Contents

• Introduction
• Review of State Targets
  – Where is Washington going and how does it compare to present day?
• Scenario Descriptions
• Demand Side Results
• Supply Side Results
• Decarbonization Costs
• Key Findings
• Technical Appendix
  – Methodology overview
  – Key assumptions
Introduction
Transforming Washington’s Energy System

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

Emissions targets for State Energy Strategy:

2020: 1990 levels
2030: 45% below 1990
2040: 70% below 1990
2050: 95% below 1990
2050: Net zero
Approach to Modeling Decarbonized Energy Supply

- **Explores** how Washington can achieve deep decarbonization across all energy sectors to meet the emissions targets
- **Conservative** assumptions about existing technologies and cost projections from public sources
- **Modeling determines optimal investment** in resources with least-cost, constrained by scenarios that balance different state objectives
- **Decarbonizing energy supply**—electricity, pipeline gas, liquid fuels
- Models integrated electricity and fuels systems that extend beyond Washington’s borders to **capture regional opportunities and challenges**
Investigate State Strategy through DDP Modeling: Three Framing Questions

• Where are we now?
  – *What is the current state of Washington’s energy system?*

• Where do we want to go?
  – *What are Washington’s most desirable pathways to meeting emissions goals?*

• How should we get there?
  – *What policies and actions get us to where we want to go?*
Where Are We Now?

What does the energy system look like today and what will shape it going forward?

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

### Existing Washington policies and targets through 2030 and 2050
- Utility resource plans
- Energy code strategy
- Energy Independence Act
- Appliance standards
- Power plant emission standards
- Clean Energy Transformation Act
Where Do We Want to Go?

Translate State objectives and potential policy pathways into constrained scenarios

• What is the best future we can envision for the state?
  – Balance of different, often competing objectives
    • Equity, affordability, reliability, competitiveness
  – Alternative least cost pathways examining different priorities

• Understanding the tradeoffs
  – How much does one pathway cost versus another?
    • Counterpoint for policymakers and stakeholders
  – Provides a target for near-term policy and action design to hit

• Understanding the uncertainties
  – How does an uncertain future impact our decisions?

Investigating policies & uncertainties through scenario analysis

100% clean electricity grid

Electrification of demand side equipment

Examples for illustration only

Constrained resource potentials

Behavior changes that lower service demands
How Should We Get There?

• By targeting favorable future pathways we can **develop and prioritize near-term policies and actions**

• Targets are not prescriptive, but provide the best guidance given current information and uncertainties
  – Common elements deployed 2020-2030: “no regrets”
  – Replace or avoid long-lived resources
  – Early action on long lead-time or hard to achieve energy transformations

• Policy development that favors Washington’s goals
  – Equity, affordability, reliability, competitiveness

• “How should we get there?” not addressed in DDP modeling, but outputs of modeling inform development of the Washington State Energy Strategy
  – Least-cost energy system planning, and policy/action design complement one another
State Targets
Clean Energy Transformation Act (CETA)

CETA Requirements

- 2025: Eliminate coal-fired electricity from state portfolios
- 2030: Carbon neutral electricity, >80% clean electricity with up to 20% of load met with alternative compliance:
  - Alternative compliance payment
  - Unbundled renewable energy certificates, including thermal RECs
  - Energy transformation projects
  - Spokane municipal solid waste incinerator, if results in net GHG reduction
- 2045: 100% renewable/non-emitting, with no provision for offsets

CETA Implementation in the Model*

- 2025: Retire all WA coal contracts
- 2030: Constrain delivered electricity generation serving WA loads to be 80% or more from clean sources
  - Accounting on retail sales rather than production, i.e., losses are not included
- 2030: Constrain the remaining 20% to come from non-delivered RECs
  - Linear transition to 100% delivered clean energy by 2045
- 2045: 100% delivered clean electricity
  - Accounting on all electricity production for in state consumption, i.e., losses are included
  - Fossil generation can supply out-of-state load

*Model assumptions on implementation developed prior to rulemaking and not indicative of final implementation
CETA Renewable Energy Credit Accounting in the Model

• **Implementation of delivered clean electricity (delivered RECs)***
  – Investments in new clean energy resources are specified, and only delivered MWhs to WA loads count towards CETA delivered energy compliance
  – Delivered RECs included in hourly system balancing
  – Available transmission required for delivery

• **Implementation of non-delivered RECs***
  – Accounting on an annual basis: WA requires clean energy credits equal to non-delivered portion of energy compliance each year
  – No hourly delivery or transmission required

*Model assumptions on implementation developed prior to rulemaking and not indicative of final implementation
## West Wide RPS/CES Targets

<table>
<thead>
<tr>
<th>State</th>
<th>Reference Case</th>
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<tr>
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<td>Washington</td>
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<td>Wyoming</td>
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Emissions Targets Set Based on the State’s 1990 GHG Footprint

Washington 1990 Emissions Inventory

- Washington’s 1990 GHG emissions footprint was **90.5 million metric tons**
- Energy and industry related CO\textsubscript{2} emissions represent ~87% of all emissions
  - CO\textsubscript{2} emissions from **electricity generation** were from coal, representing 19% of total emissions
  - Transportation (42%), RCI (20%), and Industrial CO\textsubscript{2} (6%) make up the remainder of energy and industry related CO\textsubscript{2} emissions
  - Non-CO\textsubscript{2} emissions (13%) make up the remainder
- Washington starts from a smaller share of emissions from electricity than other states because of the large hydroelectric fleet producing clean energy

**Notes:** Industrial CO\textsubscript{2} includes industrial process emissions not from fuel combustion; non-CO\textsubscript{2} emissions includes agriculture, waste management, and industrial non-CO\textsubscript{2} emissions
Washington Emissions Targets

- Washington established economy-wide emissions goals of net zero and 95% reduction in gross emissions by 2050
  - In line with IPCC targets
- Implementation of emissions goals:
  - 95% gross emissions reductions target is independent of land-based emissions reductions
  - Emissions reductions possible in non-energy and non-CO₂ sources are uncertain and need more research to develop reduction measures
    - We assume that the limited land use mitigation potential will offset the emissions from this category
- Target for the energy sector: **Net zero by 2050**
### Emissions Targets by Year

<table>
<thead>
<tr>
<th>Year</th>
<th>Non-CO₂/Non-Energy Emissions</th>
<th>Incremental Land Sink</th>
<th>CO₂ Energy and Industry</th>
<th>Economy wide CO₂ Target to reach statewide GHG limits</th>
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<td>2050</td>
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<td>-4.50</td>
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</table>

- **Forecasted from latest WA non-CO₂ inventory using EPA growth rates**
- **Starting target of 76 MMT: COVID-19 drops emissions below this target**
- **~50% reduction in energy emissions over 10 years**
- **5% gross emissions from non-CO₂, 100% offset by incremental land sink**
- **Non-CO₂ emissions reductions significant but uncertain and requires future research**
- **Net zero target in energy and industry**

- Net zero target in energy and industry

- Forecasted from latest WA non-CO₂ inventory using EPA growth rates
- Starting target of 76 MMT: COVID-19 drops emissions below this target
- ~50% reduction in energy emissions over 10 years
- 5% gross emissions from non-CO₂, 100% offset by incremental land sink
- Non-CO₂ emissions reductions significant but uncertain and requires future research
2030: The Energy Emissions Challenge

The DDP modeling analyzes how the CO2 energy and industry emissions targets can be met

- **2030 emissions target for energy and industry less than half of 2018 emissions**
  - 40 MMT assumes linear decreases in non-CO2 emissions and linear increases in incremental land sink through to 2050

- **Washington’s electricity sector is already very clean:** Early emissions reductions are required from actions in other sectors to meet the 2030 target

- **The 2030 challenge: How to cut emissions in half in 10 years?**
Options and Obstacles to Reaching 2030 Targets

- Decarbonizing all electricity generation from 2018 leaves 28.6 MMT to decarbonize (40% of remaining emissions)

- What are the options?
  - **Energy Efficiency**: Reduce energy use through more efficient appliances, processes, and vehicles
  - **Electrification**: Electrify end uses and supply with clean electricity
  - **Decarbonize fuels**: Displace primary fossil fuel use with clean fuel

