Modeling Methodology and Data Assumptions

Agenda-May 13, 2020 DDP Modeling Webinar

- Planning Framework
- Model Overview
- Model Structure and Operations
- Reliability
- Sourcing Data
- Key Results
- Introduction to Scenarios

Transforming Washington's Energy System

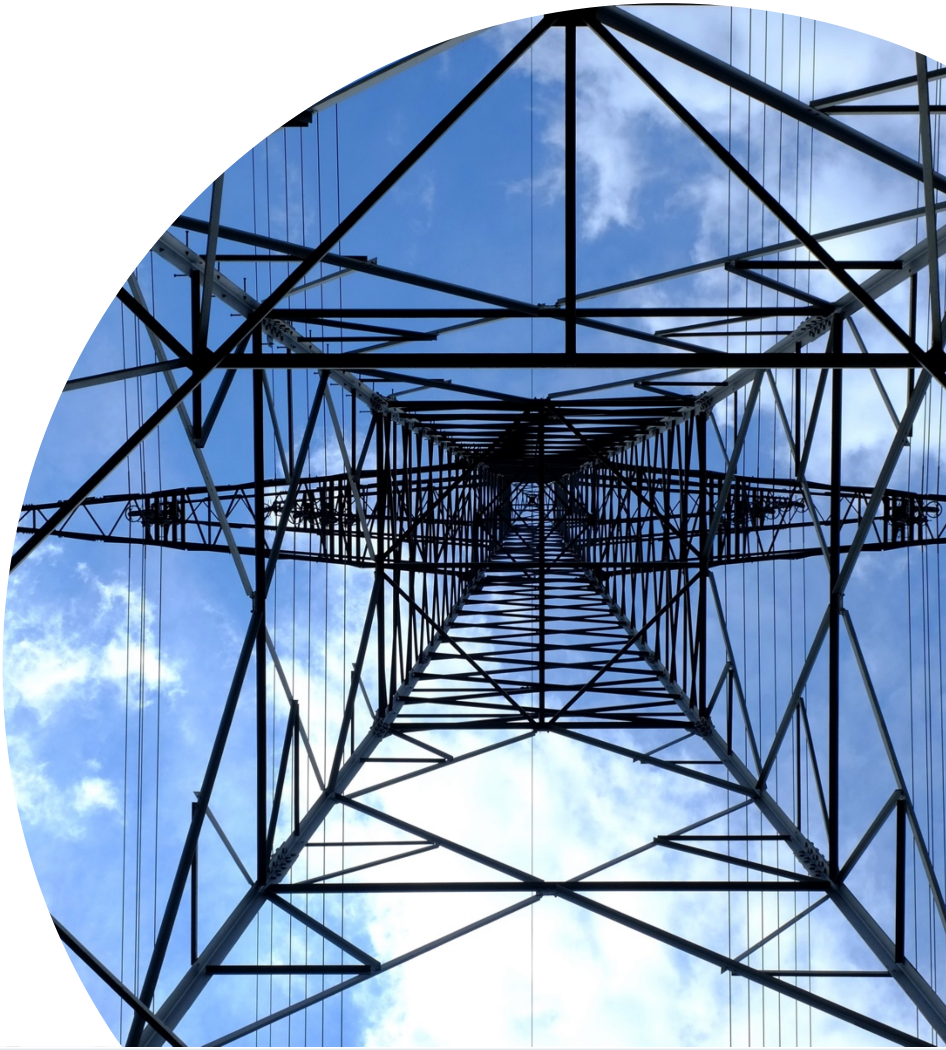
- Transformational rather than incremental change
- Aggressive action needed across all energy sectors
- Many options to get there
  - Process designed to find the best path forward for Washington State's priorities
    - Equity, affordability, reliability, competitiveness
- Building on a foundation of past studies and efforts in other states

Emissions targets for State Energy Strategy:

2020: 1990 levels
2030: 45% below 1990
2040: 70% below 1990
2050: 95% below 1990
2050: Net zero

Approach to Modeling Decarbonized Energy Supply

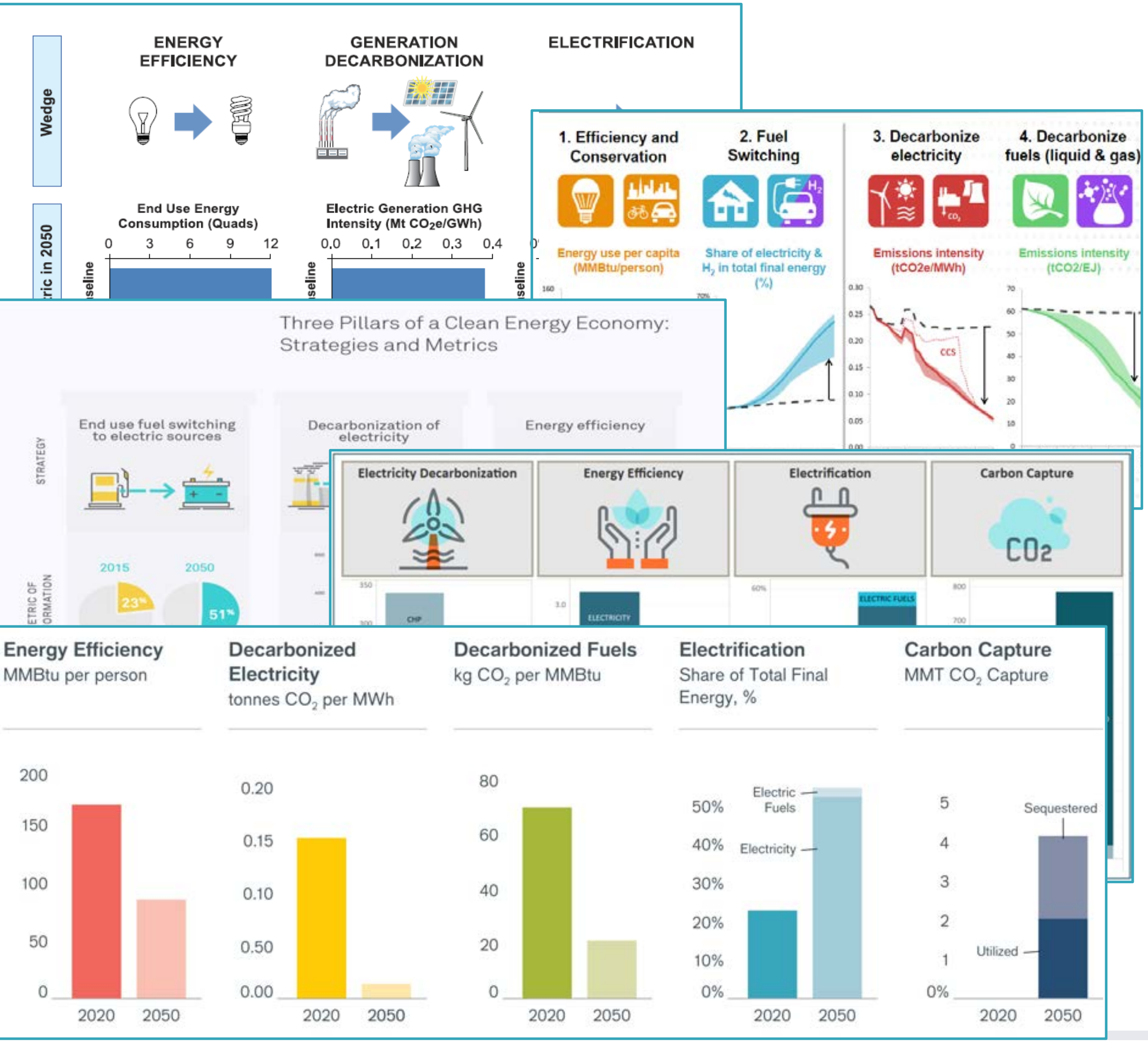
- **Conservative** assumptions about existing technology from public sources
- **Explores** how Washington can achieve deep decarbonization in all energy sectors
- **Modeling determines optimal investment** in resources with least-cost, constrained by scenarios that balance different state objectives
- **Decarbonizing energy supply**—electricity, pipeline gas, liquid fuels
- Models interactions with **western states**



Prior Decarbonization Studies

Study	Geography	Author(s)	Year
2050 Pathways Analysis	United Kingdom	Department of Energy and Climate Change (DECC)	2010
The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity	California	Jim Williams, et al.	2012
Pathways to deep decarbonization in the United States	United States	Jim Williams, et al. (E3/LBNL/PNNL)	2014
Pathways to deep decarbonization 2015 report	Sixteen countries	Deep Decarbonization Pathways Project (DDPP)	2015
What Will the Energy Transformation Cost? Pathways for transforming the German energy system by 2050	Germany	Fraunhofer ISE	2015
California PATHWAYS: GHG Scenario Results	California	E3/LBNL	2015
Policy implications of deep decarbonization in the United States	United States	Jim Williams, et al. (DDPP)	2015
United States Mid-Century Strategy	United States	The White House	2016
From Risk to Return: Investing in a Clean Energy Economy	United States	Risky Business Project; WRI; EER	2016
Deep Decarbonization Pathways Analysis for Washington State	Washington	EER; Jim Williams (DDPP)	2017
Portland General Electric Decarbonization Study	Northwest Oregon	EER	2018
Northwest Natural Gas Company (Description in Regional Studies section)	Washington and Oregon	E3	2018
350PPM Pathways for the United States, Our Children's Trust	United States	EER	2019
Clean Energy Transition Institute	Northwestern United States	EER	2019
New Jersey Energy Master Plan, New Jersey Board of Public Utilities	New Jersey	RMI/EER	2020

Commonalities among Decarbonization Studies



- Reviews of decarbonization studies show commonalities
  - CETI, 2018, 58 studies reviewed
  - Jenkins, Thernstrom, 2017, 30 studies reviewed
- Actions grouped into familiar pillars/strategies
  - Energy efficiency and conservation
  - Decarbonized electricity
  - Electrification/fuels switching
  - Decarbonized fuels
  - Carbon capture
- Actions specific by region

From top to bottom:
The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050, Williams et al., Science 2012
California Pathways: GHG Scenario Results, E3, 2015
From Risk to Return: Investing in a Clean Energy Economy, Risky Business, EER, 2016
350ppm Pathways for the United States, EER, 2019
Meeting the Challenge of Our Time: Pathways to a Low Carbon Future for the Northwest, CETI, EER, 2019

Planning Framework

Why model the future energy system?

Tailored Analytical Approach for Washington State

- Least-cost energy system planning, and policy/action design complement one another
  - Process to determine Washington State's best path forward
- 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
- Advisory Committee and technical advisory process input essential to help us define the options

Three Framing Questions

- Where are we now?
  - *What is the current state of Washington’s energy system?*
- Where do we want to go?
  - *What are Washington’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?

Washington and WECC current energy resources and infrastructure

- **Stock** of all energy producing and consuming technologies
- **Patterns** of energy consumption
- **Final energy demand of fuels and electricity** across the economy
- **WA and WECC electricity system**
- **Transmission between Washington, neighboring states, and beyond**
- **Fuel prices and sources**

Existing Washington policies and targets through 2030 and 2050

- **Electricity fuel mix disclosure**
- **Biennial energy report**
- **Utility resource plans**
- **Energy code strategy**
- **Bioenergy coordination**
- **Energy Independence Act**
- **Appliance standards**
- **Power plant emission standards**
- **Clean Energy Transformation Act**

Where Do We Want to Go?

- What is the best future we can envision for the state?
  - Balance of different, often competing objectives
    - Equity, affordability, reliability, competitiveness
  - 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

