Oregon Energy Strategy Technical Report

July 2025

Prepared for:

Oregon Department of Energy

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Acronym List

Acronym	Definition
ACC II	Advanced Clean Cars II
ASHP	Air source heat pump
B2H	Boardman to Hemingway [transmission line]
BEV	Battery electric vehicle
BTM	Behind-the-meter
CBECS	Commercial Buildings Energy Consumption Survey
CBSA	Commercial Building Stock Assessment
CC	Carbon capture
CCGT	Combined-cycle gas turbine
CCS	Carbon capture and storage
CFS	Clean Fuel Standard
CPP	Climate Protection Program
CT	Combustion turbine
DEQ	[Oregon] Department of Environmental Quality
DER	Distributed energy resources
EE	Energy efficiency
EIA	Energy Information Administration
EP	Energy Pathways [Evolved model]
EPA	Environmental Protection Agency

Acronym	Definition
ESS	Energy Storage System
EV	Electric vehicle
FAME	Fatty Acid Methyl Ester
FCEV	Fuel cell electric vehicle
G2V	Grid-to-vehicle
GHG	Greenhouse Gas
GSHP	Ground source heat pump
GW	Gigawatt
GWh	Gigawatt hour
H2	Hydrogen
HEFA	Hydroprocessed Esters and Fatty Acids
HDV	Heavy-duty vehicle
IATA	International Air Transport Association
ICE	Internal combustion engine
IOU	Investor-owned utility
IRA	Inflation Reduction Act
LDV	Light-duty vehicle
LPG	Liquid petroleum gas
MDV	Medium-duty vehicle

Acronym	Definition
MHDV	Medium- and heavy-duty vehicles
MMBtu	One million British thermal units
MMT	Million metric tons
MW	Megawatt
NEEA	Northwest Energy Efficiency Alliance
NH3	Ammonia
NWPCC	Northwest Power and Conservation Council
RBSA	Residential Building Stock Assessment
RE	Renewable energy
RECS	Residential Energy Consumption Survey
RIO	Regional Investment and Operations [Evolved model]
SEDS	State Energy Data System
TBtu	One trillion British thermal units
TNC	The Nature Conservancy
TWh	Terawatt hour
Tx	Transmission
V2G	Vehicle-to-grid
VMT	Vehicle miles traveled
ZEV	Zero emissions vehicle

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Modeling Overview

Overview of Modeling Approach

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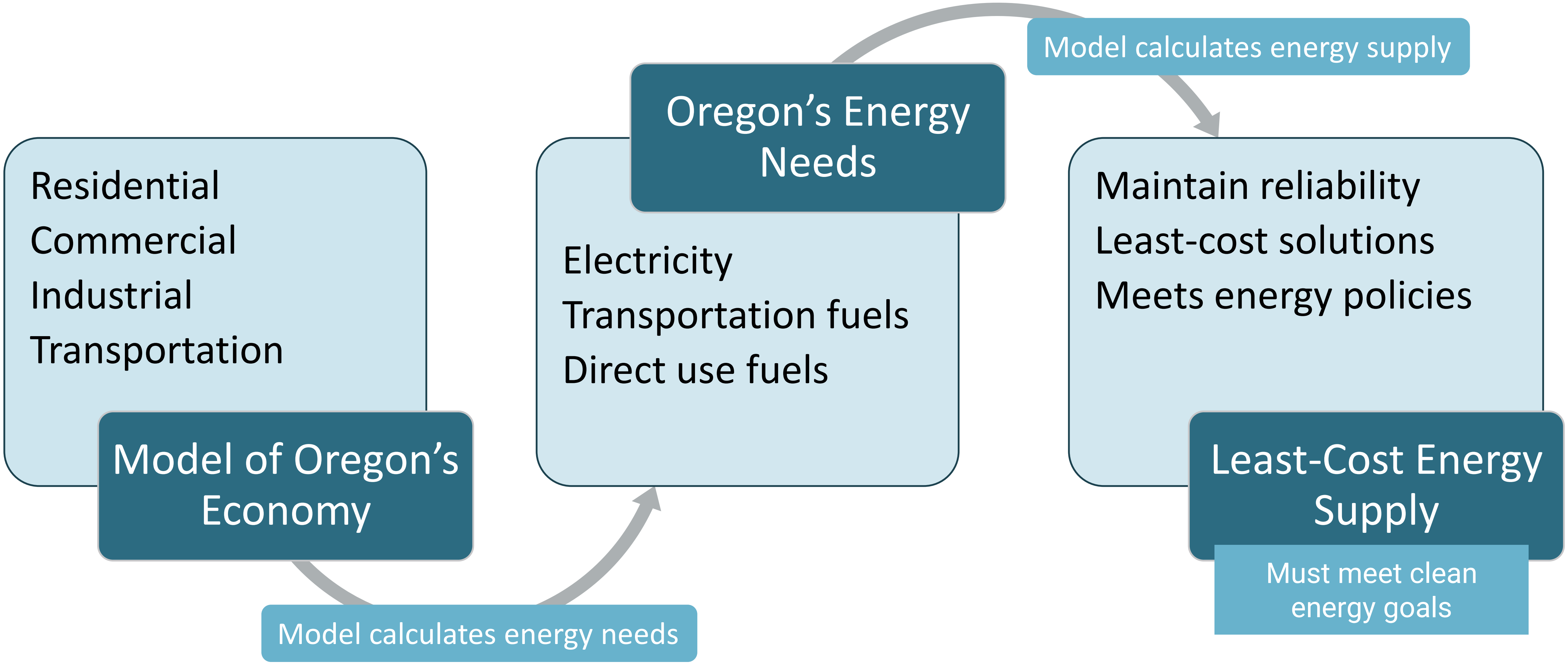
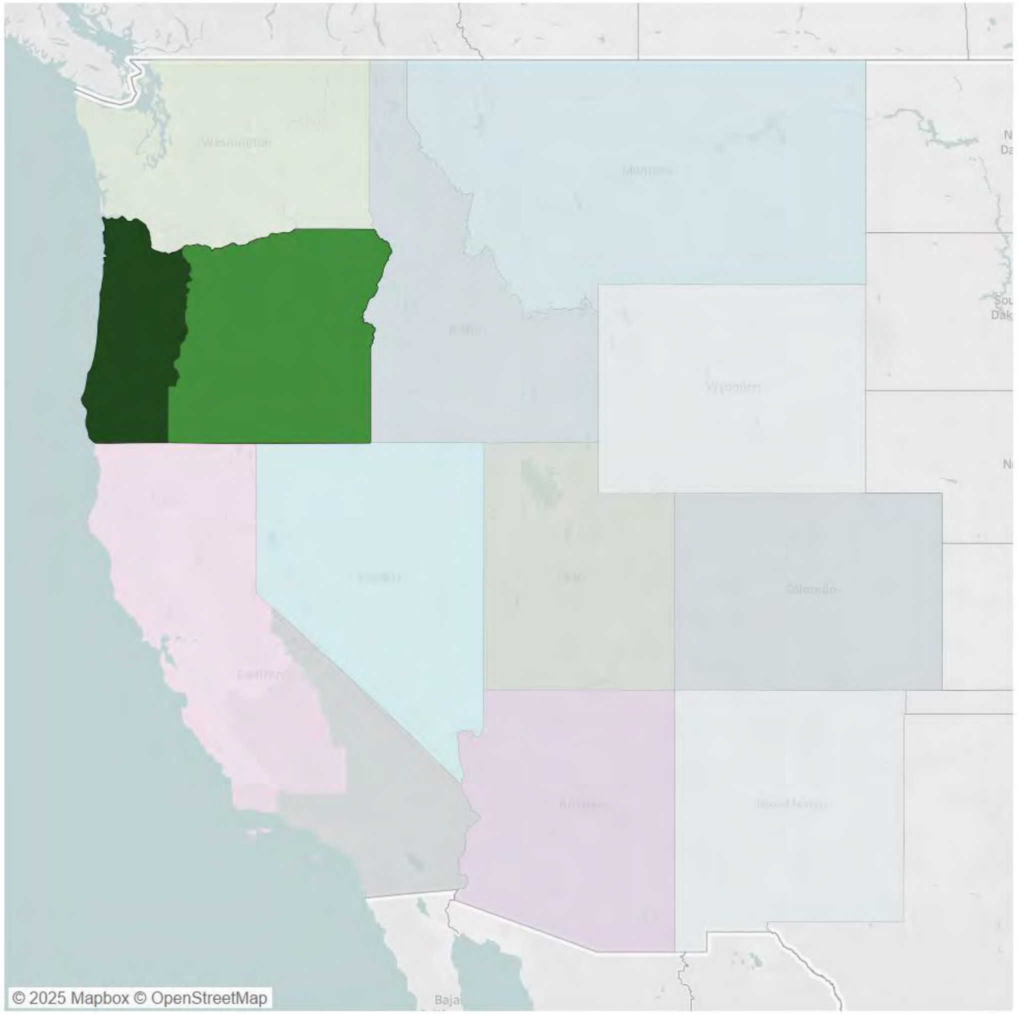


Model Geography: Oregon in Context of the West

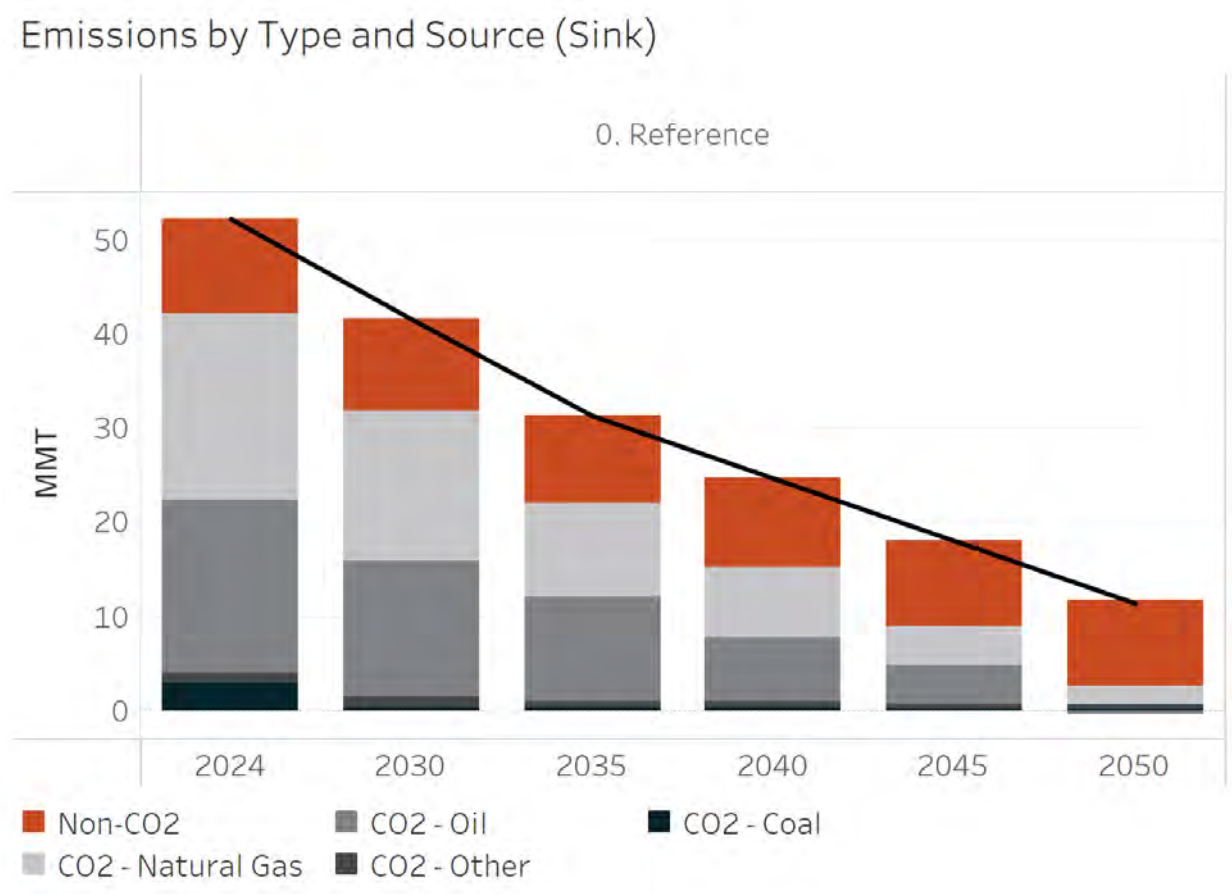
- Oregon modeled as part of larger energy system
- All states in the West modeled with their specific energy policies
  - Resource and load diversity
  - Resource competition for Oregon
- Oregon modeled as two zones: East and West of the Cascades
- Transmission between zones modeled with existing transmission capability and the opportunity to expand with an associated cost



Modeling is Structured to Comply with Oregon Laws

- Oregon has aggressive climate policies and goals, including 80% reduction in greenhouse gas emissions economy-wide by 2050
- Each modeled scenario shows a pathway to achieving Oregon's goals
- Nearly all emission reductions come from energy sector-related CO_2 emissions

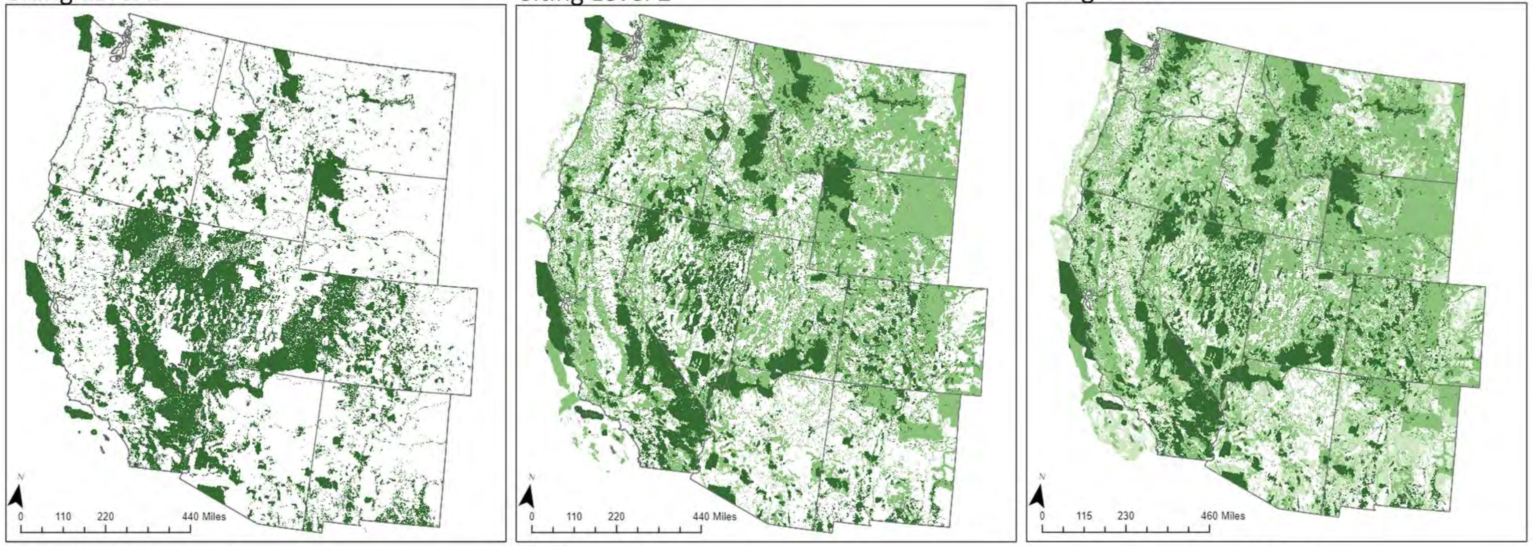
Note: Analysis was undertaken using Oregon's Climate Protection Program as proposed.



Modeling is Structured to Reflect Land Use and Natural Resource Constraints

- Land use considerations are an input to the model through screening at a disaggregated level of where infrastructure projects could be located
- Every scenario complies with most restrictive land use constraints in The Nature Conservancy's *Power of Place-West* study: legally protected, administratively protected, and high conservation value lands (Levels 1 – 3) (See methodology on pages 204-209.)

Siting Level 1 | Siting Level 2 | Siting Level 3



Excludes Category 1 | Excludes Category 1, 2 | Excludes Category 1, 2, 3

Reference Scenario Database Development with Oregon-Specific Data

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- Oregon-specific data collected from up-to-date Oregon datasets, past studies, and consultations
  - Transportation Data—Oregon Department of Transportation, EPA Motor Vehicle Emission Simulator (MOVES)
  - Building Data—NEEA Residential and Commercial Building Assessments (RBSA & CBSA), EIA Residential & Commercial Building Energy Consumption Survey (RECS) & (CBECS)
  - EIA State Energy Data System (SEDS)
  - Oregon Department of Environmental Quality GHG Emissions Inventory
  - Planned resource investments
  - Data center and crypto forecast data
  - Portland State University Population Research Center
- Review of Oregon resources and input from ODOE and data holders in identifying available datasets

Key Study Questions

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- What resources must be built to meet Oregon's climate and energy goals between now and 2050?
- What is the impact of delayed energy efficiency and building electrification?
- What is the impact of delayed electrification of medium- and heavy-duty vehicles?
- What happens if demand response participation is limited?
- What would happen if utility-scale electricity generation were limited in Oregon?
- What benefit do rooftop solar and behind-the-meter storage bring to the grid when transmission is limited to reconductoring?
- What might an alternative portfolio of flexible resources for electricity reliability look like if Oregon doesn't build any new clean gas plants?
- Does decarbonization reduce criteria pollutants, and what is the impact on health metrics in the Northwest if it does?
- How does household energy spending change with different technology adoption for cars and space heating?

What if Scenarios and Sensitivities

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0. Reference: What are the key elements of a least-cost pathway to meeting Oregon's energy policy objectives?

0a. What if per capita vehicle miles traveled (VMT) remained the same from the present until 2050?

0b. What if electricity demand supplied for data center and technology growth were 50% lower than the forecast used for the Reference Scenario?

0c. What if there were no electrification targets for medium- and heavy-duty vehicles through 2035, thus deferring transportation electrification further than Scenario 2?

1. What if energy efficiency and building electrification is delayed by 10 years?
2. What if full transportation electrification of medium- and heavy-duty vehicles is delayed 10 years, from 2040 to 2050?
3. What if there is limited demand response participation?
4. What if there is limited utility-scale electricity generation in Oregon?
5. What if there are higher levels of rooftop solar and behind-the-meter storage and transmission is limited to reconductoring only (no new build)?

5a. What if the higher levels of rooftop solar and behind-the-meter storage and transmission is limited to reconductoring, and per capita VMT remained the same from the present until 2050?

6. What might an alternative portfolio of flexible resources for electricity reliability look like?

<table>
<tr><th>Scenario Assumptions</th><th>0. Reference</th><th>1. Delayed EE and BE</th><th>2. Delayed TE</th><th>3. Ltd DR</th><th>4. Ltd Gen</th><th>5. High DER + Ltd Tx</th><th>6. Alt Flex Res</th></tr>
<tr><td>Clean Electricity Policy</td><td colspan="7">HB2021, 80% below baseline (2010-2012) by 2030, 90% by 2035, zero emission retail electricity sales by 2040 applied to PGE, PAC, and ESSs (~62.1% of Oregon retail electricity sales, equal to higher percentage of total customers).</td></tr>
<tr><td>Federal Incentives</td><td colspan="7">IRA demand and supply side incentives</td></tr>
<tr><td>Resource Availability</td><td colspan="4">Retain thermal resources if economic, no coal after 2030 for IOUs, only gas burning h2, biogas, or with CCS oxyfuel permitted in 2035 and onwards limited to less than 25 MW, TNC TX and RE potential. NREL ATB mid resource prices and consensus forecast H2 infra prices. Tx and pipeline expansion available in 2035 and onwards. B2H comes online 2030. OR East West potential set by planned transmission expansion</td><td>Limit potential for wind, solar, and geothermal in Oregon to half of what is built in the Reference Scenario</td><td>Allow only reconductoring transmission projects</td><td>No new gas or biogas electricity generators allowed in Oregon</td></tr>
<tr><td>Clean Fuel Standard</td><td colspan="7">DEQ CPP, 50% emissions reduction by 2035, 90% by 2050, applied to diesel, gasoline, and natural gas emissions. Not constrained unless the model violates this requirement.
DEQ CFS, applied every year, likely only binding in 2026 in the model because of EV credits</td></tr>
<tr><td>Distributed Energy Resources</td><td colspan="5">Minimum 10% from 20 MW or smaller systems. NWPCC Forecast of rooftop solar. 42 MW/ 25 MWh of BTM storage (1% of households install storage systems, 20% of them participate in offering grid services, 50% of stored energy available)</td><td>7 GW of rooftop solar. 2.1 GW/1.3 GWh participating BTM storage capacity (40% of solar customers with storage, 50% participation, 50% of stored energy available)</td><td>Same as 0</td></tr>
<tr><td>Economy-Wide GHG Policy</td><td colspan="7">EO 20-04: 45% below 1990 levels by 2035, 80% below 1990 levels by 2050</td></tr>
<tr><td>Non-CO_2 emissions</td><td colspan="7">EPA emission reduction supply curves for Oregon</td></tr>
<tr><td>Buildings: Electrification</td><td>Same as 2-6</td><td>10-year delay on electrified space and water heating targets</td><td colspan="5">Res Heating: 65% heat pump sales by 2030; 90% by 2040. Sales of woodstoves (res heating): 75% ASHP hybrid, 20% woodstoves, 5% HP by 2050.
Commercial Heating: Small/large commercial 50/50 split. Small commercial same as residential. Large commercial: 15% HP, 10% other electric/hybrid by 2030, 50% HP, 40% other electric/hybrid by 2045.
Water heating targets: Residential includes 2029 federal standards, 95% heat pump sales by 2045; Commercial small follow residential, commercial large 15%/10% by 2035, 50%/40% by 2045 (HP, other electric). Appliance sales: 95% electric by 2035</td></tr>
<tr><td>Buildings: Efficiency and Weatherization</td><td colspan="7">100% LED lighting sales by 2025. Latest vintage of all equipment, compliant with energy efficiency regulations.
3000 homes a year with whole home retrofits</td></tr>
<tr><td>Transportation: LDV</td><td colspan="7">ACC II for LDV sales reaching 100% in 2035</td></tr>
<tr><td>Transportation: MHDV</td><td colspan="2">Same as 3-6</td><td>Advanced Clean Trucks through 2035
100% BEV by 2050, except transit 75% EV/25% FCEV and long haul 65% EV/35% FCEV by 2050</td><td colspan="4">Advanced Clean Trucks through 2035
Post 2035: 100% ZEV sales by 2040 for Class 2b-8 vehicles
For long haul: 65% BEV/35%H2 (all other classes 100% electric)
School buses: 100% EV sales by 2036
Transit buses: 100% EV sales by 2036, 75%/25% EV/FCV by 2040</td></tr>
<tr><td>Transportation: Other</td><td colspan="7">Maritime: 50% ammonia, 20% liquid H2, 10% electric domestic, 60% ammonia, 20% liquid H2 international by 2050. Rail 70% H2, 20% electricity by 2050 (logistic growth starting in 2030). Aviation 15-20% efficiency gain through 2050 (IATA).</td></tr>
<tr><td>Vehicle Miles Traveled</td><td colspan="7">20% VMT reduction per capita by 2050 applied only to light duty</td></tr>
<tr><td>Industry</td><td>Same as 2-6</td><td>0.5%/yr process efficiency. Fuel switching halved</td><td colspan="5">1%/yr process efficiency improvements. Fuel switching measures from fuels to electricity from 2030 through 2050. Not including data centers.</td></tr>
<tr><td>Demand Response</td><td colspan="3">50% res/com heating, water heating (wh), and air conditioning (AC) by 2050 (0 in 2025). 2/3 res EVs by 2030 (0 in 2020) G2V. 1/3 com EVs by 2030 (0 in 2020) G2V. 26% V2G res EVs by 2050 (can discharge down to 40% battery capacity)</td><td>5% res/com heating, wh, AC by 2050, 20% of res EVs by 2030, no com. No V2G (res)</td><td>Same as 0</td><td>2/3 V2G for residential EVs in 2050</td><td>Same as 0</td></tr>
</table>

Scenario 1. Delayed Energy Efficiency and Building Electrification (1. Delayed EE & BE)

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Input	Reference Scenario	Alternative Scenario
Residential Space Heating	• Assume existing policies play out for all space heating technologies • 65% heat pump sales by 2030; 90% by 2040	• Assume existing policies play out for all space heating technologies • ***65% heat pump sales by 2040; 90% by 2050***

Commercial Space Heating	Weighted average of large and small commercial space heating loads, with the following framing:
	• Small commercial: follow residential
	• Large commercial:
	  • 2030: Electric heat pumps 15% of overall sales; other electric + electric hybrid systems (including hybrid heat pumps) 10% of overall sales
	  • 2045: Electric heat pumps 50% of overall sales; other electric + electric hybrid systems (including hybrid heat pumps) 40% of overall sales
		Weighted average of large and small commercial space heating loads, with the following framing:
		• Small commercial: follow residential
		• Large commercial:
		  • ***2040: Electric heat pumps 15% of overall sales; other electric + electric hybrid systems (including hybrid heat pumps) 10% of overall sales***
		  • ***2055: Electric heat pumps 50% of overall sales; other electric + electric hybrid systems (including hybrid heat pumps) 40% of overall sales***

Residential Water Heating	• Incorporate Federal Energy Conservation Standards for Consumer Water Heaters (from May 6, 2029) • Electric heat pump sales rising to 95% of overall sales by 2045	• Incorporate Federal Energy Conservation Standards for Consumer Water Heaters (from May 6, 2029) • ***Electric heat pump sales rising to 95% of overall sales by 2055***

Commercial Water Heating	Weighted average of large and small commercial water heating loads, with the following framing:
	• Small commercial: follow residential
	• Large commercial:
	  • 2035: Electric heat pumps for water heaters 15% of overall sales, other electric technologies 10% of overall sales
	  • 2045: Electric heat pumps for water heaters 50% of overall sales, other electric technologies 40% of overall sales
		Weighted average of large and small commercial water heating loads, with the following framing:
		• Small commercial: follow residential
		• Large commercial:
		  • ***2045: Electric heat pumps for water heaters 15% of overall sales, other electric technologies 10% of overall sales***
		  • ***2055: Electric heat pumps for water heaters 50% of overall sales, other electric technologies 40% of overall sales***

Scenario 1. Delayed Energy Efficiency and Building Electrification (1. Delayed EE and BE), cont.

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Input	Reference Scenario	Alternative Scenario
Industrial Processes	• 1% process efficiency improvements per year in all sectors • Fuel switching measures from fuels to electricity	• ***0.5% process efficiency improvements per year in all sectors*** • Fuel switching measures from fuels to electricity
Electrification	• 100% of machine drives by 2035 • 100% of low temperature heat by 2050, including in Oregon's largest industries such as computer and electronics products • 50% of heat in bulk chemicals production, 25% of heat in glass production • 50% of integrated steam production, including in food manufacturing, by 2045 • 100% of refrigeration by 2040 • 75% of industrial HVAC loads across industrial subsectors by 2050 • 80% of industrial vehicles including in agriculture by 2050 • 50% of construction energy demand by 2050	• ***50% of machine drives by 2035*** • ***50% of low temperature heat by 2050, including in Oregon's largest industries such as computer and electronics products*** • ***25% of heat in bulk chemicals production, 12.5% of heat in glass production*** • ***25% of integrated steam production, including in food manufacturing, by 2045*** • ***50% of refrigeration by 2040*** • ***37.5% of industrial HVAC loads across industrial subsectors by 2050*** • ***40% of industrial vehicles including in agriculture by 2050*** • ***25% of construction energy demand by 2050***
Switch to Hydrogen	• 50% of heat in bulk chemicals (not a large industry in OR) • 20% of integrated steam production, including in food manufacturing, by 2050 • 20% of construction energy demand • 20% of industrial vehicles by 2050	• ***25% of heat in bulk chemicals (not a large industry in OR)*** • ***10% of integrated steam production, including in food manufacturing, by 2050*** • ***10% of construction energy demand*** • ***10% of industrial vehicles by 2050***

Scenario 2. Delayed Transportation Electrification (2. Delayed TE)

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Input	Reference Scenario	Alternative Scenario
MDV and HDV sales shares – post 2035	Transit and School Buses: 100% zero emission vehicle (ZEV) sales by 2036; All other Class 2b-8 vehicles: 100% ZEV sales by 2040. Advanced Clean Trucks through 2035 Of the ZEVs: • For transit: 75% of ZEVs are assumed to be battery electric vehicles (BEVs), 25% are assumed to be hydrogen fuel cell electric vehicles (FCEVs) • For long haul: 65% of ZEVs are assumed to be BEVs, 35% are assumed to be hydrogen FCEVs • All other classes are assumed to be 100% BEVs	***For all Class 2b-8 vehicles, including buses: 100% zero emission vehicle (ZEV) sales by 2050. Advanced Clean Trucks through 2035*** Of the ZEVs: • For transit: 75% of ZEVs are assumed to be battery electric vehicles (BEVs), 25% are assumed to be hydrogen fuel cell electric vehicles (FCEVs) • For long haul: 65% of ZEVs are assumed to be BEVs, 35% are assumed to be hydrogen FCEVs • All other classes are assumed to be 100% BEVs

Scenario 3. Limited Demand Response (3. Ltd DR)

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Input	Reference Scenario	Alternative Scenario
Demand Response – Households participation	50% of homes with demand response capability are participating in some form of firm demand response program by 2050 (linear growth from 2025) Residential EVs: Start at 0, ramp up to 2/3 of residential EVs participate in managed charging by 2030	***5% of homes with demand response capability are participating in some form of firm demand response program by 2050 (linear growth from 2025)*** ***Residential EVs: Start at 0, ramp up to 20% of residential EVs participate in managed charging by 2030***
Demand Response - Commercial	50% of commercial spaces with demand response capability are participating in some form of firm demand response program (linear growth from 2025) Commercial EVs: Start at 0, ramp up to 1/3 of commercial EVs participate in managed charging by 2030	***5% of commercial spaces with demand response capability are participating in some form of firm demand response program (linear growth from 2025)*** ***Commercial EVs: No commercial EV participation in managed charging***
Vehicle-to-grid (V2G)	26% V2G for residential EVs, assuming utilities can discharge battery down to 40% capacity (so use 60% of EV battery)	***No V2G for residential EVs***

Scenario 4. Limited Utility-Scale Electricity Generation in Oregon (4. Ltd Gen)

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Input	Reference Scenario	Alternative Scenario
New Electric Resource Availability	Economic selection of new grid-scale electricity resources required to meet rising demand over time and in line with Oregon's energy policy objectives and reliability constraints, limited by resource potentials identified in TNC Power of Place-West study.	***Limit potential for new grid-scale wind, solar, and geothermal generation in Oregon to half of that built in Reference Scenario.***

Scenario 5. High Distributed Energy Resources + Limited Transmission (5. High DER + Ltd Tx)

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Input	Reference Scenario	Alternative Scenario
Transmission Development	Tx and pipeline expansion available from 2035 onwards. B2H comes online 2030.	B2H comes online 2030. ***Only reconductoring projects allowed.***
Distributed Energy Resources	NWPCC Forecast for rooftop solar. 42 MW/25 MWh of BTM storage (1% of households install storage systems; 20% of them participate in offering grid services, 50% of stored energy available).	***7GW of rooftop solar.*** ***2.1GW/1.3 GWh participating BTM storage capacity (40% of solar customers with storage, 50% participation, 50% of stored energy available).***
Demand Response: V2G	26% V2G for residential vehicles by 2050	***2/3 V2G for residential vehicles by 2050***

Scenario 6. Alternative Flexible Resources (6. Alt Flex Res)

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Input	Reference Scenario	Alternative Scenario
Resource Availability	Option for 100% hydrogen- or new biogas-supplied new electricity plants under 25 MW.	***No new gas or biogas electricity generators of any size allowed in Oregon.***

Sensitivity Questions

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- **0a. No Change in VMT in Reference Scenario**
  - What if per capita vehicle miles traveled (VMT) remained the same from the present until 2050 instead of a 20% reduction in VMT per capita in light duty vehicles in the Reference Scenario?
- **0b. 50% Lower Tech Load Growth in Reference Scenario**
  - What if electricity demand supplied for data center growth and chip fabrication loads were 50% lower than the 2029 Northwest Power and Conservation Council's Power Supply Adequacy Assessment 2029 mid-higher forecast?
- **0c. No Advanced Clean Trucks Regulation in Delayed Transportation Electrification Alternative Scenario**
  - What if there were no electrification targets for medium-and heavy-duty vehicles through 2035, thus deferring transportation electrification further than Scenario 2?
- **5a. No Change in VMT in High Distributed Energy Resources + Limited Transmission Scenario**
  - What if the higher levels of rooftop solar and behind-the-meter storage and transmission is limited to reconductoring, and per capita VMT remained the same from the present until 2050?

Sensitivities

Sensitivity Analyses		
***Sensitivity 0a*: No Change in VMT in Reference Scenario.**		
Input	Reference Scenario	Sensitivity
VMT Assumption	20% reduction in LDV VMT per capita by 2050	No change in VMT per capita from today
***Sensitivity 0b:* 50% Lower Tech Load Growth in Reference Scenario.**		
Input	Reference Scenario	Sensitivity
Tech Load Growth	NWPCC Northwest Power Supply Adequacy Assessment for 2029 mid-higher case assumed by 2030, with 1.5% load growth annually 2030-2050	50% of Reference Scenario tech loads electricity demand by 2030, with 1% load growth annually 2030-2050
***Sensitivity 0c:* No Advanced Clean Trucks Regulation in Delayed Transportation Electrification Alternative Scenario**		
Input	Scenario 2. Delayed TE	Sensitivity
MHD Electrification Assumption	• Advanced Clean Trucks targets through 2035 • 100% ZEV sales for transit/school buses by 2036 • 100% ZEV sales for all other MHD vehicle classes by 2050	• 100% ZEV sales for all MHD vehicle classes by 2050 • No interim electrification targets for MHD

Sensitivities

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Sensitivity Analyses		
***Sensitivity 5a*: No Change in VMT in High Distributed Energy resources + Limited Transmission Scenario**		
Input	Scenario 5. High DER + Ltd Tx	Sensitivity
VMT Assumption	20% reduction in LDV VMT per capita by 2050	No change in VMT per capita from today

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Key Findings

Top-Level Findings

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- The modeling results confirm that Oregon's existing policies are important to meet the state's clean energy goals
- Oregon's clean energy goals require more action than current policies will deliver
- The modeling explores some least-cost options available to achieve the state's clean energy goals, while maintaining reliability
- The modeling results give us information to consider the effects of different choices

Reference Scenario is the Least-Cost Pathway

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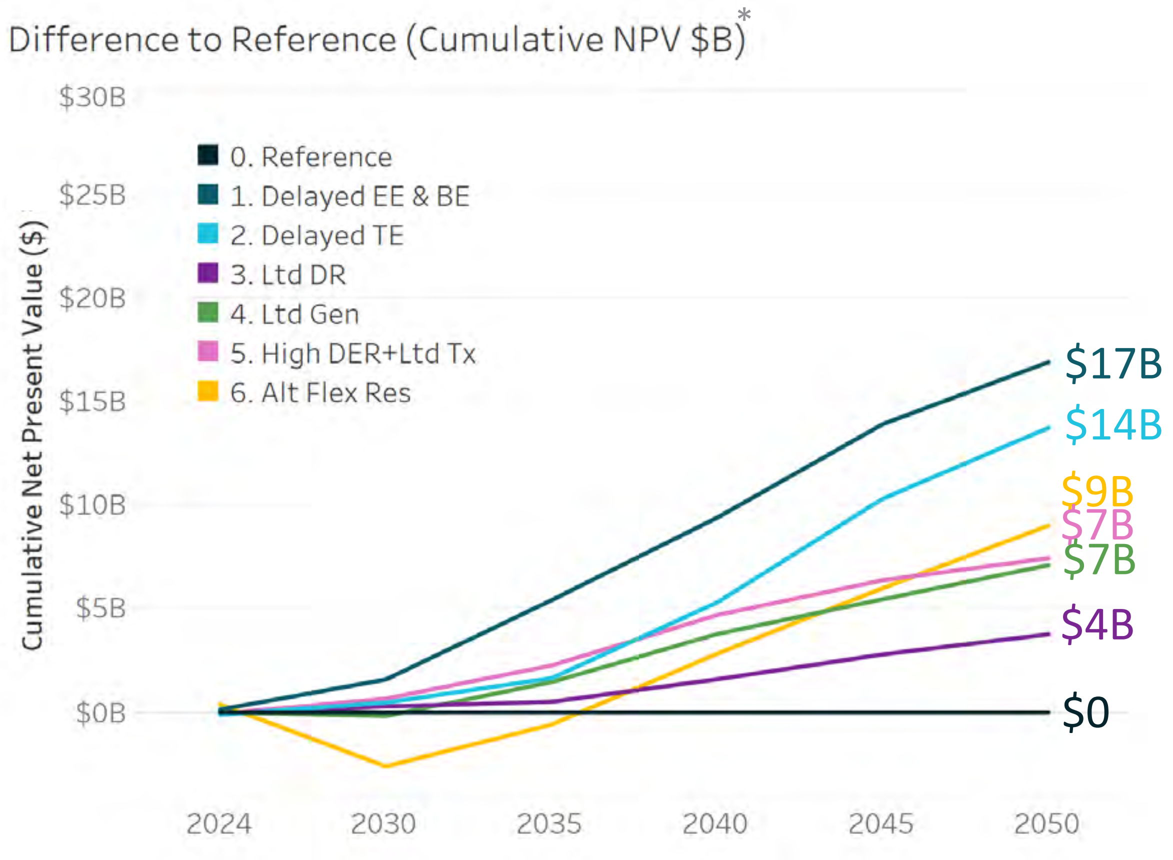
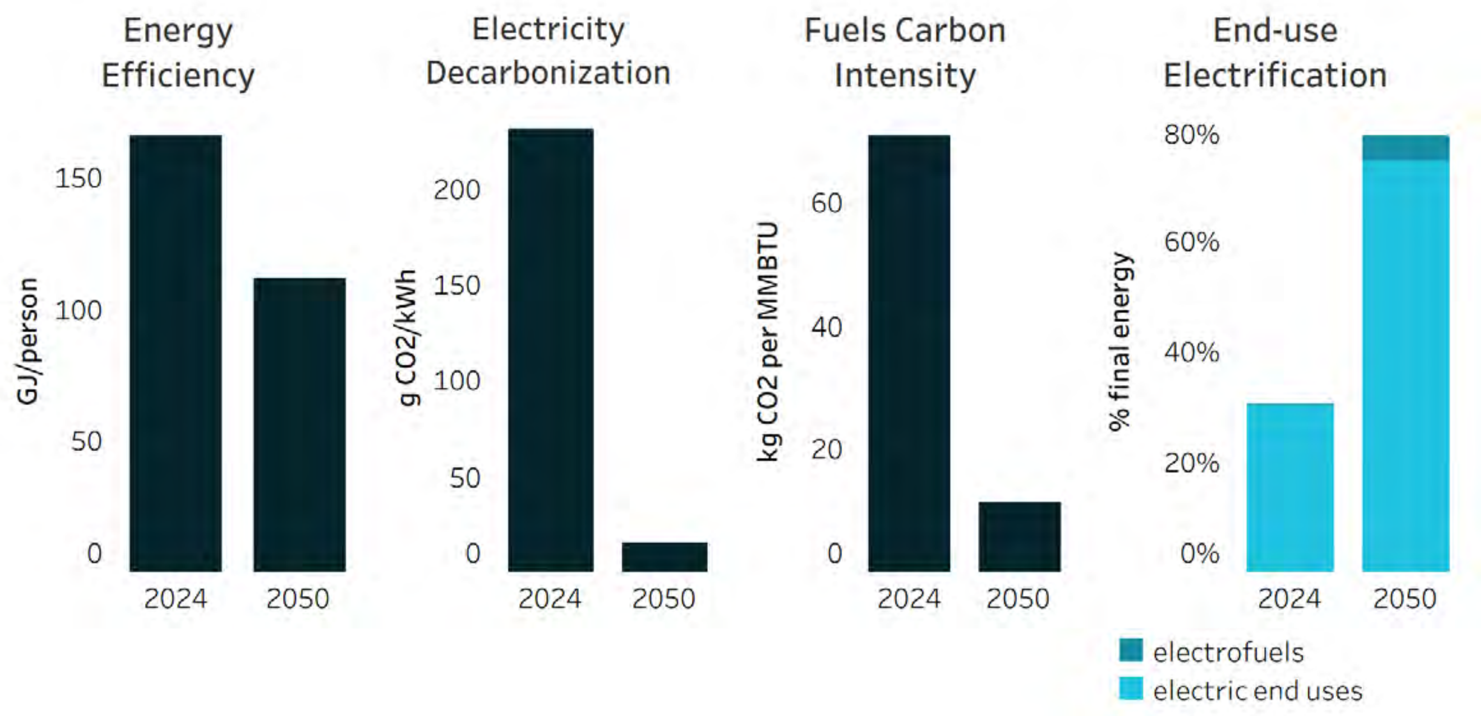
- All alternative scenarios lead to increase in costs relative to the Reference
- Existing transportation electrification policies are essential to ensure cost-effective transition
- Electrification and energy efficiency in buildings are key to cost containment



*Net present value costs calculated with a 3% societal discount rate

Pillars Of Deep Decarbonization: Reference



- Oregon's economy-wide energy use per capita decreases by a third, electricity supply becomes almost 100% clean, fuels are mostly decarbonized, and 80% of end use energy uses electricity or electrofuels from hydrogen electrolysis by 2050

Demand for Energy Decreases While Demand for Electricity Increases

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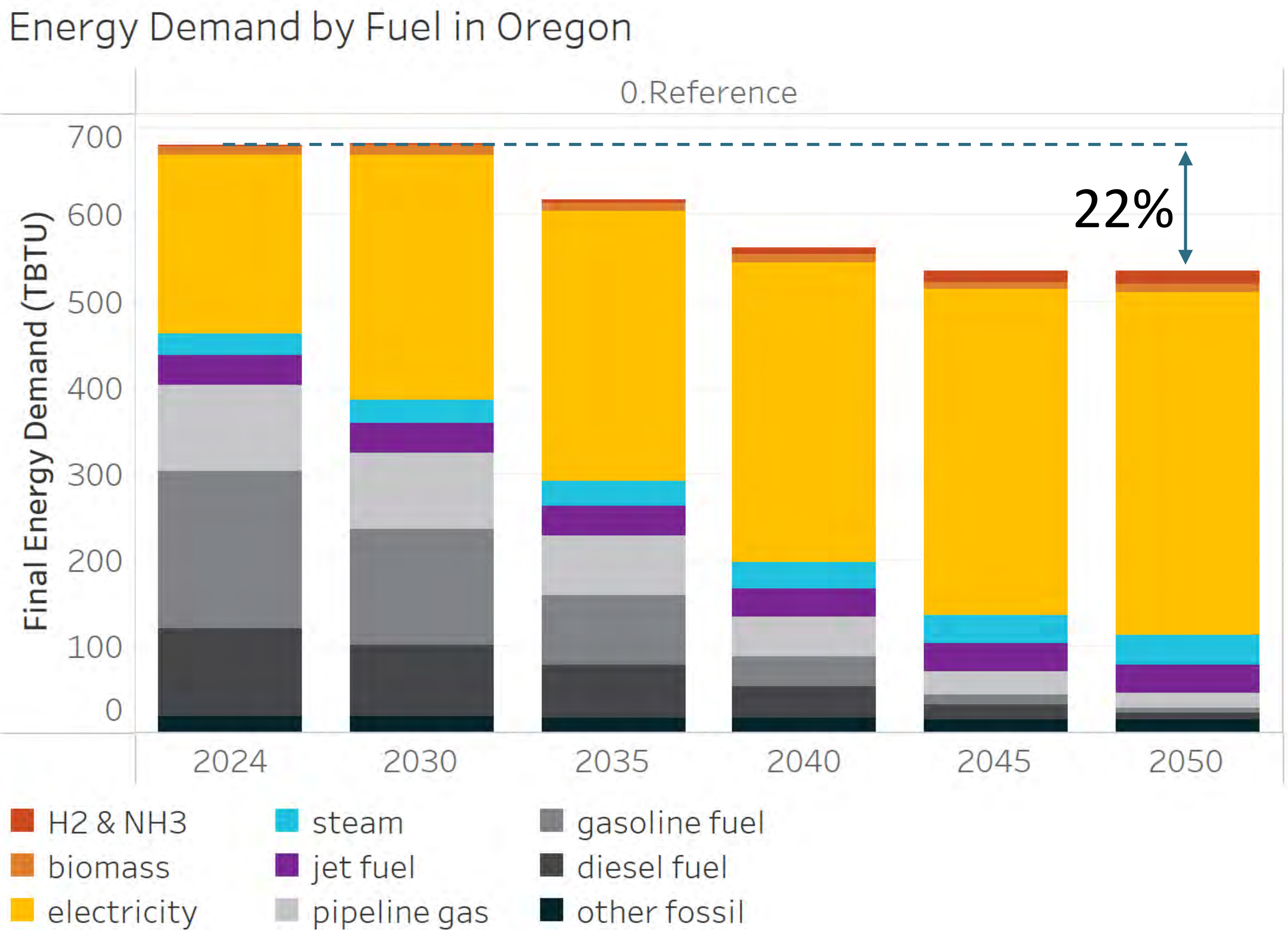


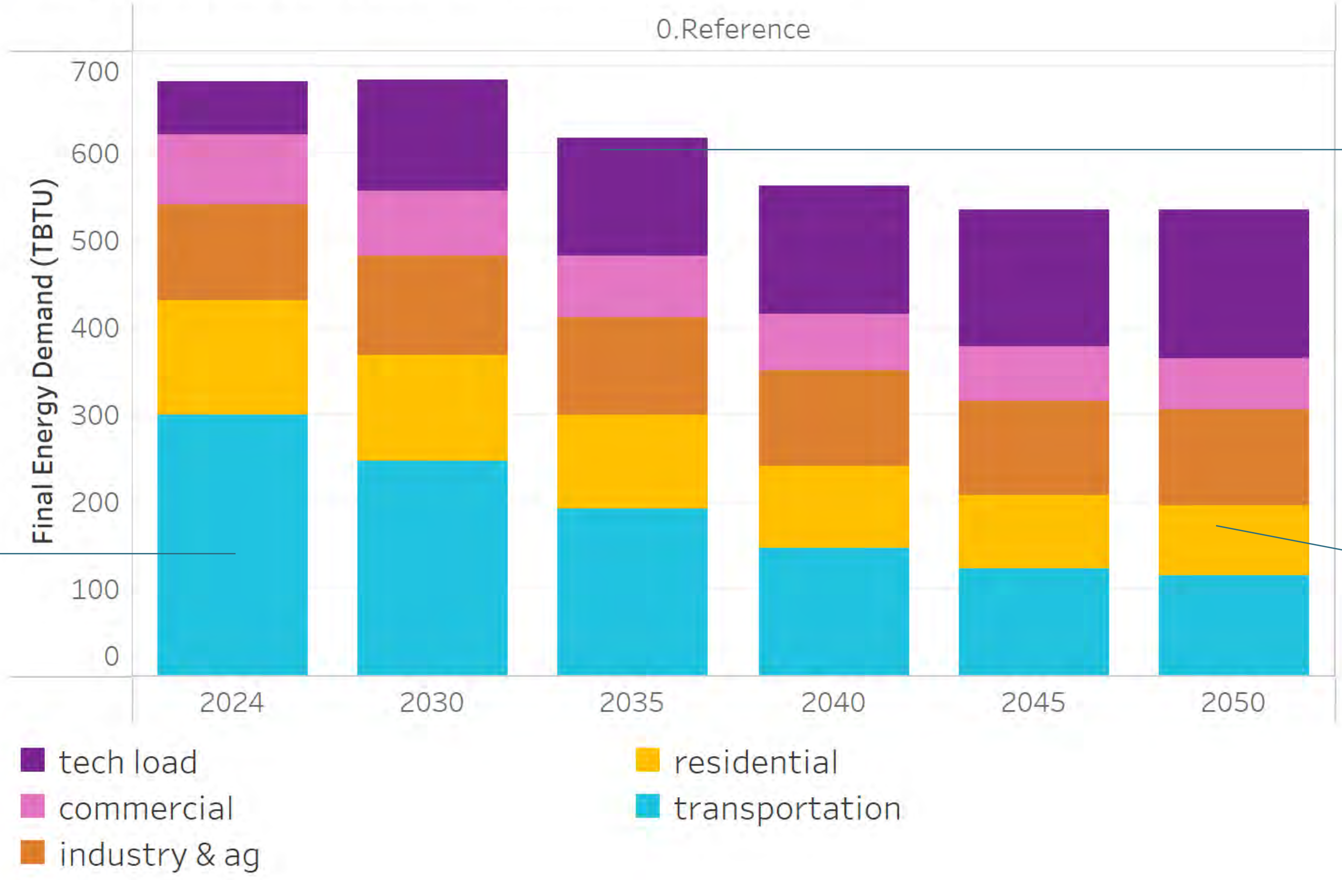
Total energy demand decreases by 22%

Electricity demand doubles

Notes: 1) "other fossil" includes fuel oil, lpg, oil, coal, and petroleum coke. Steam is a heat input to many industrial processes. Like electricity, it can be generated from clean or dirty sources. 2) H2 = Hydrogen; NH3 = Ammonia

Tech Loads Increase Demand; Transportation and Building Electrification and Efficiency Contain It

Energy Demand by Sector in Oregon



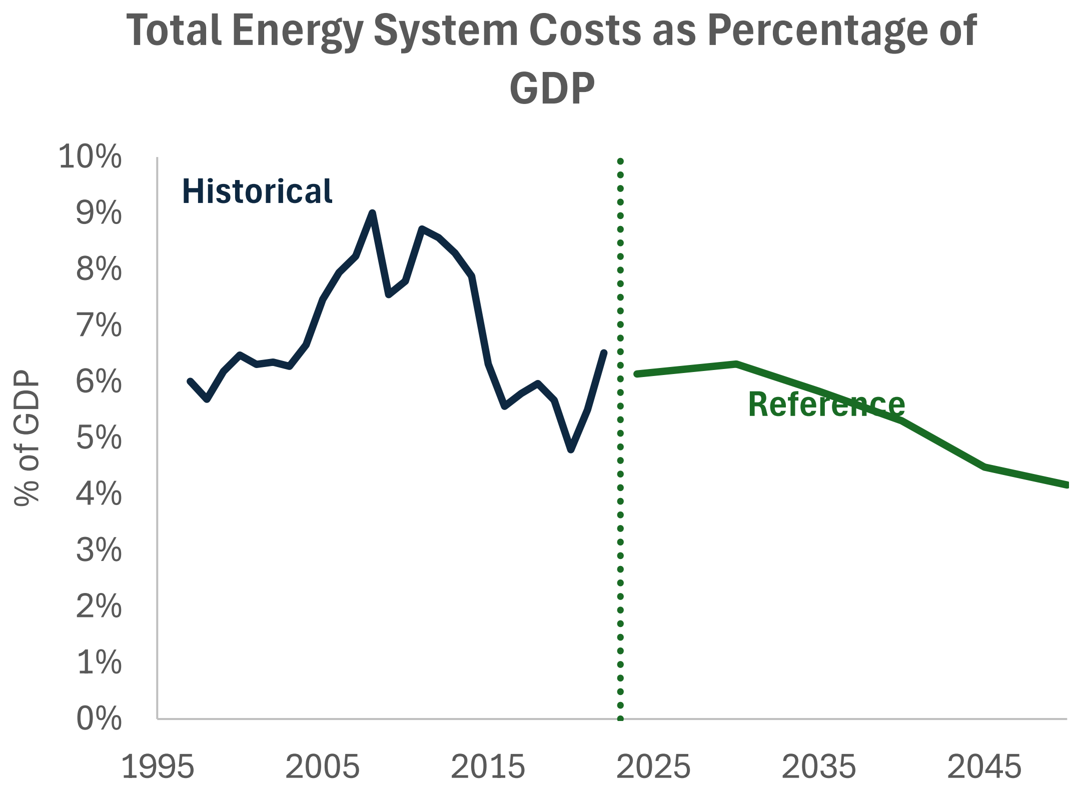
Data centers and chip fabrication facilities will likely add significant load to the system

Electrification of cars and trucks delivers the biggest efficiency gains, driving down overall demand

Building electrification and efficiency improvements reduce demand in homes

Level of Investment Needed is Not Unprecedented

- Total energy-related spending declines economywide, with reduced spending on imported fuels and greater investment in local and regional infrastructure, particularly for the electricity sector
- Trades global volatility in oil and gas markets for uncertainties about critical minerals, supply chains
- Keeping more money in-state and in-region
- Jobs study and follow-on workforce analysis will help identify how to meet workforce needs



Clean Fuels are Needed to Meet Energy and Emissions Goals

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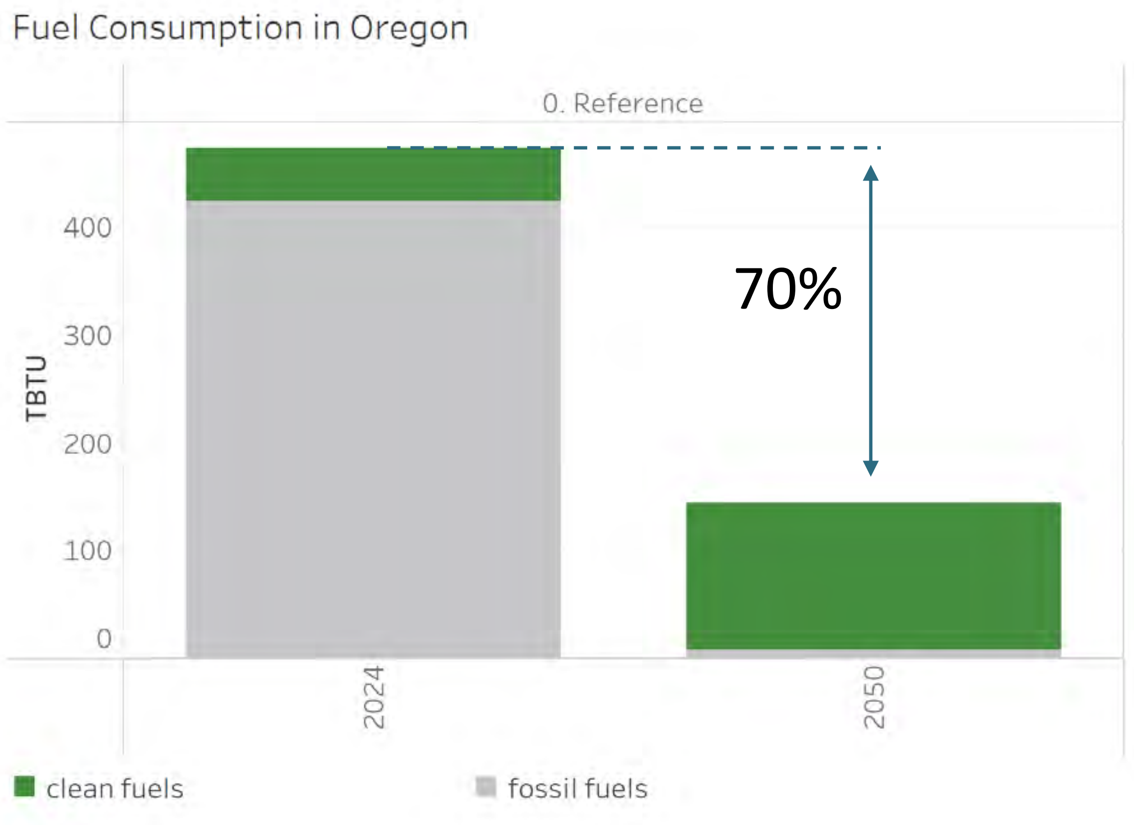
- Fuel demands decrease over time but their importance does not
  - Hardest to electrify applications
  - Resilience
  - Time for electric technologies to replace fossil
- Clean fuels include biogas, bio liquids, e-fuels, hydrogen, ammonia, and geothermal steam



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Reference Scenario

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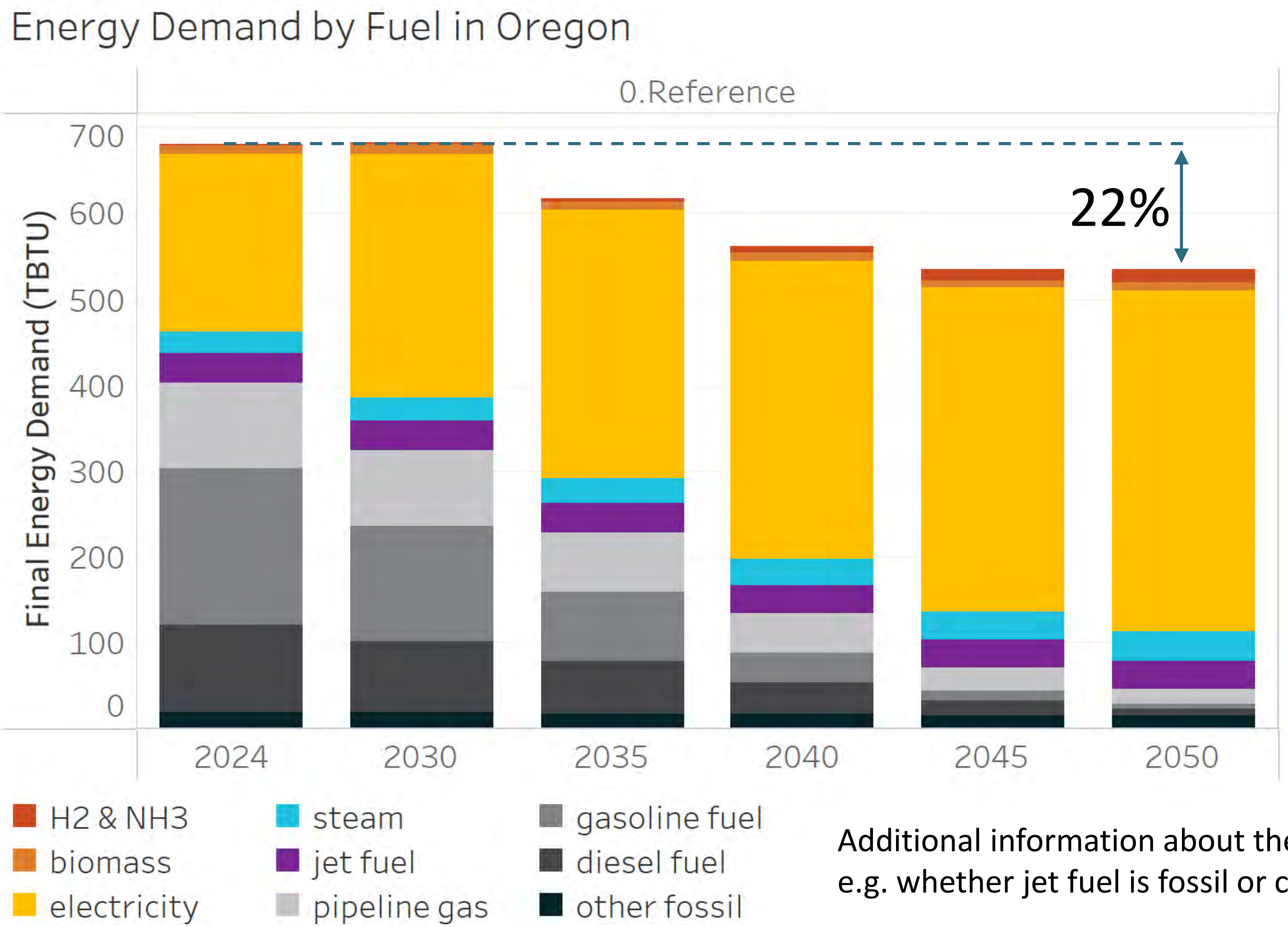
Reference Scenario

Demand-Side Results

Reference Scenario
Energy Demand by Fuel in Oregon



Total energy demand decreases by 22%

Electricity demand doubles

Additional information about the composition of fuel blends, e.g. whether jet fuel is fossil or clean fuel is available on slide 77

Note: "other fossil" includes fuel oil, lpg, oil, coal, and petroleum coke. Steam is a heat input to many industrial processes. Like electricity, it can be generated from clean or dirty sources.