- What are the obstacles?
  - Efficiency and electrification require new demand-side technology investments
    - Dependent on customers replacing inefficient technologies with efficient and/or electrified options
    - Dependent on stock rollover: A customer with a new ICE vehicle won’t replace it the next year with an electric one
  - Decarbonized fuels require bio or synthetic fuels technologies that have yet to be deployed at scale
  - **Limits to what can be achieved in 10 years**
West-Wide Emissions Targets

States without targets follow trajectory for 80% economy wide emissions reductions in decarb cases

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Scenario Descriptions
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<th>Summary</th>
<th>Key Question</th>
<th>Policy Mandates</th>
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<td>Reference</td>
<td>Business as usual</td>
<td>Assumes current policy is implemented and no emissions target</td>
<td>No constraints on emissions.</td>
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<tr>
<td>Electrification</td>
<td>Investigates a rapid shift to electrified end uses</td>
<td>What if energy systems achieved aggressive electrification and aggressive efficiency, and relatively unconstrained in-state and out-of-state technology were available?</td>
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<tr>
<td>Transport Fuels</td>
<td>Investigates reaching decarbonization targets with reduced transportation electrification</td>
<td>What alternative investments are needed when larger quantities of primary fuels remain in the economy?</td>
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<td>Gas in Buildings</td>
<td>Investigates reaching decarbonization targets by retaining gas use in buildings</td>
<td>What is the difference in cost of retaining gas appliances in buildings?</td>
<td>Meets 2050 net zero emissions target</td>
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<tr>
<td>Constrained Resources</td>
<td>Investigates a future that limits potential for transmission expansion into Washington</td>
<td>What alternative investments in in-state resources would Washington make if transmission expansion is limited due to siting/permitting challenges?</td>
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<tr>
<td>Behavior Changes</td>
<td>Investigates how lower service demands could impact decarbonization</td>
<td>What if policy-driven or natural behavior changes (i.e., more telecommuting post COVID-19) lower service demands?</td>
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## Scenario Summary

<table>
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<tr>
<th>Scenario Assumptions</th>
<th>Reference (R)</th>
<th>Electrification (E)</th>
<th>Transport Fuels (TF)</th>
<th>Gas in Buildings (GB)</th>
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<td>CETA: Coal retirements 2025; 100% carbon neutral 2030 (with alternative compliance); 100% RE 2045</td>
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<td><strong>Economy-Wide GHG Policy</strong></td>
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<td>Reduction below 1990: 45% by 2030; 70% by 2040; 95% and net zero by 2050</td>
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<td>Fully electrified appliance sales in most sub-sectors by 2050</td>
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<td><strong>Buildings: Energy Efficiency</strong></td>
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<td>Sales of high efficiency tech: 100% in 2035</td>
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<td><strong>Transportation: Light-Duty Vehicles</strong></td>
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<td>100% electric sales by 2035</td>
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<td>Half the electric sales/no hydrogen adoption</td>
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<td>Generic efficiency improvements over Reference of 1% a year; fuel switching measures; 75% decrease in refining and mining to reflect reduced demand</td>
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<td><strong>Service Demand Reductions</strong></td>
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<td>Baseline service demand informed by AEO</td>
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<td>NREL resource potential; 6 GW of additional transmission potential per path; SMRs permitted</td>
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<td>Washington: No new TX</td>
<td>Same as R, E, TF, and GB Cases</td>
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Structure of results

• The results are structured as follows:
  – Economy-wide GHG emissions: Emissions reductions by fuel to reach net zero by scenario
  – Energy demand: how energy demand evolves over time under the assumptions in each scenario
  – Supply side: Investments in and operations of electricity and fuels supply
    • Electric and fuels sector metrics show the scale and rate of change required
    • Grid balancing and the integration of electric and fuels sectors
  – Costs: Comparison of decarbonization scenario costs and the Reference Scenario
  – Key Findings: Implications of decarbonization overall and by sector
CO₂ Emissions by Scenario

Similar emissions profile to achieving net zero in energy by 2050 across scenarios

- Emissions levels by fuel type remain relatively constant in Reference Case
- Product and bunkering CO₂ provide negative emissions in accounting
- Similar trajectories as end use demand drives reductions in gas use while liquid fuels are decarbonized

**Coal**
**Diesel, Gasoline, Jet Fuel**
**Natural Gas**
**Other**
**Residual Fuel Oil**
**Product and Bunkering CO₂**

*Emissions offset for CO₂ captured in products, or not WA’s responsibility, i.e. portion of international shipping emissions*
Total Gross Emissions: Reference vs Electrification Scenarios

Emissions reduction shown by sector

- Washington Historical and Projected Gross Emissions
  - Historical Emissions
  - Projected Emissions
  - Reference Scenario
  - Electrification Scenario

- Non-energy reductions assumed in decarbonization cases

- Incremental biological or geological sequestration measures assumed to offset remaining non-energy emissions in 2050

- Drop between 2018 and 2020 due to Covid-19

Emissions targets relative to 1990 levels
Final Energy Demand

Electrification and efficiency drive lower total energy demand

- **COVID:** 10% drop in demand in 2020 due to COVID impact
- **Electrification:** 90% growth in electricity sector over 2020 levels, displacing fuels
- **Transport Fuels:** Demand for fuels remains in 2050
- **Buildings:** Higher demand for gas due to less electrification
- **Behavior:** Fewer energy services drive demand lower

**Final Energy Demand (Tbtu)**

- **Diesel Fuel**
- **Gasoline Fuel**
- **Jet Fuel**
- **Pipeline Gas**
- **Electricity**
- **Other**
- **Hydrogen**
- **Residual Fuel Oil**

**Reference**

- **2020**
- **2030**
- **2040**
- **2050**

**Electrification**

- **28%**

**Transport Fuels**

- **23%**

**Gas in Buildings**

- **24%**

**Behavior Change**

- **32%**
Final Energy Demand: Electricity

Electricity use in all decarbonization scenarios grows significantly.

- Transport electrification is the largest differentiator between cases.
- Decreased electrification reduces electricity need in buildings relative to the Electrification Scenario.
- Behavior change drives lower demand in transport and buildings.

The diagram shows the final energy demand for electricity in different scenarios from 2020 to 2050, categorized by industrial, commercial, and residential sectors.
Light-Duty Vehicles: BEVs are Key to Lower Energy Demands

Lower energy demands reduce the need for investment in clean energy technologies to meet net zero.

Projected Sales, Stock, and Final Energy Demand

73% of vehicles are ICE in 2030 in the Electrification Case.

Electrification Case final energy demand for fuels remains high in 2030: 74% of Reference in 2030.
Heavy-Duty Vehicles: Hydrogen Demand in Long Distance by 2050

Adoption of hydrogen in long-haul and electric in long and short-haul drives changes in demand.

<table>
<thead>
<tr>
<th>Sales Share</th>
<th>Stock</th>
<th>Final Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference</strong></td>
<td>ICE</td>
<td>ICE</td>
</tr>
<tr>
<td><strong>Electrification</strong></td>
<td>ICE, Electric</td>
<td>ICE, Electric, Hydrogen</td>
</tr>
<tr>
<td><strong>Transport Fuels</strong></td>
<td>ICE, Electric</td>
<td>ICE</td>
</tr>
</tbody>
</table>

Projected Sales, Stock, and Final Energy Demand
More efficient home heating is driven by adoption of more efficient and/or electrified technologies

2030 Challenge: Delay in stock rollover turning sales into stock and energy changes

Significant reductions in energy demand by 2050 due to efficiency and electrification

Fuel use for heating can be served by fossil or clean fuel alternatives
Behavior Change: Transportation

- VMT reductions increasing over time
  - 29% in light-duty vehicles by 2050
  - 15% in medium- and heavy-duty vehicles by 2050
- 2030 reductions are modest and provide little help to solving the 2030 Challenge
  - Are there more aggressive behavior change measures that can happen faster?

Example: Final Energy Demand from Light-Duty Autos

- 29% percent reduction in sales of fuels and electricity vs. Electrification Case by 2050
Behavior Change: Residential and Commercial

- Package of service demand measures for residential and commercial sectors
  - Reductions for several subsectors, including air conditioning, heating, lighting, and water heating
- Service demand measures achieve 7% overall reduction by 2050 in the residential and commercial sectors
  - 2% reduction in 2030
Supply Side
Electricity Capacity in Washington

Washington relies heavily on imports of clean energy so capacity builds stay relatively flat.

