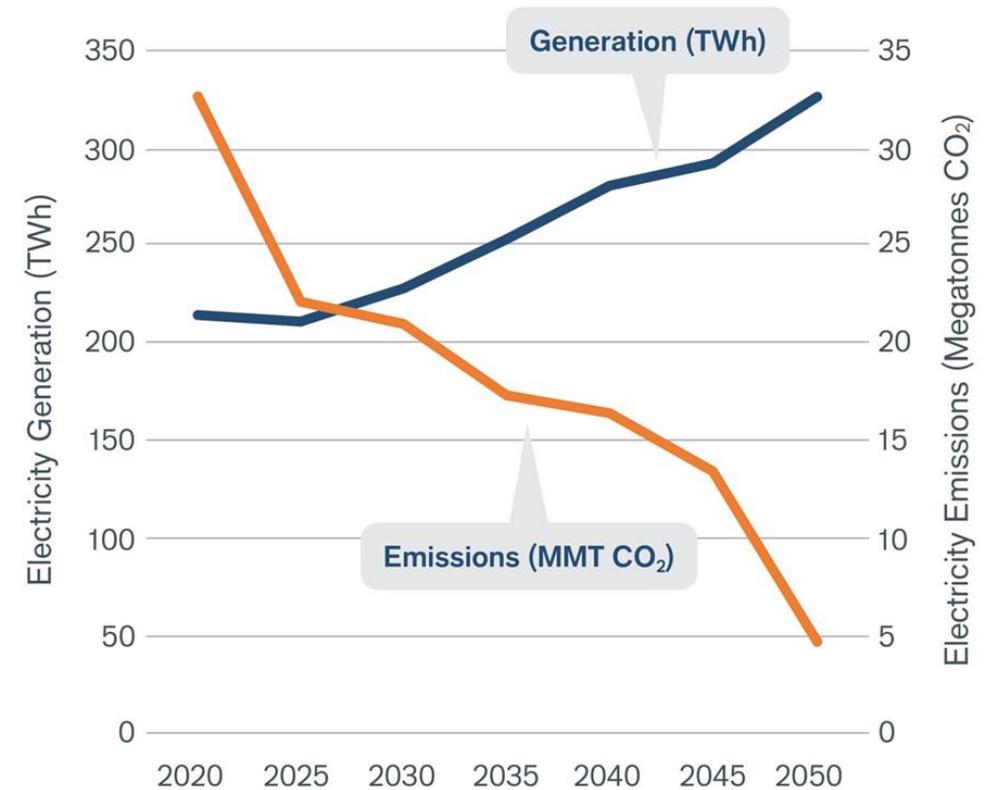
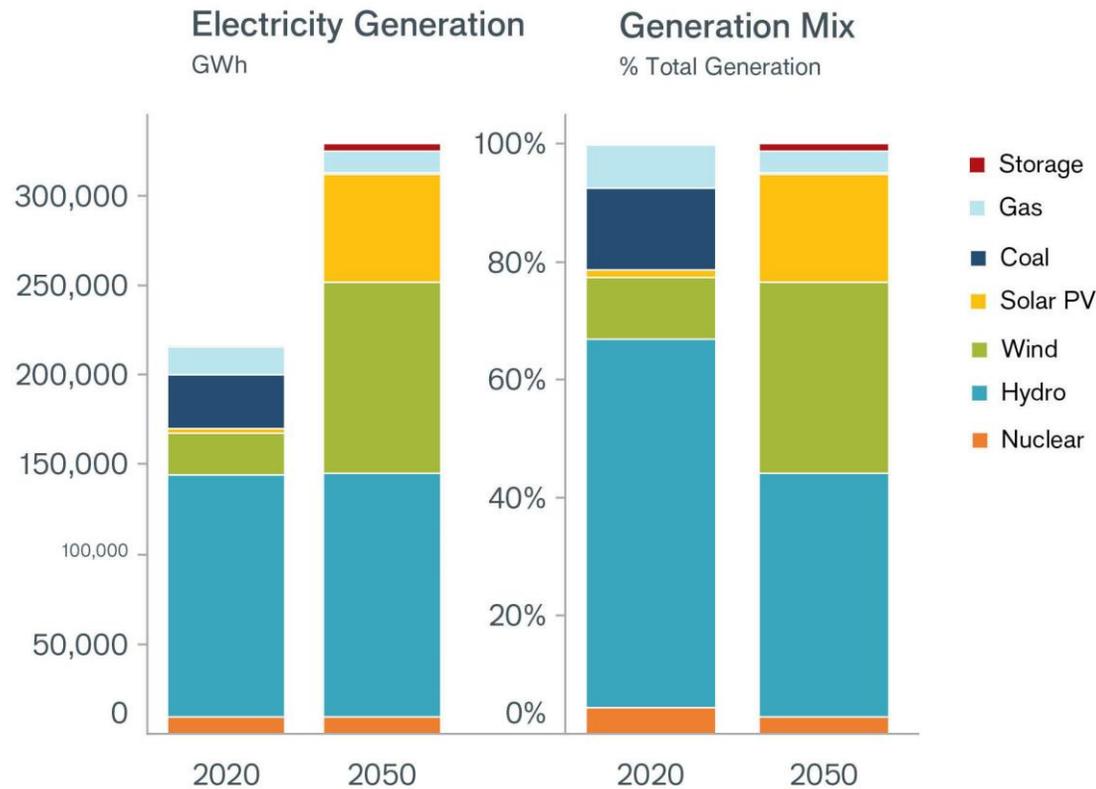
By 2050:

- Diesel and jet fuel fully decarbonized, primarily using biofuels.
- 25% of pipeline fuels partially decarbonized
- Synthetic fuels play a key role



Electricity: 96% Carbon Free

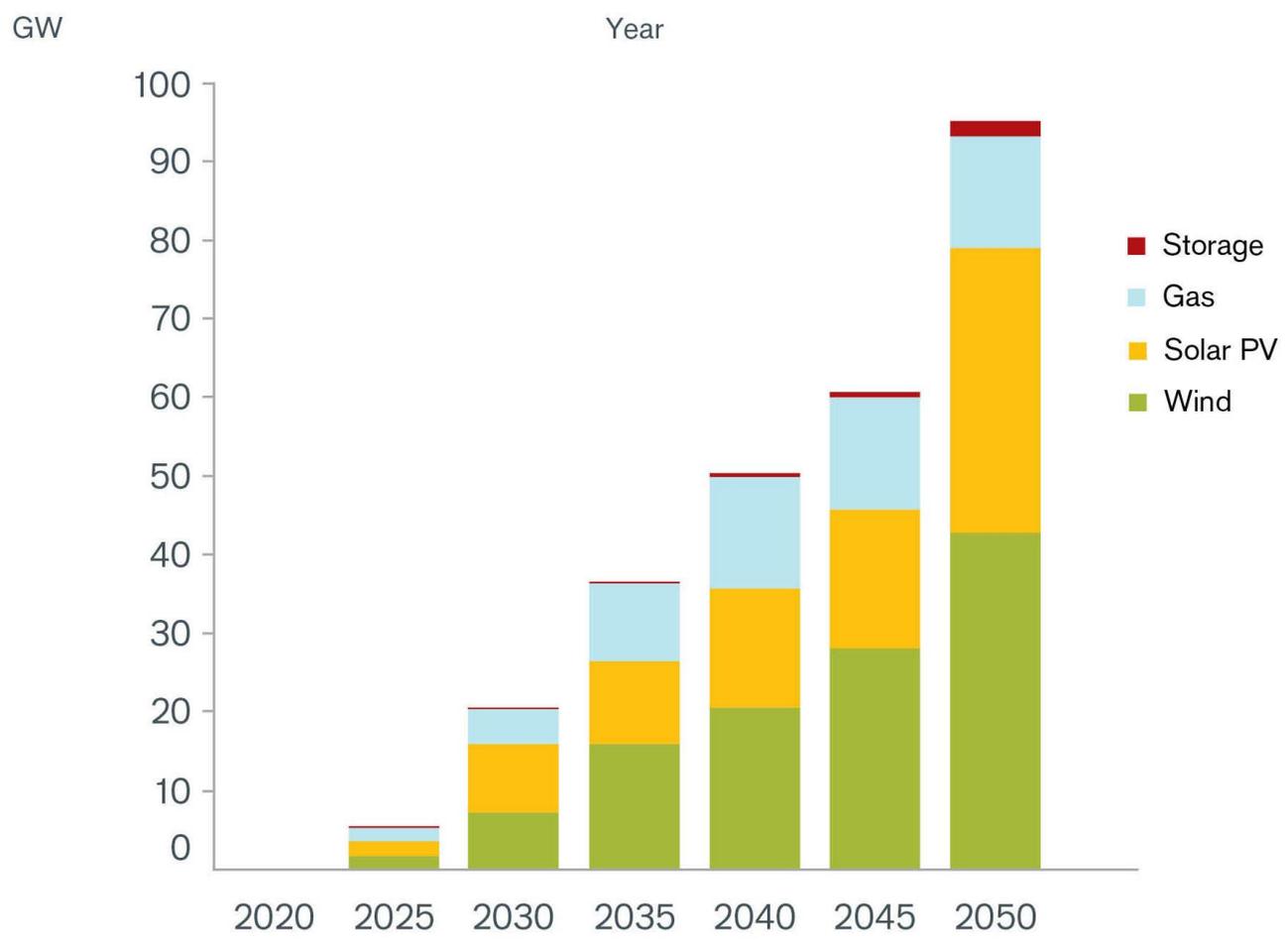
Generation increases 53%, with fossil fuel use at 4%, emissions decline by 86%.



Electricity: Expands to Serve 55% of Energy Demand

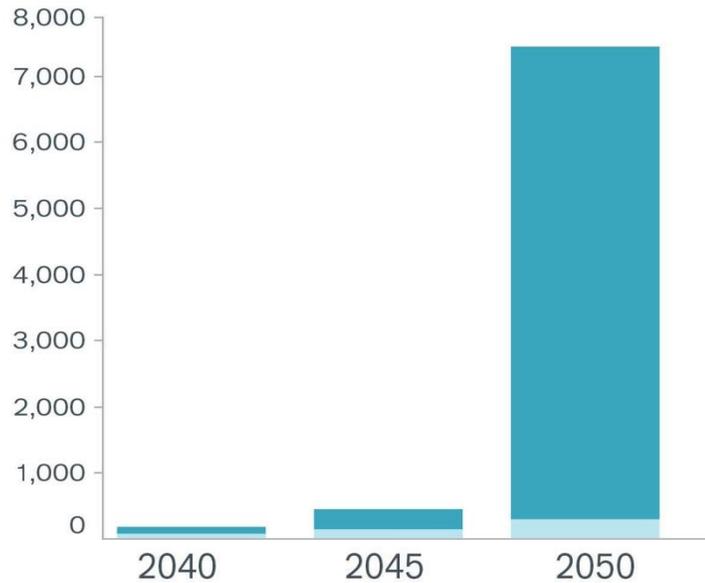
- By 2050, 95 GW of generation capacity added.
- 44 GW wind, 35 GW solar
- 14 GW gas, primarily for reliability, capacity value in times of low hydro, wind, solar combined with high demand
- 2 GW storage