No Nuclear Extension

Examples for illustration only

Evaluating uncertainties

Limited Electrification & Efficiency

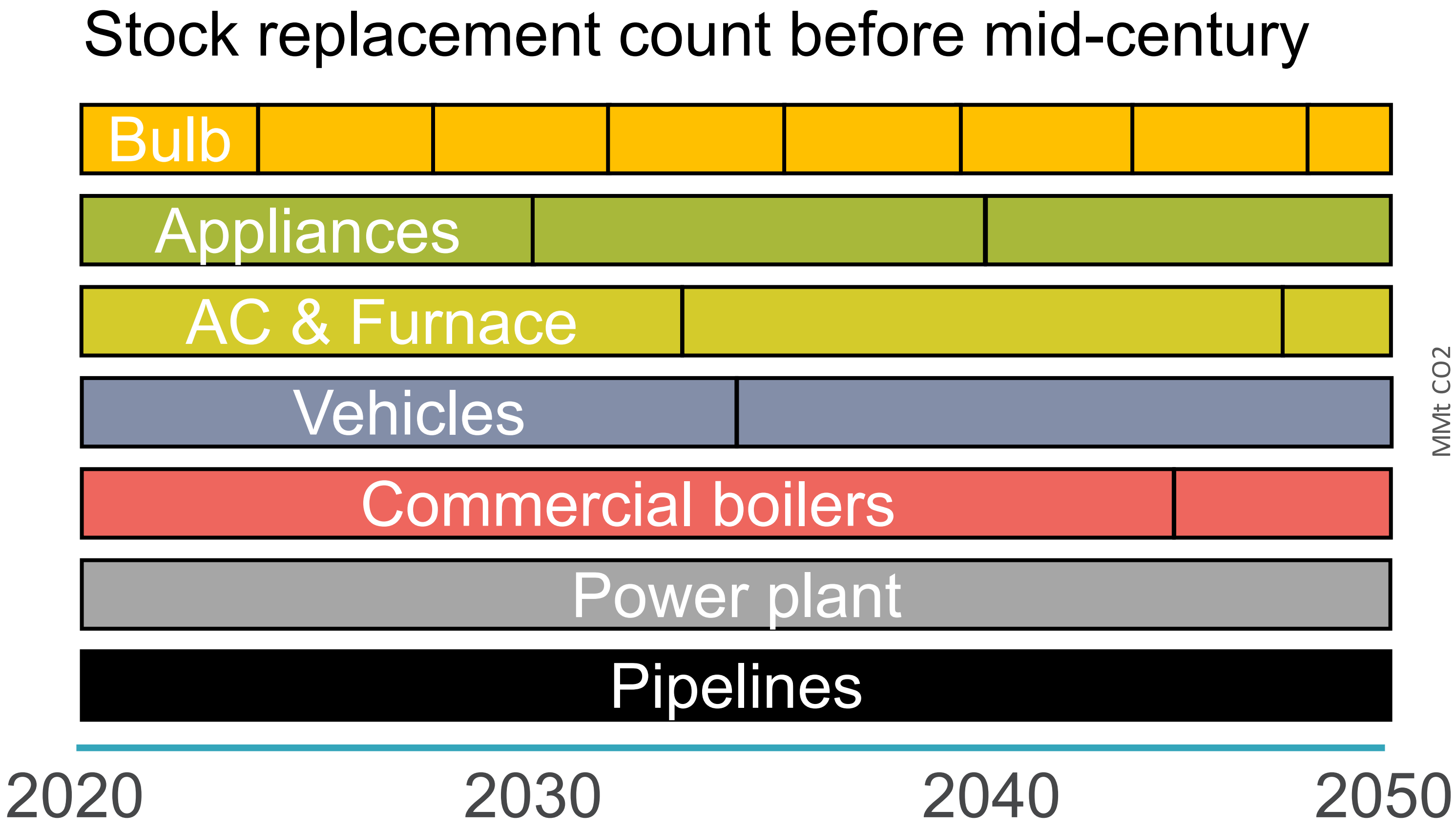
Limited Biomass for Liquid Fuels

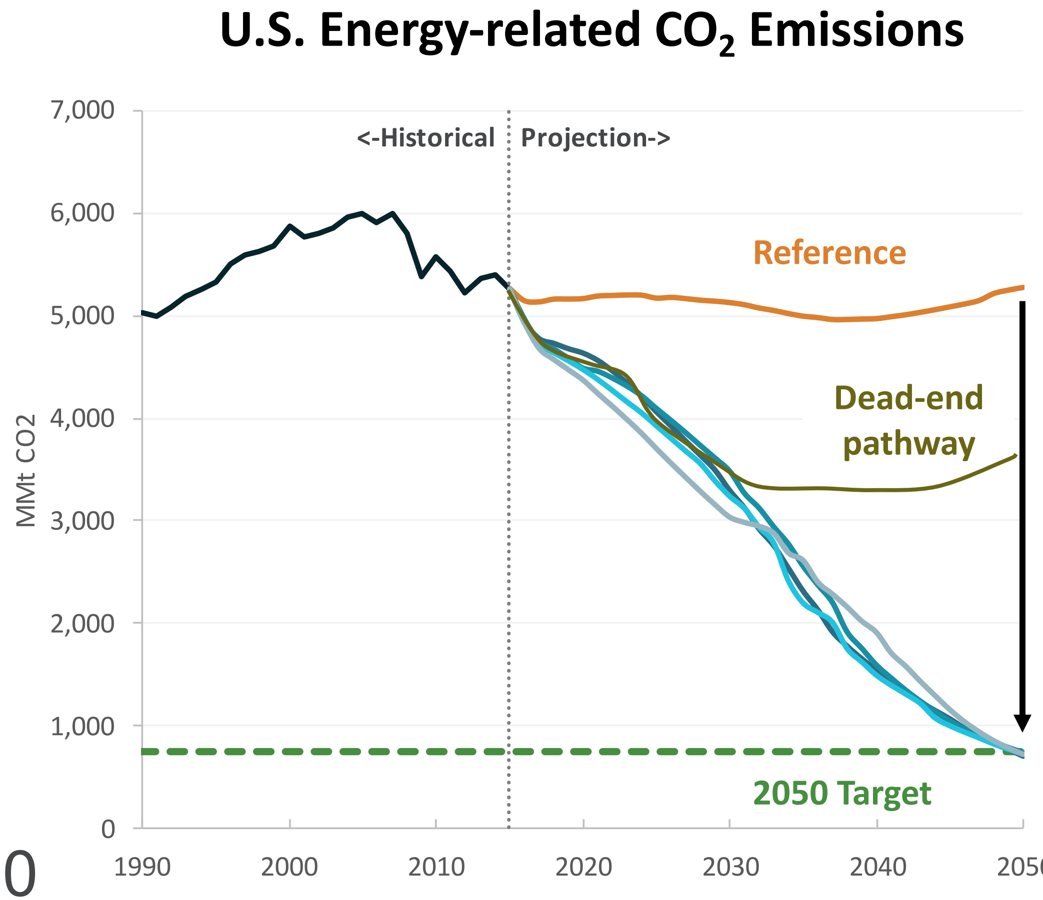
How Should We Get There?

- 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 Washington’s goals
  - Equity, affordability, reliability, competitiveness

Near-Term Focus on Long-Lived Assets

Long-lived infrastructure should be an early focus to avoid carbon lock-in or stranded assets





Model Overview
High level description of our approach

High-Level Description of Modeling Approach

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

Model of Washington's economy

Residential
Commercial
Industrial
Transportation

→ **1: Model calculates energy needs**

Washington's energy needs

Electricity
Liquid Fuels
Gaseous Fuels

→ **2: Model calculates energy supply**

Constrained by clean energy goals

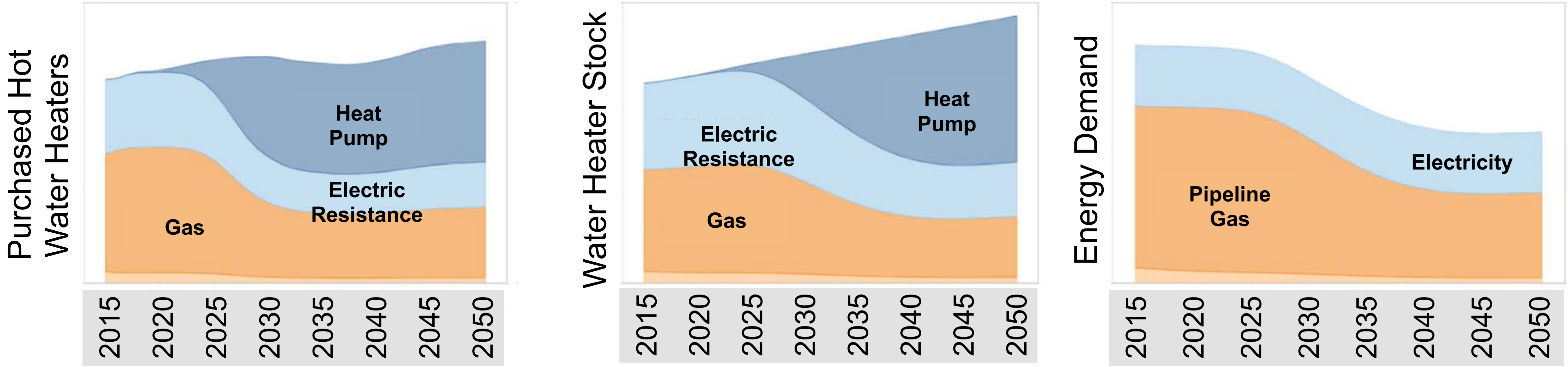
Supply energy reliably at least cost

Generation
Transmission
Storage
Fuel supply
Carbon

1. 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



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

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

Example: Electricity

Electricity includes all economic sectors

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

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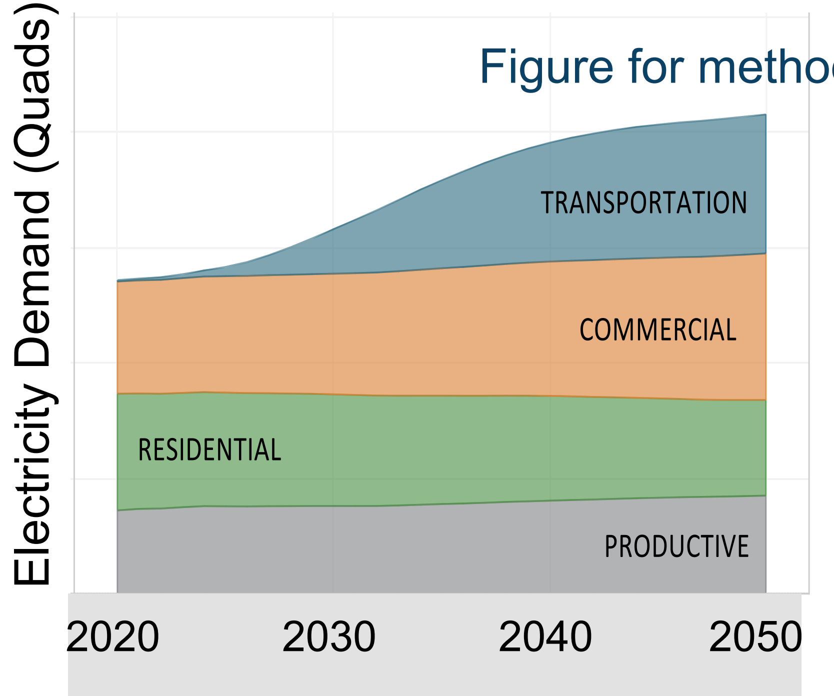
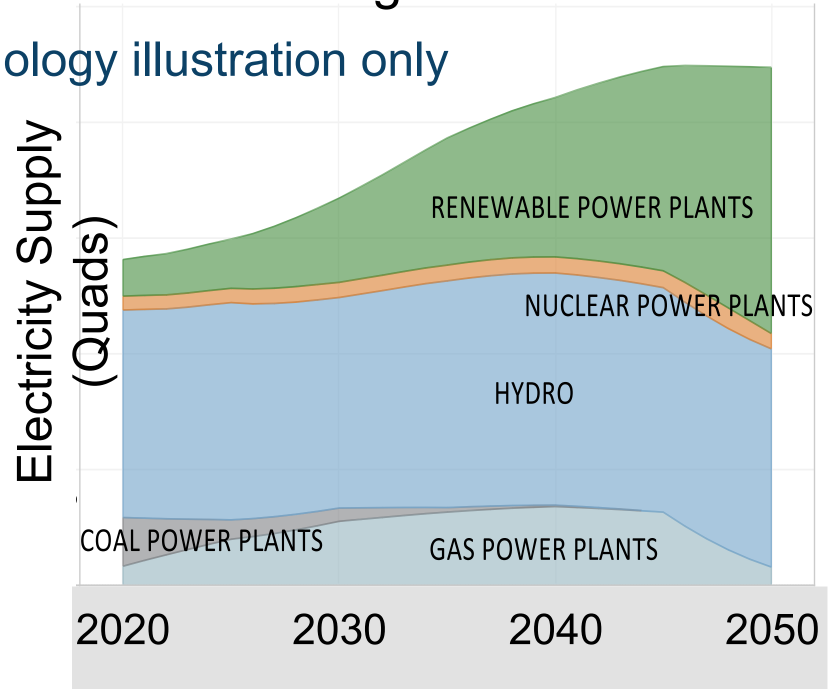




- **Reliability**: Model requires supply is met during rare, severe weather events, while maintaining reserve margin
- Fuel and electricity supply are optimized together
- Model uses best available public data

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	

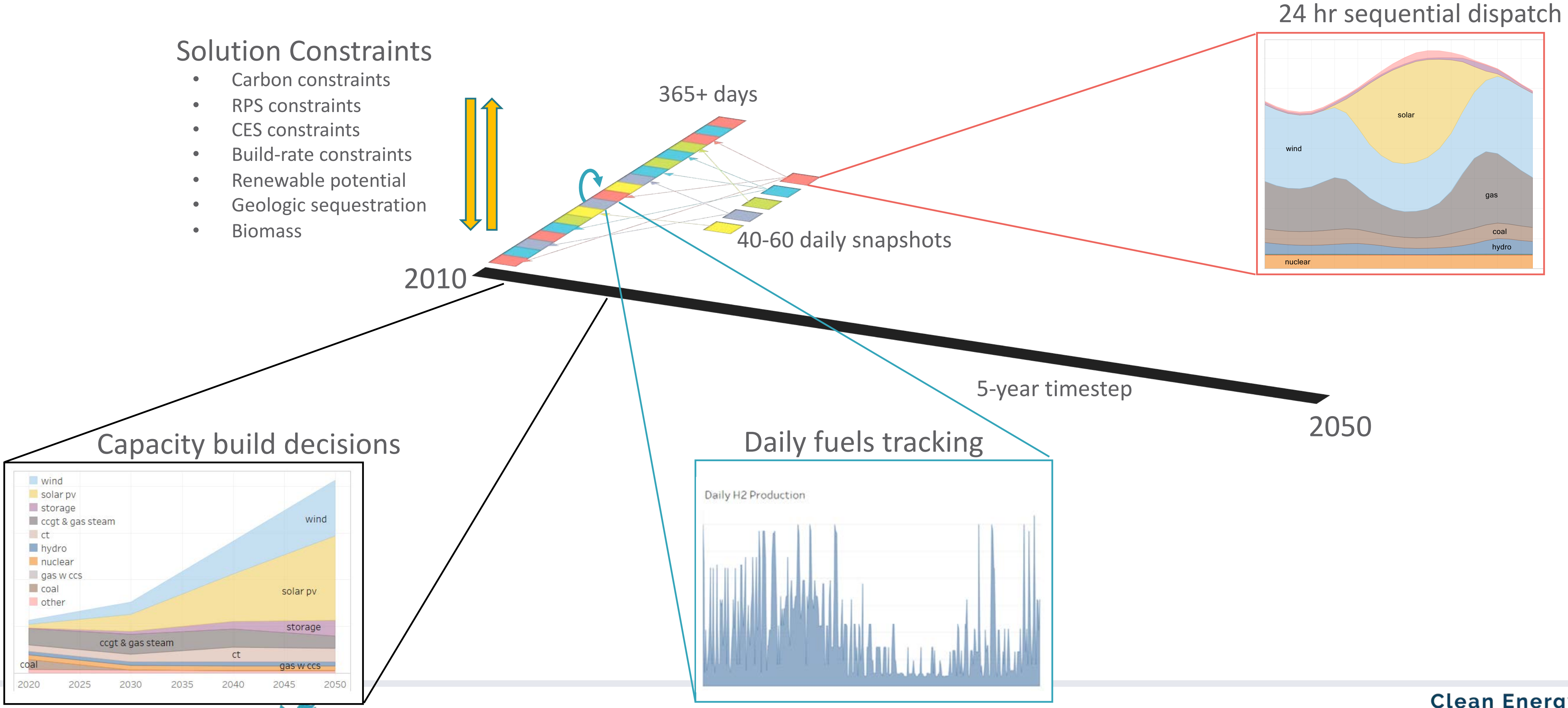
Days
365 days * 1-3 weather years
= 365 – 1095 days