- CGS not extended. O&M costs too high compared to alternatives.
- Similar builds across decarbonization cases other than Constrained Resource Case.
- Constrained Resource Case builds offshore wind and more solar to compensate for lost TX.

Relatively little growth in capacity due to significantly increased imports.
Capacity Additions in Washington and the Northwest

Washington part of a larger integrated electricity system

- Wind-dominant system complements solar resource of the Southwest
- Lower forecasted costs drive large offshore wind resource by 2050

11 GWs of gas capacity additions provide reliability in the Northwest, operated at low capacity factors. De minimus gas use in Washington, used only for rare reliability events.
Generation and Load in Washington

Increases in imports provide clean energy for expanding electricity sector

Growing reliance on clean imports to meet load growth, CETA, and emissions goals

Imports provide 43% of electricity in Electrification Case by 2050

Growth in clean electricity in Constrained Resources case due to offshore wind

Doubling of 2020 load by 2050, including new flexible loads (electrolysis, boilers)

Gas exports not prohibited under CETA but model assumes emissions count towards state inventory in decarbonization cases
Where do Imports Come from?
Clean electricity imports from Electrification Case

High quality wind resources from Wyoming and Montana account for 36% of WA clean electricity in 2050
Expanding Transmission Facilitates Imports

Increased TX capacity required to import so much energy

- Expansion of up to 6 additional GWs of TX between states permitted in the model
  - MT->WA: Maximum 6 GW added by 2050
  - ID->WA: 5 GW added by 2050
- Western states become far more interconnected, taking advantage of least cost clean energy resources
- Additional solar and offshore wind build in Constrained Resources Case from inability to expand interties
Regional Capacity in 2050

Electrification Case

Offshore wind built in Northwest and California to meet 2050 clean energy needs.

Gas capacity provides reliability but very little energy in 2050.

Large quantity of storage built in solar states for diurnal balancing.

Large wind resource complements Southwestern solar resource.

Inland states become major exporters of wind with majority wind capacity systems by 2050.
Clean Fuels are Important to Reach Decarbonization Targets

Washington starts from a clean electricity sector and needs emissions reductions from other sectors

- All liquid fuels are fully decarbonized by 2050
- Decreasing fuel consumption over time with electrification and efficiency
- Liquid fuels (gasoline, diesel, jet fuel, others) significantly decarbonized by 2030 with synthetic and biofuels
  - Significant growth in clean fuels industries with few current commercial operations
  - Challenge for Washington to reach 2030 targets
- Hydrogen demand driven by long-haul trucking fleet
- Majority emissions in 2050 from natural gas in primary end uses
Where do Clean Fuels Come from?

Heavy reliance on clean fuel imports from the rest of the country in Washington

Decline as ICEs are electrified followed by increase to reach full decarbonization

34% higher clean fuel demand in Transport Case vs Electrification

2030 peak in clean fuel demand due to large number of ICEs still on the road

*Deployed fuels technology is sensitive to uncertain performance and cost assumptions. The type of fuels production processes used to displace fossil fuels will be a function of relative prices and the ability to retool existing refineries
Fuels Production Capacity by 2050

National production capacity to serve US needs: Electrification Case

- Large total conversion capacity investment needed across the US to produce clean fuels
  - Includes demand from other states
- WA demand met with investment in fuels conversion infrastructure, biomass, and clean electricity
- Greater capacity investment needed to meet bio and synthetic fuels demand in Transport Fuels Case
  - Increased WA demand met with investment in fuels production infrastructure
National Fuels Industry in 2050: Hydrogen and Carbon

Building blocks of synthetic fuels, drives demand for biomass and renewable energy
Balancing the System: High Energy and Low Energy Days in 2050

Washington relies on flexible loads, imports, hydro, and electrolysis to balance load.

Unconstrained energy day in March: imports and electrolysis

Constrained energy day in November: flexible loads, clean gas generation, reduced imports, no electrolysis

Western States

Significant storage build in the rest of the west helps balance diurnal solar shape

Flexible Load
Energy Storage
Imports
Solar
Wind
Hydro
Gas

Flexible Load
Storage
Other Conversion
Electrolysis
End-use Load
Seasonal Balancing in 2050: West Wide

Fuels production an integral part of balancing the electricity grid in 2050

- Seasonal imbalance of intermittent renewable energy availability
  - Shifting energy across seasons difficult with current storage technologies such as lithium ion

- Clean fuels demand is an opportunity for seasonal balancing
  - Store electricity in liquid fuels

- Large flexible electrolysis loads can help balance the grid over different time scales

Peak end-use demand in 2050 coincides with lowest renewable availability and decrease in fuels production

Renewable Generation and Electrolysis in 2050 (TWh)

2050 End-use Demand

Electrolysis

Offshore Wind
Onshore Wind
Solar
Hydro

Solar
Onshore Wind
Offshore Wind
Hydro
Washington’s Main Balancing Resources

Hydro, imports, electrolysis, and flexible loads are principal balancing resources in WA

- Positive: Load
- Negative: Supply

Lower summer electrolysis due to reduced imports

Flexible loads drive down peak loads

Gas generation provides capacity towards reliability requirements but does not deliver energy to Washington loads

Hydro operated flexibly, adhering to historically observed minimum flow, ramp, and energy constraints

Washington loads higher in the winter in contrast to the West as a whole
Takeaways by Scenario

• There are common trends across all scenarios
  – Strengthened Western grid to take advantage of resource and geographic diversity
  – Large build of solar in the Southwest and wind in the inland states (MT, WY)
  – A large clean fuels industry developed based on biofuels and hydrogen from electrolysis

• The scenarios show how Washington would respond differently under different conditions
  – The Transport Fuels Case drives a 32% increase in clean fuel use in the state with reduced electricity consumption
  – The Gas in Buildings Case drives clean gas production not seen in other cases to ensure decarbonization goals are met
  – The Behavior Change Case reduces Washington’s need for clean energy and fuels
  – The Constrained Resources Case drives additional solar build and offshore wind in Washington

• Bottom line: how much do these solutions cost relative to one another?
Costs
Understanding the Costs of Decarbonization

Costs and benefits of Electrification Case relative Reference Case in 2050 shown

Increased costs relative to Reference Case:
- Demand side equipment
- Supply side equipment
- Operating costs

Cost savings relative to Reference Case:
Avoided equipment and operating costs (predominantly fuel purchases)

Results from decarbonization modeling include direct costs and avoided costs of decarbonization (reported in next slides)

Health benefits from improved air quality*

Net benefits* of decarbonization including health costs

*Not calculated in this study and illustrative only. Will be published in a later report and include the economic impacts of decarbonization. If the rest of the world takes similar action, Washington may receive additional climate mitigation benefits
How much does Decarbonization Cost?

Increase in average energy expenditures vs Reference Case. Early costs followed by later savings.

On average, spending slightly higher than Reference Case. Driven by increased costs to reach 2030 target. Decarbonization net benefit in the 2040s.

Average Annual Energy Expenditure (%GDP/yr)

- Reference
- Electrification
- Transport Fuels
- Gas in Buildings
- Limited Resources

Costs:
- Transport Fuels
- Gas in Buildings

Savings:
- Electrification
- Limited Resources

Net Cost Relative to Reference Case (%GDP/yr)

- Costs:
  - 2020: 1.1%
  - 2030: 0.8%

- Savings:
  - 2020: 0.0%
  - 2030: 0.0%

Year

2020 2025 2030 2035 2040 2045 2050
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Net Cost (GDP/2018$B/yr) Relative to Reference Scenario*:</th>
<th>Cost Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2030</td>
<td>2050</td>
</tr>
<tr>
<td>Electrification</td>
<td>0.9%/$6.8B</td>
<td>-0.1%/-$1.4B</td>
</tr>
<tr>
<td>Transport Fuels</td>
<td>1.0%/$8.2B</td>
<td>0.2%/$2.4B</td>
</tr>
<tr>
<td>Gas in Buildings</td>
<td>1.0%/$7.3B</td>
<td>0.2%/$2.0B</td>
</tr>
<tr>
<td>Constrained Resources</td>
<td>1.0%/$7.0B</td>
<td>-0.1%/-$0.9B</td>
</tr>
</tbody>
</table>