Reference Scenario
Energy Demand by Sector in Oregon

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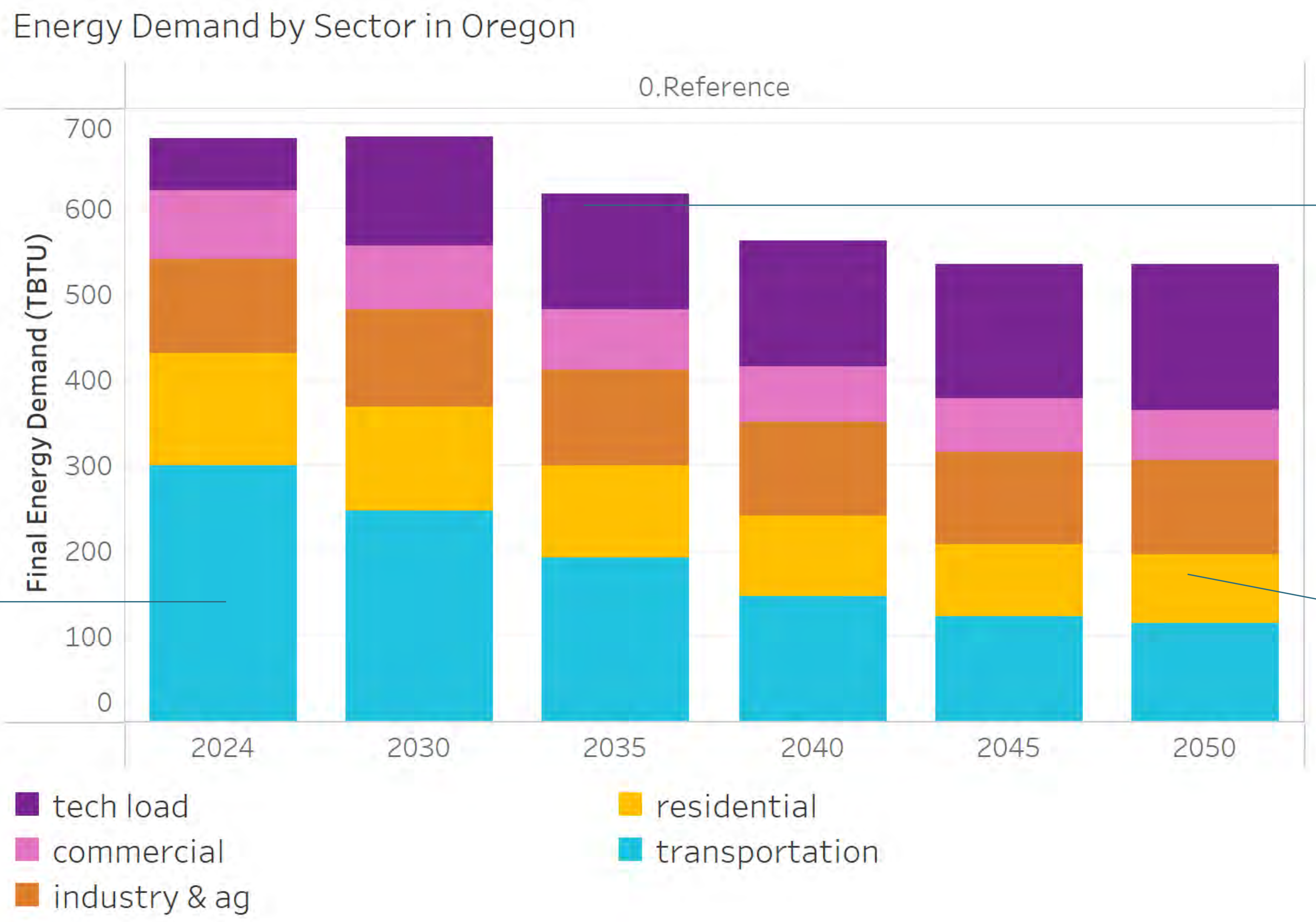
Electrification of cars and trucks delivers the biggest efficiency gains, driving down overall demand

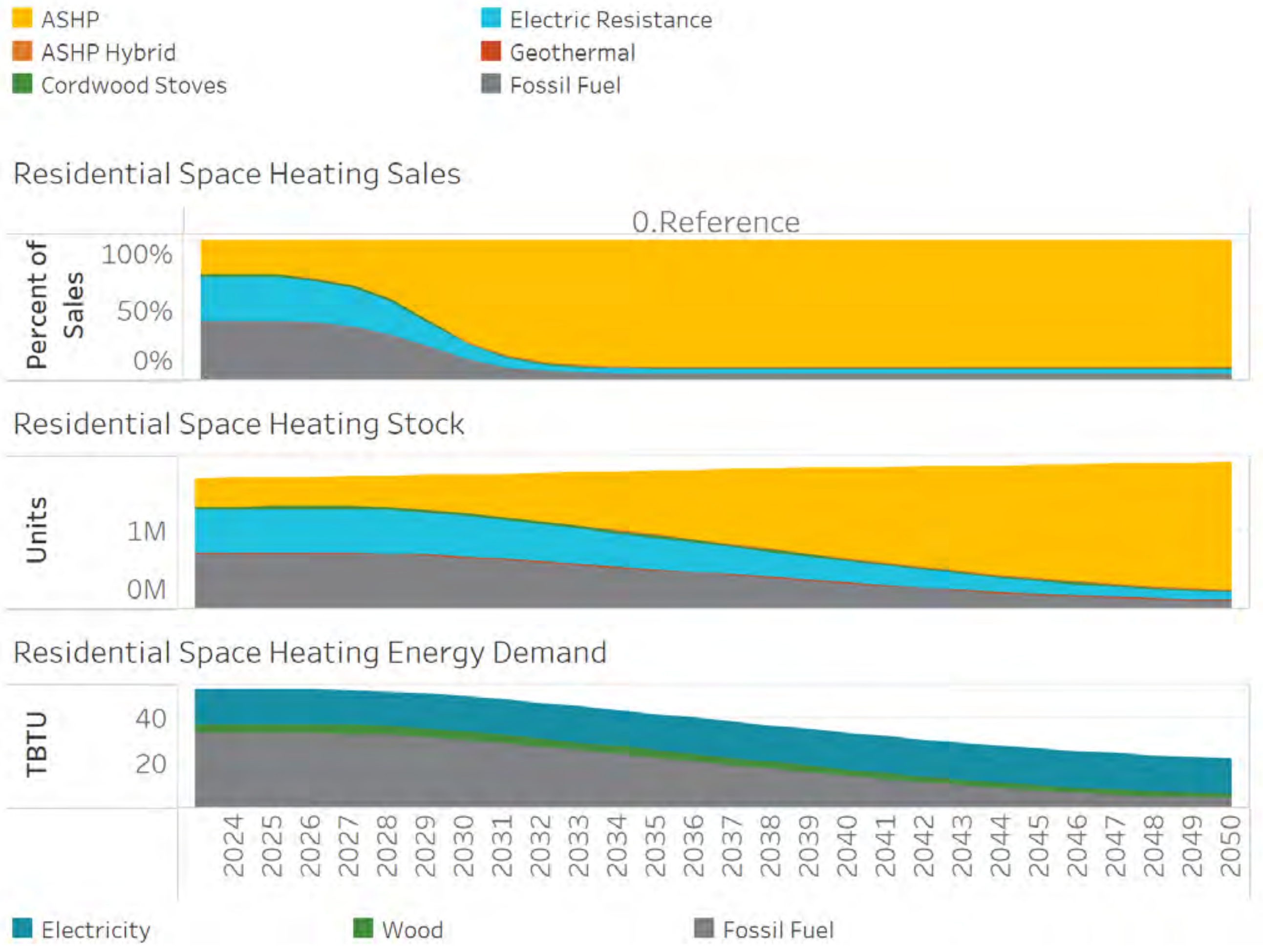


Data centers and chip fabrication facilities will likely add significant load to the system

Building electrification and efficiency improvements reduce demand in homes

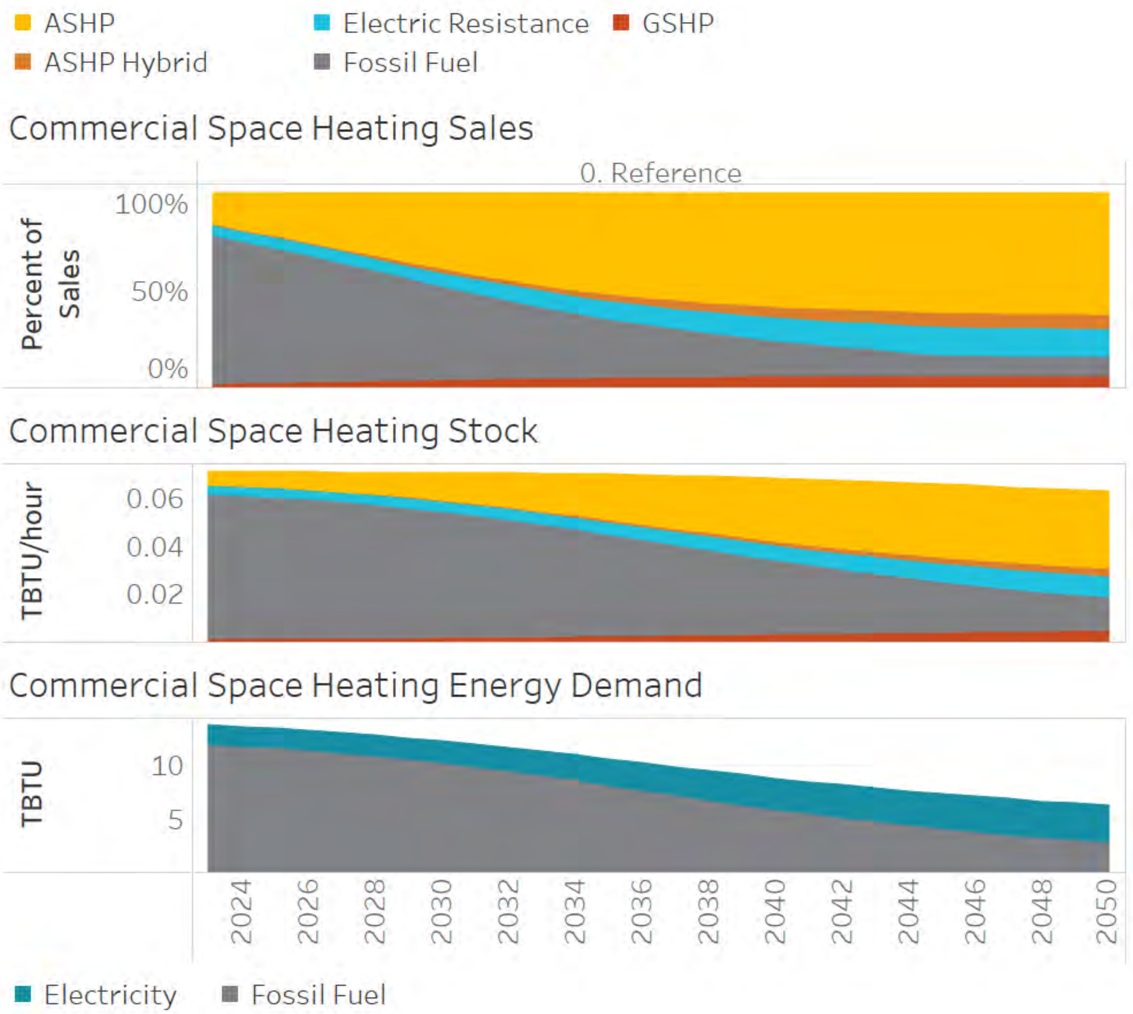
Reference Scenario
Residential Space Heating

- Fuel switching to electric heat pumps drives down overall energy demand
  - Electricity demand relatively unchanged as electric efficiency gains offset growth from electrification
- 65% air-source heat pump (ASHP) sales by 2030 and 90% ASHP sales by 2040
- Wood burning stoves supplemented with hybrid systems



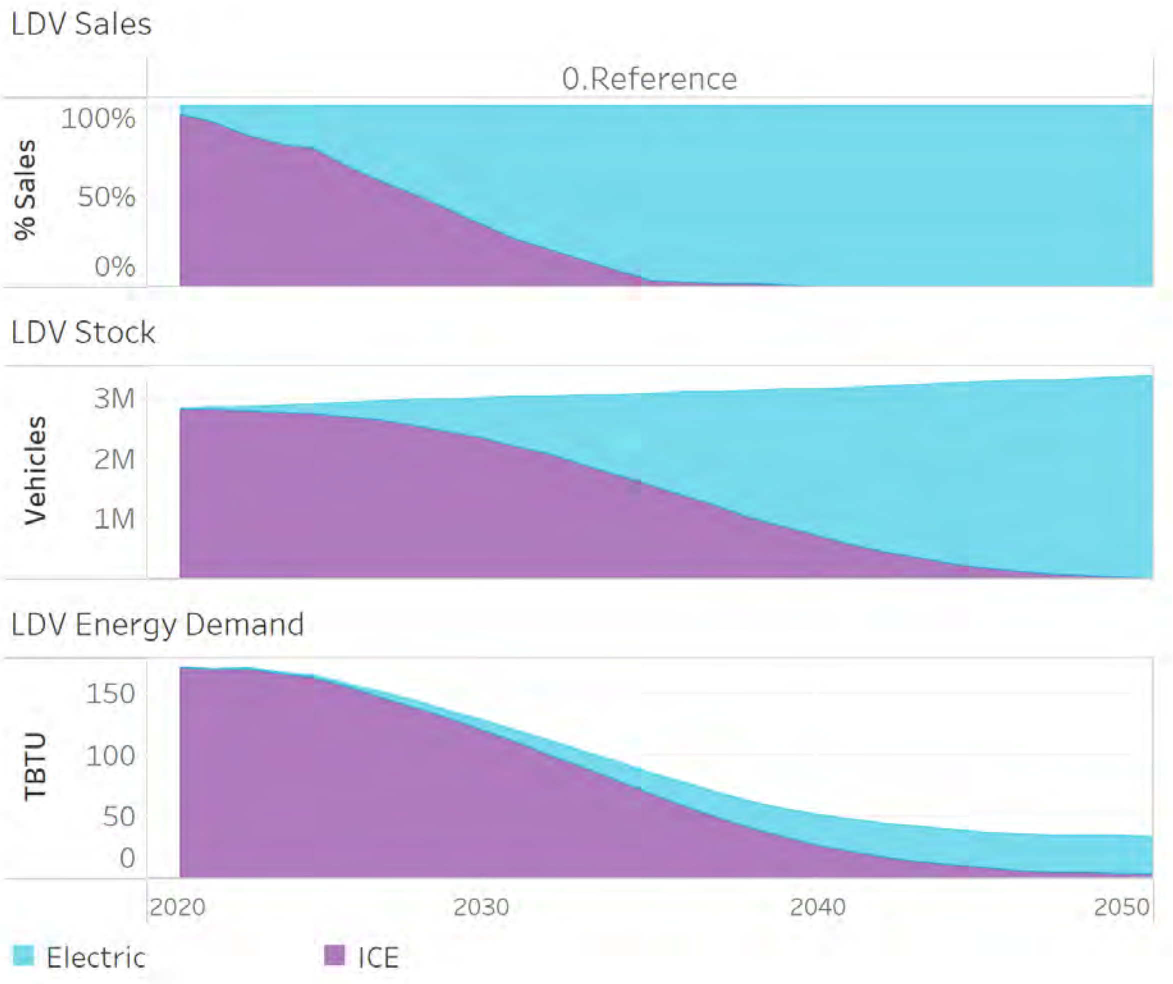
Reference Scenario
Commercial Space Heating

- Small commercial (50% of buildings) use the same assumptions as residential
- Large commercial (50% of buildings):
  - 15% ASHP, 10% electric + hybrid by 2030
  - 50% ASHP, 40% electric + hybrid by 2040
- Electricity demand doubles with 60% reduction in overall energy use by 2050



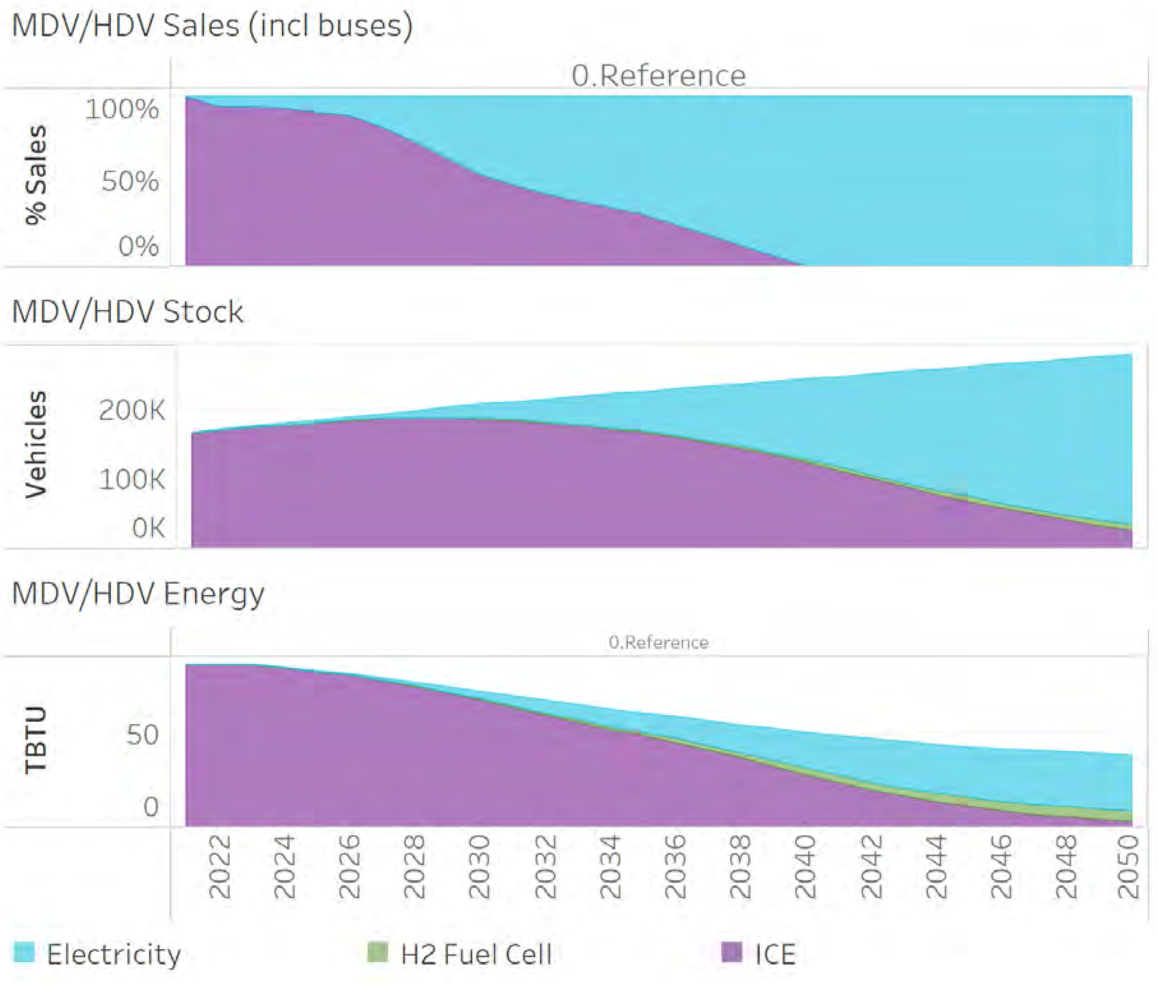
Reference Scenario
Light-Duty Vehicle Sales, Stock, Energy

- 100% zero emissions vehicle sales achieved in 2035
- Drop in energy demand from both better drive chain efficiency and 20% reduction in vehicle miles traveled by 2050



Reference Scenario
Medium- and Heavy-Duty Vehicles Sales, Stock, Energy

- School buses: 100% zero emission vehicle sales (ZEV) by 2036
- Transit buses:
  - 100% ZEV sales by 2036 target
    - 100% battery electric by 2036
    - 75% sales assumed battery electric (BEV)/25% sales assumed fuel cell electric (FCEV) by 2040
- Long-Haul: 65% BEV, 35% FCEV by 2040
- Short-Haul: 100% BEV by 2040
- 45% decrease in energy use for MDV/HDV by 2050



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Reference Scenario

Supply-Side Results

Reference Scenario Supply-side Overview

- This section answers the question "**How do we serve the energy demands of the economy reliably and at least cost?**"
  - Subject to the constraints defined for the Reference Scenario, such as electricity policy, emissions policy, resource availability, etc.
- Supply-side analysis is concerned with investments in physical infrastructure and system operating costs
  - Evaluating electricity generation and transmission needs and opportunities
  - Evaluating fuel supply needs and opportunities
- Analysis does not answer questions about how costs are assigned and paid for
  - e.g., What rate do customers pay for electricity for their electric vehicles?
  - Analysis aims to minimize the size of the total cost pie. How that pie is apportioned, shared, and paid for can be informed by further work

Reference Scenario Electricity Balance

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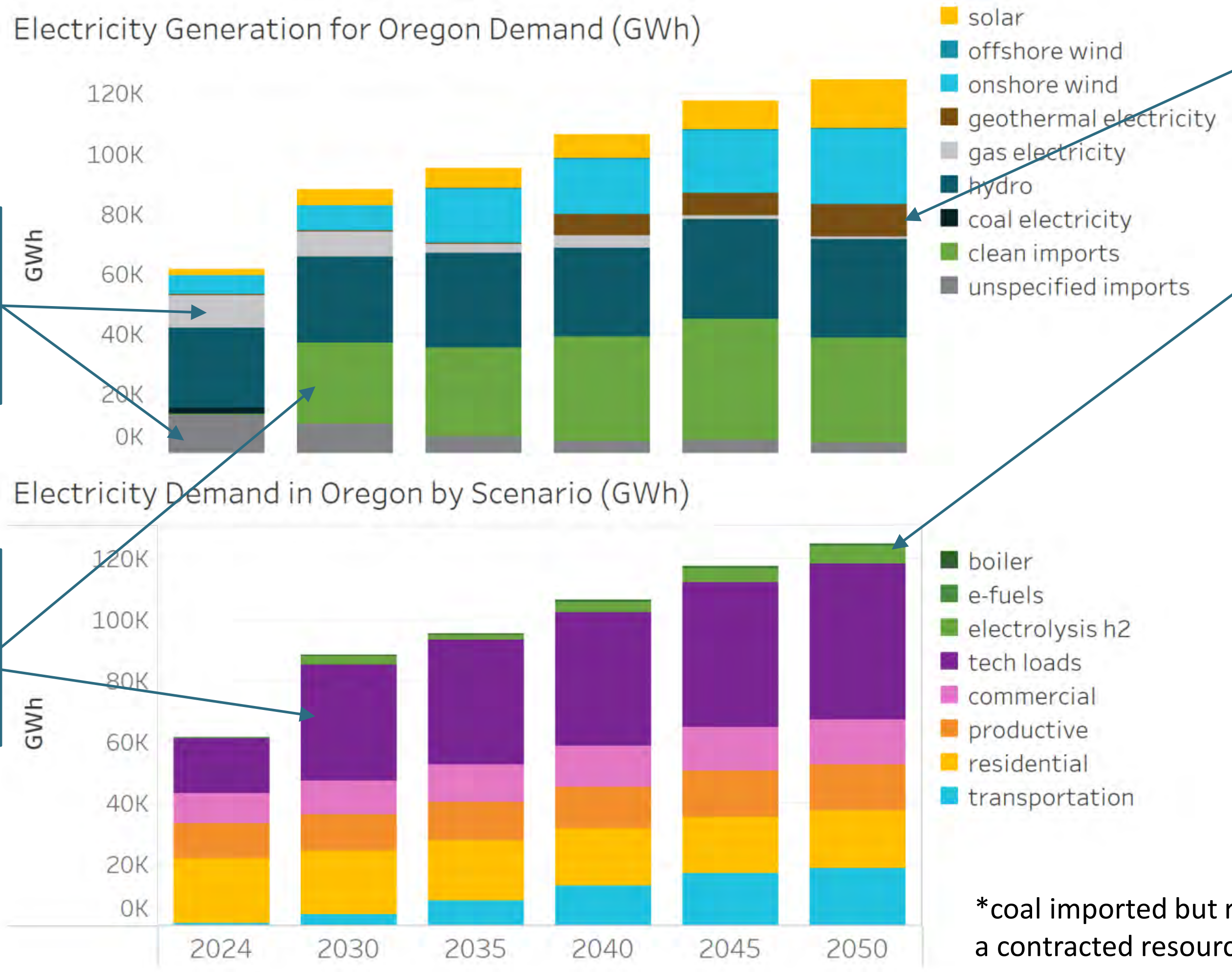
In-state gas generation and unspecified imports decrease as HB 2021 and EO 20-04 drive a cleaner electricity sector

Load growth, primarily from tech loads and electrification, is met with in-state generation and specified clean imports



Geothermal power becomes an important share of clean generation past 2040

Flexible industrial loads, primarily from electrolysis, help balance the grid and provide clean fuel

Near-term demand for clean electricity requires near-term action.

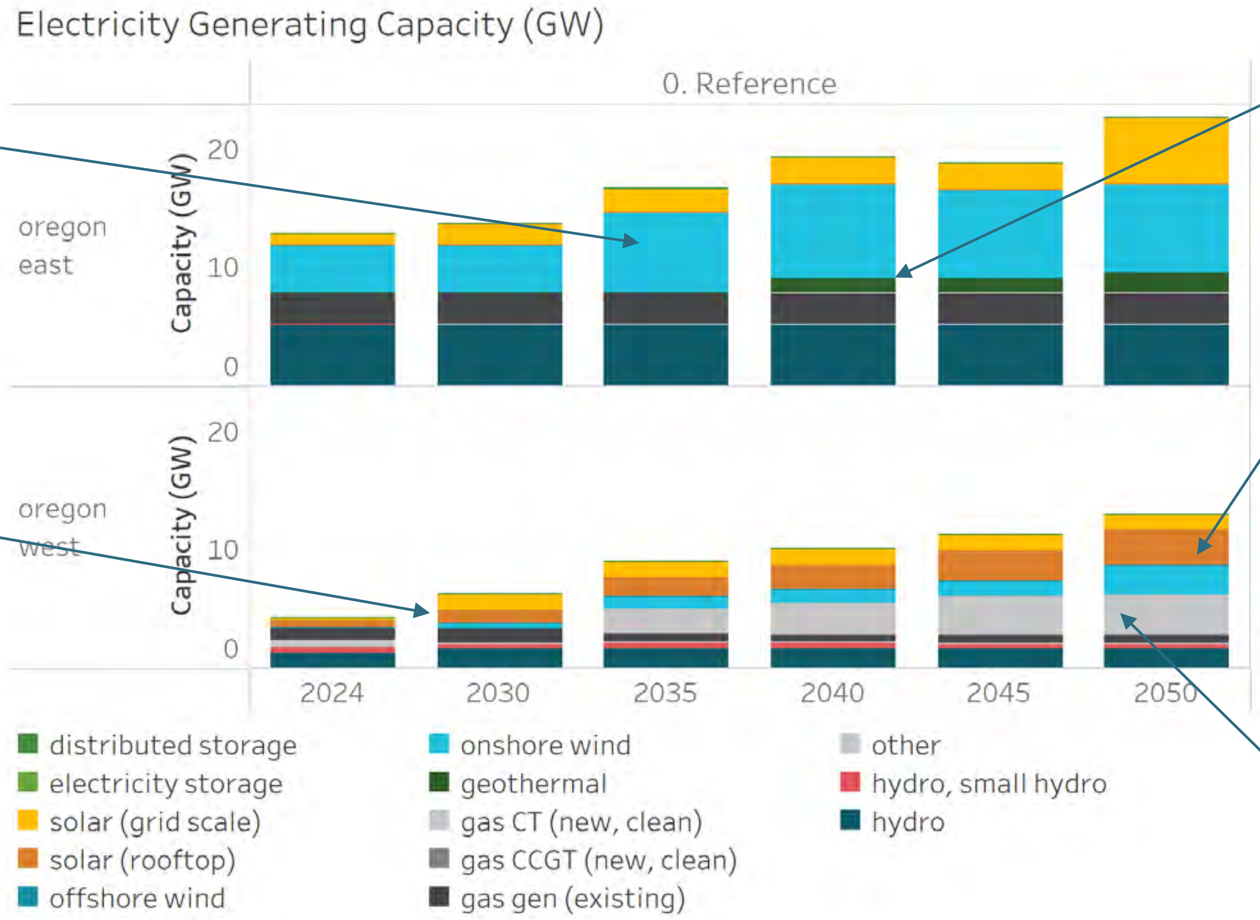
When the model selects a resource, it comes online with development planning assumed to have already been completed.

*coal imported but represented as a contracted resource in modeling

Reference Scenario Generation Capacity

Early growth of onshore wind in Oregon East

Rooftop solar growth in Oregon West alongside early grid scale solar additions



1.2 GW of enhanced geothermal growing to 1.6 GW by 2050

3 GW of rooftop solar by 2050 based on NWPCC forecast

Clean gas additions for reliability. Low volumes of gas consumption but large contribution to reserves

Reference Scenario Generation Capacity Map

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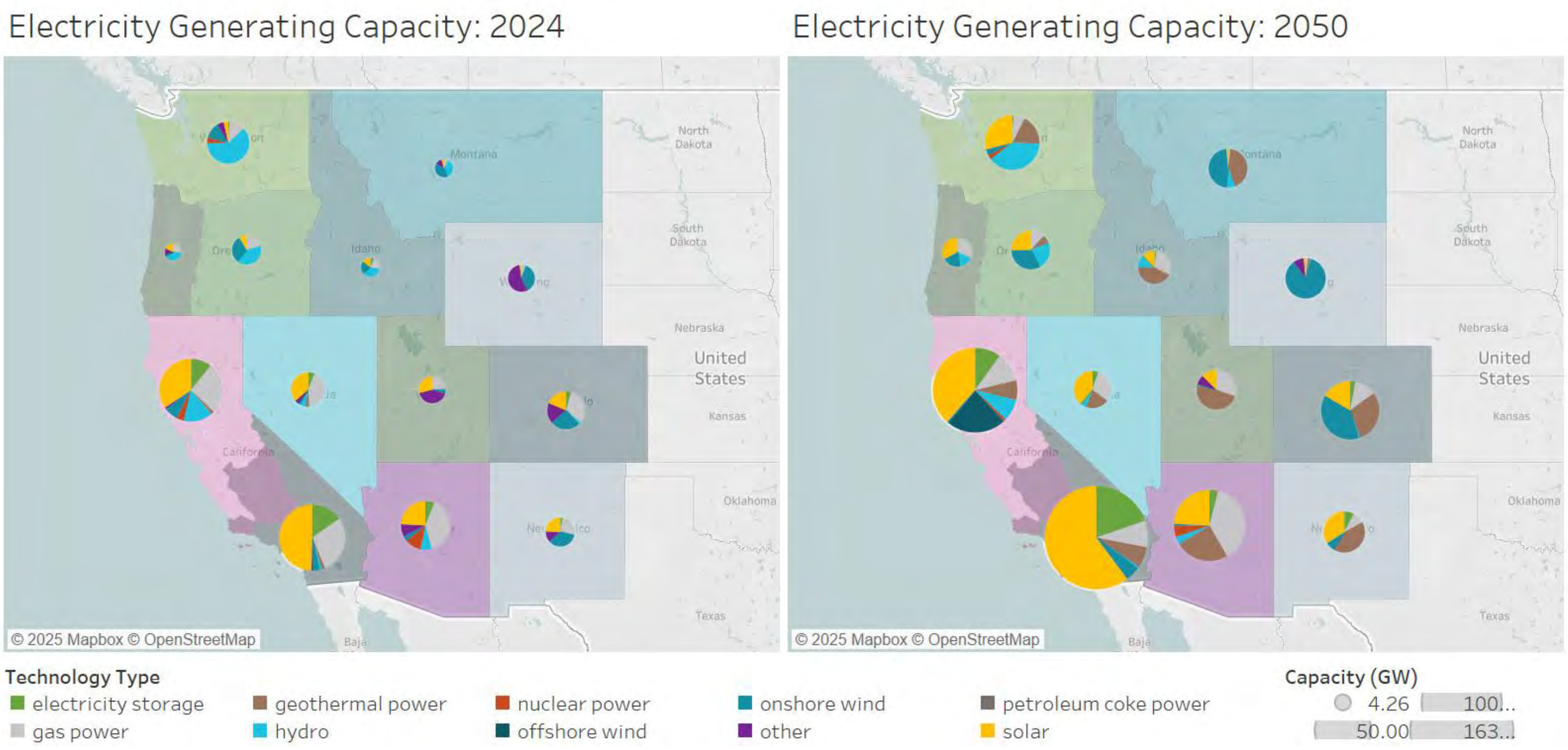
- From 2024 to 2050, total generation capacity grows dramatically in the West and renewables dominate

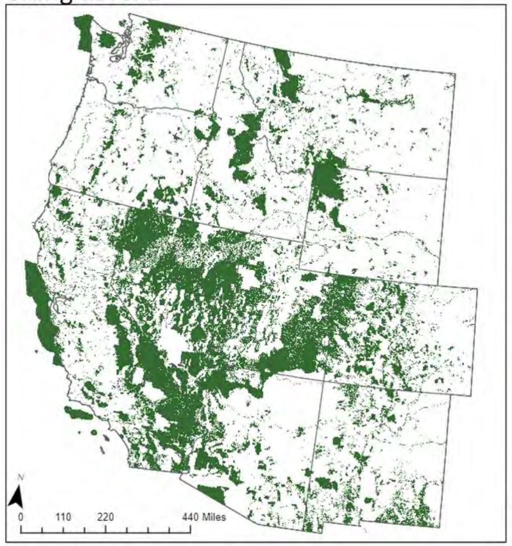


BPA hydropower is attributed to zones based on EIA representation

Modeling is Structured to Reflect Land Use and Natural Resource Constraints

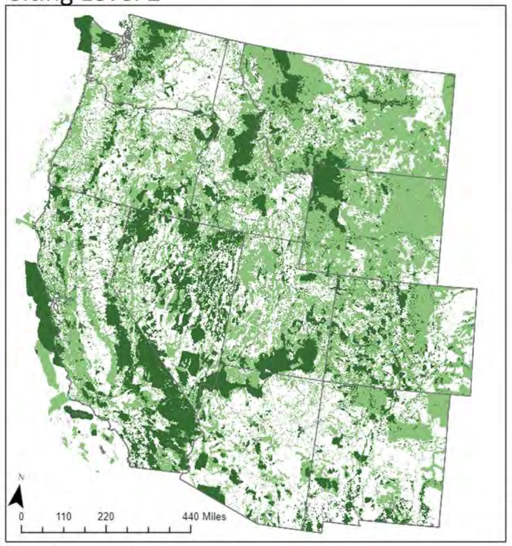
- Land use considerations are an input to the model through screening at a disaggregated level of where infrastructure projects could be located
- Every scenario complies with most restrictive land use constraints in [The Nature Conservancy's *Power of Place-West* study]: legally protected, administratively protected, and high conservation value lands (Levels 1 – 3) (See methodology on pages 204-209.)

Siting Level 1



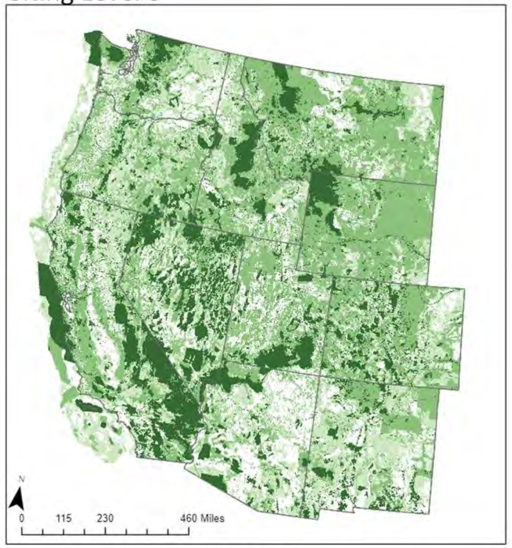
Excludes Category 1

Siting Level 2



Excludes Category 1, 2

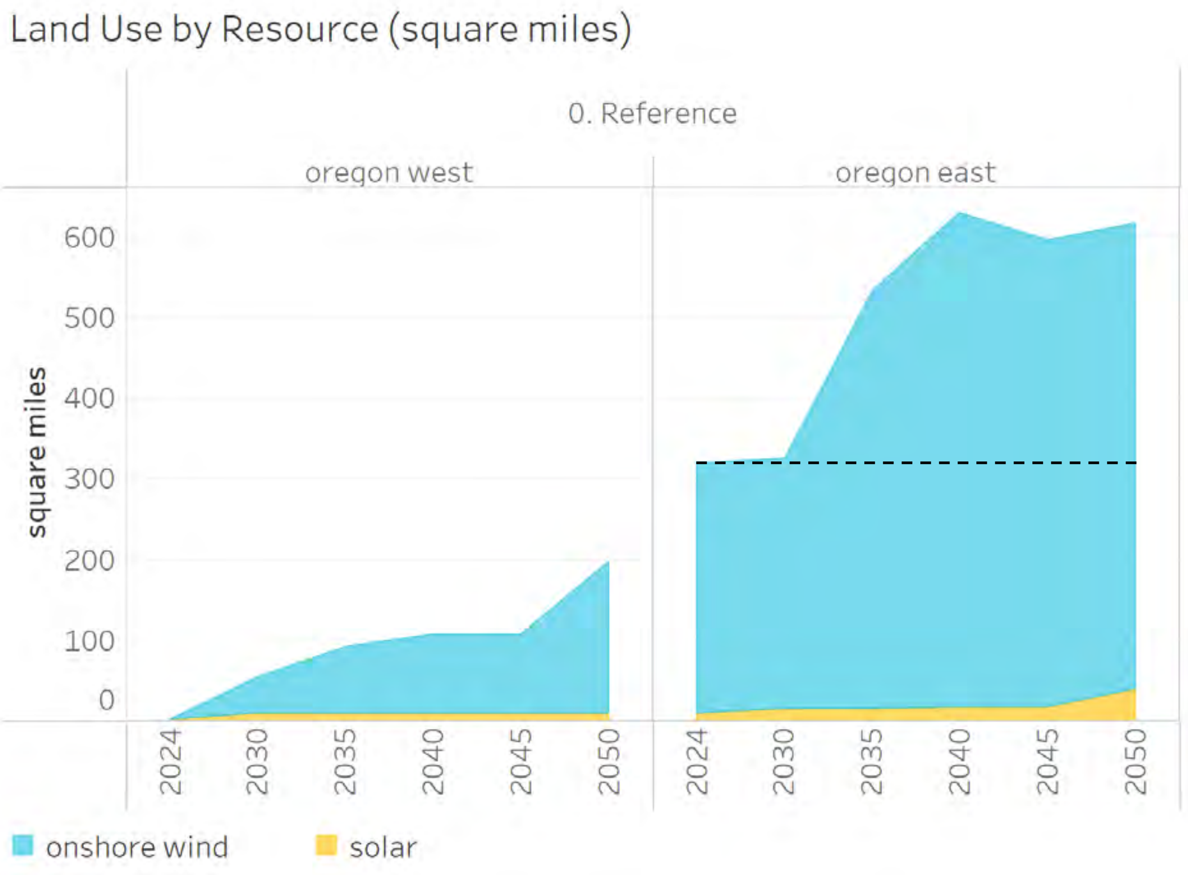
Siting Level 3



Excludes Category 1, 2, 3

Wind and Solar Account for Largest Incremental Land Use Footprint of New Generating Resources

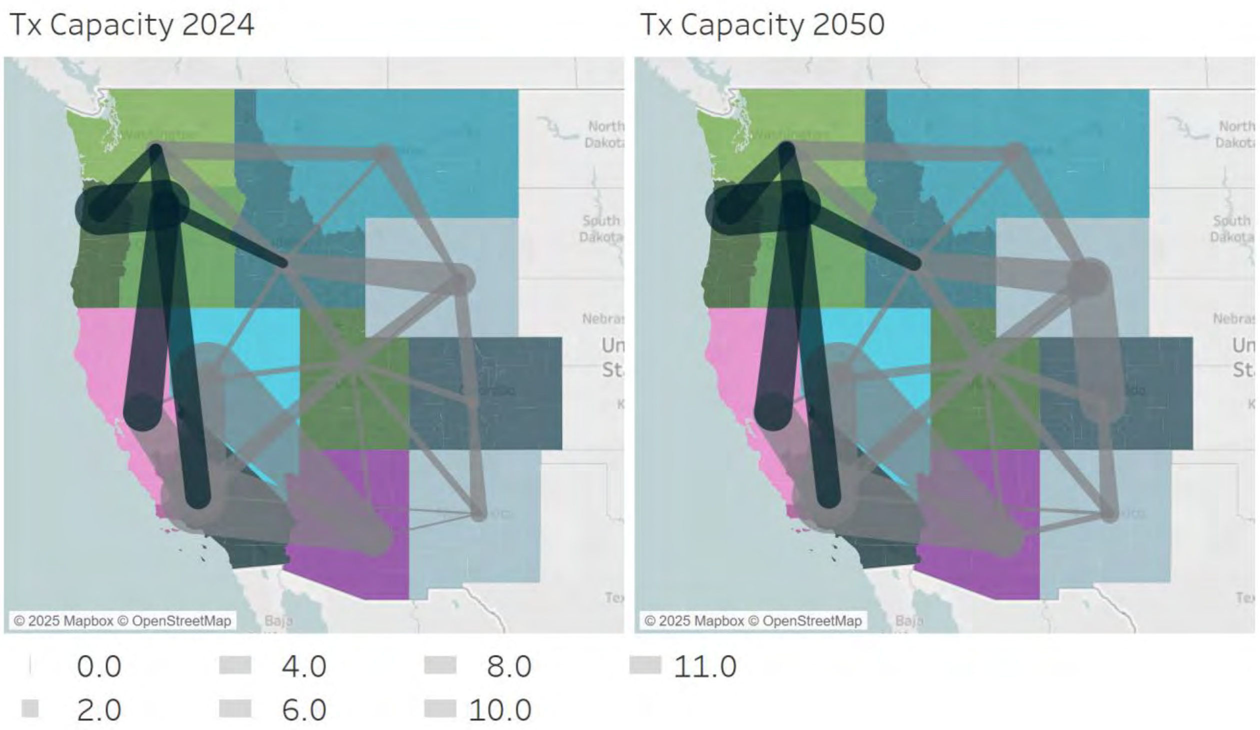
- Reference finds 620 square miles of development in Oregon East and 200 square miles in Oregon West by 2050
- Scenarios affect scale of land use and natural resource footprint
  - 31% reduction when limit development
  - 15% increase when take out clean gas as a reliability resource
- Other generating resources will have a footprint but wind and solar are the largest contributors
  - New transmission and distribution will also have a footprint but are not quantified in this analysis



We use NREL estimates of wind and solar land use. [Wind: 78 square miles/GW](). [Solar: 7 square miles/GW](). Land use is determined for the entire renewable project. This is subjective, particularly for wind, because unlike direct land use for pads, interconnection lines, etc., the entire project includes mostly indirect land use between turbines.

Oregon Needs More Transmission Capacity

- Transmission expansion focuses between zones:
  - Across the Cascades, and from Oregon to Idaho, Washington, and California
- The transmission model is linear, so investments can be made in fractions of new transmission lines
- Pipeflow representation of physical transmission capacity across modeled area as single balancing area with a single, centralized system operator
- These results are indicative of transmission need but do not replace detailed transmission planning
- Growth of transmission into Oregon West and Boardman to Hemingway transmission project into Oregon East
- If less clean gas capacity built in Oregon West or demand response is limited, more transmission is needed

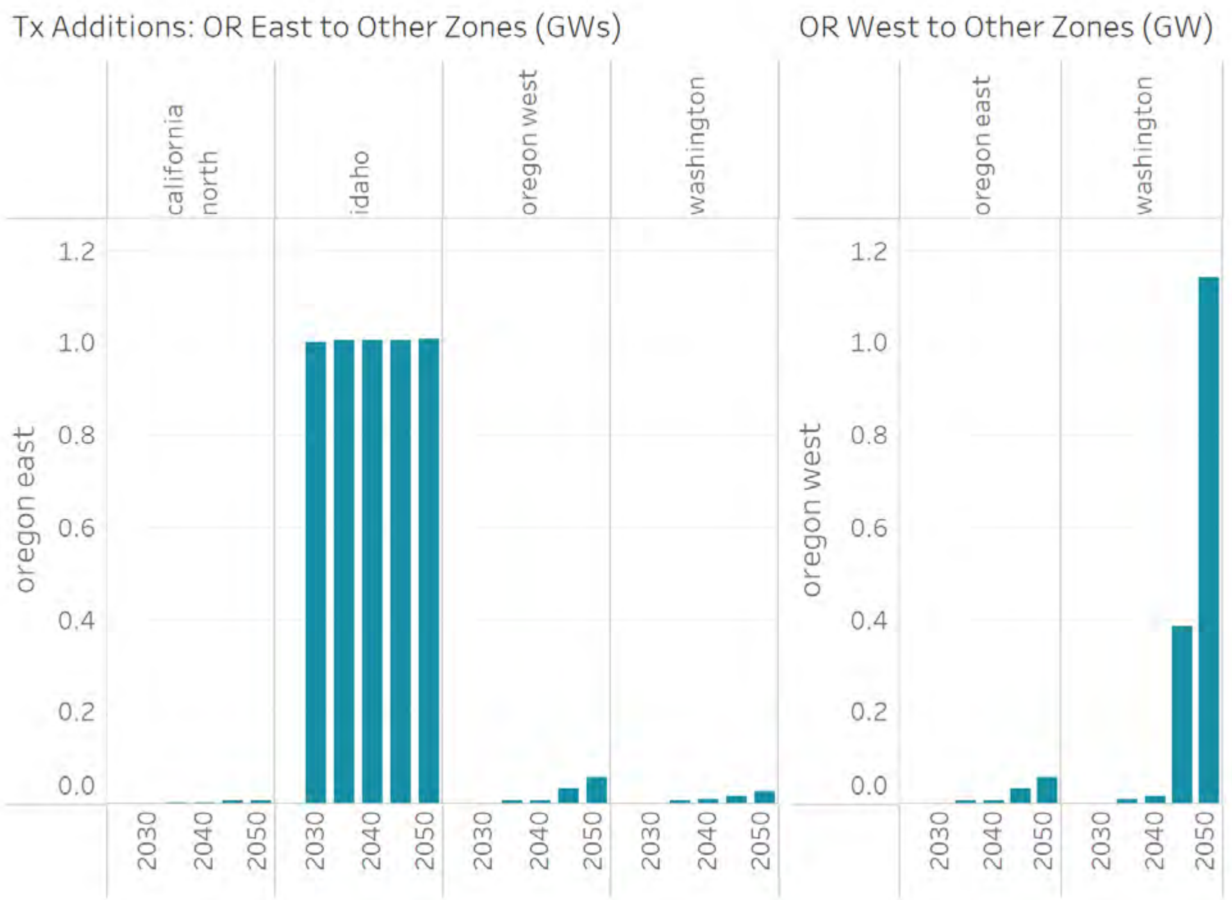


Within Zone Transmission

- Need for in-state transmission and distribution expansion and upgrades to deliver electricity from in-state generation
- No physical representation of within zone transmission or distribution
  - High-level approach to estimating electric and gas T&D costs
  - Correlates in-state electric transmission and distribution capacity expansion costs with the total increase in net distribution system peak
- Captured with historical transmission and distribution costs
  - Uses historical $/MWh from EIA
- Investments in T&D infrastructure are largely driven by load growth
  - Distribution upgrade costs can be avoided or deferred with load shifting in the model

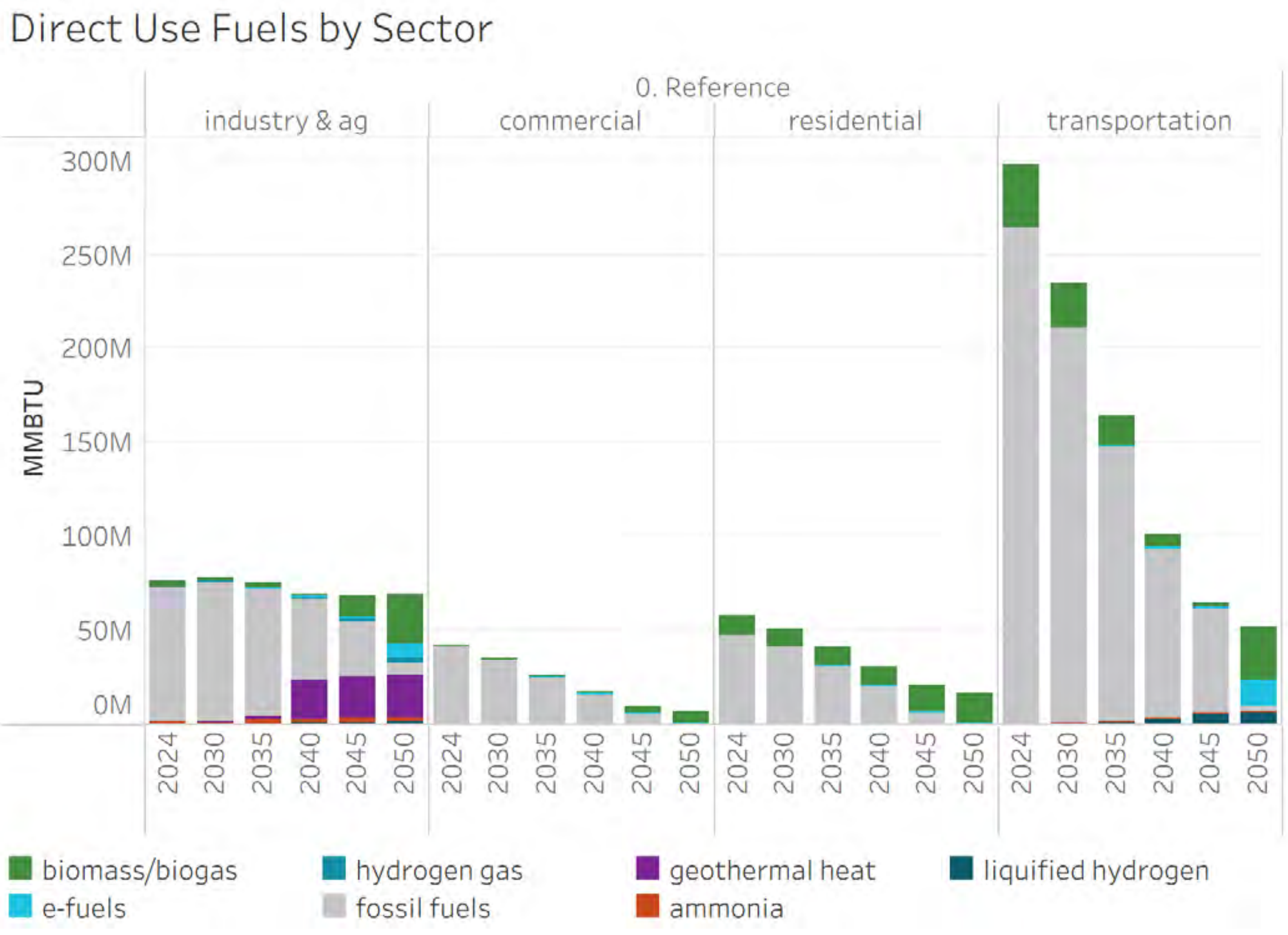
Reference Scenario
Transmission Between Zones

- Transmission expansion between Oregon zones and other zones is not permitted in the modeling until 2035 to represent the long lead time of transmission projects
  - The exception is Boardman to Hemmingway, which comes online as planned in 2030
- Transmission expansion facilitates imports of renewables from other regions as well as Oregon East-West electricity flows
- The transmission model is linear, so investments can be made in fractions of new transmission lines
- These results are indicative of transmission need but do not replace detailed transmission planning
- These additions are on top of existing transmission into the states surrounding Oregon. The full transmission capability to surrounding states is given on slide 127



Reference Scenario
Origin of Fuels used in Oregon's End Uses

- Demand for fuels declines over time largely driven by energy efficiency and electrification of end uses
- Fuel demand remains similar in industrial sector but switches to dependence on low-carbon fuels
- By 2050 the supply of liquid and gaseous fuels is almost fully decarbonized



Liquid E-Fuels are Imported from Other States whereas Hydrogen Gas is Produced Locally

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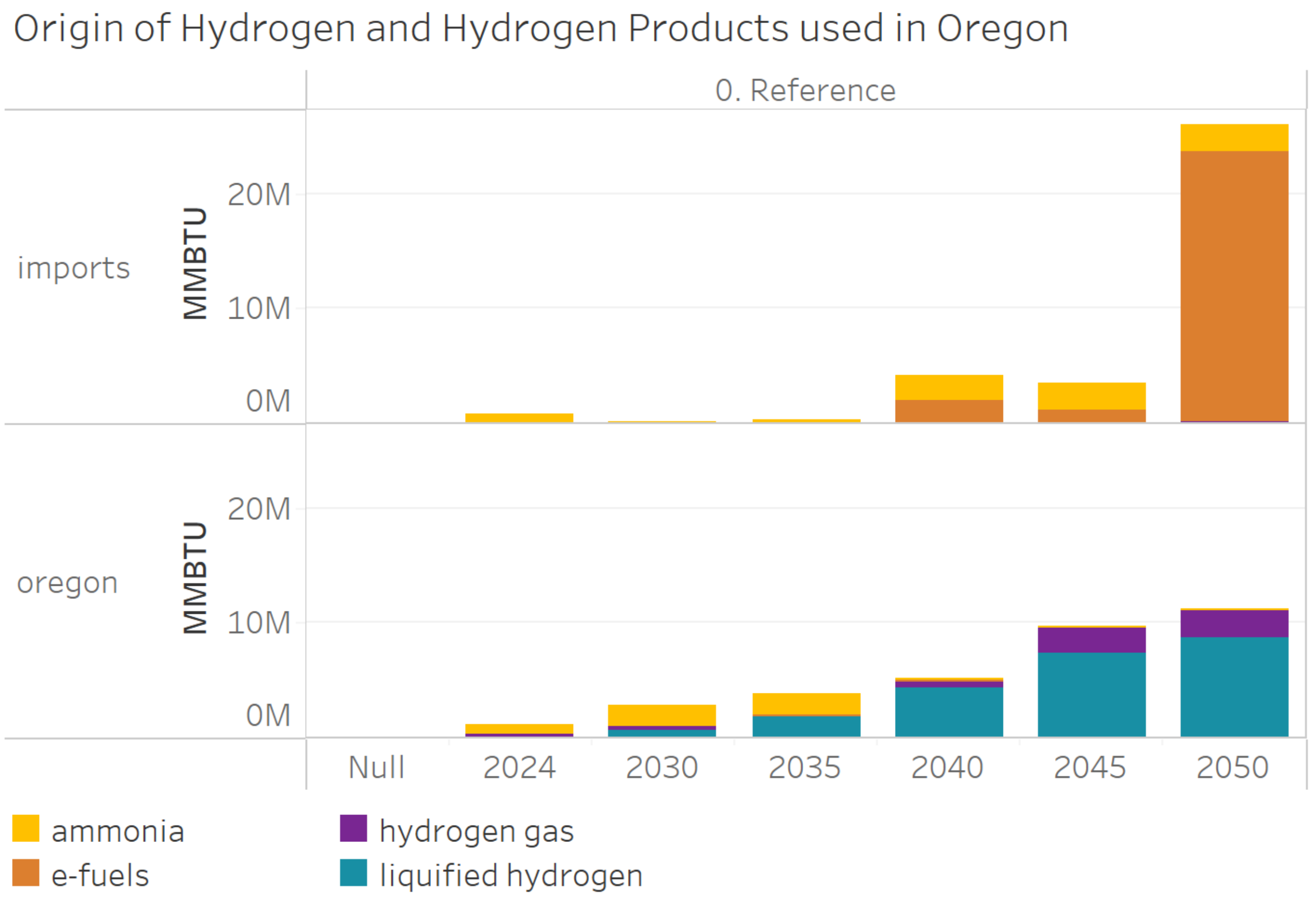
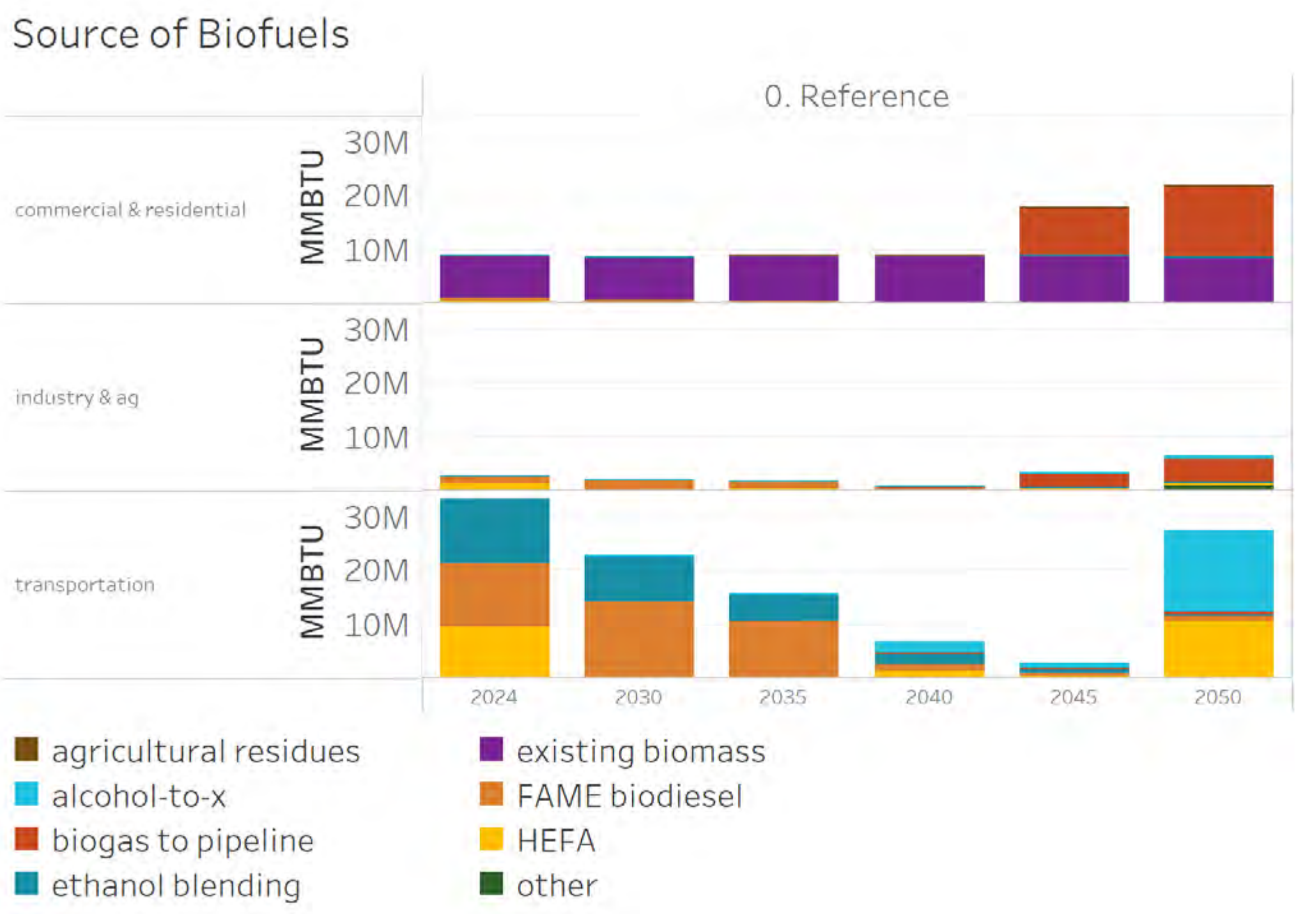
- Hydrogen products consumed in Oregon shown on the previous slide are sourced from inside and outside of Oregon
- Liquid e-fuels are relatively inexpensive to import because they share the same chemical structure as fossil fuels and can be “dropped in” and distributed through existing infrastructure
- Liquified hydrogen and hydrogen gas are produced within Oregon and ammonia production is split between in-state and out-of-state production



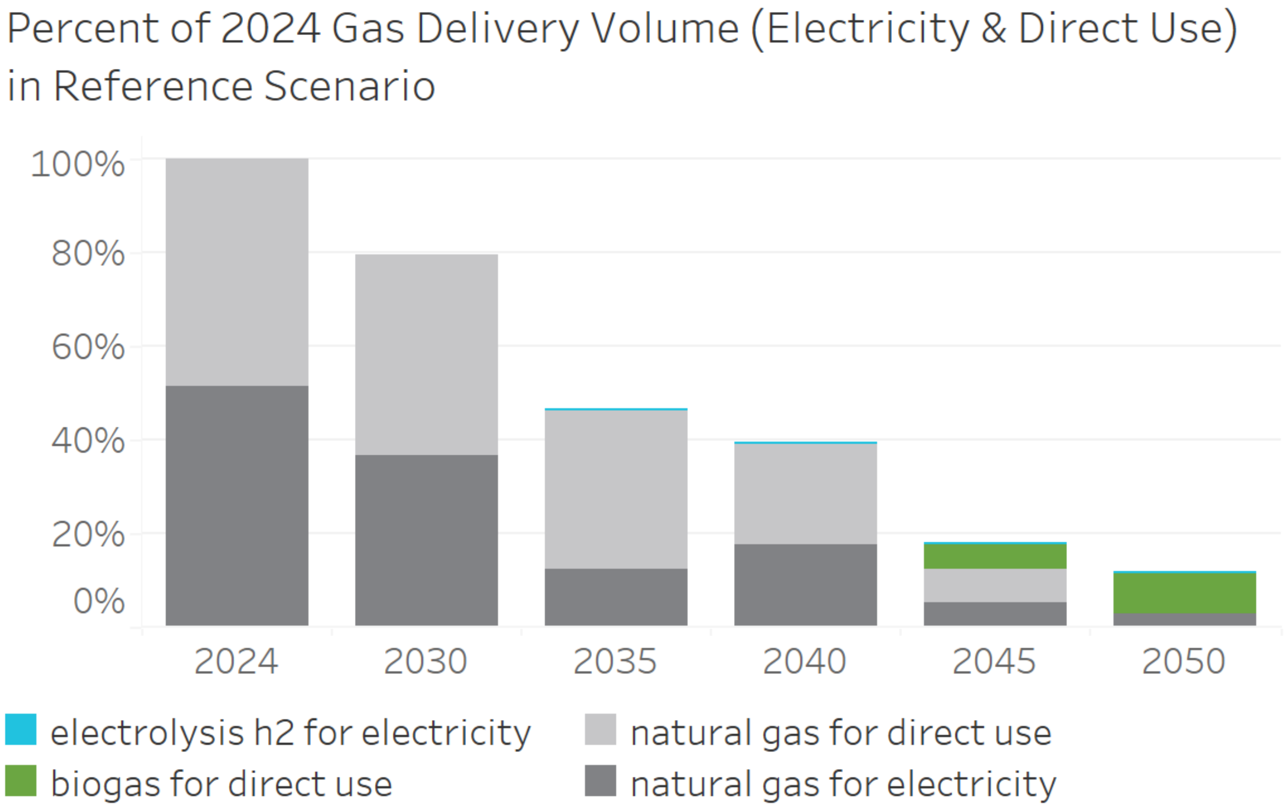
Reference Scenario Biofuels

- Biofuels in 2024 consist of wood burned in residences and biofuels in transportation, including HEFA, FAME, and ethanol
- Volumes in transportation decrease as the fleet is electrified and emissions from fossil fuels decrease, but increase in 2050 to decarbonize remaining fuel use
- Biogas begins replacing natural gas consumption in 2045



Reference Scenario
Gas Pipeline

- Gas volumes decline over time with reductions in MWh of generation from gas turbines and electrification of end uses
- Small amounts of electrolytic hydrogen used in power generation in new clean gas turbines
- Remaining volumes of direct use gas fully decarbonized with biogas