Cumulative New Resource Build

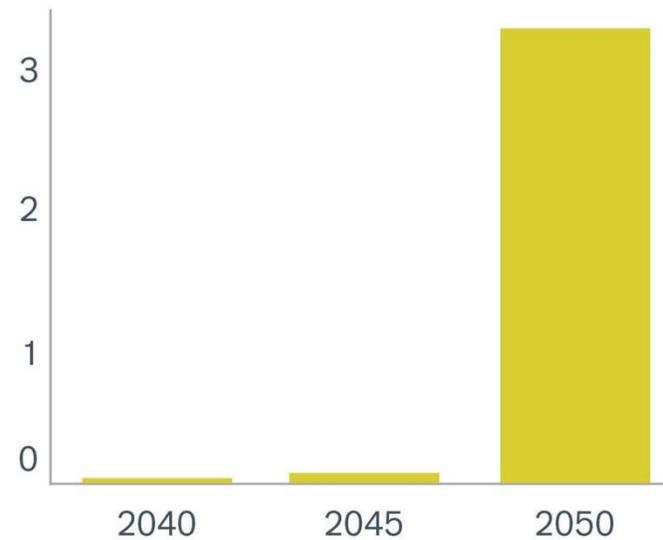


Electricity: New Technologies Reduce Curtailment & Meet Demand for Decarbonized Liquid Fuels

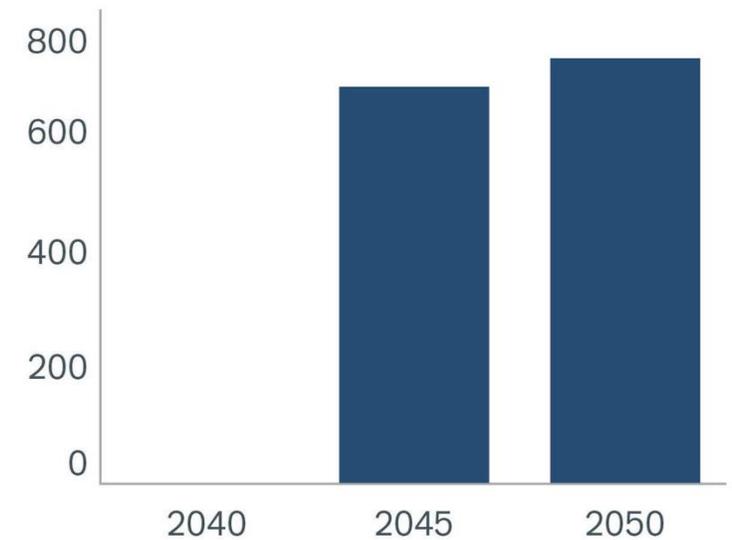
Electrolysis Capacity (MW)



DAC Total Capture Capacity (MMT)



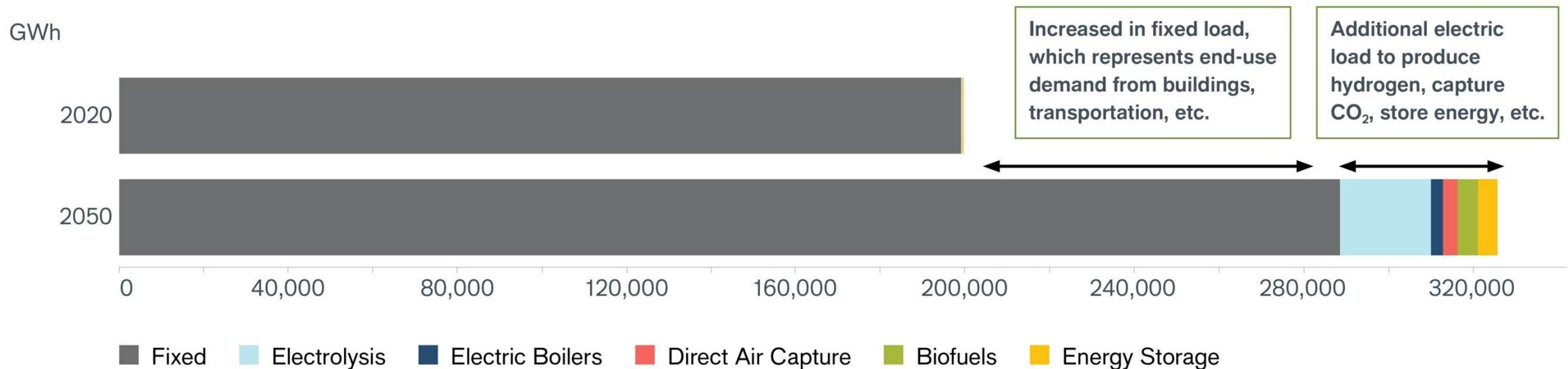
Electric Boiler Capacity (MW)



- **Electrolysis uses 21,400 GWh; DAC uses 3,340 GWh; and Electric Boiler uses 2,950 GWh**

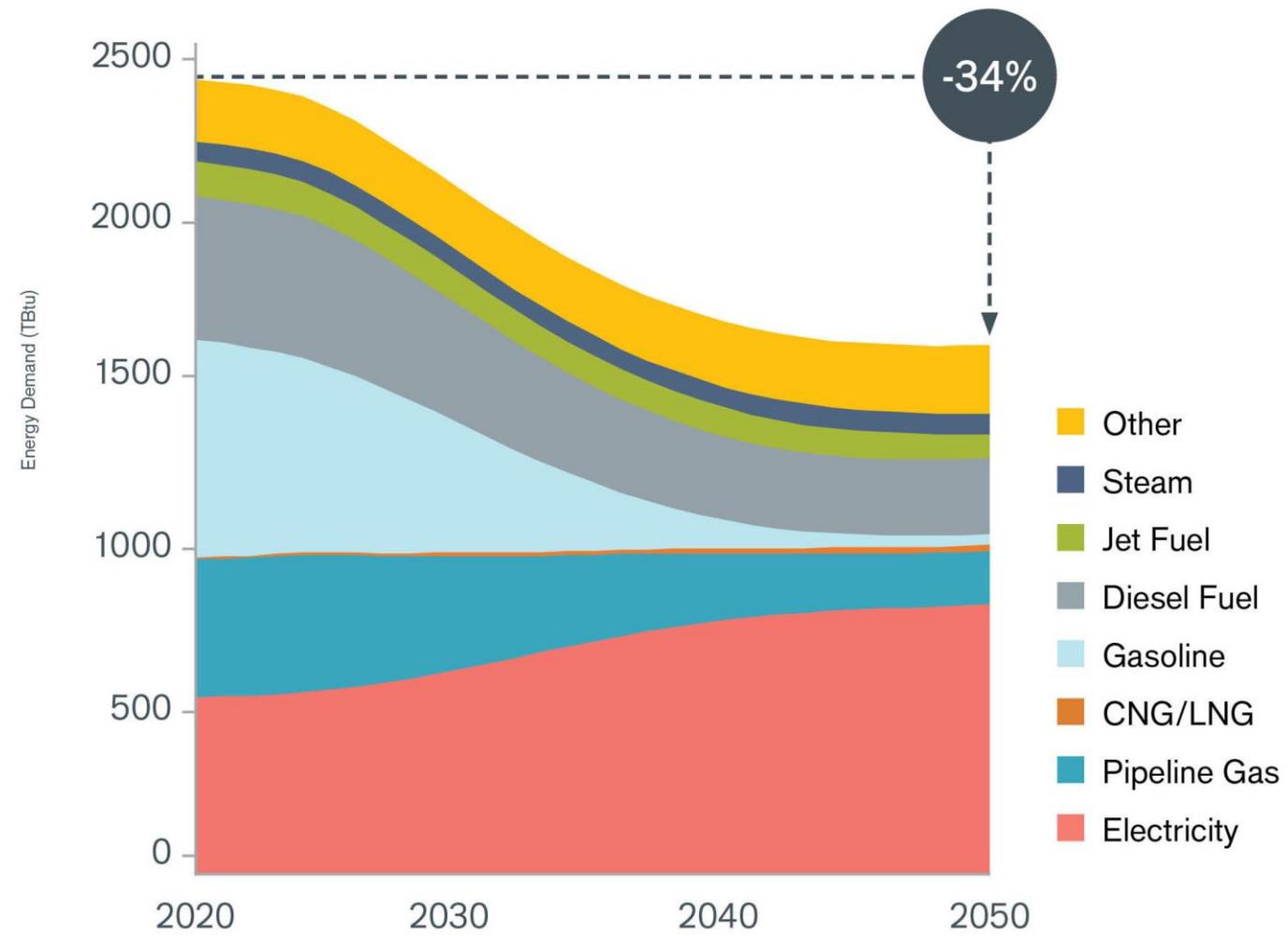
Electricity Sector: Serves Increasing Fixed Load, Produces New Sources of Decarbonized Energy

- 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
- Significant portion is from other demand sources



Final Energy Demand Declines, Even as Region Grows

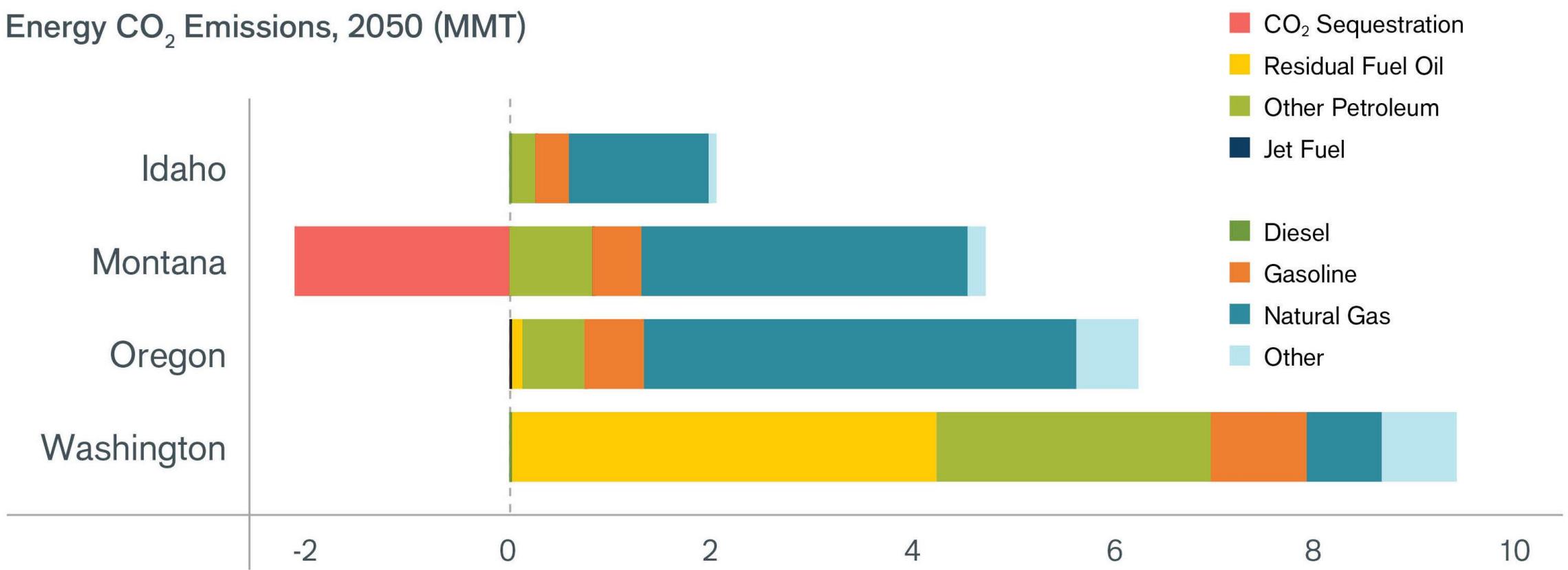
- ▶ In the Central Case energy demand is down 34% and electricity consumption is up more than 50% in 2050.
- ▶ Even as population increases from 14.7 million people in 2020 to 19 million in 2050 and economy grow



State-Level Energy CO₂ Emissions in 2050

In three of four states, the majority of remaining emissions in the Central Case in 2050 are from natural gas combustion.