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

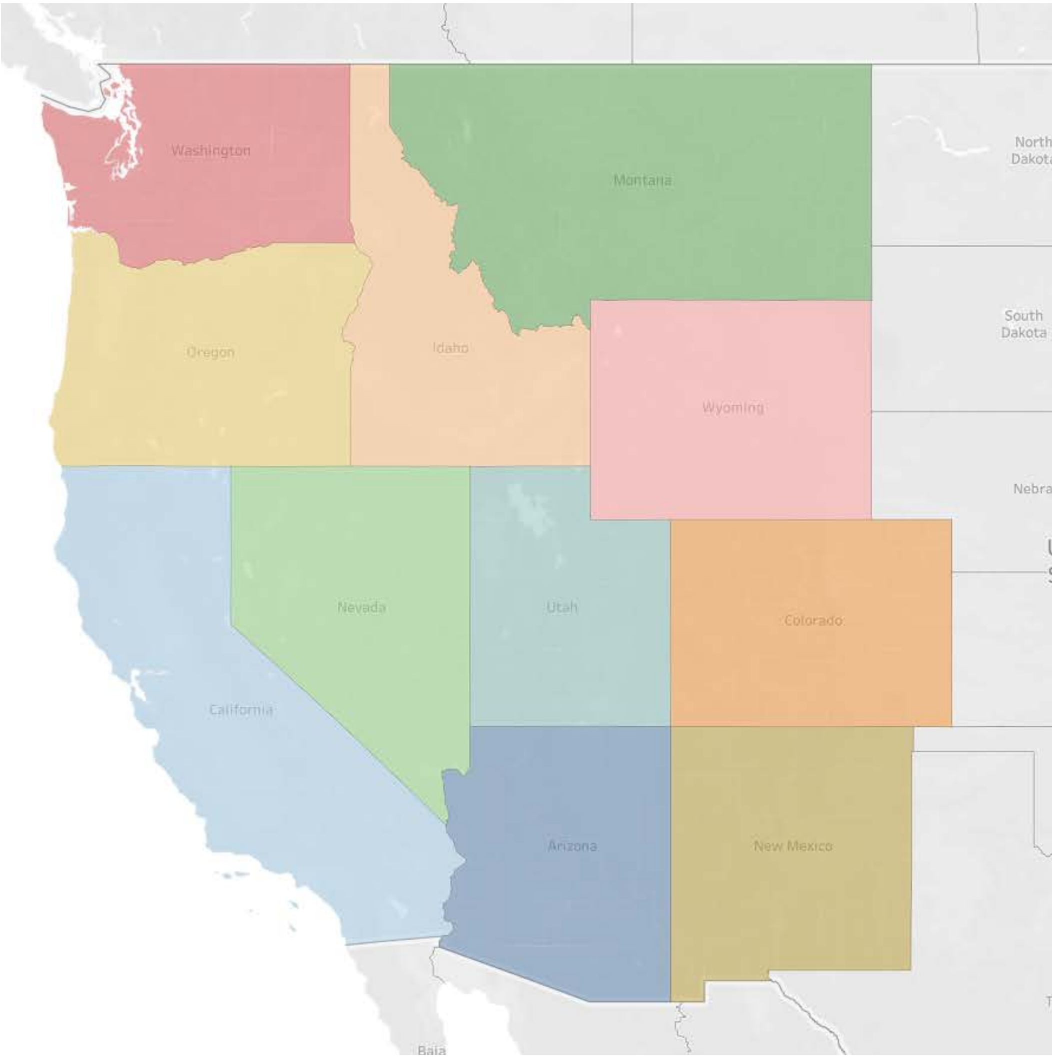
Decision Variables	Key Results
Emissions from Operations	Total Annual Emissions
RPS Supply and Demand	RPS Composition
Capacity Build, Retirement & Repower	Incremental Build, Retirement, & Repower
	Thermal Capacity Factors
	Annual Average Market Prices
	Marginal Cost of Fuel Supply

RIO Optimizes across Time-Scales



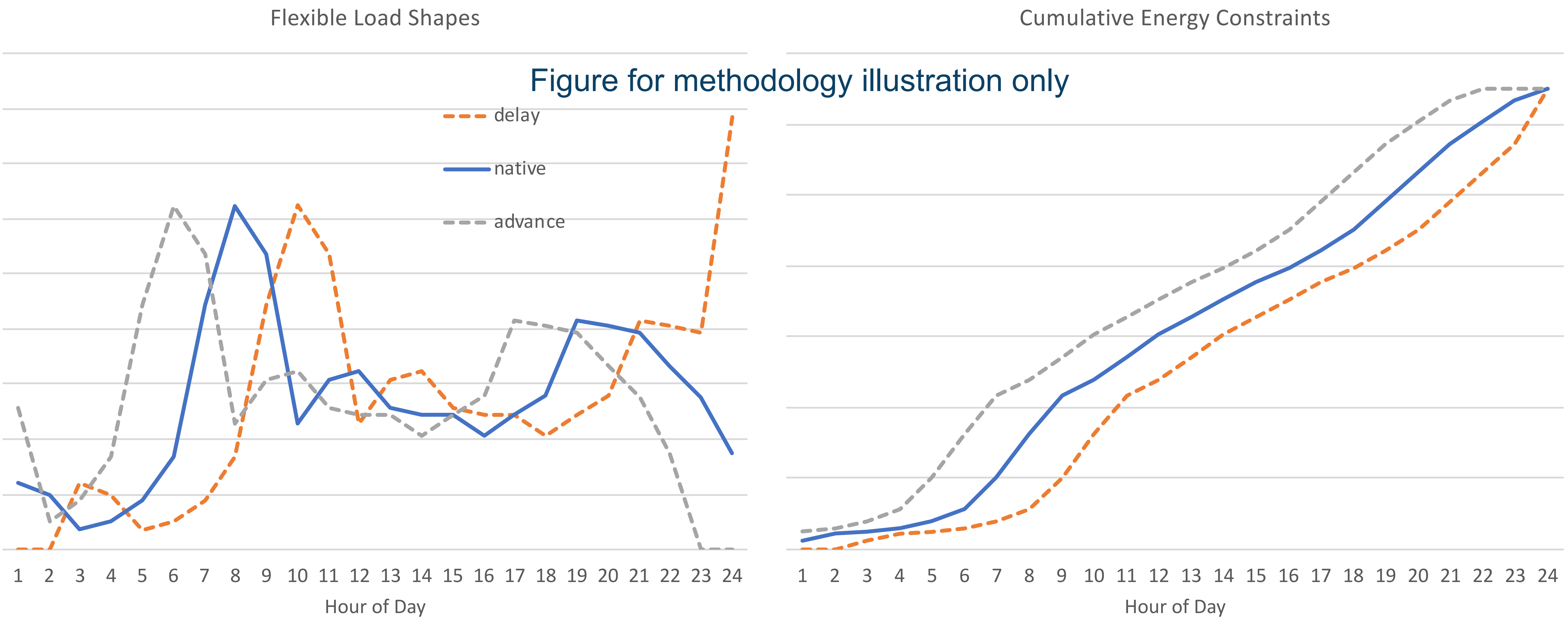
RIO optimizes across Geographic Constraints

- 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



Flexible Load Operations

Cumulative energy constraints



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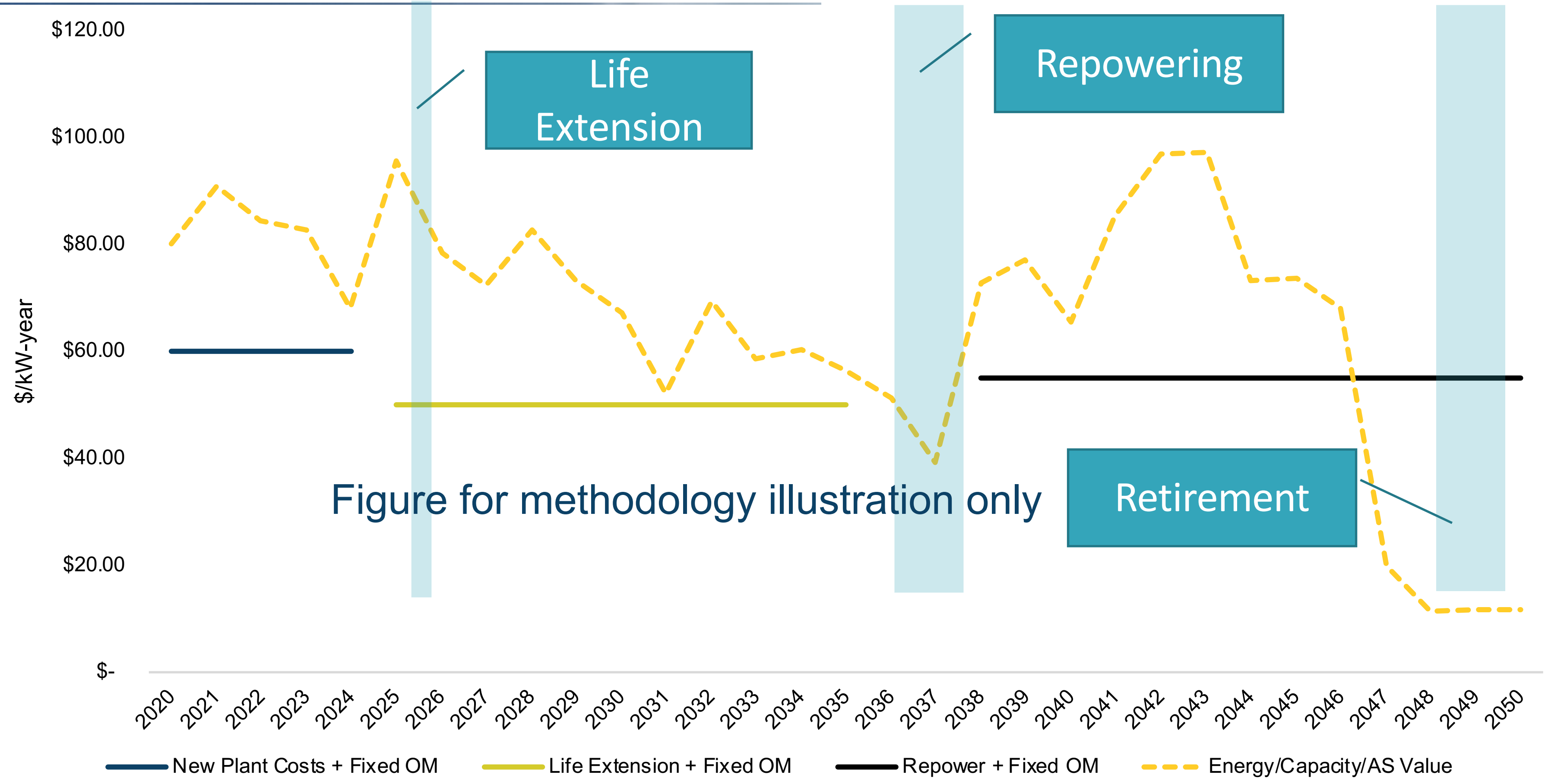
Economic Generator Lifecycles

