Meeting the Challenge of Our Time: Pathways to a Clean Energy Future for the Northwest

An Economy-Wide Deep Decarbonization Pathways Study • June 2019

Agenda

- Clean Energy Transition Institute & Evolved Energy Research
- Northwest Deep Decarbonization Pathways Study
- Summary of Scenarios
- Key Findings
- Next Steps
- Q & A

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

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

Background

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

Study Questions

- **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

- **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

Comparison to Prior Decarbonization Studies

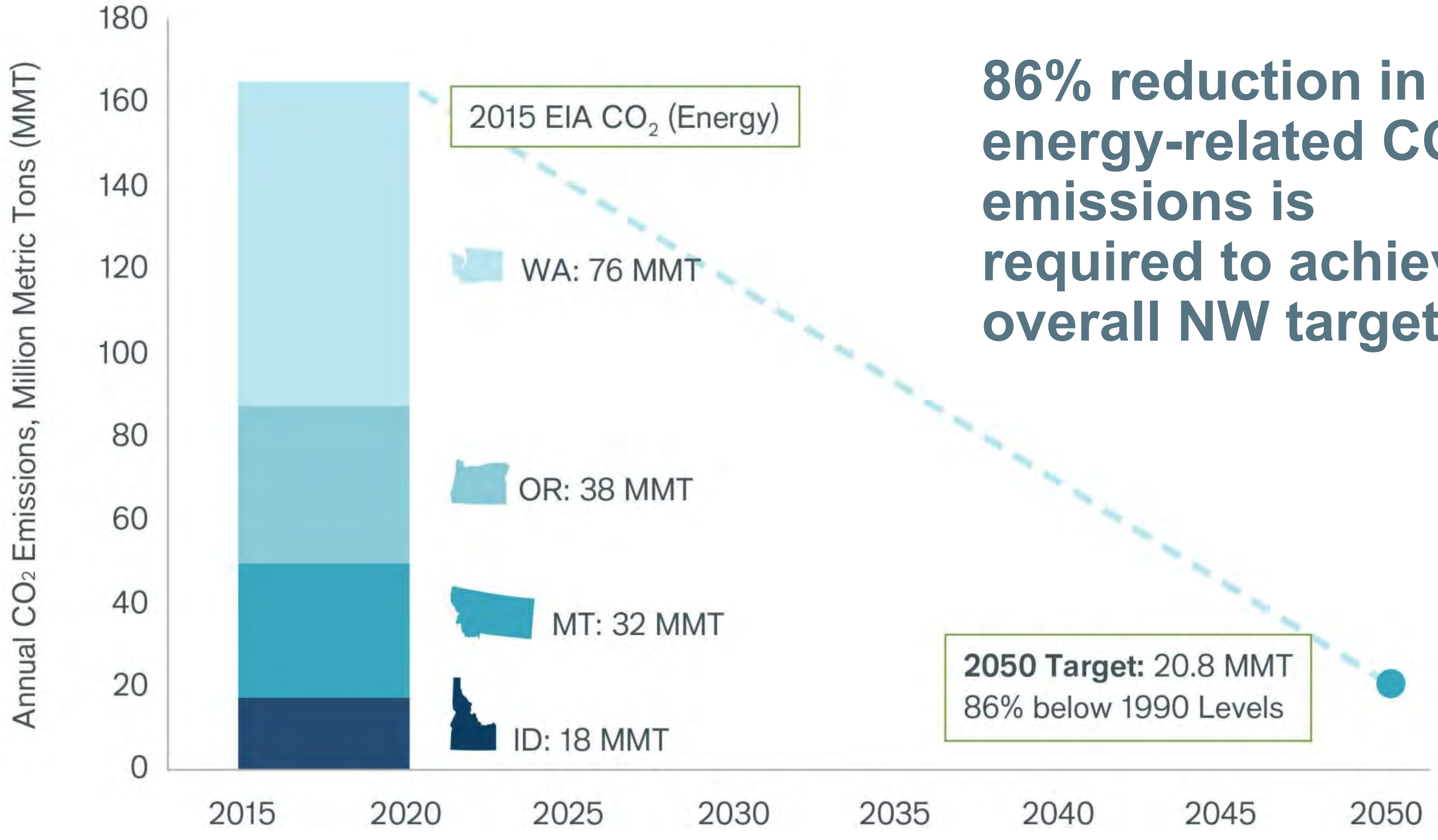
Year	Study	Scope	WA	OR	ID	MT
2016	State of Washington Office of the Governor	All sectors	●	○	○	○
2017	Public Generating Pool	Electricity sector only	●	●	◔	◔
2018	Portland General Electric	All sectors	○	◐	○	○
	Climate Solutions	Electricity sector only	●	●	◔	◔
	Northwest Natural Gas Company	All sectors; 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	●	●	●	●

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 CO_2 emissions is required to achieve overall NW target.

Key Conclusions

Key Findings-Deep Decarbonization Achievable

- **Electricity generation approaches 100% clean** without a specific mandate
- **Aggressive vehicle electrification and highly efficient built environment** powered by clean electricity are **essential**
- **Biomass primarily allocated to jet and diesel fuel**, even after partial electrification of freight
- **Thermal generation important for reliability** in periods of low hydro and renewable output (low capacity factor)
- **New technologies and flexible electric loads combined with storage likely to play key role** producing pipeline fuels & balancing the grid
- **Significant cost savings** if the Northwest and California **grids are better integrated**

Transformations Needed on the Demand Side

- **Aggressive demand-side electrification** with commensurate reductions in fuel demand
  - Either fuels are quantity constrained (biofuels) or Fuels become increasingly expensive per unit of fuel produced (electric fuels)
- **Electrifying transportation**
- **Biomass most efficiently allocated to jet and diesel** fuel rather than pipeline gas

Transformations Needed in Electricity Supply

- **Significant cost savings possible with expanded interties** between regions of the West
- **New technologies can play a key cross-sector role**
- **Thermal generation as a capacity resource** important for reliability
- **Role for carbon capture** on biofuels facilities or direct air capture (DAC)

Modeling Approach

Proven Toolkit

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

Approach to Decarbonizing Energy Supply

- **Least-cost, optimization framework**
- **Already applied** in certain industries to plan for future energy needs
- **Modeling determines optimal investment** in resources
- **Fuel and supply-side infrastructure decisions determined simultaneously** while considering constraints, such as electricity system reliability and biomass availability

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

Model of Northwest economy

Residential
Commercial
Industrial
Transportation

1: Model calculates energy needs

Northwest energy needs

Electricity
Liquid Fuels
Gaseous Fuels

2: Model calculates energy supply

Constrained by clean energy goals

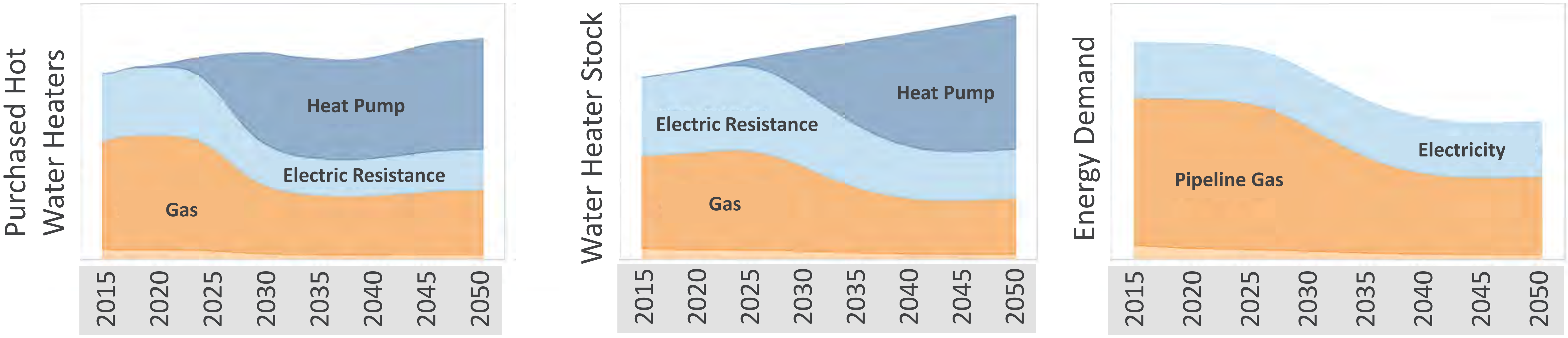
Supply energy reliably at least cost

Generation
Transmission
Storage
Fuel supply
Carbon

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

Key Consuming End-Use 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

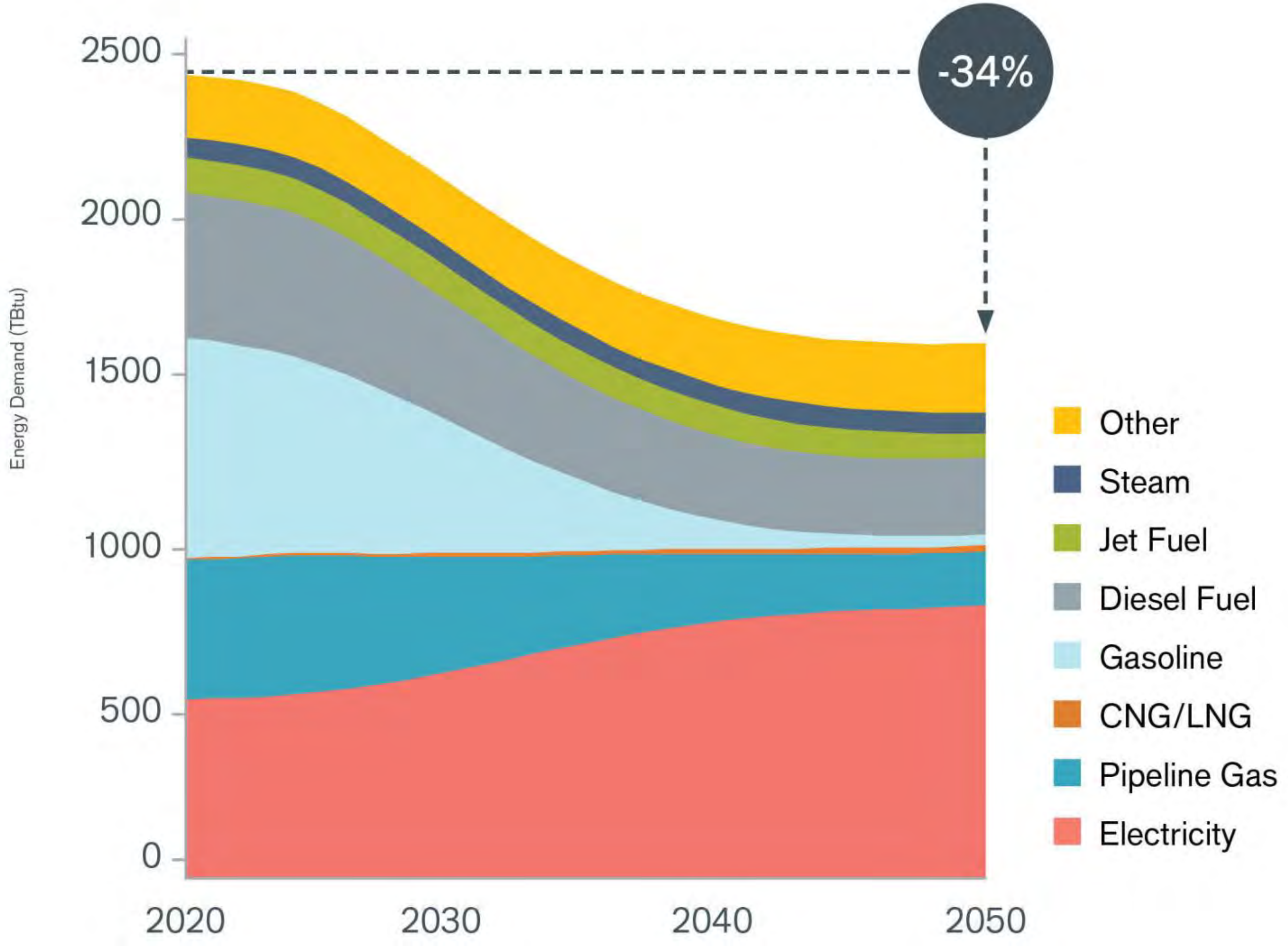
Industrial Sector
- Boilers
- Process heat
- Space heating
- Curing
- Drying
- Machine drives
- Additional subsectors (e.g., machinery, cement)

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.