Energy CO₂ Emissions, 2050 (MMT)



Insights from Alternative Pathways



Alternative Pathways Results

-  **100% Clean Electricity Grid**
 - Easier with economy-wide approach; electric fuels achieves additional 4%
-  **Limited Electrification & Efficiency**
 - Enormous supply/cost implications; scale of facilities prohibitive; imports likely
-  **No New Gas Plants for Electricity**
 - More energy storage & renewables for reliability; approximately double the cost
-  **Limited Biomass for Liquid Fuels**
 - Similar energy system impacts to the No New Gas, though not as costly
-  **Increased NW-CA Transmission**
 - Saves \$11.1B; avoid development of low-quality renewables in CA & in NW

Electrification and Biomass Implications

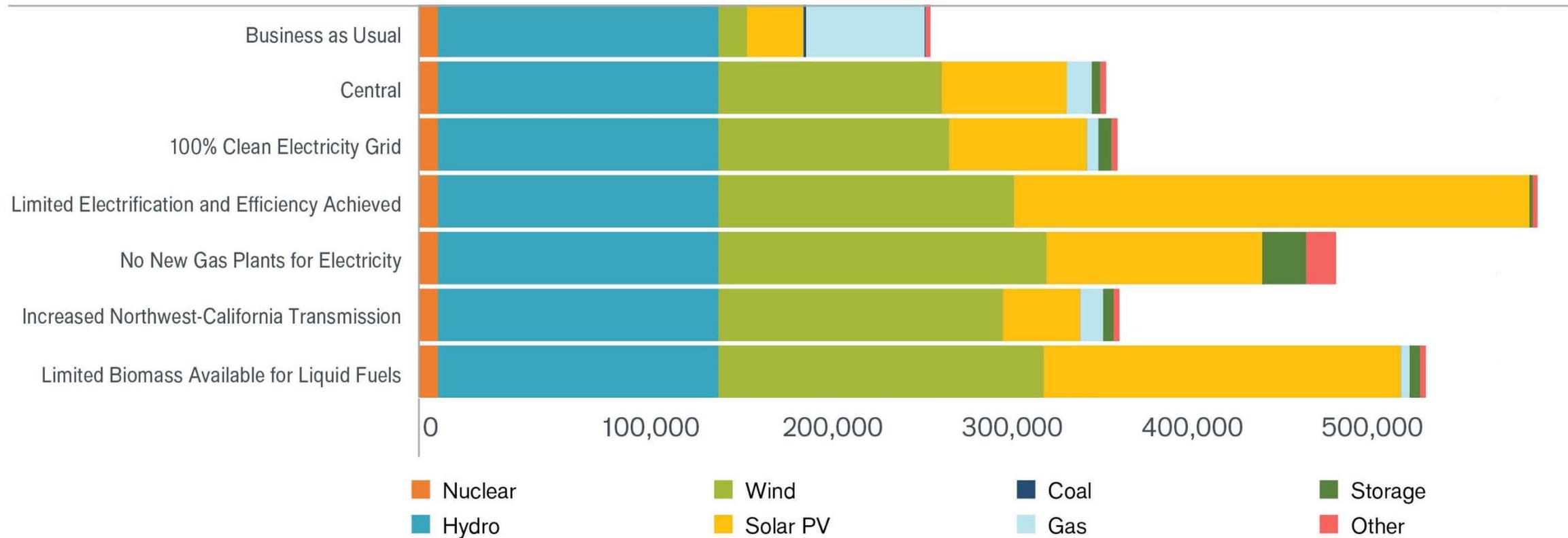
- **Failure to electrify** = Enormous implications for supply
 - Scale of new facilities could be prohibitive in implementation
 - May require imports of electric fuels produced elsewhere
- **Restricted biomass availability** = Similar energy system impacts
- The “**backstop**” resource is synthetic electric fuels



Electricity Resources All Cases in 2050

Electricity Generation by Resource Type (GWh)

2050



Costs

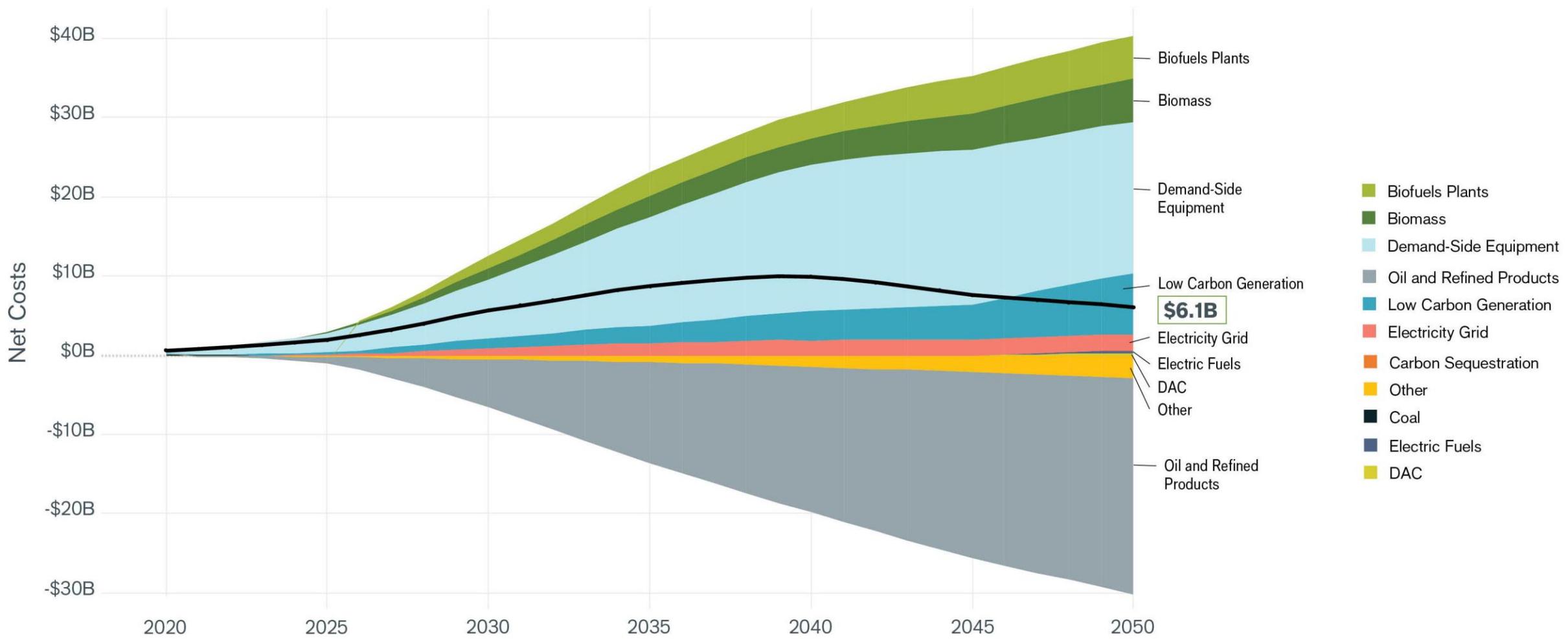


Estimated Net Cost to Achieve Target Roughly 1% of GDP

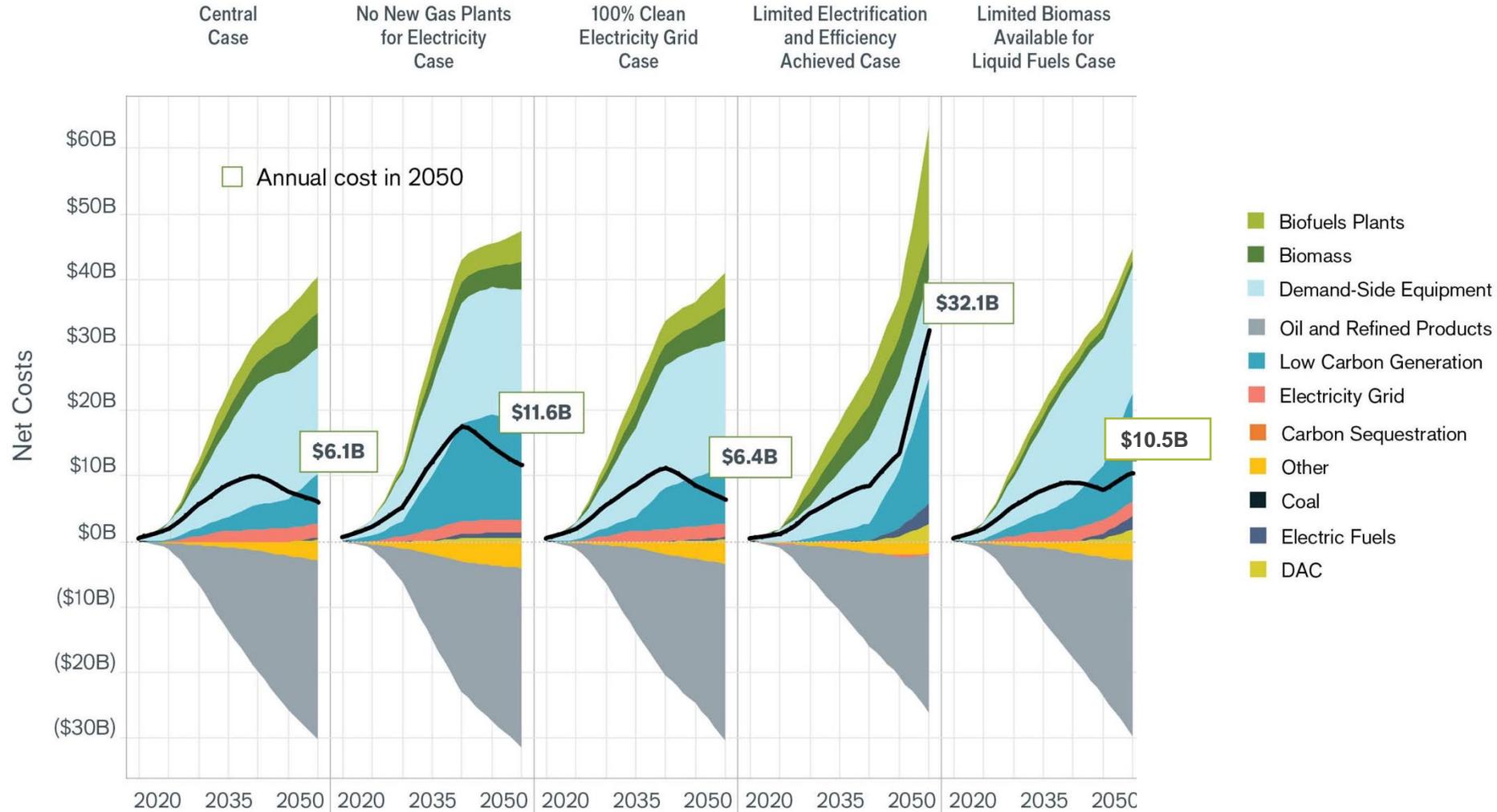
- Cumulative costs of decarbonizing the energy system in the Central Case are 9.5% higher than the capital and operating expenses of the Business as Usual energy system
 - Represents roughly 1% of region's GDP
- \$48/avoided ton of carbon
- Does not include benefits from avoiding climate change, reducing air pollution, improved health



Net Annual Energy Costs



Annual Net Energy System Costs, Six Cases



Implications



Bottom Line: Deep Decarbonization Achievable

Deep decarbonization is achievable but will require:

- Energy System Transformation
- Deployment of Multiple Strategies
- Investment and R & D
- Technology, Business Model, and Policy Innovation