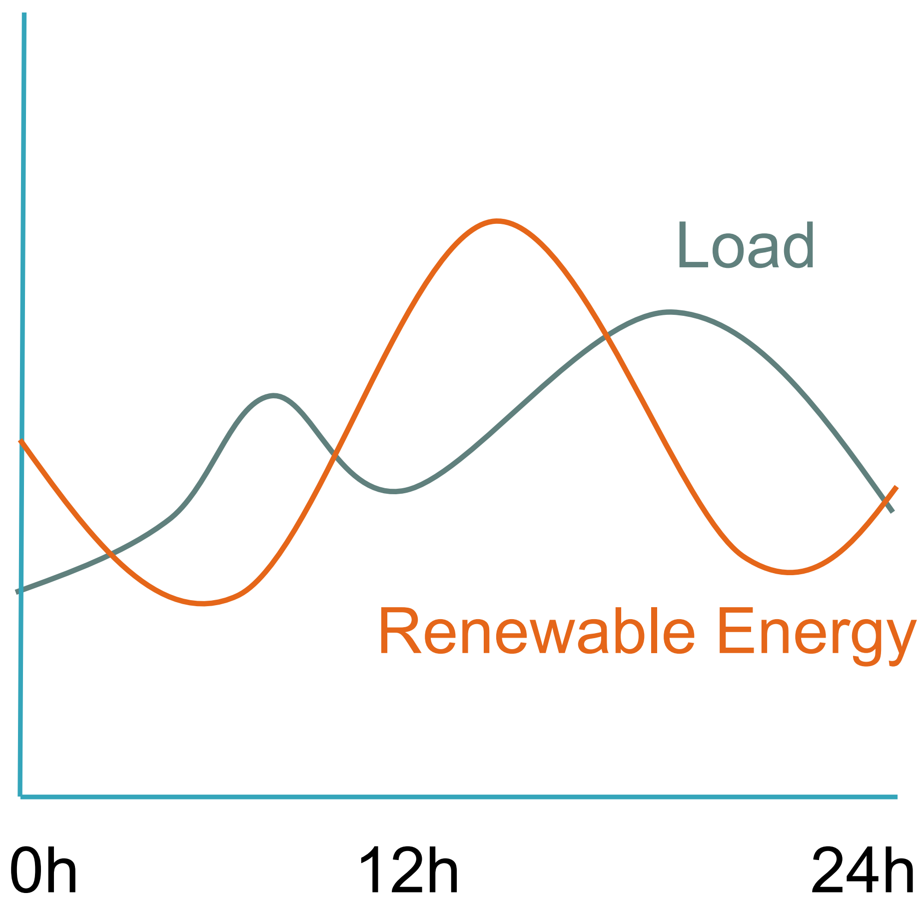
RIO optimizes plant investment decisions including life extensions, repowering, and retirements based on system value and ongoing costs



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



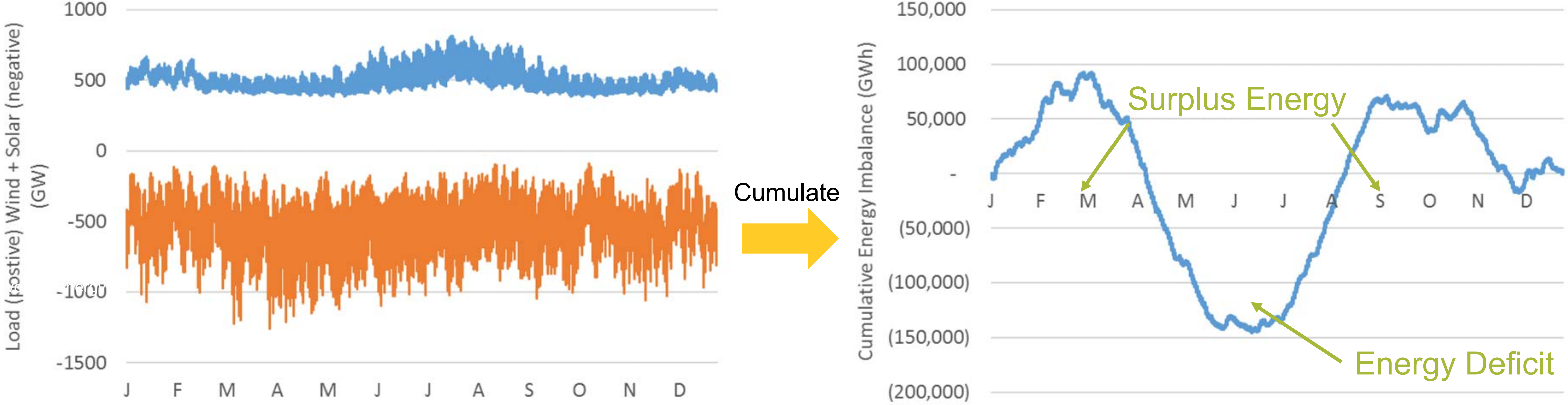
- Renewable energy produced when the sun shines and the wind blows
- Inconvenient because it does not match production exactly with load
- Already happening in regions with significant renewable penetration
- Need to disconnect instantaneous load and supply
  - Overgeneration conditions
  - Diurnal energy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

Load and 100% Renewables

Cumulative Net-load

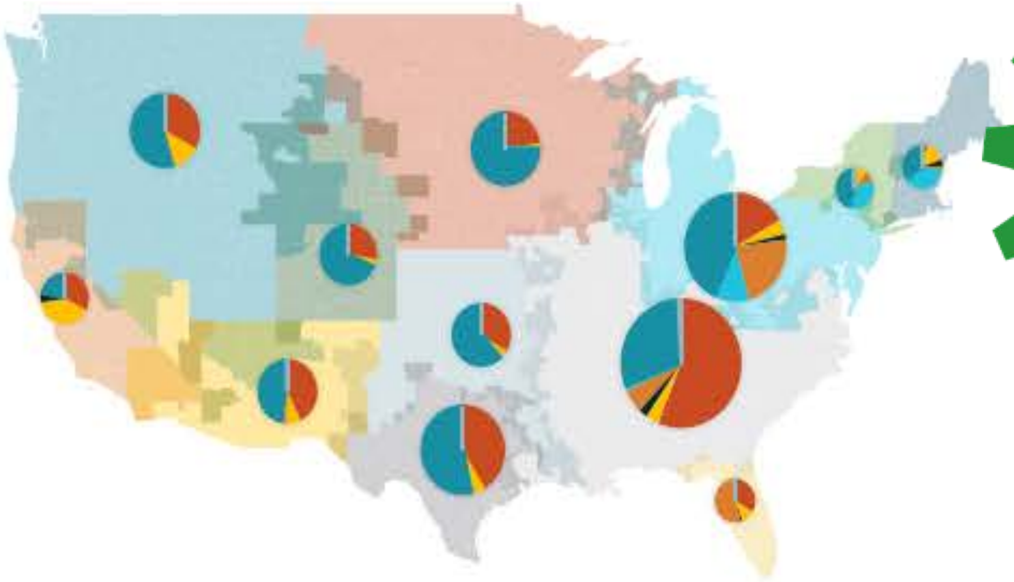


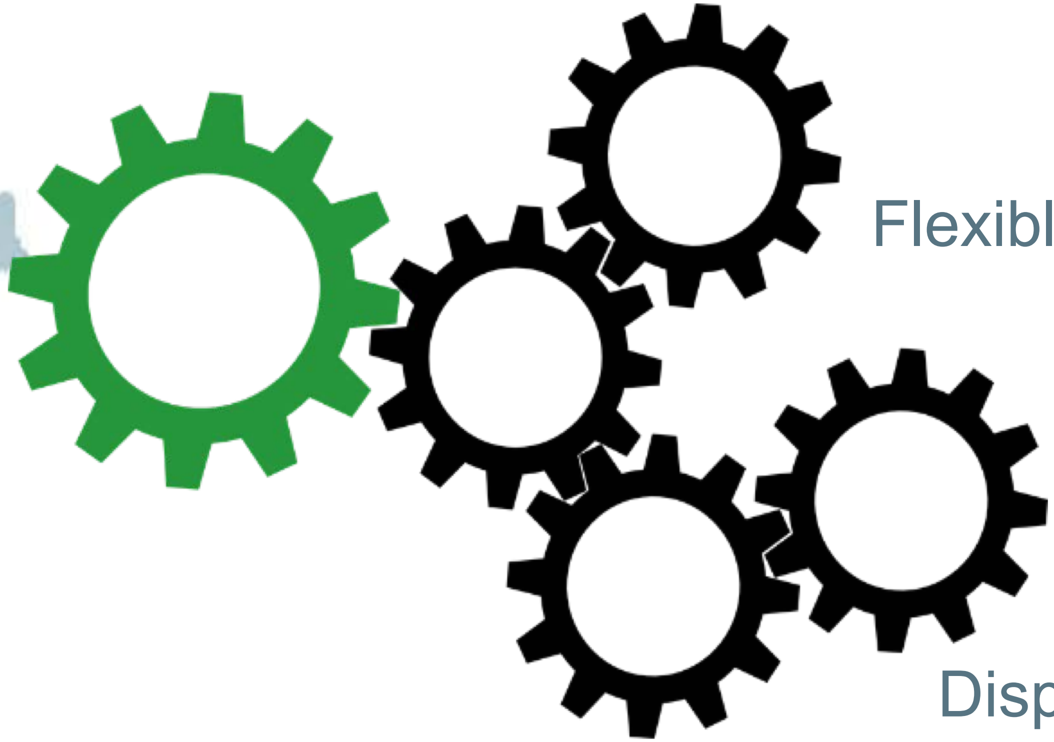
U.S. Eastern Interconnect 2015 Load with simulated 40% Solar & 60% Onshore Wind by Energy