2. Aggregate Energy Demand by Fuel Type across Economy

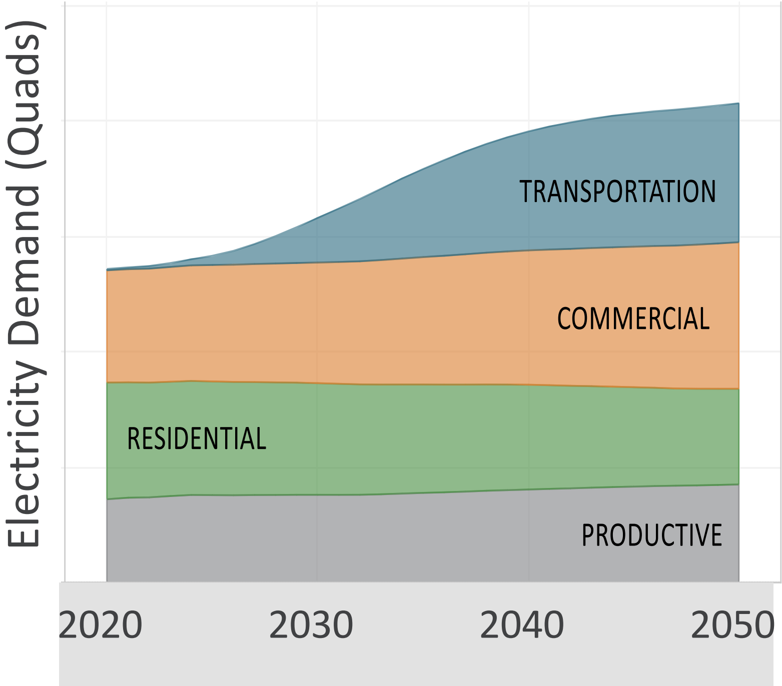
- Combining energy demand from stock rollover logic provides final energy demand by fuel type in each year
- Final energy demand is an input to the supply side model
  - How to meet these demands at least cost?



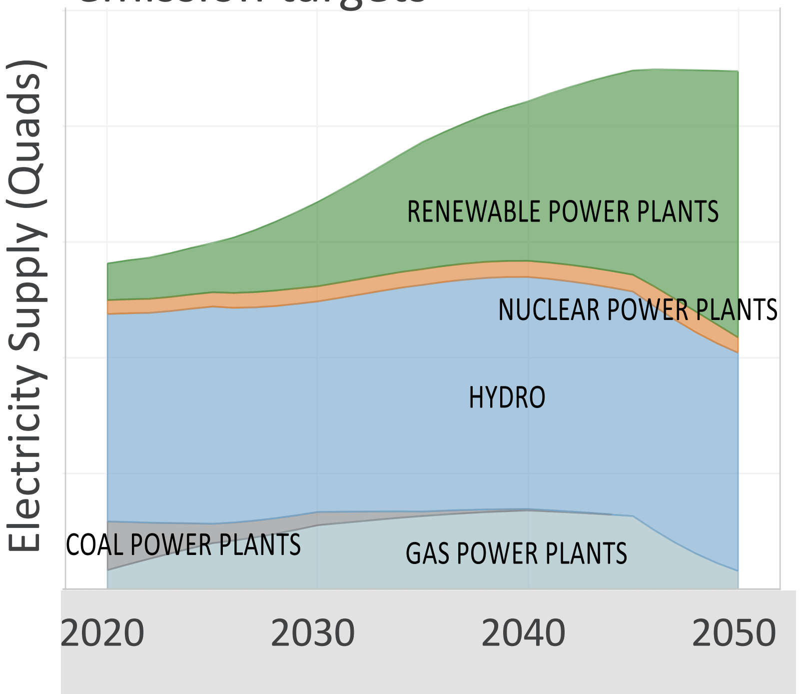
3. Model Optimizes Energy Infrastructure Investments for Northwest Energy Demands and Emissions Constraints

Example: Electricity

Electricity includes all economic sectors



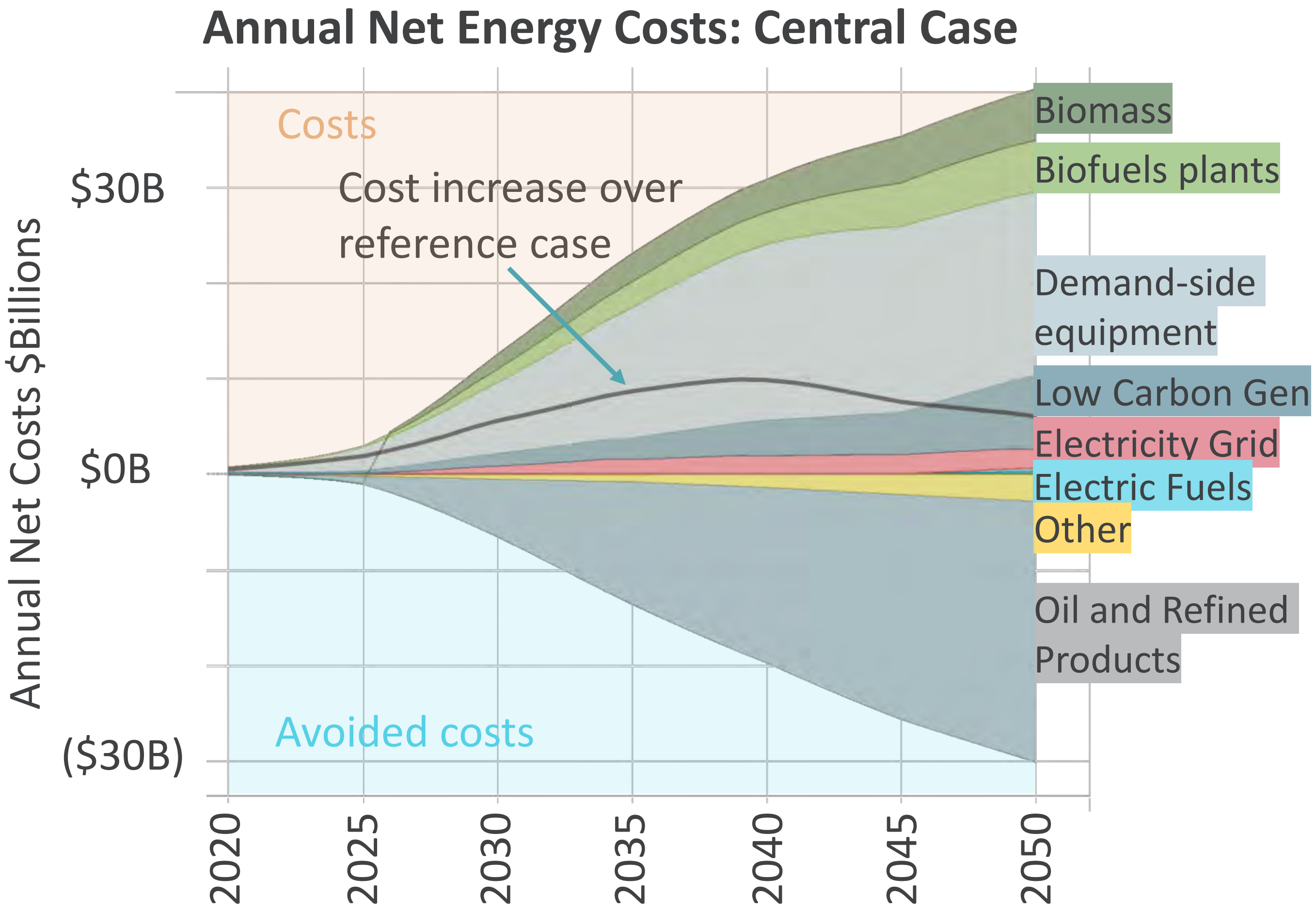
Model optimizes investments to meet demand, reliability, and emission targets



- **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

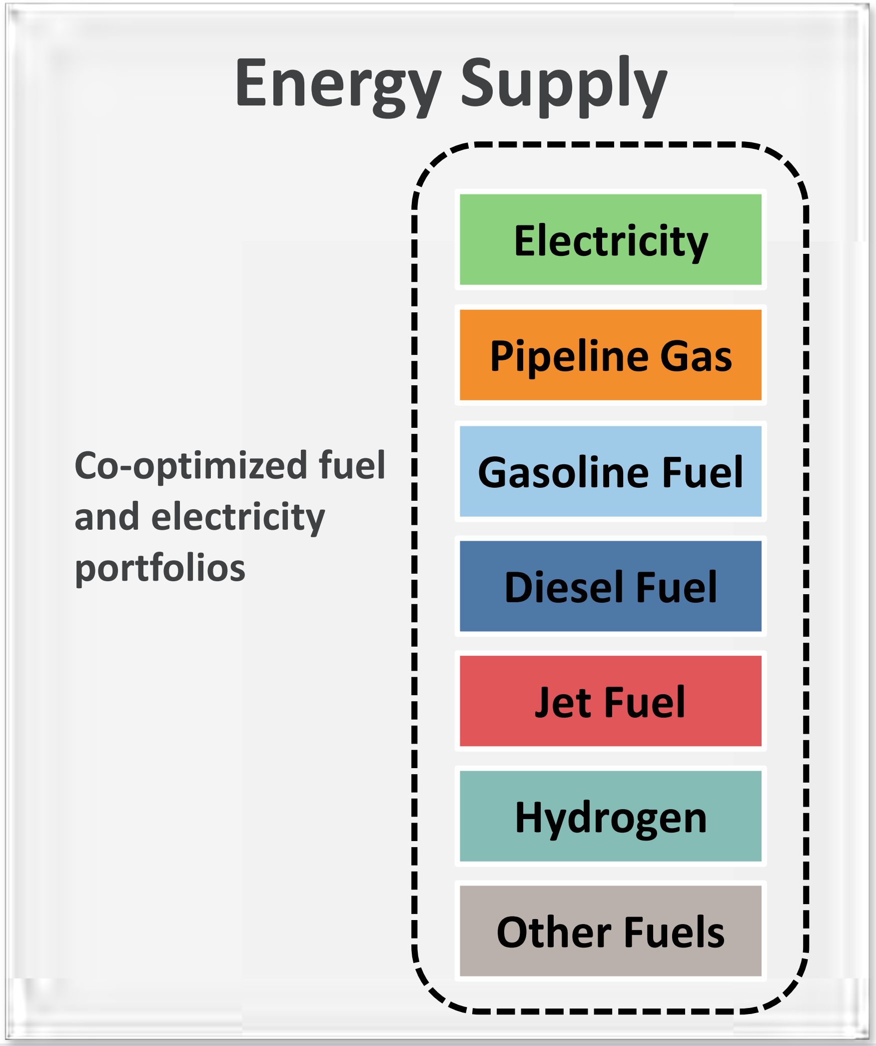


Modeling Framework-Pairing ENERGY Pathways & RIO

	ENERGY PATHWAYS	RIO
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)

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

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

Options to Supply End Use Fuel Demands

Supply-side resource options.