Policy, Investment, and Innovation Framework

- Equity implications must be explored and addressed
- Implementing widespread transportation electrification
- Severely limiting natural gas in buildings, transport, and the grid
- Achieving better grid integration between the Northwest and California
- Assessing actual biomass in the Northwest for jet and diesel biofuels
- Determining the role power-to-X, electrolysis, direct air capture in the Northwest



Thank you

Eileen V. Quigley
Executive Director
Clean Energy Transition Institute
eileen@cleanenergytransition.org

Jeremy Hargreaves
Principal
Evolved Energy Research
jeremy@evolved.energy

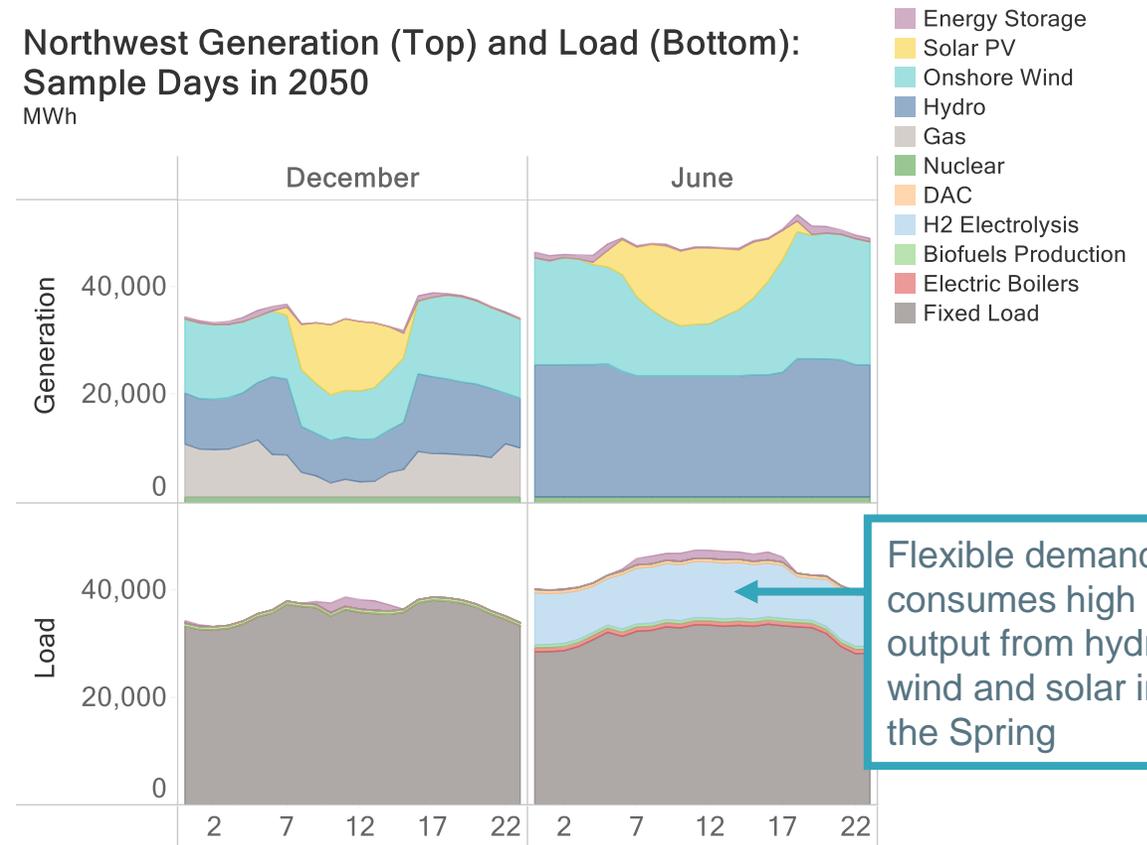


Appendix: Modeling Approach

Hourly Electricity Operations-Central Case

- 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

Northwest Generation (Top) and Load (Bottom):
Sample Days in 2050
MWh



Flexible demand consumes high output from hydro, wind and solar in the Spring

End-Use Sectors: Approximately 80 Demand Sub-Sectors

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: Northwest Deep Decarbonization Pathways Study, May 2019, Evolved Energy Research, page 24.

Options to Supply End Use Fuel Demands

Supply-side resource options.

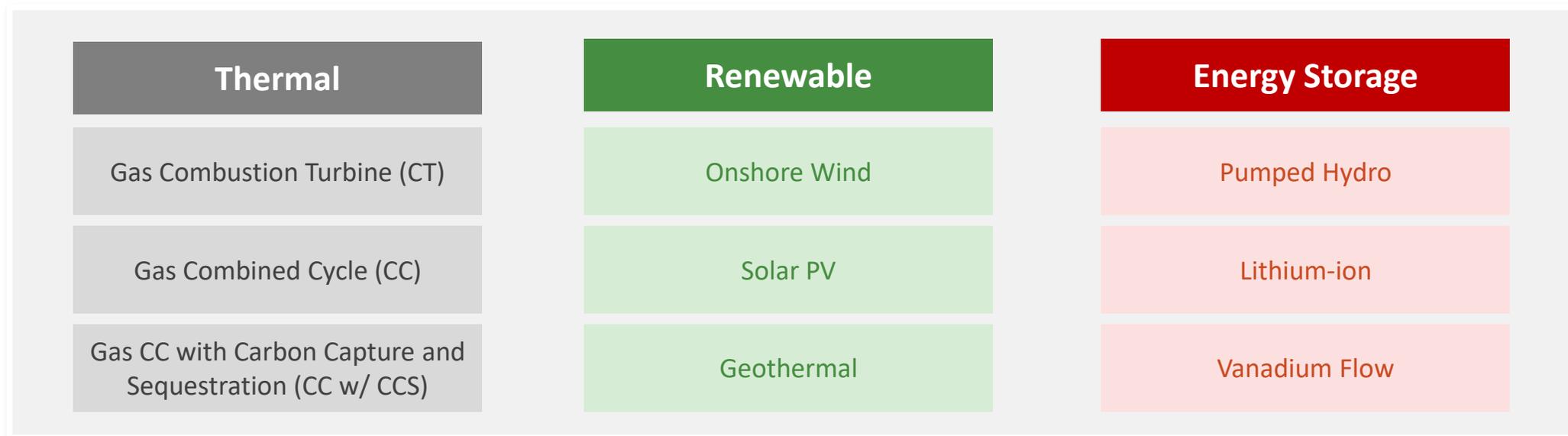
Diesel Fuel	Jet Fuel	Pipeline Gas	Liquid Hydrogen	Gasoline Fuel
Power-to-Diesel	Power-to-Jet-Fuel	Power-to-Gas	Electrolysis	Corn Ethanol
FT Diesel	FT Jet Fuel	Hydrogen	Natural Gas Reforming	Cellulosic Ethanol
FT Diesel with CCS	FT Jet Fuel with CCS	Biomass Gasification	Natural Gas Reforming with CCS	Steam
FT Diesel with CCU	FT Jet Fuel with CCU	Biomass Gasification with CCS	Natural Gas Reforming with CCU	Fuel Boilers
		Biomass Gasification with CCU	Direct Air Capture	CHP
		Landfill Gas	DAC with CCS	Electric Boilers
			DAC with CCU	

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

Source: Northwest Deep Decarbonization Pathways Study, May 2019, Evolved Energy Research, page 41.

New Electric Sector Resource Options

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



Modeling Framework-Pairing ENERGY Pathways & RIO



ENERGY
PATHWAYS



Description

EnergyPATHWAYS (EP)

Scenario analysis tool used to develop demand-side scenarios across all end-use sectors

Regional Investment and Operations (RIO)

Tool to develop cost-optimal energy supply portfolios for all fuel types

Track Record

Many regional, US wide, and international decarbonization studies

Decarbonization studies of the US, Northwest, California, Northeast, Mexico, and Europe

Application

Scenario design allows for alternative electrification and efficiency measures, which produces:

- Annual energy demand for all fuels (electricity, pipeline gas, diesel, etc.)
- Hourly electricity load shape

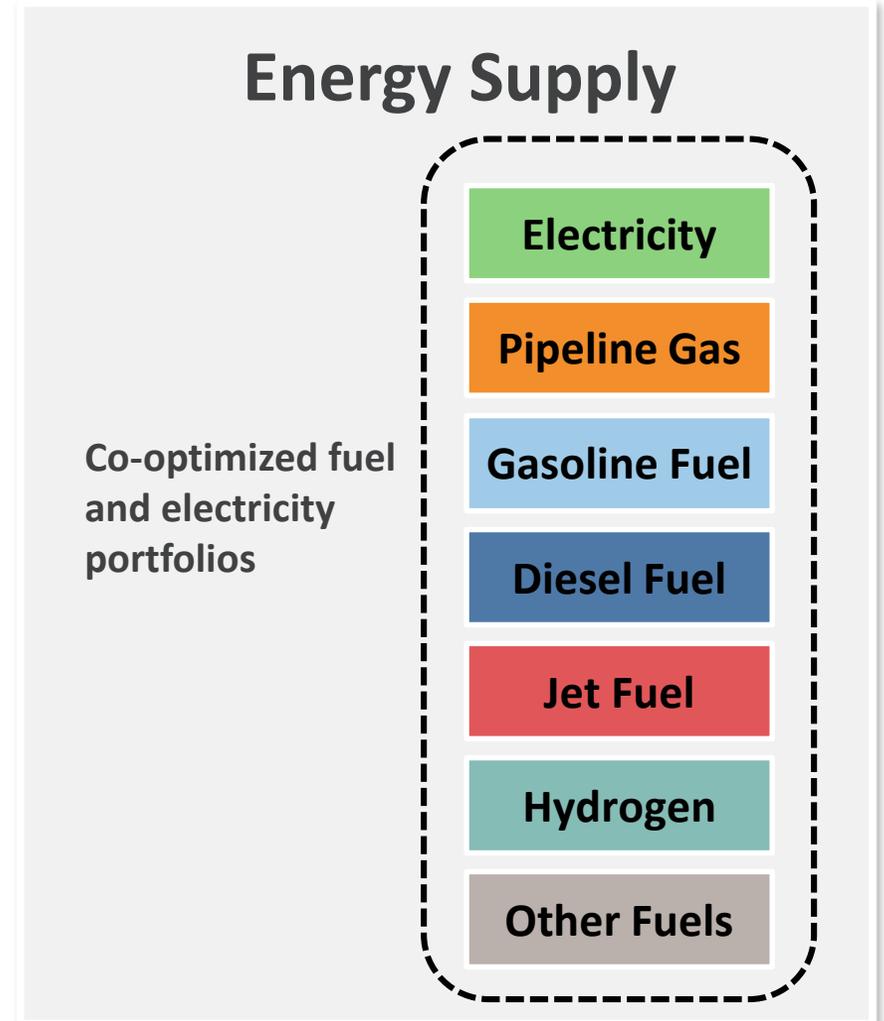
These energy demand parameters are inputs to RIO

Demand projections from EP used to produce cost-optimal energy supply portfolios:

- Electricity sector capacity expansion
- Biomass allocation across fuels
- Synthetic electric fuel production
- Direct air capture deployment

Regional Investment and Operations (RIO)

- RIO is a capacity expansion tool that produces cost-optimal resource portfolios
- Includes electric sector capacity expansion and the optimization of all energy supply options
 - Optimization allows for trade-offs of limited resources across the energy system, such as biomass, to be determined simultaneously
- Model decides the suite of technologies to deploy over time to meet annual emissions and other constraints