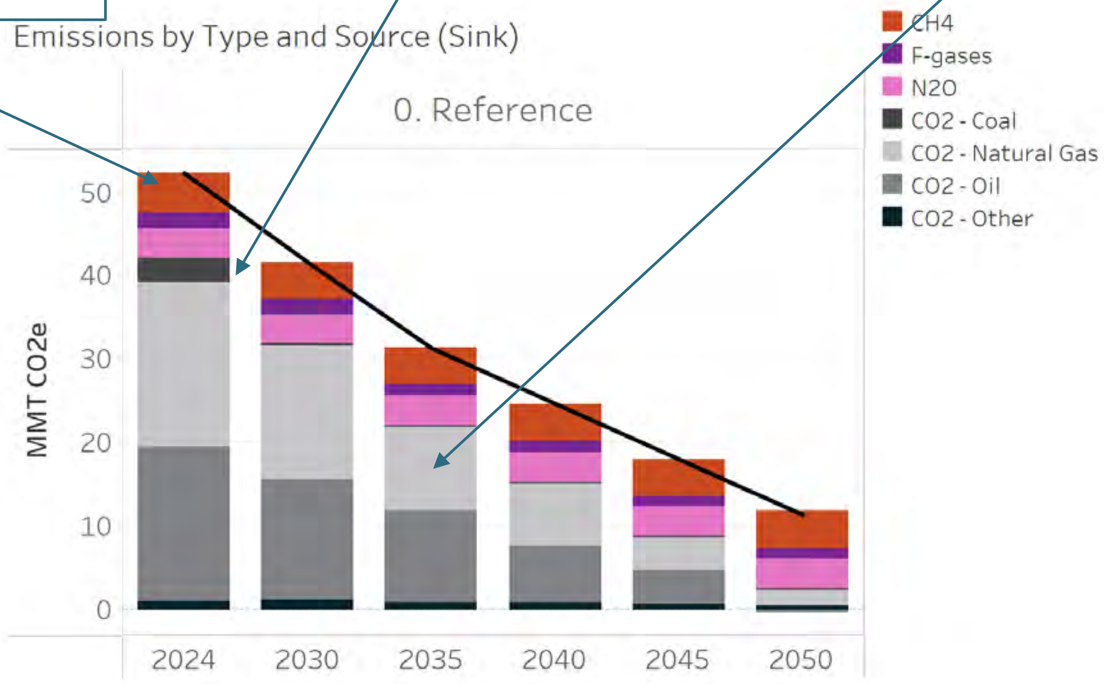


Reference Scenario Emissions

Nitrous oxide (N_2O) and methane (CH_4) from agriculture difficult to decarbonize and remain in the economy

Early removal of coal from the electricity portfolio

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



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Sector Insights

Sector Insights

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- The following sections describe what we learned from the Reference Scenario and the alternative scenarios to inform decision-making in Oregon for electricity, fuels, transportation, and buildings
- The alternative scenarios were designed to answer key questions identified through consultation with Phase 1 Working Groups, the Advisory Group, public forums, through public feedback, and in discussions with ODOE and other Oregon agencies

Top Sector Takeaways

- Electrification and energy efficiency are key to reducing the size of the overall energy “pie” and to cost containment
- Fuels play a strategic role in the transition, with a shift toward clean fuel alternatives toward 2050
- All scenarios indicate a need to build infrastructure in Oregon
- Tech loads are the biggest driver of electricity demand growth but are also uncertain in when and where they could emerge

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Electricity Sector Insights

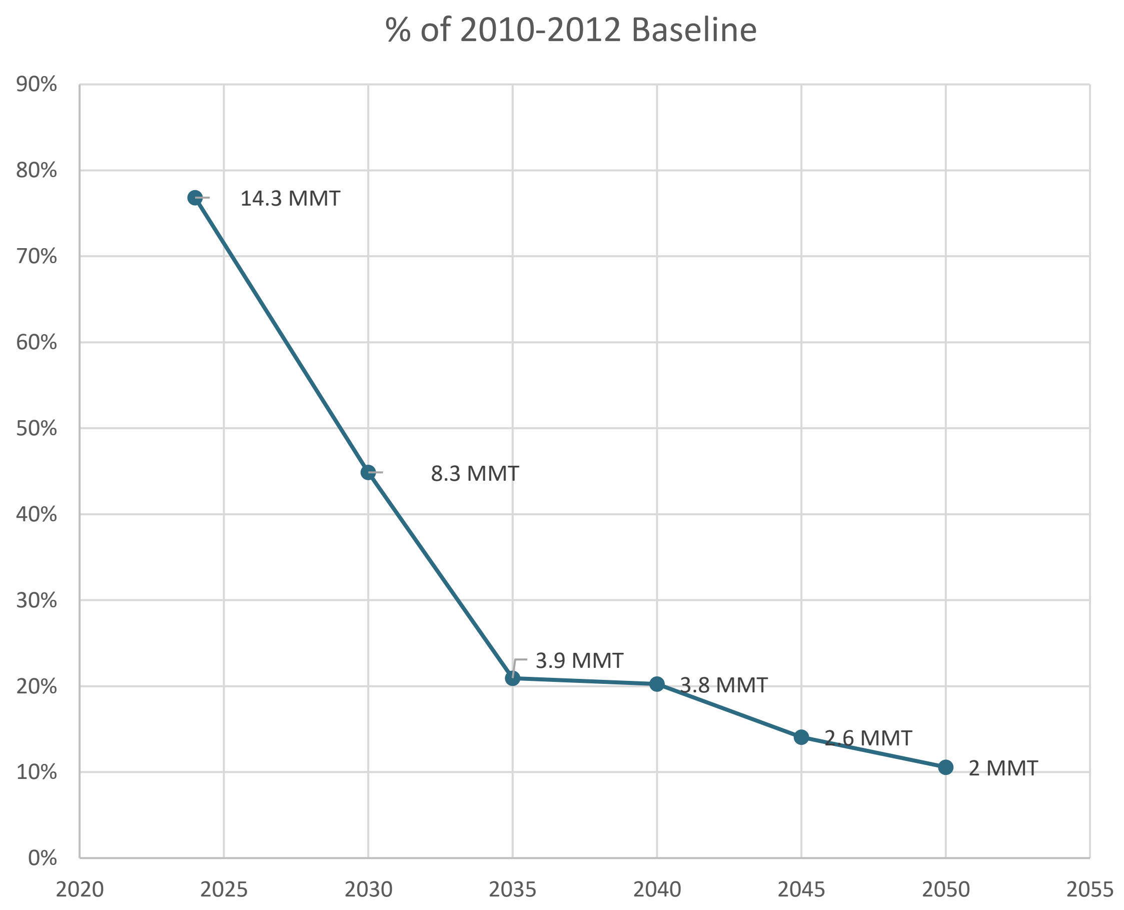
Electricity Sector Key Insights
Oregon Needs More Electricity Infrastructure

- Even with aggressive levels of energy efficiency, the electricity sector must expand significantly to remain reliable
- Market forces and HB 2021 drive near-term decarbonization while EO 20-04 requires action beyond HB 2021
- The model selects transmission expansion as part of a least-cost portfolio
- There are competing priorities with in-state and out-of-state resource development, and a diverse mix of resources is likely the least risky approach

Credit: Paulo Esteves https://stock.adobe.com/images/maintenance-in-a-high-voltage-electrical-substation/564704152

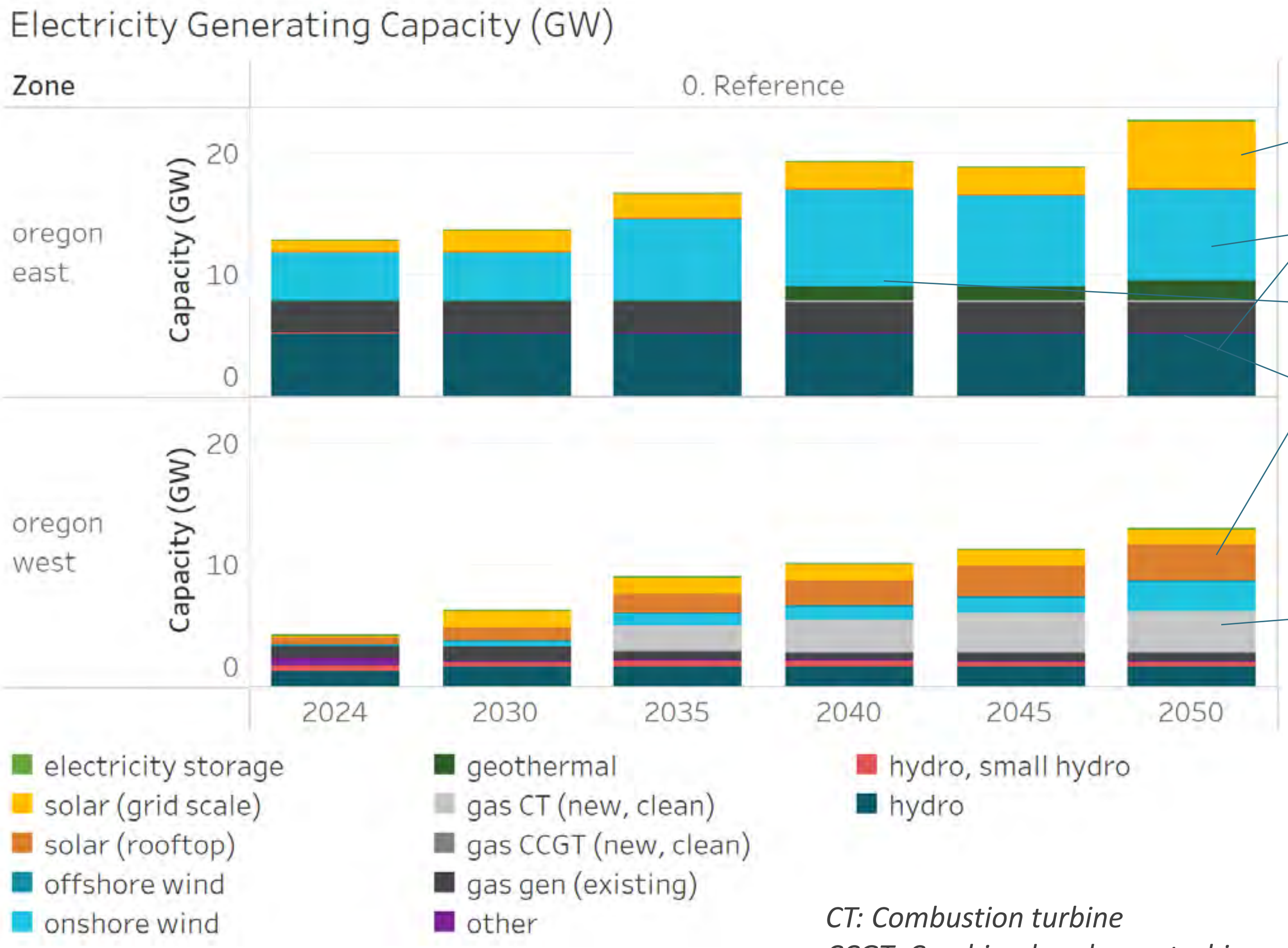
Increasingly Clean Electricity Meets HB 2021 Targets and Helps Achieve EO20-04

- HB 2021 targets 80% emissions reductions by 2030, 90% by 2035, and 100% by 2040 below a 2010-2012 baseline for PacifiCorp, Portland General Electric and ESSs (62.1% of load*)
- New tech loads otherwise allowed to consume emitting electricity
- EO 20-04 requires reductions beyond HB 2021 alone



*2023-Oregon-Utility-Statistics-Book.pdf

Oregon Needs More In-State Generation Capacity



CT: Combustion turbine
CCGT: Combined-cycle gas turbine

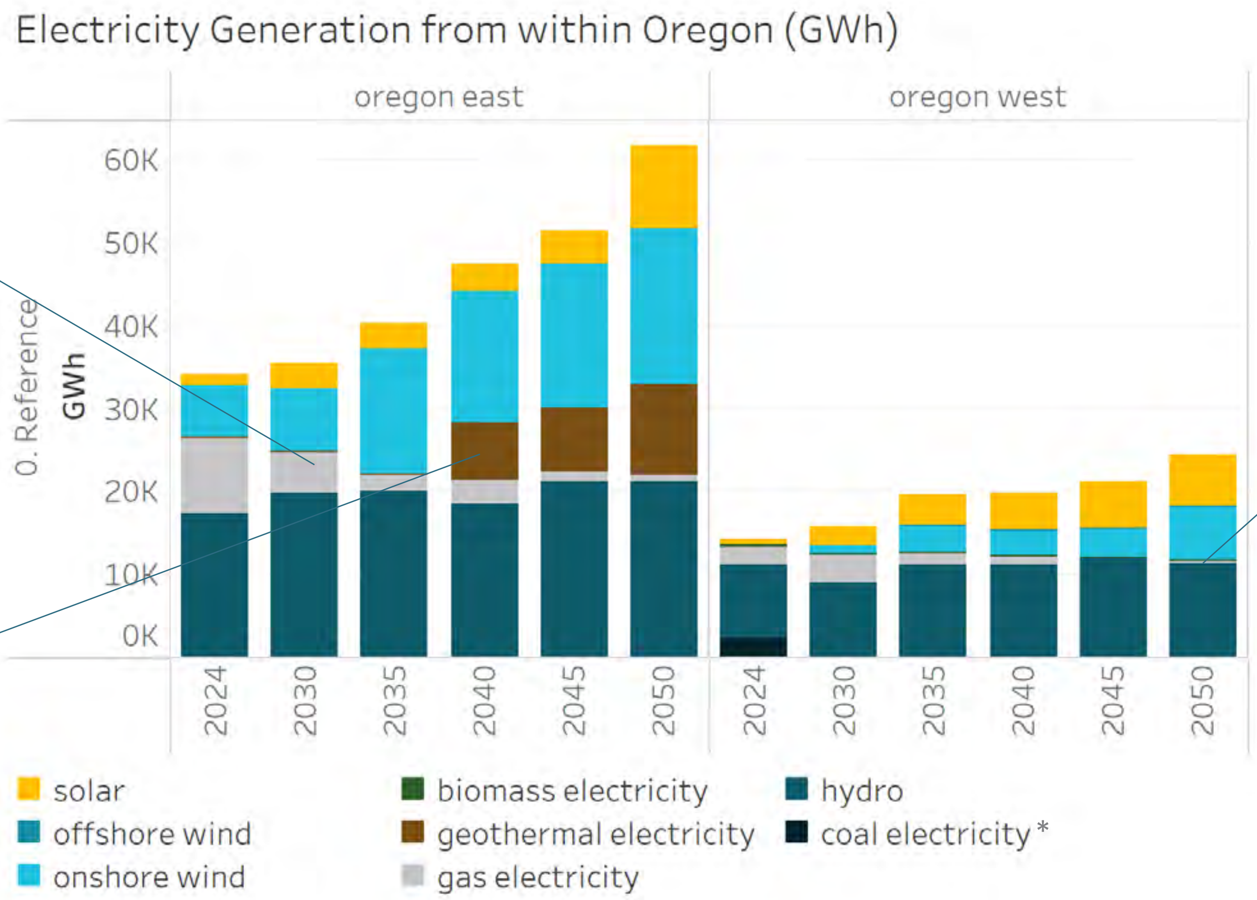
- Hydropower remains a foundational resource
- Solar grows, both grid-scale and rooftop
- Onshore wind continues to be an important part of Oregon's resource mix
- In 2040, enhanced geothermal comes onto the system
- Model achieves HB 2021 emissions reductions but some existing gas remains in the statewide mix
- New, clean gas is built (but runs only rarely for reliability purposes)
- Some additions of in-state generation will require expansion of in-state transmission

This diverse mix of resources provides flexibility and reliability to a nearly non-emitting power system

Hydro, Wind, and Solar are Oregon's Top Suppliers of Clean Electricity Over Time

2030
Still have some gas; model built to hit HB2021 targets

2040
Enhanced geothermal emerges as key resource



*coal imported but represented as a contracted resource in modeling

2050
Electricity generation is almost 100% non-emitting

Oregon Also Relies on Imported Electricity

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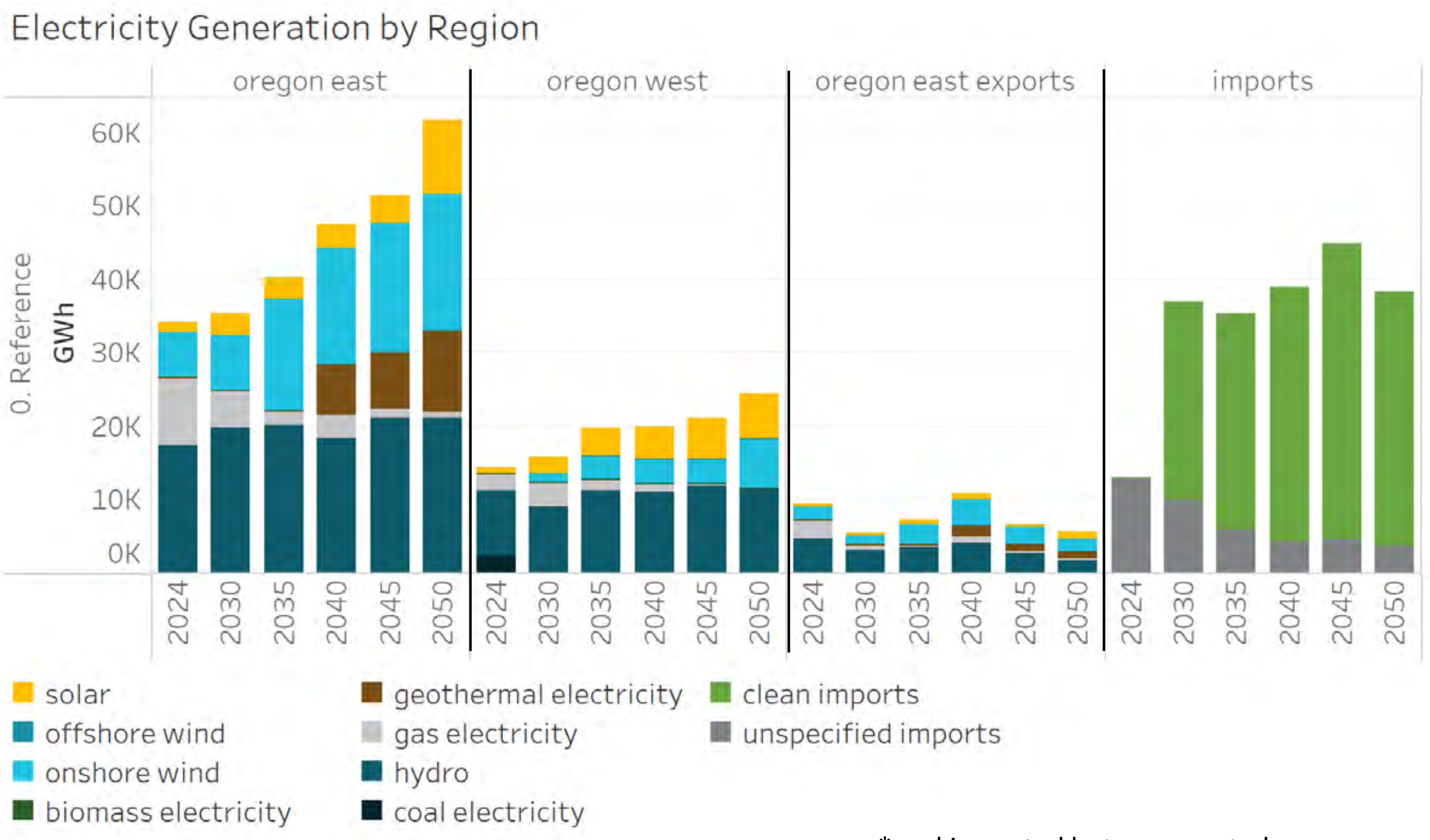
- Oregon is part of a regional electricity system
- Even if more in-state resources are built as the model shows, also need increasing levels of clean imported electricity
- Oregon exports power at times of surplus



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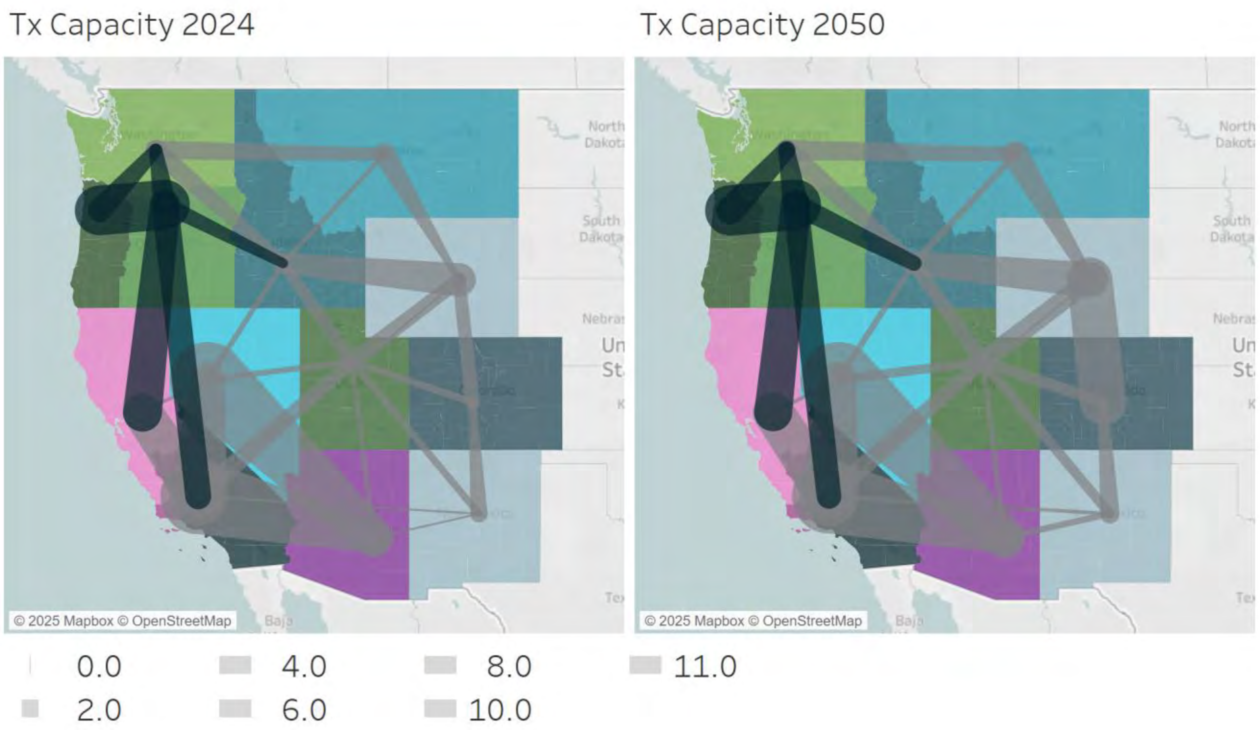
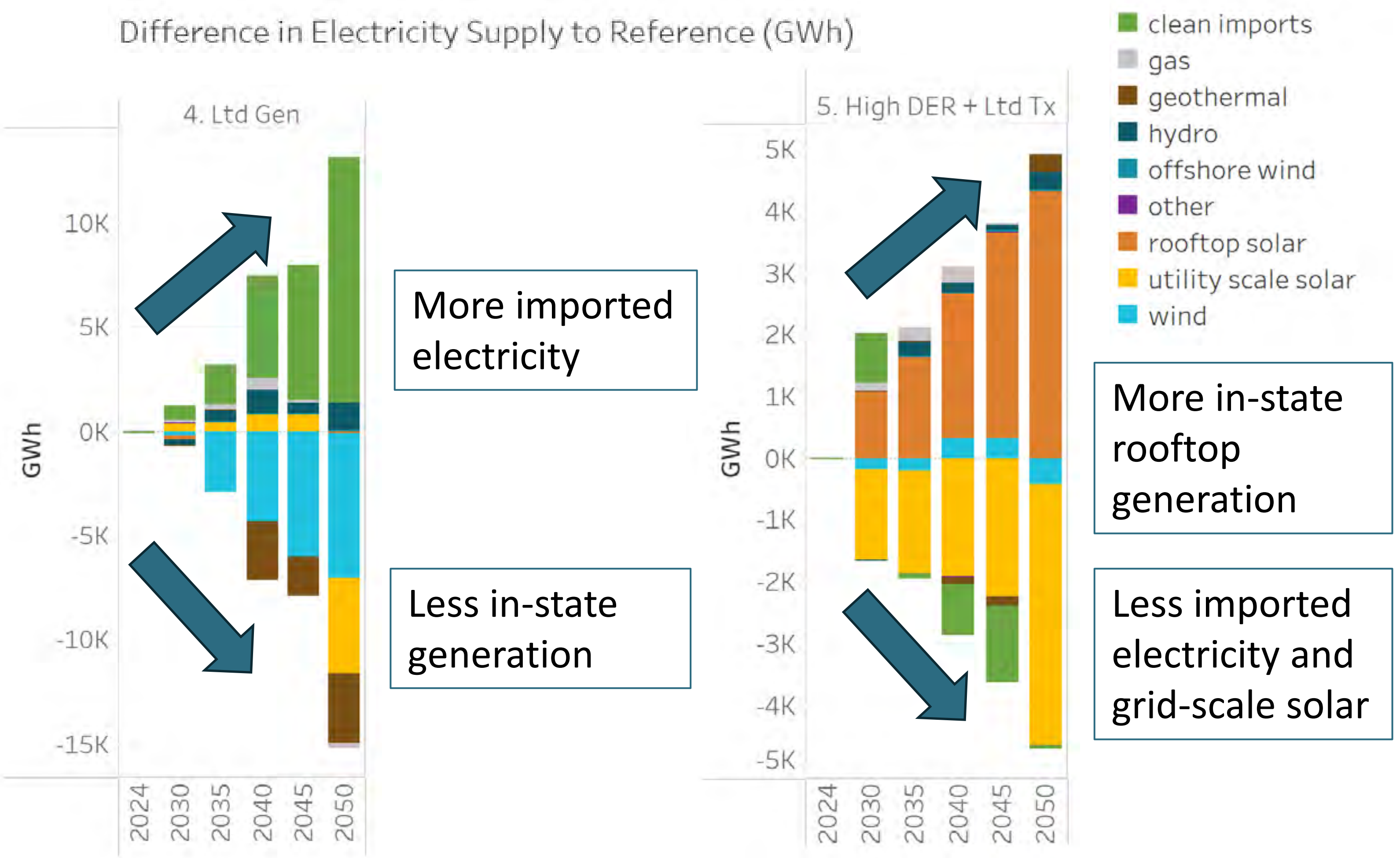


The Balance of In-State vs. Imported Generation Can Change

- If cannot build more in-state generation, need to import more (using more transmission capacity)
- If cannot import more (due to lack of transmission capacity), have to build more in-state
- Both alternatives cost more than the Reference Scenario



Wind and Solar Account for Largest Incremental Land Use Footprint of New Generating Resources

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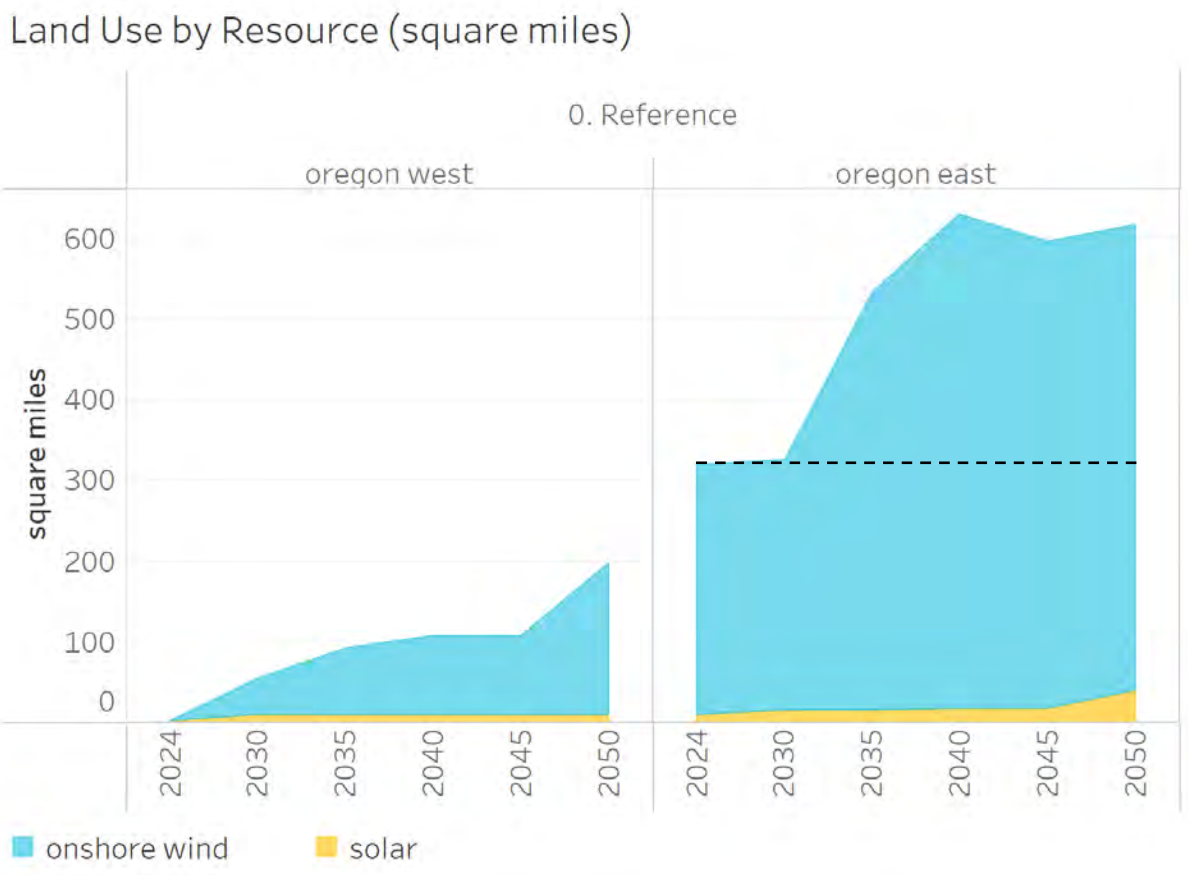

We use NREL estimates of wind and solar land use. Wind: 78 square miles/GW. Solar: 7 square miles/GW. Land use is determined for the entire renewable project. This is subjective, particularly for wind, because unlike direct land use for pads, interconnection lines, etc., the entire project includes mostly indirect land use between turbines.

Scenario Impact on Land Use

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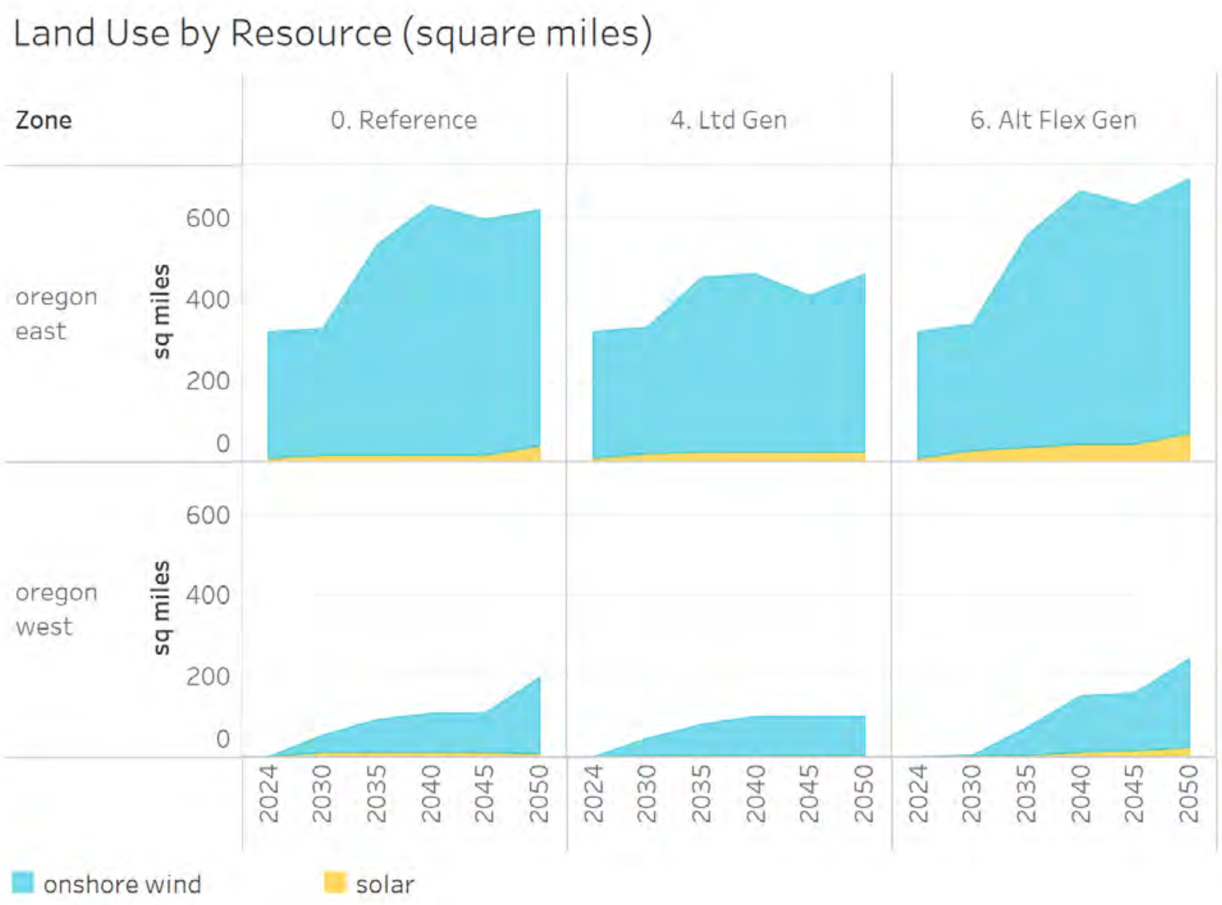

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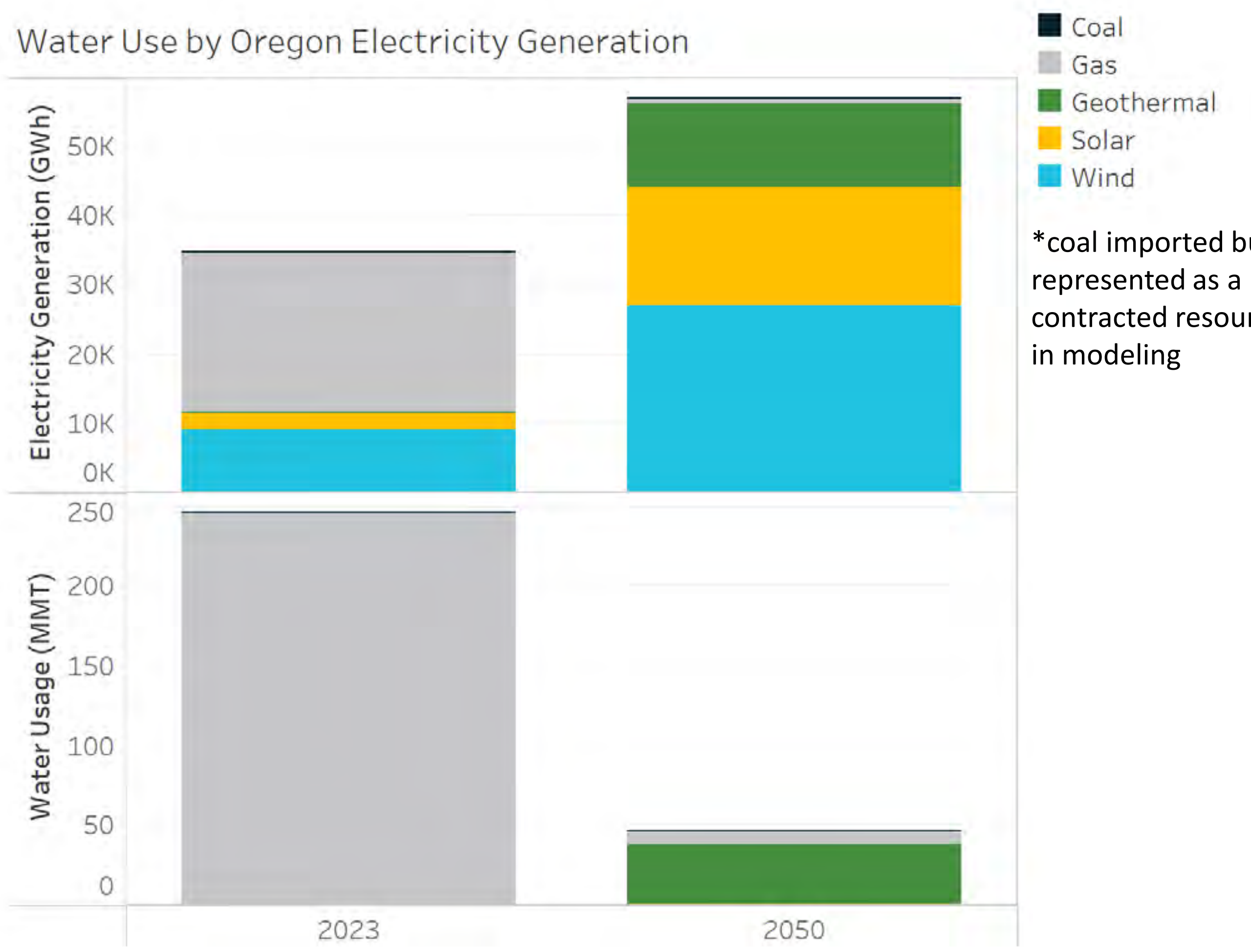
Water Consumption from Oregon Electricity Generation

- Water usage in electricity generation decreases by 81% from 2023 to 2050 as thermal electricity generation is replaced
  - Showing 2023, the most recent available year of historical generation data from EIA, and modeled 2050 numbers
  - Not showing hydro

Resource	gallons/MWh	Source
Gas	2803	Energy Information Administration[1]
Coal	19185	Energy Information Administration[1]
Solar	20	Solar Energy Industries Association[2]
Wind	0	Union of Concerned Scientists[3]
Geothermal	800	Argonne National Lab[4] (assumes binary high temperature EGS)

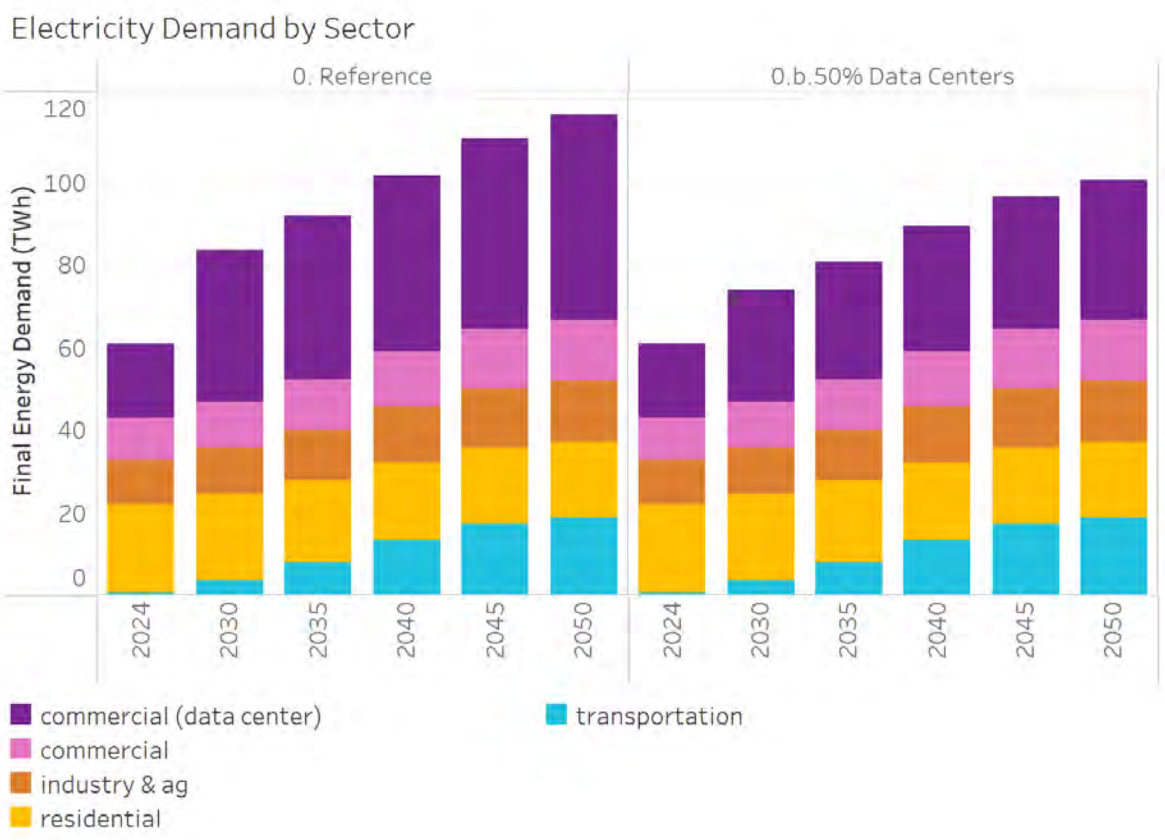
1 https://www.eia.gov/todayinenergy/detail.php?id=56820#:~:text=In%202021%2C%20natural%20gas%20combined,very%20low%20water%2Dwithdrawal%20intensity.
2 https://seia.org/water-use-management/
3 https://www.ucs.org/resources/environmental-impacts-wind-power#:~:text=Water%20use-,Water%20use,and%20cement%20for%20wind%20turbines.
4 https://gdr.openei.org/files/464/ANL:EVS-14:14%20(1).pdf



*coal imported but represented as a contracted resource in modeling

Electricity Demand by Sector: Reference vs. 50% Data Centers

- Electric load growth through 2030 is largely driven by NWPCC forecasted tech load needs
- Tech load growth is uncertain. If 50% lower than Reference Scenario:
  - Electric loads are 11% lower by 2030 and 14% by 2050 compared to the Reference
  - Electricity demand from other sectors still increases overall load by over 25% by 2030



Reduced Resource Need if Uncertain Data Center Growth is Lower

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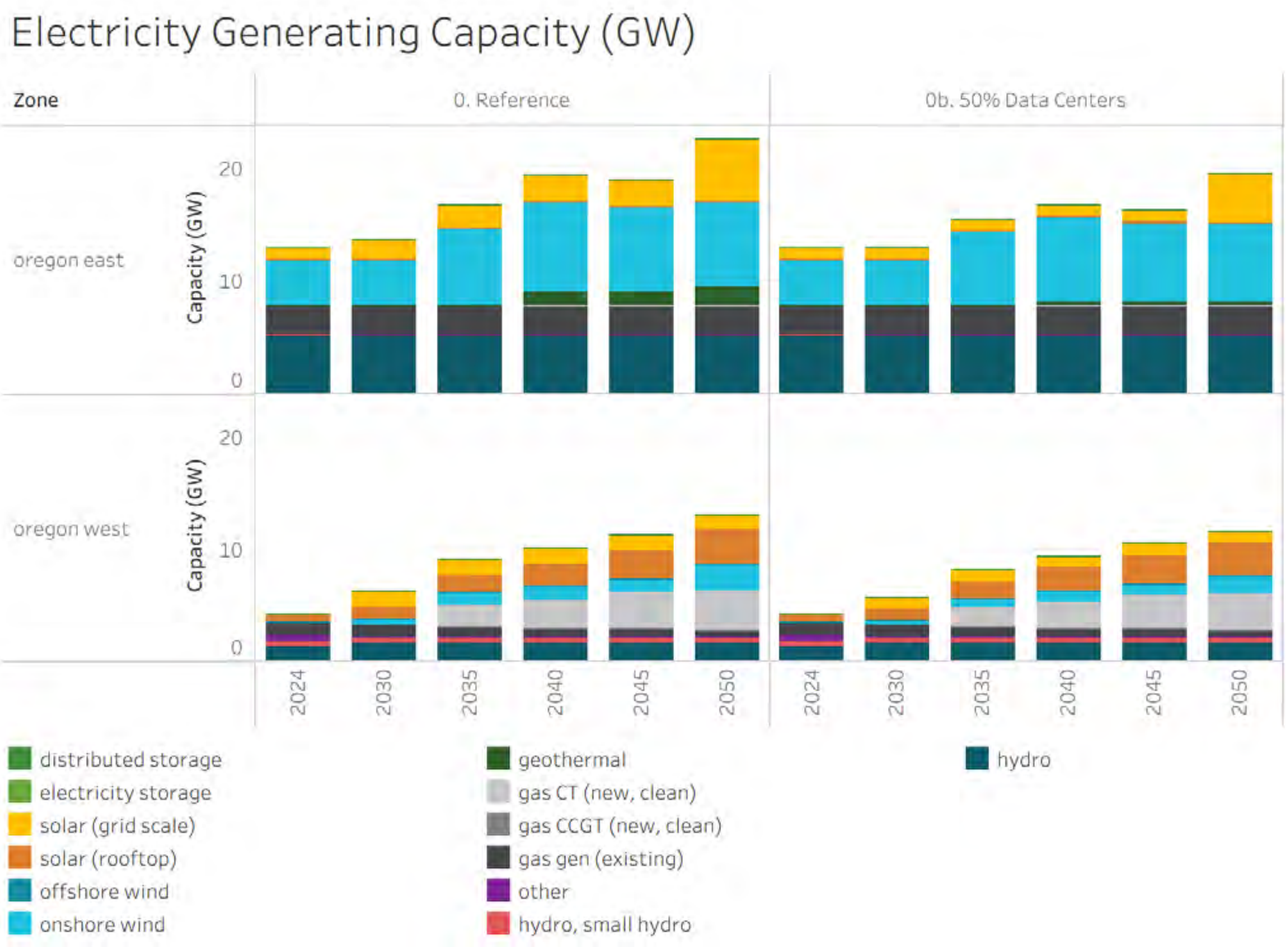
- Oregon relies on greater electricity imports in the near-term, as well as increased in-state capacity to meet load growth in the Reference
- Cutting data center load forecasts by 50% reduces – but does not eliminate – the need for imports and capacity additions in Oregon



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Fuels Sector Insights

Fuels Sector Key Model Insights

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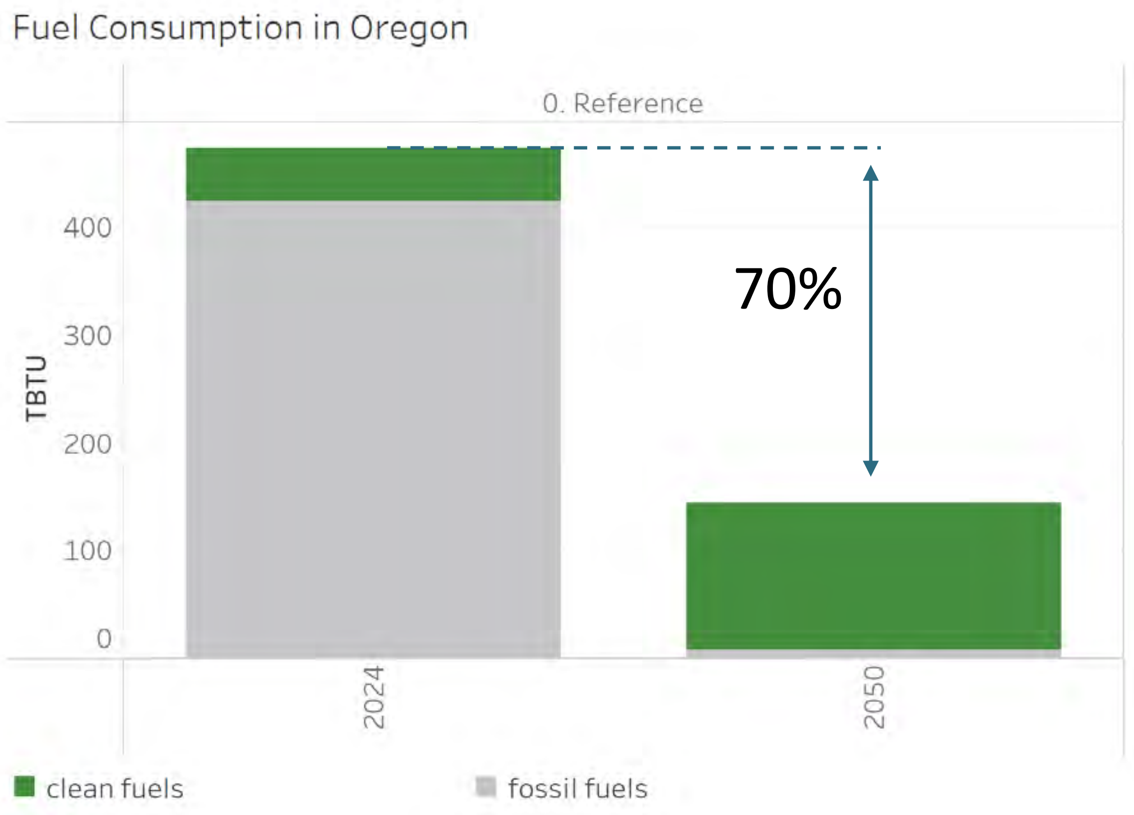
- Fuel use decreases with the electrification of many applications
- Low-carbon fuel demand gradually replaces fossil fuel demand
- New dispatchable capacity from fuel-based generation maintains a reliable electricity system
- Low-carbon fuels most cost-effective when used strategically for the hardest-to-electrify industrial and transportation applications and to maintain a reliable electric grid during net peak periods

Clean Fuels are Needed to Meet Energy and Emissions Goals

- Fuel demands decrease over time, but their importance does not
  - Hardest to decarbonize sectors
  - Resilience
  - Time for electric technologies to replace fossil
- Clean fuels include biogas, bio liquids, e-fuels, hydrogen, ammonia, and geothermal steam



Fuels in Transportation Decrease due to More Efficient Electric Drivetrains and Convert to Clean

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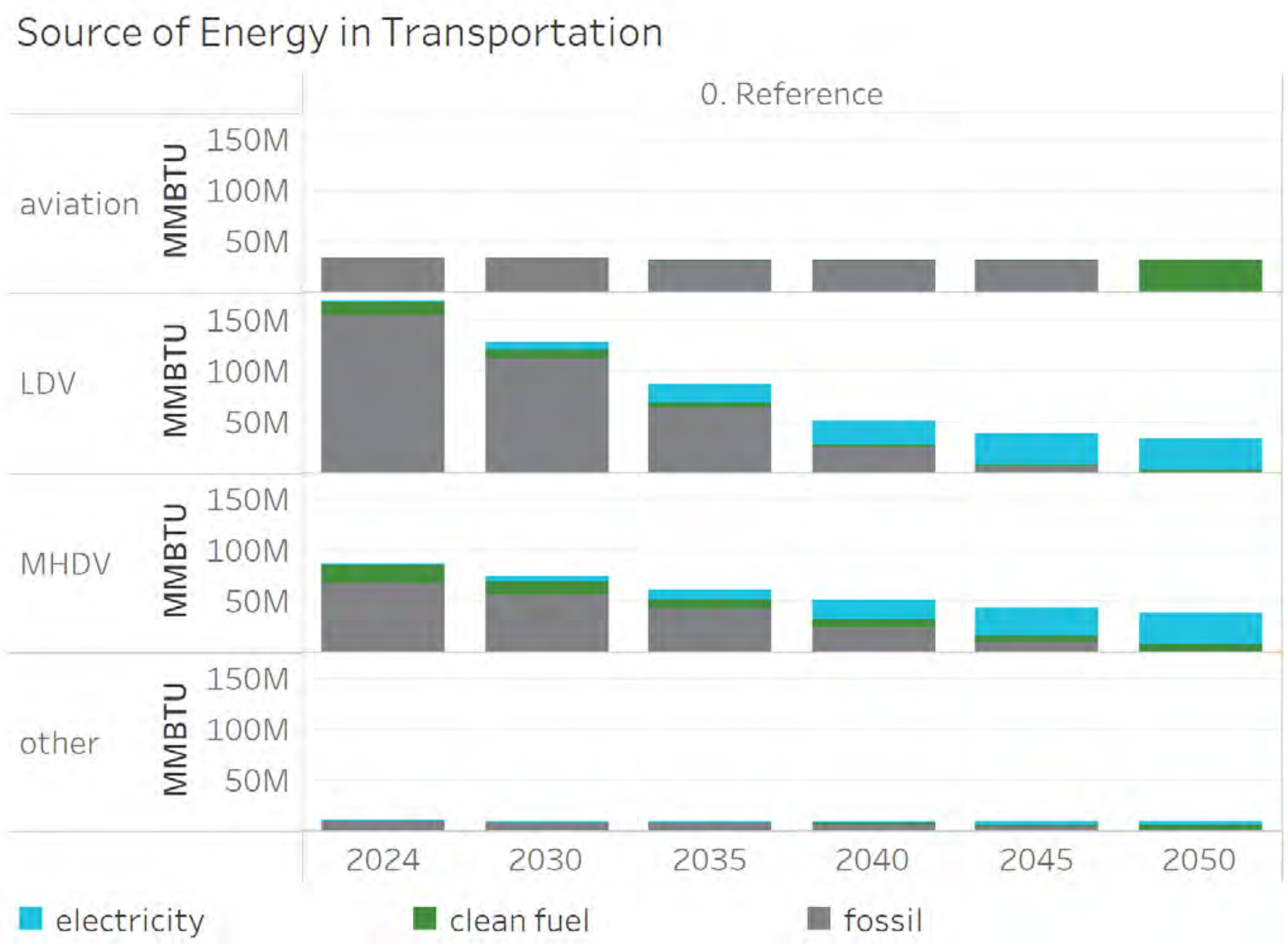
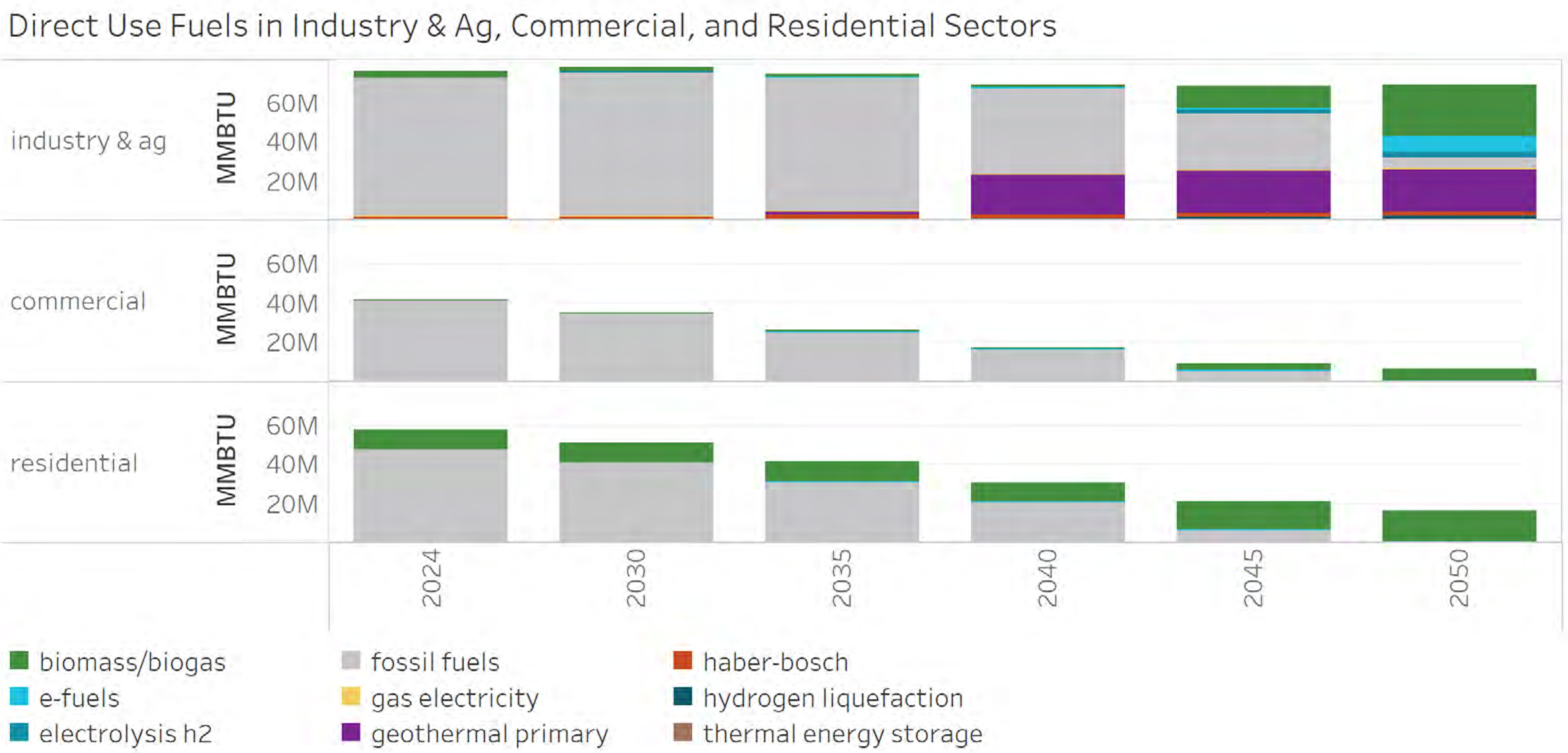
- Electrification of light-duty and medium-duty vehicles
- Dependent on clean fuels:
  - Aviation
  - Medium- and Heavy-Duty Vehicles
  - Freight rail
  - Maritime

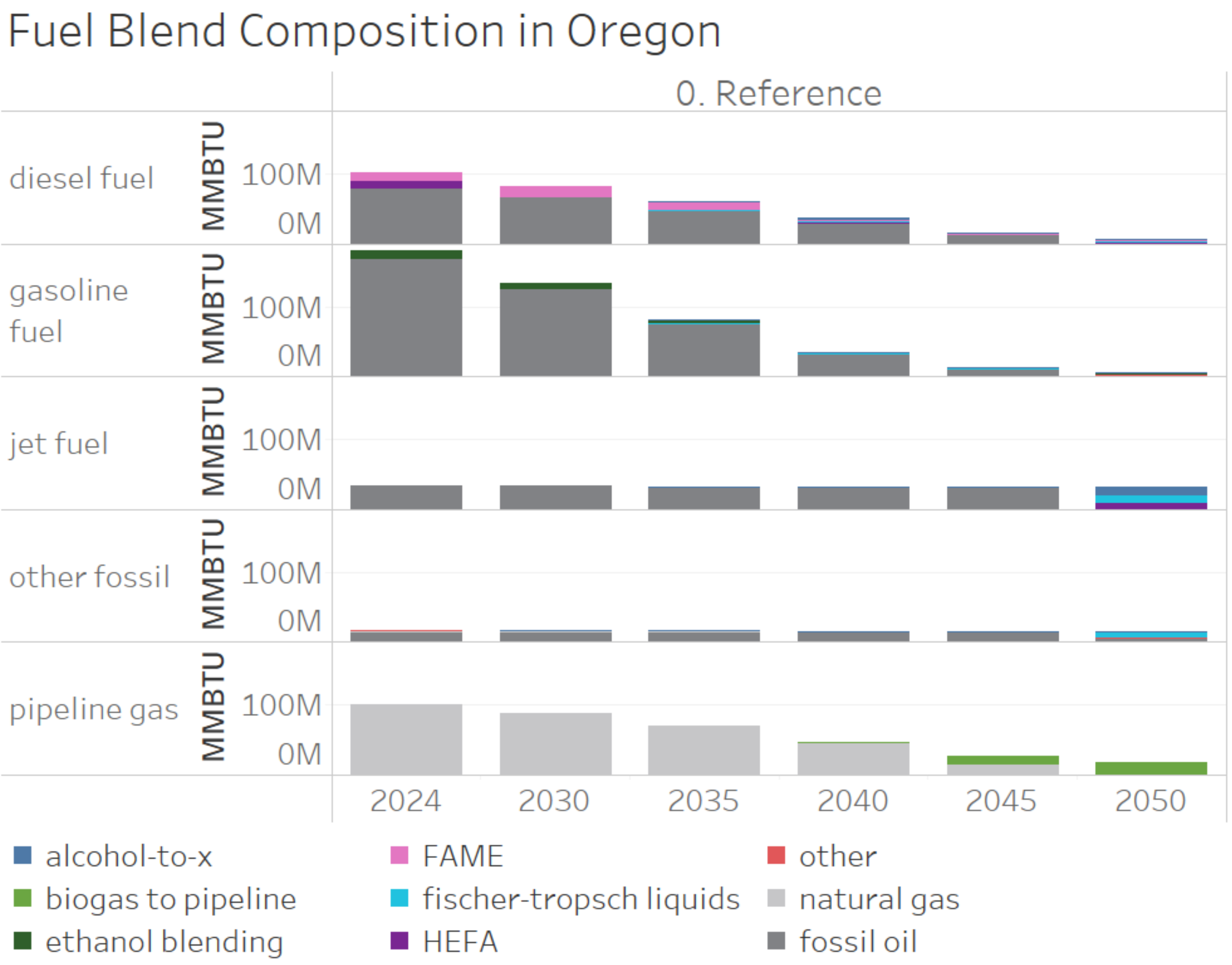


Direct Use Fuels Support Industrial Production and Mostly Phase Out in Buildings



Fuel Blends Drop in Volume and become Cleaner

- Most fuel blends (diesel, gasoline, jet fuel, pipeline gas, and other liquids) decrease in volume with electrification
  - Jet fuel is the exception with no currently economically viable alternative
- Remaining fuel consumption is decarbonized in later years with clean alternatives, including biofuels and hydrogen derived fuels



The Electricity System Relies on Installed Gas Capacity to Provide Flexibility and Reliability

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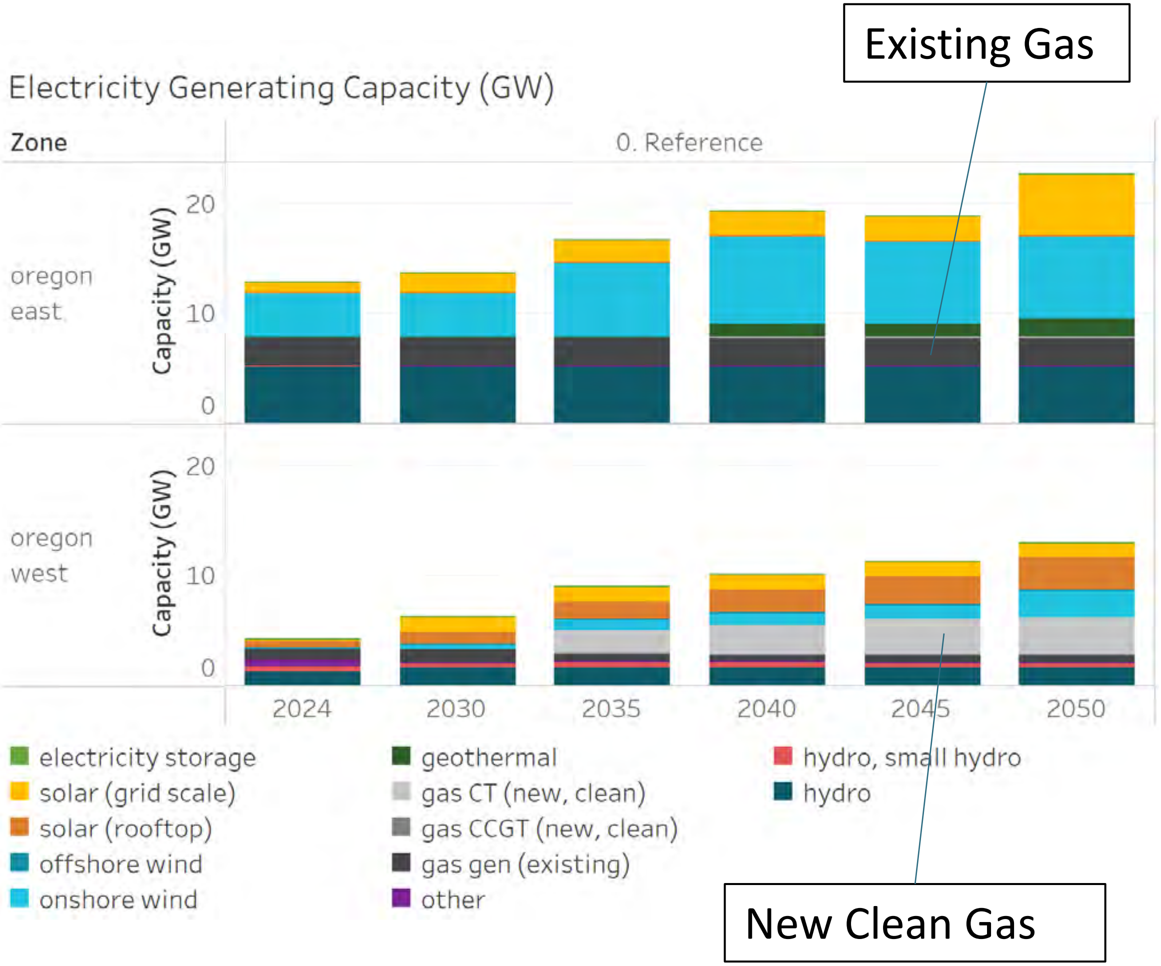
- Flexible capacity is needed to makes sure the system stays reliable
- New clean gas resources can only burn hydrogen or new sources of biogas
- Existing gas and new clean gas capacity run at lower capacity factors over time
- New clean gas resources almost never operate
  - Expensive fuel but cheap capacity



What if We Couldn’t Rely on Clean Gas Plants for Reliability?