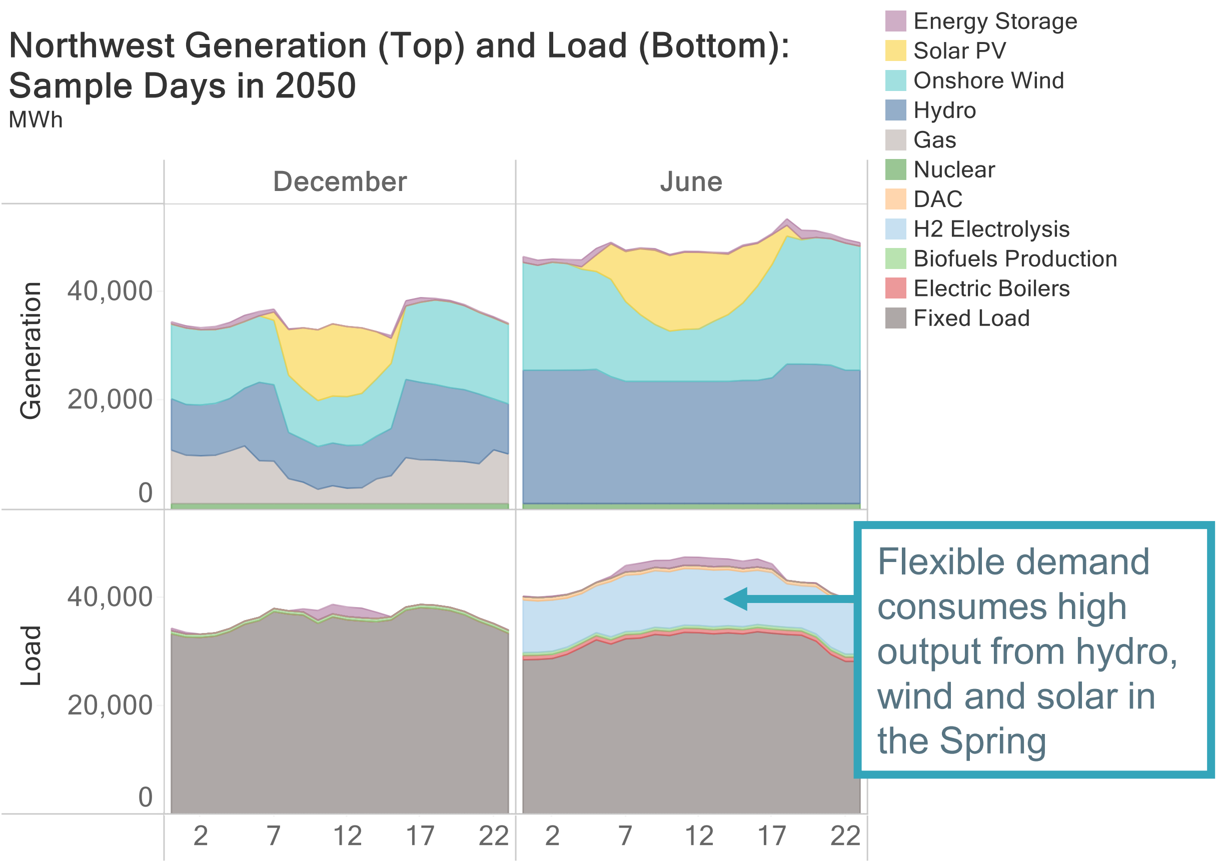
Diesel Fuel	Jet Fuel	Pipeline Gas	Liquid Hydrogen	Gasoline Fuel
Power-to-Diesel	Power-to-Jet-Fuel	Power-to-Gas	Electrolysis	Corn Ethanol
FT Diesel	FT Jet Fuel	Hydrogen	Natural Gas Reformation	Cellulosic Ethanol
FT Diesel with CCS	FT Jet Fuel with CCS	Biomass Gasification	Natural Gas Reformation with CCS	**Steam**
FT Diesel with CCU	FT Jet Fuel with CCU	Biomass Gasification with CCS	Natural Gas Reformation 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.

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



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?
- RIO enforces a capacity reserve constraint across all model hours, not just peak load hours or days
- RIO 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)

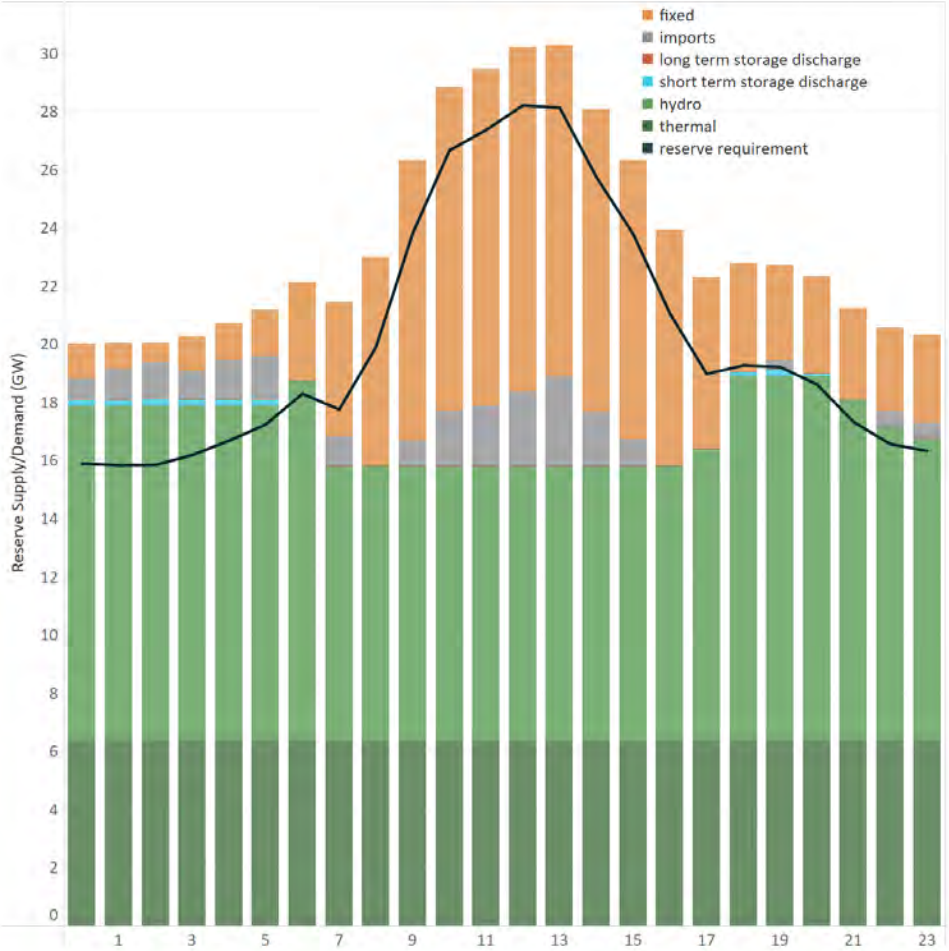
Hourly Planning Reserve Constraints by Zone

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



Study Overview

- **Explores** multiple pathways for decarbonizing the NW energy system
- **Addresses** policy questions and potential implementation challenges in the context of economy-wide carbon limits
  - **Central Case** represents our core deep decarbonization pathway (DDP)
  - **Additional DDP cases** developed *as sensitivities to* the Central Case
  - **Reference Case (BAU)** developed to compare the DDP cases against
- **Allows** for a better understanding of across the energy system, assuming:
  - Alternative levels of electrification
  - Mandates (100% clean electricity) or prohibitions (no new gas plants)
  - Constraints on the use of biomass
  - Further electricity sector integration between the Northwest and California

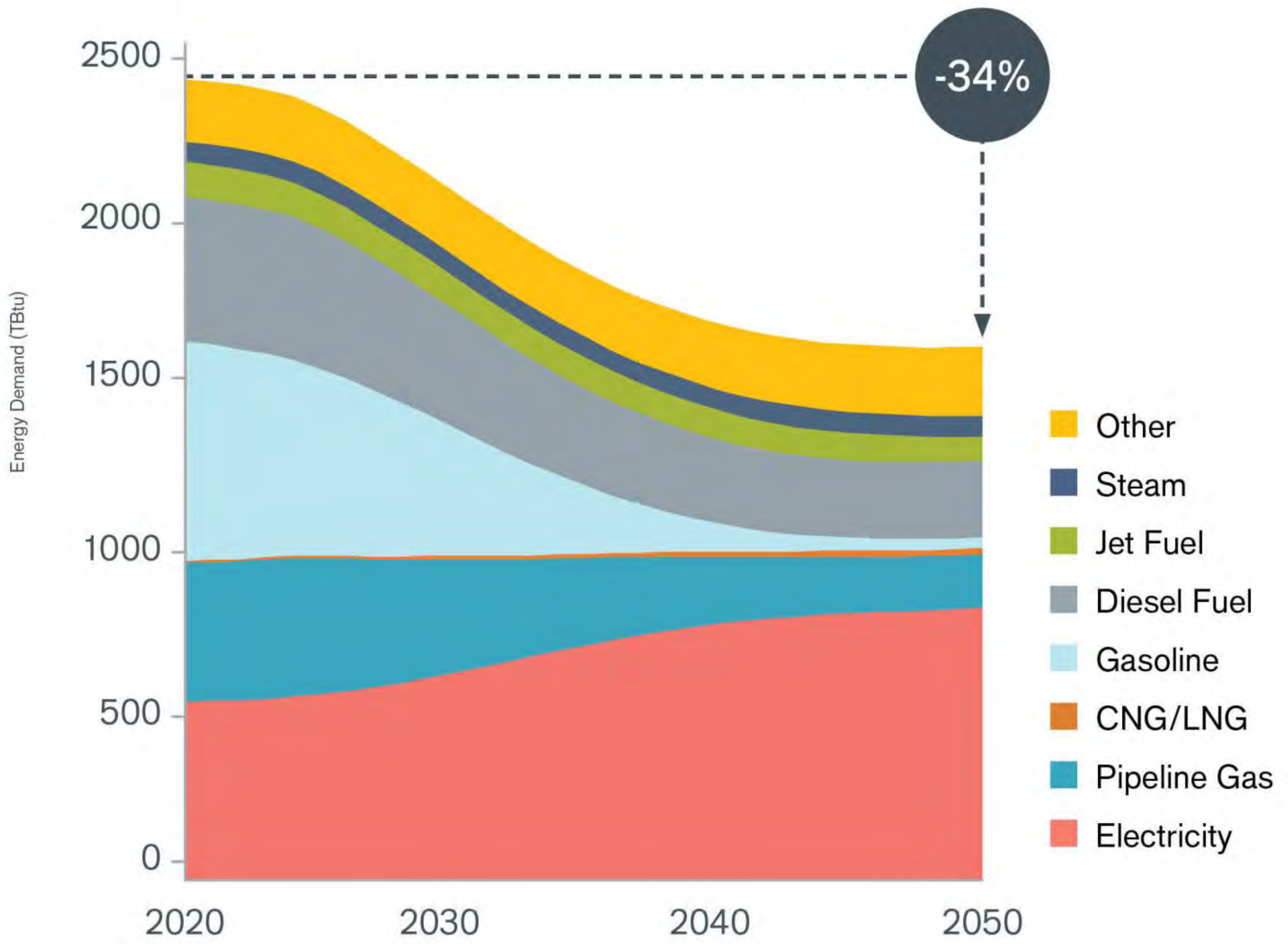
Eight Pathway Scenarios Examined

- 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
- Pipeline Gas for Freight Vehicles

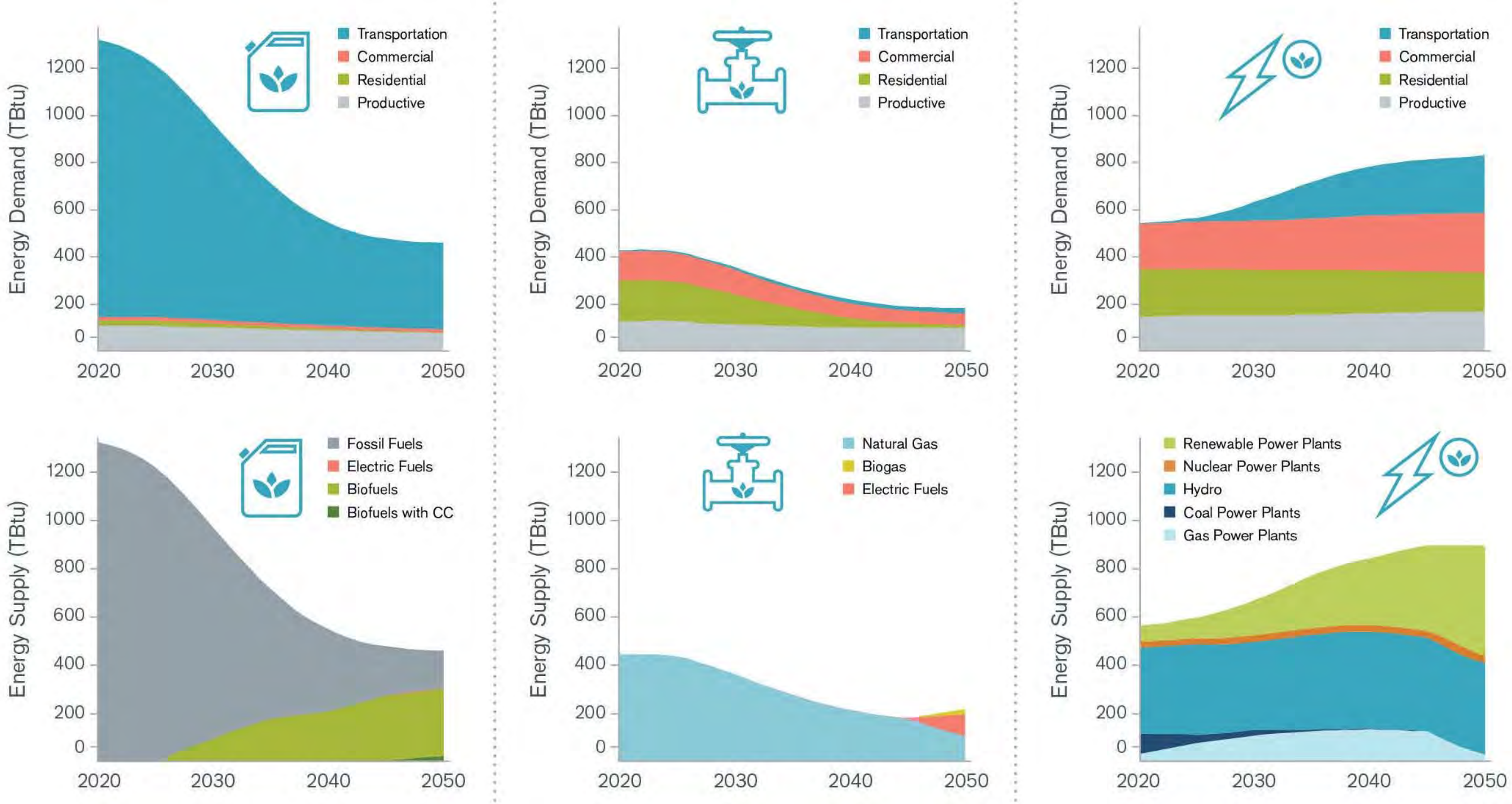
Overview of Central Case

Aggregate Energy Demand across the Economy

In the Central Case energy demand is down 34% and electricity consumption is up more than 50% in 2050.