Balancing Load and Supply in a Decarbonized System

Transmission

Clean Energy Mix





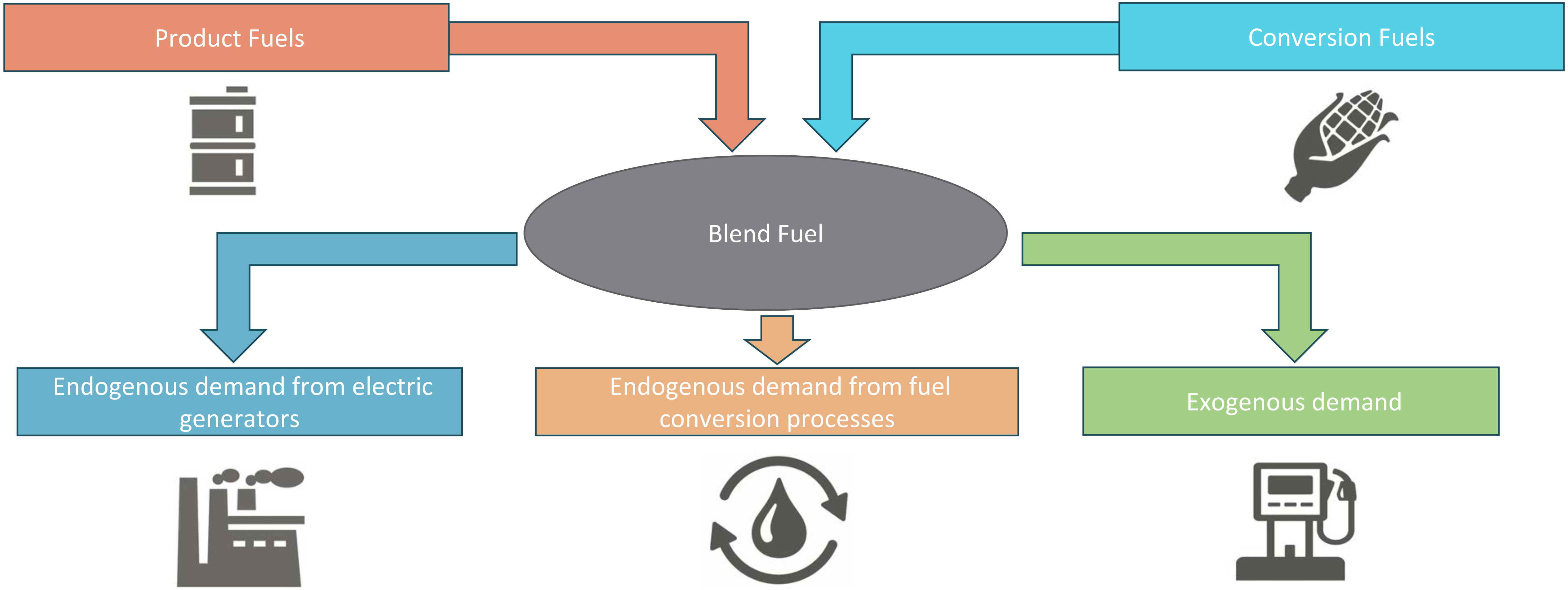
Flexible Loads

Dispatchable Generation

Battery Storage

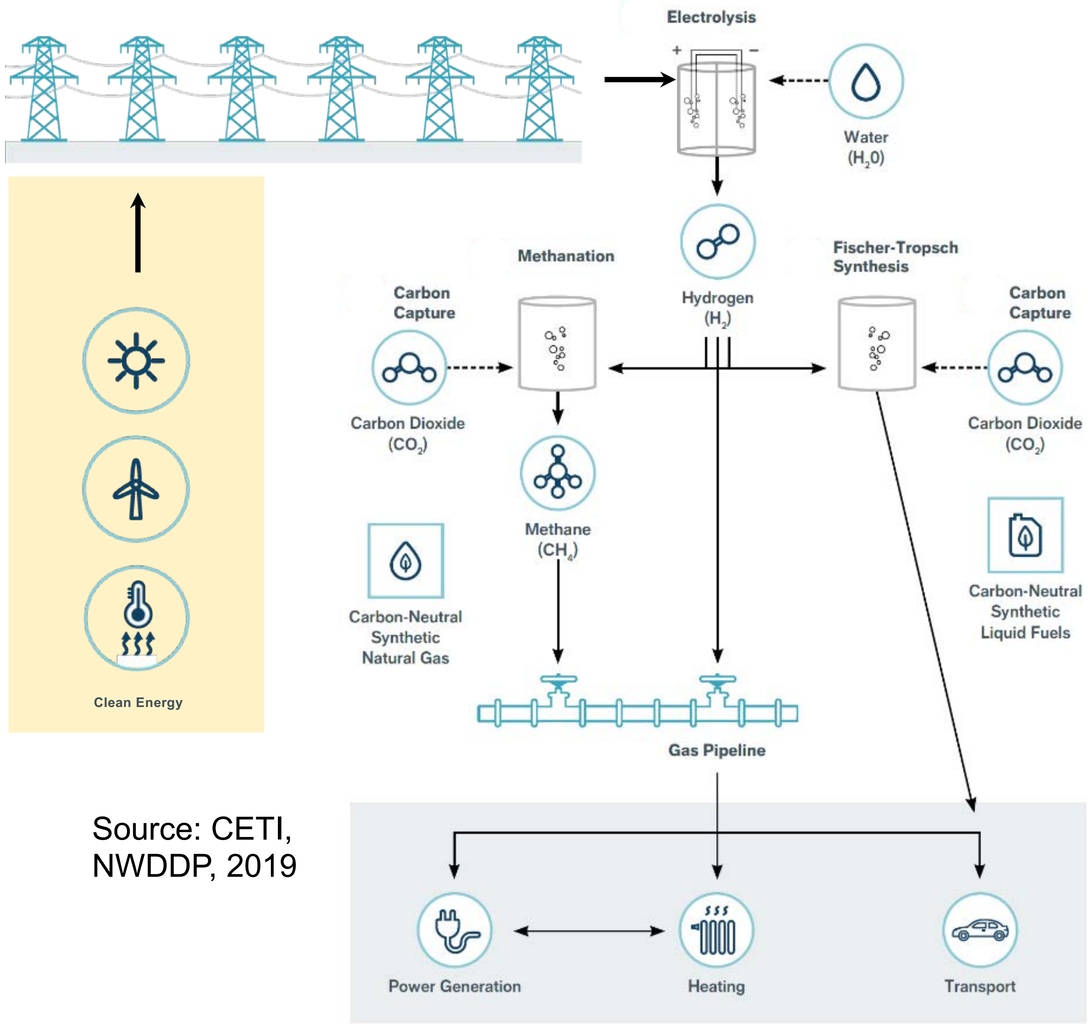
RIO Fuels Structure

Optimally invest in fuels transportation, storage, and conversion infrastructure



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

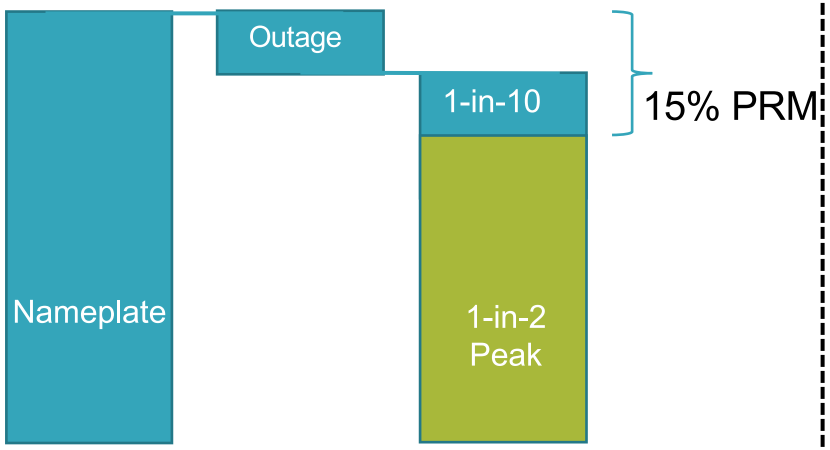
Reliability

Reliable operations in a rapidly changing electricity system

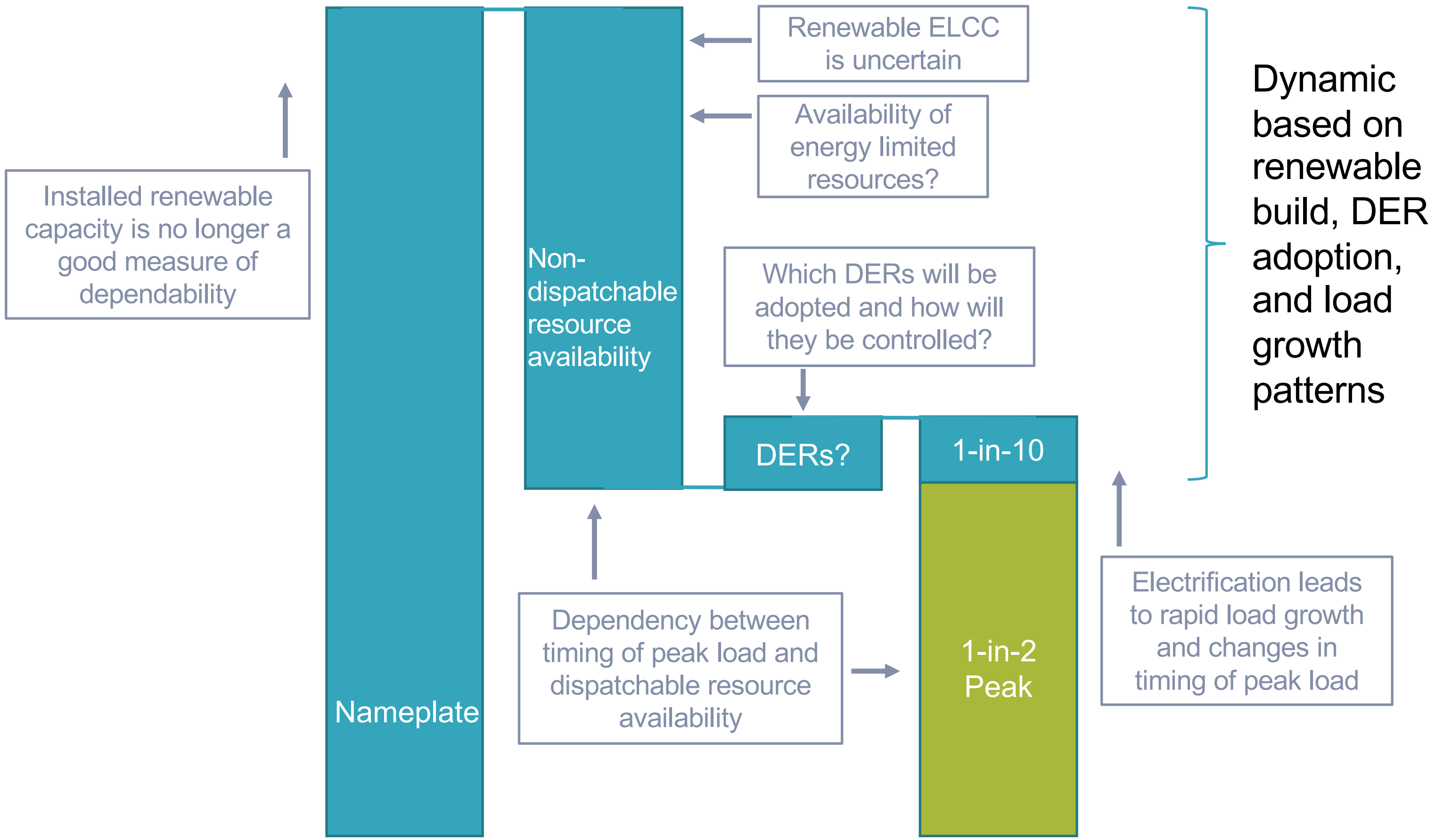
Hourly Reserve Margin Constraints by Zone

Assessing Reliability Becomes Challenging in Low-Carbon Electricity Systems

Traditional Reserve Margin



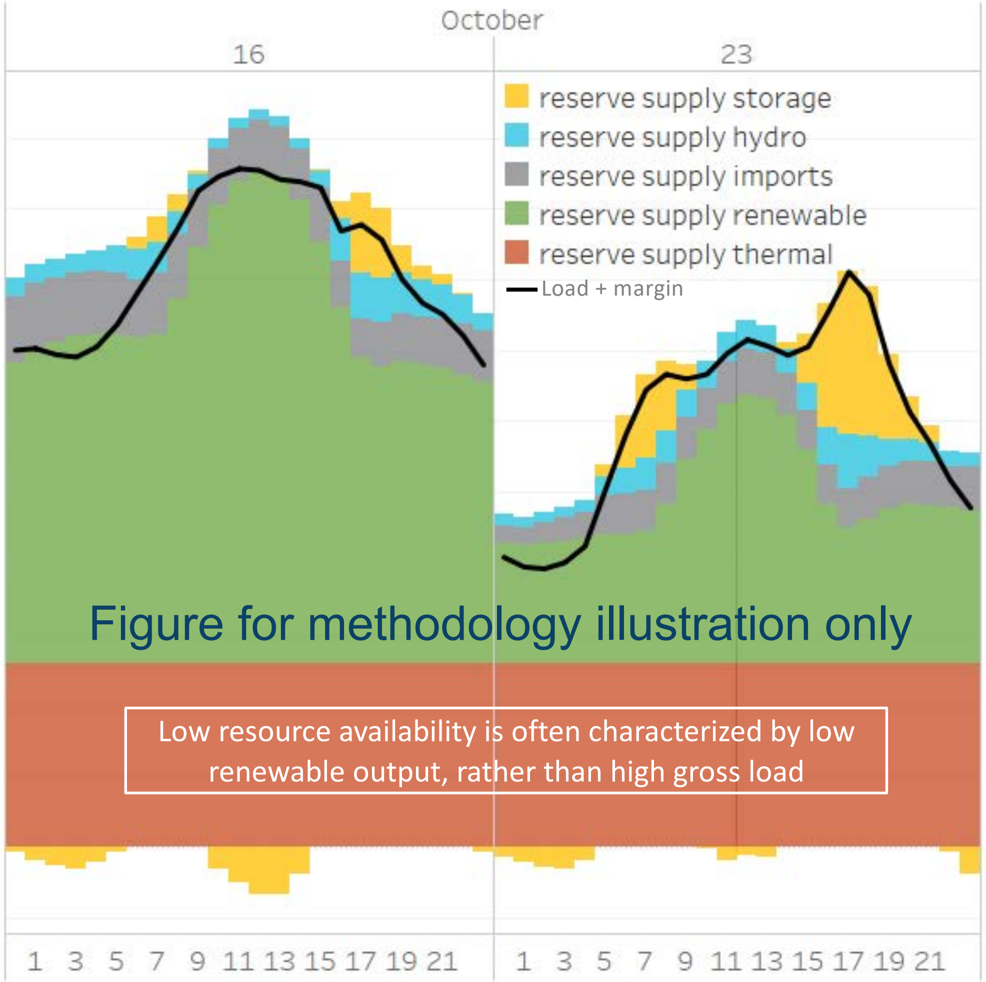
Future System Reliability Assessment



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>
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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

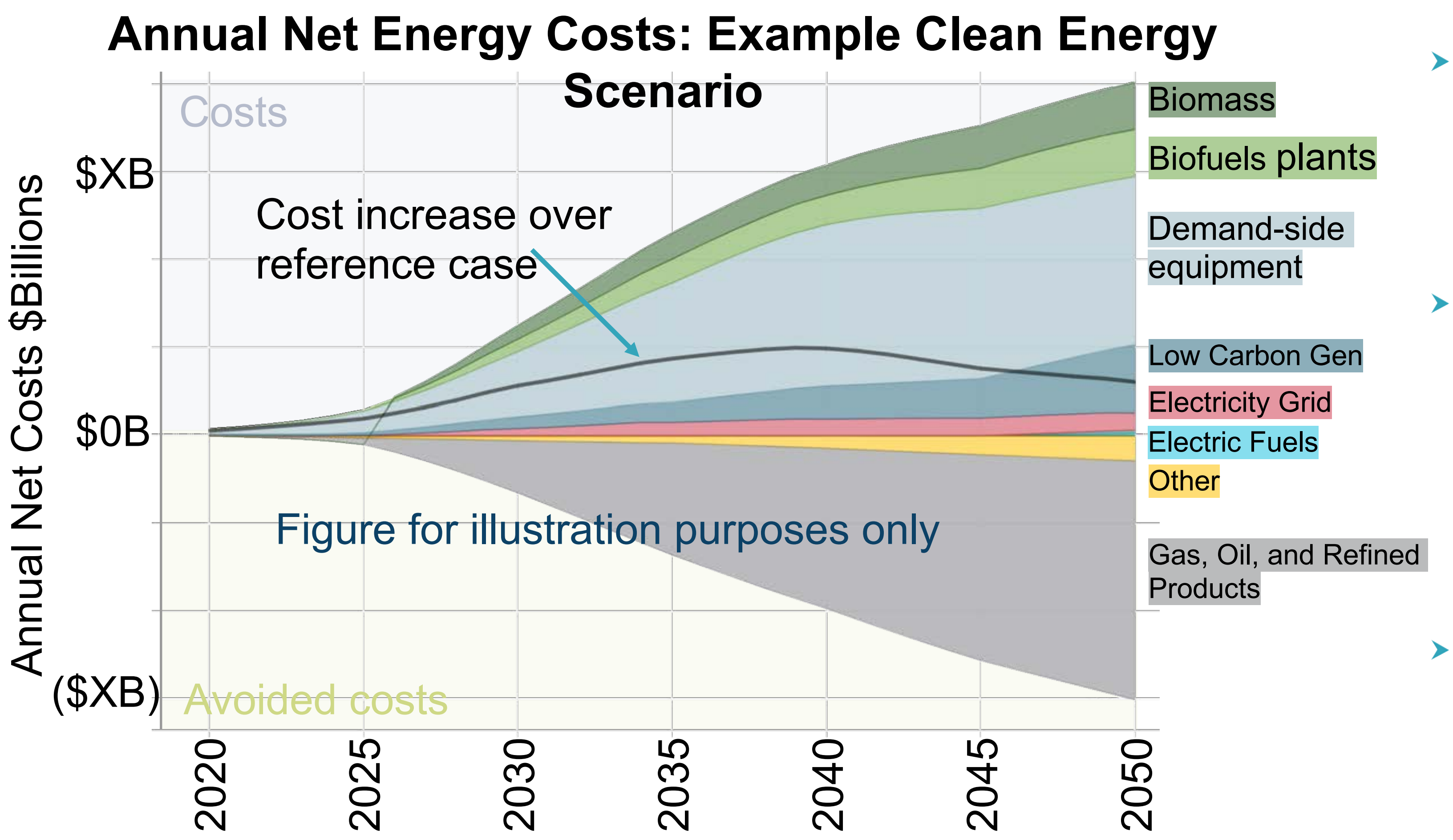
Data Category	Data Description	Supply Node	Source
Technology Cost and Performance	Renewable and conventional electric technology installed cost projections	Nuclear Power Plants; Onshore Wind Power Plants; Offshore Wind Power Plants; Transmission – Sited Solar PV Power Plants; Distribution – Sited Solar 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