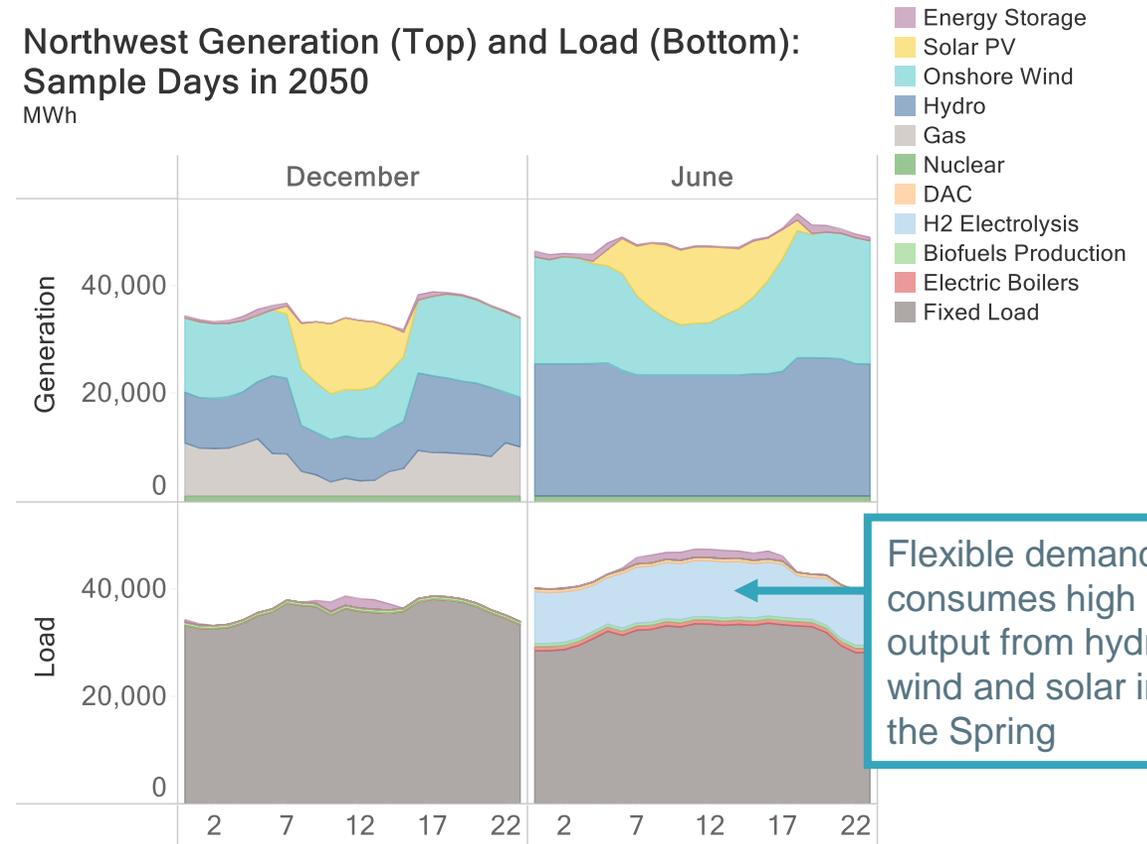
RIO: Electricity Sector

- Simulates sequential hourly system operations for each year
 - Hourly dispatch ensures sustained peaking capability of energy-limited resources such as hydro is captured
- Incorporates long-duration energy storage resources
 - Energy can move between days over the course of the year
 - Necessary at high renewable penetrations, avoiding excessive curtailment and overbuild of resources
- Optimizes economic additions and retirement of resources
- Operations and investment are simulated while accounting for dynamics across the energy system, such as:
 - Electric fuel production competes with other forms of energy storage to balance system
 - Bioenergy could be allocated to pipeline gas for power plants or diesel fuel
 - Changing dynamics in neighboring regions (e.g., California and its 100% clean electricity requirement)

Hourly Electricity Operations

- Electricity balancing – key challenge of decarbonized system
- Many studies of low-carbon electricity limit balancing to thermal and energy storage resources
- Limited options - specifically when dealing with imbalances that can persist over days and weeks
- This study expands the portfolio of options
 - Including flexible electric fuel production (e.g., electrolysis) in addition to energy storage, thermal, and transmission

Northwest Generation (Top) and Load (Bottom):
Sample Days in 2050
MWh



Load, Hydro, and Renewables

- ▶ In order to capture a range of electricity system operating conditions in RIO, we incorporate load, wind, solar and hydro profiles from multiple weather years
 - Weather-driven or seasonal trends in load, hydro availability and renewable production cause operational challenges that can persist over long periods
- ▶ **Load, wind and solar**
 - Hourly profiles are from three weather years: 2010, 2011 and 2012
 - Load shapes further account for scenarios-specific electrification and energy efficiency impacts over time
- ▶ **Hydro**
 - Hourly hydro generation from three historical years is used to derive operational constraints, including energy budgets, minimum and maximum capabilities and ramp rates
 - Dry, normal and wet hydro conditions based on data from WECC for 2001, 2005 and 2011, respectively

Meeting Reliability

- Detailed loss of load studies with large quantities of historical data
- Reserve margins are used as a proxy for meeting system reliability standards
 - Typical industry margins vary from 10-15%
- Challenges to this metric in high renewable systems:
 - Low wind and solar output drive reliability constrained conditions, rather than peak load: contribution of renewables towards reliability is low compared to conventional resources
 - Increasing reliance on energy limited resources (hydro, storage): how to reliably meet prolonged energy deficits from low wind and solar output?
- RTO enforces a capacity reserve constraint across all model hours, not just peak load hours or days
- RTO models the full year of chronological days:
 - Captures prolonged energy deficit conditions
 - Finds lowest cost investments in energy storage and flexible load options (hydro, batteries, gas, hydrogen, synthetic fuels)

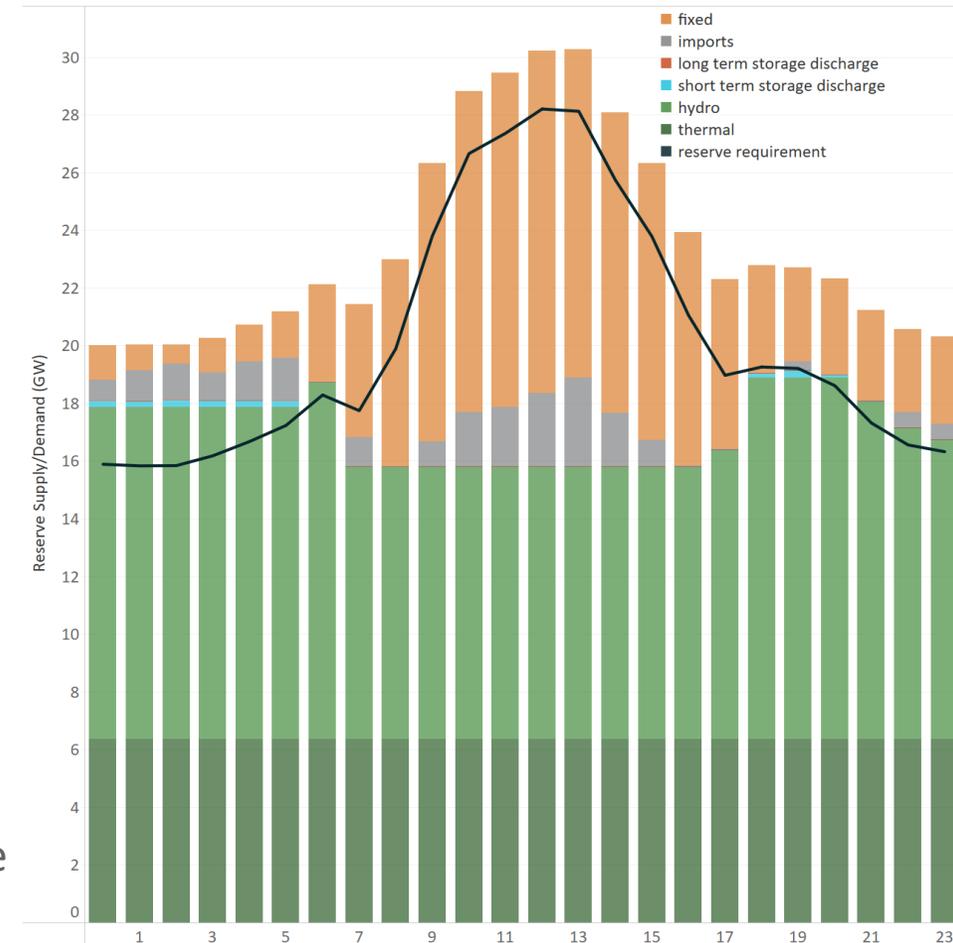
Hourly Planning Reserve Constraints by Zone

Accounting for non-dispatchable and energy-limited resources

- Reserve requirement = 107% of gross load representing weather-related risk of load exceeding that sampled
- Reserve supply must exceed the reserve requirement across all hours in all years with:
 - Thermal: derated* nameplate
 - Hydro: derated hourly output
 - Renewables: derated hourly output
 - Energy storage: derated hourly discharge minus charge
 - Imports: derated net flows
 - Flexible loads: net from load (not pictured)

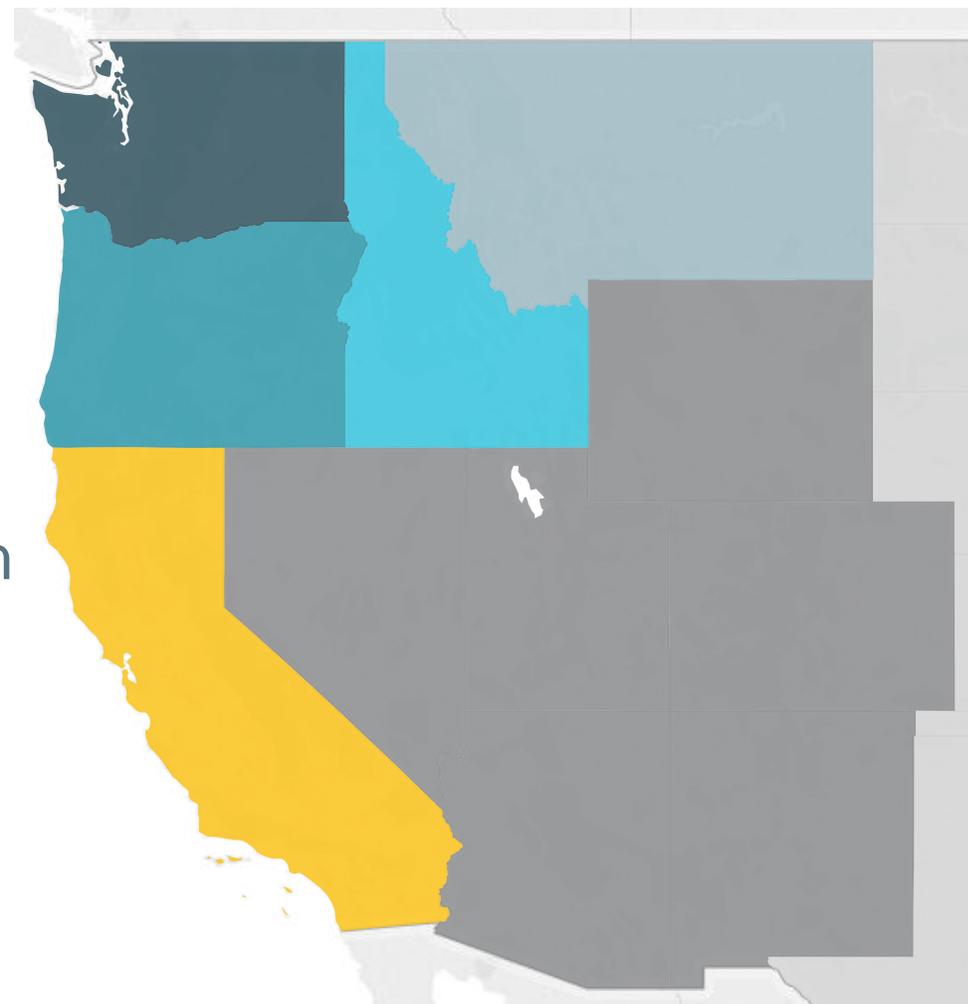
*All resources are given a resource specific derate representing forced outage rates, energy limited risk, and weather-related risk