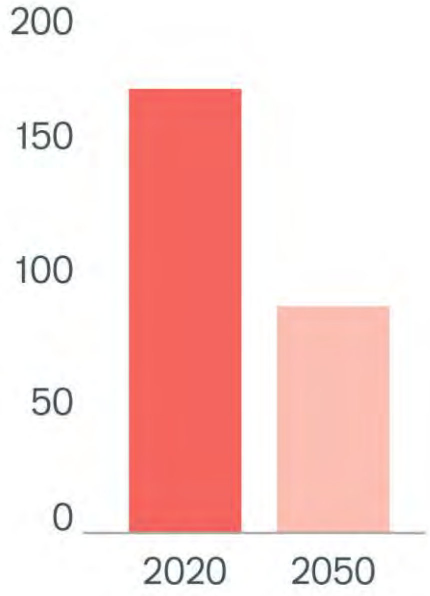


Change in Energy and Supply 2020-2050

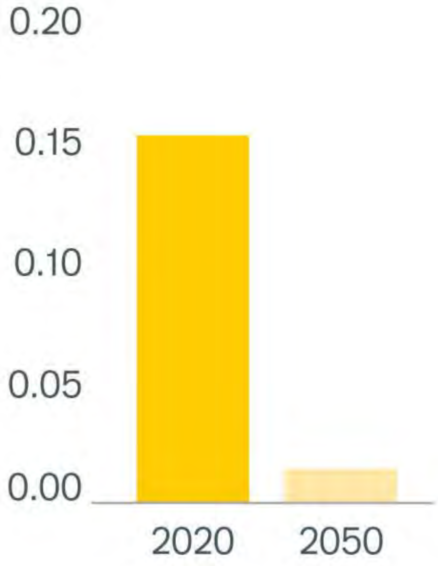


Five Decarbonization Strategies Deployed

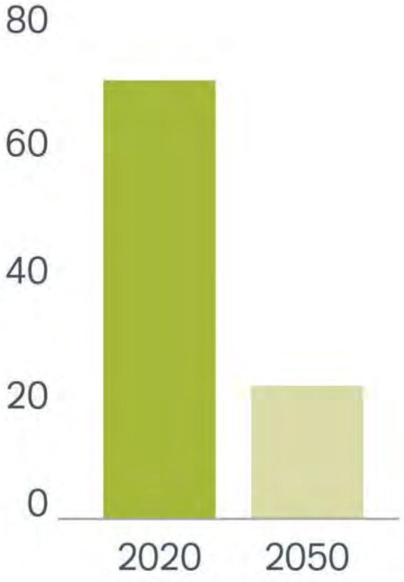
Energy Efficiency
Per capita energy decreases 50%



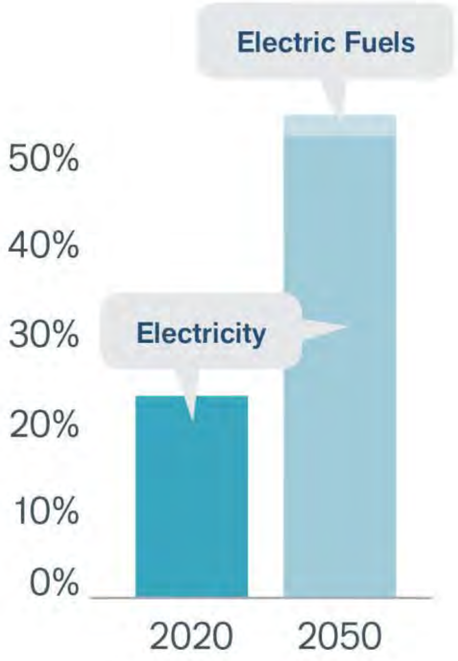
Electricity Decarbonization
96% Clean by 2050



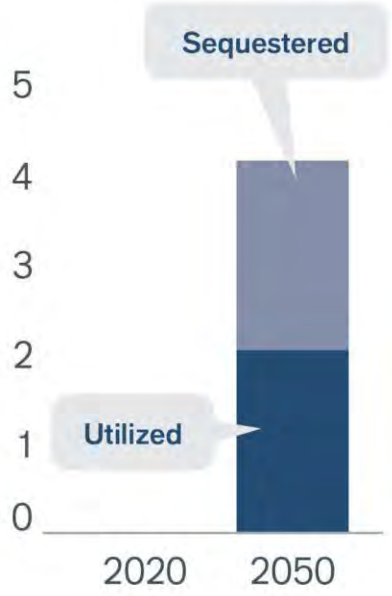
Fuel Decarbonization
70% decrease



Electrification
Doubles from 23% to 55%

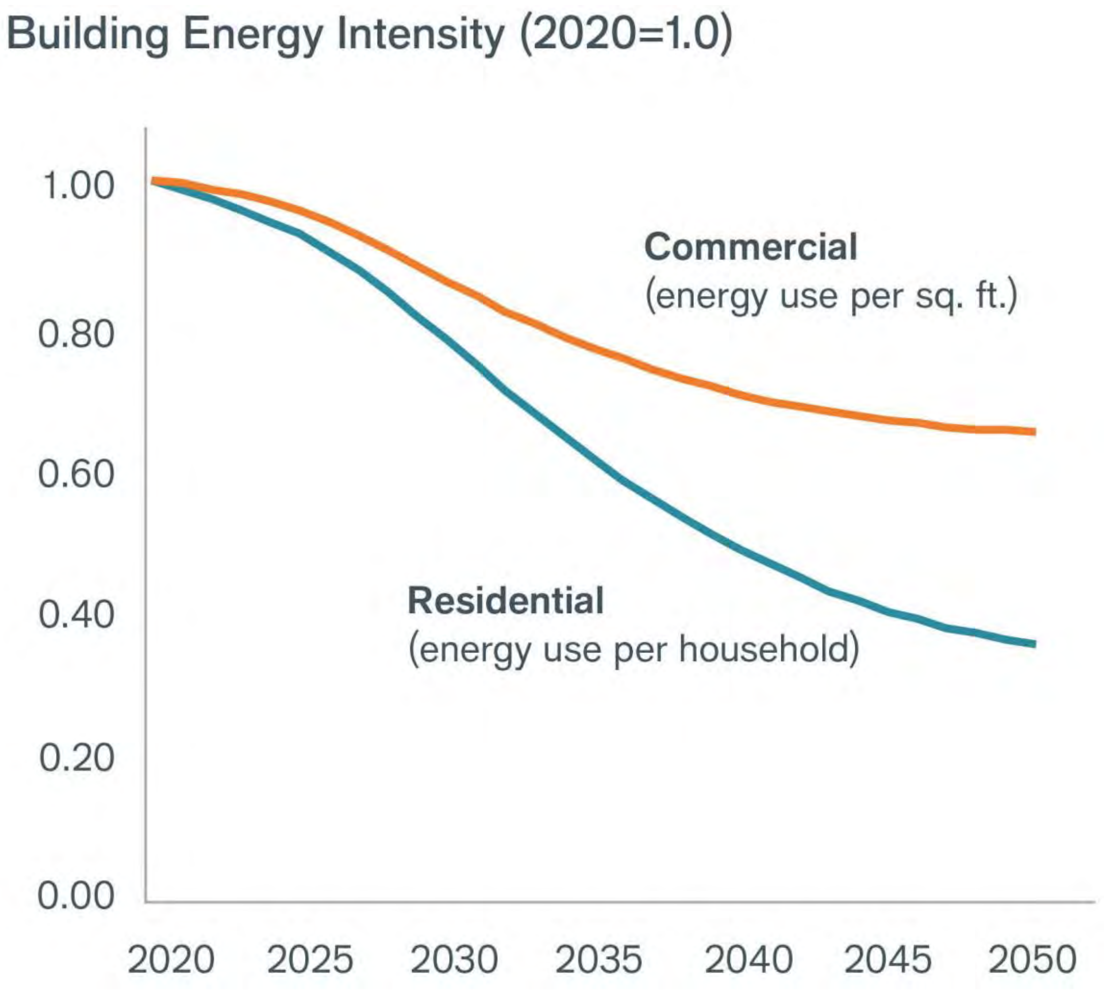


Carbon Capture
1/2 fuel; 1/2 sequestered



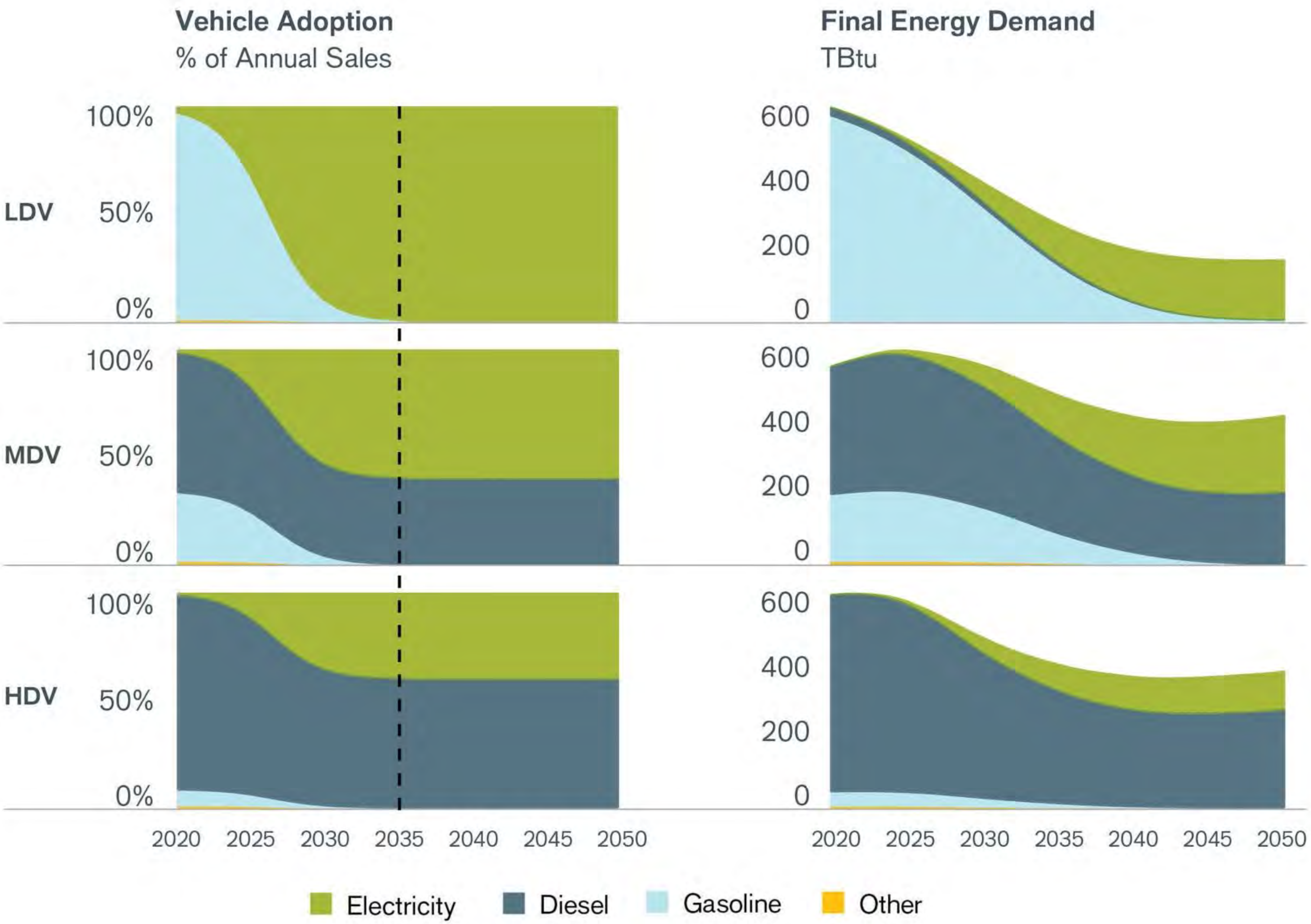
Buildings: Energy Efficiency & Electrification Impacts

Decline in building energy intensity for commercial and residential buildings from 2020 to 2050.