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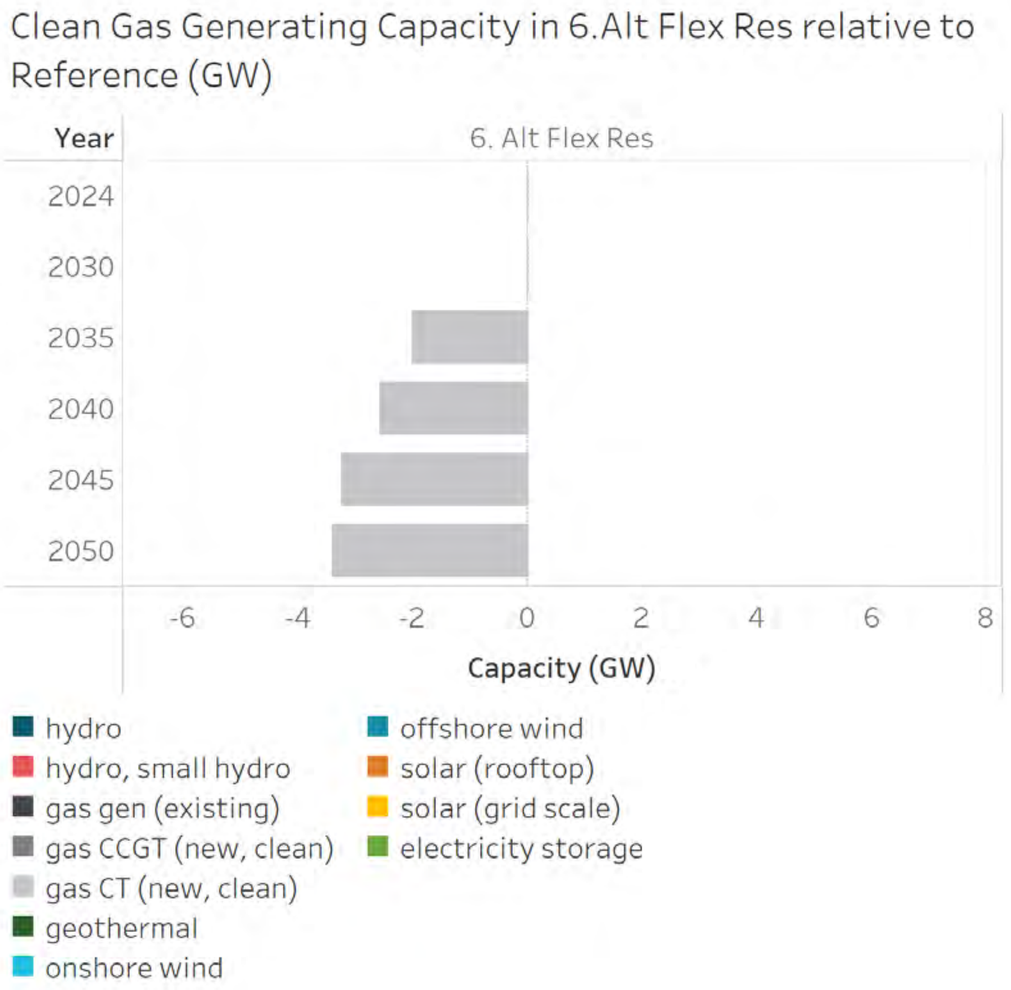
- The Alternative Flexible Resources scenario does not permit the build of new clean gas
- Doubling of electric end use loads and increasingly renewable electricity supply
  - What flexible resources are required to ensure reliability?
- Different options but the model takes a hydrogen and transmission path



What if We Couldn't Rely on Clean Gas Plants for Reliability? (1)

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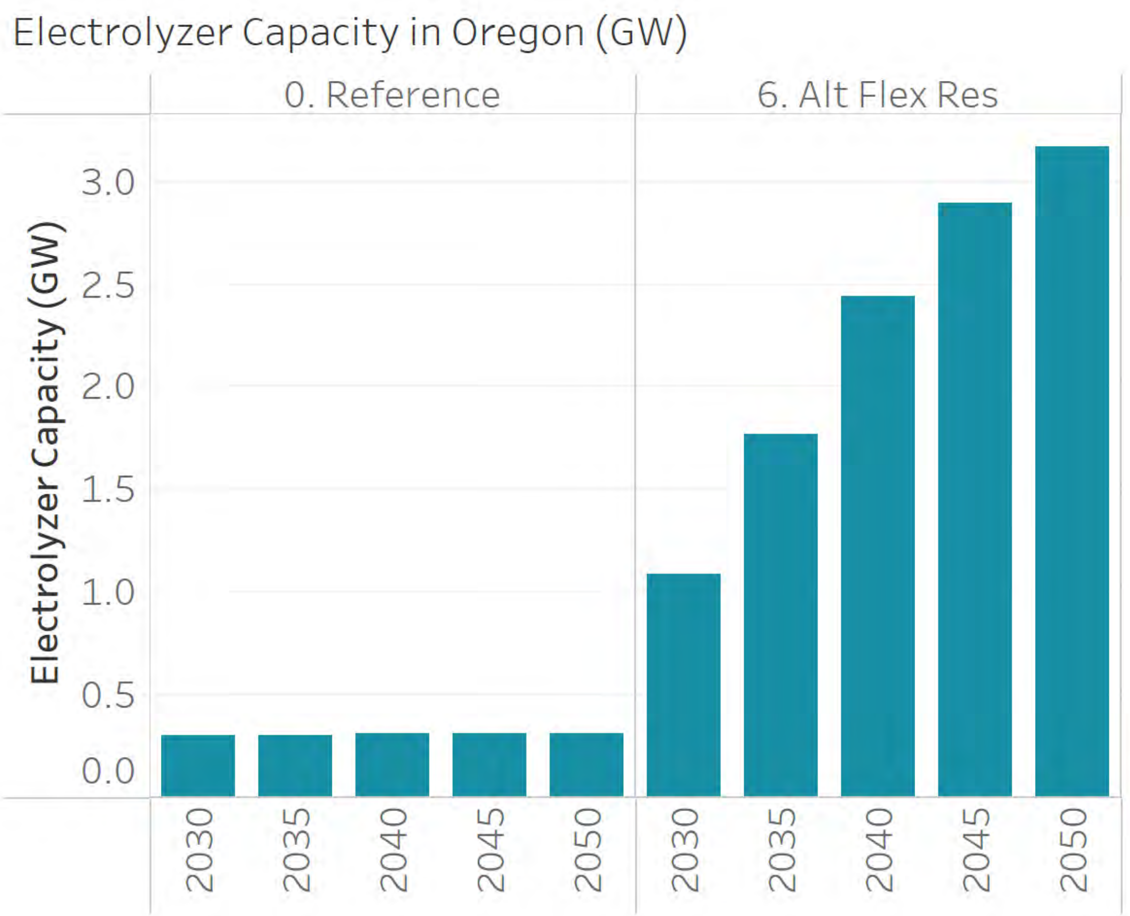
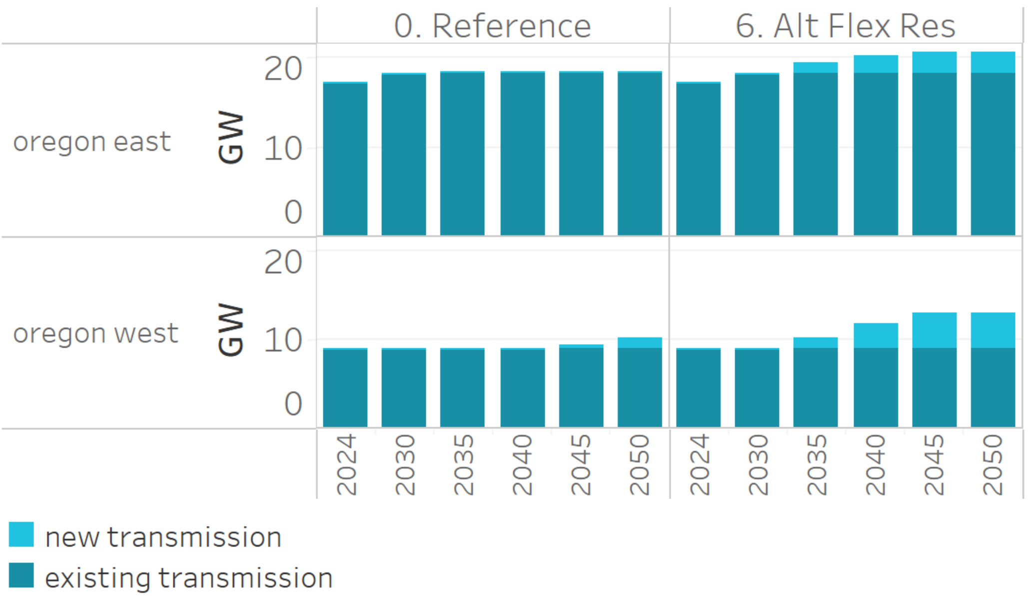
- Clean fuels production from hydrogen occurs outside of Oregon in the Reference Scenario
- Large new flex load: electrolysis becomes valuable to Oregon West in Alt Flex Res
- Movement of electrolysis from out of state into Oregon West: Turn on loads when high renewable energy generation and turn off when low
  - Ammonia produced from hydrogen exported to Western ports



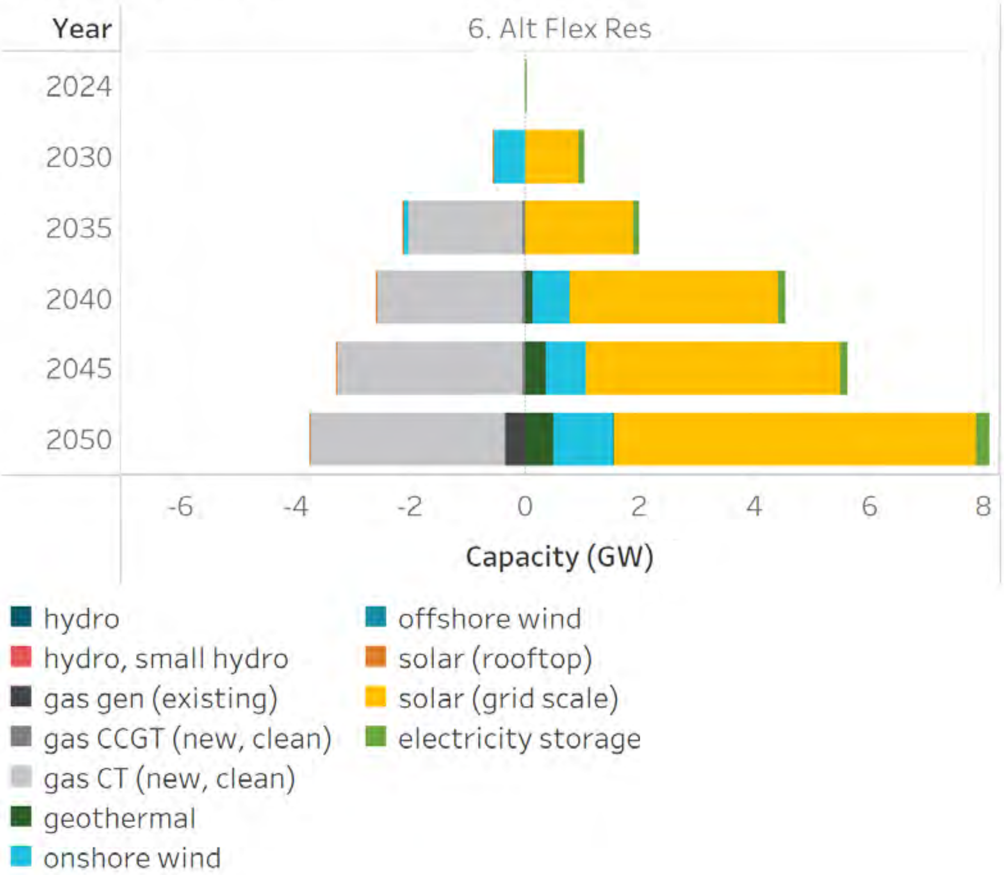
What if We Couldn't Rely on Clean Gas Plants for Reliability? (2)

- Increased loads from electrolysis supported by increased renewables and transmission

Transmission to other zones (GW)

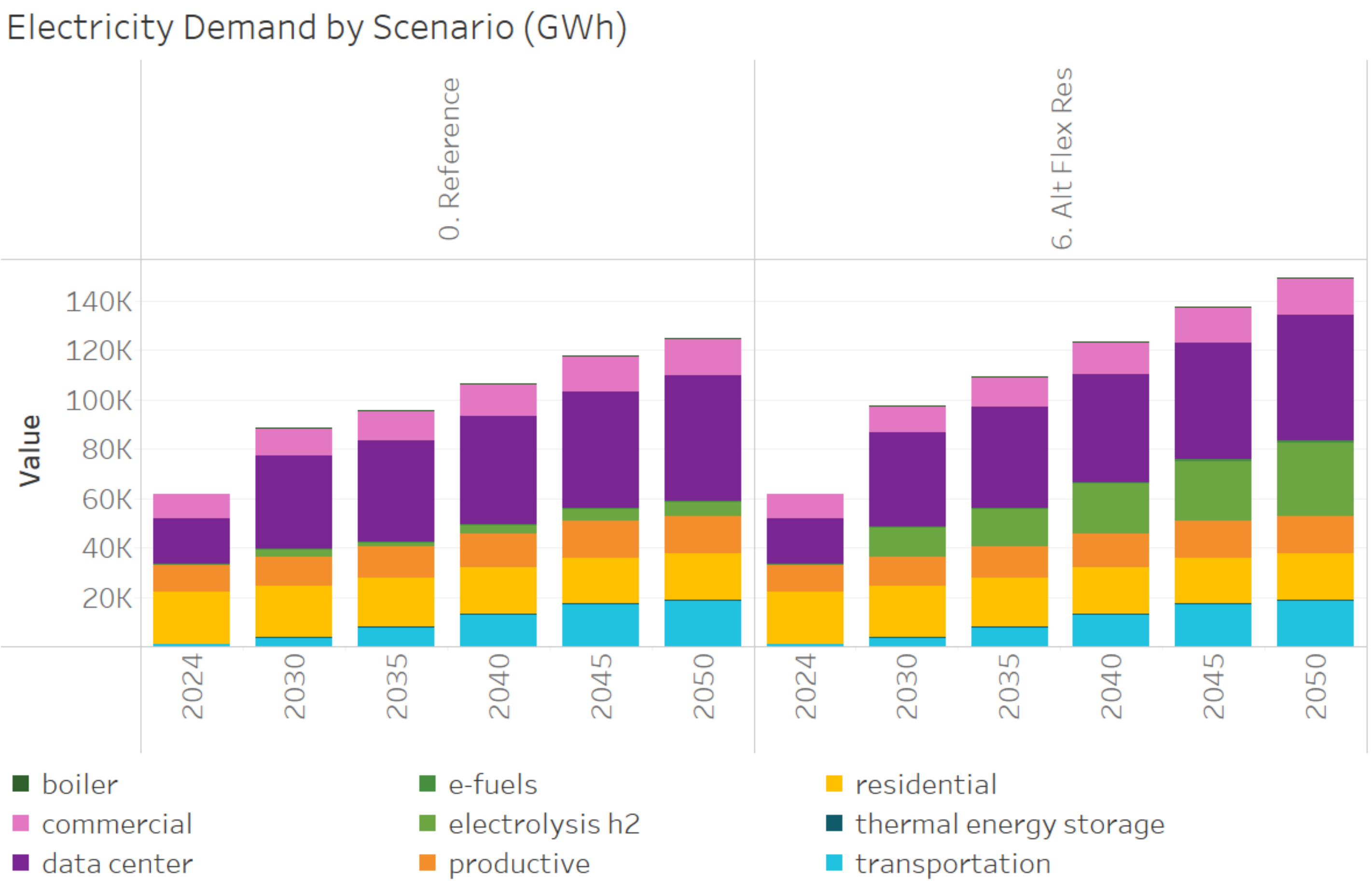


Electricity Generating Capacity in 6.Alt Flex Res relative to Reference (GW)



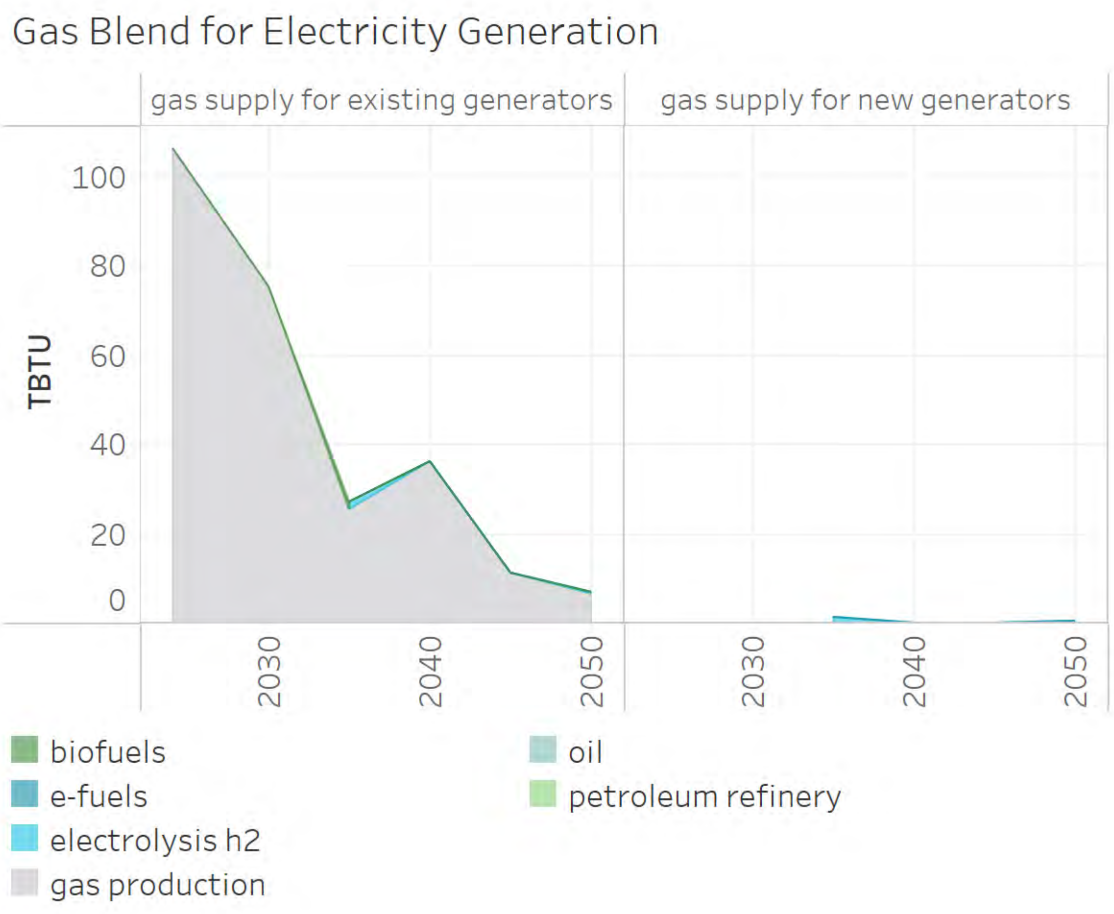
What if We Couldn't Rely on Clean Gas Plants for Reliability? (3)

- Additional electrolyzer loads drive up total loads versus the Reference Scenario
- The result is an overall larger electricity sector in the Western Zone of Oregon where flexibility needs are met with flexible electrolyzer operations and additional transmission development



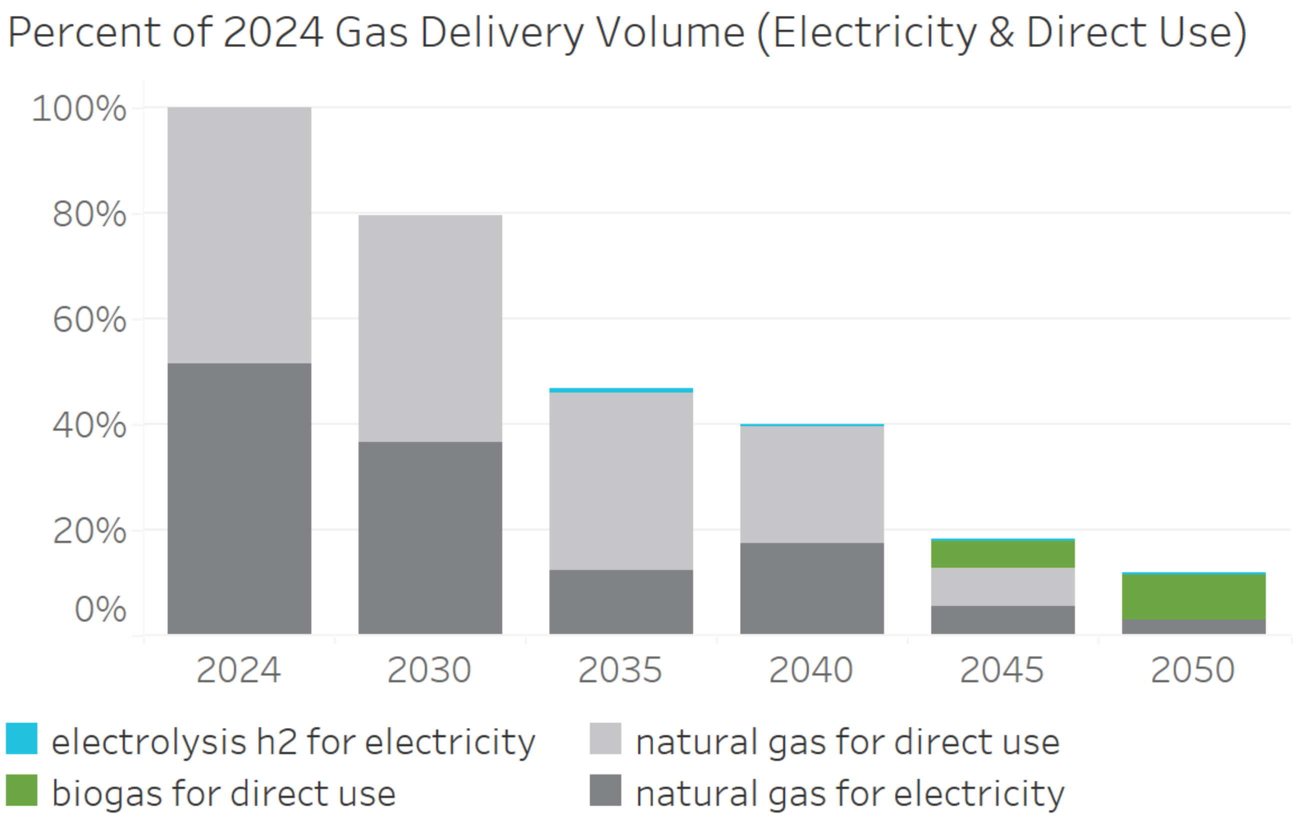
Gas Generators Use Very Little Fuel in the Future

- High value flexibility role on the system
- Providing capacity during periods of low renewable output/high loads/low hydro conditions requires low volumes of fuel
- New clean gas resources use the most expensive fuel so use the lowest fuel volumes



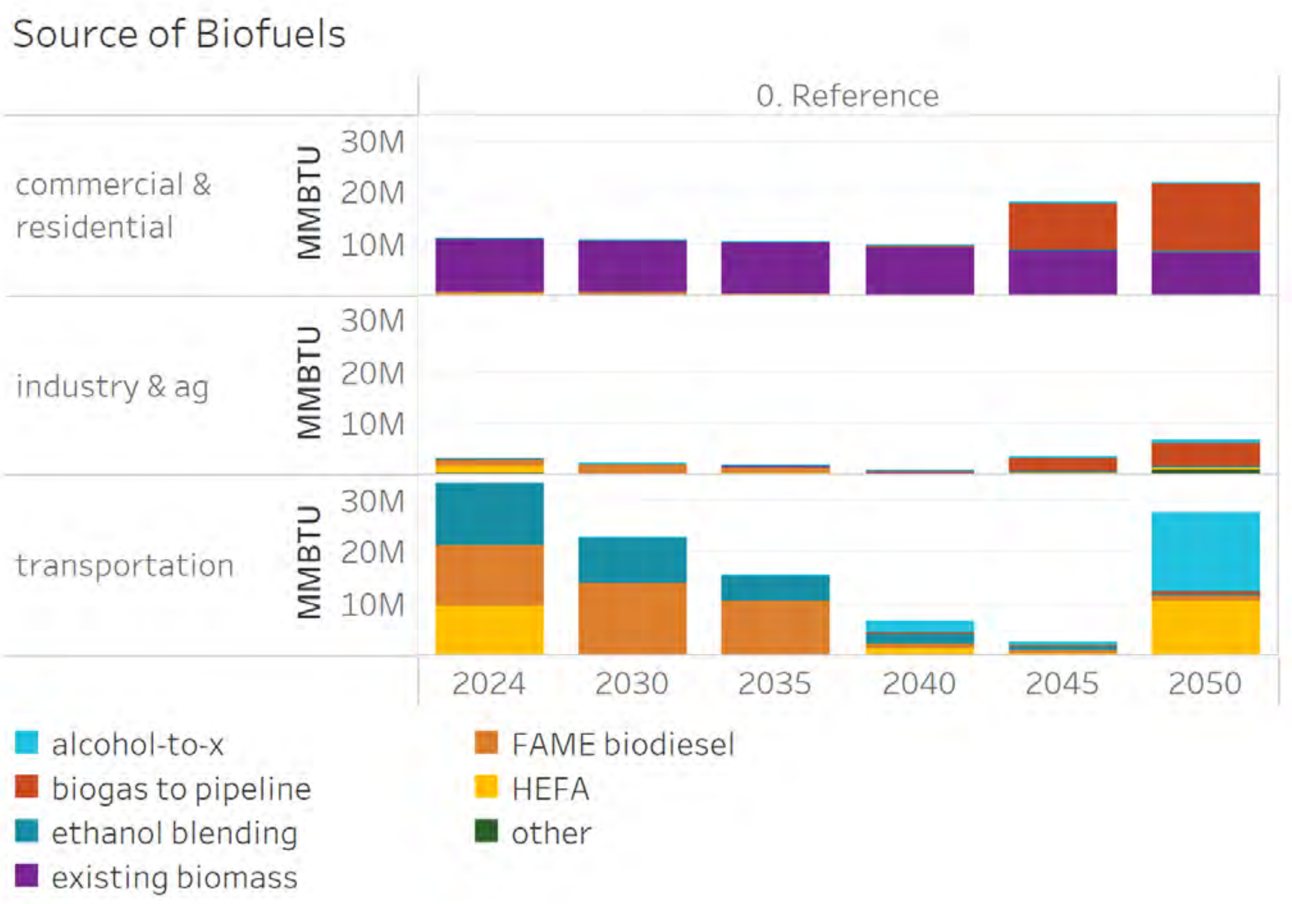
Volumes of Gas Delivered to Electricity Generators and End Users Declines Over Time

- Gas volumes decline over time with reductions in MWh of generation from gas turbines and electrification of end uses
- Small amounts of electrolytic hydrogen used in power generation in new clean gas turbines
- Remaining volumes of direct use gas fully decarbonized with biogas



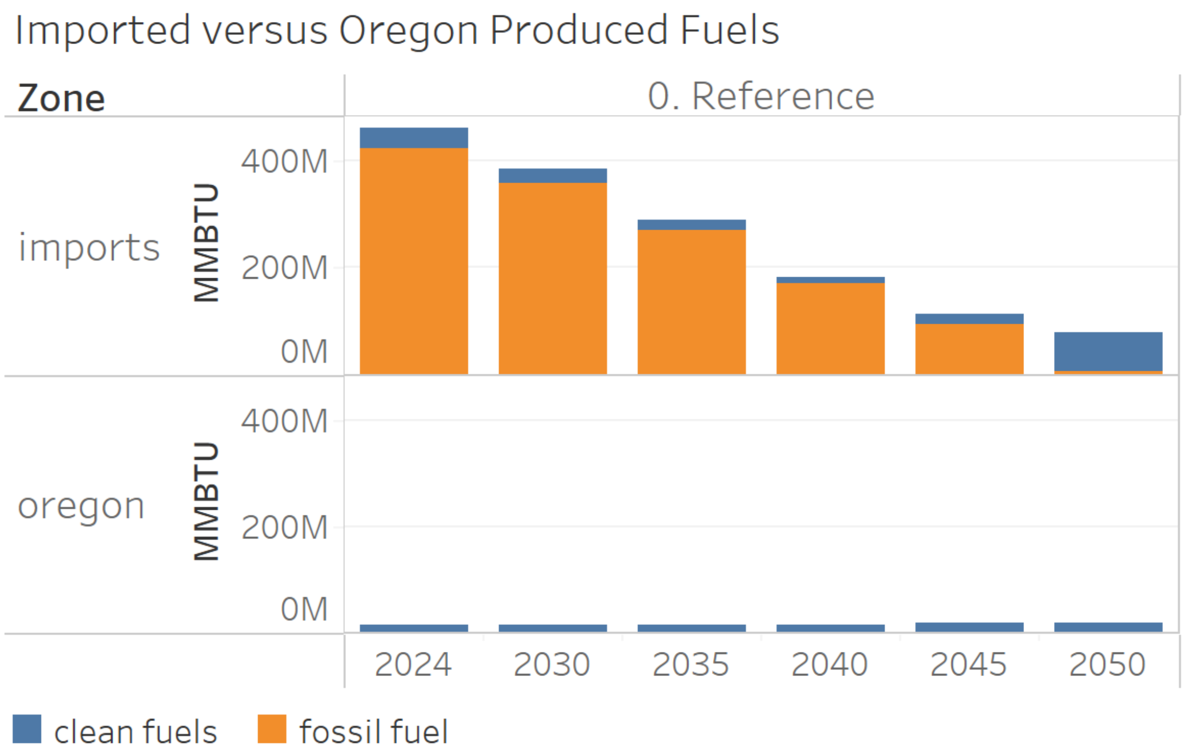
Biofuels are Important to Decarbonize the Low Volumes of Remaining Fuel Use in 2050

- Biofuels in 2024 consist of wood burned in residences and biofuels in transportation, including HEFA, FAME, and ethanol
- Volumes in transportation decrease as the fleet is electrified and emissions from fossil fuels decrease, but increase in 2050 to decarbonize remaining fuel use
- Other sectors consume biogas in 2045 and 2050 to remove emissions from remaining gas use



Fuels: Imported vs. Produced in OR in Reference and Alternative Scenarios

- Fossil fuels are sourced entirely from out of state, relying on larger oil and gas markets, and out-of-state refining
- Fuel imports decline as fuel use declines
- The majority of clean fuels are sourced out of state
- In-state clean fuel growth from direct use of electrolysis H2 and hydrogen liquefaction



Liquid E-Fuels are Imported from Other States whereas Hydrogen Gas is Produced Locally

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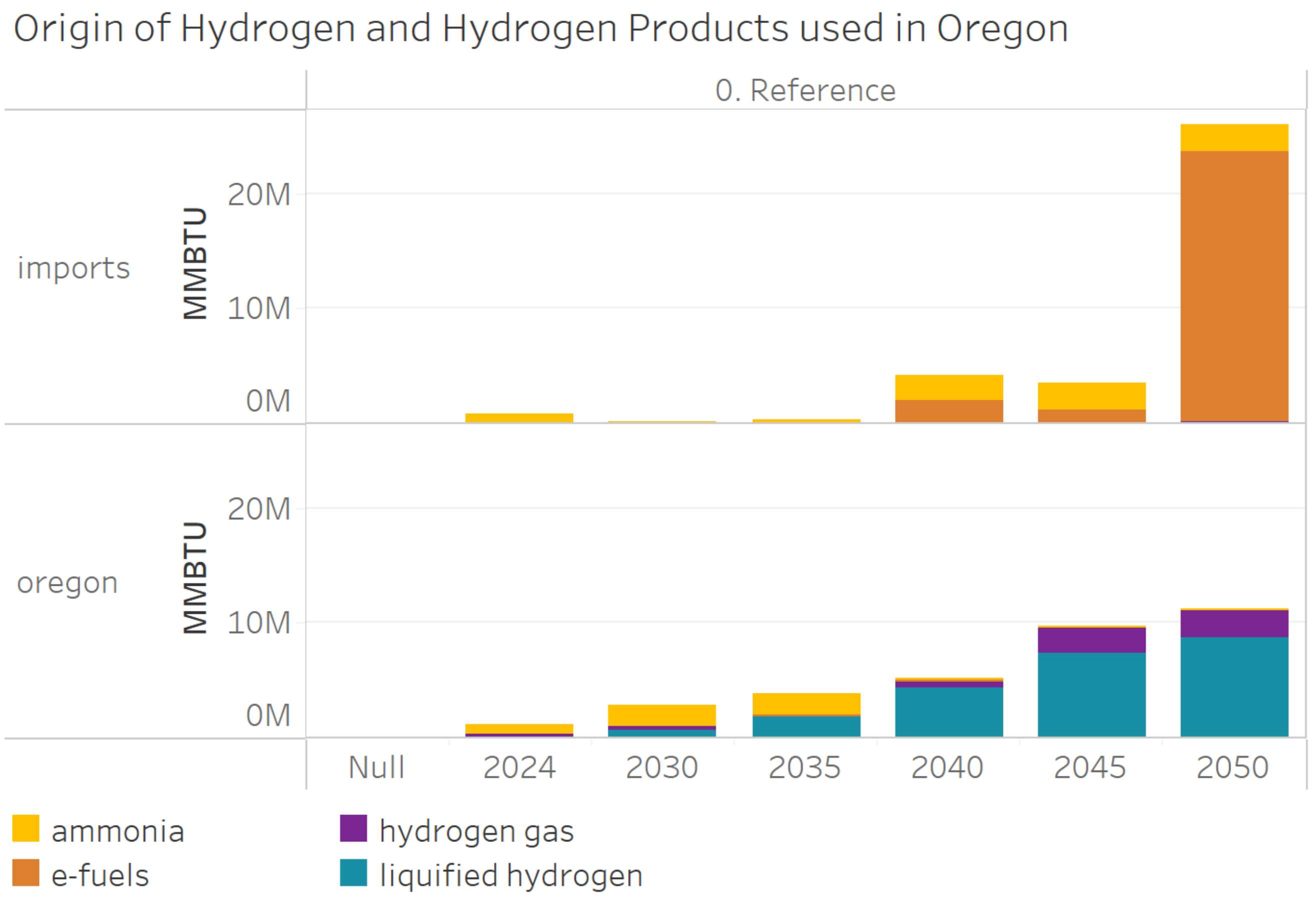
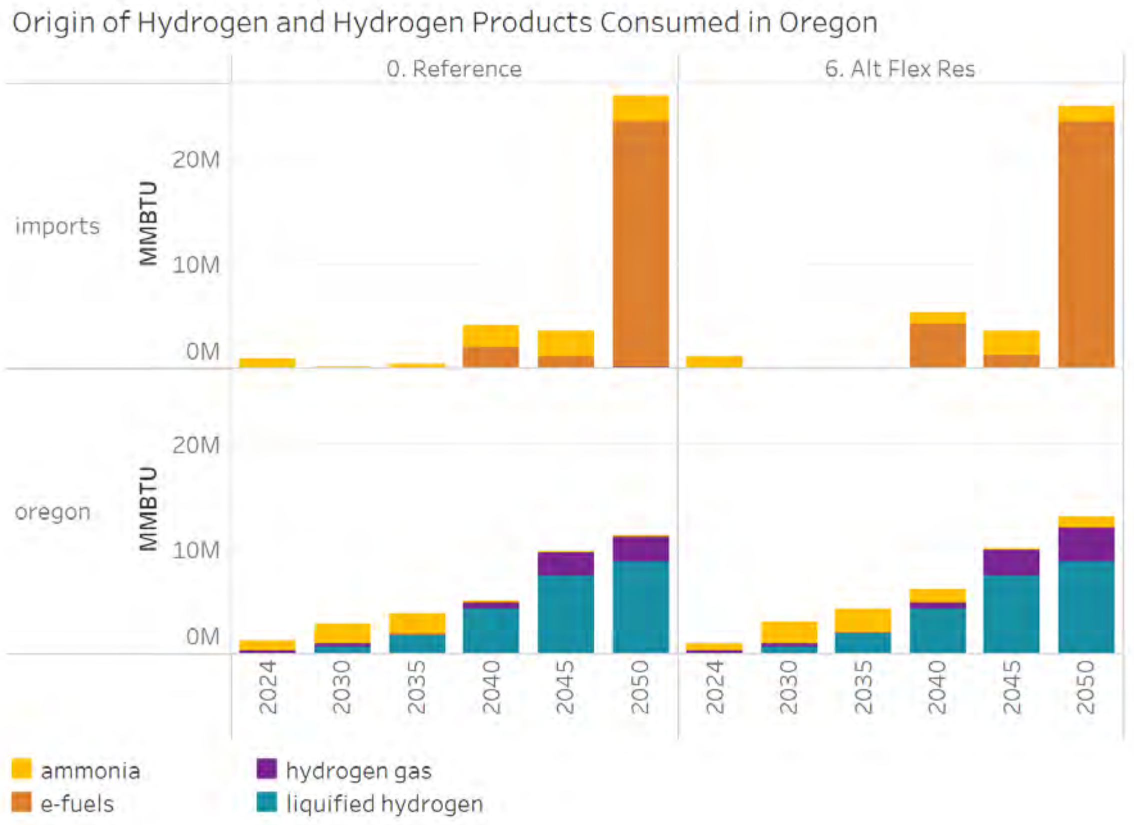
- Hydrogen products consumed in Oregon shown on the previous slide are sources from inside and outside of Oregon
- Liquid fuels are cheap to import, and e-fuel liquids are imported from other states
- Liquified hydrogen and hydrogen gas are produced within Oregon and ammonia production is split between in-state and out-of-state production



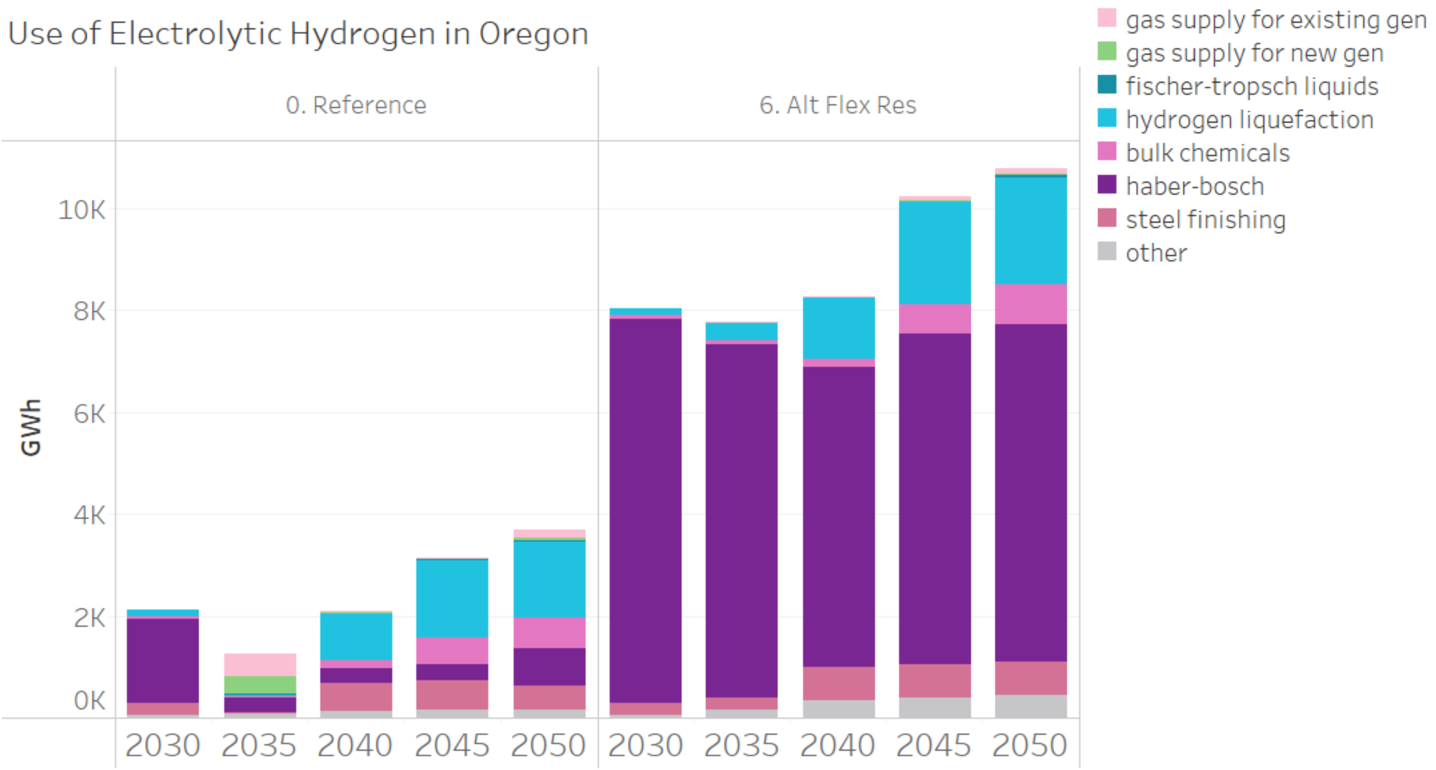
Origin of Hydrogen and Hydrogen Products Consumed in Oregon

- Hydrogen consumption in Oregon is little changed in Scenario 6, even though large numbers of electrolyzers are built
- Products from additional electrolyzer capacity are largely exported in the form of ammonia to other states



Hydrogen Products produced in Oregon including for Export Market

- Electrolyzers built in Scenario 6 in Oregon West provide flexibility to the system
- They displace electrolyzer capacity built elsewhere in the West in the Reference Scenario that produce ammonia for international shipping in West Coast ports
- Additional hydrogen produced in Oregon exported in the form of ammonia



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Transportation Sector Insights

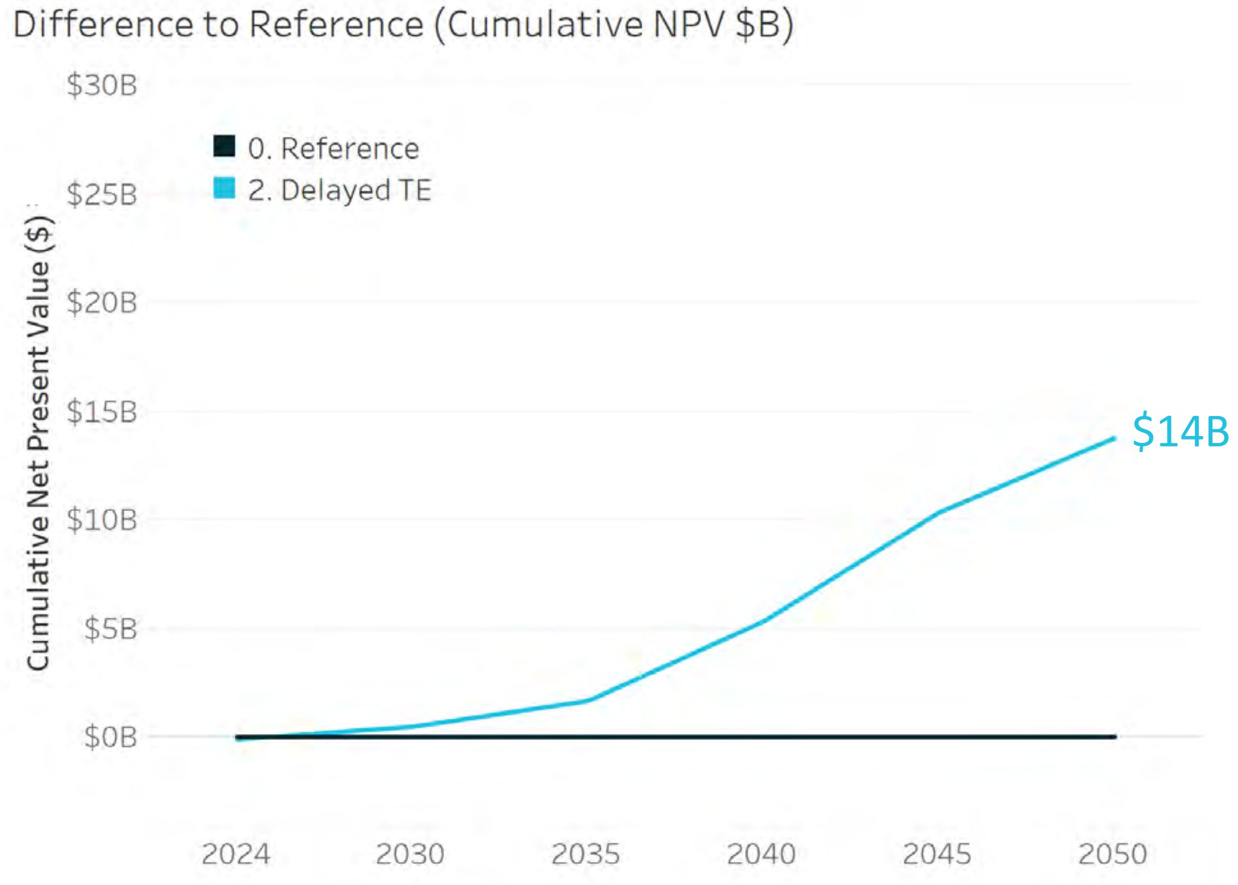
Transportation Sector Key Insights
Transportation Electrification is Critical

- Transportation electrification plays significant role in reducing system-wide energy demand across all scenarios, despite tech sector growth
- Early adoption of electric vehicles, including MHDVs, reduces the costs of decarbonization
- EVs are a significant driver of increased electric loads but can provide a net benefit to the grid if managed flexibly
- Reducing VMT per capita provides significant value but will require investment
- Low carbon fuels play a strategic role in decarbonizing transportation and this role increases as pace of TE slows

Delaying Electrification of Trucks beyond 2040 is More Costly

EVOLVED ENERGY RESEARCH

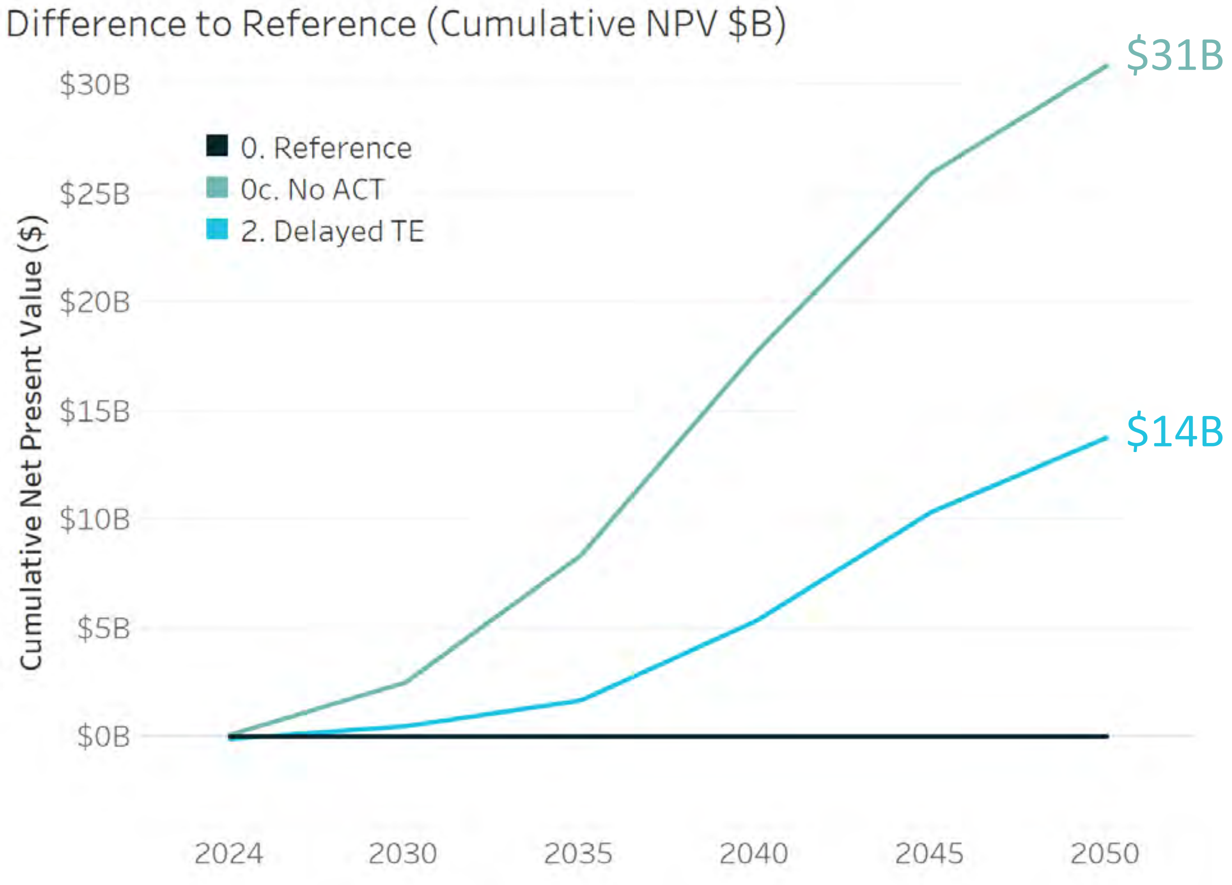
- Delaying when Oregon reaches 100% medium- and heavy-duty ZEV sales by 10 years (to 2050) increases costs
- Puts more pressure on clean fuels to meet targets
- Efficiency losses mean total demand 0.7% higher in 2040 and 0.9% higher in 2050
- To meet emissions target, **almost all vehicle fuel must be clean by 2050**



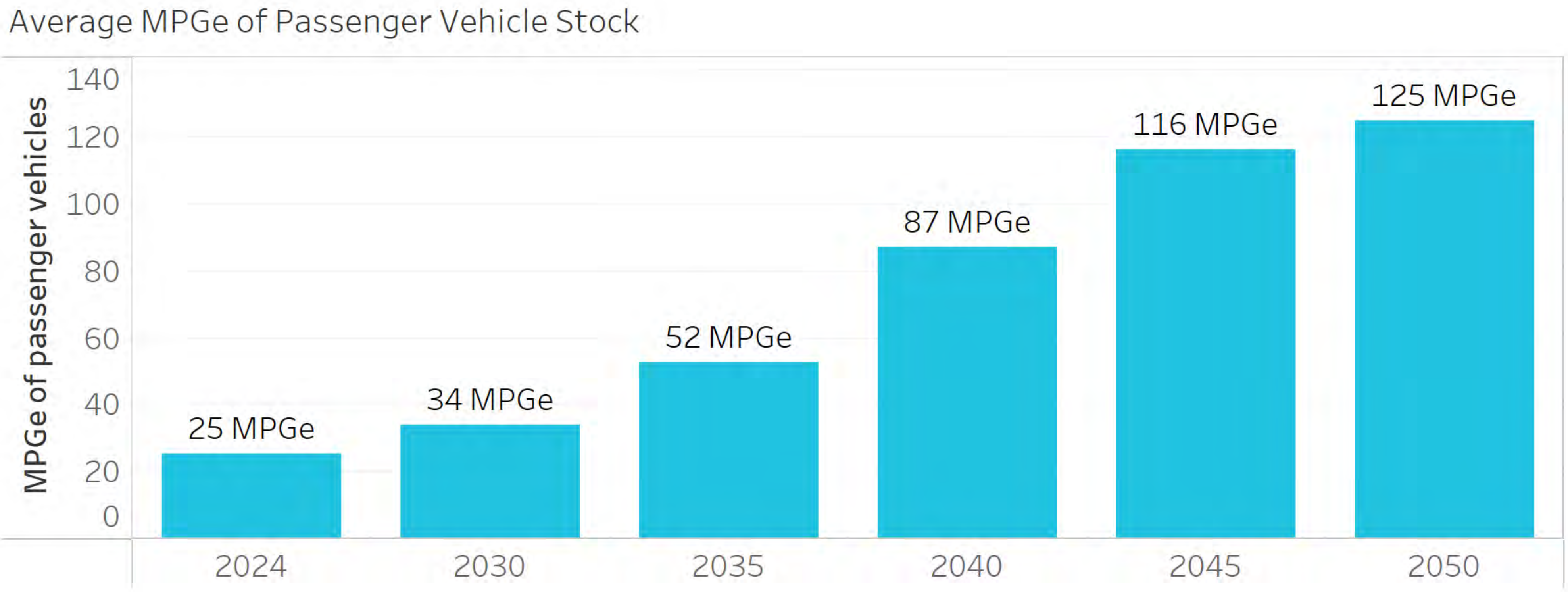
Delaying Electrification of Trucks beyond 2040 is More Costly

EVOLVED ENERGY RESEARCH

- Without the MHD ZEV targets required by the Advanced Clean Trucks rule, costs increase significantly
  - More than double Delayed TE
- Early adoption of EVs, including MHD EVs, is critical for cost containment
- No ACT is $17B NPV higher over 25 years than Delayed TE



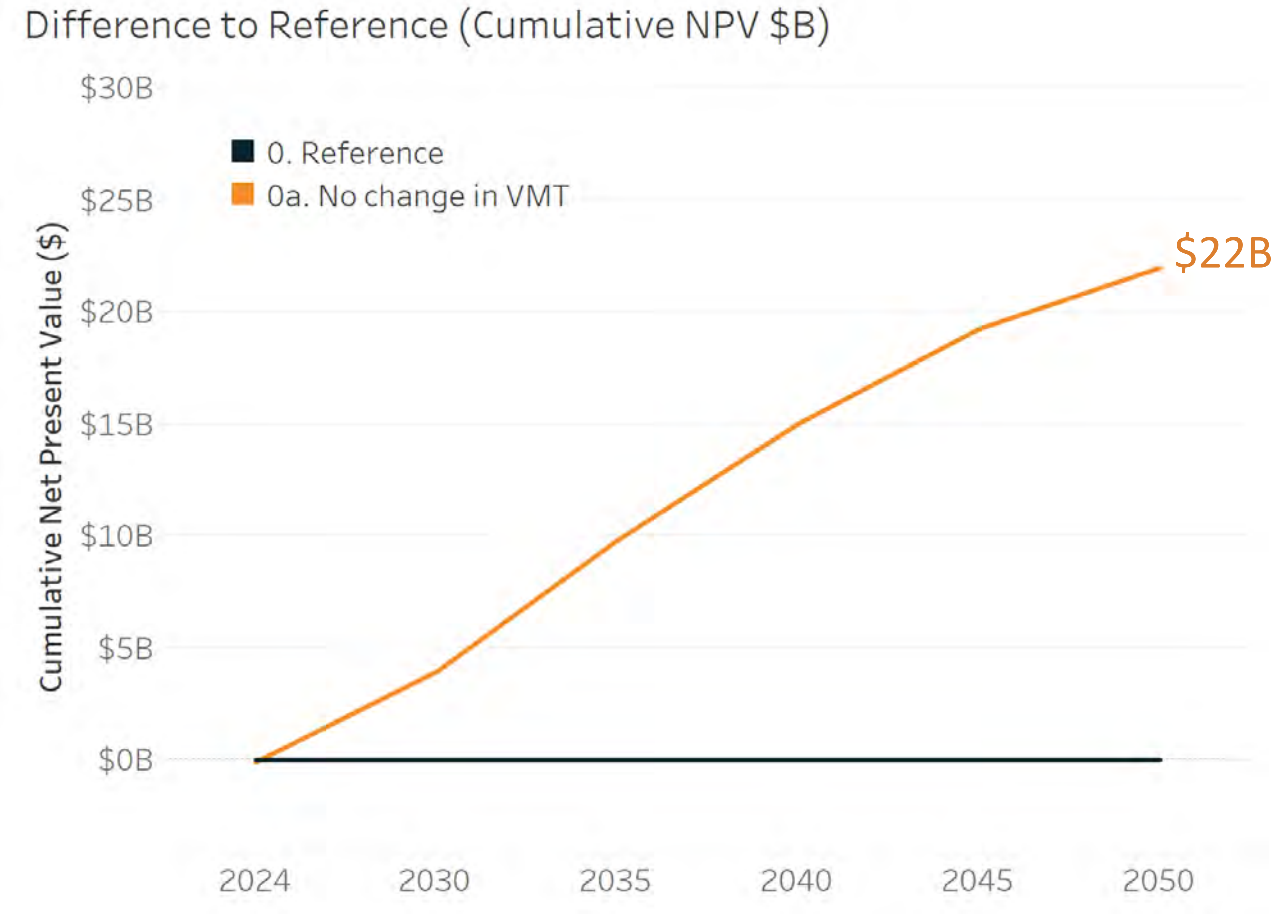
Electric Cars Are a Key Part of the Picture



- Electric cars deliver huge efficiency gains
- Together with electrification of trucks, responsible for reducing the size of the whole energy sector by 27% over 2024 loads