*Costs reflect changes in investments in demand and supply side equipment, operations costs, and avoided fuel costs versus the Reference Scenario. Not reflective of ratepayer costs, economic impacts, health benefits, or climate mitigation.
Cost Components of Decarbonizing Relative to Reference Case

Costs by component

- Cost increases in 2030 driven by demand for clean fuels
- Projected technology cost decreases by 2050 result in net savings over reference case
- Transport Fuels and Gas in Buildings: greater demand for synthetic and biofuels
- Constrained Resources: Greater spend on renewables but reduced investment in new transmission

Annual Net Cost relative to Reference Case (%GDP/yr)

- Electrification
- Transport Fuels
- Gas in Buildings
- Constrained Resources

Direct Air Capture
Electricity Storage
Biofuels
Electricity Grid
Gas Power Plants
Nuclear Power Plants
Other
Renewables
Demand Side Equipment
Synthetic Fuels
Liquid Fossil Fuels
Natural Gas
Gas Pipeline
Liquid Fuel Delivery
Historical Context: Total Energy Spending as Percentage of Washington GDP

Forecasted decarbonization spending stays below historical average in all years

- Decarbonization spending in Electrification Case stays below historical average in all years
- Significant increase in GDP spending in the near-term with benefits in the long-term

- Historical energy spending between 4-8% of GDP
- Spikes in GDP from fossil fuel price volatility and the 2008 recession

Drop in % of GDP from 2018 to 2020 because of COVID: 0.3% GDP contraction* and assumed 10% drop in energy demand

GDP rebound in 2021 of 3.9%. GDP growth rates annually of between 2% and 3%*

*GDP projections for Washington sourced from REMI
Uncertainty in Cost Inputs

Decarbonization costs are uncertain

- 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

Electrification Case Net Cost

Total Energy Spending %GDP

Range from 2.5% to 3.0% of GDP based on +/-10% clean vehicle related costs in 2050

-/+ $2.4B/yr (0.2%GDP) by 2050 from -/+ 10% clean vehicle costs
Behavior Change Case

Significant savings but unknown costs. Further work: what service demand options does the state have?

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<td>Behavior Change</td>
<td>0.8%/$6.0B</td>
<td>-0.3%/-$3.0B</td>
</tr>
</tbody>
</table>

Behavior Change case does not include the costs of achieving VMT reductions

• 2030 behavior change impact is 6% VMT and 2% in res/com, so relatively small changes have significant value
• Not directly comparable to the other decarbonization cases because the results do not include the cost of achieving behavior change
• Results show the value of achieving service demand reductions
  – Spending up to the value of the reductions to achieve them would be cost effective, i.e. can spending <$1.5B/yr by 2050 achieve 29% VMT and 7% res/com reductions?
  – Additional benefits if vehicle sales as well as VMT were reduced
  – Not accounting for ancillary benefits such as reduced road maintenance, local pollution etc.
• Topics for further study: what types of measures could achieve service demand reductions cost effectively? How fast could these be implemented?
Key Findings
Key Findings

- Challenges of decarbonization are pace of action in the near-term (2030) and scale in the long-term (2050)
- Washington’s electricity supply emitted 16.2 MMT CO2e in 2018 of the 44.8 MMT CO2e required to reach the 2030 goal, so decarbonizing the 2018 electricity supply cannot play a large role in accomplishing the 2030 goal
- Even with GHG-neutral electricity under CETA, 2030 emissions target is challenging
  - Focus must be on demand side and fuels: Energy efficiency, electrification, decarbonized fuels
  - Stock rollover of technologies with long lives raise the question of how much efficiency and electrification can be accomplished in 10 years
- Some actions to meet 2030 target may not contribute to 2050 target
  - Diesel and gasoline use reduces dramatically with electrification of transportation by 2050
  - Infrastructure to decarbonize fuels should focus on fuels that remain in the economy through 2050
- Washington requires regional energy solutions to accomplish the emissions targets
  - Significant imports of clean energy in the form of electricity and fuels are present in all scenarios
Key Findings

• Significant imports of clean energy from wind-rich states support Washington’s electricity needs – 43% by 2050 in Electrification Case
  – Regional coordination is key to Washington and Western decarbonization
• Synthetic fuels production plays a major role in decarbonizing Washington’s economy as well as balancing the electricity grid
  – Balancing through electrolysis in the state and as part of the regional balancing solution
  – Early need for clean fuels to meet Washington targets, displacing transport and industrial fuels
• 11 GW (3 GW in Washington) of natural gas plants added in the Northwest for reliability by 2050. Washington burn de minimus quantities of gas after 2030 because of the need to reduce emissions and the large balancing capabilities of both the hydro system and electrolysis built for fuels production by 2030
  – However, these gas generators provide capacity during infrequent reliability events. CETA requires 100% clean electricity delivered to loads by 2045 in Washington. By 2045, all gas burned during these events is clean gas
• Washington state resource balancing provided by hydro, electrolysis, flexible loads, and imports as part of the integrated balancing capability of the rest of the West
Transportation

• Transportation electrification key to cost effectively decarbonizing Washington's economy
  – Average spend 0.2% of GDP more annually in Transport Fuels Case than in Electrification Case

• 2030 decarbonization costs driven by expensive clean fuels production
  – Early electrification measures avoid investment in hydrogen and associated infrastructure and the energy needed for it. Early action that reduces clean fuel demand has significant benefits

• Demand for gasoline and diesel decrease through electrification, whereas jet fuel remains harder to replace because of technological challenges
  – Focusing early clean fuel production on jet fuel may avoid stranding assets or retooling because long-term demand is higher probability

• Small changes in vehicle cost projections have large impacts on forecasted decarbonization costs
  – Vehicles are the largest energy consuming infrastructure purchase that many customers and businesses make.
Buildings

• Electrification of buildings lowers costs over retaining gas use
  – Long-term benefits of avoiding the need for clean gas: 0.2% of GDP savings annually in Electrification case vs. Gas in Buildings case by 2050

• Investment in clean fuels in 2030 can be avoided through greater efficiency and electrification in buildings
  – Stock rollover of technologies limits action that can be taken prior to 2030
  – Benefits of measures in buildings that reduce energy use is high in the near-term and long-term, supporting early and aggressive action

• Not all efficiency measures will be cost effective
  – However cost effectiveness should be evaluated in the context of the lifetime of the measure and the changing environment it will encounter, including the higher avoided costs from marginal clean fuels production in 2030 and beyond
Industry

- Measures taken to reduce energy consumption in industry are not well defined in the model due to lack of information about the opportunities
  - Results indicate the value of the opportunities for industry rather than suggested policy
- Large quantities of synthetic fuels are required in 2030 to reach the 45% target
  - Avoided cost of carbon reductions from industry in 2030 comes from avoiding synthetic fuel production
  - Cost effective electrification and/or efficiency measures that avoid fuels production will lower total decarbonization costs
- A significant fraction of the carbon stream used to produce synthetic fuels comes from industrial carbon capture
  - Is there potential for that in Washington and if so, how much and how fast can it be implemented?
- New industrial flexible loads are a major new industry in the future, producing hydrogen through electrolysis
Electricity

• Expanding the electricity sector by electrifying end uses is a cost effective decarbonization strategy
  – Demand for electricity increase by 97% over 2020 levels and 143% including new industrial loads (e.g., electrolysis) by 2050 in the Electrification Case

• Washington meets these new loads by increasing clean energy imports through 2040 from low cost renewable sources, primarily Montana and Wyoming wind
  – In state solar and offshore wind is built in 2045 and 2050 to supplement out of state energy
  – 43% of electricity comes from out of state in 2050 of which 36% is from Montana and Wyoming wind

• Lowest cost compliance with electricity and economy wide clean energy targets requires these large imports of clean energy from other states
  – Increased flows of energy across multiple states/balancing areas
  – Investment in new transmission
  – Efficient use of imports as balancing resource, single BA operations West wide assumed in the model
Electricity

• Transmission expansion across the West is a key part of lowering costs in the model results
  – Expanding transmission, however, is a long, difficult process with many hurdles to overcome
  – Early planning and determination of feasible projects and project costs should begin now to prepare for transmission in the future