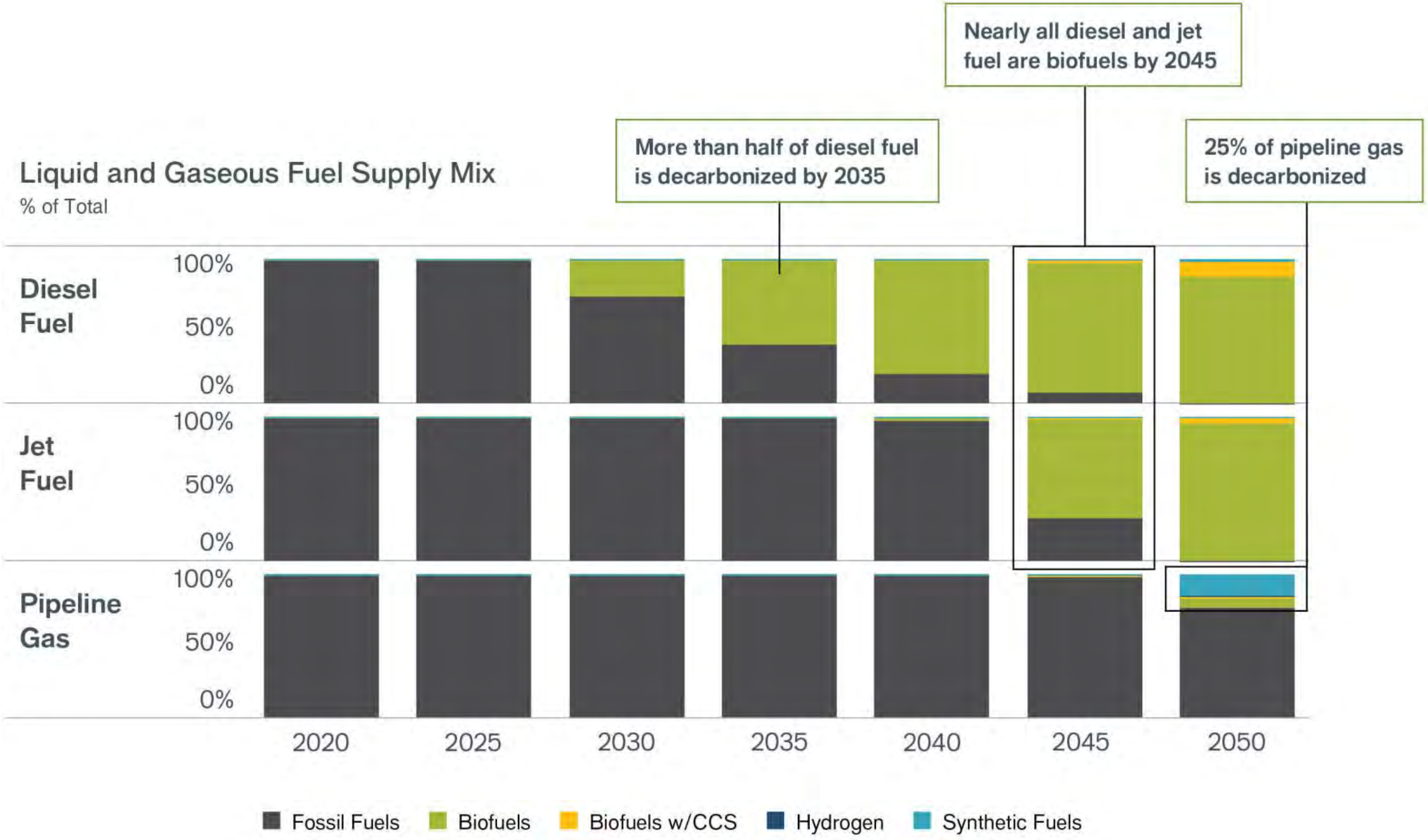
Transportation: Rate of Adoption and Fuel Mix

The rate of vehicle adoption as a percentage of annual sales by fuel type from 2020 to 2050 in the Central Case.



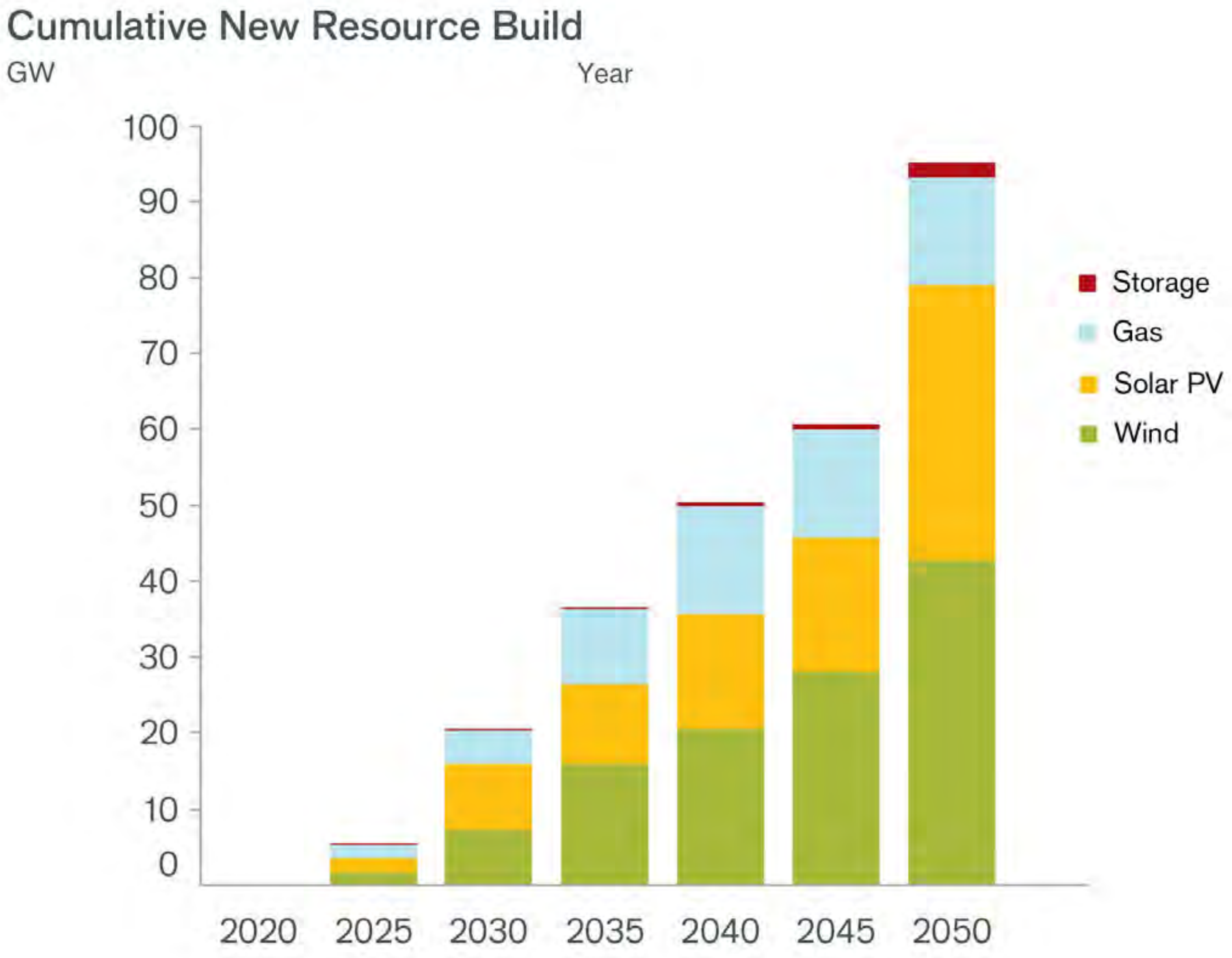
Decarbonizing Diesel, Jet, and Pipeline Gas

The composition of the liquid and gaseous fuel supply mix in the Central Case in five-year increments from 2020 to 2050.

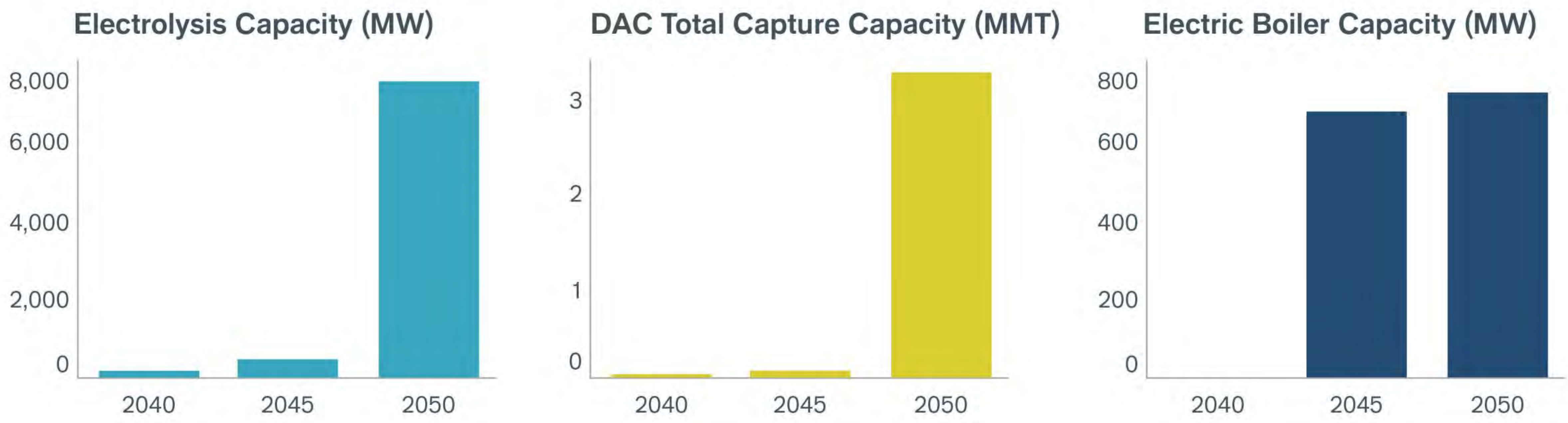


Electricity Sector: New Generation Resource Build

The Northwest region would build 95 gigawatts of new electric generation in the Central Case.



New Sources of Electric Load: Central Case



- Flexible electrolysis capacity is added starting in 2040 in the Central Case to address balancing challenges and produce synthetic fuels and gas.