Illustrative Hourly Reserve Requirement and Supply



Electric Topology

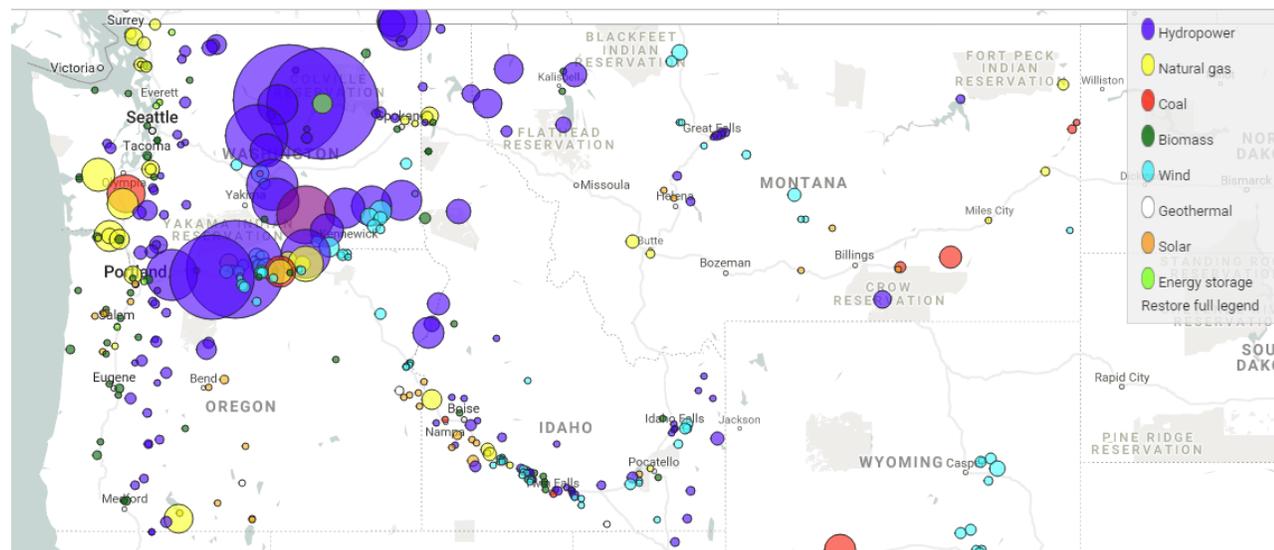
- Electricity sector operations and investment modeled across
 - Northwest states
 - California
 - Rest of the Western Electric Coordination Council (WECC)
- Transfer capability between zones is based on major WECC paths and their line ratings
- Capacity of major remote generation resources (e.g., Colstrip) is allocated to states based on utility ownership



Existing Generation Resources

- ▶ Capacity from the existing hydroelectric system is assumed to remain constant through 2050
- ▶ Study incorporates planned retirement of coal-fired resources
- ▶ Plants without a planned retirement year are assumed to retire at the end of their economic lifetimes

Map of Existing Power Supply



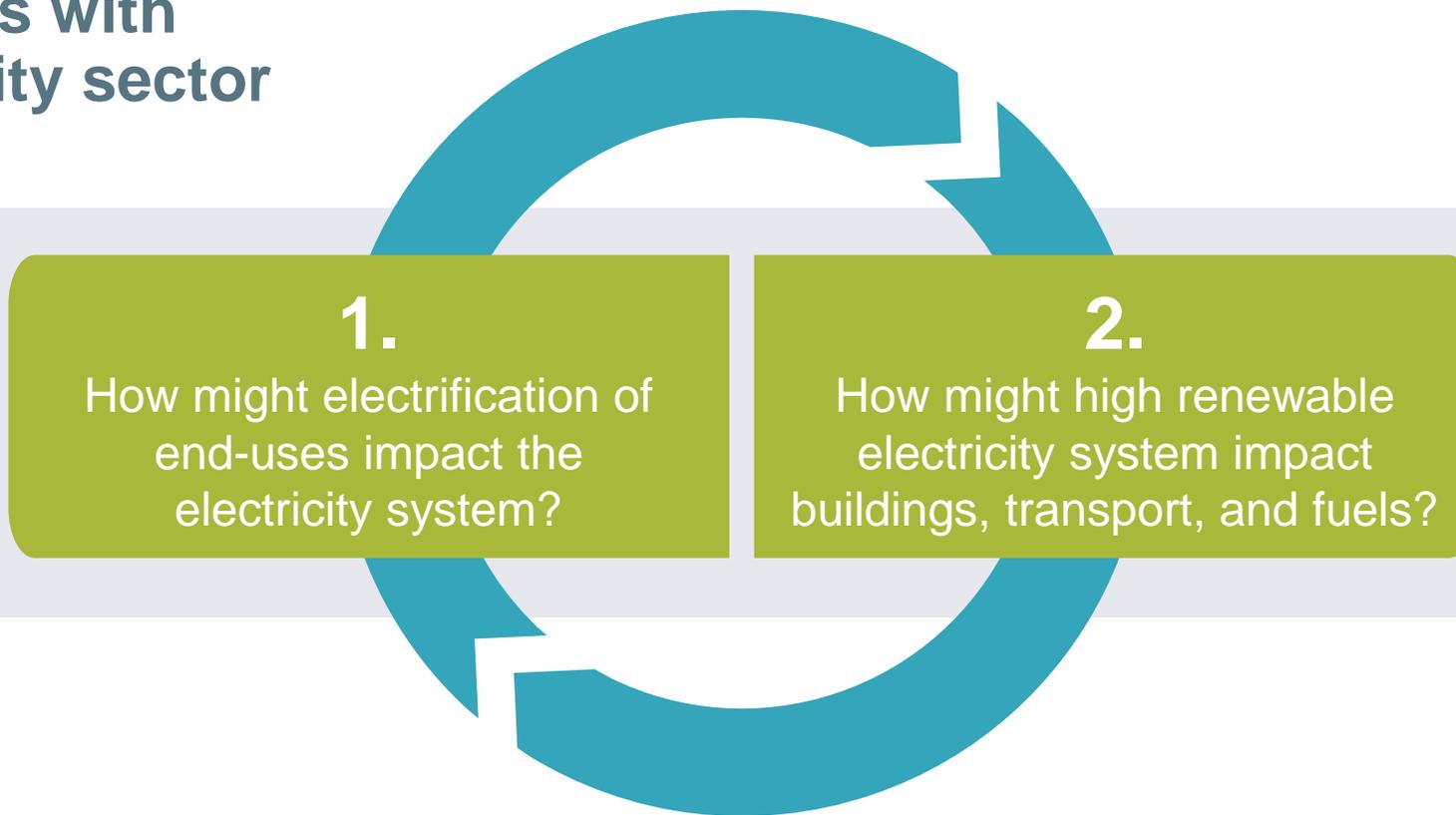
Source: image from [NWPPCC](#)

Comparison to Prior Decarbonization Studies

		 WA	 OR	 ID	 MT	
2016	State of Washington Office of the Governor	All sectors				
2017	Public Generating Pool	Electricity sector only				
2018	Portland General Electric	All sectors				
	Climate Solutions	Electricity sector only				
	Northwest Natural Gas Company	All sectors; optimized decisions limited to electricity sector only				
2019	Public Generating Pool	Electricity sector only; reliability study				
	Clean Energy Transition Institute	All sectors; optimized decisions across entire energy supply side				

Relevancy to Power Planning

Economy-wide decarbonization interacts with electricity sector



Limited Demand-Side Transformation Case

Sector	Subsector	Central Case	Limited Demand-Side Transformation Case
 Transportation	Light-duty vehicles	90% battery electric 10% plug-in hybrid electric	45% battery electric 5% plug-in hybrid electric
	Medium-duty trucks	60% battery electric	30% battery electric
	Heavy-duty trucks	50% battery electric	20% battery electric
 Buildings	Space Conditioning	Primarily air source heat pump	One-half of the Central Case
	Water Heating	Primarily heat pump water heater	One-half of the Central Case
 Industry	Various	Electrification adoption similar to NREL EFS 'High scenario'	One-half of the Central Case

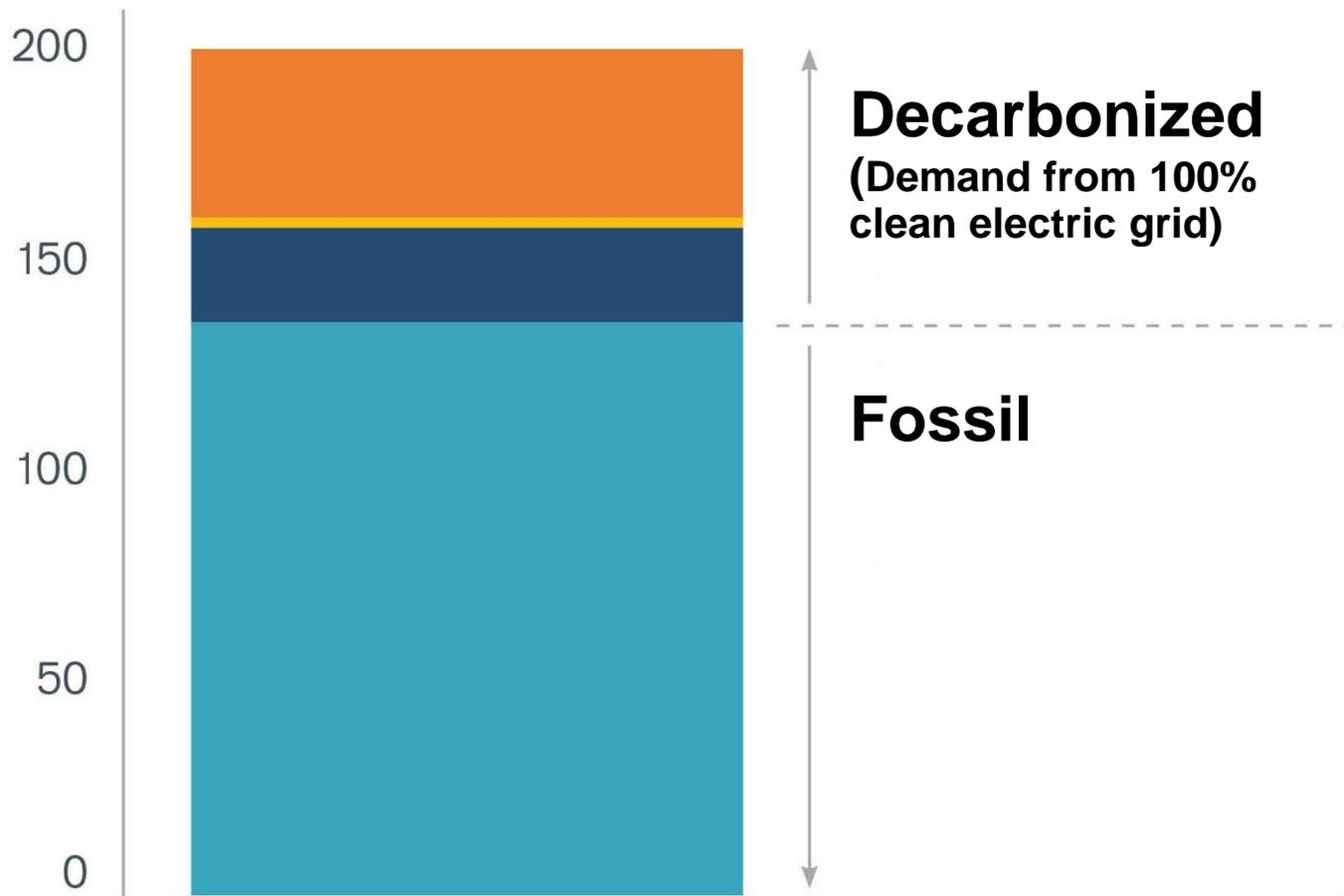
100% Clean Electricity Generation Case

In the 100% Clean Electricity Grid Case, decarbonized pipeline gas can fully supply power plants.