• Savings from expanding WA interties are relatively low ($0.5B/yr by 2050) however planning for expansion of the interties is recommended
  – Planning for expansion of WA transmission is shown to be cost effective and retains optionality in decarbonizing the grid
  – Optionality leaves more than one pathway open in case of unforeseen hurdles in other pathways
Electricity

• The emissions cap drives thermal generation to negligible amounts in 2030 and beyond
  – The Constrained Resource Case continues to burn small amounts of gas in state for reliability. By 2045, this gas is 100% clean
• 11 GW of gas capacity exists in the Northwest by 2050, with 3 GW in Washington in the Electrification Case
  – Washington gas capacity is not used other than at low capacity factors in the Constrained Resource Case when clean gas is burned, but offers low cost capacity for meeting reliability requirements
• In the Reference Case, electricity is generated from gas in Washington and exported to the rest of the West. By 2045, all electricity delivered to Washington loads is 100% clean.
Electricity

• In the Electrification and other decarbonization cases, a combination of hydro, flexible loads, electrolysis, and transmission flows balance loads in Washington by 2050
  – Integrated Western grid balancing using strengthened interties

• Seasonal imbalances of wind and solar become more impactful on system balancing needs across the West as the grid becomes cleaner
  – Shifting energy across seasons is difficult with current storage technologies such as lithium ion
  – Clean fuels demand is an opportunity for seasonal balancing
    • Store energy from times of plentiful renewable production using electrolysis to produce liquid fuels that can be stored cheaply
    • Back off electrolysis loads during times of limited renewable production, using these new large flexible loads to balance the grid and stored fuels for liquid fuel end uses
Appendix: Study scope and methodology
Study Evaluates Deep Decarbonization of Washington’s economy

- All energy sectors represented
  - Residential and commercial buildings, industry, transportation and electricity generation
- Regional representation
  - Other state’s actions will impact the availability and cost of solutions Washington has to decarbonize
  - State representation in the west captures electricity system operations and load, transmission constraints, biofuel and sequestration potential, and competition for resources as others meet their own targets
- Remainder of the U.S.: also modeled to factor in electricity sector dynamics and the availability of renewable resources, biofuels and sequestration
## Analysis Covers Washington’s Entire Energy System

### Demand-Side

<table>
<thead>
<tr>
<th>Subsectors</th>
<th>Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Residential Buildings</td>
</tr>
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</table>

### Supply-side

<table>
<thead>
<tr>
<th>Subsectors</th>
<th>Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electricity</td>
</tr>
</tbody>
</table>

- **EnergyPATHWAYS** model used to develop demand-side cases
- Applied electrification and EE levers
- Strategies vary by sub-sector (residential space heating to heavy duty trucks)
- **Regional Investment and Operations (RIO)** model identifies cost-optimal energy supply
- Net-zero electricity systems
- Novel technology deployment (biofuels; hydrogen production; geologic sequestration)

**CO₂ Emissions**
Demand-Side Modeling

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

**Input: Consumer Adoption**
EV sales are 100% of consumer adoption by 2035 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
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

- Bulb
- Appliances
- AC & Furnace
- Vehicles
- Commercial boilers
- Power plant
- Pipelines

U.S. Energy-related CO₂ Emissions

- Historical
- Projection
- Reference
- Dead-end pathway
- 2050 Target
Supply-Side Modeling

- Capacity expansion tool that produces cost optimal resource portfolios across the electric and fuels sectors
  - Identifies least-cost clean fuels to achieve emissions targets, including renewable natural gas and hydrogen production
- Simulates hourly electricity operations and investment decisions
  - Electric sector modeling provides a robust approximation of the reliability challenges introduced by renewables
- Electricity and fuels are co-optimized to identify sector coupling opportunities
  - Example: production of hydrogen from electrolysis
### Energy Pathways and RIO

<table>
<thead>
<tr>
<th>Description</th>
<th>Scenario analysis tool that is used to develop economy-wide energy demand scenarios</th>
</tr>
</thead>
</table>
| Application | EnergyPATHWAYS (EP) scenario design produces parameters for RIO’s supply-side optimization:  
  - Demand for fuels (electricity, pipeline gas, diesel, etc.) over time  
  - Hourly electricity load shape  
  - Demand-side equipment cost  

<table>
<thead>
<tr>
<th>Optimization tool to develop portfolios of low-carbon technology deployment for electricity generation and balancing, alternative fuel production, and direct air capture</th>
</tr>
</thead>
</table>
| RIO returns optimized supply-side decisions to EP:  
  - Electricity sector portfolios, including renewable mix, energy storage capacity & duration, capacity for reliability, transmission investments, etc.  
  - Biomass allocation across fuels |
Demand- and Supply-Side Modeling Framework

EnergyPATHWAYS (EP)

- Annual End-Use Energy Demand
- Hourly Load Shape

Regional Investment and Operations (RIO)

- Inputs
  - End-use energy demand
  - System emissions constraints
  - RPS or CES constraints
  - Technology and fuel cost projections
  - New resource constraints
  - Biomass and CO$_2$ Sequestration costs
  - Hourly load shape

- Outputs
  - Electricity sector
    - Wind/solar build
    - Energy storage capacity/duration
    - Capacity for reliability
    - Curtailment
    - Hourly operations
  - Hydrogen production
  - Synthetic electric fuel production (H2/SNG)
  - Biomass allocation
  - CO$_2$ sequestration
RIO & EP Data and Methods Have Improved across Many Past Studies

<table>
<thead>
<tr>
<th>Project</th>
<th>Geography</th>
<th>EP</th>
<th>RIO</th>
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<tbody>
<tr>
<td>Risky Business Project From Risk to Return</td>
<td>National</td>
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<tr>
<td>National Renewable Energy Laboratory Electrification Futures Study</td>
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<td>National Renewable Energy Laboratory North American Renewable Integration Study</td>
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<td>Our Children’s Trust 350 PPM Pathways for the United States</td>
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<td>Hydro Québec Deep Decarbonization in the Northeastern U.S.</td>
<td>Regional</td>
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<tr>
<td>State of Washington: Office of the Governor Deep Decarbonization Pathways Analysis</td>
<td>State</td>
<td>WA</td>
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<tr>
<td>Confidential California utility Economy-wide GHG policy analysis</td>
<td>State/Utility Service Territory</td>
<td>CA</td>
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<tr>
<td>Clean Energy Transition Institute Northwest DDP Study</td>
<td>Regional</td>
<td>ID, MT, OR, WA</td>
<td></td>
</tr>
<tr>
<td>New Jersey Board of Public Utilities Integrated Energy Plan</td>
<td>State</td>
<td>NJ</td>
<td></td>
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<tr>
<td>Portland General Electric Deep Decarbonization Pathways Analysis</td>
<td>Utility territory</td>
<td>PGE</td>
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<td>Inter-American Development Bank Deep Decarbonization of Mexico</td>
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<td>Mexico/5 Regions</td>
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<td>Confidential Client Zero Carbon European Power Grid</td>
<td>Regional</td>
<td>EU/8 Regions</td>
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<td>Confidential Client Low Carbon Electricity in Japan</td>
<td>National</td>
<td>Japan/5 Regions</td>
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<td>Princeton University Low-Carbon Infrastructure Project (ongoing)</td>
<td>National</td>
<td>US/16 Regions</td>
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<td>Pathways for Florida</td>
<td>State</td>
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<td>Massachusetts State Energy Plan</td>
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<tr>
<td>State of Washington: State Energy Strategy</td>
<td>Regional</td>
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</table>
### RIO Decisions Variables and Outputs

#### Hours
- 24 hr * 40 – 60 sample days = 960 – 1440 hr

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

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

<table>
<thead>
<tr>
<th>Decision Variables</th>
<th>Key Results</th>
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<tbody>
<tr>
<td>Generator Dispatch</td>
<td>Hourly Dispatch</td>
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<td>Transmission Flows</td>
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<td>Operating Reserves</td>
<td>Market Prices</td>
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<td>Curtailment</td>
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<table>
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<th>Decision Variables</th>
<th>Key Results</th>
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<td>Fuel Energy Balance and Storage</td>
<td>Daily Electricity Balances</td>
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<tr>
<td>Long Duration Electricity Storage</td>
<td>Daily Fuel Balances</td>
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<td>Dual Fuel Generator Blends</td>
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<th>Decision Variables</th>
<th>Key Results</th>
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<td>Emissions from Operations</td>
<td>Total Annual Emissions</td>
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<td>RPS Supply and Demand</td>
<td>RPS Composition</td>
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<td>Capacity Build, Retirement &amp; Repower</td>
<td>Incremental Build, Retirement, &amp; Repower</td>
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<td>Thermal Capacity Factors</td>
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<td>Annual Average Market Prices</td>
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<tr>
<td></td>
<td>Marginal Cost of Fuel Supply</td>
</tr>
</tbody>
</table>
RIO Optimizes across Time-Scales