Reliability

- RIO is primarily an economic model. However it makes conservative assumptions about load and resource availability to build a reliable system
- RIO ensures that 107% of load is covered by dependable contributions from available resources in every modeled hour of the 3 weather years (including dry hydro conditions and prolonged low renewable periods)
- The selected gas build for reliability aligns well with the E3-PGP reliability study findings:

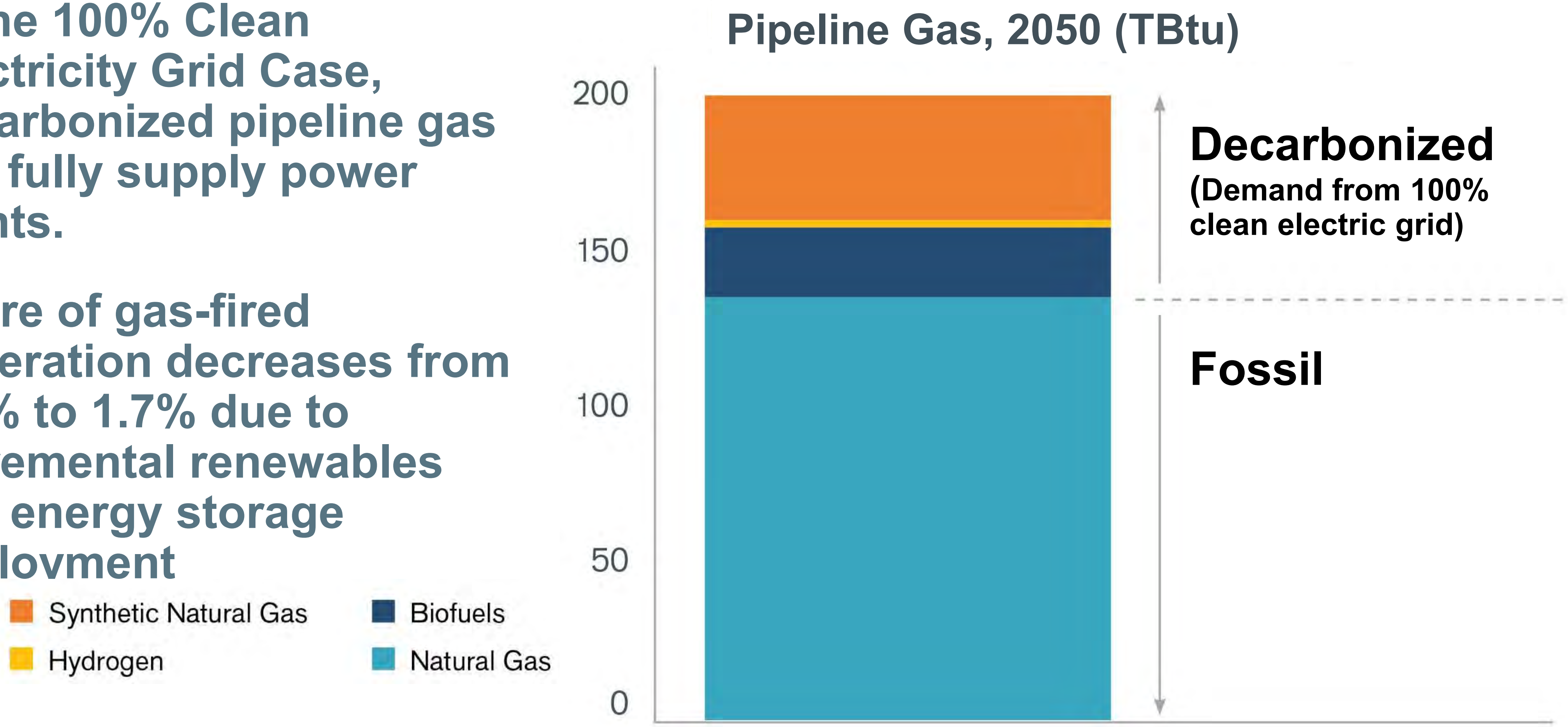
Year	Gas build in Northwest DDP	Gas build in E3-PGP Reliability Study
2030	5 GW, assuming 10 GW of wind and 10 GW of solar in 2030. RIO selects the most cost-effective resources to build including those with the greatest diversity benefit. The E3-PGP study describes diversity benefits increasing wind ELCC from 9% to 20% and solar ELCC from 14% to 20% in 2050 (however, this would also depend on future loads)	8 GW, assuming no new renewable build between now and 2030 (7.1 GW of wind and 1.6 GW of solar in 2030) and a larger service territory including Utah. No diversity benefit from new build renewables over 2018 fleet
2050	14 GW in 2050 for 96% decarbonization in the Central Case, though there are many other factors to consider in making this comparison	14 GW in 2050 for 98% decarbonized electricity for the larger service territory including Utah

Additional Scenarios

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 deplovment



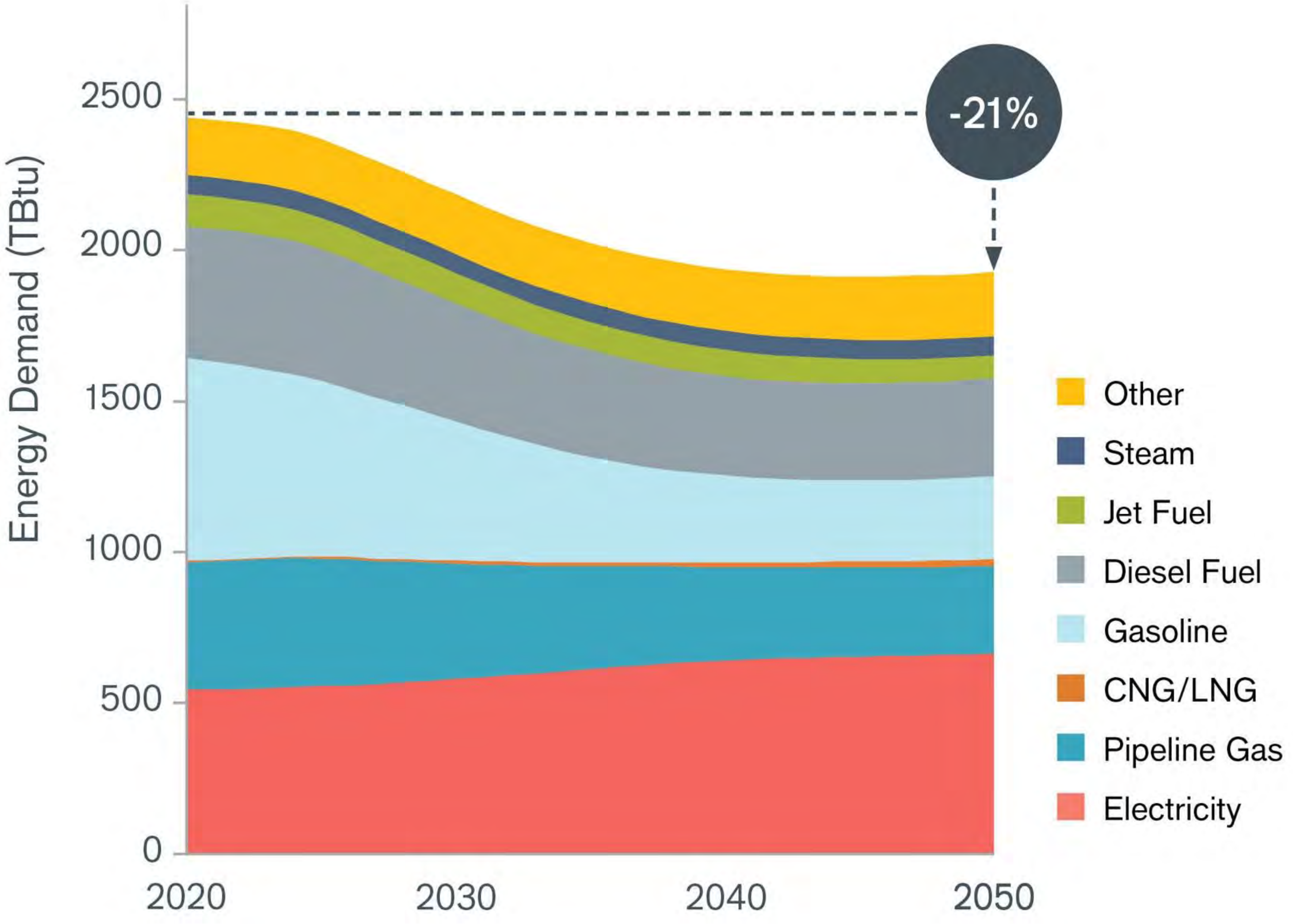
Limited Demand-Side Transformation Case

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

Limited Efficiency & Electrification

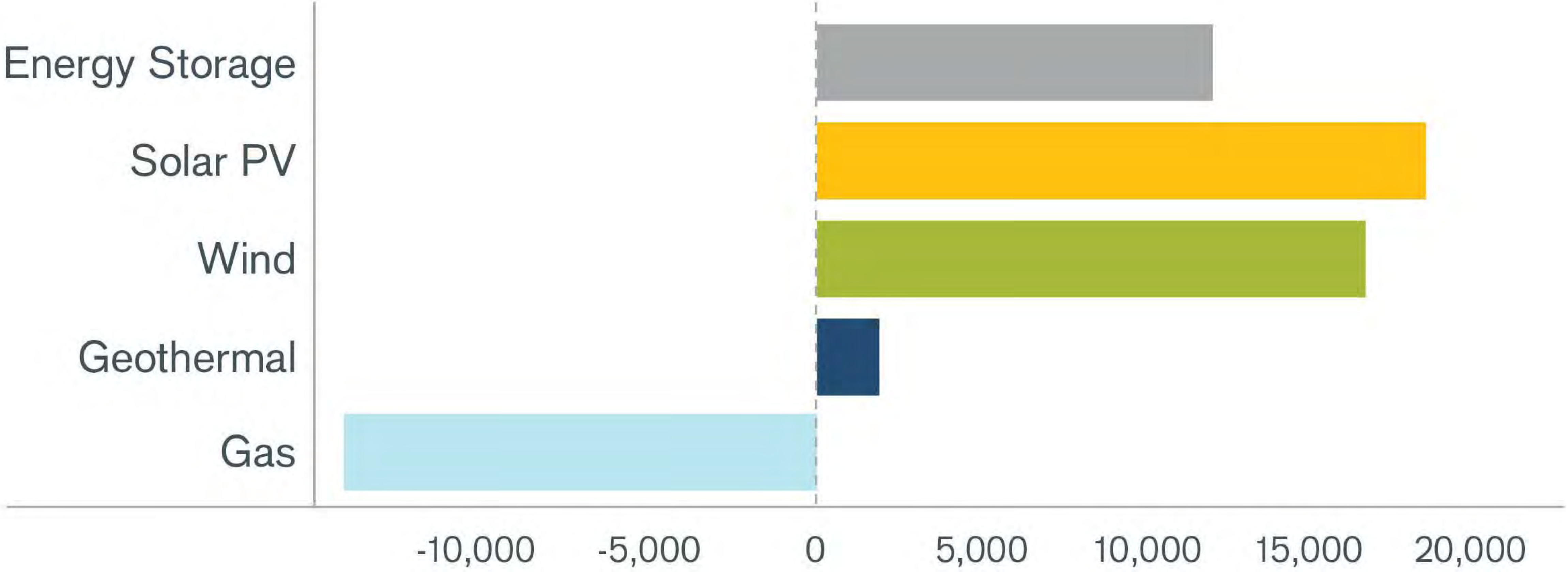
Energy demand declines by 21% in the Limited Electrification and Efficiency Achieved Case vs. 34% in the Central Case.

Less energy demand reduction means greater investment in fuels, most of which need to be decarbonized with expensive biofuels and synthetic fuels