Share of gas-fired generation decreases from 3.7% to 1.7% due to incremental renewables and energy storage deployment

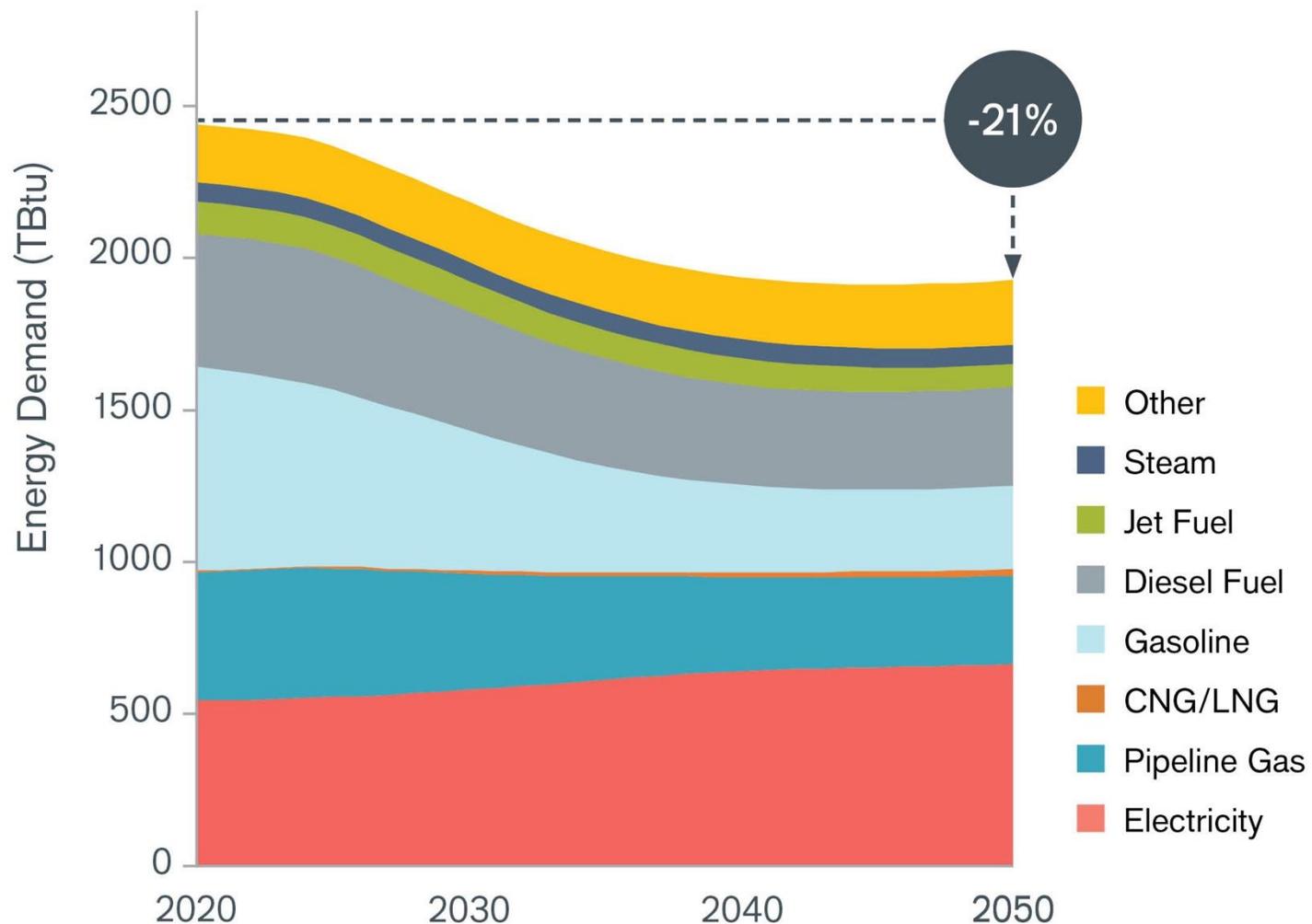
- Synthetic Natural Gas
- Hydrogen
- Biofuels
- Natural Gas

Pipeline Gas, 2050 (TBtu)



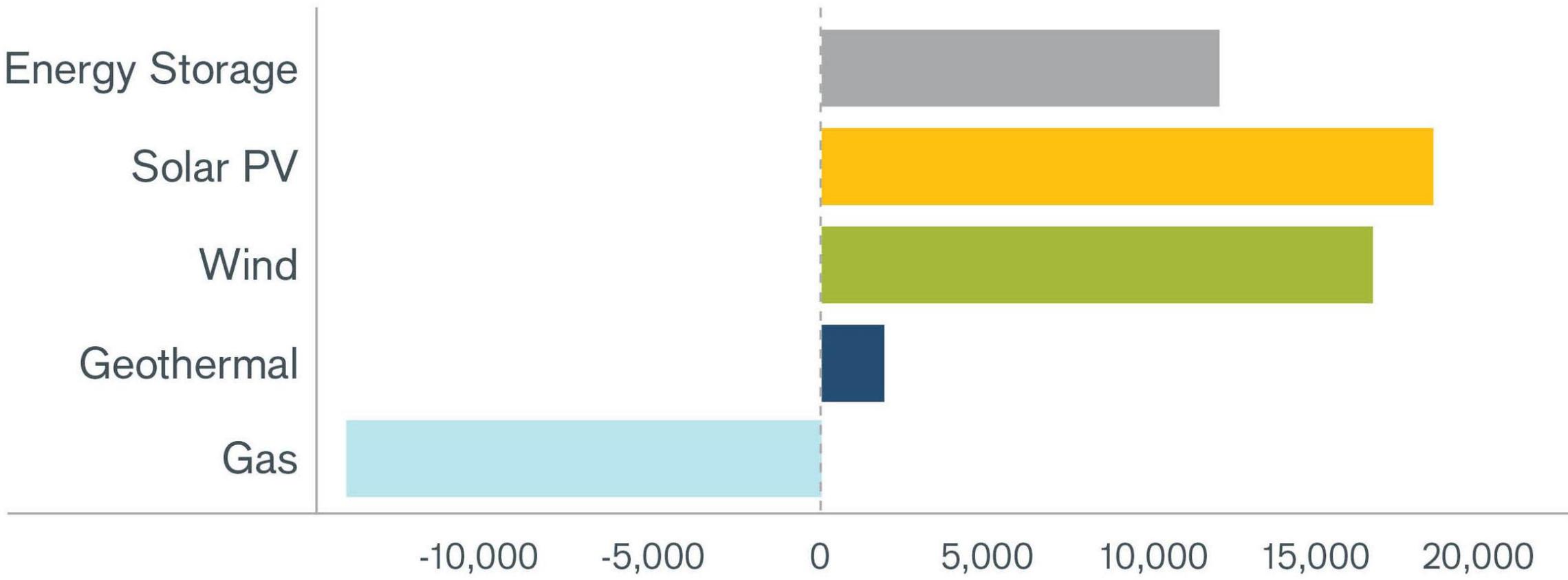
Limited Efficiency & Electrification

- Energy demand declines by 21% in the Limited Electrification and Efficiency Achieved Case vs. 34% in the Central Case.
- Less energy demand reduction means greater investment in fuels, some of which need to be decarbonized with expensive biofuels and synthetic fuels
- Costs \$26.1B relative to the Central Case in 2050



If No New Gas Plants Case

Change in Installed Capacity Relative to Central Case, 2050 (MW); \$5.6B Relative to Central Case in 2050

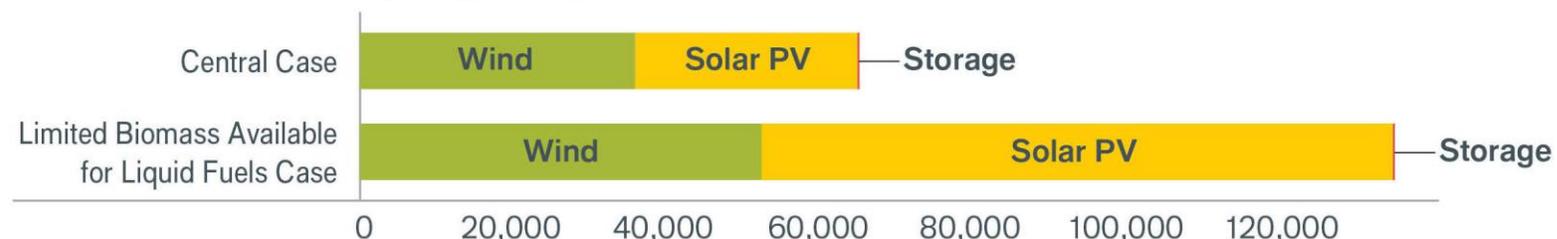


Limited Biomass

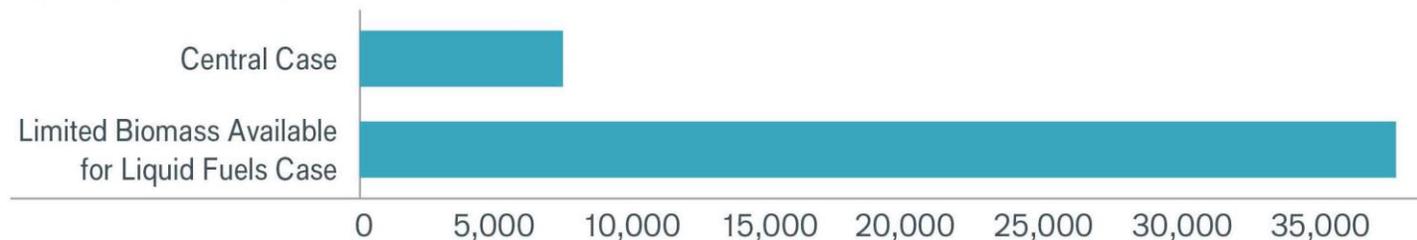
The substantial infrastructure implications of the Limited Biomass Available for Liquid Fuels Case.