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

Capacity build decisions

2010

365+ days

24 hr sequential dispatch

40-60 daily snapshots

5-year timestep

2050

Daily fuels tracking

Daily H2 Production

2010
RIO Optimizes across Geographic Constraints

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

Flexible Load Shapes

- delay
- native
- advance

Clock for methodology illustration only

Cumulative Energy Constraints

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

Figure for methodology illustration only.
Electricity and Fuels Sector Integration

• Traditional capacity expansion approaches have narrowly defined their problem in terms of the electric sector

• Decarbonization and pushes towards 100% renewables has revealed the inadequacy of that approach as both will require sectoral integration

• A key opportunity for sectoral integration is in the fuel-supply sector, as it may be counted on to provide low-carbon fuels for thermal generation/primary end uses and provide electricity balancing services to the grid

• Endogenizing decisions in both allows us to explore opportunities for sectoral integration that have escaped other modeling frameworks
• Traditional capacity expansion approaches have narrowly defined their problem in terms of the electric sector

• Goals of economy-wide decarbonization and push towards 100% zero-emissions electricity generation requires sectoral integration

• A key opportunity for commodity sector integration is in the fuels sector, as it may be counted on to provide low-carbon fuels for thermal generation and provide electricity balancing services to the grid
## RIO Commodities Module Definitions

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>Exogenously specified commodity type defined with price, emissions rates and available volumes</td>
<td>Natural Gas; Refined Fossil Diesel; Coal; Biomass</td>
</tr>
<tr>
<td>Conversion</td>
<td>Capital investment defined with cost of production capacity and efficiency of production</td>
<td>Biomass SNG; Power-to-Gas; Direct Air Capture</td>
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<tr>
<td></td>
<td>(blend x -&gt; blend y and/or electricity-&gt;blend y)</td>
<td></td>
</tr>
<tr>
<td>Blend</td>
<td>Aggregation point for product and conversion commodities. All inputs (conversion and products) are drop-ins for an individual blend.</td>
<td>Pipeline Gas; Diesel Fuel; Hydrogen; Captured CO2</td>
</tr>
</tbody>
</table>
RIO Fuels Structure

Optimally invest in fuels transportation, storage, and conversion infrastructure

- Endogenous demand from electric generators
- Endogenous demand from fuel conversion processes
- Exogenous demand

Product Fuels

Conversion Fuels

Blend Fuel
RIO Commodities Structure: Pipeline Gas Blend Example

Product: Natural Gas

Endogenous demand from electric generators:
- Gas CCGT
- Gas CT
- Gas Steam Turbine...

Endogenous Conversion Demand:
- H2 Reformation
- Gas Boiler

Conversion:
- Electrolysis
- Methanation
- BioSNG
- BioSNG w/CCU

Exogenous Demand:
- Industrial Process Heat
- Water Heating
- Space Heating
  ....

Blend
Conventional means of “balancing” may not be the most economic or meet clean energy goals.

New opportunities: Storage and flexible loads.

Fuels are another form of energy storage.

Large flexible loads from producing decarbonized fuels: Electrolysis, synthetic fuels production.

Hourly Reserve Margin Constraints by Zone

Assessing Reliability Becomes Challenging in Low-Carbon Electricity Systems

Traditional Reserve Margin

Future System Reliability Assessment

Installed renewable capacity is no longer a good measure of dependability

Renewable ELCC is uncertain

Dependency between timing of peak load and dispatchable resource availability

Availability of energy limited resources?

Which DERs will be adopted and how will they be controlled?

Dynamic based on renewable build, DER adoption, and load growth patterns

Electrification leads to rapid load growth and changes in timing of peak load

Installed renewable capacity is no longer a good measure of dependability

Renewable ELCC is uncertain

Dependency between timing of peak load and dispatchable resource availability

Availability of energy limited resources?

Which DERs will be adopted and how will they be controlled?

Dynamic based on renewable build, DER adoption, and load growth patterns

Electrification leads to rapid load growth and changes in timing of peak load
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
Appendix: Key Assumptions
Demand Subsectors

EnergyPATHWAYS database includes 67 subsectors

- Primary data-sources include:
  - Annual Energy Outlook 2020 inputs/outputs (AEO; EIA)
  - Residential/Commercial Buildings/Manufacturing Energy Consumption Surveys (RECS/CBECS/MECS; EIA)
  - State Energy Data System (SEDS; DOE)
  - NREL

- 8 industrial process categories, 11 commercial building types, 3 residential building types
- 363 demand-side technologies w/ projections of cost (capital, installation, fuel-switching, O&M) and service efficiency

commercial air conditioning
commercial cooking
commercial lighting
commercial other
commercial refrigeration
commercial space heating
commercial ventilation
commercial water heating
district services
office equipment (non-p.c.)
office equipment (p.c.)
aviation
domestic shipping
freight rail
heavy duty trucks
international shipping
light duty autos
light duty trucks
lubricants
medium duty trucks
military use
motorcycles
residential clothes washing
residential computers and related
residential cooking
residential dishwashing
residential freezing
residential furnace fans
residential lighting
residential other uses
residential refrigeration
residential secondary heating
residential space heating
residential televisions and related
residential water heating
Cement and Lime CO2 Capture
Cement and Lime Non-Energy CO2
Iron and Steel CO2 Capture
Other Non-Energy CO2
Petrochemical CO2 Capture
agriculture-crops
agriculture-other
aluminum industry
balance of manufacturing other
food and kindred products
glass and glass products
iron and steel
machinery
metal and other non-metallic mining
paper and allied products
plastic and rubber products
transportation equipment
wood products
bulk chemicals
cement
computer and electronic products
construction
electrical equip., appliances, and components
passenger rail
recreational boats
school and intercity buses
transit buses
residential air conditioning
residential building shell
residential clothes drying
## Load Shape Sources

<table>
<thead>
<tr>
<th>Shape Name</th>
<th>Used By</th>
<th>Input Data Geography</th>
<th>Input Temporal Resolution</th>
<th>Source</th>
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<tbody>
<tr>
<td>Bulk System Load</td>
<td>initial electricity reconciliation, all subsectors not otherwise given a shape</td>
<td>Emissions and Generation Resource Integrated Database (EGRID) with additional granularity in the western interconnection</td>
<td>hourly, 2012</td>
<td>FERC Form No. 714</td>
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<td>Light-Duty Vehicles (LDVs)</td>
<td>all LDVs</td>
<td>week-day/weekend average, separated by home vs. work charging</td>
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<td>Evolved Energy Research analysis of 2016 National Household Travel Survey</td>
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<tr>
<td>Water Heating (Gas Shape)*</td>
<td>residential hot water</td>
<td>United States</td>
<td>month-hour-weekday/weekend average</td>
<td>Northwest Energy Efficiency Alliance Residential Building Stock Assessment Metering Study (Northwest)</td>
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<td>Other Appliances</td>
<td>residential TV &amp; computers</td>
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<td>California Load Research Data</td>
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<td>Lighting</td>
<td>residential lighting</td>
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<td></td>
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<td>Clothes Washing</td>
<td>residential clothes washing</td>
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<td>Clothes Drying</td>
<td>residential clothes drying</td>
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<td>Dishwashing</td>
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<td>Residential Refrigeration</td>
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<td>Residential Freezing</td>
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<td>Residential Cooking</td>
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<td>Industrial Other</td>
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<td>Commercial Water Heating</td>
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<td>Commercial Lighting Internal</td>
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<td>Commercial Refrigeration</td>
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* Gas Shape is used in this table for reference.
Load Shape Sources, Continued