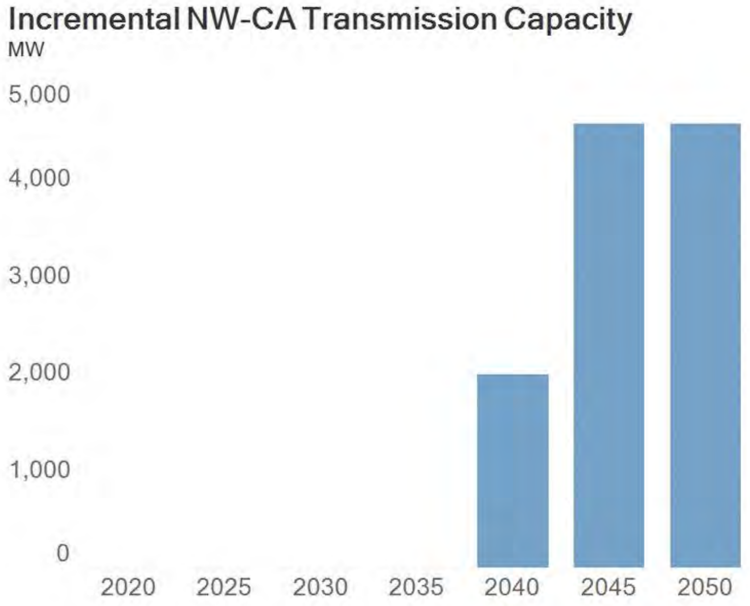
If No New Gas Plants Case

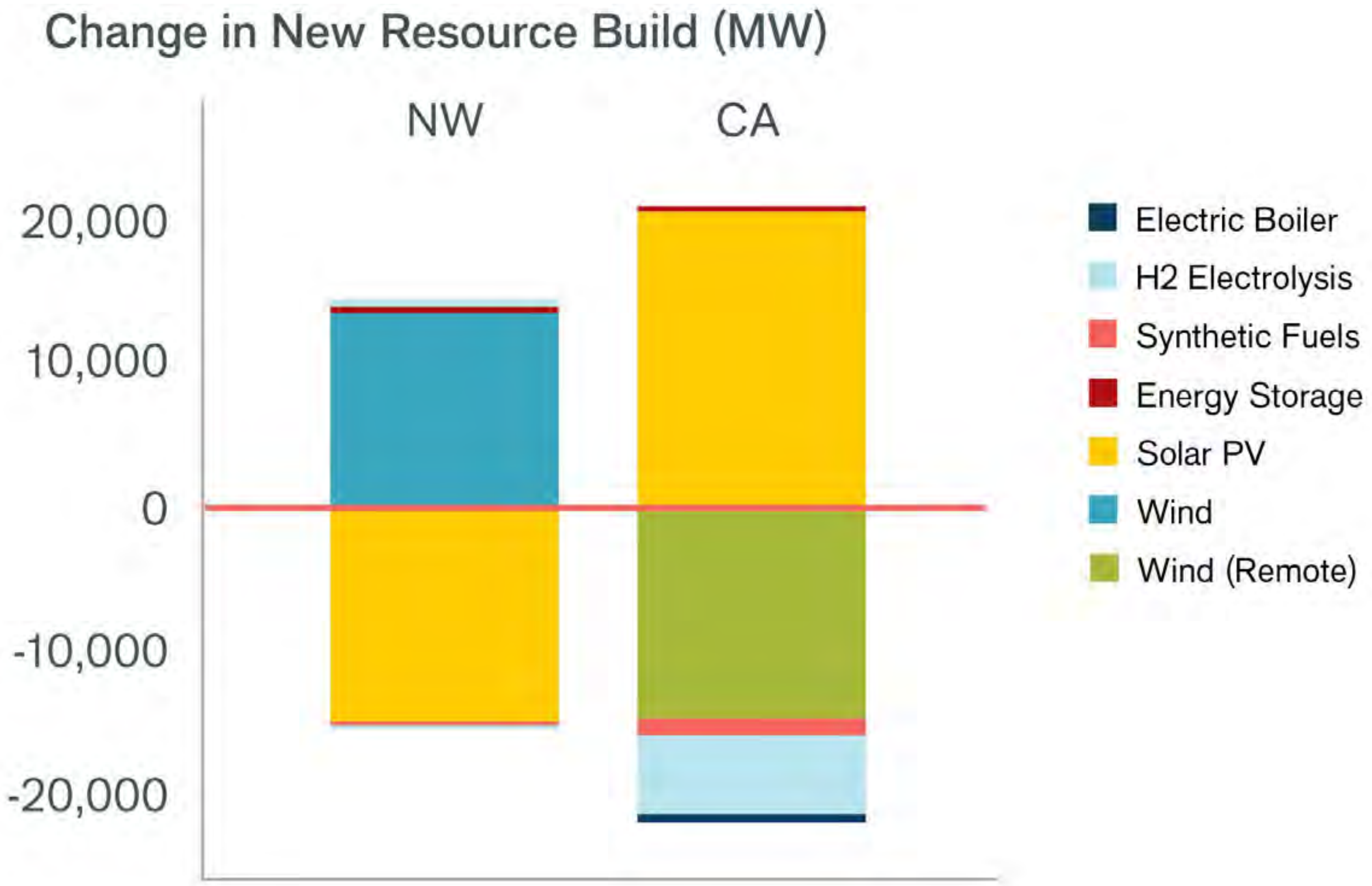
Change in Installed Capacity Relative to Central Case, 2050 (MV)



Increased NW-California Transmission

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

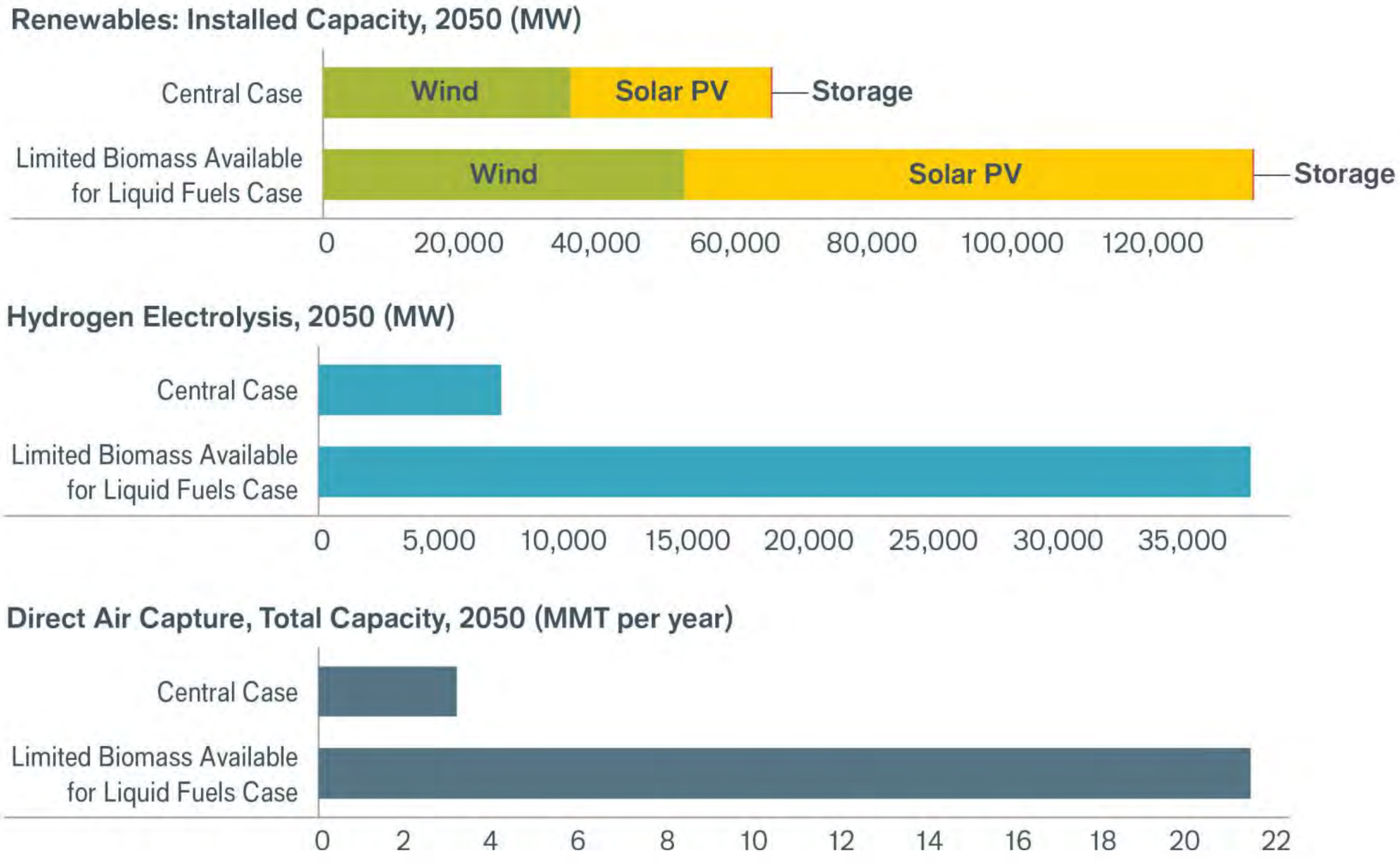




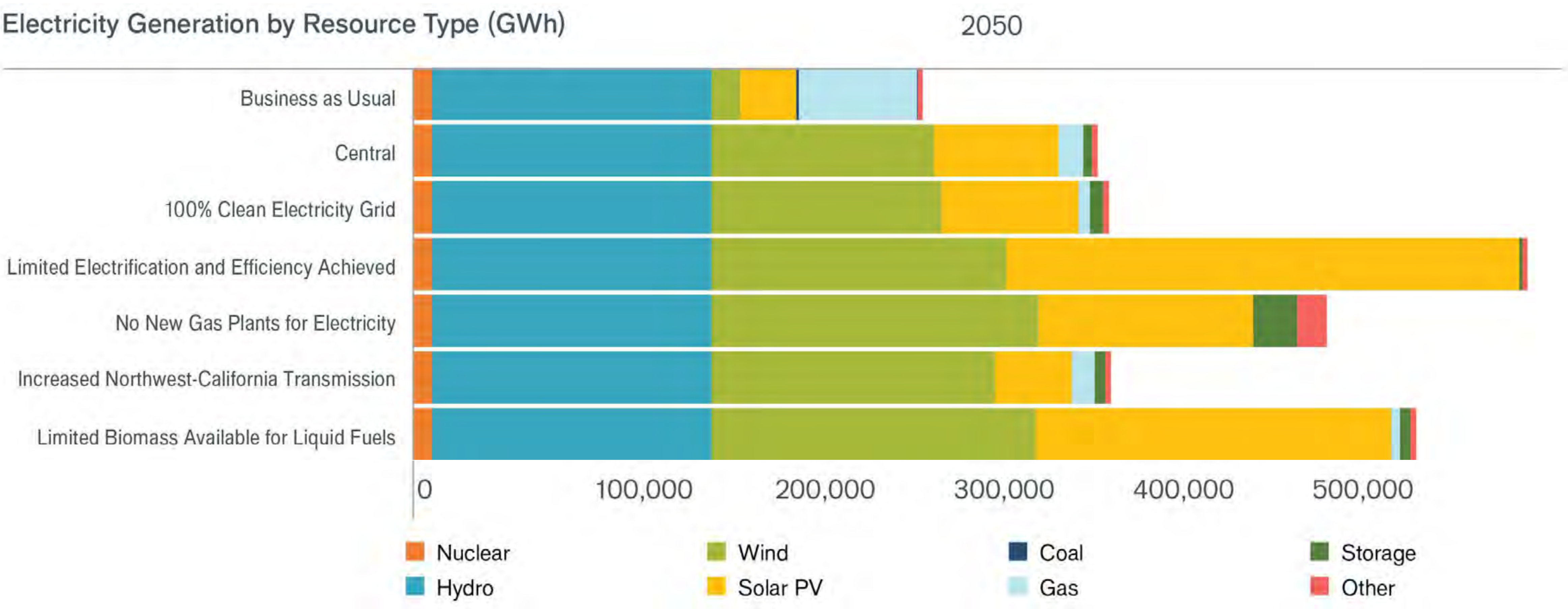
Limited Biomass

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



Electricity Resources All Cases in 2050



Insights from Alternative Pathways

Electricity Sector Insights: Part One

- **100% Clean Electricity Grid Case**
  - Gap between 100% Clean Electricity and Central scenarios much smaller than anticipated
  - Achieving 100% clean electricity easier with economy-wide decarbonization; resources with low-carbon co-products across the energy system (e.g., hydrogen) are considered
- **No New Gas Plants for Electricity Case**
  - Results in additional energy storage and renewables that can provide reliable supply
  - Cost of implementing managed by electric fuels using excess renewables
  - Approximately double the incremental costs of the Central Case:
    - $6.1B net energy system cost in the Central Case
    - $11.6B net energy system cost in the No New Gas Plants Case

Electricity Sector Insights: Part Two

- **Increased NW-CA Transmission Case**
  - Achieve decarbonization at potentially lower costs
  - Long-term planning changes beyond near-term challenges and issues
- **Impacts**
  - 4,500 MW of incremental transmission capacity
  - Altered optimal electricity portfolios in each region
  - Avoided development of low-quality renewables
  - Net present value of savings is $11.1 billion; offsets higher investment
- **Scale of benefits** indicates deeper investigation needed