Reducing Vehicle Miles Traveled Saves Money

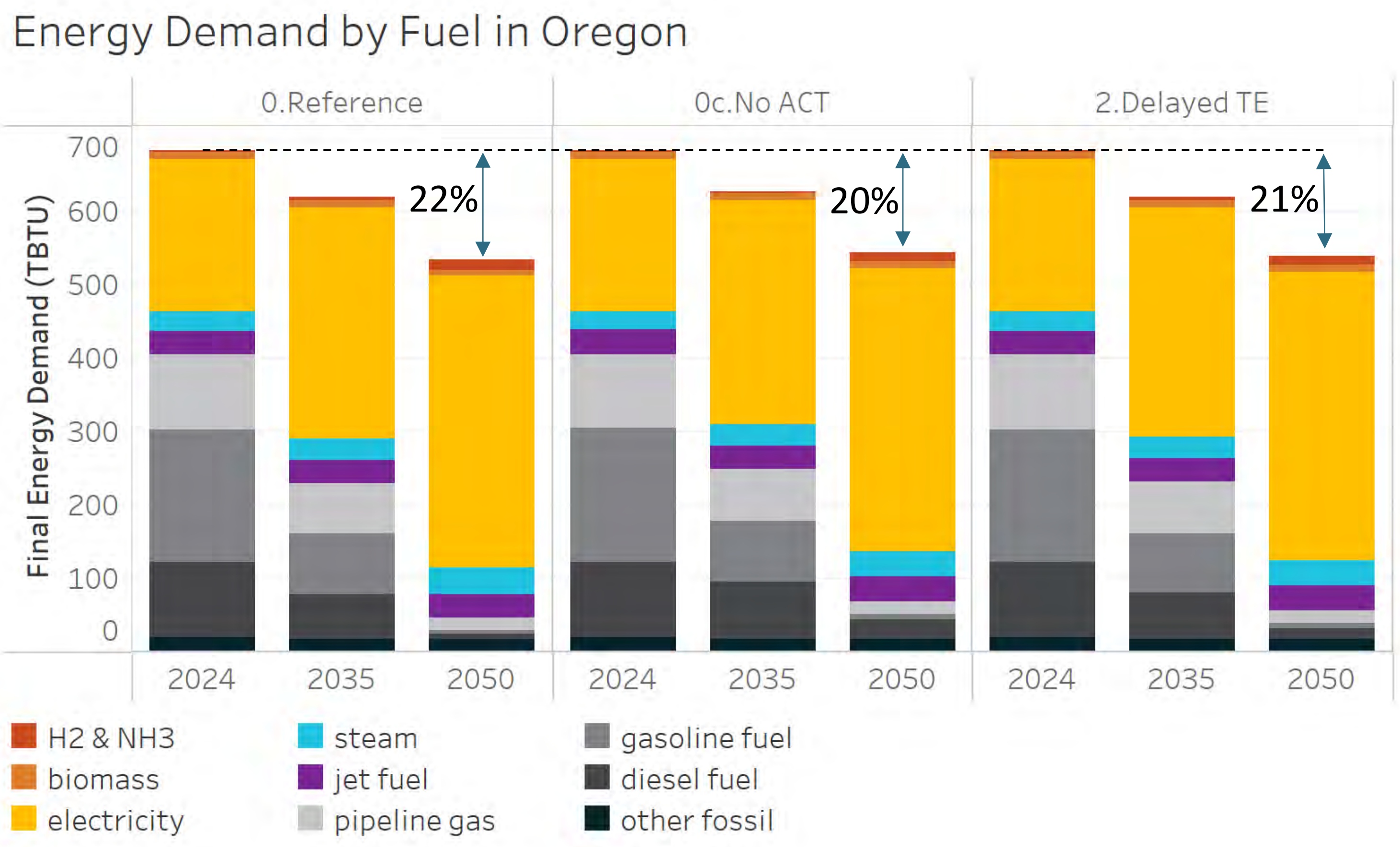
- VMT reductions save $22B over 25 years
- The Reference Scenario incorporates Oregon's goal of a 20% reduction in VMT per capita by 2050
- Removing improvements in VMT drives up costs by increasing the overall energy demand in the economy
- Will require additional investment - scenario does not account for any costs associated with achieving VMT reductions



Impact on Economy-wide Energy Demand

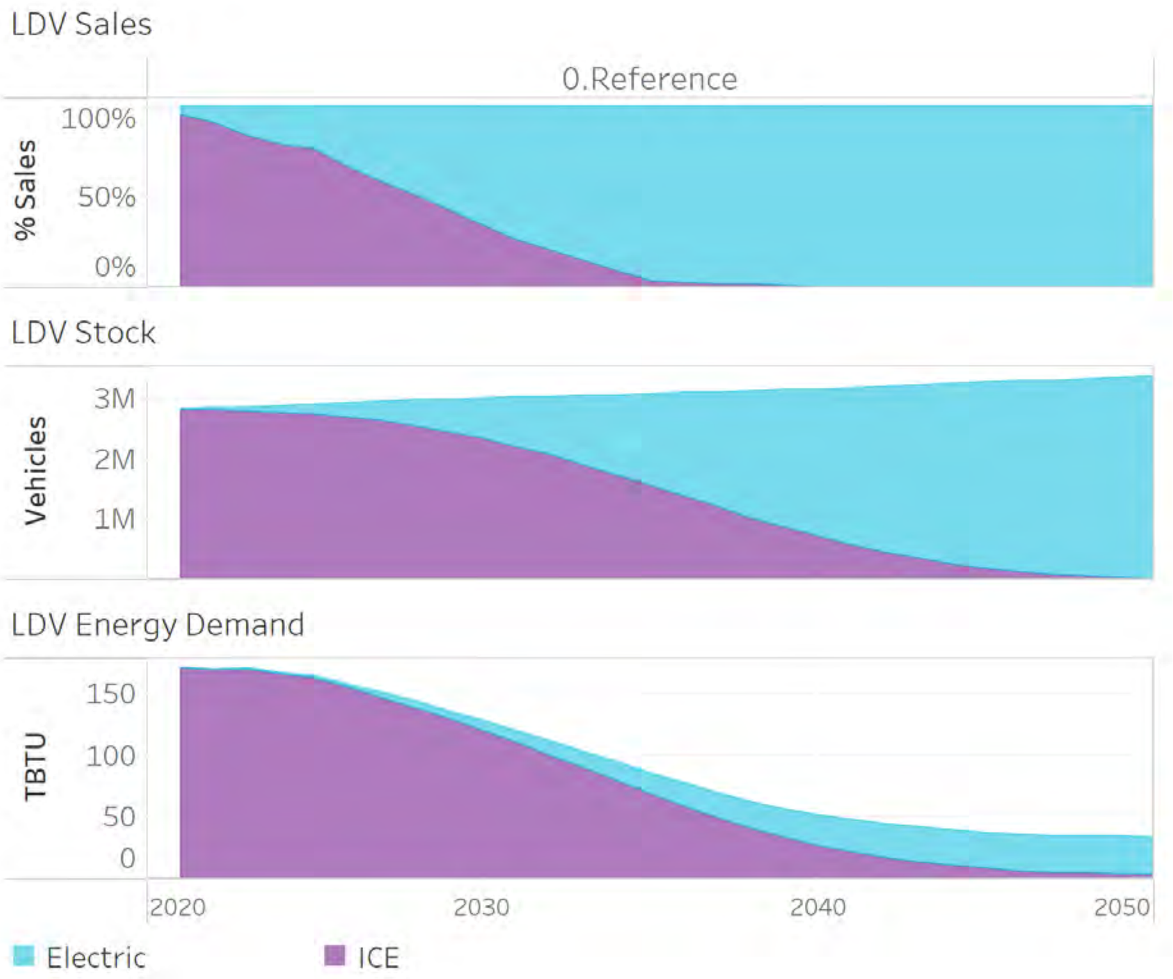
EVOLVED ENERGY RESEARCH

- Overall energy demands are impacted by the level of MHDV electrification
- More significant is the impact on fuel use
  - No ACT: Diesel consumption is 25% higher in 2035 and 270% higher in 2050 than in the Reference Scenario
  - Delayed TE: Diesel consumption is 110% higher in 2050 than in the Reference Scenario
- Additional fuel use increases the volume of clean fuel needed in the long term



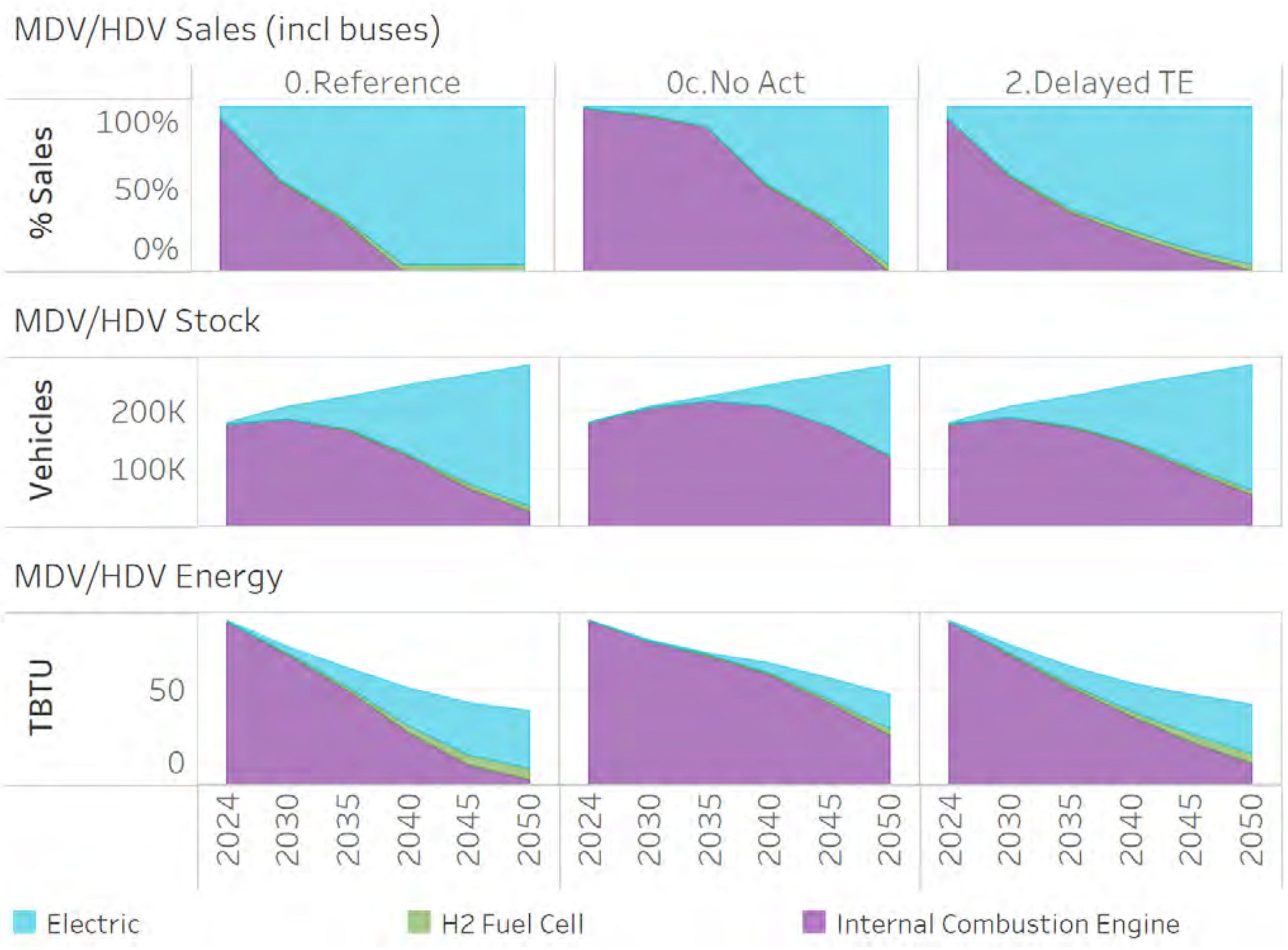
Reference Scenario
Light Duty Vehicle Sales, Stock, Energy

- 100% zero emissions vehicle sales achieved in 2035
- Drop in energy demand from both better drive train efficiency and 20% reduction in vehicle miles traveled by 2050



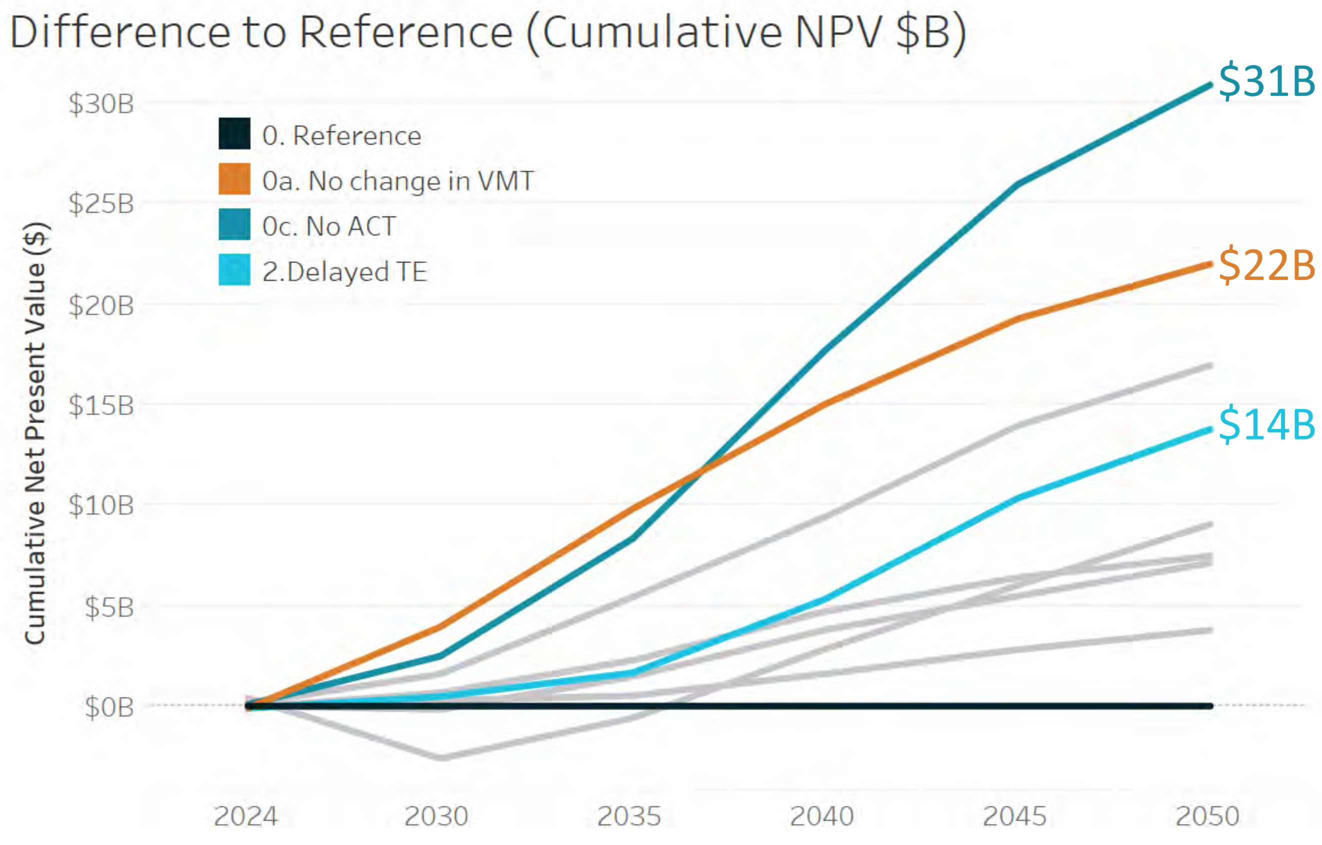
Impact of Delays on Sales, Stocks, and Energy

- Medium and heavy-duty vehicle sales are delayed in 0c. No ACT and 2. Delayed TE
  - No ACT has relatively few sales of zero emission vehicles through 2035, achieving 100% sales by 2050
  - Delayed TE has the same trajectory as Reference through 2035, delaying reaching 100% sales from 2040 to 2050
- The impact of the delays is to increase stocks of internal combustion engine vehicles, driving up energy demand



Costs: TE Scenarios Difference to Reference

- Delaying when Oregon reaches 100% medium- and heavy-duty ZEV sales by 10 years increases costs
  - Puts more pressure on clean fuels to meet targets
- Oregon's goal of 20% VMT reductions saves $22B NPV over 25 years
- No ACT is $16B NPV higher over 25 years than Delayed TE
  - Shows stock rollover of MHDVs in the 2030s is important for cost containment



Energy Reductions from Vehicle Electrification, Efficiency, and VMT Reductions Equal to 27% of Today's Energy Demand

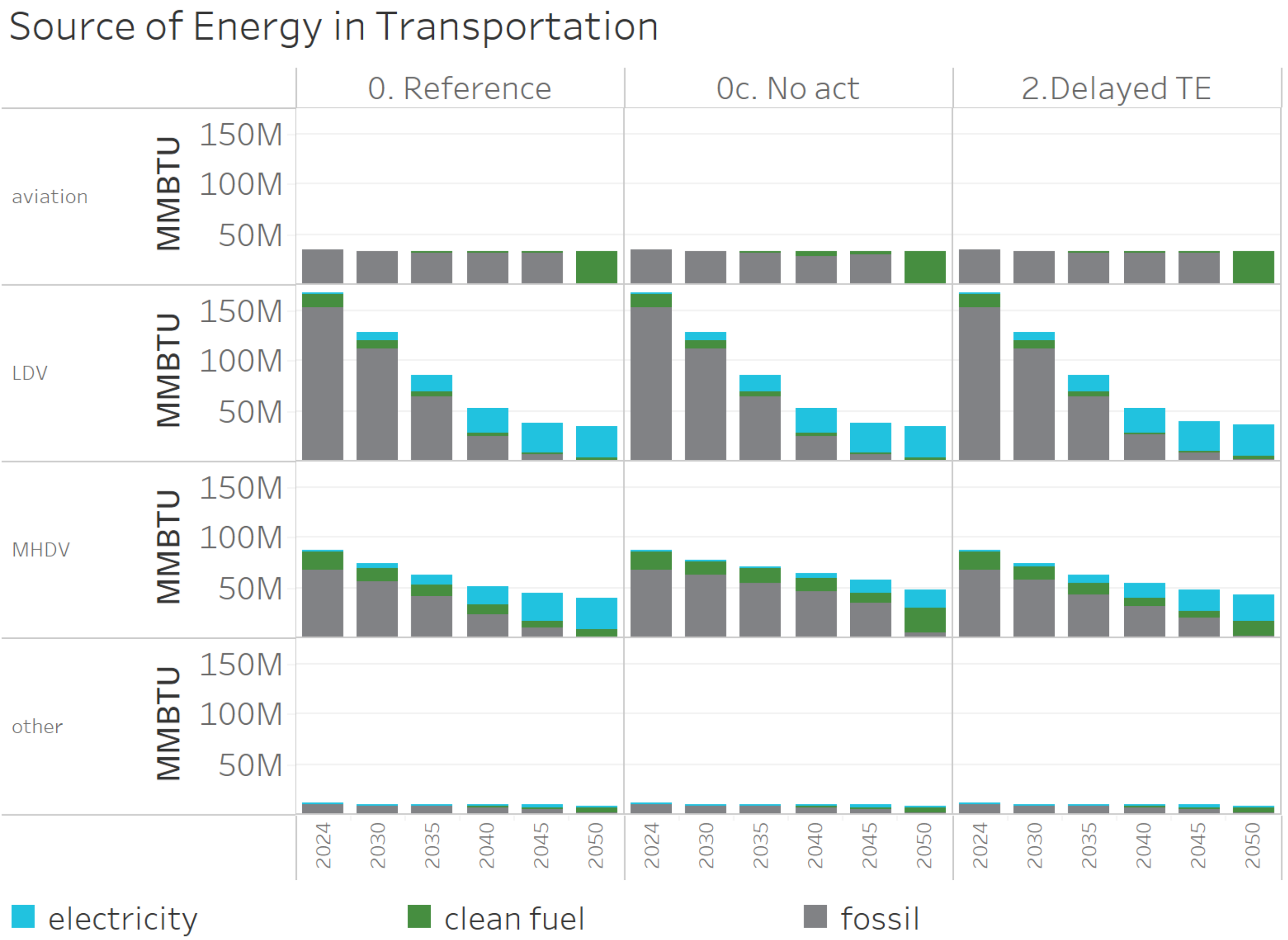
EVOLVED ENERGY RESEARCH

- Vehicle electrification, efficiency, and VMT reductions play an important role in reducing the overall size of the future energy system
- By 2050, the reduction in energy demand from vehicles is 27% of 2024 energy demands in the Reference Scenario
  - 20% of the reduction is attributable to the light duty vehicle fleet
  - 7% of the reduction is attributable to medium- and heavy-duty vehicles
- Overall energy reductions by 2050 vs 2024 are 22%, due to significant energy savings in transportation, residential and commercial sectors on the one hand, and growth in data centers on the other

			Percentage reduction of 2024 Final Energy Demand			
		Total Final Energy Demand (TBTU)	Total	LDV	MHDV	Other
0.Reference	2024	682.4	0.0%	0.0%	0.0%	0.0%
0.Reference	2035	618.8	15.9%	12.0%	3.6%	0.3%
0.Reference	2050	535.0	27.1%	19.6%	6.9%	0.5%

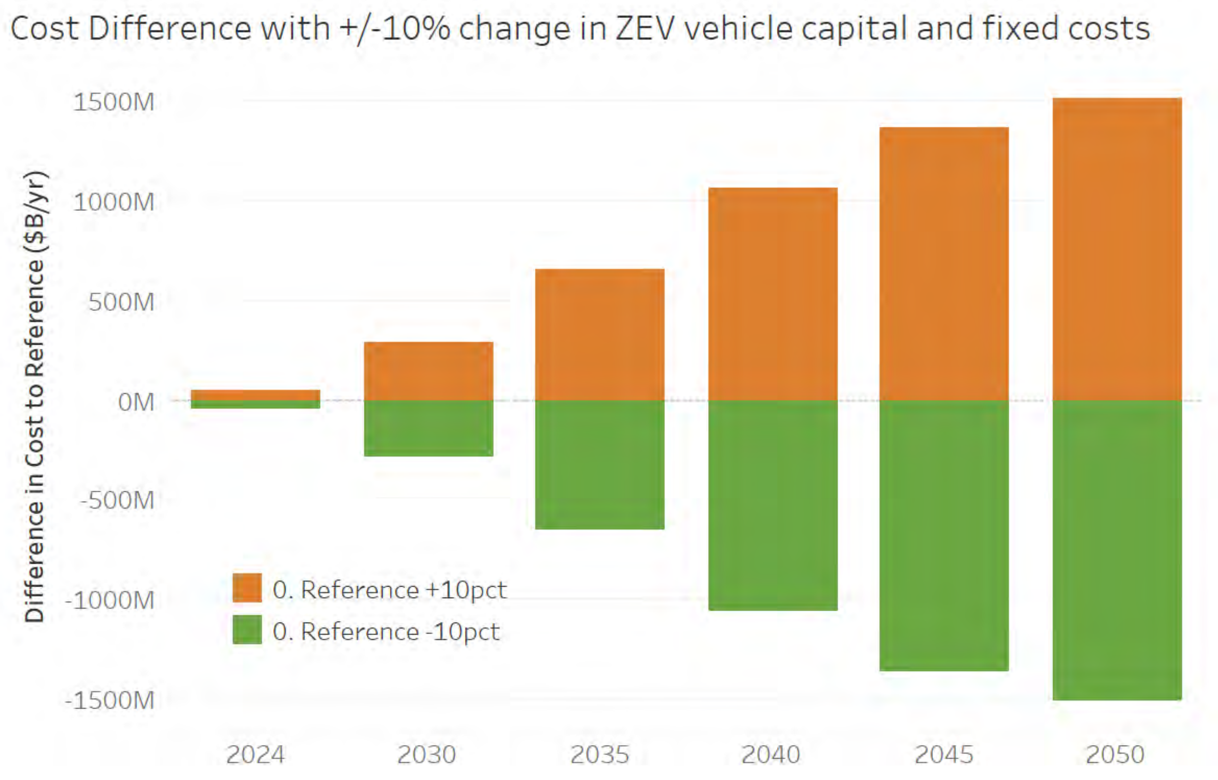
Transportation Subsector Fuel Consumption by Transportation Scenario

- The transportation scenarios investigate differences in medium and heavy-duty vehicles
  - The transition to clean energy across other subsectors is similar across scenarios
- Delays in medium and heavy-duty vehicles drives greater need for clean fuels by 2050



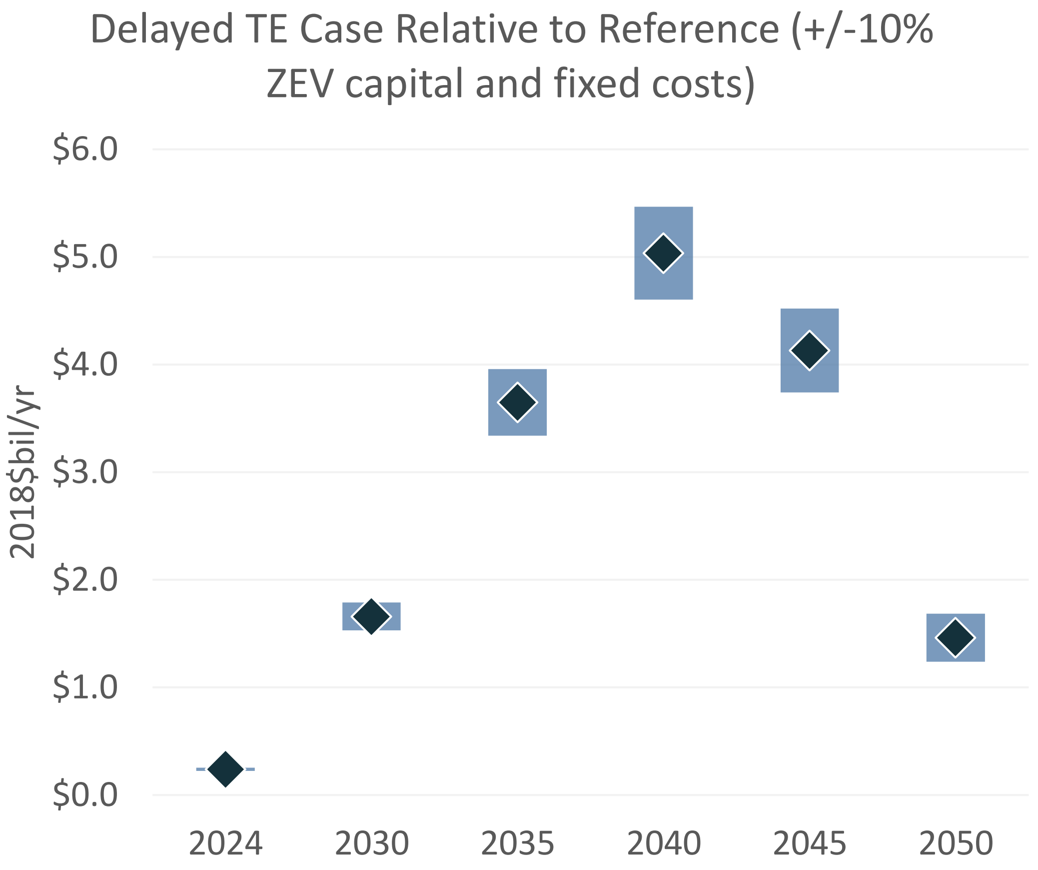
Zero Emission Vehicle Price Sensitivities (1)

- Increasing uncertainty over time
- Results are particularly sensitive to some inputs, e.g.,
  - Fossil fuel costs
  - Vehicle prices
- Example: +/-10% on clean vehicle and vehicle infrastructure costs (EVs and hydrogen)
- Decarbonization acts as hedge against fuel prices from volatility in international markets but sensitive to zero emission vehicle prices



Zero Emission Vehicle Price Sensitivities (2)

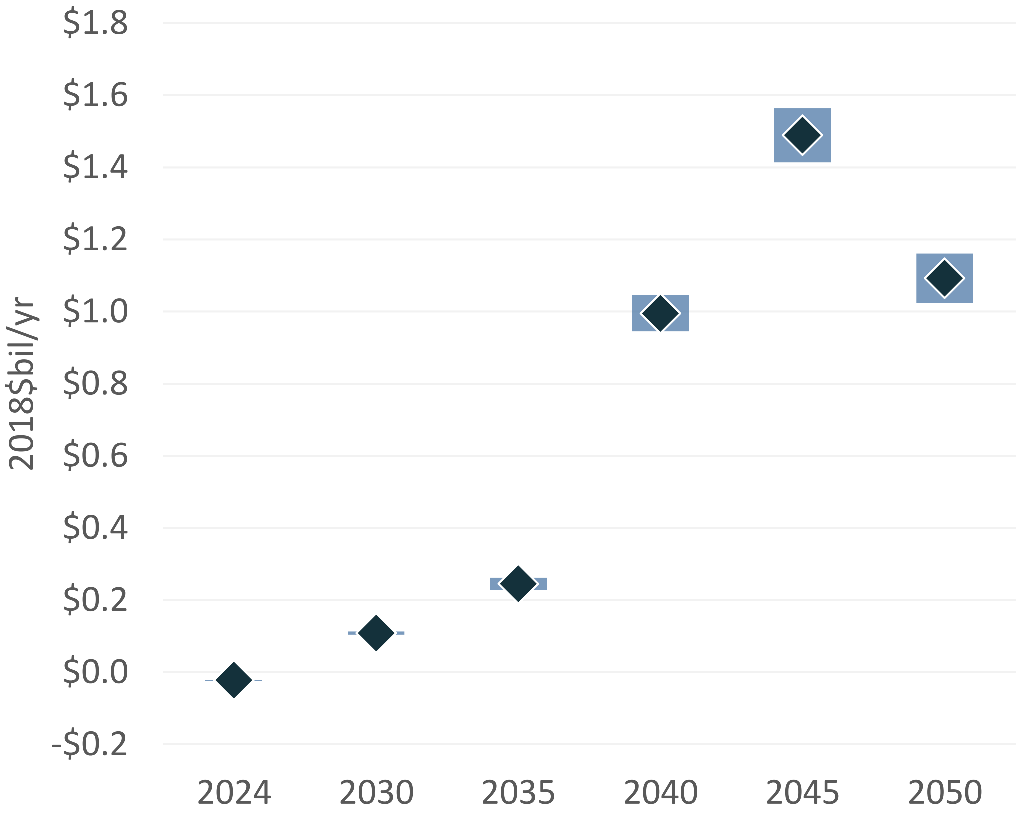
- Cost sensitivities of +/-10% on ZEV capital and fixed costs (including vehicle prices, fixed O&M, and installation costs) relative to Reference remain higher than Reference
- The strategy of vehicle electrification remains cost effective under vehicle cost changes



Electrification Remains Cost Effective with Changes in Vehicle Pricing

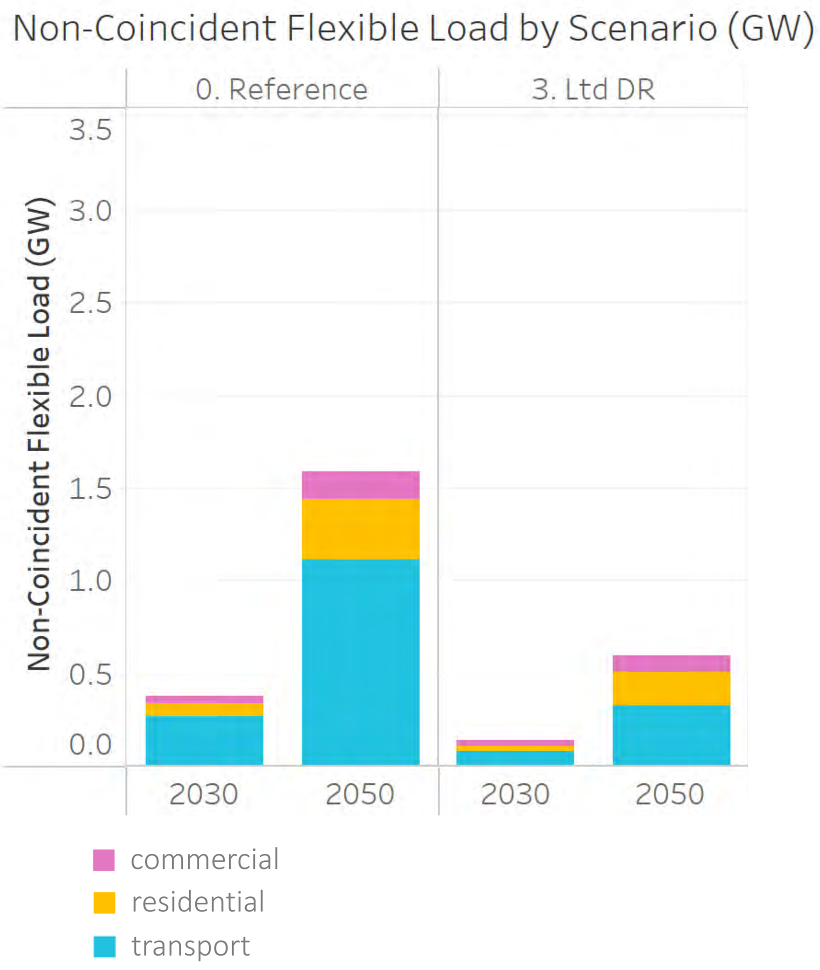
- Cost sensitivities of +/-10% on ZEV capital and fixed costs (including vehicle prices, fixed O&M, and installation costs) relative to Reference remain higher than Reference
- The strategy of vehicle electrification remains cost effective under vehicle cost changes

Difference in Annualized Cost between Delayed TE and Reference. Error Bars for +/-10% ZEV Cost



Flexible Loads Dependent on Customer Participation in the Future

- The largest contribution to non-industrial flexible load comes from managed charging in the transportation sector
- The Reference Scenario assumes active participation of customers in demand response programs
- The capacity of flexible load contributions by 2050 will vary based on customer participation
- Limited participation costs $4B on a cumulative NPV basis over 25 years



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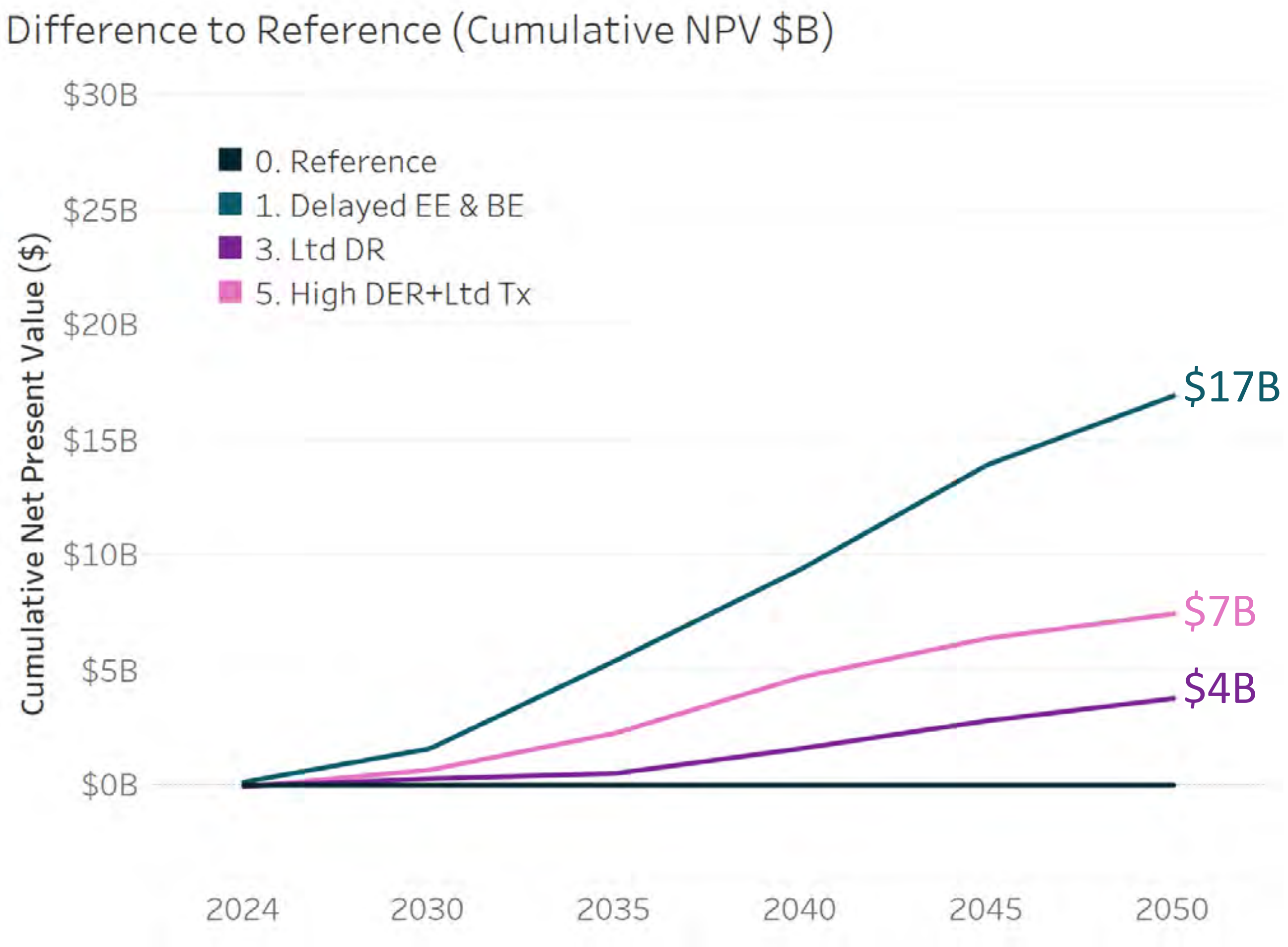
Buildings Sector Insights

Buildings Sector Key Model Insights

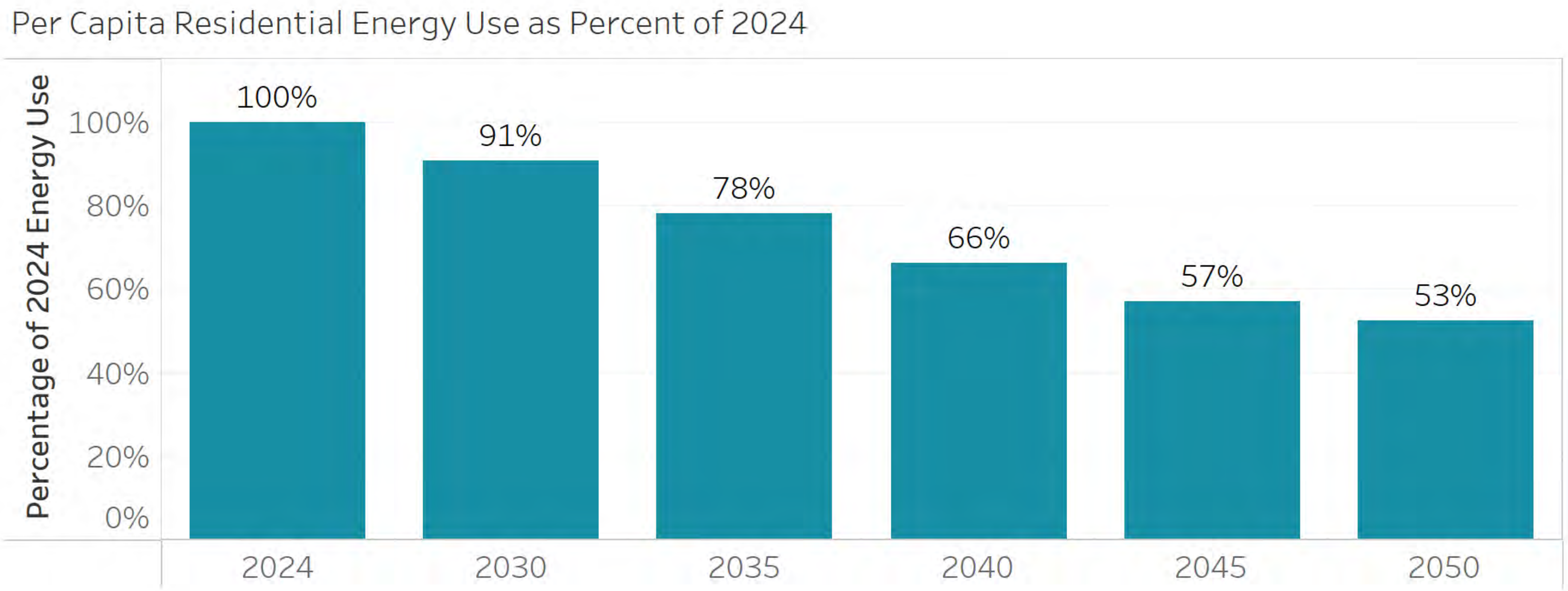
- Energy efficiency and demand response reduce the size of future energy systems
- Delaying energy efficiency and building electrification will result in higher costs for Oregonians
- Demand response programs reduce future capacity and transmission needs
- Increasing rooftop solar installations reduces some land use impacts associated with utility scale solar

Energy Efficiency, Building Electrification, PV, and DERs Are Important to a Least-Cost Pathway

- Delaying energy efficiency and building electrification drives up costs by $17B cumulative NPV over the next 25 years, showing the importance of these measures in buildings
- The higher DER scenario increases costs by $8B cumulative NPV, but reduces the need for grid scale renewables and T&D infrastructure investment, potentially easing siting and permitting pressures
- The Limited Demand Response scenario drives up costs by $4B cumulative NPV showing the value of customer participation with new electrified end uses



Residential Electrification and Energy Efficiency Mean a Lighter Lift to Meet Energy Demand

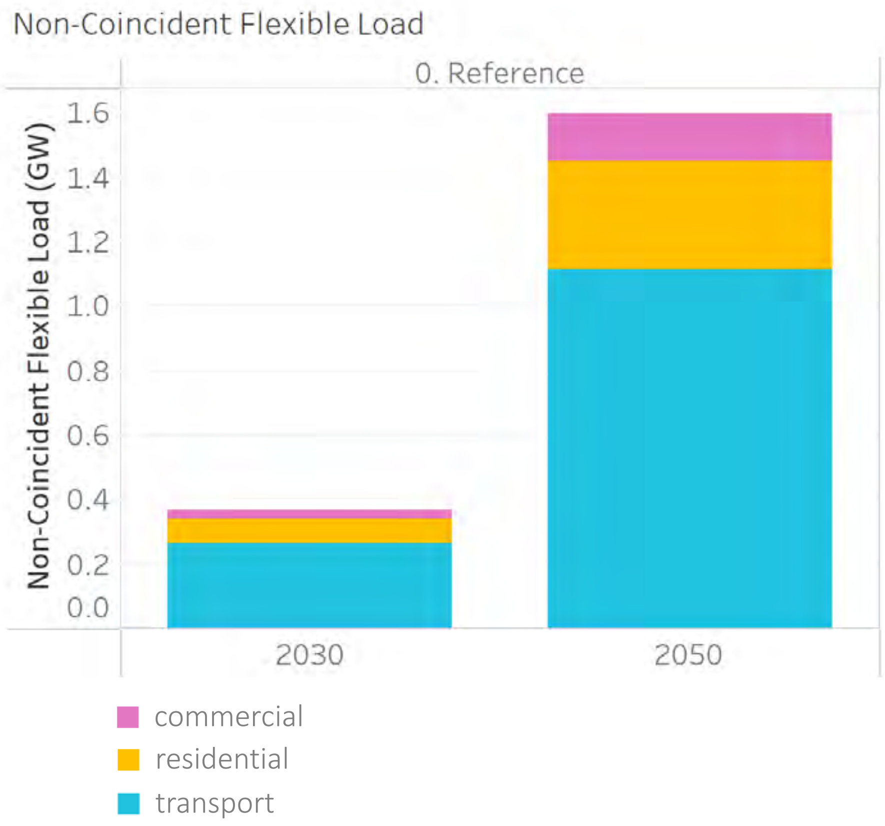


- Electrification of space and hot water heating are the biggest drivers of energy savings
- Other efficiency improvements from weatherization and other equipment (lighting, fridges…)
- Commercial and industrial efficiency improvements further drive down demand

As the Electricity Sector Grows, So Do Opportunities for Consumers

EVOLVED ENERGY RESEARCH

- Demand response programs reduce future capacity and transmission needs
  - Customers with smart thermostats, smart water heaters, battery storage systems and electric vehicles enroll in utility programs to shift loads to off-peak periods
  - Reducing peak demands on the grid displaces the most expensive future energy resources
  - Limiting demand response in the model results in more west side storage
- Rooftop solar reduces land use impacts in eastern Oregon



Delaying Energy Efficiency and Building Electrification Increases Fuels and Electricity Use

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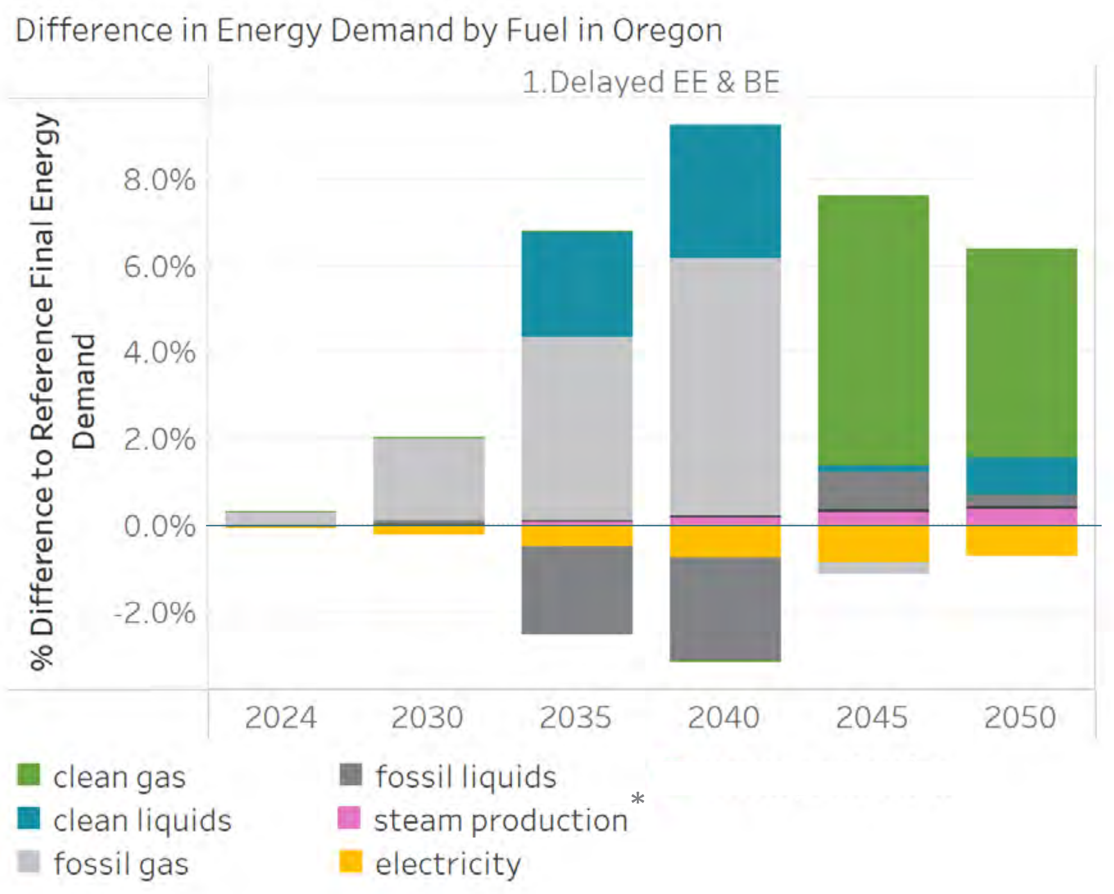
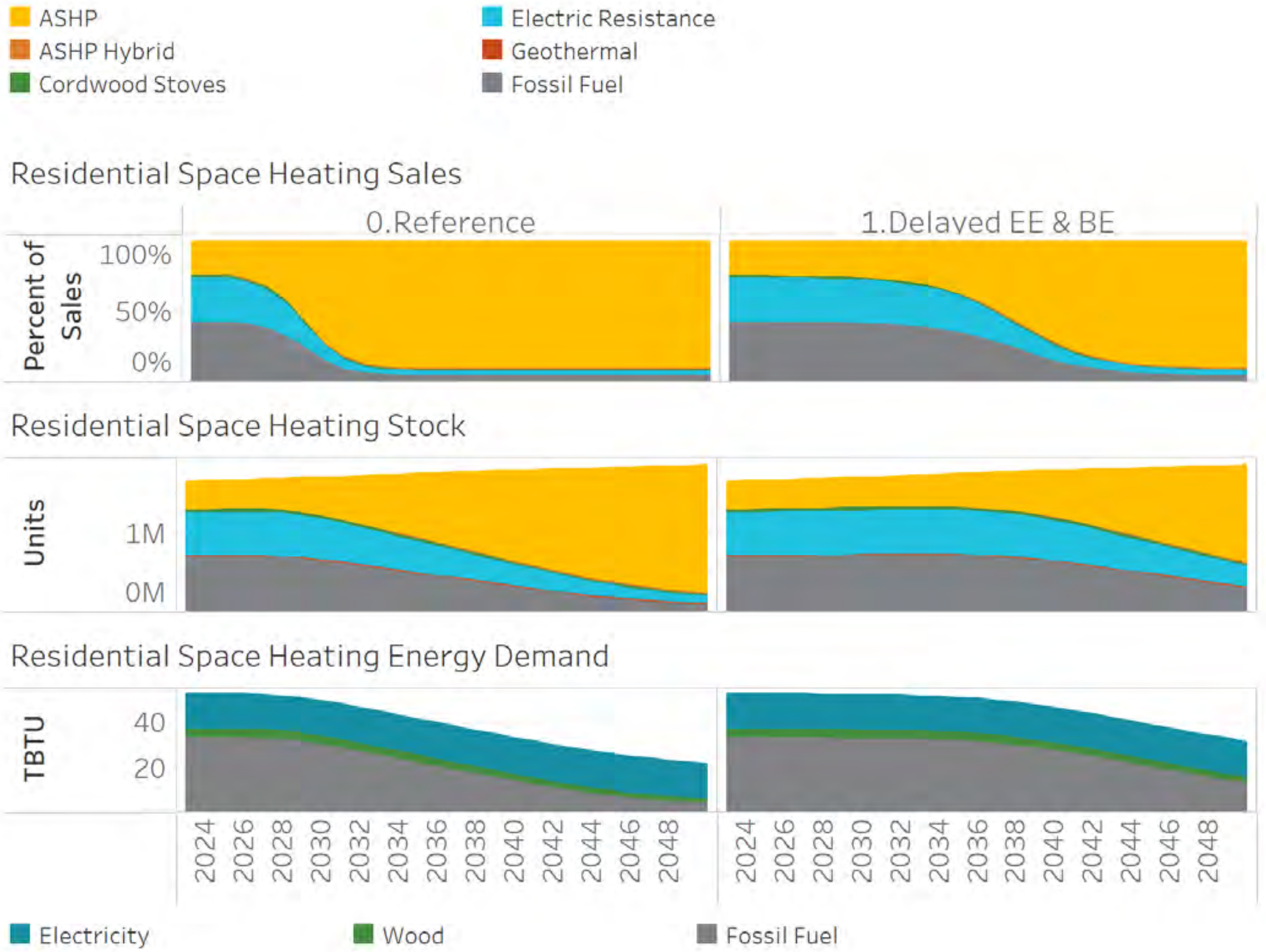
- Increased gas use
- Reduced electricity use
- Total energy demand 2% higher in 2030 and 6% higher in 2050
- Increases cost by $17B net present value
- Transition from fossil to clean may need to happen more gradually than shown



*Steam production is 55% geothermal and 35% biogas by 2050

Reference Scenario
Residential Space Heating

- Fuel switching to electric heat pumps drives down overall energy demand
- 65% air-source heat pump (ASHP) sales by 2030 and 90% ASHP sales by 2040
- Wood burning stoves supplemented with hybrid systems



Reference Scenario
Commercial Space Heating

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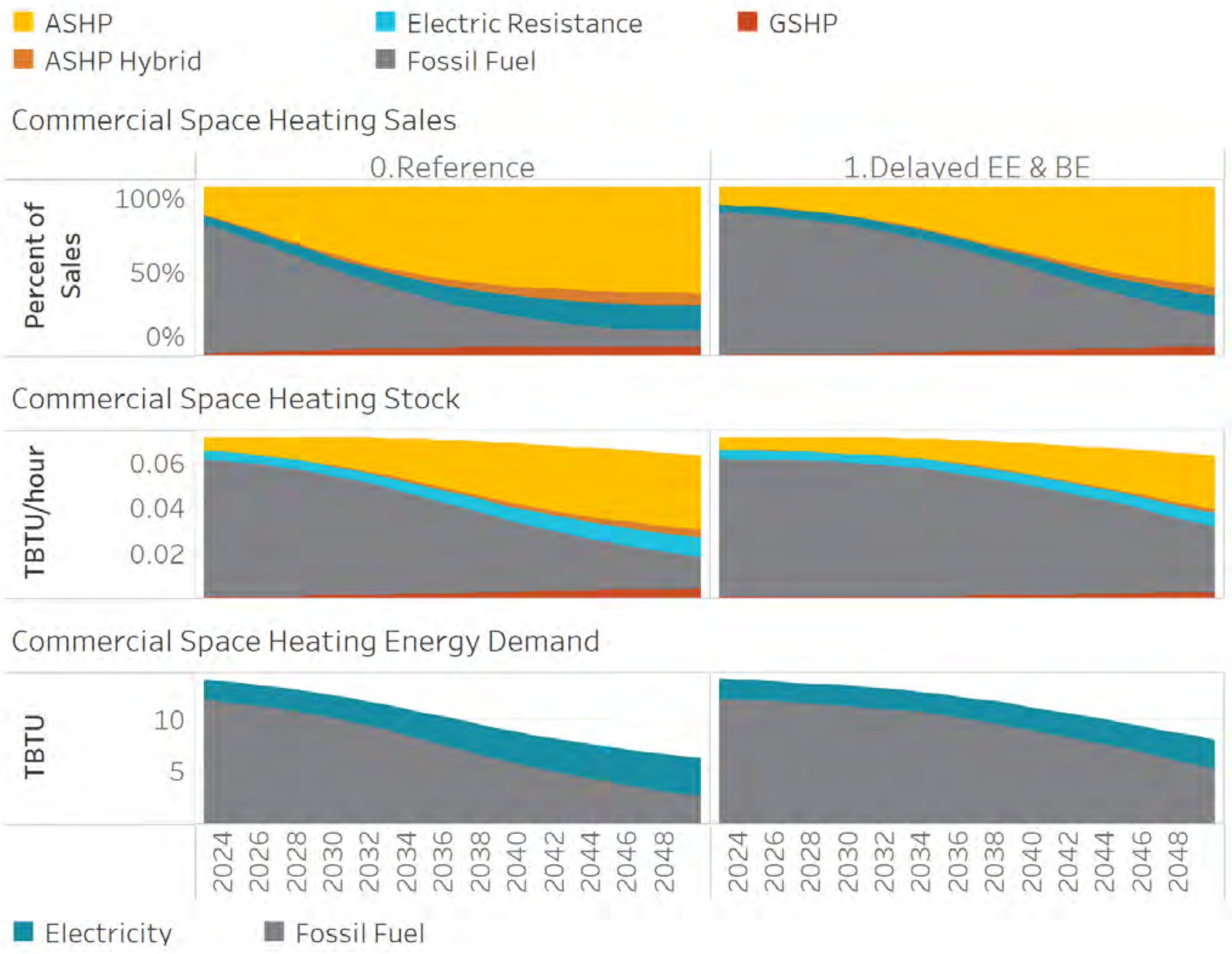
- Small commercial (50% of buildings) use the same assumptions as residential
- Large commercial (50% of buildings):
  - 15% ASHP, 10% electric + hybrid by 2030
  - 50% ASHP, 40% electric + hybrid by 2040
- Electricity demand doubles with 60% reduction in overall energy use by 2050



Impact of Delayed EE & BE on Economy-wide Energy Demand

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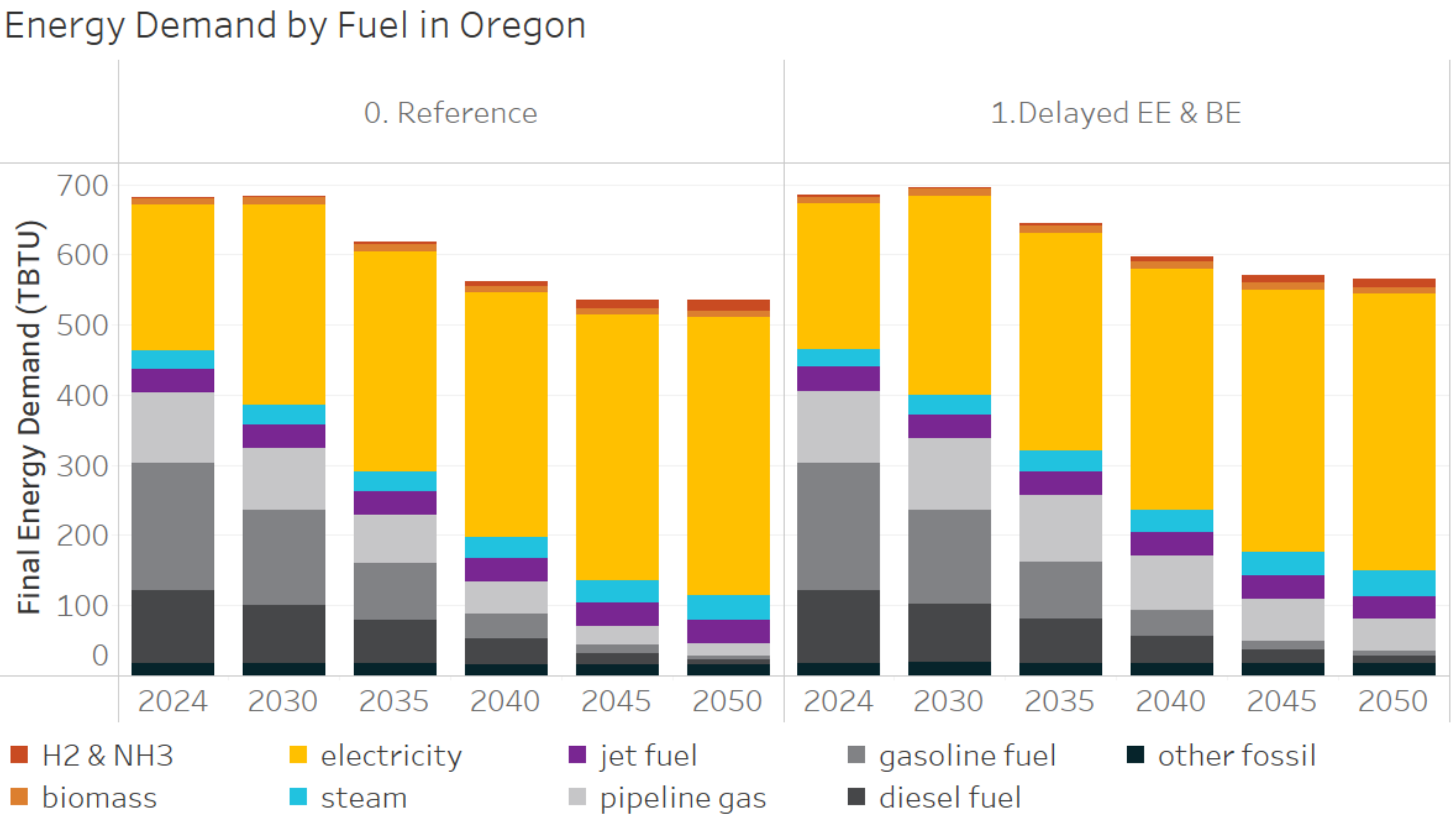
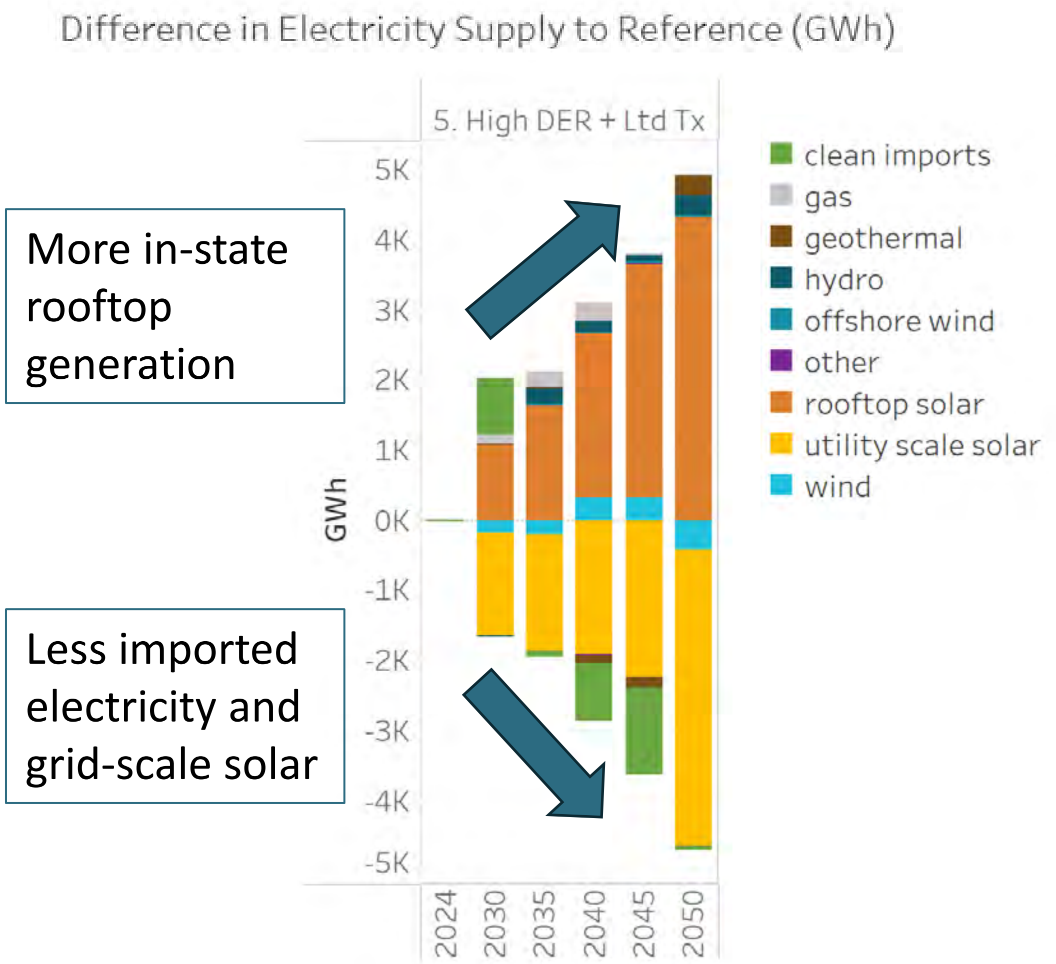
- Delaying energy efficiency and building electrification drives greater demand for pipeline gas in buildings and industry, as well as greater steam demand
- Electric loads are 1% lower by 2050 in Delayed EE & BE but that's not enough to offset the increased energy use in other fuels
- Overall energy demand is 6% higher by 2050 in Delayed EE & BE



Rooftop solar in OR West reduces need for imports and grid-scale solar in OR East

- Rooftop solar additions displace some grid scale solar energy
- Majority of rooftop additions over the Reference Scenario are in Oregon West
- Majority of grid scale solar displaced is in Oregon East
- Rooftop solar also displaces some imported clean energy from other states