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<th>Input Temporal Resolution</th>
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<td>Commercial Ventilation</td>
<td>commercial ventilation</td>
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<td>Evolved Energy Research</td>
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<td>Commercial Office Equipment</td>
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<td>Regressions trained on NREL building simulations in select U.S. cities for a typical meteorological year and then run on county level HDD and CDD for 2012 from the National Oceanic and Atmospheric Administration (NOAA)</td>
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<td>Industrial Machine Drives</td>
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<td>commercial electric furnaces</td>
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<td>Flat shape</td>
<td>MDV and HDV charging</td>
<td>United States</td>
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* natural gas shape is used as a proxy for the service demand shape for electric hot water due to the lack of electric water heater data.
# Supply-Side Data

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<th>Data Description</th>
<th>Supply Node</th>
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<tbody>
<tr>
<td>Resource Potential</td>
<td>Binned resource potential (GWh) by state with associated resource performance</td>
<td>Transmission – sited Solar PV; Onshore Wind; Offshore Wind; Geothermal</td>
<td>(Eurek et al. 2017)</td>
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<td>(capacity factors) and transmission costs to reach load</td>
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<tr>
<td>Resource Potential</td>
<td>Binned resource potential of biomass resources by state with associated costs</td>
<td>Biomass Primary – Herbaceous; Biomass Primary – Wood; Biomass Primary – Wood; Biomass Primary – Waste; Biomass Primary – Corn</td>
<td>(Langholtz, Stokes, and Eaton 2016)</td>
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<tr>
<td></td>
<td>costs</td>
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<tr>
<td>Resource Potential</td>
<td>Domestic production potential of oil</td>
<td>Oil Primary – Domestic</td>
<td>(U.S. Energy Information Administration 2020)</td>
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<tr>
<td>Product Costs</td>
<td>Commodity cost of natural gas at Henry Hub</td>
<td>Natural Gas Primary – Domestic</td>
<td>(U.S. Energy Information Administration 2020)</td>
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<tr>
<td>Product Costs</td>
<td>Undelivered costs of refined fossil products</td>
<td>Refined Fossil Diesel; Refined Fossil Jet Fuel; Refined Fossil Kerosene; Refined Fossil Gasoline; Refined Fossil LPG</td>
<td>(U.S. Energy Information Administration 2020)</td>
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<tr>
<td>Product Costs</td>
<td>Commodity cost of Brent oil</td>
<td>Oil Primary – Domestic; Oil Primary - International</td>
<td>(U.S. Energy Information Administration 2020)</td>
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<tr>
<td>Delivery Infrastructure Costs</td>
<td>AEO transmission and delivery costs by EMM region</td>
<td>Electricity Transmission Grid; Electricity Distribution Grid</td>
<td>(U.S. Energy Information Administration 2020)</td>
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<tr>
<td>Delivery Infrastructure Costs</td>
<td>AEO transmission and delivery costs by census division and sector</td>
<td>Gas Transmission Pipeline; Gas Distribution Pipeline</td>
<td>(U.S. Energy Information Administration 2020)</td>
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<tr>
<td>Delivery Infrastructure Costs</td>
<td>AEO delivery costs by fuel product</td>
<td>Gasoline Delivery; Diesel Delivery; Jet Fuel; LPG Fuel Delivery; Kerosene Delivery</td>
<td>(U.S. Energy Information Administration 2020)</td>
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<tr>
<td>Data Category</td>
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<tr>
<td>Technology Cost and Performance</td>
<td>Renewable and conventional electric technology installed cost projections</td>
<td>Nuclear Power Plants; Onshore Wind Power Plants; Transmission – Sited Solar PV Power Plants; Distribution – Sited Solar PV Power Plants; Rooftop PV Solar Power Plants; Combined – Cycle Gas Turbines; Coal Power Plants; Combined – Cycle Gas Power Plants with CCS; Coal Power Plants with CCS; Gas Combustion Turbines</td>
<td>(National Renewable Energy Laboratory 2019)</td>
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<tr>
<td>Technology Cost and Performance</td>
<td>Nth plant Direct air capture costs for sequestration and utilization</td>
<td>Direct Air Capture with Sequestration; Direct Air Capture with Utilization</td>
<td>(Keith et al. 2018)</td>
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<td>Technology Cost and Performance</td>
<td>Gasification cost and efficiency of conversion including gas upgrading.</td>
<td>Biomass Gasification; Biomass Gasification with CCS</td>
<td>(G. del Alamo et al. 2015)</td>
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<tr>
<td>Technology Cost and Performance</td>
<td>Cost and efficiency of renewable Fischer-Tropsch diesel production.</td>
<td>Renewable Diesel; Renewable Diesel with CCS</td>
<td>(G. del Alamo et al. 2015)</td>
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<tr>
<td>Technology Cost and Performance</td>
<td>Cost and efficiency of industrial boilers</td>
<td>Electric Boilers; Other Boilers</td>
<td>(Capros et al. 2018)</td>
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<tr>
<td>Technology Cost and Performance</td>
<td>Cost and efficiency of other, existing power plant types</td>
<td>Fossil Steam Turbines; Coal Power Plants</td>
<td>(Johnson et al. 2006)</td>
</tr>
</tbody>
</table>
Federal Tax Incentives

We include federal incentives but not local incentives

- Federal incentives included because they benefit WA by lowering total costs
  - ITC 26% in 2020, then 10% afterwards (for commercial solar only)
  - PTC expires too soon to impact build decisions
- Any local incentives are not included because they are transfer payments and do not lower total costs
- In current policy 10% ITC is available in perpetuity. We roll off ITC in 2030, forecasting a change in policy
  - Near term support for renewable investments, driving recovery in jobs and investment coming out of Covid
  - Won’t last forever, particularly as renewable prices continue to drop
  - Federal incentives may be better spent on emerging clean technologies in the future
In-state Solar

- NWPCC has estimates of rooftop solar through 2045
- We schedule NWPCC adoption of rooftop solar for WA through 2030 of 500 MW
  - Simulation, assumes customer behavior based on existing trends, rates etc. through 2030
- 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 no detailed distribution system model
  - Rooftop may be desirable for other reasons such as promoting jobs within state, or avoiding land use challenges siting bulk system level solar
- Bulk system solar potential capped using [NREL’s Regional Energy Deployment System](https://www.nrel.gov/) database
Columbia Generating Station (CGS) Extension

• We assume that the CGS can be extended for an additional 20 years of life at 1,210 MW gross output

• Extending CGS:
  – Cost assumptions developed by Energy Northwest and consistent with NWPCC 2021 Power Plan
  – License renewal
    • $50M extension capital cost
    • $400M fixed O&M based on O&M estimates in the Energy Northwest Fiscal Year 2021 Budget
Small Modular Reactors (SMRs)

• SMRs are included as a resource option in the model for Washington State
• Costs assumptions from NWPPCC 2021 Power Plan
  – https://nw council.app.box.com/s/nnfkfiq9vuqg3umtb2e8np0tqm78ztni
• Capital Cost: $5,400/kW
• Earliest online date: 2030
• Maximum resource build by 2030: 500 MW
• Maximum resource build by 2050: 3420 MW
• Operating costs from NREL
Climate Impacts on Load and Hydro

- **EIA** incorporates climate impacts into the Annual Energy Outlook based on extrapolated change in heating degree days (HDD) and cooling degree days (CDD) from the past 30 years
  - For the Pacific region, change in number of HDD: -0.7%/year, number of CDD: 1.2%/year
- **Seattle City Light** finds no clear trend in impacts on hydro across models reviewed – some models project wetter conditions, others predict drier conditions
  - Lower summer rainfall predicted (6% to 8%, with some models predicting >30%) but rainfall is very low in the summer anyway
  - Predicted changes in precipitation extremes – more frequent short-term heavy rain
  - Predicted reduced snowpack, increased fall and winter stream flows and reduced summer stream flows
  - Not a clear path forward to adjustments in hydro availability
    - Shape changes as well as total energy availability
    - More work needed to characterize this impact for future studies
- We use three hydro years – low, average, and high hydro energy availability to capture challenges of meeting clean energy requirements
Hydroelectric System

- 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
- Operational constraints for regional hydro fleets are derived using hourly generation data from WECC for 2001, 2005 and 2011, which represent dry, average and wet hydro years, respectively.
  - Operational constraints vary by week of the year (1 through 52) and hydro year (dry, average and wet).
Existing Efficiency Policy in Buildings

What are the efficiency policies that impact Reference and Decarbonization case assumptions?