Electrifcation & Biomass Implications

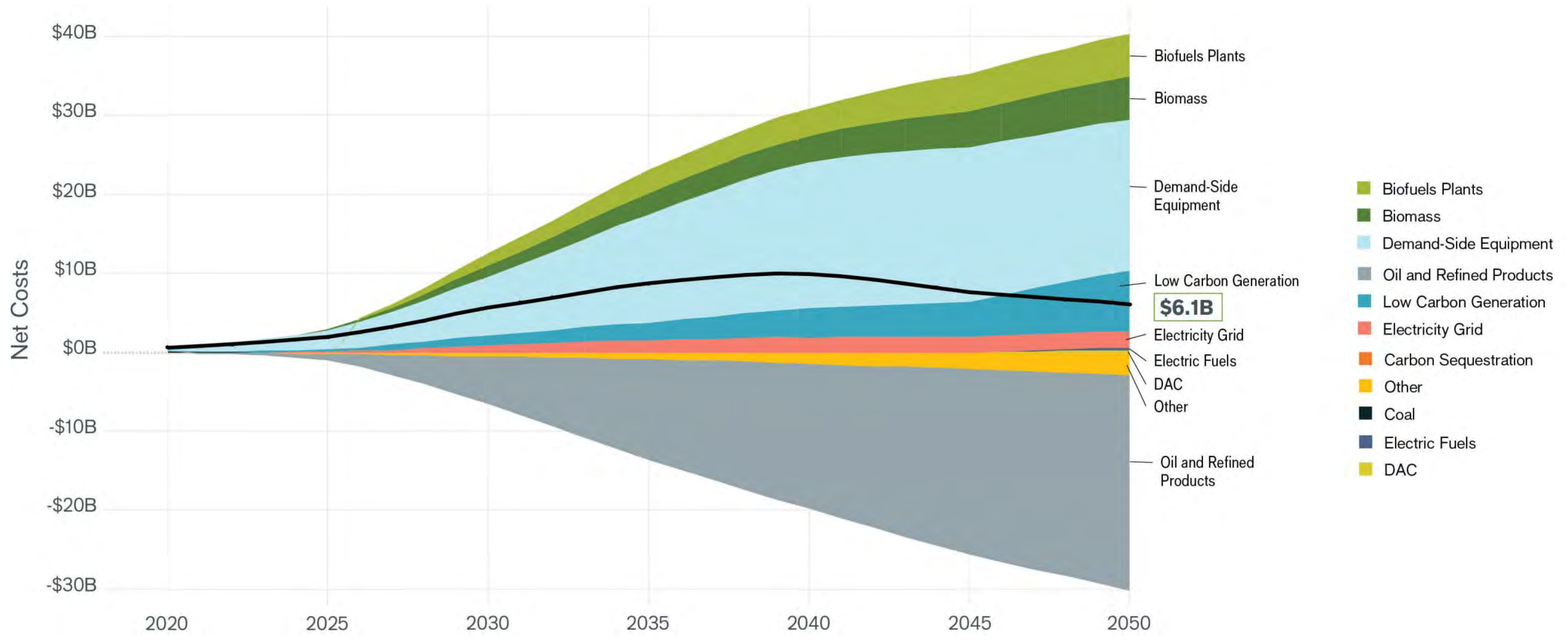
- **Failure to electrify** = enormous implications for supply
  - Scale of new facilities could be prohibitive in implementation
  - May require imports of electric fuels produced elsewhere
- **Restricted biomass availability** = similar energy system impacts
- **The "backstop" resource** is synthetic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

Costs

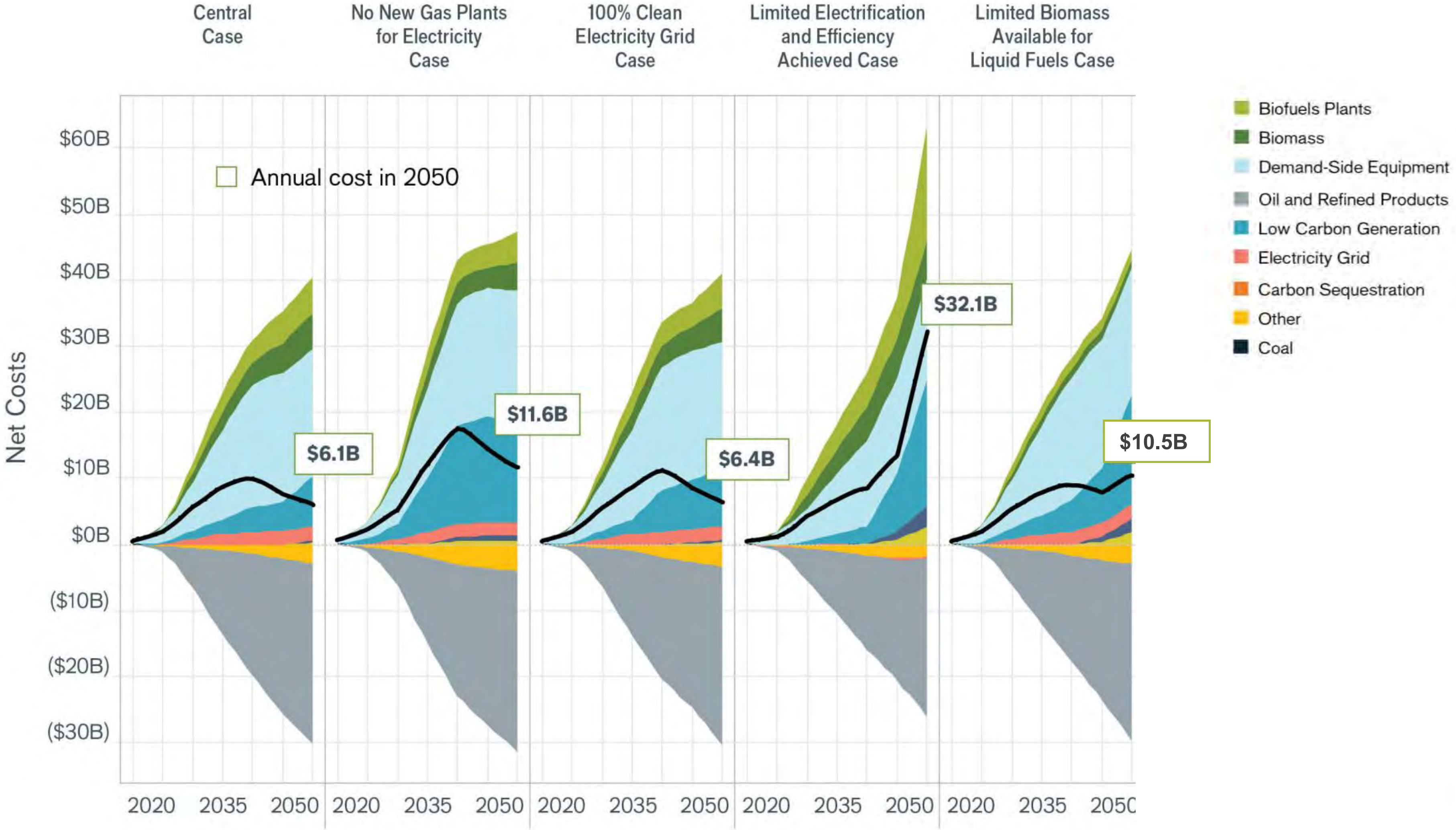
Costs

- 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
- Net costs for most of the scenarios range from $4B-$11B, with the Central Case's annual net cost $6.1B in 2050
  - However, deep decarbonization is five times more expensive ($32B) if efficiency targets and aggressive electrification are not achieved

Net Annual Energy Costs



Annual Net Energy System Costs, Six Cases



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Thank you

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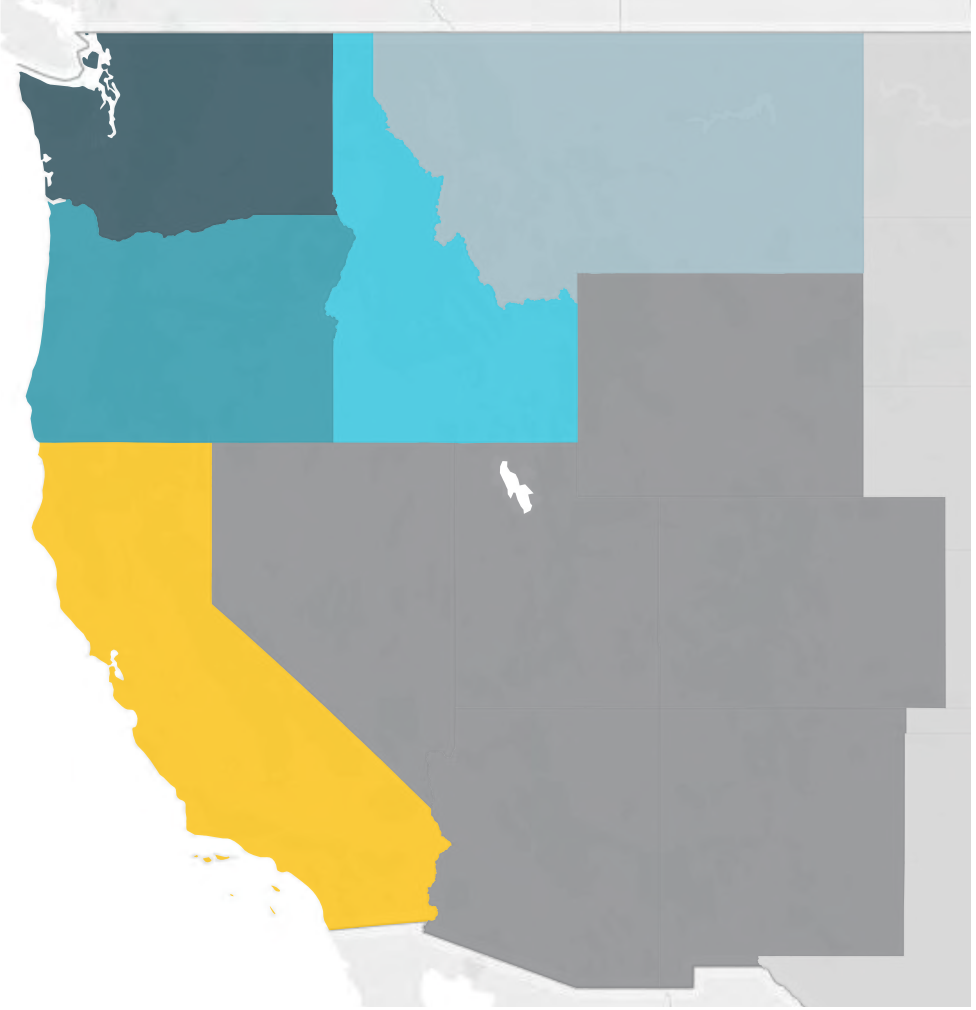
Appendix: Modeling Approach

Electric Topology

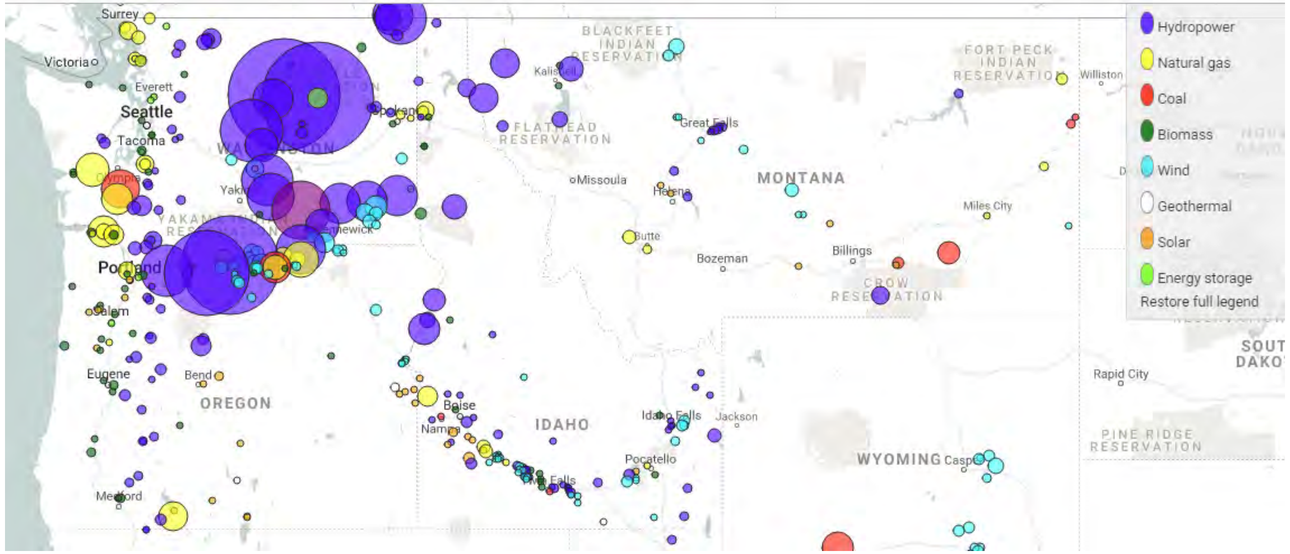
- Electricity sector operations and investment modeled across
  - Northwest states
  - California
  - Rest of the Western Electric Coordination Council (WECC)
- Transfer capability between zones is based on major WECC paths and their line ratings
- Capacity of major remote generation resources (e.g.,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