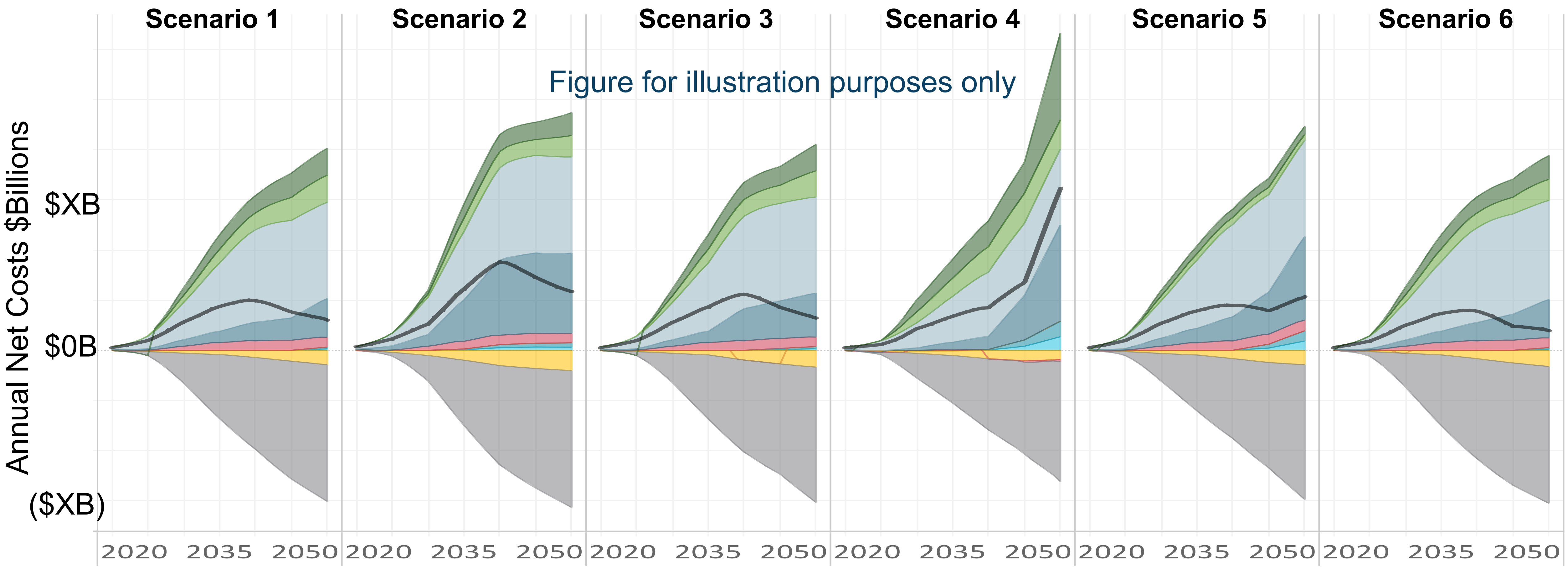
Key Results

Fuels and Infrastructure Investment vs. Business and Usual



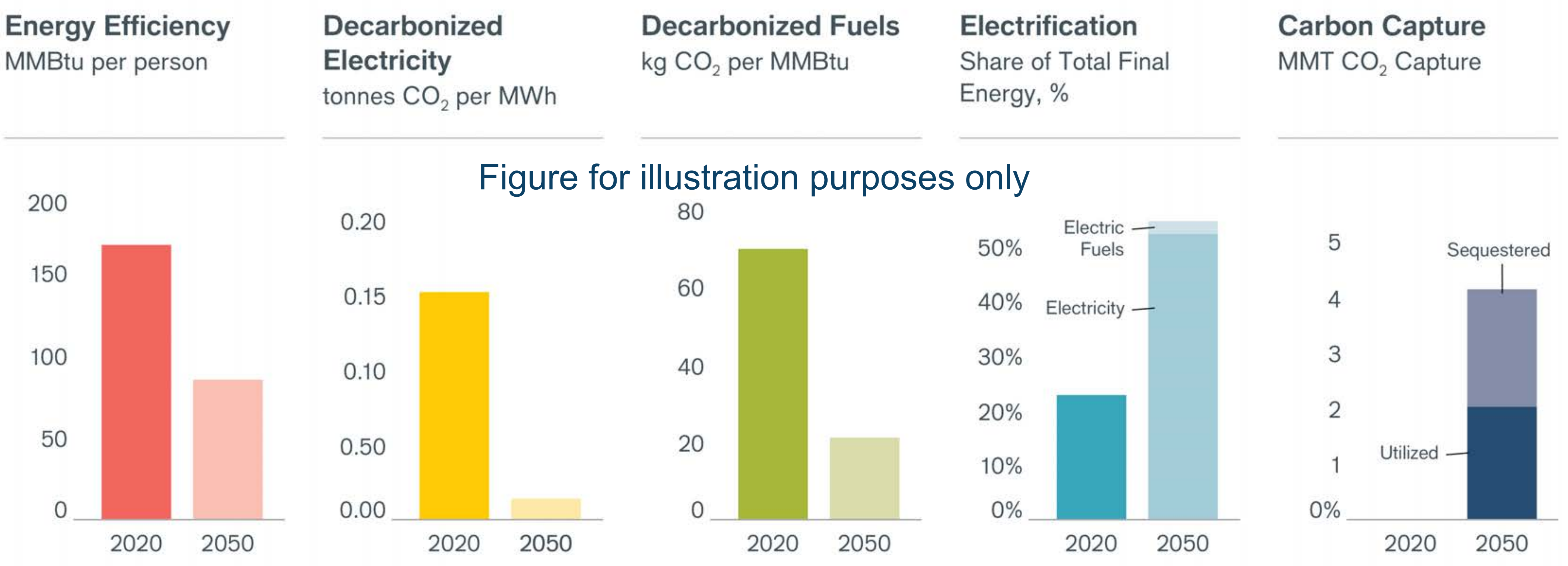
- The reference scenario is needed because business-as-usual is not zero-cost.
- Total cost to meet clean energy goals are offset by avoided BAU costs such as fossil fuels
  - Actual Washington avoided costs, not social cost of carbon
- Annual costs compare clean energy policy versus the alternative

Net Energy System Costs by Scenario



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

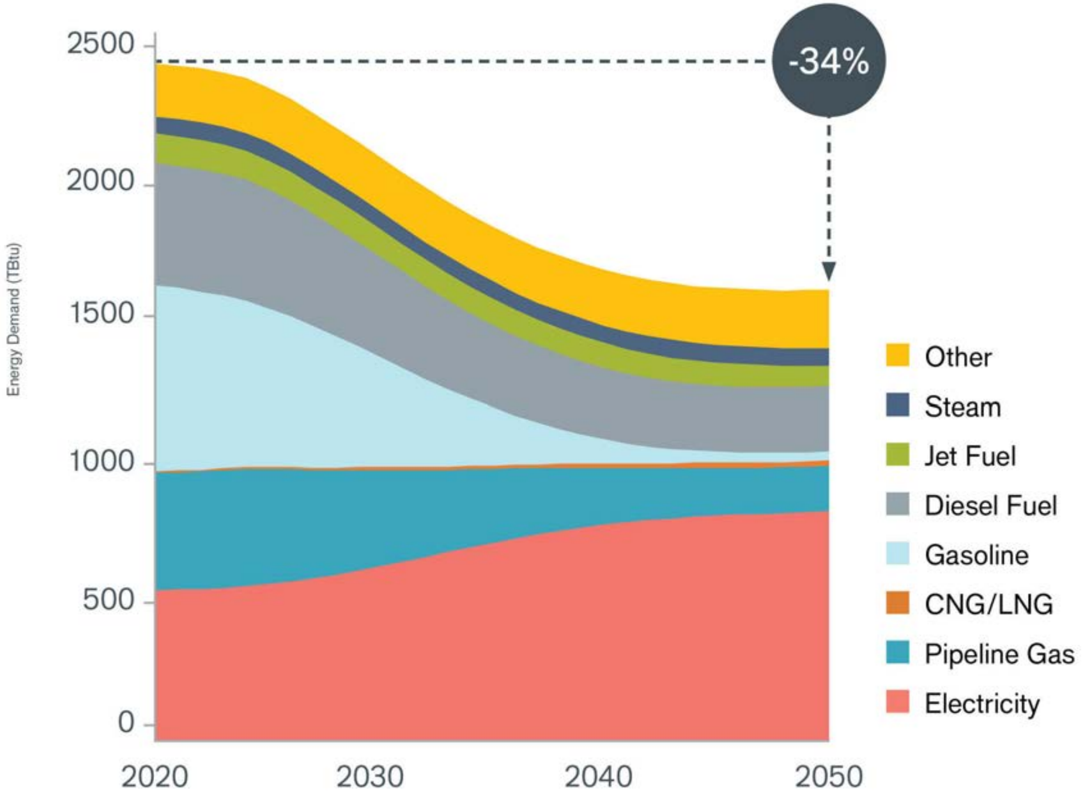
What Are the Least Cost Strategies that Policy Should Target?

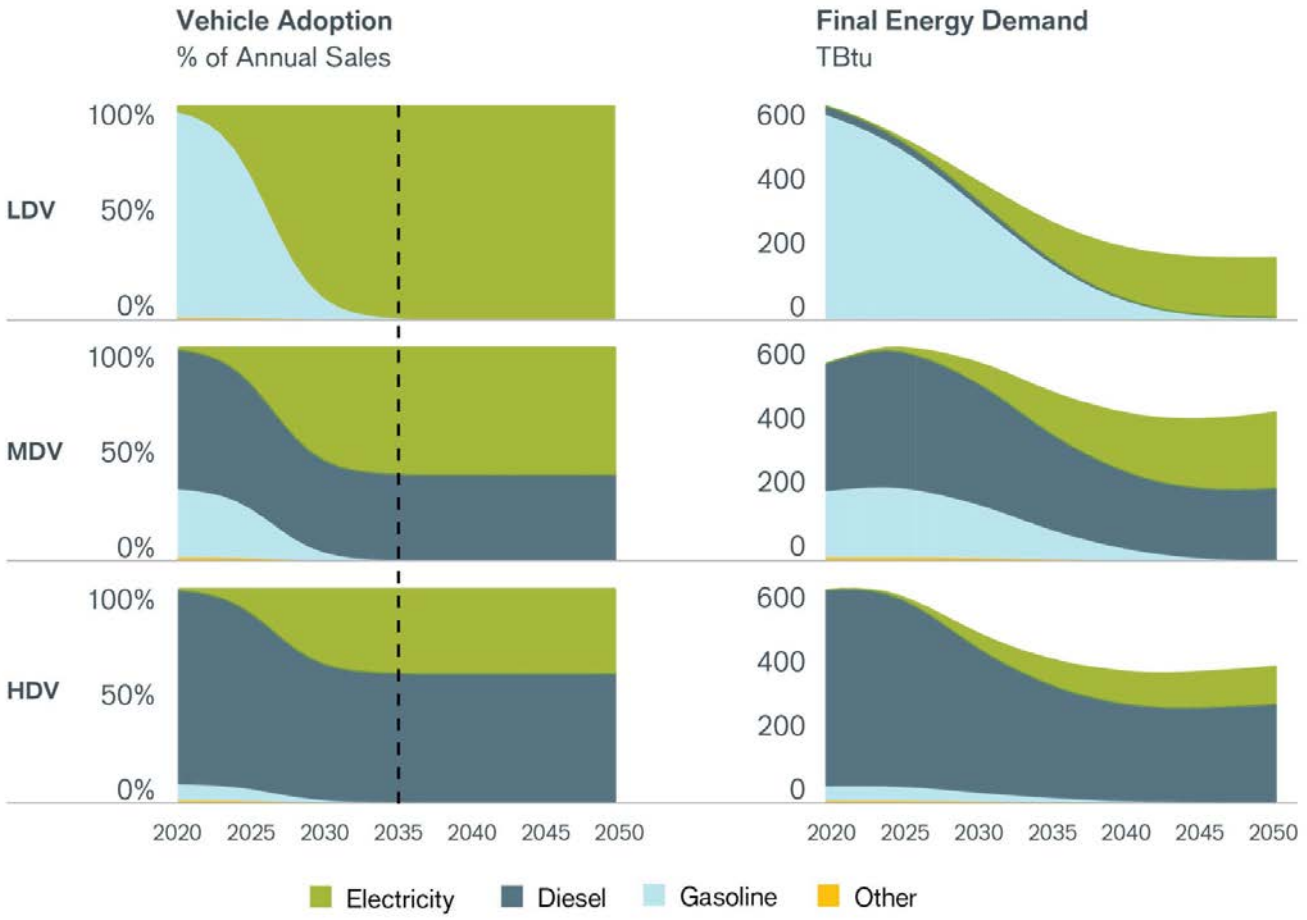


Source: Northwest Deep Decarbonization Pathways Study, June 2019, Evolved Energy Research