- **Energy Independence Act (EIA) I-937**
  - “Utilities must pursue all conservation that is cost-effective, reliable and feasible. They need to identify the conservation potential over a 10-year period and set two-year targets.”

- **Clean Energy Transition Act (CETA)**
  - Same requirement as EIA but applicable to all utilities, not just those over 25000 customers

- **Clean Buildings Bill**
  - Incentives and mandates applied to commercial buildings over 50000 square feet and incentives applied to multi family buildings
    - 2021-2026: voluntary incentive program
    - 2026 onwards: mandatory requirements (for large commercial buildings)
  - Require demonstration of energy reduction to below energy use intensity target

- **Efficiency standards**
Modeled Efficiency

• NWPCC work in efficiency
  – Lays out achievable potential by sector and year
  – Not directly useful for inputs

• Aggressive efficiency improvements are being driven through existing policy
  – Not modellable with the complexity of the compliance process and the way that the programs are defined

• Modeling approach: set high level targets that reasonably align with levels of ambition in Reference and other cases
Buildings

• **Energy Efficiency**
  – Reference Case: 50% sales HE by 2035, 75% sales HE by 2050
  – Electrification Case: 100% high efficiency by 2035
  – Gas in Buildings: 100% high efficiency by 2035

• **Electrification Rates**
  – Reference Case: No electrification
  – Electrification Case: 90% - 100% electric sales by 2035 depending on sub sector
  – Gas in Buildings: Replace gas appliances with new efficient gas appliance rather than electrify
Renewable Resources

• Candidate onshore wind and solar resources
  – State-level resource potential, capacity factor and transmission costs are derived from NREL’s Regional Energy Deployment System database
  – Capital cost projections are from NREL’s Annual Technology Baseline 2019
• We incorporate hourly profiles for wind and solar resources throughout the WECC for weather years 2010 through 2012
  – Wind profiles are from NREL’s Wind Integrated National Dataset (WIND) Toolkit
  – Solar profiles are derived using data from the NREL National Solar Radiation Database and simulated using the System Advisor Model
## Vehicle Electrification Targets

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Class</th>
<th>Sub class</th>
<th>Target Sales Share</th>
<th>By Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrification</td>
<td>HDV</td>
<td>long haul</td>
<td>25% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Electrification</td>
<td>HDV</td>
<td>long haul</td>
<td>75% Hydrogen FCV</td>
<td>2045</td>
</tr>
<tr>
<td>Electrification</td>
<td>HDV</td>
<td>short haul</td>
<td>100% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>HDV</td>
<td>long haul</td>
<td>12.5% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>HDV</td>
<td>long haul</td>
<td>0% Hydrogen FCV</td>
<td>2045</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>HDV</td>
<td>short haul</td>
<td>50% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Electrification</td>
<td>MDV</td>
<td></td>
<td>70% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Electrification</td>
<td>MDV</td>
<td></td>
<td>30% Hydrogen FCV</td>
<td>2045</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>MDV</td>
<td></td>
<td>35% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>MDV</td>
<td></td>
<td>0% Hydrogen FCV</td>
<td>2045</td>
</tr>
<tr>
<td>Electrification</td>
<td>LDV</td>
<td>autos</td>
<td>100% Electric</td>
<td>2035</td>
</tr>
<tr>
<td>Electrification</td>
<td>LDV</td>
<td>trucks</td>
<td>100% Electric</td>
<td>2035</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>LDV</td>
<td>autos</td>
<td>75% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>LDV</td>
<td>trucks</td>
<td>75% Electric</td>
<td>2045</td>
</tr>
<tr>
<td>Electrification</td>
<td>Buses</td>
<td></td>
<td>100% Electric</td>
<td>2040</td>
</tr>
<tr>
<td>Low Electrification</td>
<td>Buses</td>
<td></td>
<td>50% Electric</td>
<td>2040</td>
</tr>
</tbody>
</table>
Industrial Sector Targets

• Great deal of uncertainty about industrial opportunities
  – Not a lot of information
  – Specific to industry/company/geography
  – Tied to competitiveness/labor force considerations

• Using “keep it simple” approach
  – 1% per year improvement in energy intensity across industrial subsectors
  – Fuel switching to electricity in 50% of process heating, 100% of machine drives, and 75% of building heating and cooling in industry by 2050
  – Designed to model some benefits of reductions in energy from efficiency and electrification while acknowledging industrial sector improvements will come from negotiation

• Maintaining industrial activity as forecast by AEO, except mining and refining
  – Refining in Washington assumed to drop by 75% by 2050 from reduced fossil fuel demands
Data Center Loads

- Data center load not well represented in the AEO load representation of Washington
  - Updated to NWPC data center assumptions for Washington and Oregon from 7th Power Plan
    - [https://www.nwcouncil.org/sites/default/files/7thplanfinal_appdixe_dforecast_1.pdf](https://www.nwcouncil.org/sites/default/files/7thplanfinal_appdixe_dforecast_1.pdf)
  - Washington and Oregon total assigned to each state based on population
Vehicle Miles Traveled Reduction

Included in the Behavior Change Case

- Vehicle miles traveled reductions in Behavior Change case based on consultation with Climate Solutions on their report on Washington and Oregon Transportation Modeling
  - personal and freight vehicle assumptions about what reductions in vehicle miles traveled may be possible
- Overall total for the state: 29% personal VMT reduction by 2050
- Freight reduction: 15%
- We assume that people retain vehicles but drive them less, thus total vehicle numbers are not impacted
  - Conservative, reduced numbers of vehicles purchased would increase cost savings

<table>
<thead>
<tr>
<th>Category</th>
<th>Passenger Miles Traveled Reduction</th>
<th>Equivalent Vehicle Miles Traveled Reduction</th>
<th>Equivalent to Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>35%</td>
<td>47%</td>
<td>London</td>
</tr>
<tr>
<td>Suburban</td>
<td>35%</td>
<td>39%</td>
<td>Washington DC and London Average</td>
</tr>
<tr>
<td>Small City</td>
<td>15%</td>
<td>20%</td>
<td>New York State</td>
</tr>
<tr>
<td>Rural</td>
<td>10%</td>
<td>10%</td>
<td>CA, CT, NJ, IL</td>
</tr>
</tbody>
</table>
Fossil Fuel Price Projections

- AEO 2020 Reference scenario is the starting point for projections through 2050
- The advantage of using AEO across fuel types is that all prices are internally consistent

Figure source: [https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf](https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf)
Conversion Technology Cost and Performance

- **EU ASSET: Technology Pathways in Decarbonisation Scenarios**
  - Hydrogen electrolysis
  - Hydrogen gas reformation

- **IEA Bioenergy: Implementation of bio-CCS in biofuels production**
  - Biomass Fischer-Tropsch
  - Biomass synthetic natural gas

- **IRENA: Advanced Liquid Biofuels**
  - Cellulosic ethanol

- **Princeton University**
  - Autothermal reforming
  - BECCS hydrogen
  - Biomass pyrolysis

![Electrolysis Cost](chart.png)
Biomass Feedstocks: Updated Estimates for Woody Biomass using LURA Model

Northwest woody biomass potential update

- Billion Ton Study 2016 Update the default source of cost and potential data for biomass
  - Supply curve by state and year developed for the US, supporting modeling of a biomass and biofuels market
- Reviewed by WSU and Commerce: Inadequate representation of Northwest woody biomass potential
- Michael Wolcott and team at WSU updated estimates for woody biomass in the Northwest using the **LURA** model for this study
  - These have been incorporated into the assumptions
Acronyms used in this Presentation

- BEV: Battery Electric Vehicle
- CES: Clean Energy Standard
- CETA: Clean Energy Transformation Act
- HDV: Heavy-Duty Vehicle
- ICE: Internal Combustion Engine
- IPCC: Intergovernmental Panel on Climate Change
- LDV: Light-Duty Vehicle
- MDV: Medium-Duty Vehicle
- MMT: Million Metric Tons
- O & M: Operations and Maintenance
- RCI: Residential, Commercial, Industrial
- RE: Renewable Energy
- RECs: Renewable Energy Credits
- RPS: Renewable Portfolio Standard
- SMR: Small Modular Reactor
- TBtu: Trillion British Thermal Units
- TX: Transmission
- VMT: Vehicle Miles Traveled