Increasing Rooftop Solar Substitutes for Some Grid Scale Solar Builds

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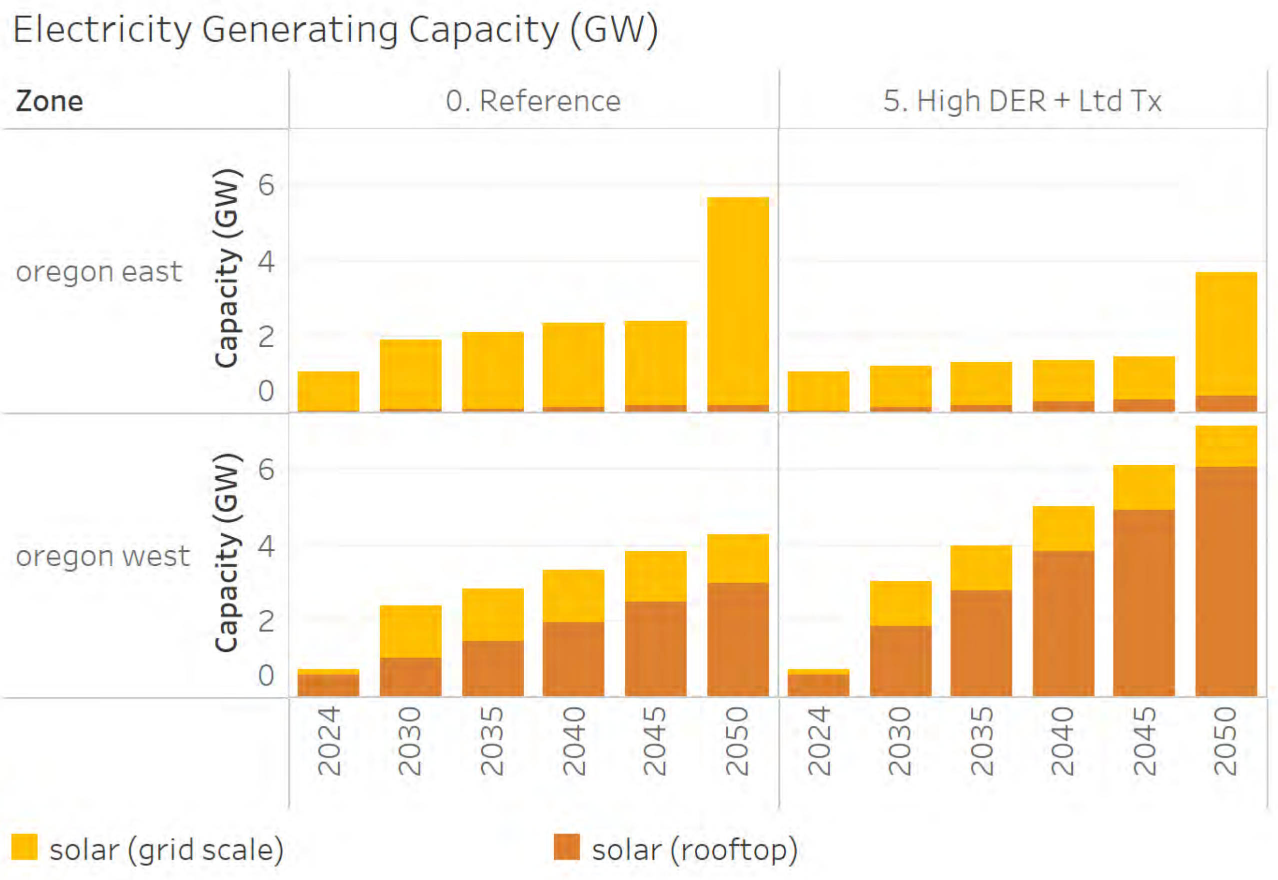
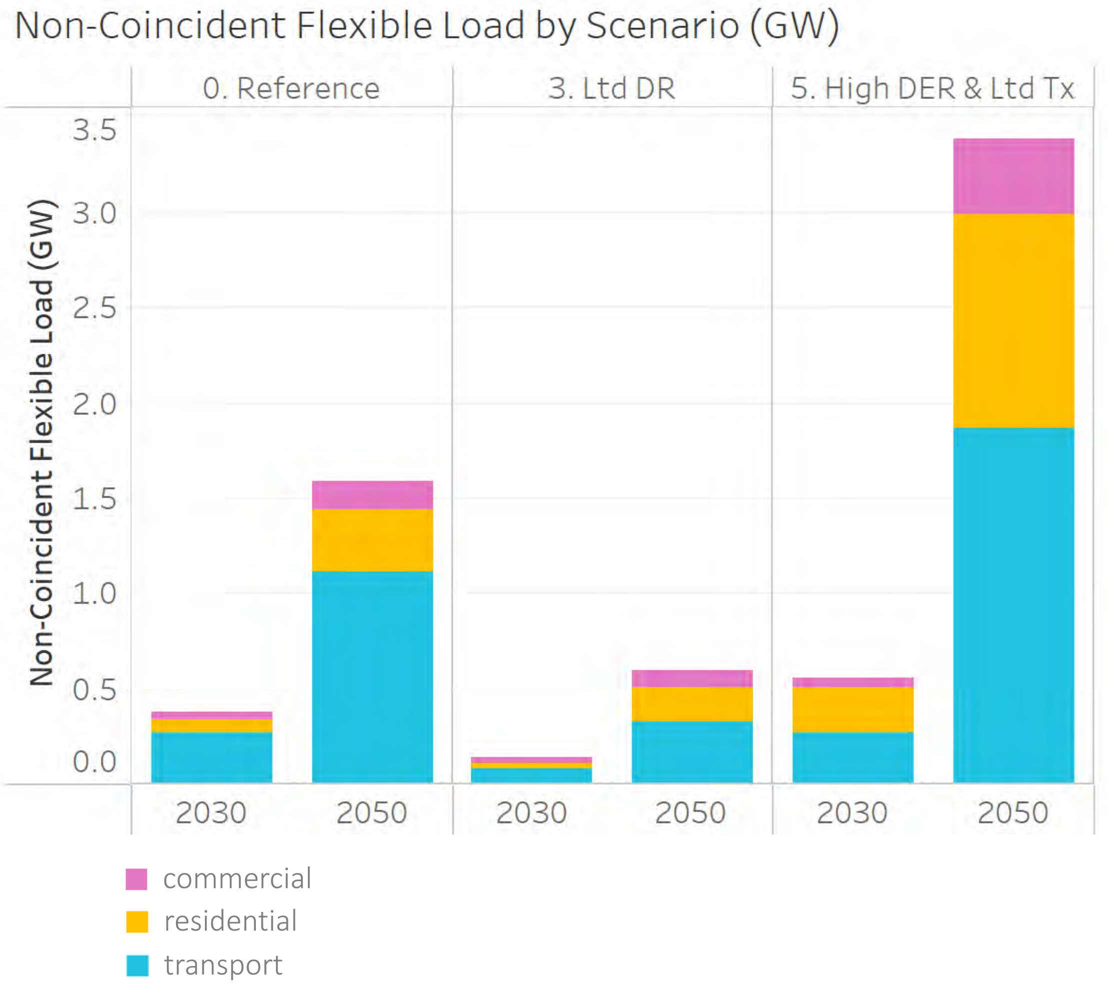
- Increasing rooftop solar to 7 GW across Oregon rather than the 3 GW in the Reference Scenario reduces both the overall need and the pace of grid scale solar build
- May mitigate challenges to siting and permitting large additions of grid scale renewables



Flexible Loads Dependent on Participation in the Future

- The Reference Scenario assumes active participation of customers in demand response programs
  - Residential and commercial buildings contribute to demand response through participating water heating, space heating, and air conditioning systems
- The capacity of flexible load contributions by 2050 will vary based on participation
- Limited participation costs $4B on a cumulative net present value basis over 25 years



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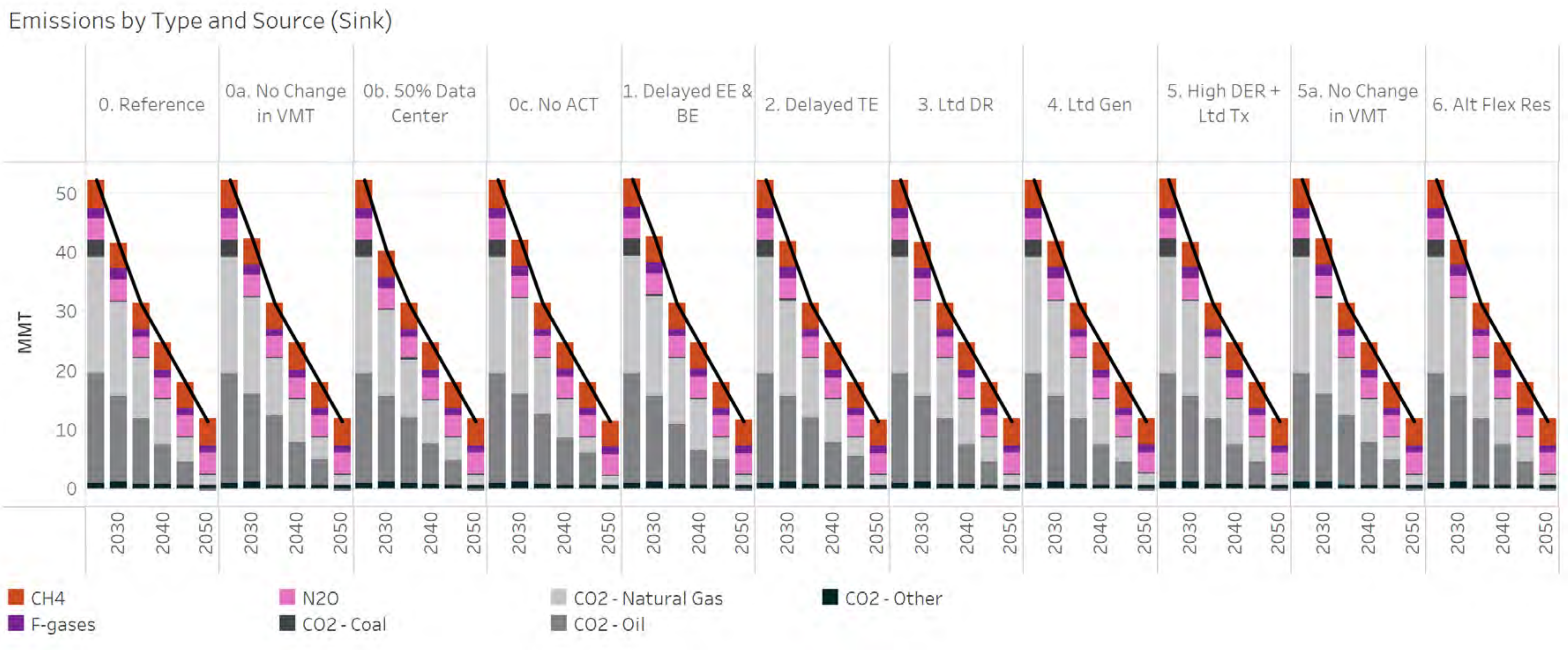
All Results for All Scenarios

Introduction

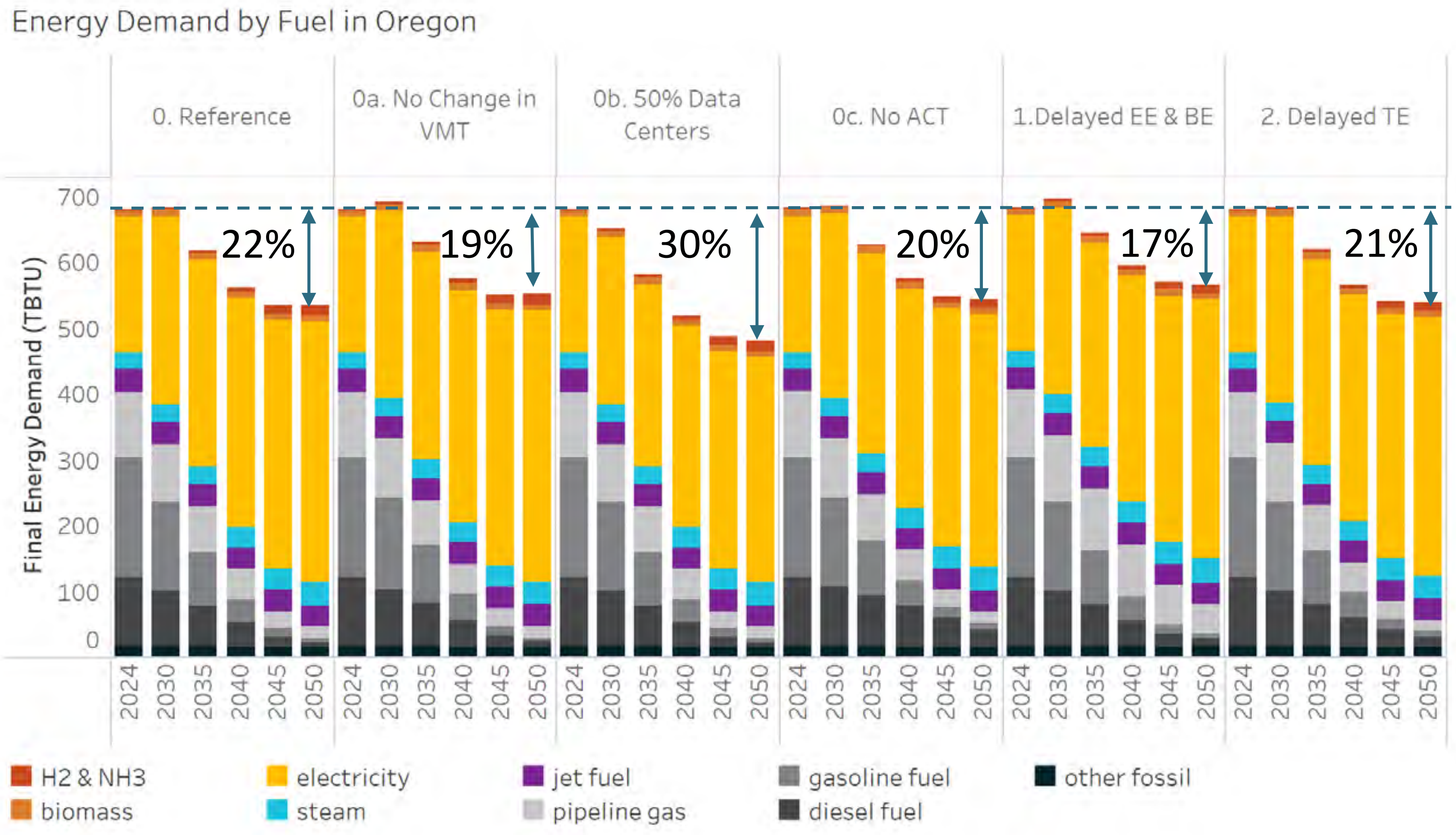
- In the previous sections, we support study findings by comparing results from specific scenarios where showing all scenario results would be challenging visually
- In this section, we show all scenario results side-by-side for the different outputs shown in the previous sections
- This section aligns with the accompanying data library to this report

GHG Emissions Decline for All Scenarios



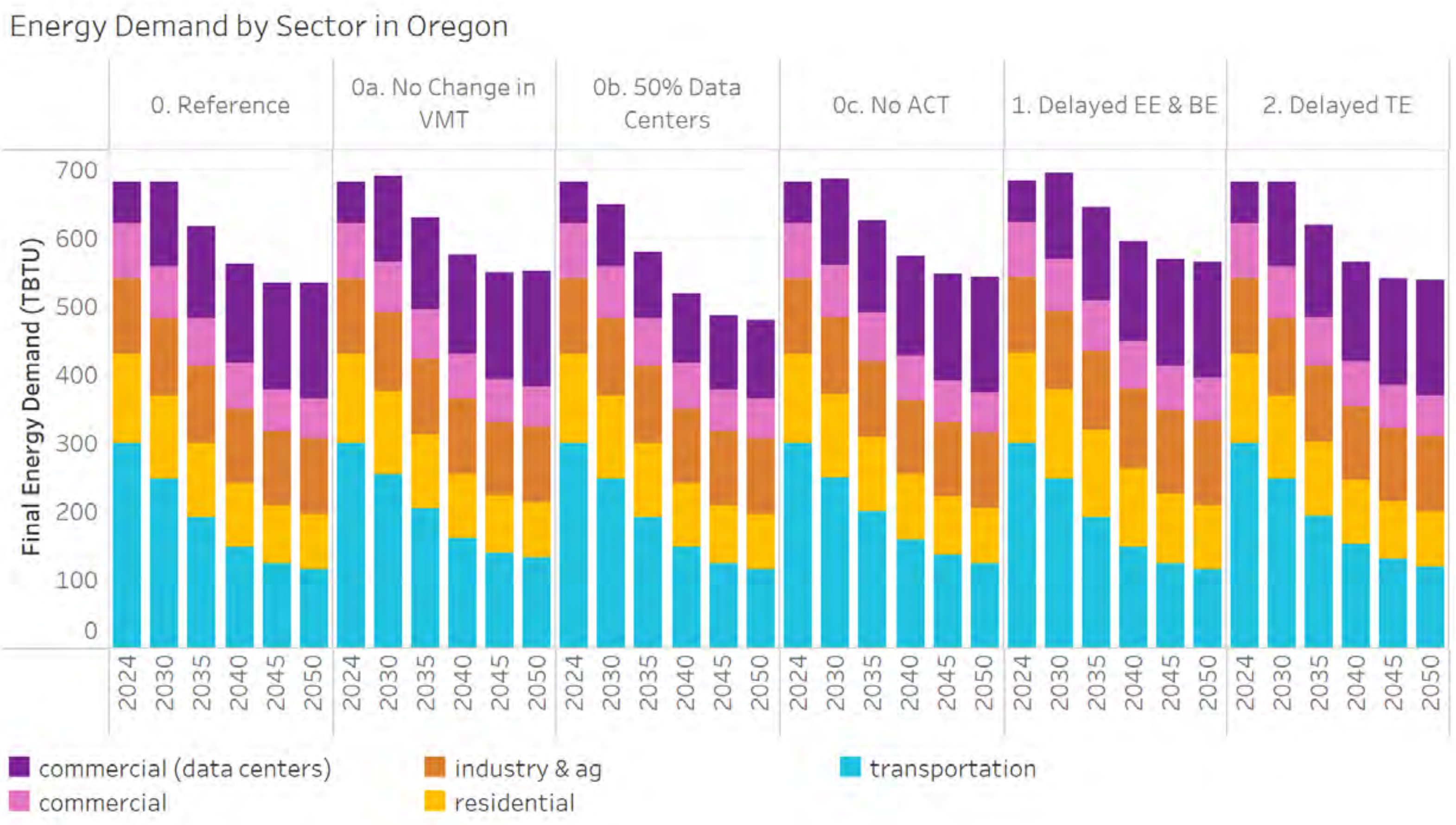
Emissions by Sector Within Oregon for All Scenarios

End Use Energy Demand for All Scenarios



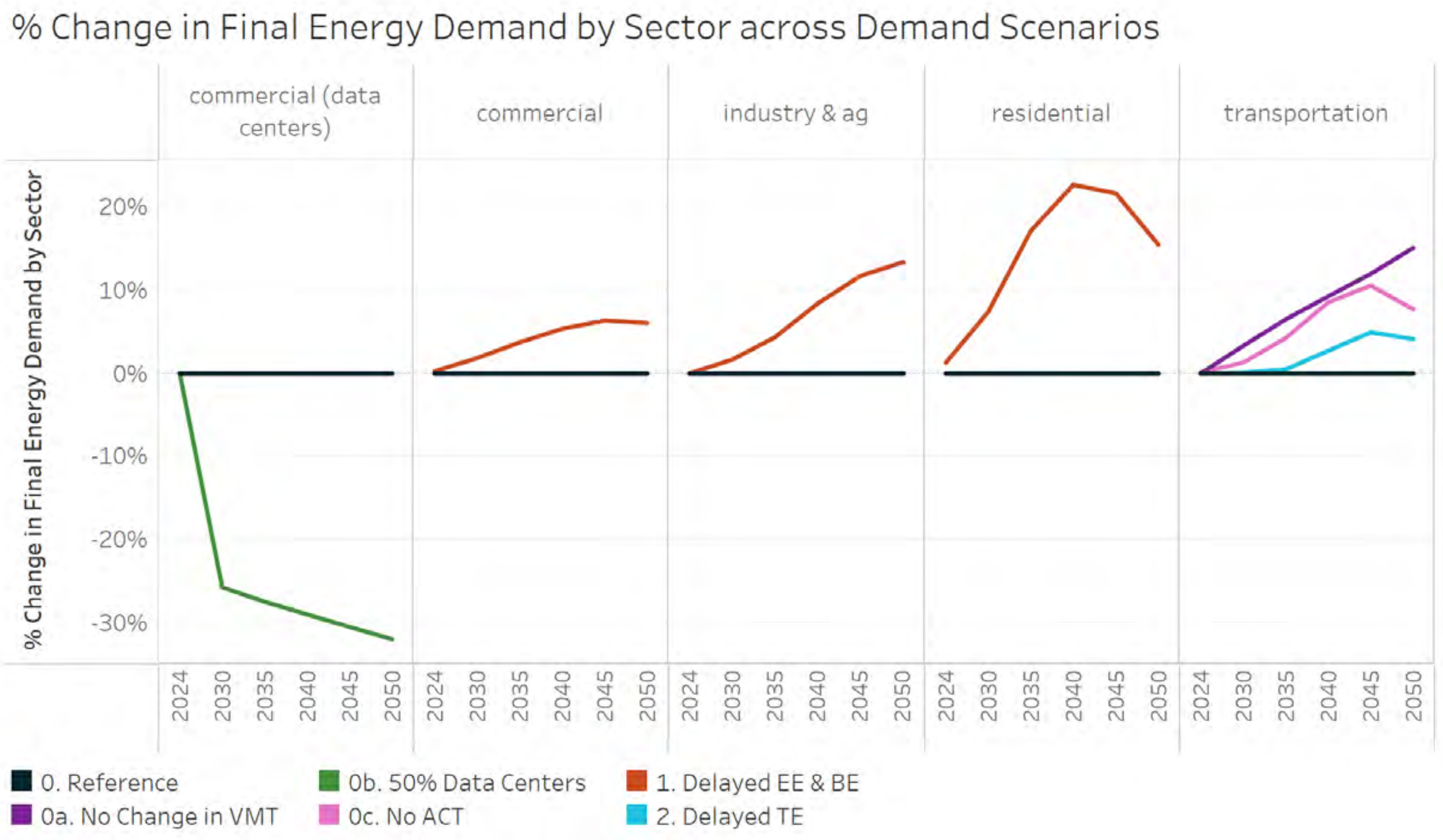
Scenarios **3**, **4**, **5**, and **6** share the same energy demand as **0**; **5a** shares the same demand as **0a**

Energy Demand by Sector for All Scenarios



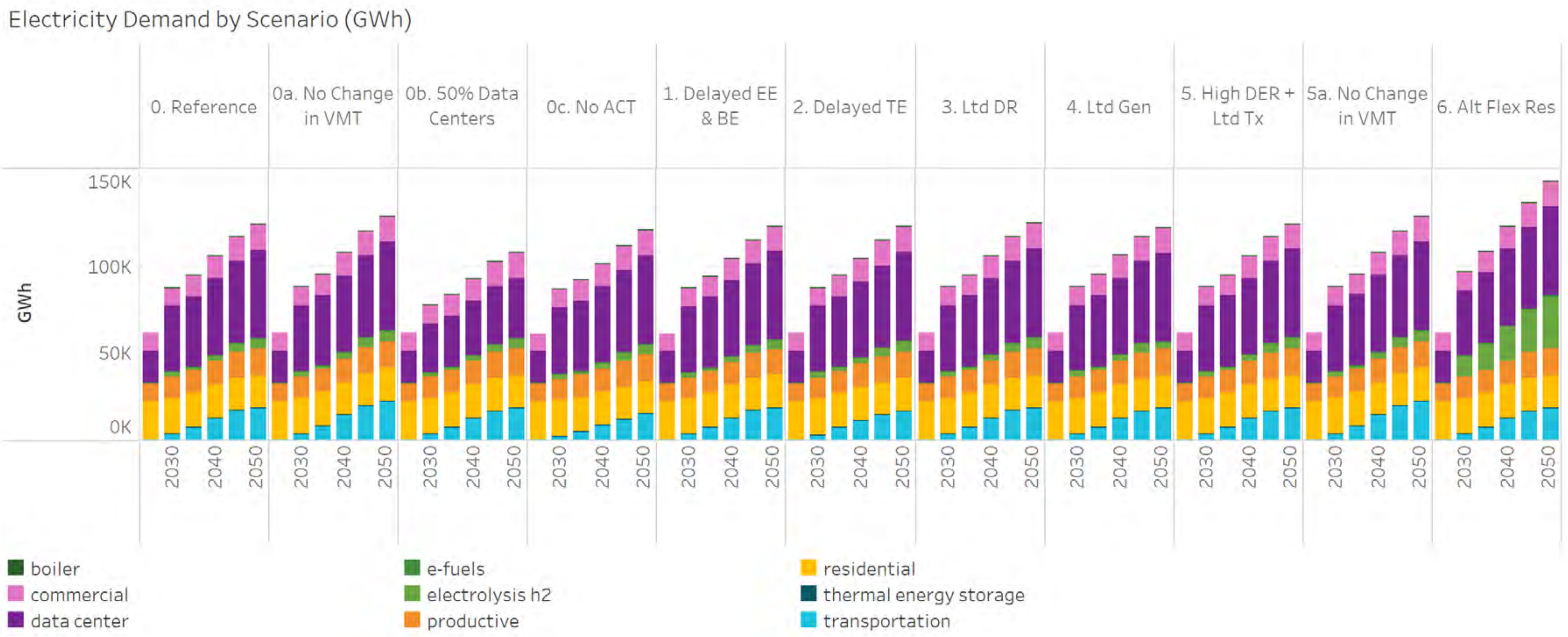
Scenarios **3**, **4**, **5**, and **6** share the same energy demand as **0; 5a** shares the same demand as **0a**

Sectoral Percentage Changes in Energy Demand for All Scenarios



Scenarios **3**, **4**, **5**, and **6** share the same energy demand as **0; 5a** shares the same demand as **0a**

Electricity Demand for All Scenarios



In-State and Imported Electricity for All Scenarios

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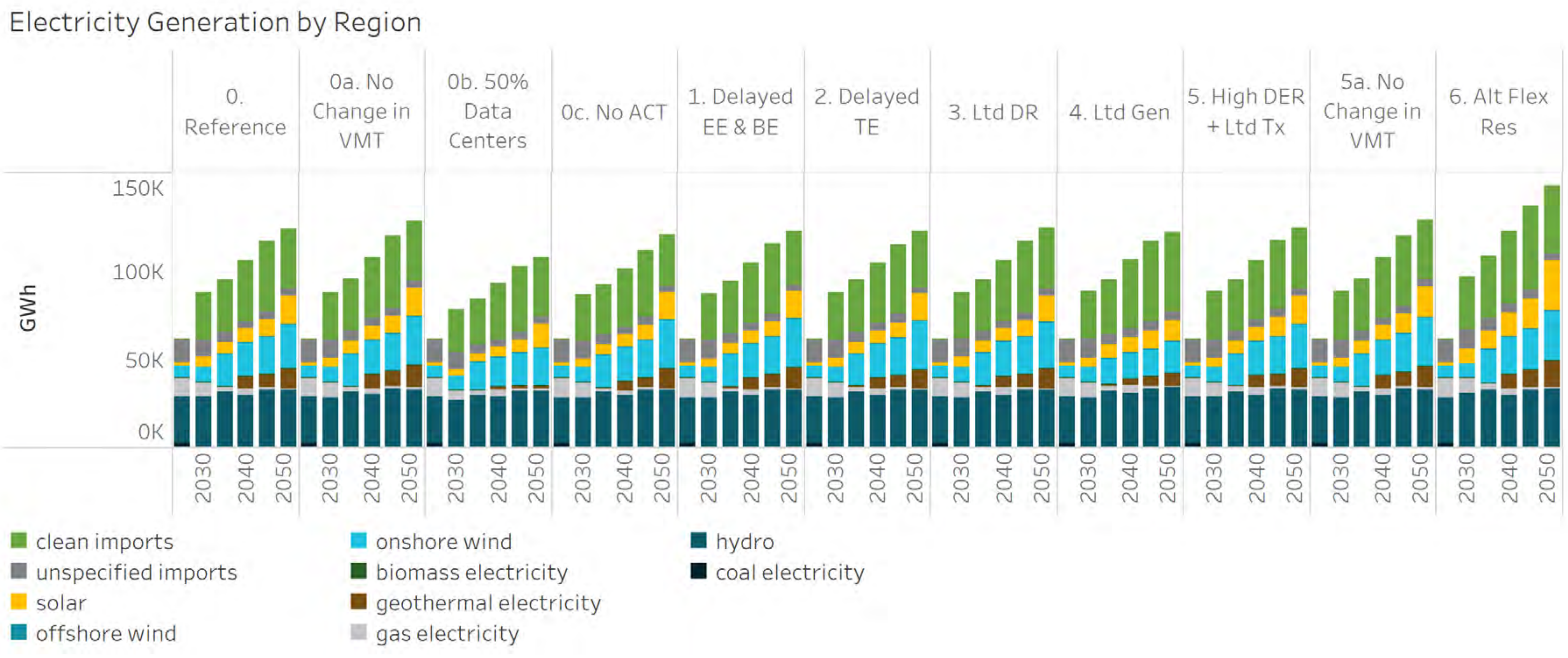

Oregon Installed Capacity for All Scenarios

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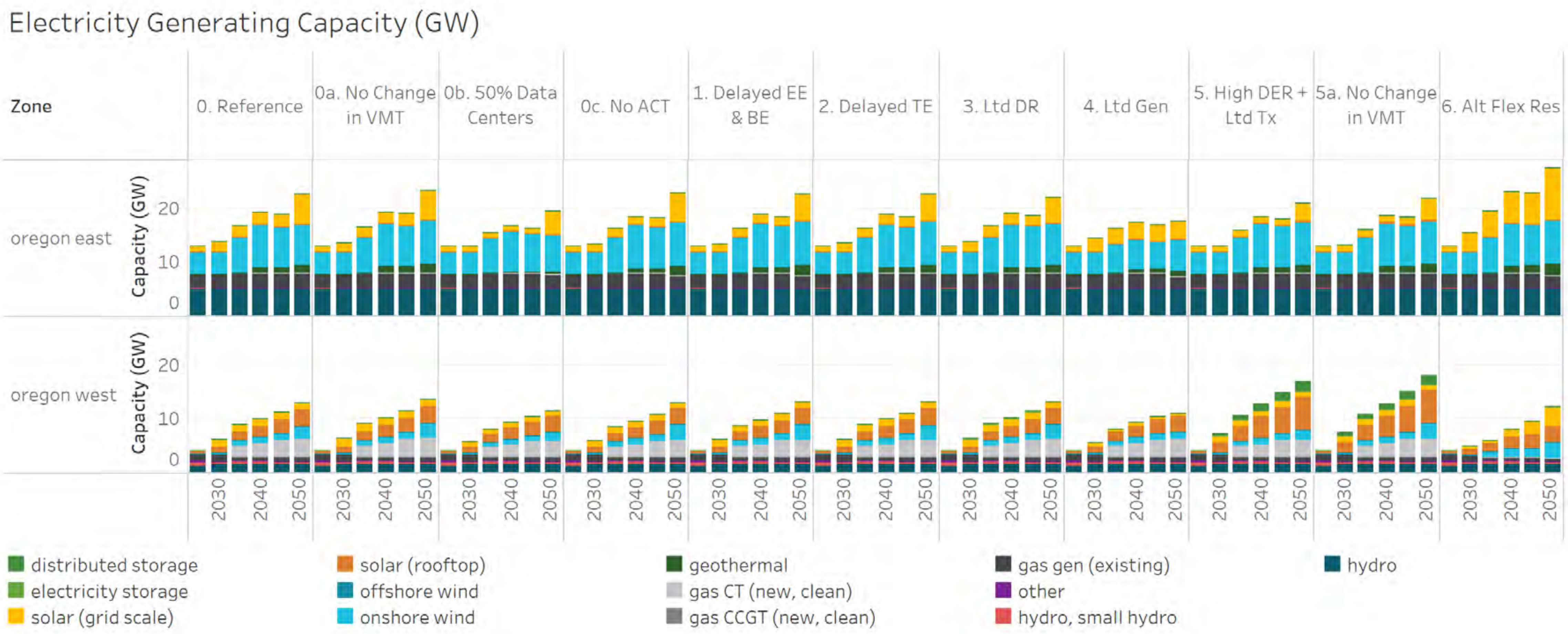
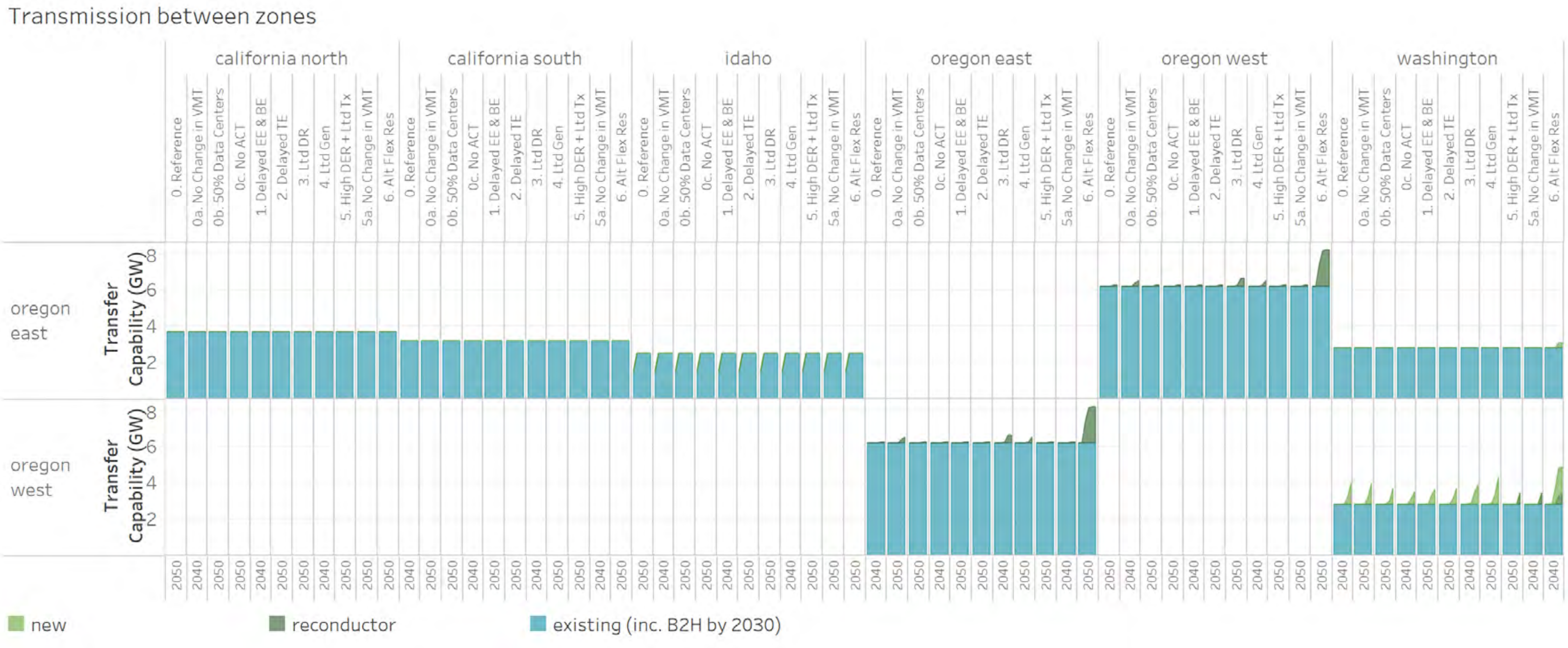
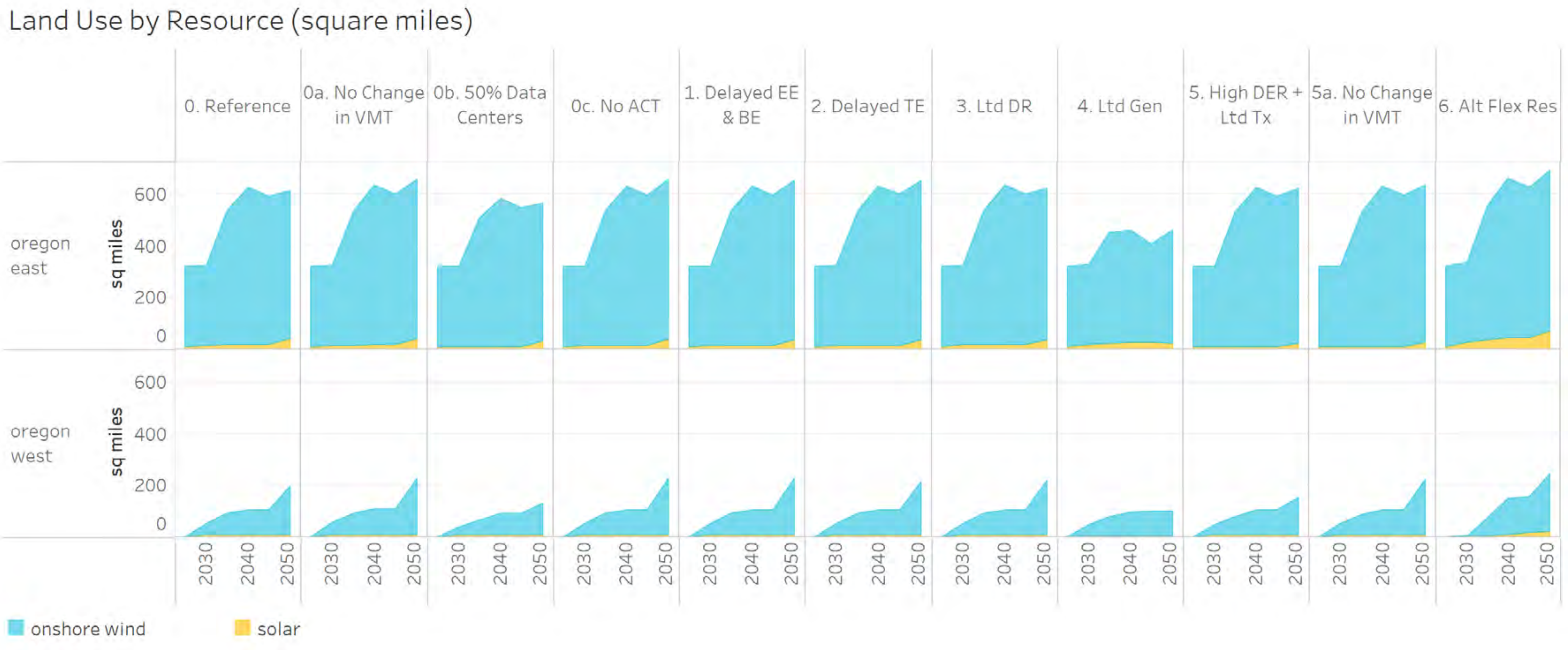


Transmission Between Zones for All Scenarios

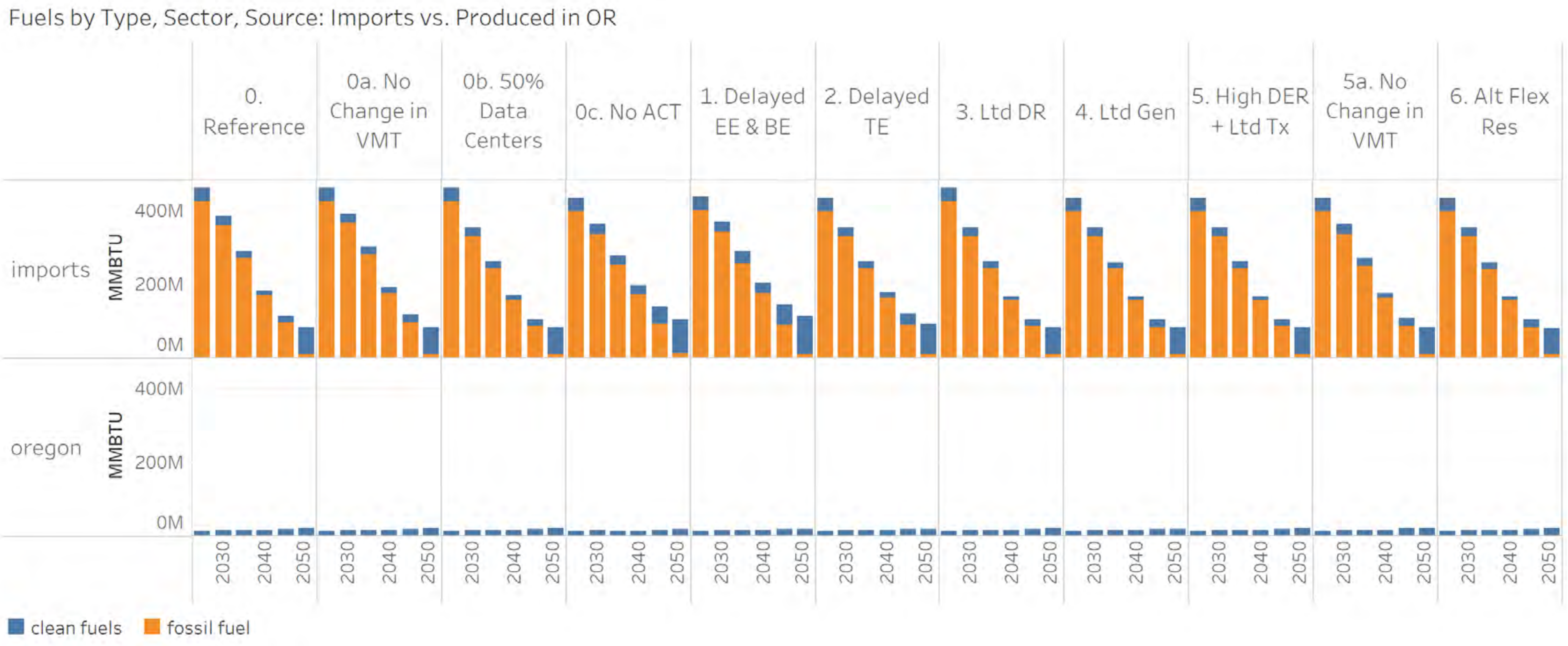


Land Use for Wind and Solar for All Scenarios

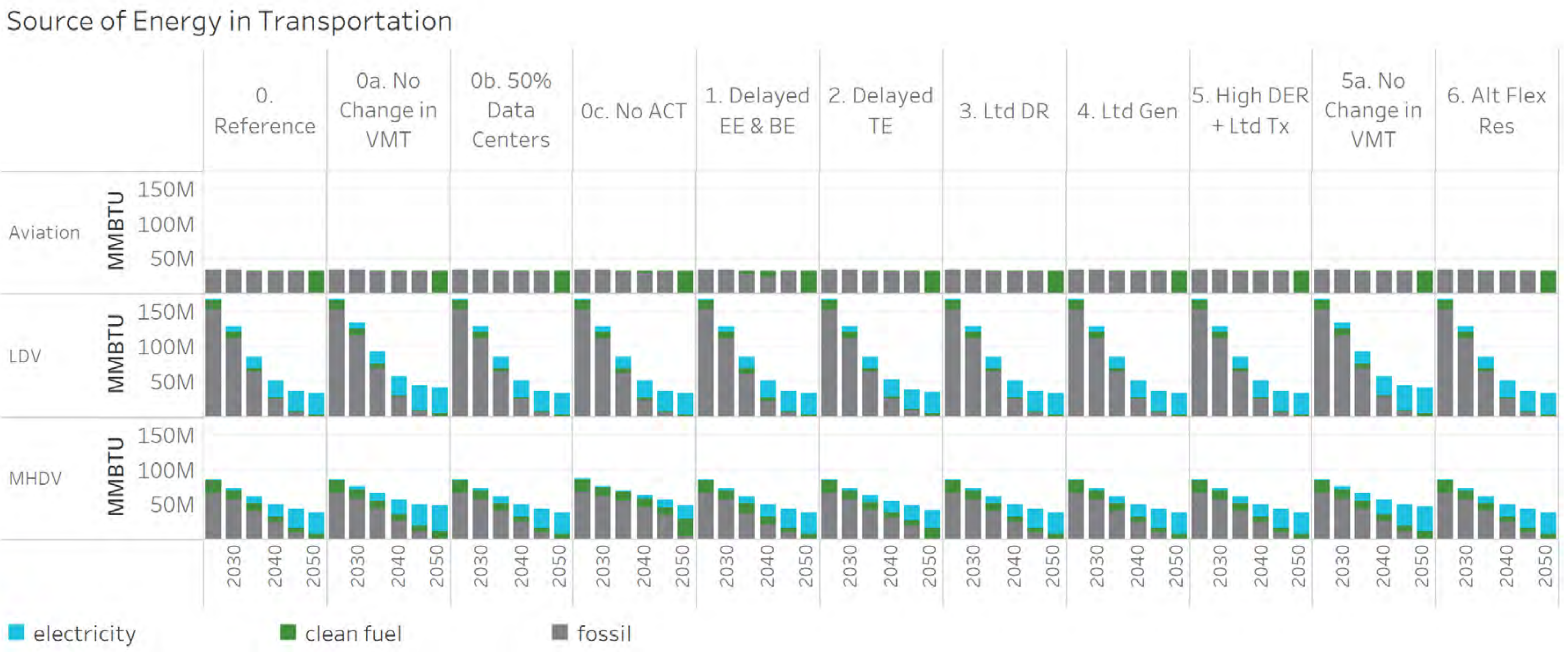


Direct Use Fuels for All Scenarios

Fuels: Imported vs. Produced for All Scenarios



Source of Energy in Transportation for All Scenarios



Fuel Consumption in Oregon for All Scenarios

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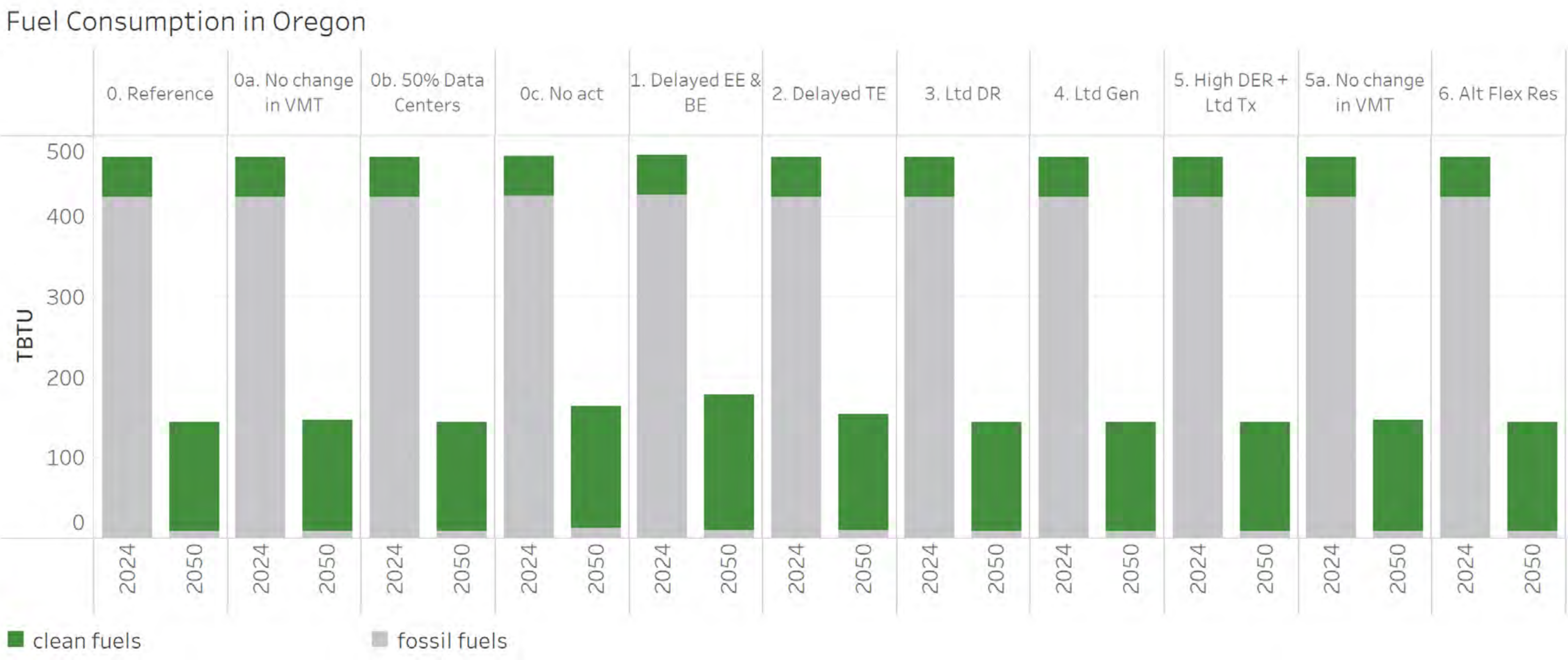

Hydrogen Usage in Oregon, including Production of Fuels for Export, for all Scenarios

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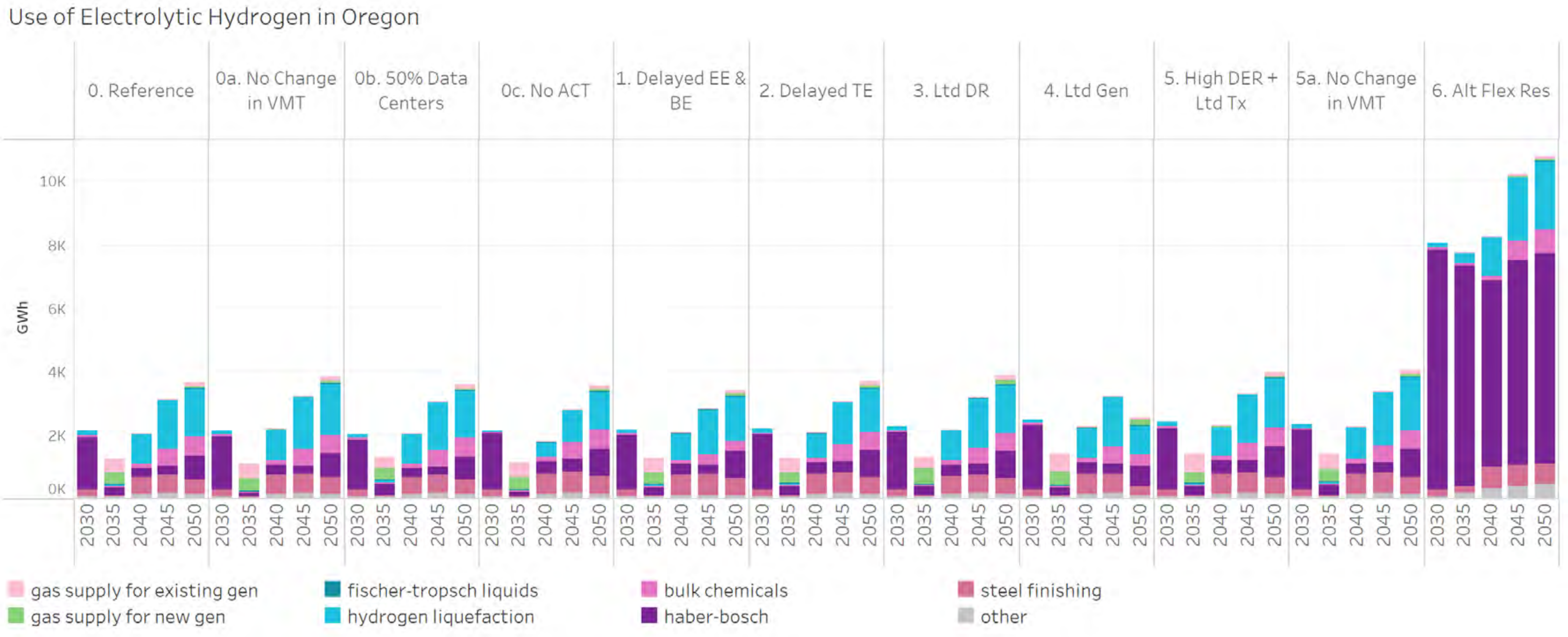
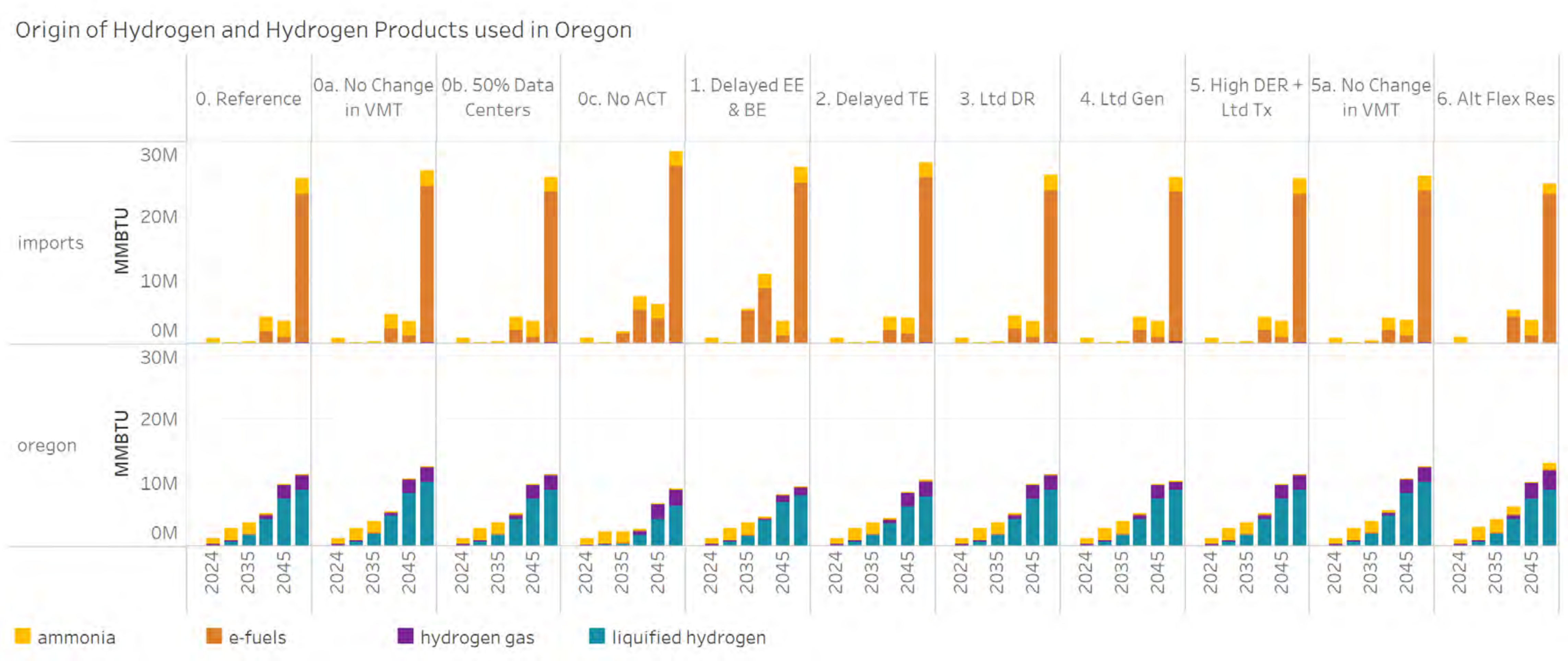


Origin of H2 Products Consumed in Oregon for All Scenarios



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Appendix-Methodology

EVOLVED ENERGY RESEARCH

Modeling Overview

Evolved Energy Research

Past partners

NGOs

NRDC, TNC, SDSN, GridLab, Sierra Club, CETI, OCT, UCS, EDF, CATF, BPC, Audubon Society, Breakthrough Energy Foundation, Third Way, RMI, and others

State & Local Energy Offices

Massachusetts, Maine, Washington, California, New Jersey

Utilities

PGE, DTE, Hydro Quebec, and others

Others

Princeton University, University of Queensland, Breakthrough Energy Ventures, Inter-American Development Bank, DOE, NREL, UVA

What are Energy Pathways Modeling Characteristics?