Final Energy Demand

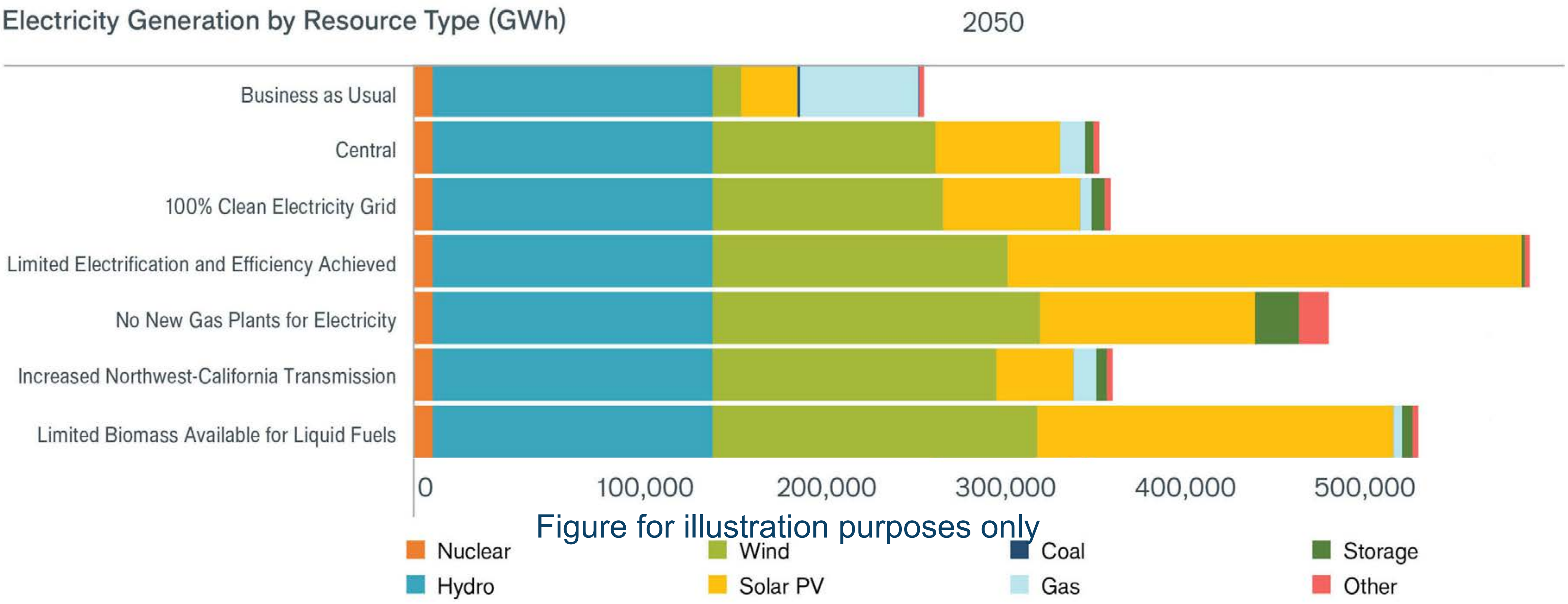
Figure for illustration purposes only





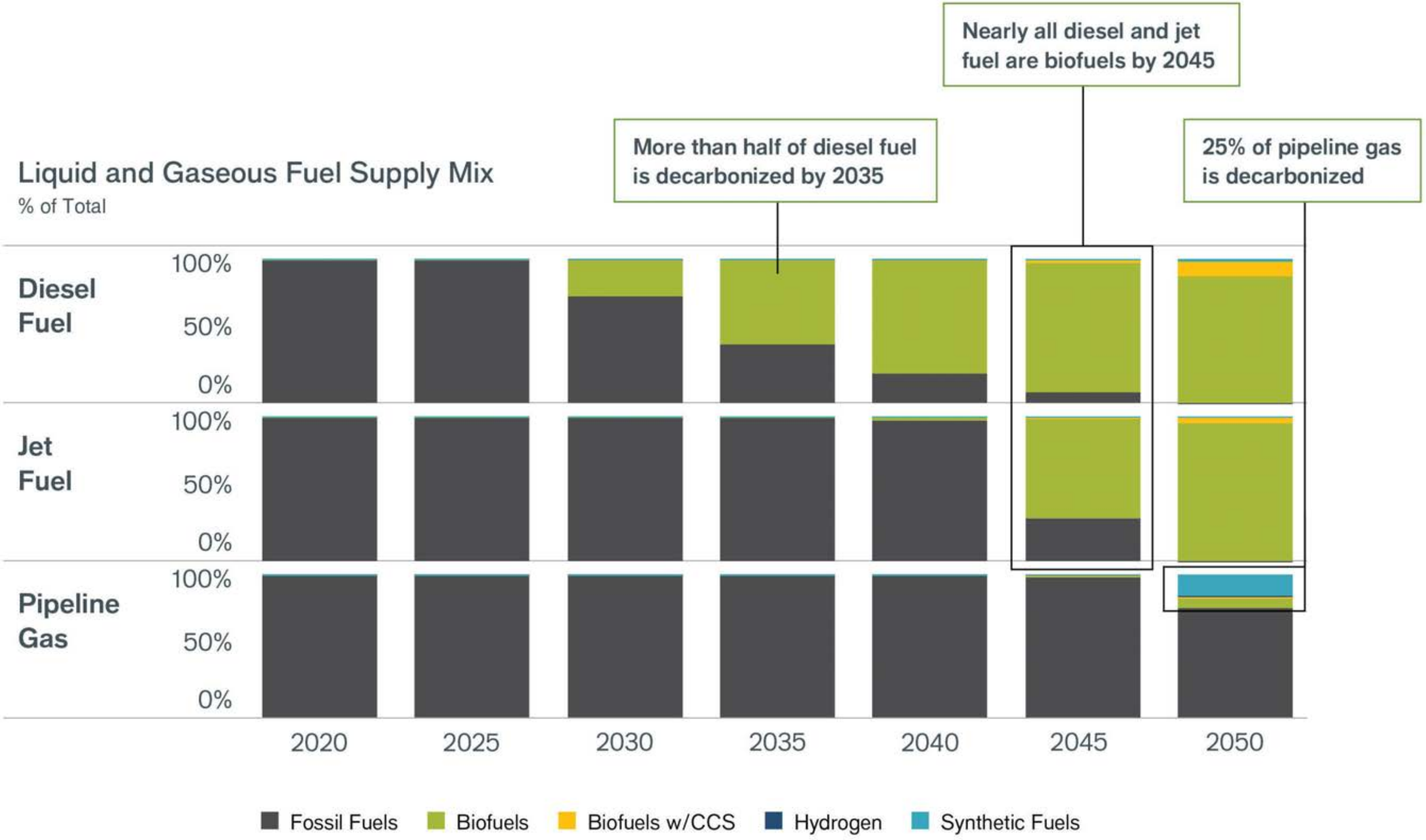
Source: Northwest Deep Decarbonization Pathways Study, June 2019

Energy Supply: Electricity Generation



Source: Northwest Deep Decarbonization Pathways Study, June 2019

Energy Supply: Liquid and Gaseous Fuel Composition Over Time



Emissions Reductions from Liquid/Gaseous Fuels, and Electricity

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

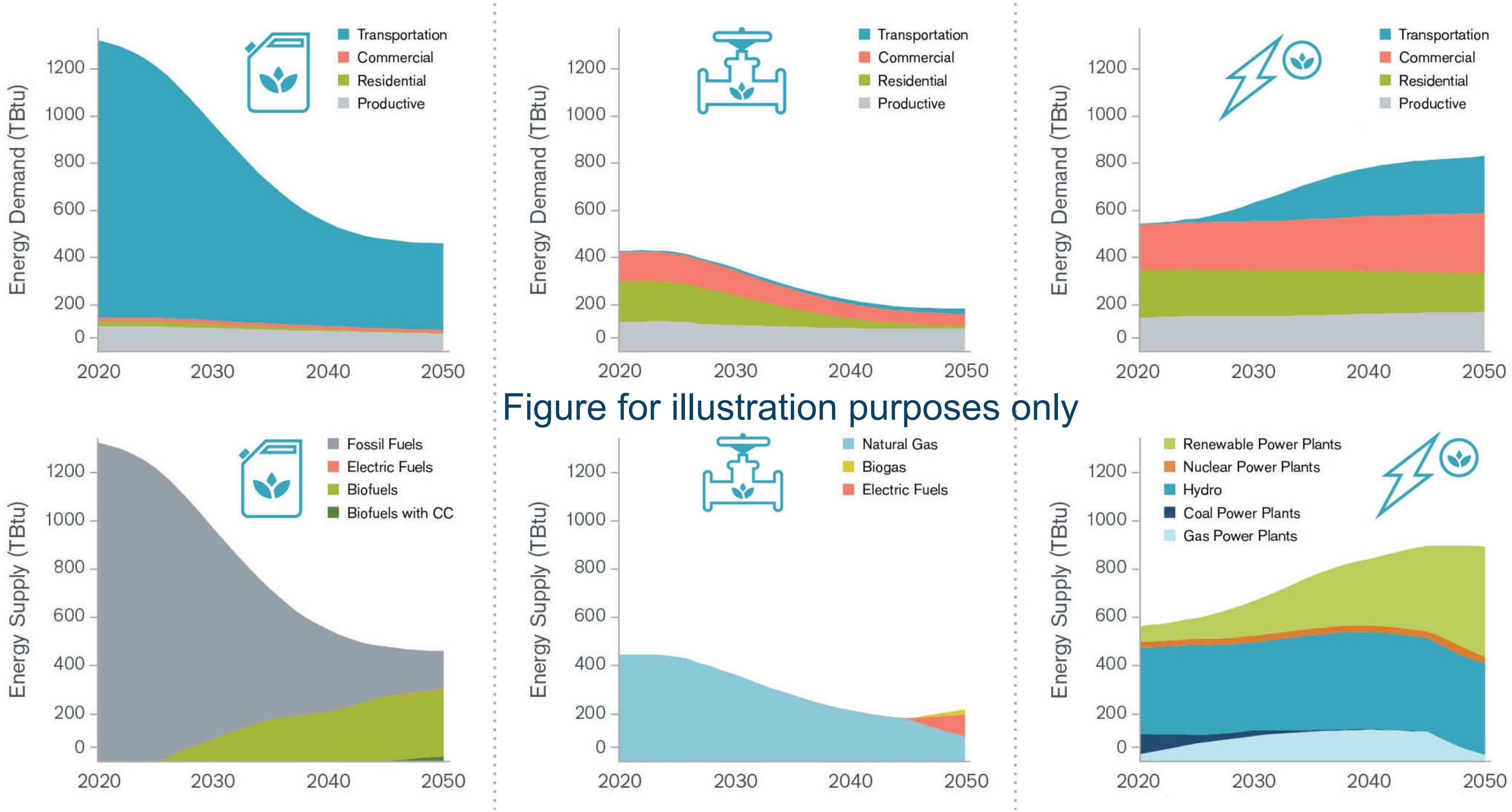
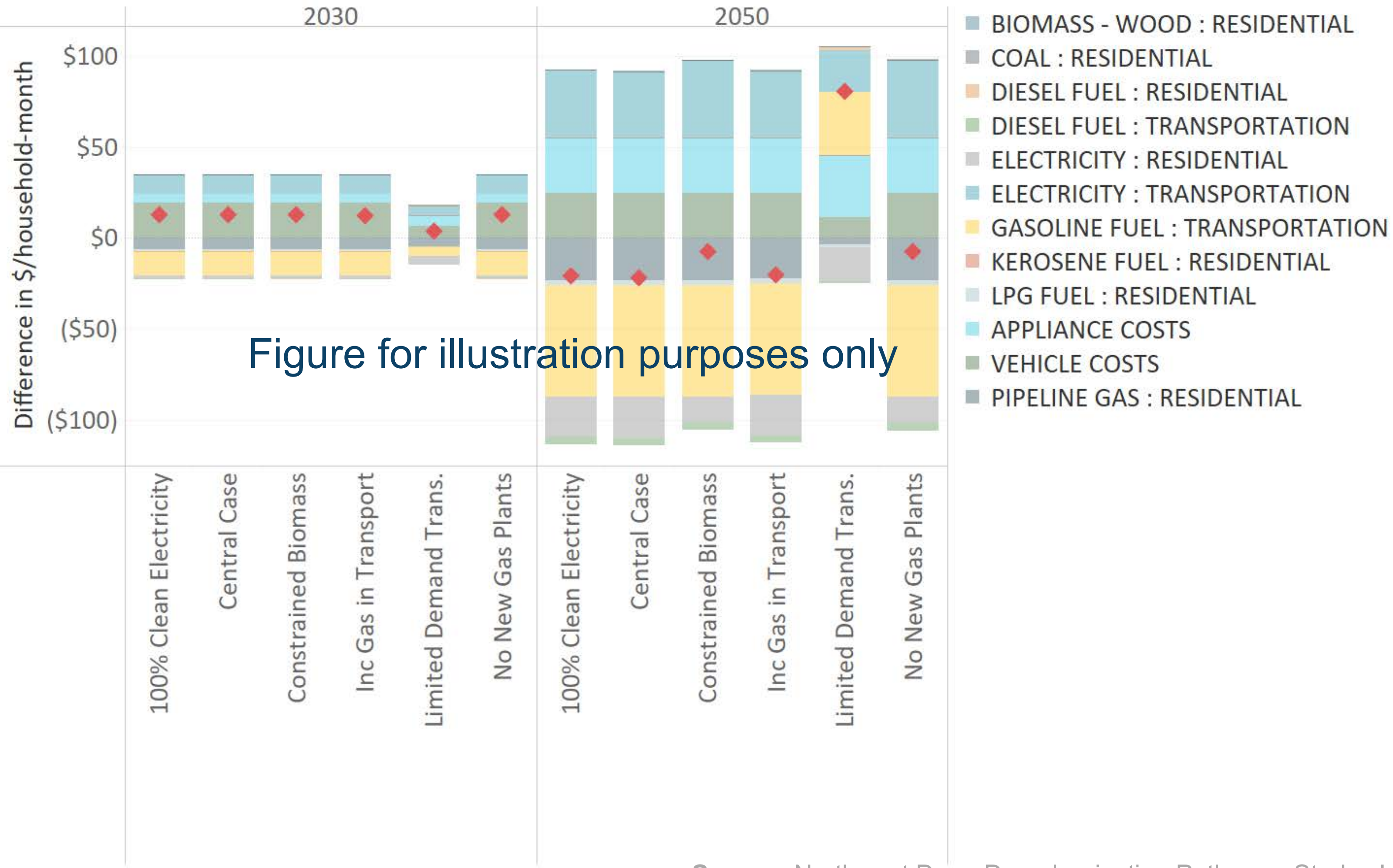