- Reduced fuels decarbonization, 2030-45
- Synthetic fuels replace biomass as alternative to diesel and jet fuel, 2045-50
- \$10.6B 2050 cost, 74% higher than optimal

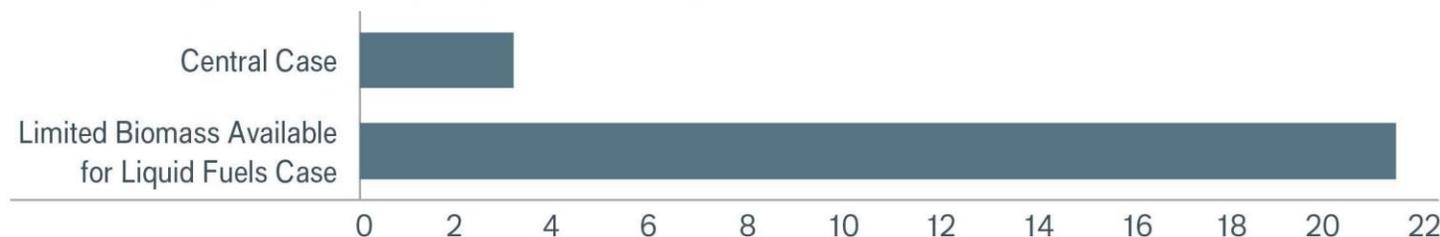
Renewables: Installed Capacity, 2050 (MW)



Hydrogen Electrolysis, 2050 (MW)



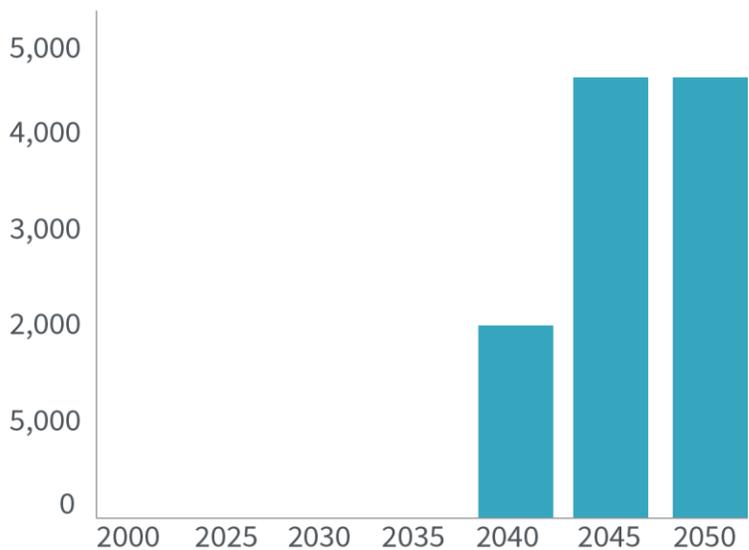
Direct Air Capture, Total Capacity, 2050 (MMT per year)



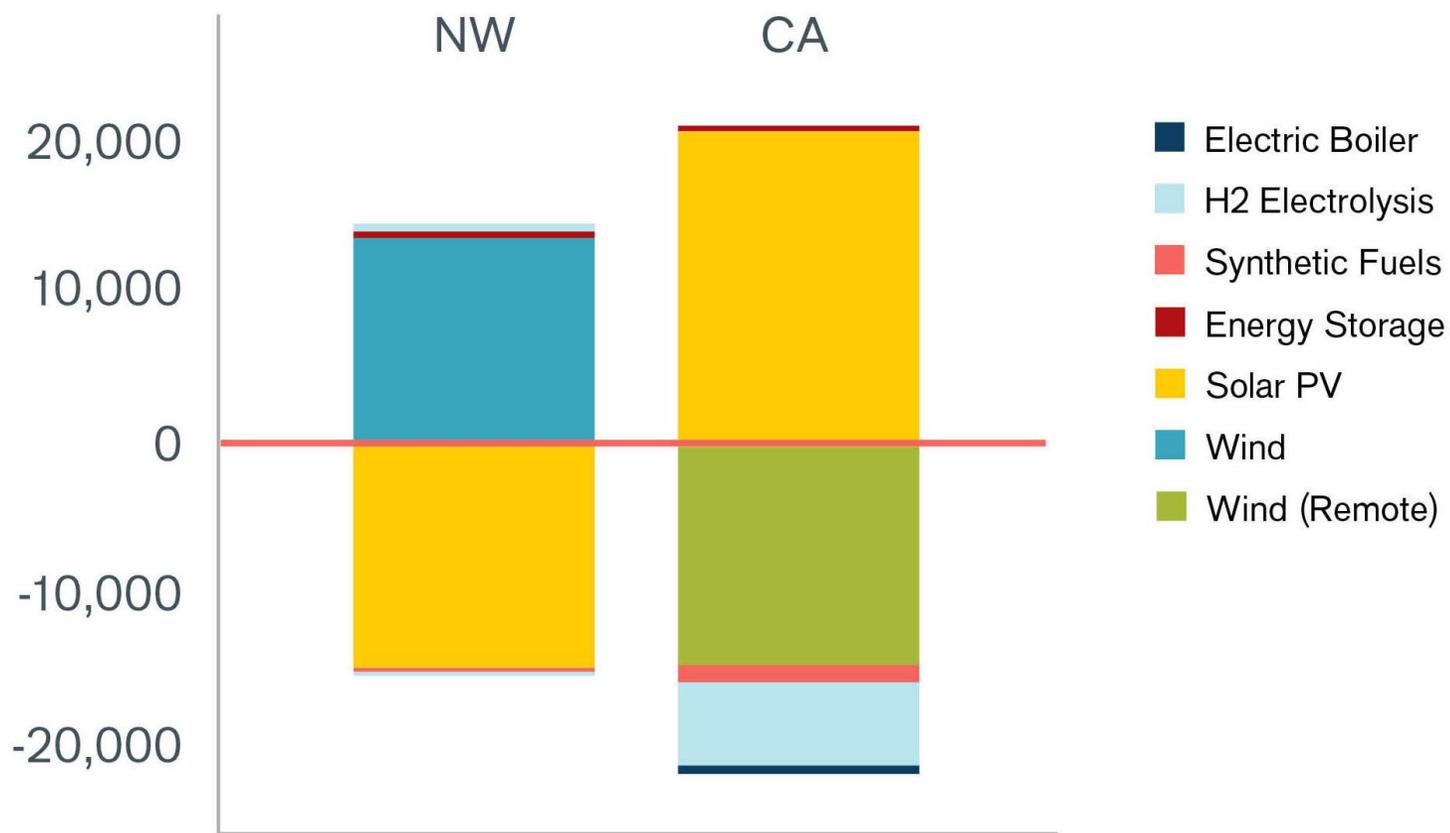
Increased Northwest-California Transmission

- 4,500 MW new capacity
- 7,000 GWH increased exports
- \$11.1B NPV savings
- Changing supply mix

Incremental NW-CA Transmission Capacity (MW)



Change in New Resource Build (MW)



Change in Energy and Supply 2020-2050

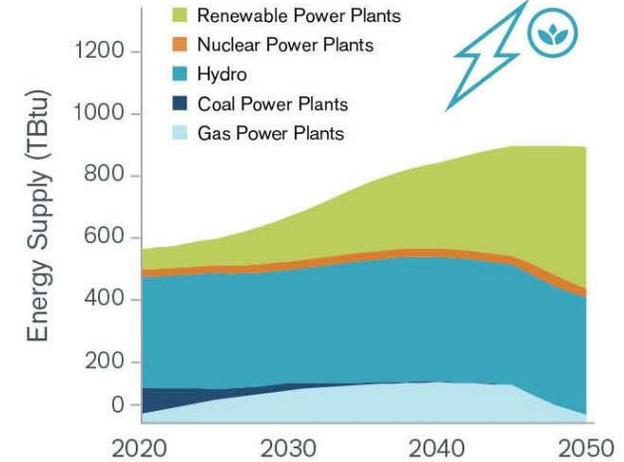
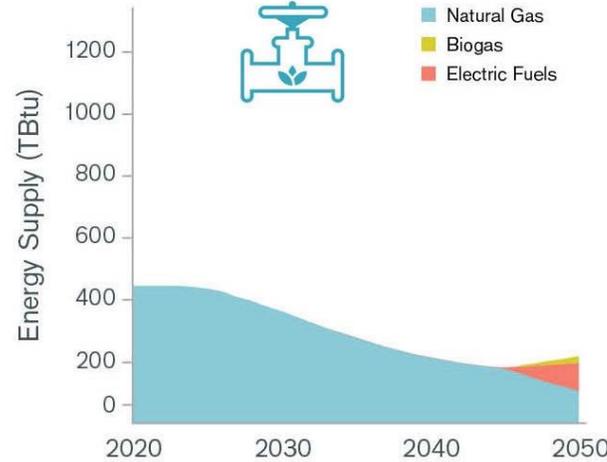
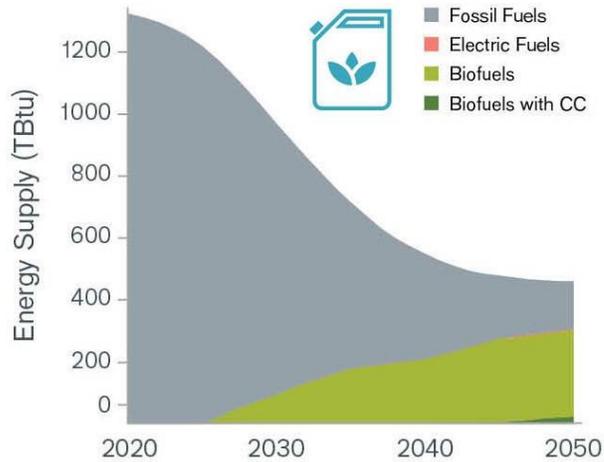
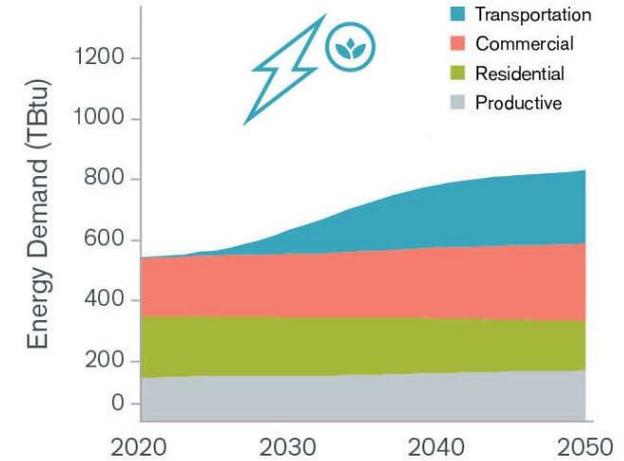
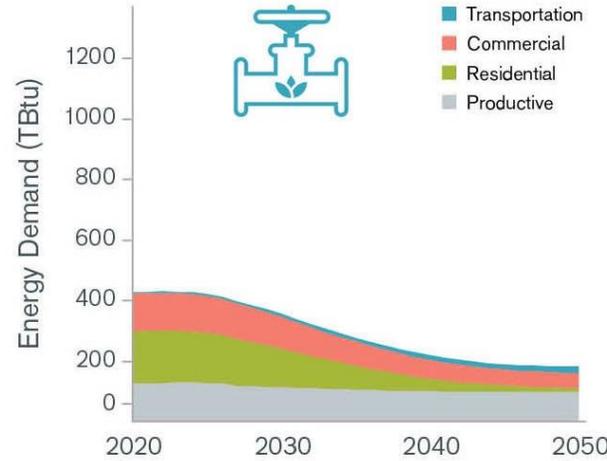
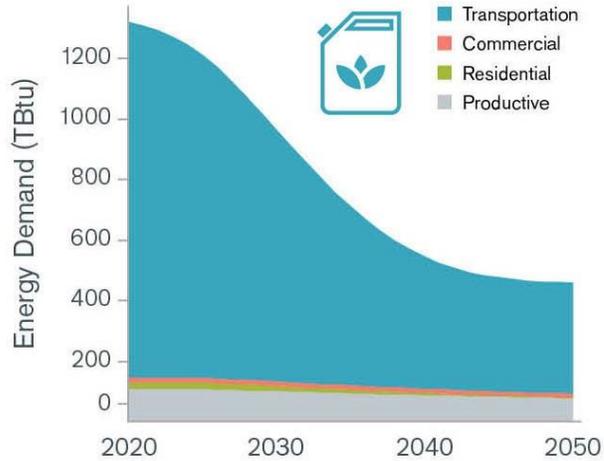


Illustration of Power-to-Gas