EVOLVED ENERGY RESEARCH

- Least-cost, energy system optimization that matches Oregon-specific energy supply and demand from now until 2050 (5-yr timesteps) in the context of the 11 Western states:
  - Considers the whole energy sector and economy and all forms of energy
  - Structured to meet Oregon's energy policy objectives
  - Grounded in ensuring reliability and looking for least-cost solutions
  - All emissions counted and modeled to be reduced over time to achieve GHG emissions targets
  - Integrated and holistic, indicates future energy supply across a specific geographic area
  - Includes supply and demand of all forms of energy, not just electricity sector
  - Uses publicly available datasets, including national resources, and Oregon specific data collected through meetings with stakeholders including utilities and the NWPCC

What Energy Pathways Modeling Does

EVOLVED ENERGY RESEARCH

- Calculates energy needed to power an economy while meeting policy targets
- Finds least-cost ways to provide needed energy with efficiency, clean electricity, electrification, clean fuels, and carbon sequestration
- Includes detailed electricity sector modeling integrated with optimized fuels supply for an economy-wide perspective
- Does not answer all questions, but provides direction and a framework to understand trade-offs between different pathways, policies, and strategies

What Energy Pathways Modeling Doesn’t Do

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- Not focused on one state or a single utility service territory in isolation
- Does not model liquid or gaseous fuels and electrification separately
- Complementary to and does not replace integrated resource planning models that utilities use
  - Not a loss-of-load probability model
  - Not a nodal production simulation
- Not a forecast
  - Helps inform near-term decision-making in the face of uncertainty
  - Determine the best way forward across multiple potential futures
  - Examines different scenarios to inform near-term decisions in the context of future goals

Overview of Modeling Approach

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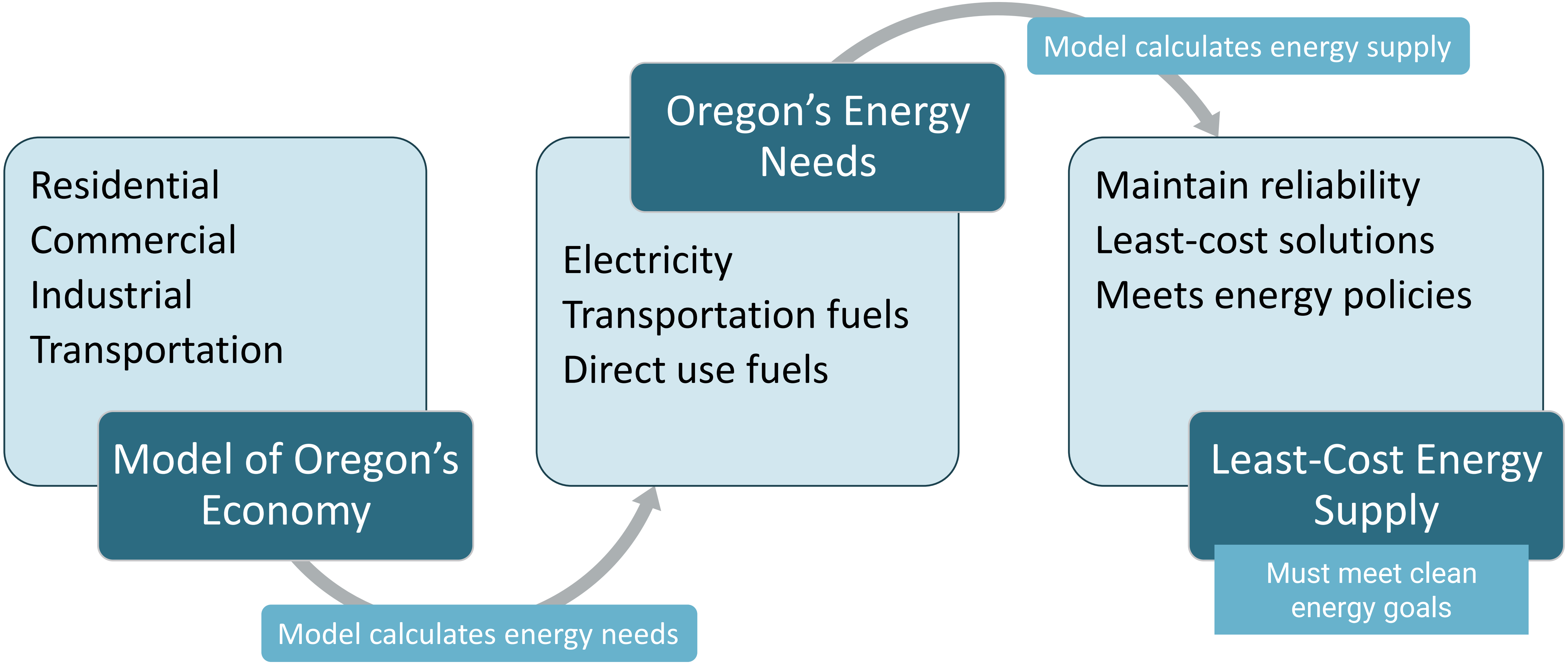

Modeling Summary (EnergyPATHWAYS and RIO)

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ENERGY PATHWAYS

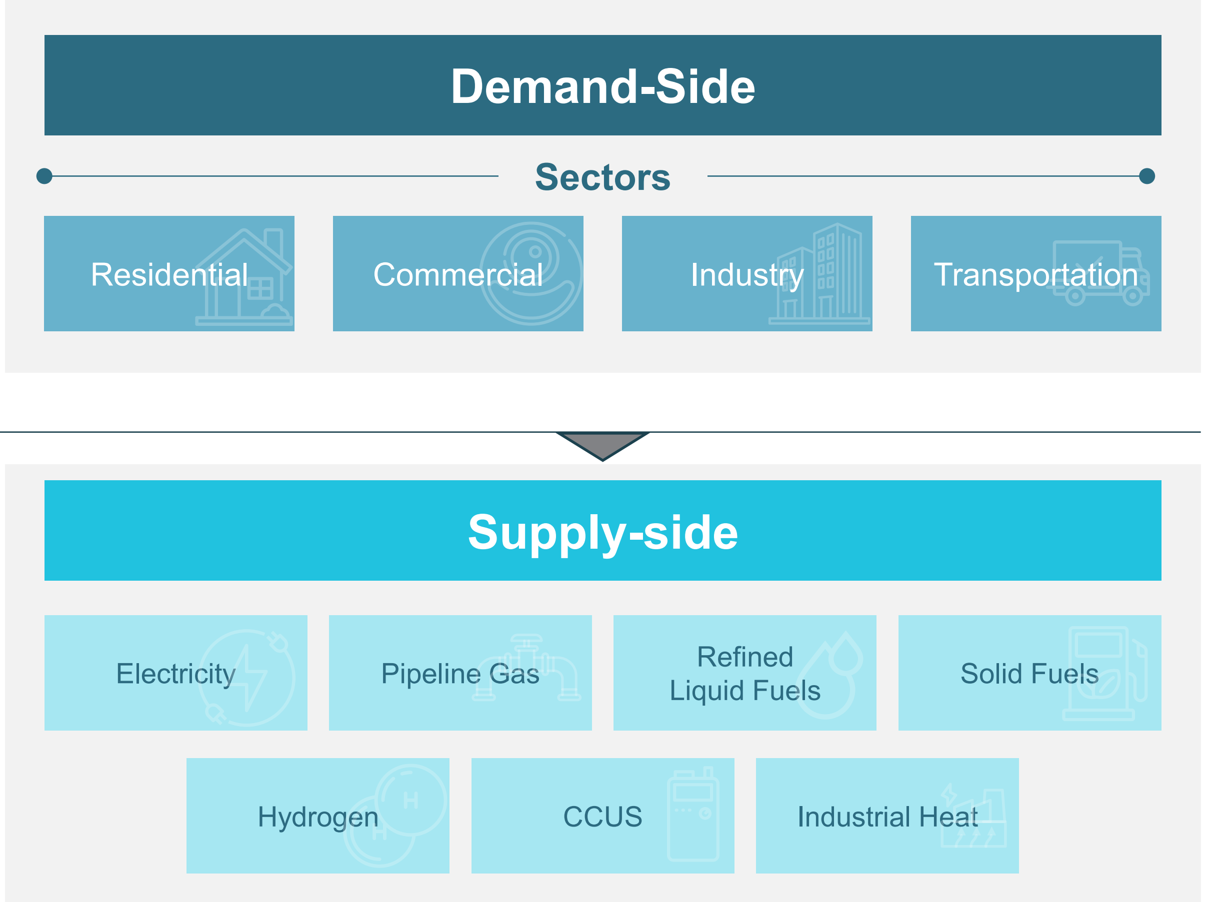
EnergyPATHWAYS model used to develop demand-side cases

- Apply fuel switching and energy efficiency levers
- Strategies vary by end-use (residential space heating to heavy-duty trucks)

RIO

Regional Investment and Operations (RIO)

- Model provides cost-optimal energy supply combining a comprehensive supply-side capacity expansion framework with hourly system operations



Economy-Wide Energy Modeling

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Scenario Assumptions

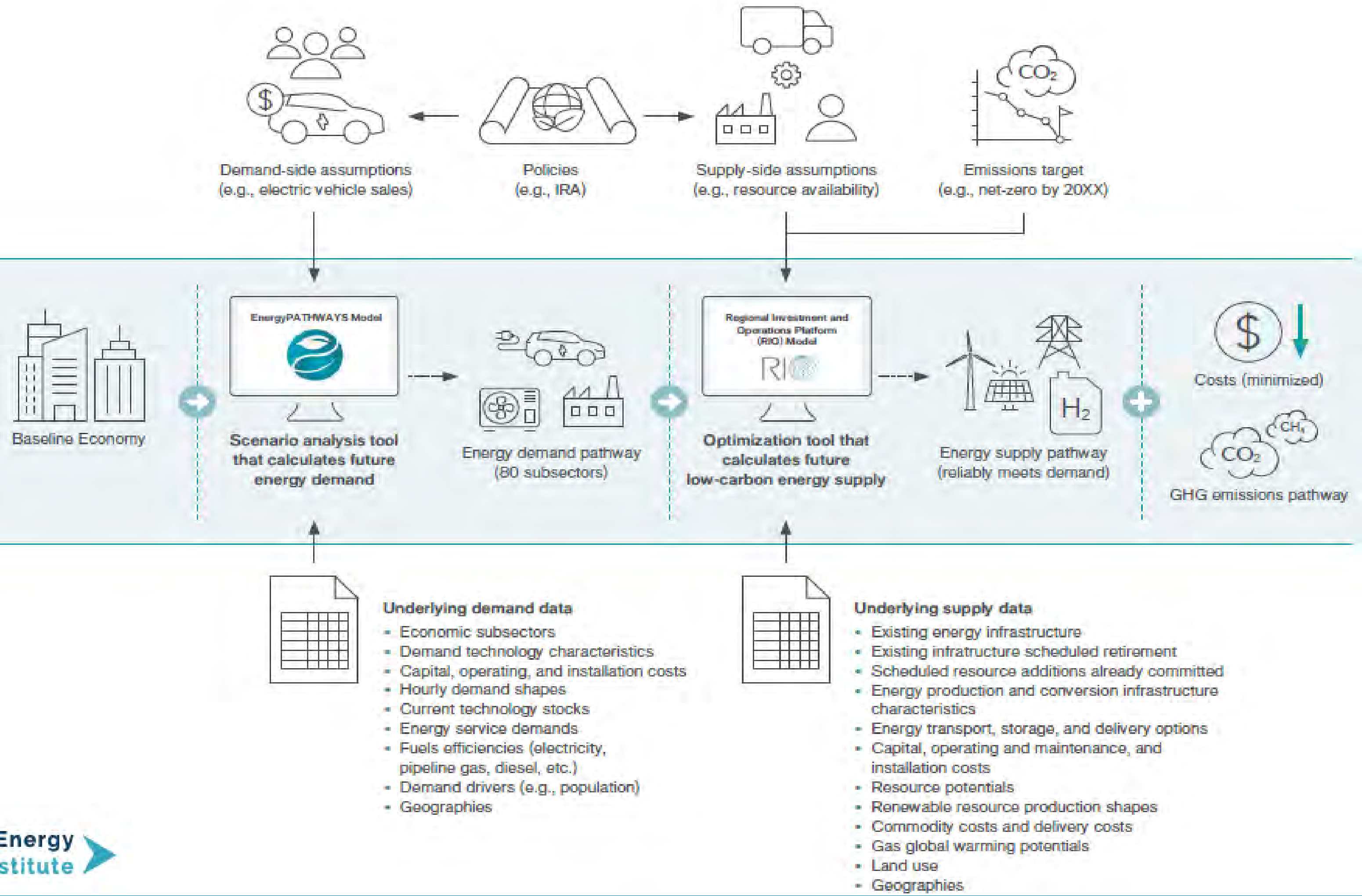
Model incorporates assumptions about demand-side uses, clean energy policies and incentives, and supply-side resources.

Energy Modeling

Evolved Energy Research uses two models to calculate the least-cost way to provide energy under an emission target: Energy Pathways for demand and RIO for supply.

Best Available Data

Model incorporates relevant and up-to-date energy data from reputable sources, substituted with local data where possible.



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Clean Energy Transition Institute

End-Use Sectors Modeled

- Approximately 81 demand sub-sectors represented
- The major energy consuming sub-sectors are listed below:

Key energy-consuming subsectors:

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

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

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

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

Source: CETI, NWDDP, 2019

Review of Existing Information and Plans - Overview and Examples

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- Reviewed Oregon energy policies and documented how modeling accounts for them:
  - HB 3630; HB 2021; SB 1547 (2016); relevant rulemakings; the Department of Environmental Quality's (DEQ) CFP rules; Executive Order 20-04; DEQ's CPP rulemaking; the "Climate Package" from the 2023 Legislative Session; other policy documents identified by ODOE and partners
- Reviewed recent relevant work to identify potential data for incorporation:
  - ODOE: 2022 Biennial Energy Report; 2023 Biennial Zero Emission Vehicle Report; 2023 Cooling Needs Study; 2022 Small-Scale Renewable Energy Projects Study; 2021 Regional Transmission Organization Study; 2022 Floating Offshore Wind Study; and the 2024 Oregon Energy Security Plan
  - Recent reports from the Oregon Climate Action Commission, including the Oregon Climate Action Roadmap to 2030
  - Recent utility IRPs
- Reviewed for regional perspective:
  - Northwest Power and Conservation Council's 2021 Northwest Power Plan, while following key developments as the Council develops the next plan; the Pacific Northwest Utilities Conference Committee's 2023 Northwest Regional Forecast; The Nature Conservancy's Power of Place-West; and the Columbia River Inter-Tribal Fish Commission Energy Vision for the Columbia River Basin
- Reviewed program design elements:
  - Western Resource Adequacy Program (WRAP), CAISO's Extended Day-Ahead Market (EDAM) and Western Energy Imbalance Market (WEIM), and SPP's Markets+ and Western Energy Imbalance Service (WEIS)
  - Regional transmission planning efforts, including the Western Transmission Expansion Coalition (WestTEC).

Forecasting vs. Backcasting

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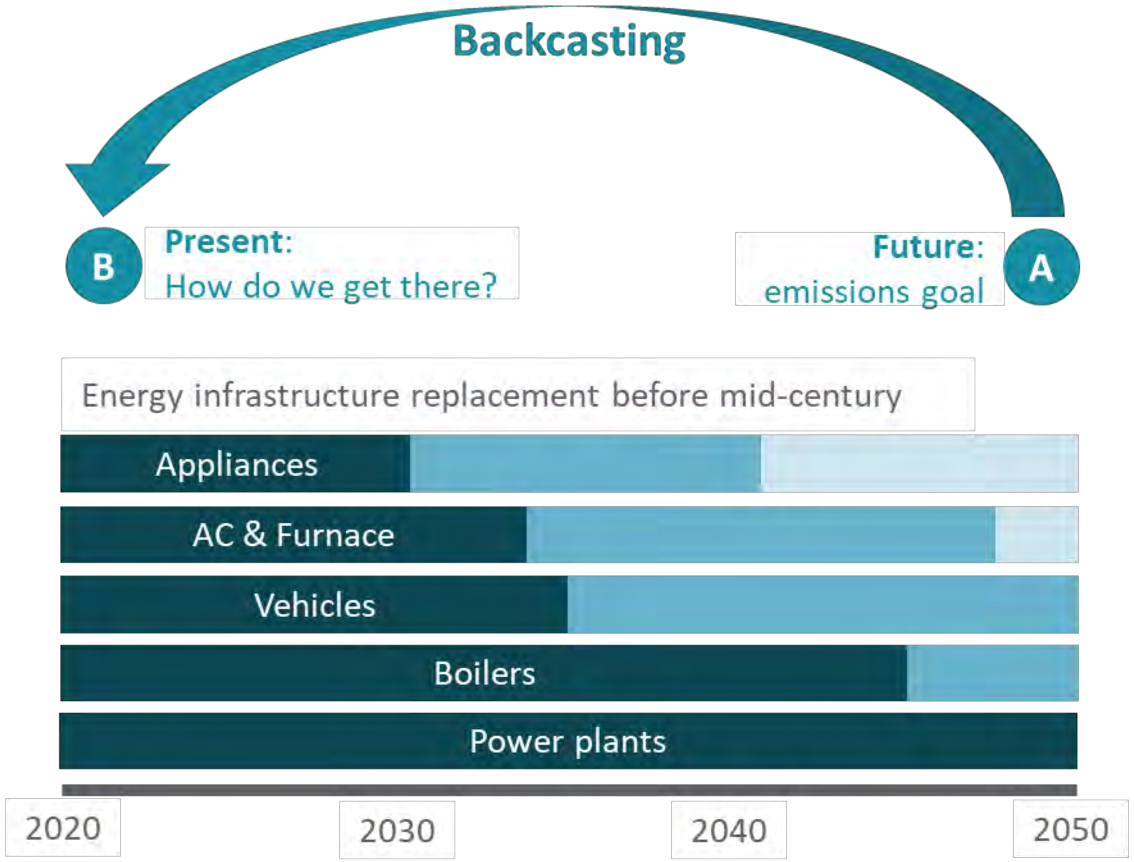
- **Forecasting**: project changes based on expected customer behavior given incentives/technology
  - e.g., result of current policy
- **Backcasting**: start with an end-point and work backwards to infer customer adoption over time
  - What is the best path to be on?
  - Target for future policymaking: Where is current policy falling short?
  - All options available in the long term



Reference Scenario Database Development with Oregon-Specific Data

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- Oregon-specific data collected from up-to-date Oregon datasets, past studies, and consultations
  - Transportation Data (ODOT, EPA MOVES)
  - Building Data (NEEA RBSA & CBSA, EIA RECS & CBECS)
  - EIA State Energy Data System (SEDS)
  - Oregon DEQ GHG Emissions Inventory
  - Planned resource investments
  - Data center and crypto forecast data
  - PSU Population Research Center
- Review of Oregon resources and input from ODOE and data holders in identifying available datasets

Supply-side Overview

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

Understanding Modeled Costs (1)

EVOLVED ENERGY RESEARCH

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

Understanding Modeled Costs (2)

EVOLVED ENERGY RESEARCH

- Cost increases and decreases are all attributed to changes in policy or realized uncertainties within Oregon
  - Assumptions in all other states are held constant
- Cost changes can therefore be attributed in their entirety to Oregon specific changes in assumptions
  - Some of the investments caused by Oregon policy changes may happen outside of Oregon. For example, restricting renewable development in state can drive more renewable growth outside of Oregon
  - These costs would be born by Oregon in the form of increased electricity costs through increased imports and changes to overall infrastructure investment
- Assuming efficient markets, the change in cost between scenarios would all be born by Oregon consumers
- Present value costs are calculated using a 3% societal discount rate

Technical Approach

Demand-side Modeling

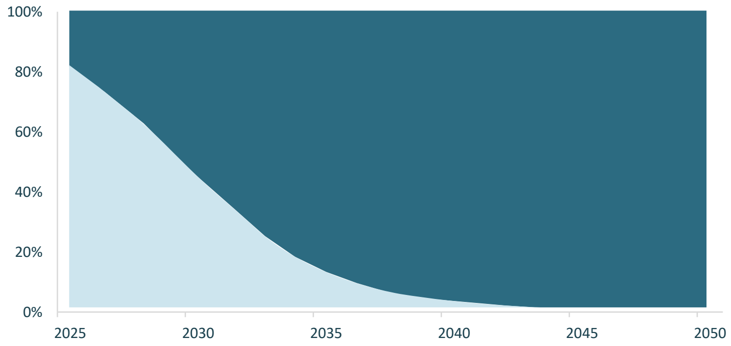
- Scenario-based, bottom-up energy model (not optimization-based)
- Simulates the change in total energy demand and load shape for every end-use
- Characterizes rollover of stock over time
- Illustration of model inputs and outputs for light-duty vehicles

Input: Consumer Adoption
EV sales are 100% of consumer adoption by 2045 and thereafter

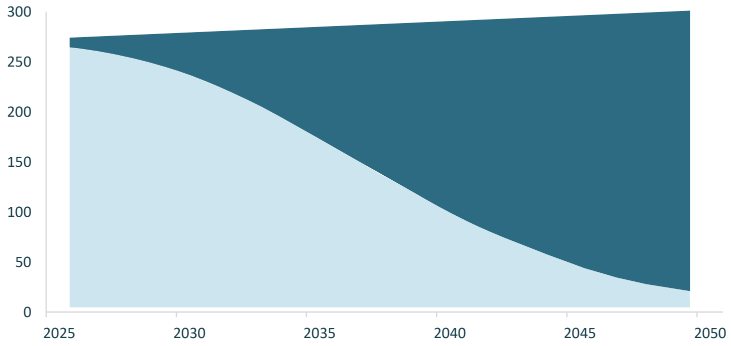
Output: Vehicle Stock
Stocks turn-over as vehicles age and retire

Output: Energy Demand
EV drive-train efficiency results in a drop in final-energy demand

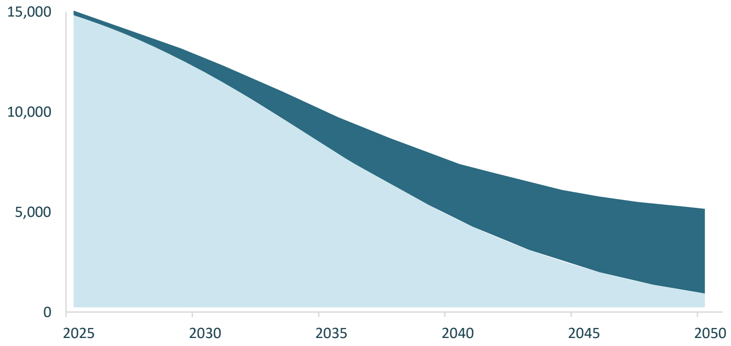
Sales Share
%



Stock
Vehicles on the road



Energy Demand
TBtu



Economy-Wide Optimization Scope

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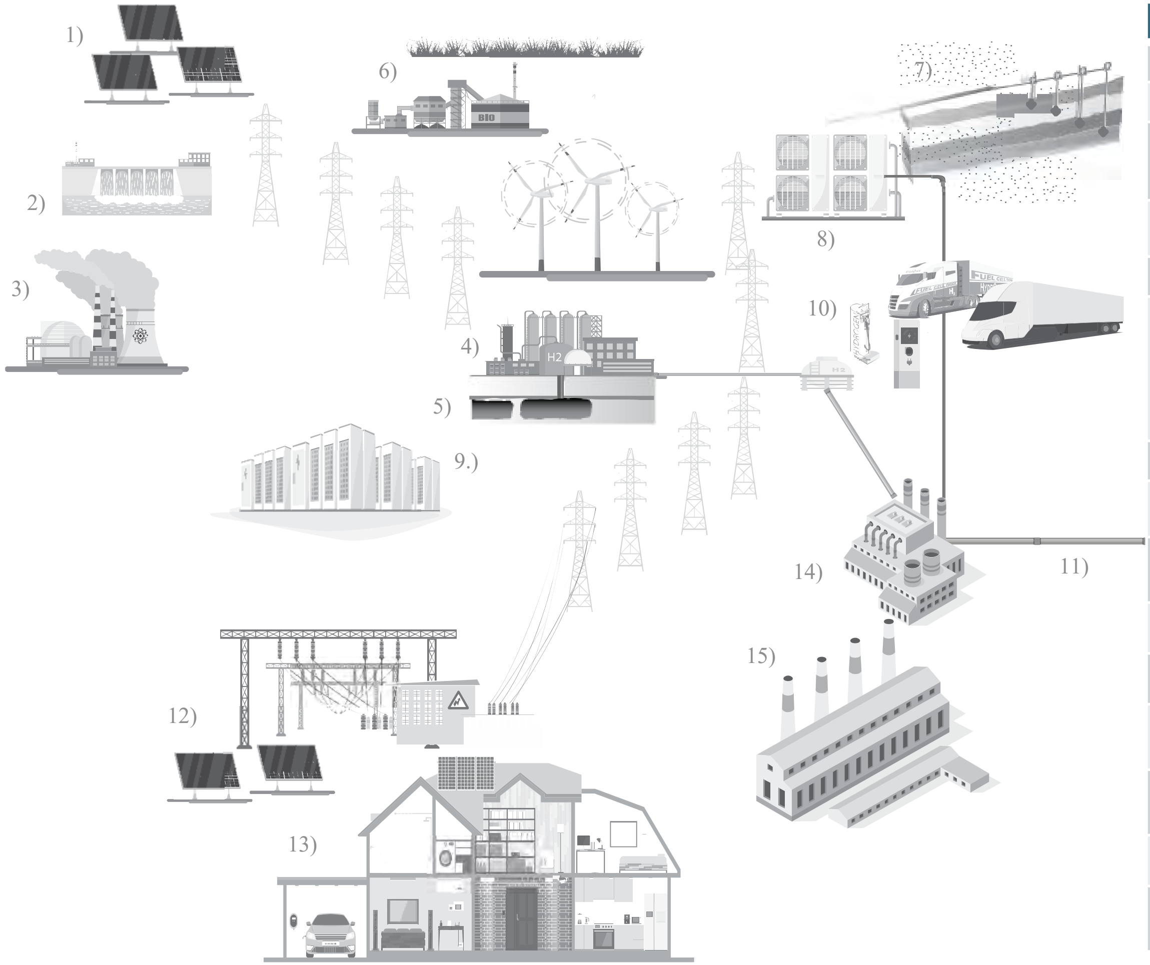
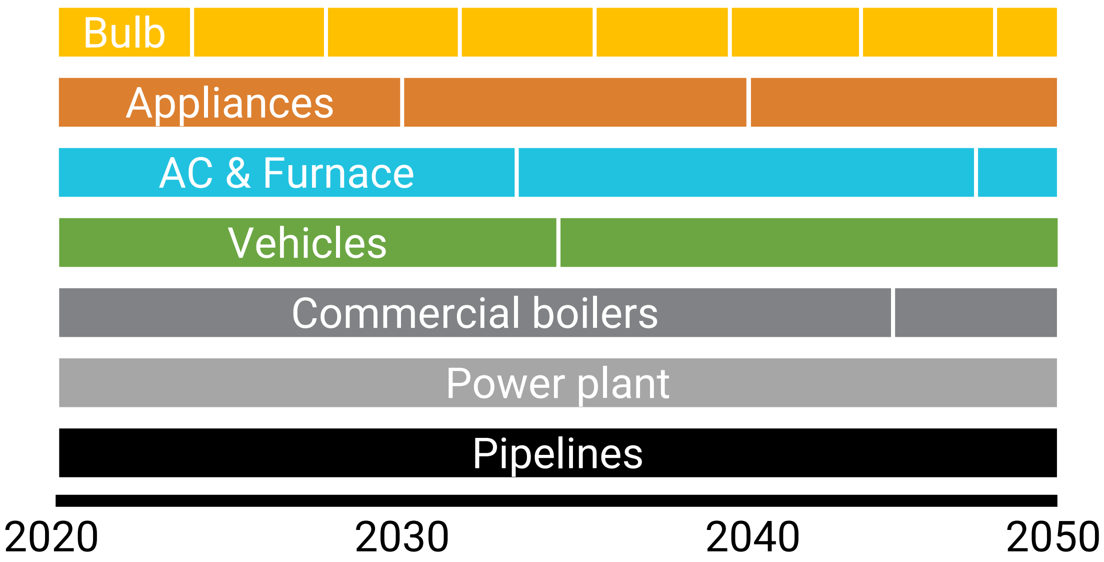


	Resource Categories	Examples
1.	Utility-Scale Renewables	Solar PV, Onshore Wind, Offshore Wind, Geothermal
2.	Dispatchable Hydroelectric	Reservoir hydro, On-Stream Pumped Hydro
3.	Thermal Power Plants	Gas CT, Gas CCGT, Coal, Coal w/CC, Gas w/;CC, Gas w/CC (Allam), SMR, Gen IV nuclear, Biomass, Biomass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

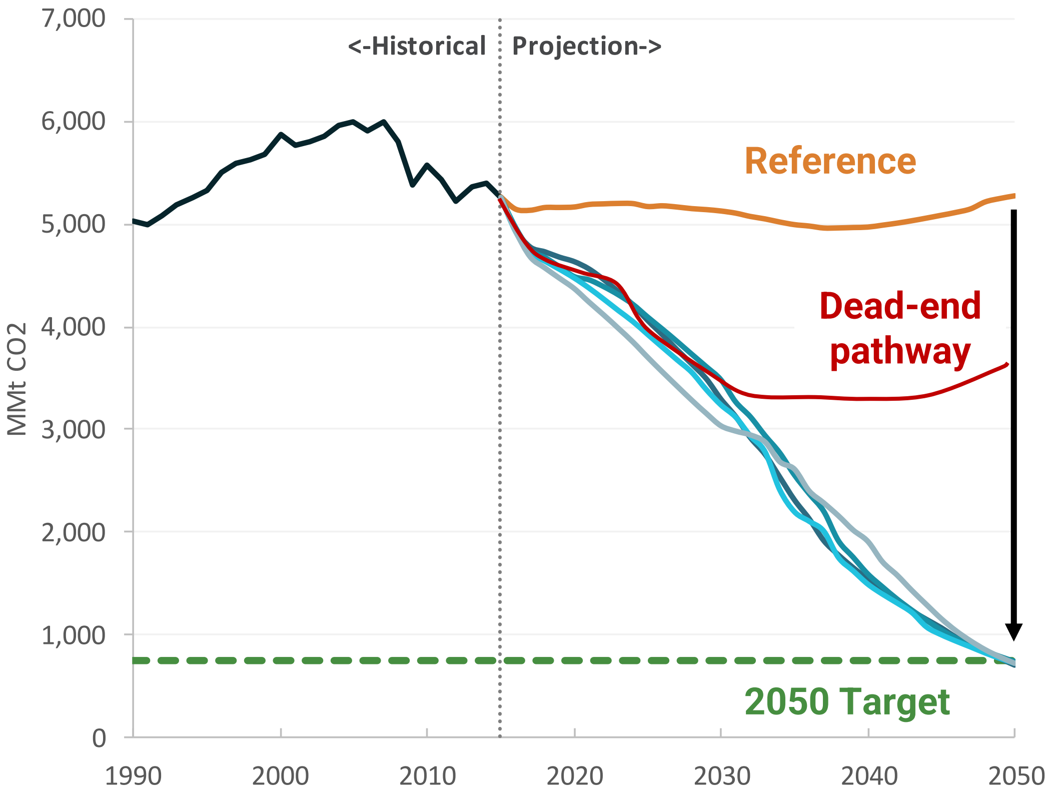
Near-Term Focus on Long-Lived Assets

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

Stock replacement count before mid-century



U.S. Energy-related CO_2 Emissions



Integrated Supply Side: Electricity and Fuels

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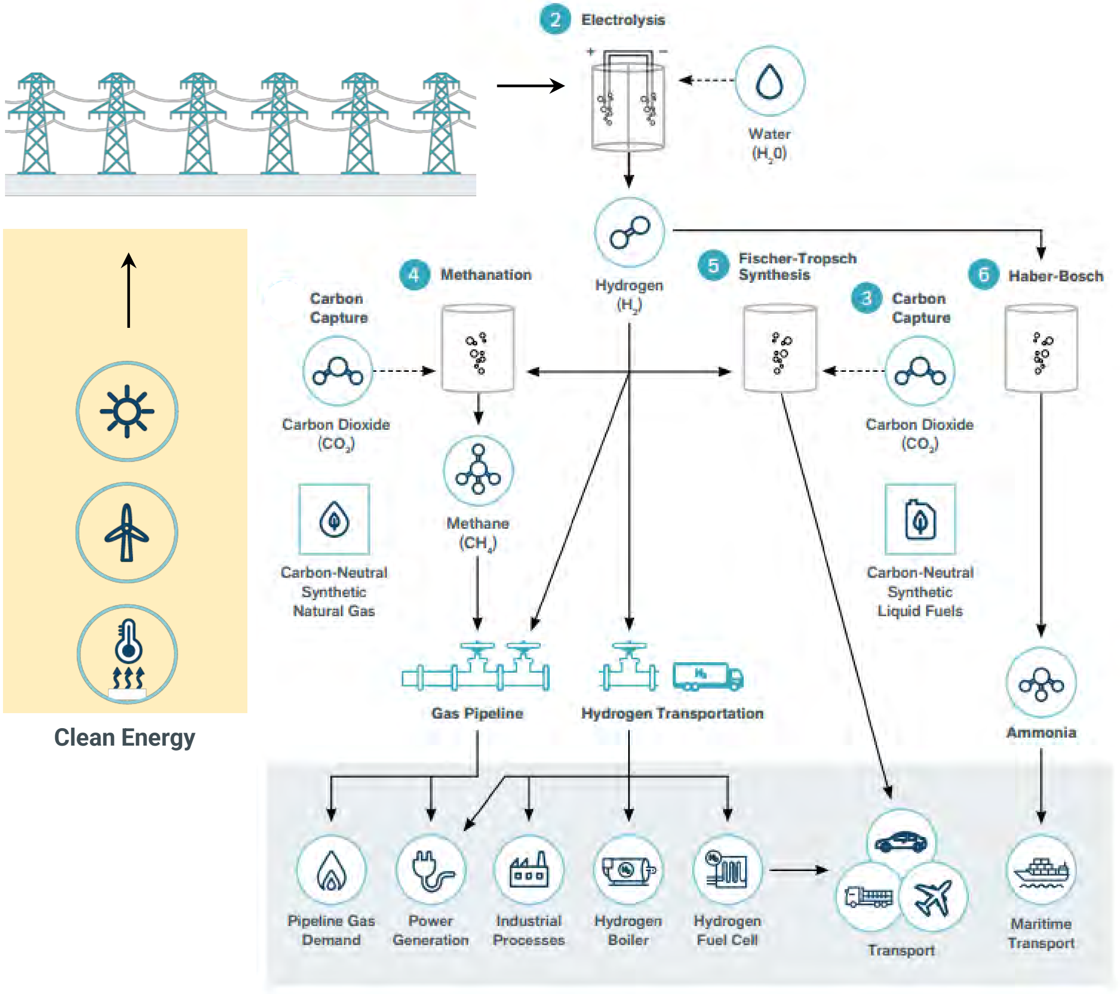
- What are the supply side investments that best meet energy demands?
- Conventional means of "balancing" the electricity grid may not be the most economic or meet clean energy goals
- New opportunities: Storage and flexible loads
- Fuels are another form of energy storage
- Large flexible loads from producing decarbonized fuels:
  - Electrolysis, synthetic fuels production



Source: CETI, NZNW, 2023

Sector Coupling: Challenges and Opportunities

EVOLVED ENERGY RESEARCH

- Economy-wide approach needed to plan for electricity and clean fuels growth and operations when targeting Oregon's emissions targets
  - What are the regional implications of fuel and electric sector coupling?
  - Future-proof investments and manage risk by understanding new opportunities and speed of change
- Make decisions in an economy-wide, temporal, and spatial context
  - Explore the tradeoffs between strategies that incorporate load growth, clean fuels, carbon management, electrification opportunities, and new industry
  - Chicken and egg: What comes first, what are the barriers to development, where should near-term efforts be focused?
  - Whack-a-mole: Doing less in one part of the economy requires more in another, understand cost and feasibility consequences of decision making

Clean Fuels Supply

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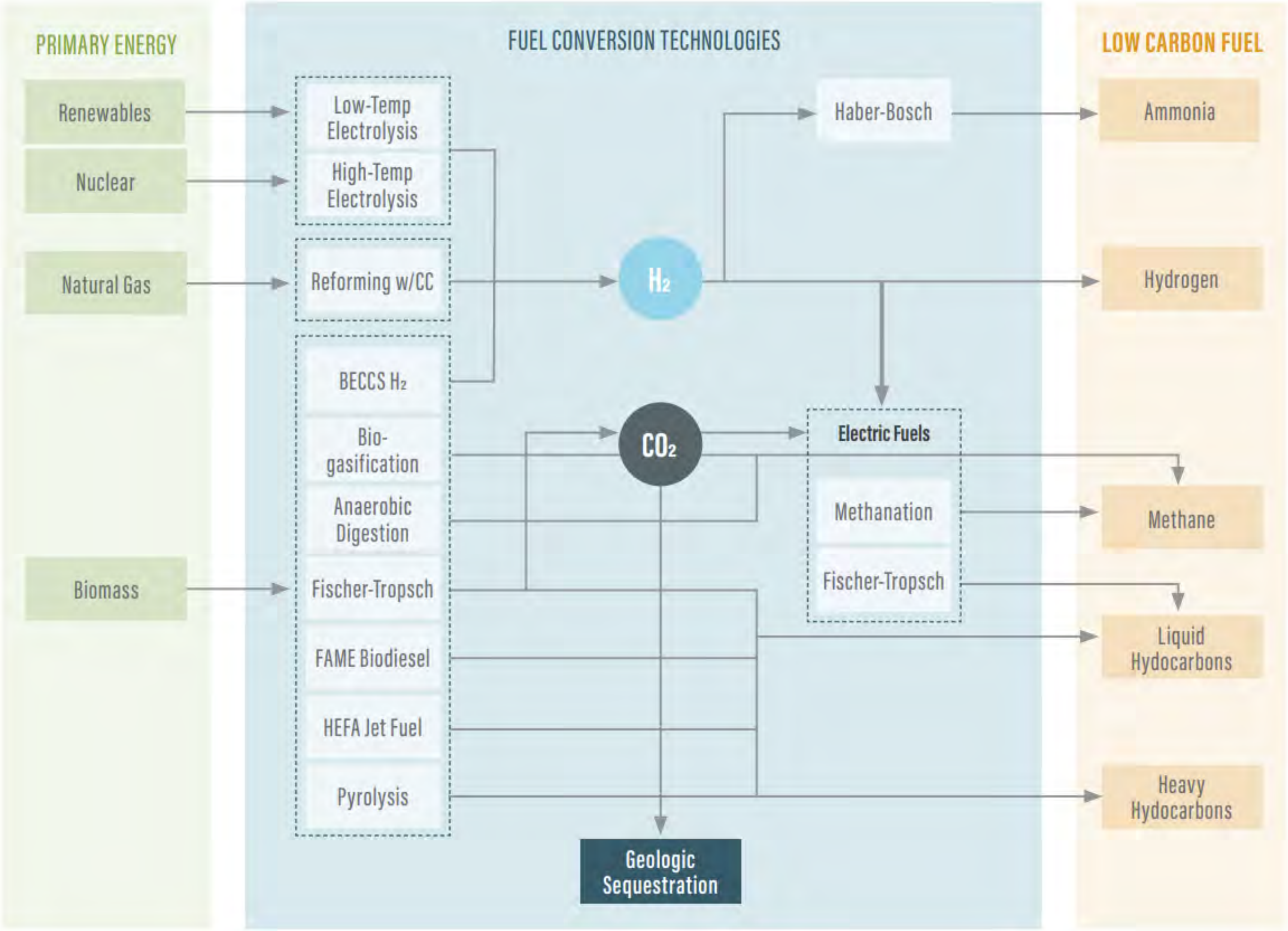
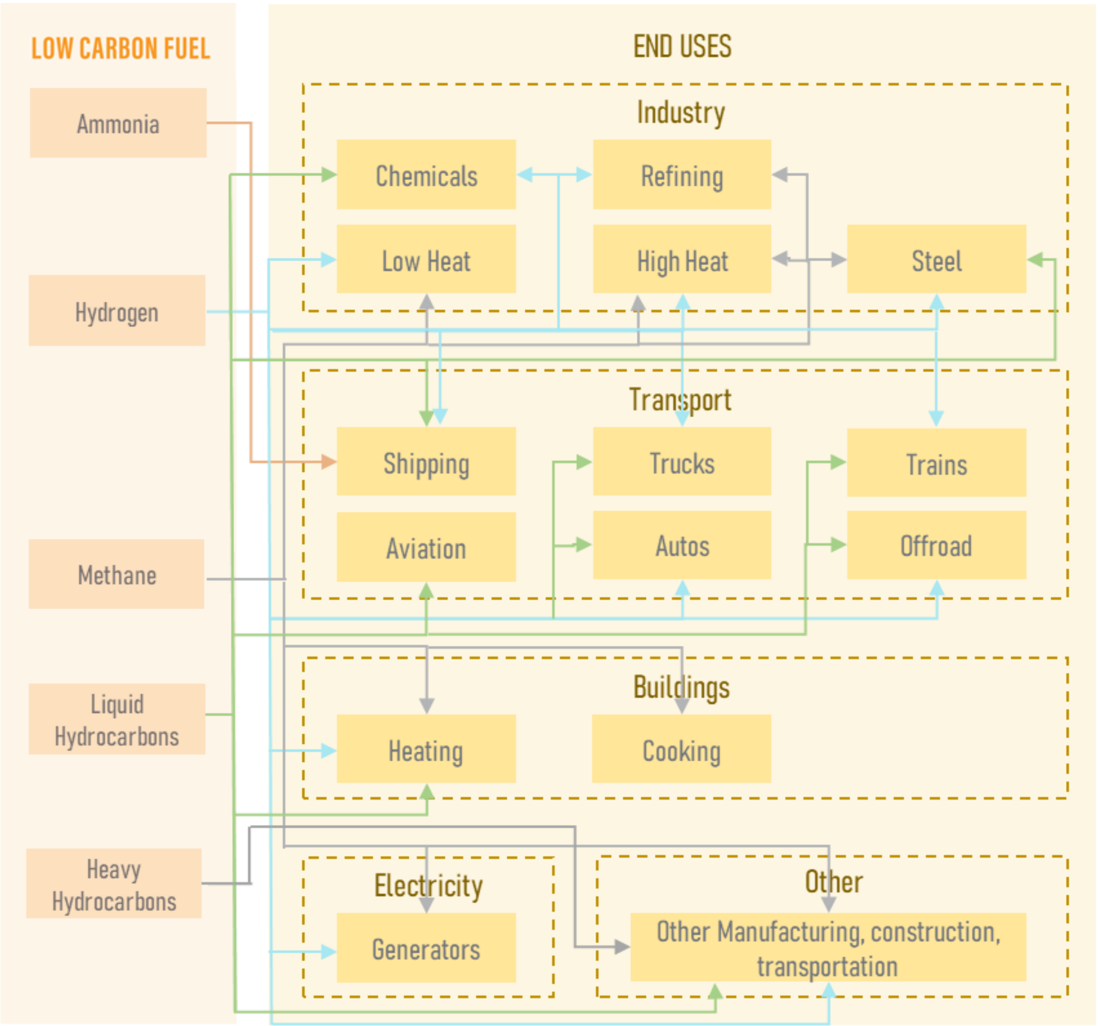
- Optimize capital investments and operations across all elements of clean fuel supply chains
  - Renewables/biomass
  - Transportation and storage
  - Conversion processes
- Scenarios used to constrain opportunities for clean fuels supply chains and electric sector development



Clean Fuels Demand

- Where are clean fuels used?
  - Replacing blue hydrogen with green
  - Drop in fuels: decarbonizing fuel blends
  - New markets for direct hydrogen use
  - New markets for ammonia
- Direct use of 100% hydrogen/ammonia blend in the economy defined with input assumptions
  - Fuel cells, 100% ammonia in maritime propulsion
- Share of clean fuels in fuel blends optimized by the model



Biomass Feedstocks: Billion Ton Study Update and LURA Model

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2023 Billion-Ton Report is the default source of cost and potential data for biomass

- https://www.energy.gov/sites/default/files/2024-03/beto-2023-billion-ton-report_2.pdf
- Supply curve by state and year developed for the US, supporting modeling of a biomass and biofuels market

Woody biomass estimates refined with Washington State University updated estimates for woody biomass in the Northwest using the LURA model, developed for the Washington 2021 State Energy Strategy

Within Zone Transmission

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- Need for in-state transmission and distribution expansion and upgrades to deliver electricity from in-state generation
- No physical representation of within zone transmission or distribution
  - High-level approach to estimating electric and gas T&D costs
  - Correlates in-state electric transmission and distribution capacity expansion costs with the total increase in net distribution system peak
- Captured with historical transmission and distribution costs
  - Uses historical $/MWh from EIA
- Model optimization decisions are not impacted by electric T&D cost assumptions; flexible load is a notable exception
  - Higher distribution upgrade cost assumptions will drive more load shifting in the model; lower costs will drive less load shifting

Natural Gas Infrastructure Cost Modeling Approach for this Study

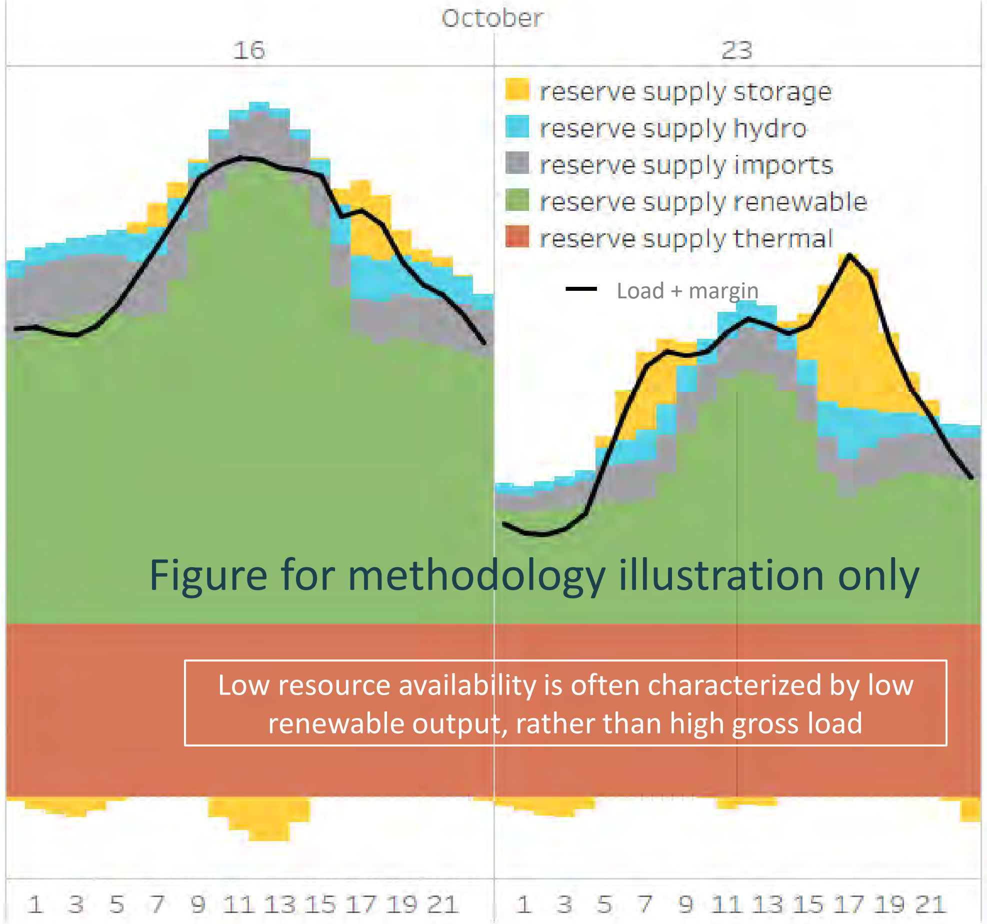
EVOLVED ENERGY RESEARCH

- Uncertainty about the impact of declining gas throughput on gas infrastructure costs
  - Are parts of the system decommissioned or do only flow rates decline?
- Conservative assumption: Assume that declining gas throughput results in zero gas infrastructure cost decline (i.e., that all gas infrastructure costs are fixed, none are variable)
- Possible to perform cost sensitivity calculations to show how costs would change under different targeted electrification/gas decommissioning cost assumptions
- This approach is suited to the gas system because EER's models do not optimize gas throughput or investment based on these cost assumptions

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

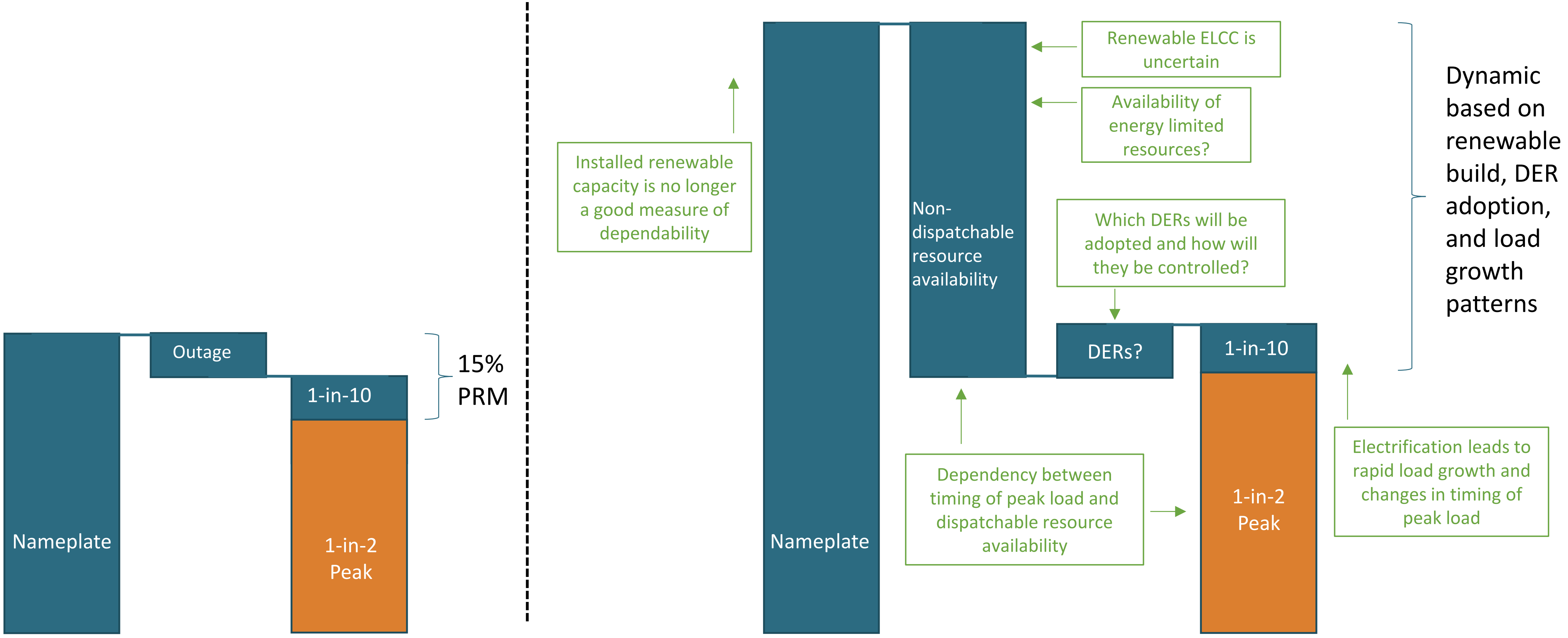
Hourly Reliability Snapshot



Hourly Reserve Margin Constraints by Zone

Traditional Reserve Margin

Future System Reliability Assessment



Hydroelectric System

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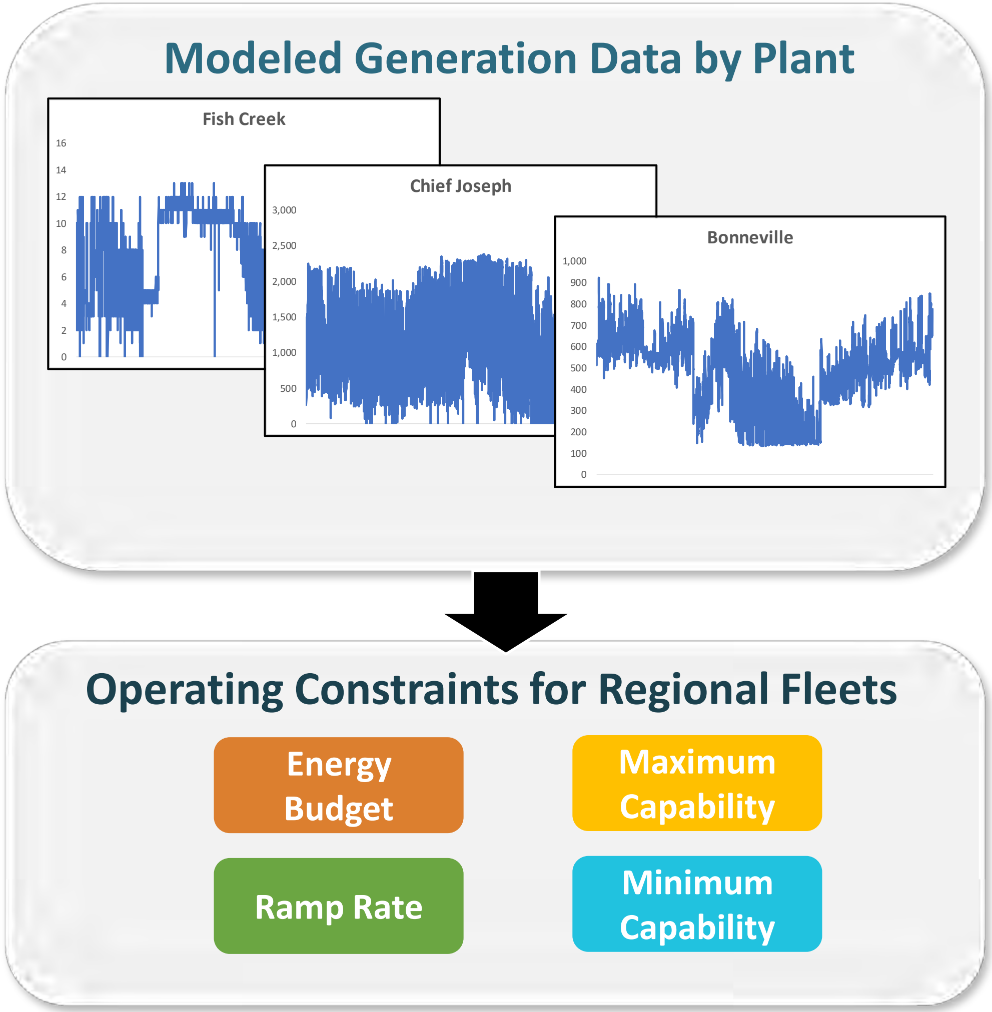
- The Pacific Northwest's hydroelectric system includes more than 30 GW of capacity, but its operational flexibility and generating capability varies year-to-year
- We model each study zone's hydro resources as an aggregated fleet and apply constraints based on historical operations
  - Maximum 1-hour and 6-hour ramp rates
  - Energy budgets
  - Dry, average, and wet hydro years
- Operational constraints for regional hydro fleets are derived using Northwest Power and Conservation Council hourly modeled generation data for 30 modeled years that incorporate climate change impacts
  - Operational constraints vary by week of the year (1 through 52) and hydro year (dry, average and wet)



Transmission Detail

EVOLVED ENERGY RESEARCH

- Economy-wide capacity expansion modeling becomes intractable at some point as more detail is added
  - What level of detail both provides the insights for the Energy Strategy while also remaining solvable?
- Nodal transmission is not compatible with economy-wide capacity expansion
  - We use zonal pipe flow constraints representing path ratings and opportunity to expand
  - Dependability factor in the model to represent reliability of line
- Characterize existing capacity, transmission under construction, and expansion opportunities, recognizing that the underlying system is more complex
  - Detailed transmission data underpinning more aggregate representation

Rio Optimizes across Time-scales

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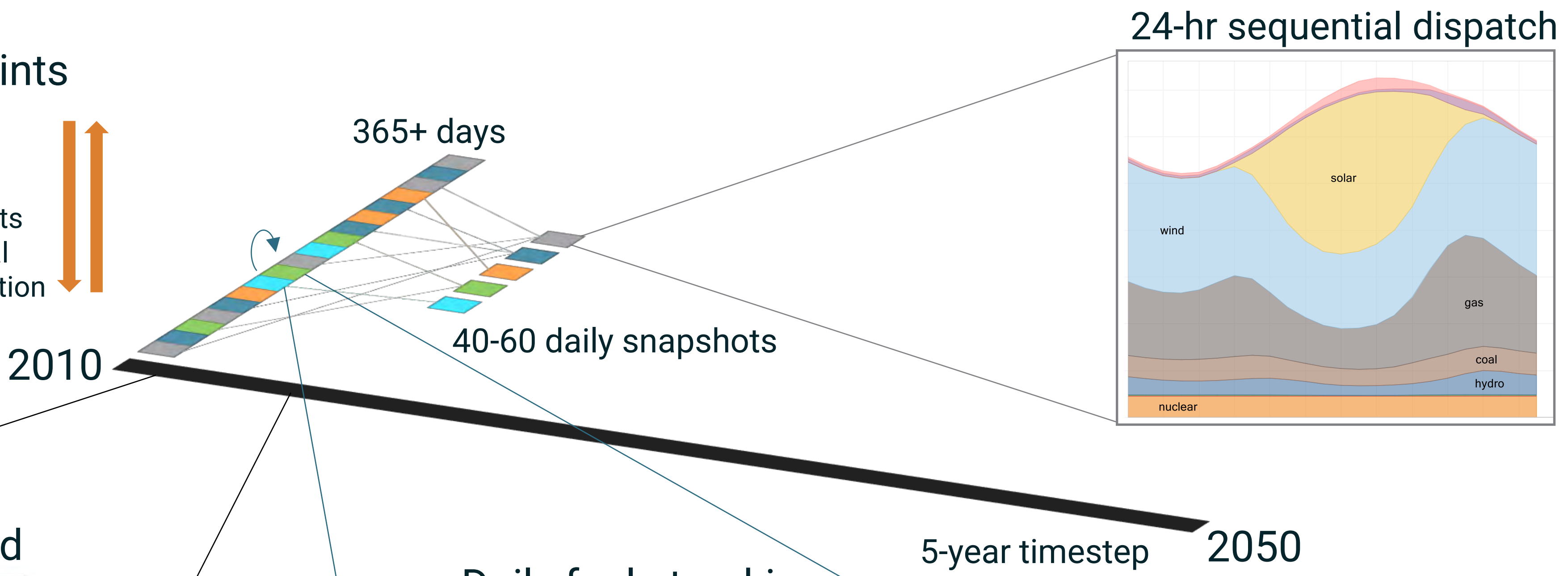
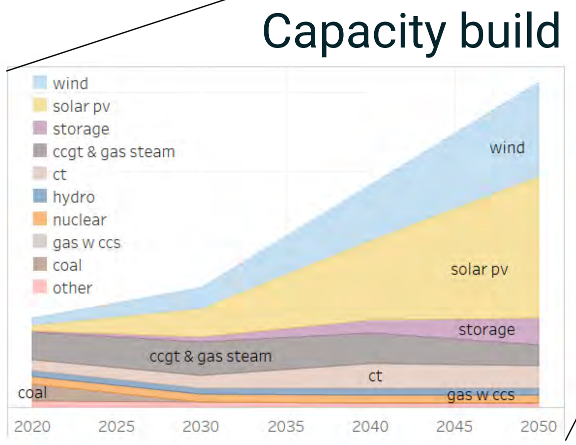
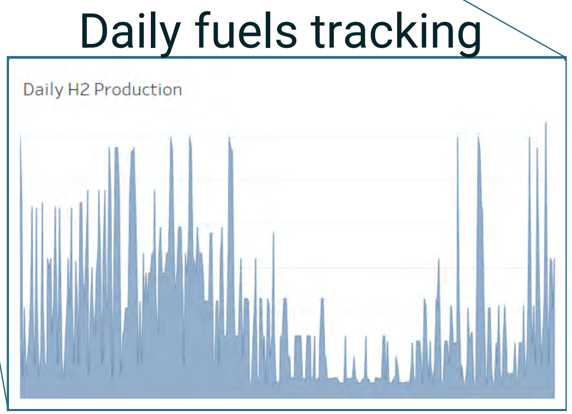
Solution Constraints

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

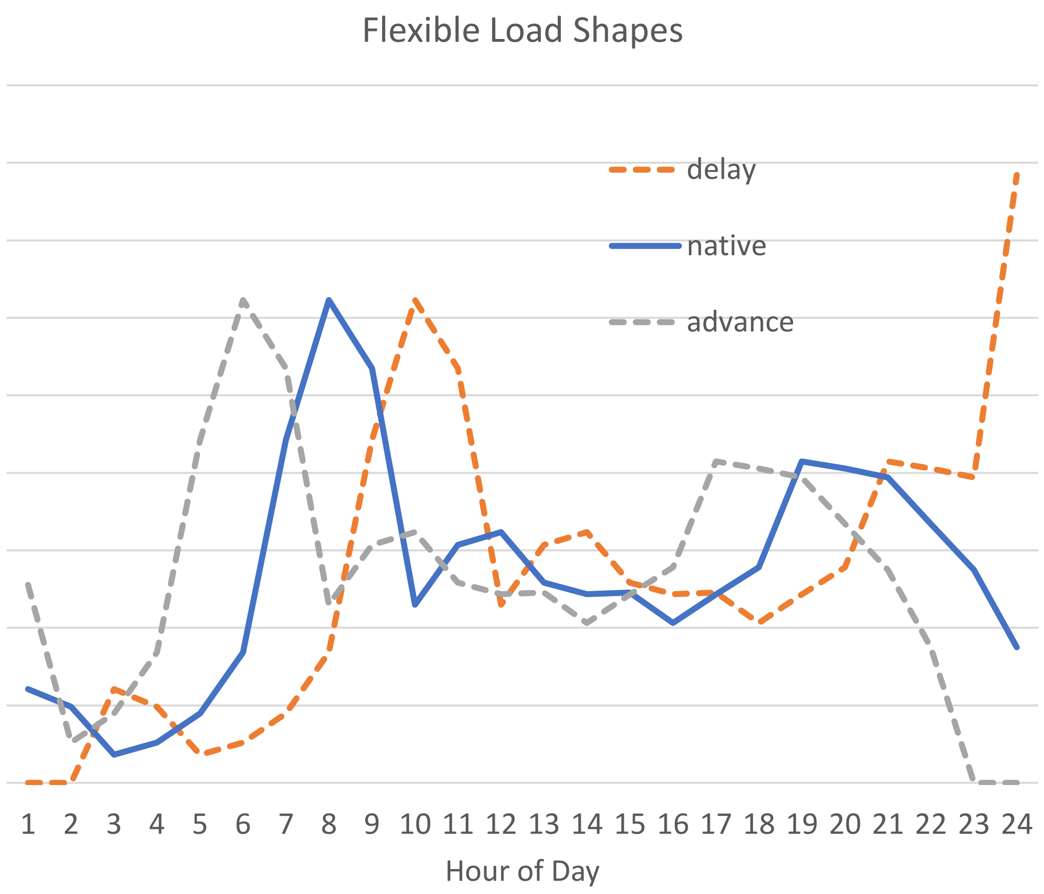


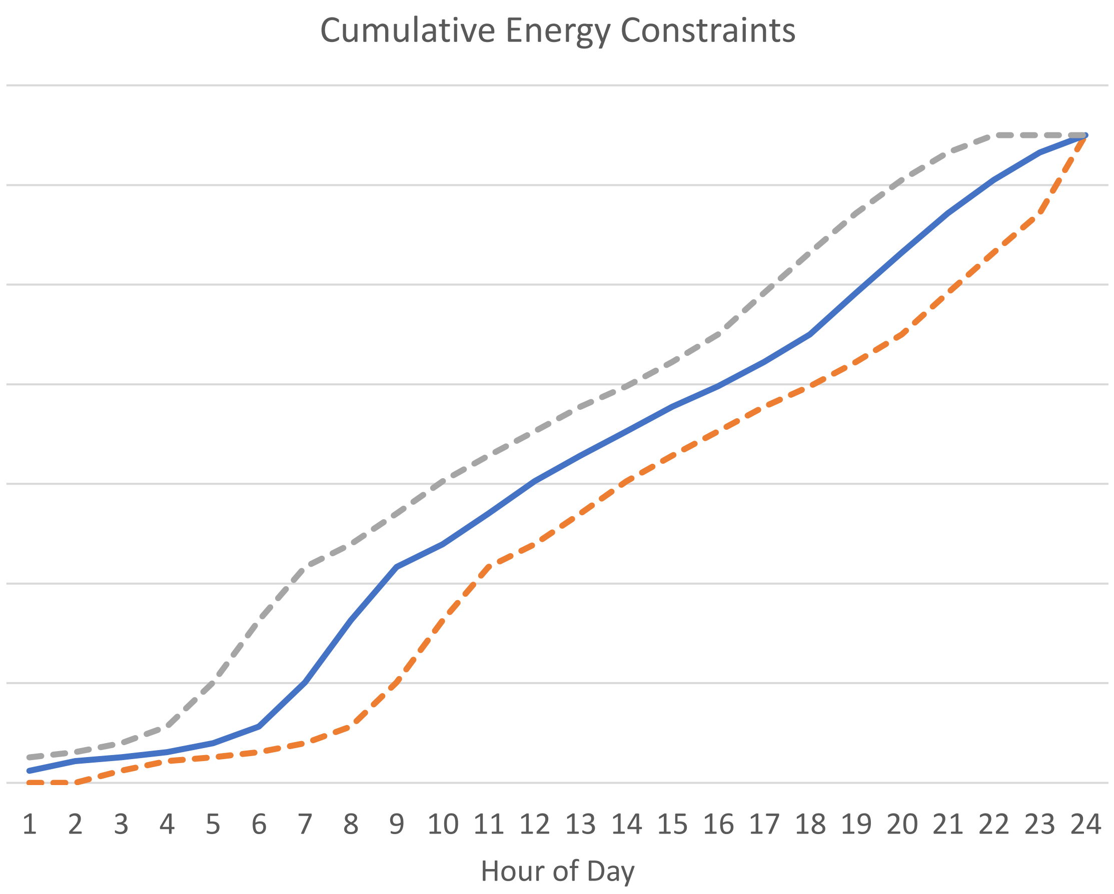




Flexible Load Operations

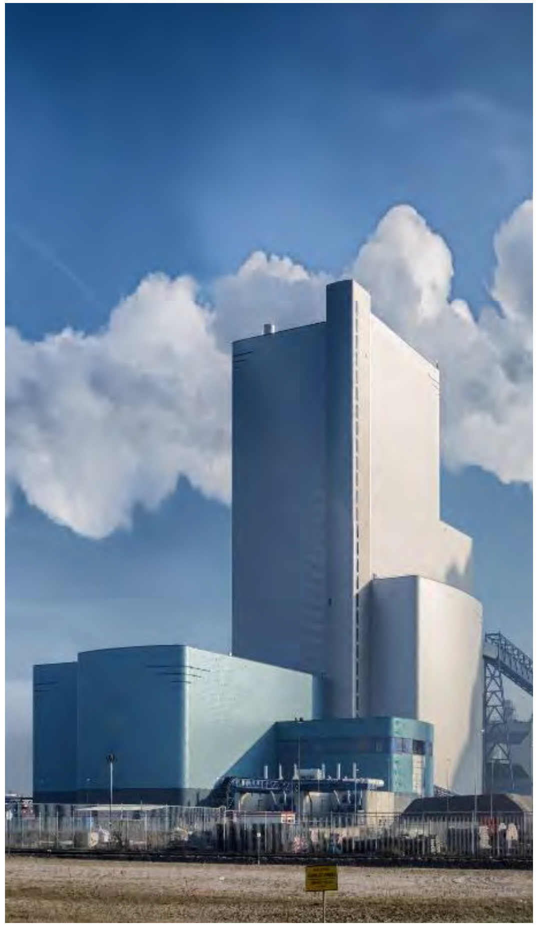
Figure for methodology illustration only