Figure for illustration purposes only

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

Cost Impacts by Sector



Source: Northwest Deep Decarbonization Pathways Study, June 2019

Scenarios

Look ahead to the next workshop

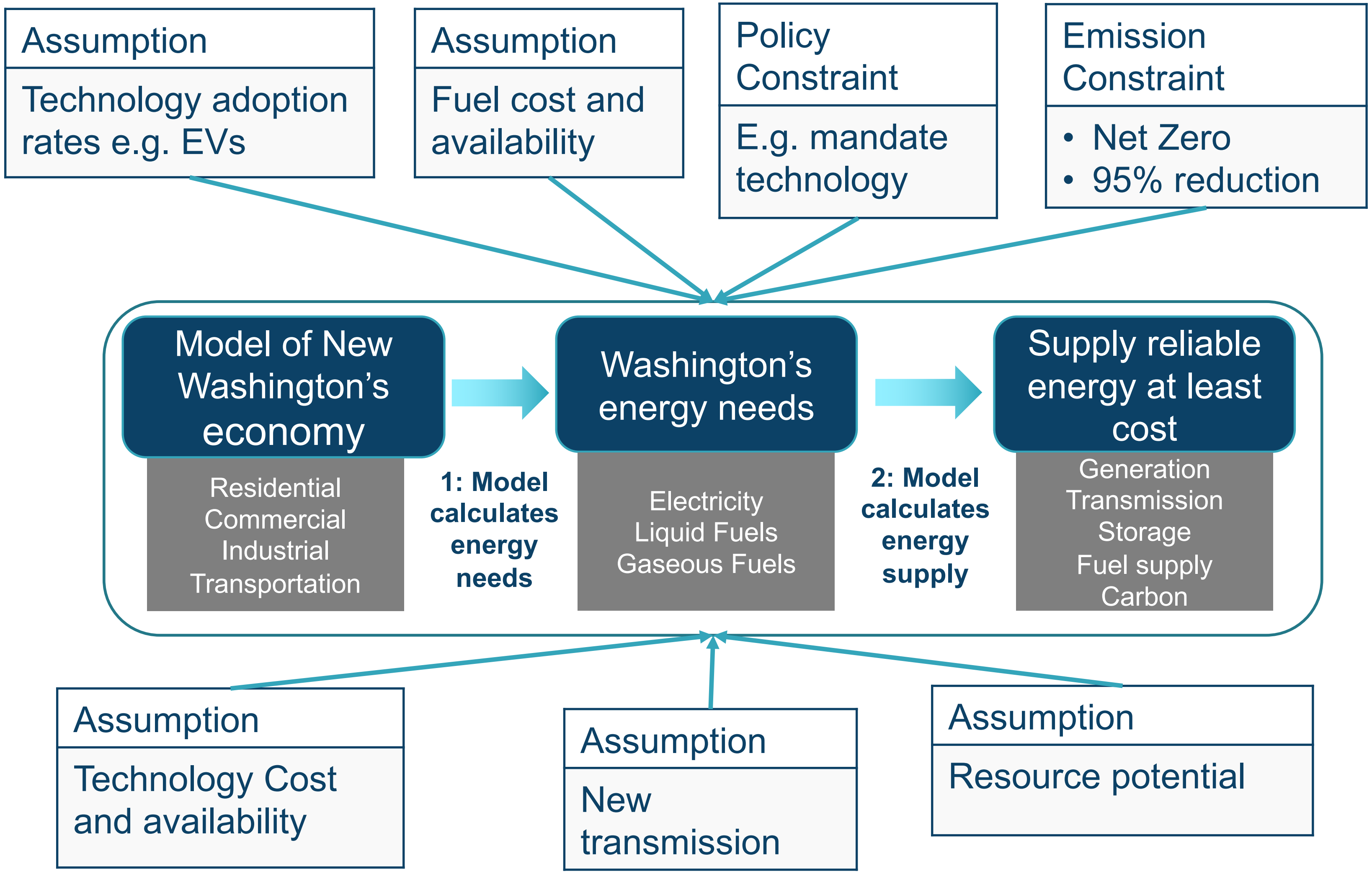
A "Reference Case" does not meet GHG Targets

What would WA do differently when meeting clean energy goals versus the status quo?

- Washington has policy they will achieve regardless of clean energy targets such as CETA
- Reference Case achieves all existing policies and holds them constant through 2050
  - e.g., carbon neutral electricity by 2030, 100% clean electricity by 2045
- Comparisons between clean energy scenarios and the Reference Case show the differences in investments, operations and overall costs needed for clean energy goals

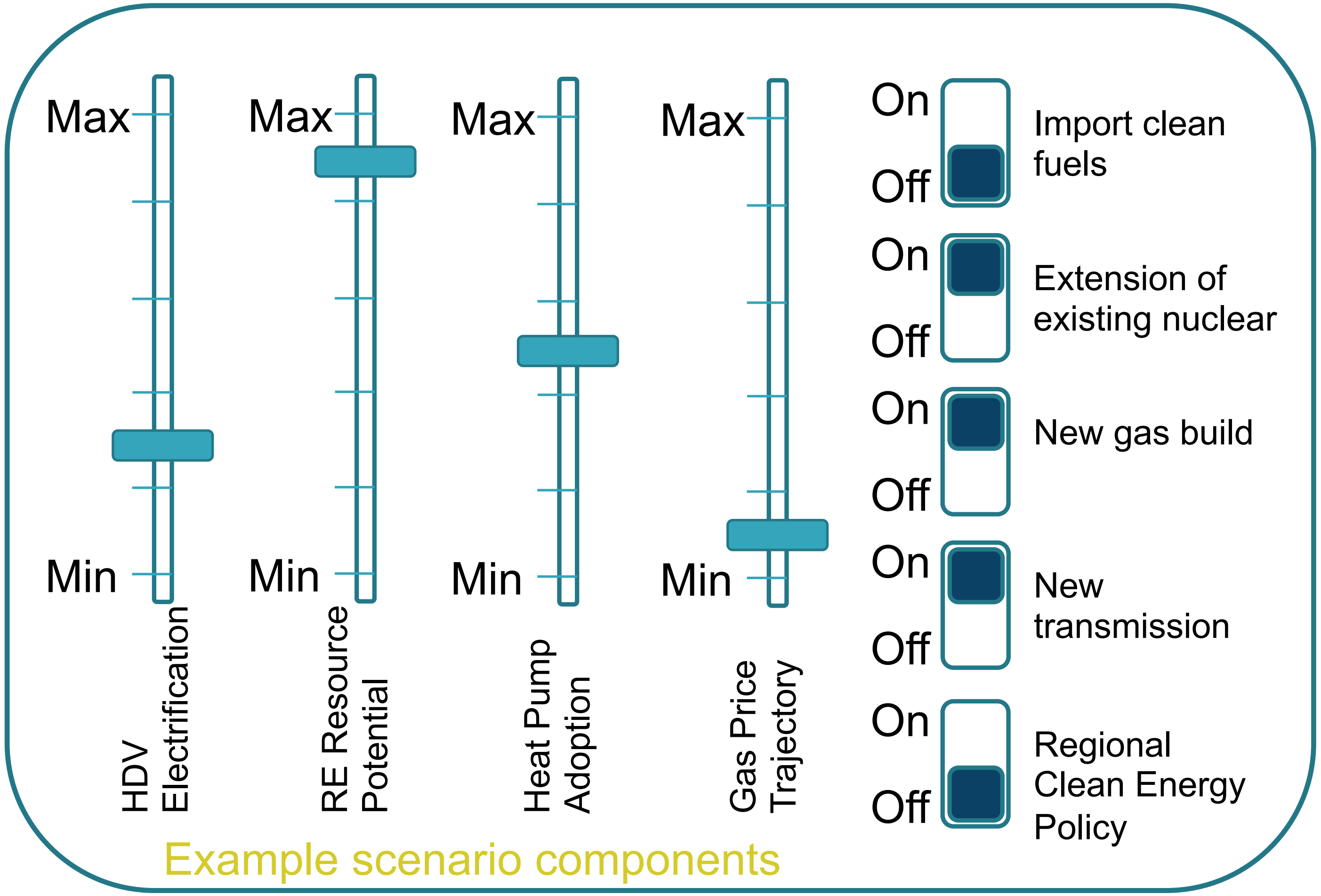
Existing Washington policies and targets through 2030 and 2050
Electricity fuel mix disclosure
Biennial energy report
Utility planned resource additions
Energy code strategy
Bioenergy coordination
Energy Independence Act
Appliance standards
Power plant emission standards
Clean Energy Transformation Act

Scenario Development: Investigate State Objectives



- Translate State objectives and potential policy pathways into constrained scenarios
- 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?

Next Workshop: Components of a Scenario

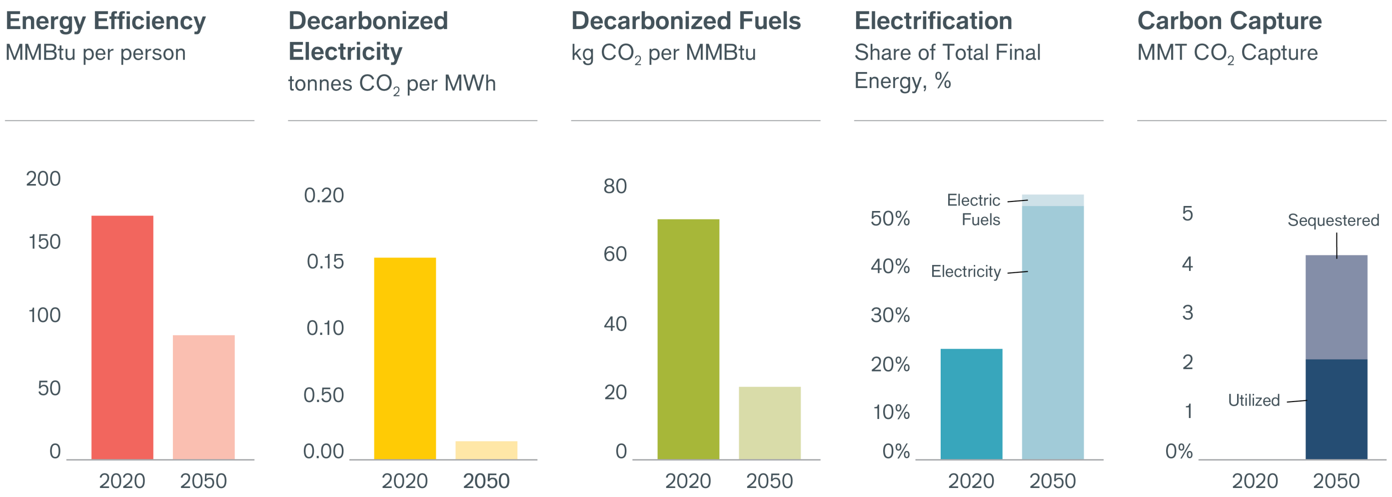


- Presentation of proposed scenarios
  - Designed to incorporate feedback from initial discussions with the Advisory Committee and feedback from prior state proceedings on decarbonization
- Scenario Purpose
- Review of the assumptions designed to achieve that purpose
- Interfacing with policy and action development

What Happens after Scenario Development?

Least Regrets Strategies

Cost effective outcomes from modeling to inform policy



Policy Development

How should we get there?

Creation of the SES

Rate reform?

Level playing field?

New business models?

Near term policies/actions that support long term goals

Transformational policy?

Infrastructure development?

2020 2025 2030 2035 2040 2045 2050

Thank you!