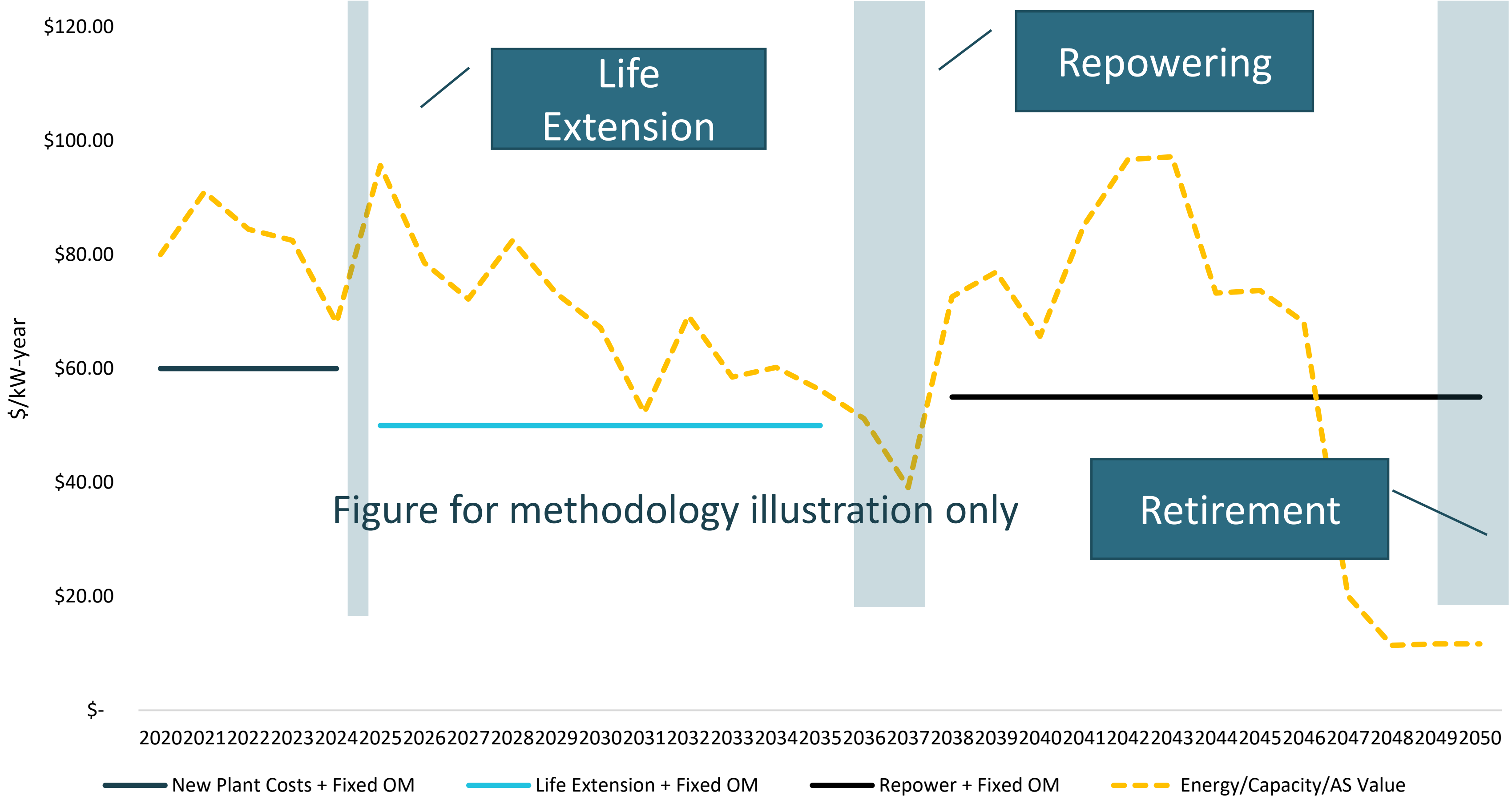




Economic Generator Lifecycles

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





RIO Commodities Module Definitions

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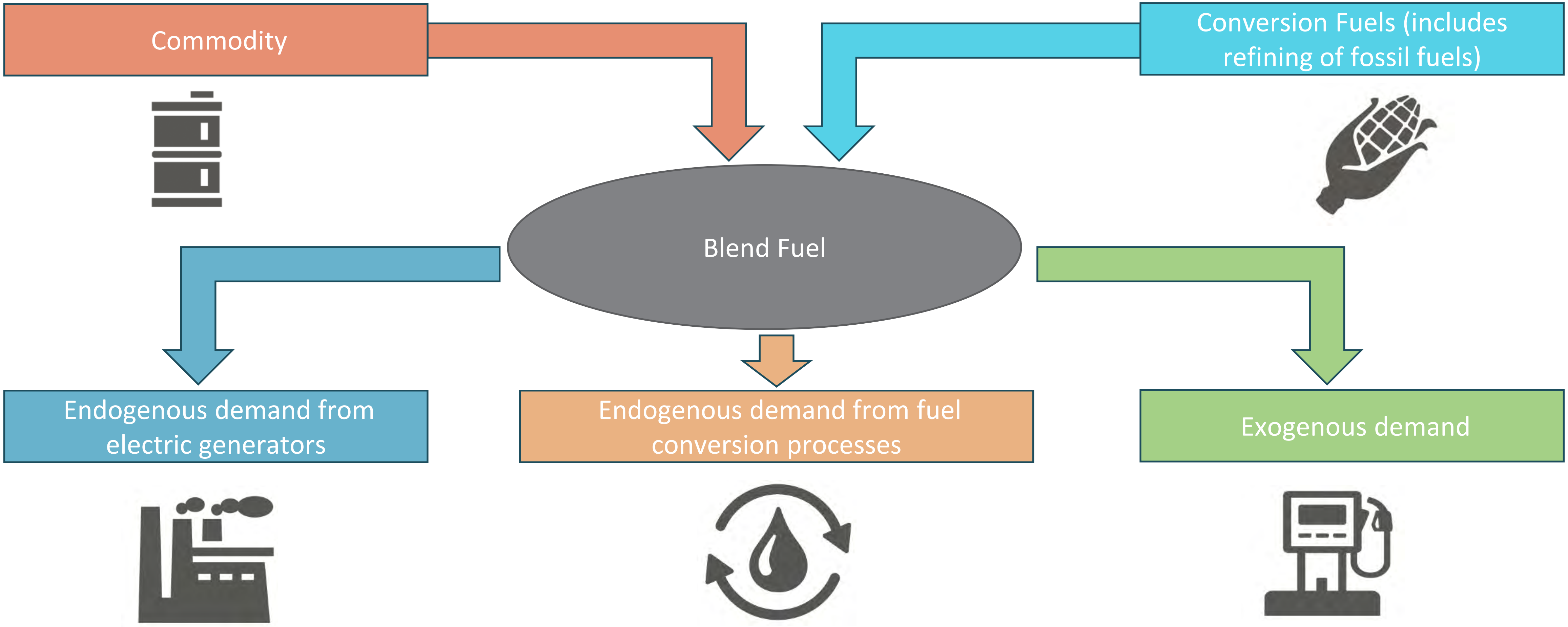
Category	Definition	Examples
Commodity	Exogenously specified commodity type defined with price supply curve, emissions rates, and available volumes	Natural Gas; Oil; Coal; Biomass
Conversion	Capital investment defined with cost of production capacity and efficiency of production (blend x -> blend y and/or electricity->blend y)	Biomass SNG; Power-to-Gas; Direct Air Capture
Blend	Aggregation point for product and conversion commodities. All inputs (conversion and products) are drop-ins for an individual blend.	Pipeline Gas; Diesel Fuel; Hydrogen; Captured CO_2

RIO Fuels Structure

Optimally invest in fuels transportation, storage, and conversion infrastructure



RIO Commodities Structure: Pipeline Gas Blend Example

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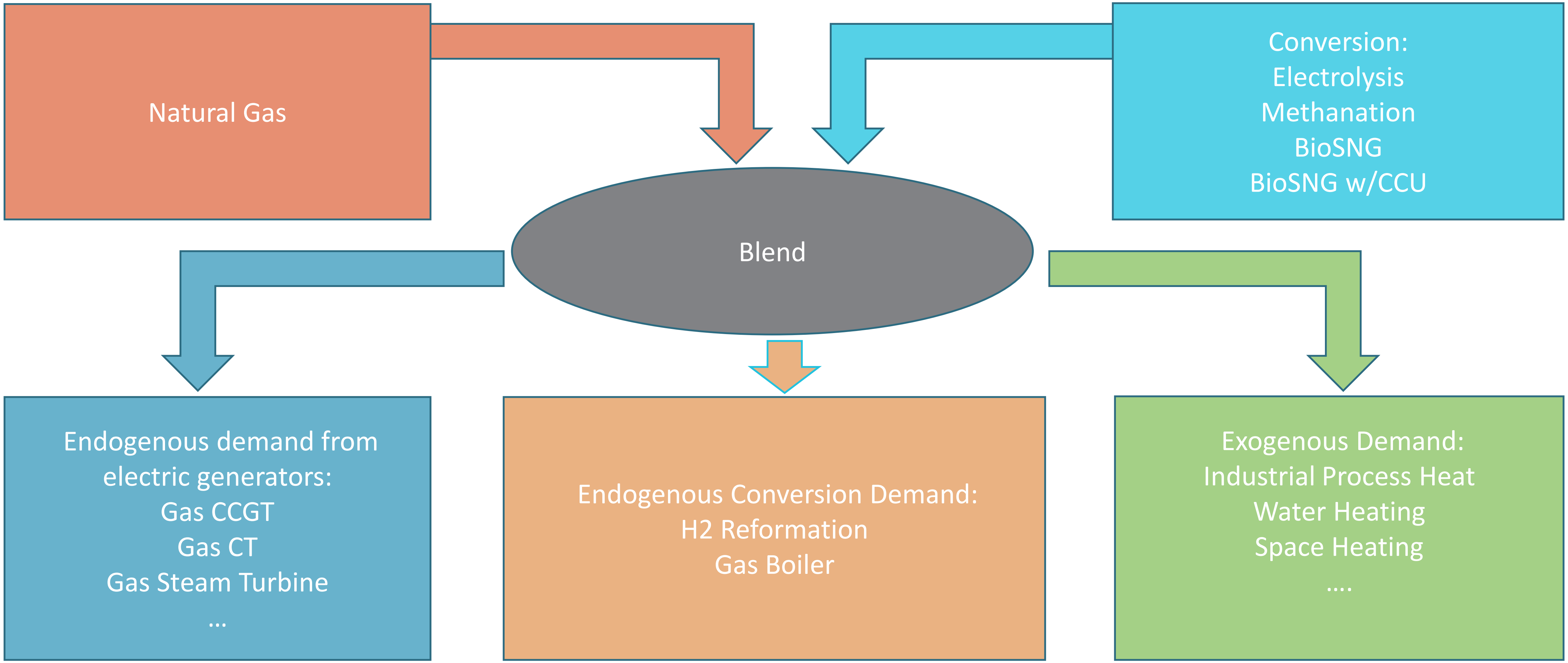

Renewable Resource Quality and Potentials

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

Rooftop Solar

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- Reference Scenario rooftop solar adoption from NWPCC 2024 solar rooftop projections
- In addition, the model can select solar as part of the optimization
- Though bulk system solar is cheaper than rooftop and will be selected ahead, we do not preclude rooftop solar as part of a future resource portfolio
  - Model does not pick up all of the benefits of rooftop solar because the RIO distribution model represents average benefits of deferring distribution infrastructure and not the full distribution
  - Rooftop may be desirable for other reasons such as promoting jobs within state, or avoiding land use challenges siting bulk system level solar
- Technical potential for rooftop solar used in the High DER scenario is 50% of installed capacity potential identified by NREL for all buildings in Oregon

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Scenarios Approach

Study Methodology
Common (Core) Principles between Scenarios

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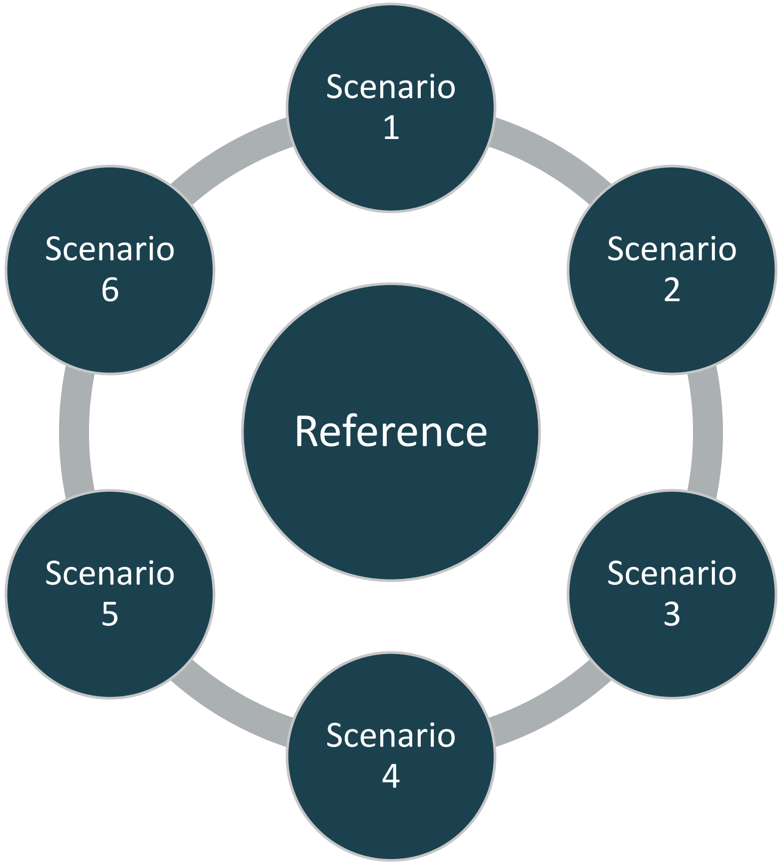
- Aggressive on efficiency and electrification
- Regional clean energy policy:
  - State-by-state clean electricity policy
- States can utilize out-of-state resources to count towards clean energy requirements in-state
- Service demands remain business as usual through 2050
- All resource options permitted for electricity and fuels production (so far as consistent with state policy)
- Fuels trading between states, including pipeline construction
- 2023 DOE Billion Ton Study for biomass availability updated with NW-specific data
- Waste gases and renewable fuels from waste oils
- Transmission expansion between states permitted – TNC supply curves
- Load management through dispatch of new flexible load technologies

Scenario Development

- Reference Scenario
  - Develop Oregon-specific database using best available resources
  - Define Reference Scenario assumptions
    - Starting point set of assumptions for stakeholders to react to and suggest changes
- Scenario Development
  - Develop set of interesting questions in collaboration with ODOE and stakeholders
    - What are the most pressing questions, uncertainties, and state priorities that will provide the most valuable information to policymakers?
  - Develop starting point study questions from stakeholder listening sessions for refinement to final scenarios to be modeled

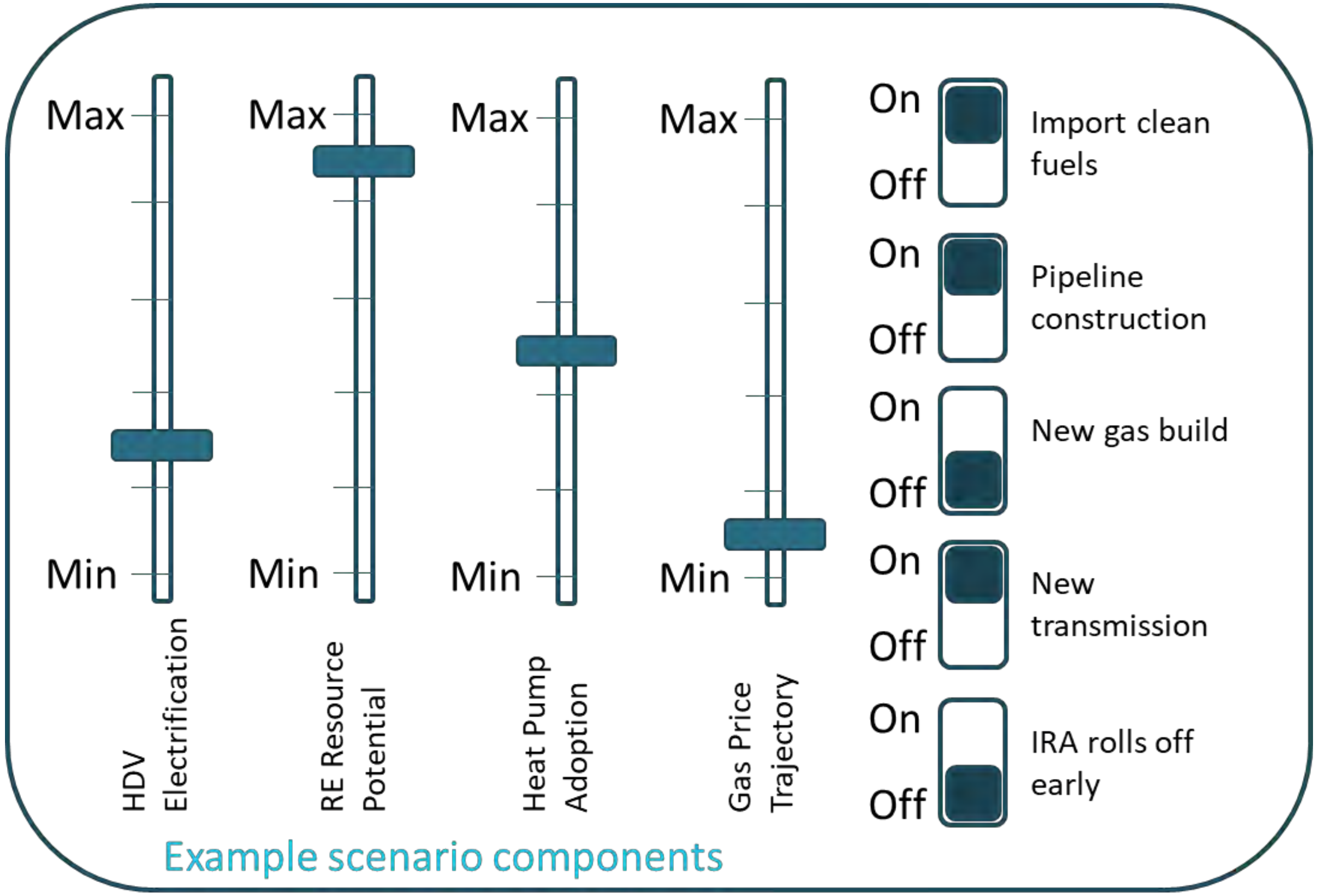


Translating “What If” Questions to Scenario Matrix – Illustrative Examples

- e.g., What if consumer adoption of heat pumps occurs more slowly than expected?
  - Reference Scenario: 100% sales of heat pumps by 2035
  - Scenario X: 50% sales of heat pumps by 2035 and through 2050
- e.g., What if transmission expansion to access resources outside of Oregon is harder than expected?
  - Reference Scenario: Relatively unconstrained transmission build
  - Scenario Y: No transmission expansion outside of Oregon

Components of a Scenario

- Many assumptions go into projecting an energy pathway
- Different levers can be set to test:
  - More or less
  - Yes/no
- The model optimizes decisions, informed by those levers
  - Test uncertainties
  - See impacts of policies/actions/ customer behavior on energy needs and how energy is supplied



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Appendix-Data and Assumptions

Reference Scenario Assumptions

Reference Scenario Database Development with Oregon-Specific Data

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- Oregon-specific data collected from up-to-date Oregon datasets, past studies, and consultations
  - Transportation Data (ODOT, EPA MOVES)
  - Building Data (NEEA RBSA & CBSA, EIA RECS & CBECS)
  - EIA State Energy Data System (SEDS)
  - Oregon DEQ GHG Emissions Inventory
  - Planned resource investments
  - Data center and crypto forecast data
  - PSU Population Research Center
- Review of Oregon resources and input from ODOE and data holders in identifying available datasets

Buildings: Stock and Stock Replacement Data

Input	Source
Residential Space Heating	Northwest Energy Efficiency Alliance (NEEA) Residential Building Stock Assessment & Home Energy Score Data*
Commercial Space Heating	NEEA Commercial Building Stock Assessment
Residential Water Heating	NEEA Residential Building Stock Assessment & Home Energy Score Data*
Commercial Water Heating	NEEA Commercial Building Stock Assessment
Residential Building Shells	NEEA Residential Building Stock Assessment & Home Energy Score Data*
Commercial Building Shells	NEEA Commercial Building Stock Assessment
Residential Technology Stock Replacement	Energy Information Administration (EIA) Updated Buildings Sector Appliance and Equipment Costs and Efficiencies (2023)
Commercial Technology Stock Replacement	Energy Information Administration (EIA) Updated Buildings Sector Appliance and Equipment Costs and Efficiencies (2023)
Residential Cooking & Other Appliances	NEEA Residential Building Stock Assessment

**Oregon's Home Energy Score data comes from Earth Advantage*

Buildings: Key Assumptions and Sources Informing Assumptions

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Input	Assumption	Source
Residential Space Heating	Assume existing policies play out for all space heating technologies 65% electric heat pump sales by 2030; 90% by 2040 Households with wood stoves: By 2050, 75% air-source heat pump (ASHP) with woodstove hybrid, 20% woodstove only, 5% heat pump only	Heat pump sales: Multi-agency memorandum of understanding (MOU); Oregon's Transformational Integrated Greenhouse Gas Emissions Reduction Project Report (TIGHGER); Langevin, J, et al. (2023); ODOE review of/work with Oregon local wood stove heating replacement assistance programs.
Small vs. large commercial building split	50/50 split	Portland Salem Medford Building Stock Characterization

Commercial Space Heating	Weighted average of large and small commercial space heating loads, with the following framing:
	• Small commercial: follow residential
	• Large commercial:
	    • 2030: Electric heat pumps 15% of overall sales; other electric + electric hybrid systems (including hybrid heat pumps) 10% of overall sales
	    • 2045: Electric heat pumps 50% of overall sales; other electric + electric hybrid systems (including hybrid heat pumps) 40% of overall sales
		Langevin, J, et al. (2023)

Residential Water Heating	• Incorporate Federal Energy Conservation Standards for Consumer Water Heaters (from May 6, 2029) • Electric heat pump sales rising to 95% of overall sales by 2045	USDOE's Energy Conservation Standards for Consumer Water Heaters rule

Commercial Water Heating	Weighted average of large and small commercial water heating loads, with the following framing:
	• Small commercial: follow residential
	• Large commercial:
	    • 2035: Electric heat pumps for water heaters 15% of overall sales, other electric technologies 10% of overall sales
	    • 2045: Electric heat pumps for water heaters 50% of overall sales, other electric technologies 40% of overall sales
		USDOE's Energy Conservation Standards for Consumer Water Heaters rule

Buildings: Key Assumptions and Sources, cont.

Input	Assumption	Source
Cooking	95% sales of new appliances are electric by 2035	TIGHGER
Technology stock replacement	Dual gas/electric heat pump systems, differentiated by climate zone, compete with other electric technologies in line with sales shares above	N/A
Whole-home retrofits	3,500 homes a year. Whole home retrofits, represented by the Advanced Envelope Efficiency Package in Evolved Energy Research's "Enhancing Building Efficiency Modeling" report	2020 OHCS Low Income Weatherization Program Report Evolved Energy Research, Enhancing Building Efficiency Modeling (2024)
Lighting	100% LED sales by 2025	HB 2531

Industry: Key Assumptions and Sources

Input	Assumption	Source
Industrial Processes	1% process efficiency improvements per year in all sectors	Assumptions based on CETI research, vetted by technical working groups
Electrification	Fuel switching measures from fuels to electricity as follows: • 100% of machine drives by 2035 • 100% of low temperature heat by 2050, including in Oregon's largest industries such as computer and electronics products • 50% of heat in bulk chemicals production, 25% of heat in glass production • 50% of integrated steam production, including in food manufacturing, by 2045 • 100% of refrigeration by 2040 • 75% of industrial HVAC loads across industrial subsectors by 2050 • 80% of industrial vehicles including in agriculture by 2050 • 50% of construction energy demand by 2050	Assumptions based on CETI research and TIGHGER Report, vetted by technical working groups USDOE, Industrial Decarbonization Roadmap (2022)
Switch to Hydrogen	• 50% of heat in bulk chemicals (not a large industry in OR) • 20% of integrated steam production, including in food manufacturing, by 2050 • 20% of construction energy demand • 20% of industrial vehicles by 2050	Assumptions based on CETI research, vetted by technical working groups
Cement	Cement process is optimized in the model, including retrofits and new build rotary kilns to include direct separation, oxy-combustion, biomass fuel, and CCS (not a large sector in Oregon)	*Assumptions based on technology options from Agora Industry Cement Transformation Cost Calculator*
Thermal Energy Storage	Economic adoption modeled in industrial sector	*Assumptions based on costs from IRENA Innovation Outlook: Thermal Energy Storage*
Hybrid Boilers	Model can invest in dual fuel electric and gas boilers as well as hydrogen boilers	*N/A*

Transportation: Stock and Sales Share Data

Input	Source
Light duty vehicle (LDV) current stocks	Environmental Protection Agency's (EPA's) Motor Vehicle Emission Simulator (MOVES) model containing data submitted by OR Dept. of Transportation – Driver & Motor Vehicle division (DMV)
Medium- and heavy-duty vehicle (MHDV) current stocks	Environmental Protection Agency's (EPA's) Motor Vehicle Emission Simulator (MOVES) model containing data submitted by OR Dept. of Transportation – Driver & Motor Vehicle division (DMV)
Transit Buses current stocks	Environmental Protection Agency's (EPA's) Motor Vehicle Emission Simulator (MOVES) model containing data submitted by OR Dept. of Transportation – Driver & Motor Vehicle division (DMV)
School Buses current stocks	OR Dept. of Transportation – DMV Data
Fuels current	OR Dept. of Environmental Quality Clean Fuels Program Data
Vehicle Miles Traveled (VMT) current	Dept. of Environmental Quality / EPA MOVES (data comes from Highway Performance Monitoring System)
Fuel Economy current	EPA MOVES, Historical average fuel economy by vintage and vehicle type
LDV sales shares	Advanced Clean Cars I / Advanced Clean Cars II* International Council on Clean Transportation (ICCT) forecasts based on IRA incentives
MHDV sales shares	Advanced Clean Trucks through 2035* ICCT forecasts based on IRA incentives

**These inputs/assumptions are based on existing state or federal policy at the time the model was run.*

Transportation: Key Assumptions and Sources

Input	Assumption/Source
MDV and HDV sales shares – post 2035	Post 2035: • 100% zero emission vehicle (ZEV) sales by 2040 for Class 2b-8 vehicles (excluding buses) • For long haul: 65% battery electric vehicles (BEVs)/35% hydrogen fuel cell vehicles (FCEVs); • All other classes: 100% electric
Transit Buses future	100% ZEV sales by 2036; 75% BEV / 25% FCEV sales by 2040 TIGHGER 2023 Biennial Zero Emissions Vehicle Report
School Buses future	100% BEV sales by 2036 (100% electric)
Rail future	20% electric, 70% hydrogen by 2050 (logistic growth starting in 2030)
Maritime Shipping future	• Domestic: 10% electric, 20% H2, 50% ammonia by 2050 (logistic growth starting in 2030) • International: 20% H2, 60% ammonia by 2050 (logistic growth starting in 2030)
Vehicle Fuels future	Clean Fuels Program*
Vehicle Mean Lifetimes	• Combination trucks: 15 years • Single unit trucks: 18 years • Transit and school buses: 12 years • Passenger cars: 16 years • Passenger trucks: 14 years • Light duty commercial truck: 12 years

These inputs/assumptions are based on existing state or federal policy at the time the model was run.

Transportation: Key Assumptions and Sources, cont.

Input	Assumption/Source
Fuel economy: Light duty cars and trucks	Environmental Protection Agency's (EPA's) Motor Vehicle Emission Simulator (MOVES) model
Fuel economy: Medium duty & heavy-duty vehicles	Environmental Protection Agency's (EPA's) Motor Vehicle Emission Simulator (MOVES) model
Fuel economy: Buses	Environmental Protection Agency's (EPA's) Motor Vehicle Emission Simulator (MOVES) model
Fuel economy: Aviation	20% efficiency gain through 2050, to reflect International Air Transport Association (IATA) Net Zero Roadmap IATA Net Zero Roadmap
VMT Assumption	20% reduction in LDV VMT per capita by 2050* 2023 Oregon Transportation Plan
Vehicle costs	Light,-Duty Vehicles: Assessment of light-duty electric vehicle costs and consumer benefits in the United States in the 2022 2035 time frame, ICCT, 2022. Medium and Heavy-Duty Vehicles: Analyzing the impact of the Inflation Reduction Act on electric vehicle uptake in the United States, ICCT, 2023 Transit / School Buses: Analyzing the impact of the Inflation Reduction Act on electric vehicle uptake in the United States, ICCT, 2023 Rail / Aviation / Maritime: Costs assumed to be same as fossil alternatives due to lack of data
Fuel costs	Annual Energy Outlook 2023 Oil and Gas Forecasts
Infrastructure costs	EV Charging: NREL Electrification Futures Study Hydrogen: U.S. Dept. of Energy Technical Targets for H2 Delivery

These inputs/assumptions are based on existing state or federal policy at the time the model was run.

Direct Use Fuels

Input	Assumption/Source
Demand Side Assumptions	Modeled residential, commercial, and industrial demand end use using assumptions about sales shares in EnergyPATHWAYS
Supply Side Assumptions	• Energy Information Administration Form EIA-860 listing existing and planned generator additions • Survey of peer reviewed and government agency sources of capital and operating costs and performance (ADP Technical Documentation 2023, p. 61)
Fuel supply and price forecasting	• Energy Information Administration (EIA) Annual Energy Outlook • NW Power and Conservation Council's Fuels Advisory Committee natural gas price forecast • U.S. Department of Energy Billion Ton Report
Alternative Clean Fuel Investment	DEQ's Climate Protection Program as regulated under Administrative Order No. DEQ-18-2024: 50% emissions reduction by 2035, 90% by 2050, applied to fossil fuel emissions
Alternative Clean Fuels	Biomass-derived fuels, hydrogen, and hydrogen-derived fuels qualify as clean (if green hydrogen used). Imported new fuels are counted as zero emission fuels (credit for negative emissions from processes like BECCS are retained by producing state). Clean Fuel Standard incorporated

Energy Efficiency and Load Flexibility

Input	Assumption	Source
Behind the Meter (BTM) Photovoltaic (PV)	Northwest Power and Conservation Council March 2024 rooftop solar projections	NWPCC 2024 solar rooftop projections
BTM Storage Adoption	Energy Information Administration's (EIA) June 2024 Survey: 10 MW assumed today 42 MW/25 MWh of BTM storage (1% of households install storage systems by 2050; 20% of them participate in offering grid services, 50% of stored energy available).	EIA June 2024 Survey Brattle, 2024. California's Virtual Power Potential: How Five Consumer Technologies Could Improve the State's Energy Affordability
Flexible Load Parameters	Space heating loads can be delayed or advanced by 1 hour Water heating loads can be delayed or advanced by up to 2 hours Air conditioning can be delayed or advanced by 1 hour Residential vehicle charging can be delayed by up to 8 hours and commercial vehicle charging up to 3 hours	
Vehicle-to-grid (V2G)	26% V2G for residential EVs by 2050, assuming utilities can discharge battery down to 40% capacity (so use 60% of EV battery)	National Grid - Distribution Future Energy Scenarios regional information

Energy Efficiency and Load Flexibility, cont.

Input	Assumption	Source
Tech Load Growth	NWPCC Northwest Power Supply Adequacy Assessment for 2029 mid-higher case, with load differentiated across modeling zones	NWPCC Pacific Northwest Power Supply Adequacy Assessment for 2029
Demand Response – Households participation	50% of homes with demand response capability are participating in some form of firm demand response program by 2050 for heating, water heating, and air conditioning (linear growth from 2025) Residential EVs: Start at 0, ramp up to 2/3 of residential EVs participate in managed charging by 2030	BPA Demand Response Potential Assessment, 2022-2045 LBNL, The California Demand Response Potential Study (2024) Portland General Electric 2023 Clean Energy Plan and Integrated Resource Plan
Demand Response - Commercial	50% of commercial spaces with demand response capability are participating in some form of firm demand response program by 2050 for heating, water heating, and air conditioning (linear growth from 2025) Commercial EVs: Start at 0, ramp up to 1/3 of commercial EVs participate in managed charging by 2030	BPA Demand Response Potential Assessment, 2022-2045 LBNL, The California Demand Response Potential Study (2024) Portland General Electric 2023 Clean Energy Plan and Integrated Resource Plan
Demand Response - Industrial	Includes dual fuel boilers, thermal energy storage, process flexibility, heating, cooling. There is no input assumption. The model will provide insights into the uptake of technologies with flexibility potential over time.	N/A

Electricity Generation Technologies

Input	Source
Energy Demand	• Results from EnergyPATHWAYS model informs Regional Investment and Operations Model (RIO) (both Evolved Energy Research models) • Tech load (data center and chip fabrication) growth trajectory (see Energy Efficiency and Load Flexibility above) • Rooftop solar scheduled additions (see above)
Electric Supply	• Existing supply minus announced coal/gas retirements • Siting restrictions apply to new generation, interconnection, transmission (see Land Use and Natural Resources below) • Out-of-state generation requires transmission
Generation Options	• Hydropower (based on simulated hourly hydro data from the NWPCC 2029 Adequacy Assessment Reference Scenario and climate scenarios projected through 2029) • Solar (photovoltaic and thermal) • Wind (onshore, offshore) • Biomass (woody, manure, biogas) • Natural gas, existing biogas, hydrogen, renewable natural gas, and new biogas supplies eligible to be burned in existing gas turbines. Option for electrolytic hydrogen or new biogas supplied new electricity plants under 25 MW • Conventional and enhanced geothermal, based on NREL ATB Advanced pricing and capped at 25% of Oregon's technical potential • Coal, gas, nuclear (siting restrictions – no new natural gas or nuclear sited in Oregon) • Costs for new geothermal generation based on NREL ATB advanced pricing; all other generation pricing based on NREL ATB mid pricing • Nuclear outside of Oregon modeled as separate investments in reactor, steam turbine, and thermal storage. Costs from US DOE funded research by Colorado State University and developed with Oak Ridge National Lab. Thermal energy storage costs from the International Renewable Energy Agency.
Transmission Availability	(See Land Use and Natural Resources below) • Existing capacity, including PacifiCorp's Gateway South segment F in 2025 • Boardman to Hemingway (B2H) project assumed online in 2030 • Otherwise no new inter-zonal transmission is built until 2035 • New inter-zonal capacity modeled based on The Nature Conservancy Power of Place West
Inflation Reduction Act Incentives	Supply-side incentives include hydrogen production, renewable electricity generation, battery storage, carbon capture, clean fuels, out-of-state nuclear

Land Use and Natural Resources

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Land Use Screens

The Reference Scenario restricted the use of legally protected (PoP[1] Level 1), administratively protected (PoP Level 2), and high conservation value (PoP Level 3) areas in Oregon for energy development using The Nature Conservancy's PoP - West study as a framework to select land use screens.

Categories of Exclusion	Definition of Category	Examples	Biomass
PoP Level 1	Legally protected: Areas with existing legal restrictions	National Wildlife Refuges, National Parks, Marine Sanctuaries, Military Training Areas	All feedstocks included, exclude potential supply from conservation reserve program land
PoP Level 2	Administratively protected: Level 1 + areas with existing administrative and legal designations where state or federal law requires consultation or review and lands owned by non-governmental organizations (NGOs) on which there are conservation restrictions.	Critical Habitat for Threatened or Endangered Species, Sage Grouse Priority Habitat Management Areas, vernal pools and wetlands, tribal lands	No net expansion of land for purpose-grown herbaceous biomass crops. Specifically, land available for herbaceous biomass crops (miscanthus and switchgrass) is limited to the share of land currently cultivated for corn that is eventually consumed as corn ethanol, which is phased out in all net zero scenarios by 2050.
PoP Level 3	High conservation value: Level 1 + Level 2 + areas with high conservation value as determined through multi-state or ecoregional analysis (e.g., state, federal, academic, NGO) and lands with social, economic, or cultural value.	Prime Farmland, Important Bird Areas, big game priority habitat and corridors, TNC Ecologically Core Areas, "Resilient and Connected Network"	Same as Level 2

1. The Nature Conservancy's Power of Place (PoP) report outlined clean energy solutions for energy planners and policymakers to consider for net-zero strategies that benefit climate, conservation, and communities.

Land Use: Key Assumptions

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Input	Source
Emissions constraint target accounting	Emissions reduction of anthropogenic emissions, using natural climate solutions and sequestration not eligible
Carbon Capture and Storage (CCS)	CCS included as a carbon reduction option in the model
Non-CO_2, non-energy	EPA developed supply curves of measures to reduce non-CO_2 and non-energy emissions, e.g., reducing methane (CH_4) leakage, reducing f-gases in industrial processes and products, reducing nitrous oxide (N_2O) from soil management. Optimized by the model against energy emissions reduction measures
Marine Environment	PoP-West Level 3 category of exclusion used for offshore wind potential

Transmission and Distribution: Key Assumptions

Input	Source
Existing capacity	Existing capacity, including PacifiCorp's Gateway South segment F in 2025
Timing of Electricity Transmission Development	No new transmission until 2035, except for IPC's Boardman to Hemingway (B2H) project online in 2030.
Electricity Distribution System Cost Assumption	Proxy value based on historic costs from Energy Information Administration (EIA)
Pipeline Infrastructure Assumptions	No new infrastructure development beyond operations and maintenance for interstate natural gas pipelines
Electricity transfer capacity between East and West Oregon	Publicly available Bonneville Power Administration (BPA) data on historical path flows. Opportunity to expand transfer capacity economically in the model in 2035 and after with costs based on proposed Big Eddy to Chemawa and Round Butte to Bethel reconductoring projects and the Cascade Renewable Transmission Project

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Policy Assumptions

Economy-wide GHG Policy

Assumption Type	Reference Scenario Assumptions
Economy-Wide GHG Policy	State targets, include EO 20-04 in Oregon

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

Implementation of Oregon Policy

- EO 20-04
  - 45% below 1990 levels by 2035, 80% below 1990 levels by 2050
  - Economy-wide emissions target implemented in the model
  - Includes all sources of emissions
- CPP
  - 50% reduction in greenhouse gas emissions from fossil fuels, including diesel, gasoline, and natural gas by 2035, and 90% by 2050 relative to 2017 to 2019 average (does not include jet fuel or maritime fuel)
  - Not implemented in the model directly, but checked model results for CPP compliance
- HB 2021
  - 80%, 90%, 100% emissions free electricity by 2030, 2035, 2040, respectively. Baseline set by 2010, 2011, 2012 emissions average. Applies only to approximately 60% of load (estimated load share of Portland General Electric, PacifiCorp, and Electricity Service Suppliers based on 2023 OPUC Utility Statistics report)
  - This was modeled as an emissions cap for electricity in 2030 of 9.8 MMT-CO2e
    - This cap roughly approximates how high statewide emissions could potentially be, considering the possibility that new tech loads in non-HB 2021 jurisdictional service territories might be served with emitting power sources
  - In the sensitivity that explored 50 percent lower tech loads, the cap was approximated at 7.6 MMT-CO2e, reflecting a lower potential for emissions to rise with less overall load growth

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Land Use Assumptions

Power of Place Study – The Nature Conservancy

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- West-wide energy modeling incorporating detailed land use and habitat information to assess the land impacts of decarbonization. Questions asked include:
  - "How much clean energy will be needed to achieve economy-wide net-zero emission reductions by 2050?"
  - "How much land and ocean area will be required for the clean energy transition?"
  - "How will protecting sensitive natural areas and working lands affect energy costs?"
  - "What are the implications of renewable and carbon-neutral energy technology choices for natural and working lands, costs, and the pace of build-out?"
- Transmission options for the West examined with detailed GIS analysis and the latest transmission capacity studies

Potential Expansion Of Interties

- Power of Place-West: Identified major substations for interties between states, the existing corridors, the potential to reconductor or co-locate transmission in those corridors, and new potential right of ways for additional transmission expansion

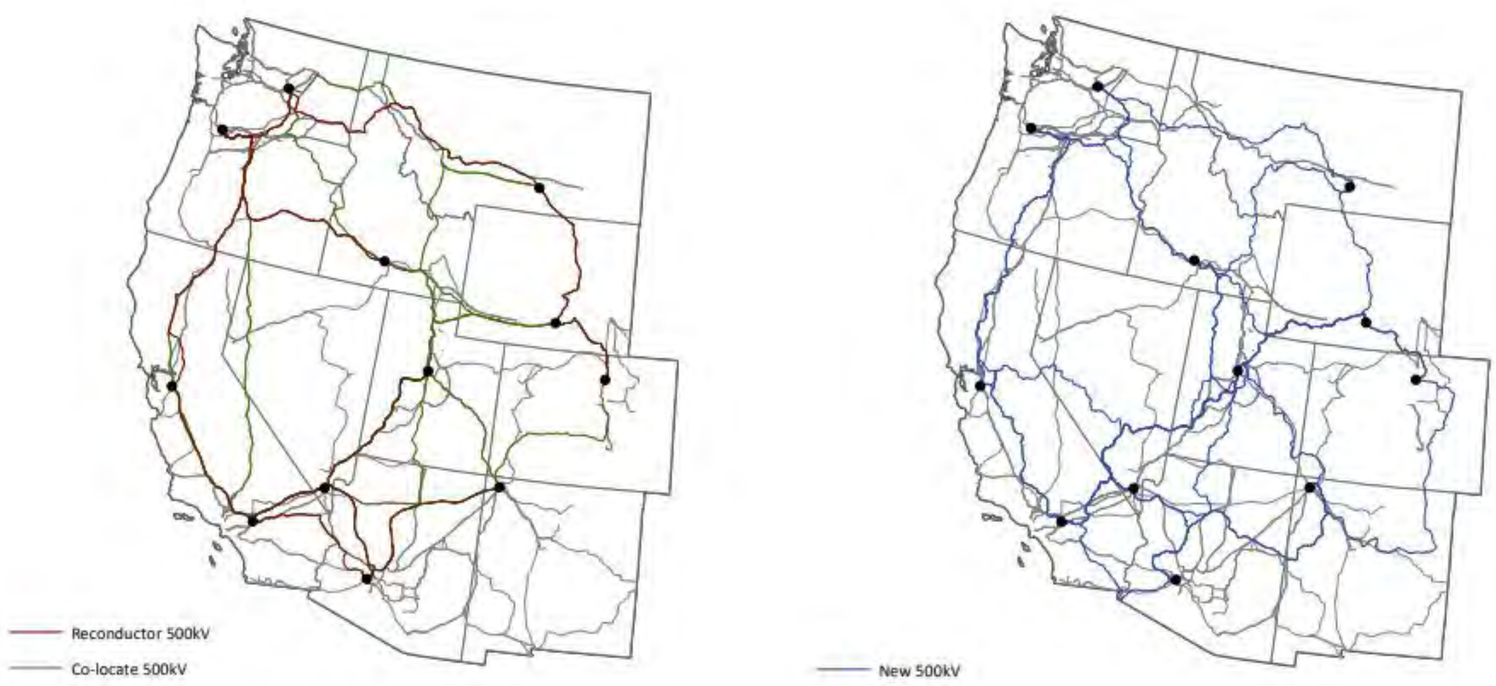


Fig. S8. Least cost path model results showing 500 kV transmission lines. Left: reconductored and co-located 500 kV lines only. Right: new 500 kV lines only.)

Source: Power of Place-West

Identifying Corridor Options

- Corridor options and their costs developed using GIS analysis of land use
- Costs developed using Black and Veatch Transmission Cost Calculator developed for the WECC transmission planning forums (TEPPC)
- Multipliers applied to costs based on terrain and type of land use
- Terrain broken up into 250km^2 grid cells and least-cost path for new transmission calculated

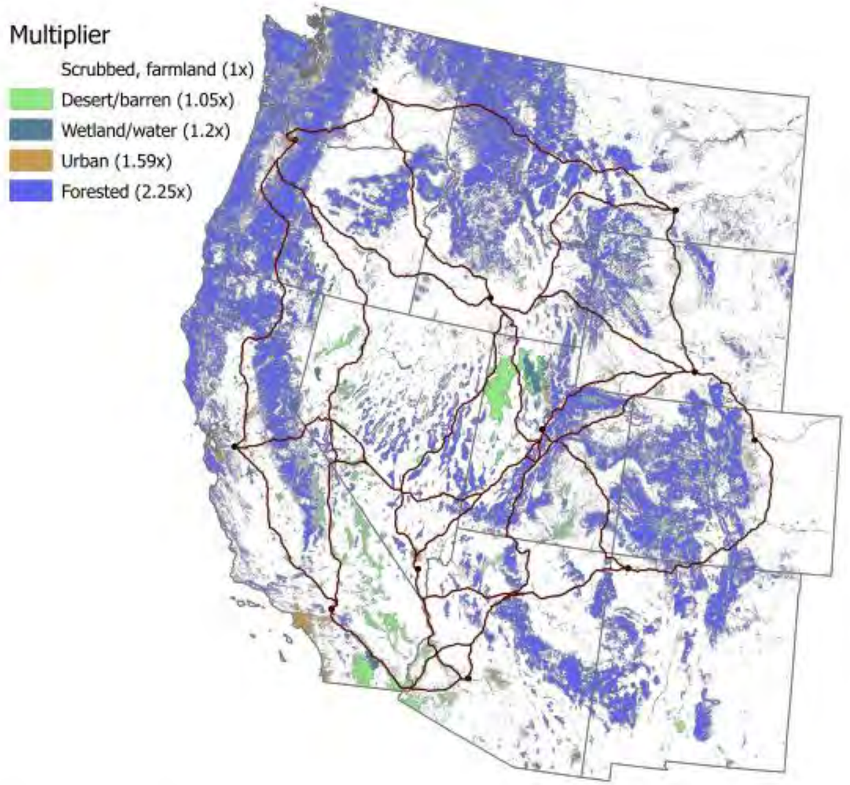
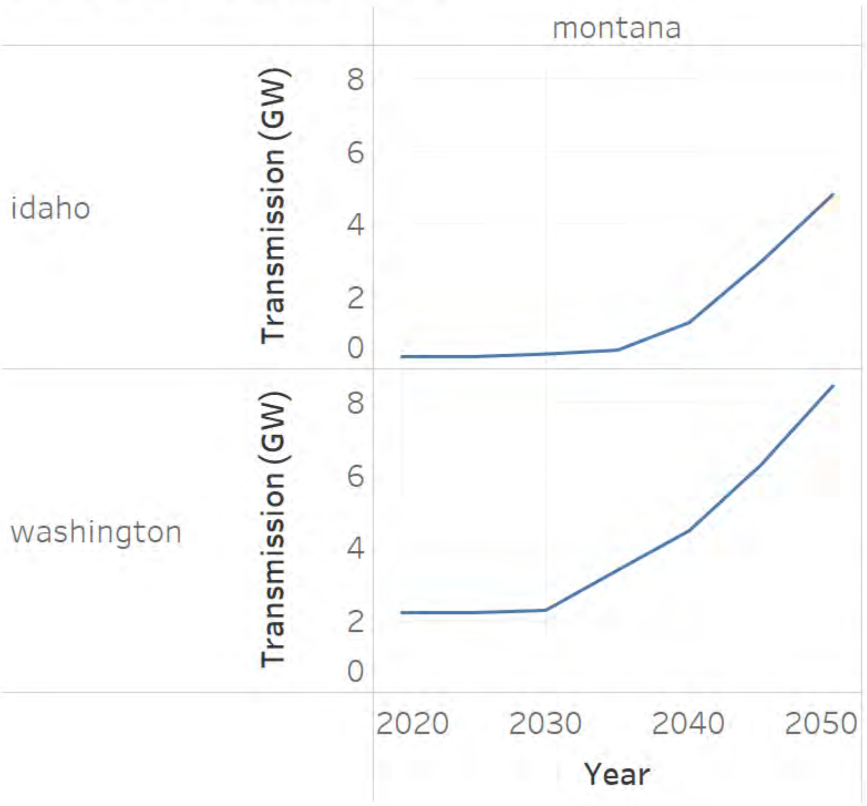


Fig. S7. Least cost path model results showing selected cost surface mutlipliers and new 500 kV transmission lines.
Source: Power of Place-West

Why we Rely on Power of Place–West

- Detailed study encompassing all interstate Tx options in the West
  - Consistency in cost estimations across varied terrain, line lengths, etc.
  - Price availability for multiple types of lines/upgrades
  - Leans towards conservatism on pricing

Transmission from Montana



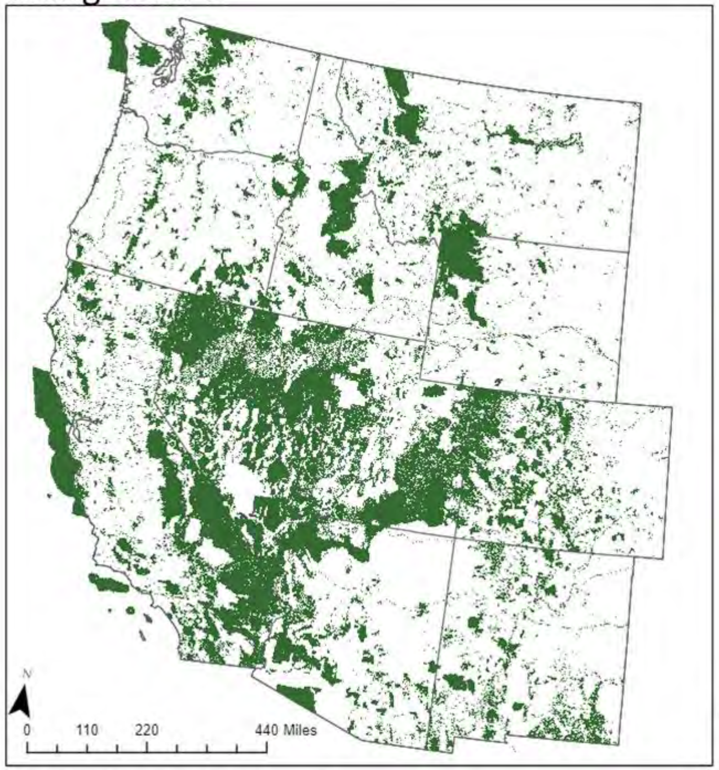
Power of Place – West Screens

Categories of Exclusion	Definition of Category	Examples	Biomass
Level 1	Legally protected: Areas with existing legal restrictions	National Wildlife Refuges, National Parks, Marine Sanctuaries, Military Training Areas	All feedstocks included, exclude potential supply from conservation reserve program land
Level 2	Administratively protected: Level 1 + areas with existing administrative and legal designations where state or federal law requires consultation or review and lands owned by non-governmental organizations (NGOs) on which there are conservation restrictions.	Critical Habitat for Threatened or Endangered Species, Sage Grouse Priority Habitat Management Areas, vernal pools and wetlands, tribal lands	No net expansion of land for purpose-grown herbaceous biomass crops. Specifically, land available for herbaceous biomass crops (miscanthus and switchgrass) is limited to the share of land currently cultivated for corn that is eventually consumed as corn ethanol, which is phased out in all net zero scenarios by 2050.
Level 3	High conservation value: Level 1 + Level 2 + areas with high conservation value as determined through multi-state or ecoregional analysis (e.g., state, federal, academic, NGO) and lands with social, economic, or cultural value.	Prime Farmland, Important Bird Areas, big game priority habitat and corridors, TNC Ecologically Core Areas, "Resilient and Connected Network"	Same as Level 2

https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/power-of-place/

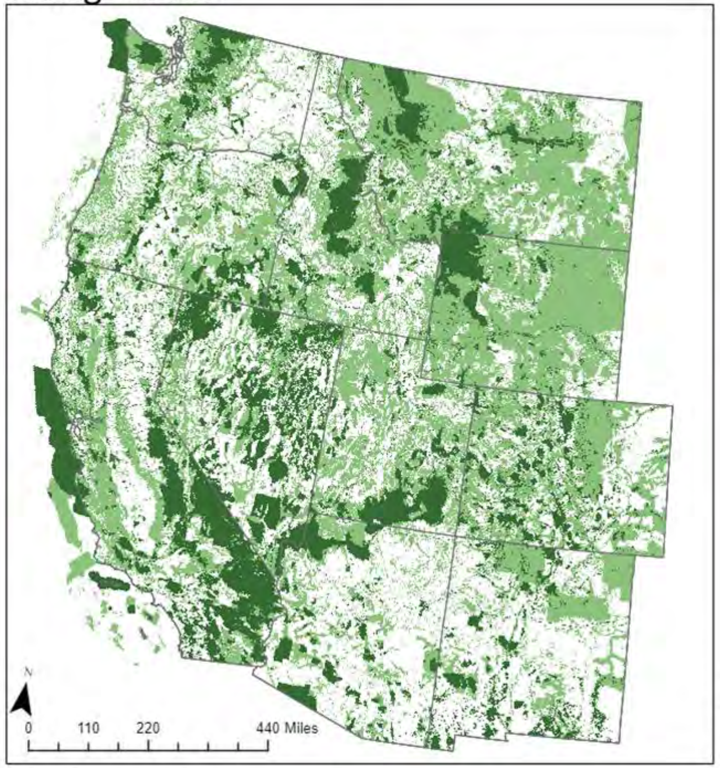
Power of Place – West Screened Out Land

Siting Level 1



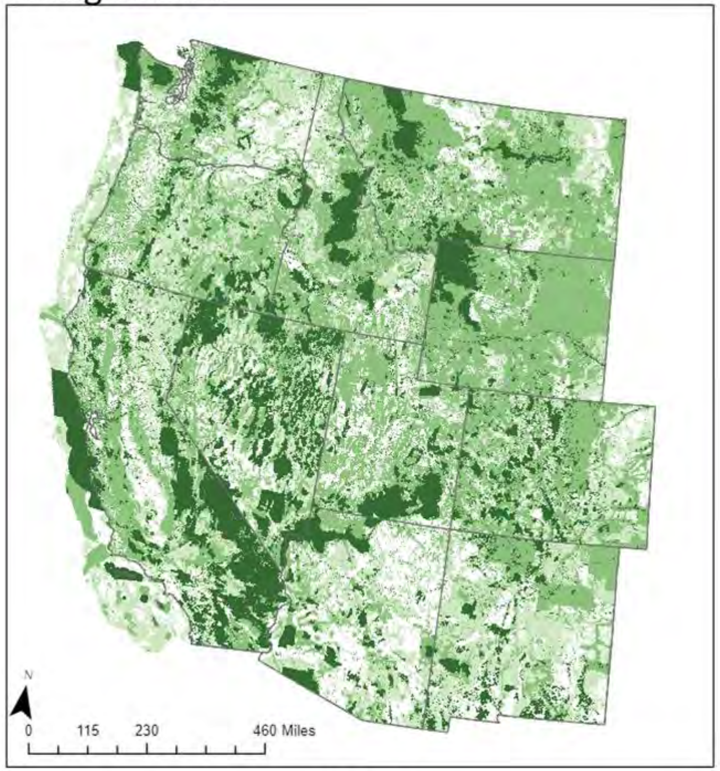
Excludes Category 1

Siting Level 2



Excludes Category 1, 2

Siting Level 3



Excludes Category 1, 2, 3

https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/power-of-place/

PoP West – Sources of Screens, General

EVOLVED ENERGY RESEARCH

Area Type	Description	Source	URL
Administratively protected areas (Environmental Category 2)	Administratively protected under current policy	Wu et al 2023, WECC Environmental Data Task Force, BLM West-Wide Wind Mapping Project	https://www.pnas.org/doi/10.1073/pnas.2204098120
High conservation value areas (Environmental Category 3)	Land with high conservation value that may not be currently protected	Wu et al 2023, Wu et al 2023, WECC Environmental Data Task Force, BLM West-Wide Wind Mapping Project	https://www.pnas.org/doi/10.1073/pnas.2204098120
Wetlands	National Wetlands Inventory (NWI)	USFWS National Wetlands Inventory	https://www.fws.gov/program/national-wetlands-inventory
Forests	Areas where the existing vegetation type life form is classified as tree	Landfire 2020	https://landfire.gov/evt.php
Conifer forest	Areas where the existing vegetation type physiognomy is conifer or conifer-hardwood	Landfire 2020	https://landfire.gov/evt.php
Shrublands	Areas where the existing vegetation type life form is classified as shrub	Landfire 2020	https://landfire.gov/evt.php
Grasslands	Areas where the existing vegetation type life form is classified as herbaceous	Landfire 2020	https://landfire.gov/evt.php
Resilient and connected network	A subset of The Nature Conservancy's Resilient Connected Network, including only Prioritized Network areas with Resilient, Concentrated Flow (Climate Informed), Recognized Biodiversity	The Nature Conservancy Resilient, Connected, Network	https://www.conservationgateway.org/ConservationPractices/ClimateChange/Pages/RCN-Downloads.aspx
Intact lands	Areas largely undisturbed by human modification. HMI < 0.082, except where modified per Hise et al 2022 (central U.S.)	Theobald Human Modification Index, others	https://datadryad.org/stash/dataset/doi:10.5061/dryad.n5tb2rbs1, https://www.mdpi.com/2073-445X/11/4/462
Intact tallgrass prairie	Landscapes in the eastern Great Plains with largely intact natural vegetation	Ostlie, W. Untilled Landscapes of the Great Plains; The Nature Conservancy: Minneapolis, MN, USA, 2003.	87

https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power_of_Place_National_Technical_Briefing.pdf

PoP West – Sources of Screens, Species

EVOLVED ENERGY RESEARCH

Area Type	Description	Source	URL
Grouse habitat (e.g., sage grouse and prairie chicken)	Habitat with conservation importance for grouse and prairie chicken species	Hise et al 2022, Wu et al 2023	https://www.mdpi.com/2073-445X/11/4/462, https://www.pnas.org/doi/10.1073/pnas.2204098120
Sensitive desert species habitat (e.g., desert and gopher tortoises)	Habitat with conservation importance for imperiled tortoise species	Wu et al 2023, USGS Southeast gopher tortoise habitat mode	https://www.pnas.org/doi/10.1073/pnas.2204098120, https://www.sciencebase.gov/catalog/item/5d0d4ba0e4b0941bde52a306
Sensitive whooping crane habitat	Key whooping crane stopover sites	Hise et al 2022	https://www.mdpi.com/2073-445X/11/4/462
Bat habitat	Key bat roosting areas in the central U.S. per Hise et al 2022, USFWS critical habitat for threatened and endangered species	Hise et al 2022	https://www.fws.gov/endangered/what-we-do/critical-habitats.html

https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power_of_Place_National_Technical_Briefing.pdf

PoP West – Sources of Screens, Social

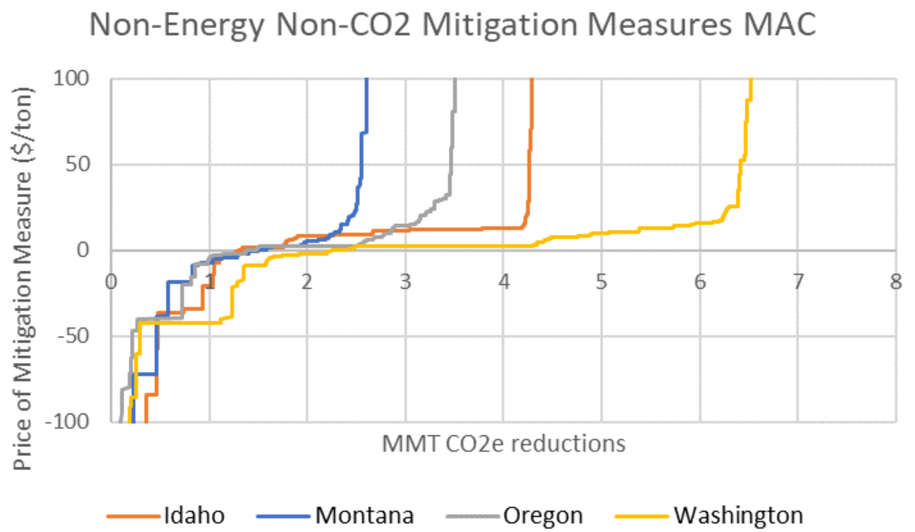
EVOLVED ENERGY RESEARCH

Area Type	Description	Source	URL
Energy Communities	Brownfields [not mapped], areas with significant fossil fuel employment, and areas with retired coal power plants	2022 Inflation Reduction Act	https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf
Low-Income Communities	Areas with high poverty rates according to the U.S. Census	2022 Inflation Reduction Act	https://www.congress.gov/117/bills/hr5376/BILLS-117hr5376enr.pdf
Croplands (general)	Vegetation of agricultural lands, including row crops, intensive pastures, orchards, vineyards, plowed or harvested fallow fields, rice paddies, and farm ponds	Landfire 2020	https://landfire.gov/evt.php
Productive farmland	Productive Versatile Resilient farmland (value = 0.53 on a scale of 0-1)	American Farmland Trust "Farms Under Threat" Report	https://farmlandinfo.org/publications/farms-under-threat-the-state-of-the-states/ https://farmlandinfo.org/wp-content/uploads/sites/2/2020/05/AFT_FUT_PVR_Fact_Sheet.pdf
Marginal farmland	Challenging soil' based on USDA Gridded Soil Survey Geographic Database	USDA Gridded Soil Survey Geographic Database	https://www.nrcs.usda.gov/resources/data-and-reports/gridded-soil-survey-geographic-gssurgo-database

https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power_of_Place_National_Technical_Briefing.pdf

Non-CO_2 and Land Use

- Non-CO_2 emissions are part of the state's emissions inventory and the modeling included both forecasts for how these might change over time and opportunities to avoid them
- These include methane emissions, fluorinated gas emissions, and nitrous oxide
- We used EPA Non-CO_2 Emissions and Mitigation Measures to project baseline non-CO2 emissions and identify opportunities to reduce them
  - Supply curve of mitigation measures for non-CO_2 reductions starts negative
    - Some measures taken have economic benefits. Examples include gas recovery, better maintenance practices, leak reduction
  - Majority of non-energy non-CO_2 measures are achievable at less than $25/ton



THANK YOU

EVOLVED ENERGY RESEARCH