Deep Decarbonization Pathways Analysis for Washington State

December 16, 2016

Prepared For:
State of Washington Office of the Governor and Office of Financial Management

Prepared By:
Ben Haley, Gabe Kwok and Ryan Jones
Evolved Energy Research

Dr. Jim Williams
Deep Decarbonization Pathways Project

Contents

- Study Background
- Modeling Approach and Assumptions
- Scenario Descriptions
- Results
  - Emissions and Final Energy Demand
  - Electric Power Sector
  - Infrastructure
  - Cost Impacts
- Summary
- Appendix

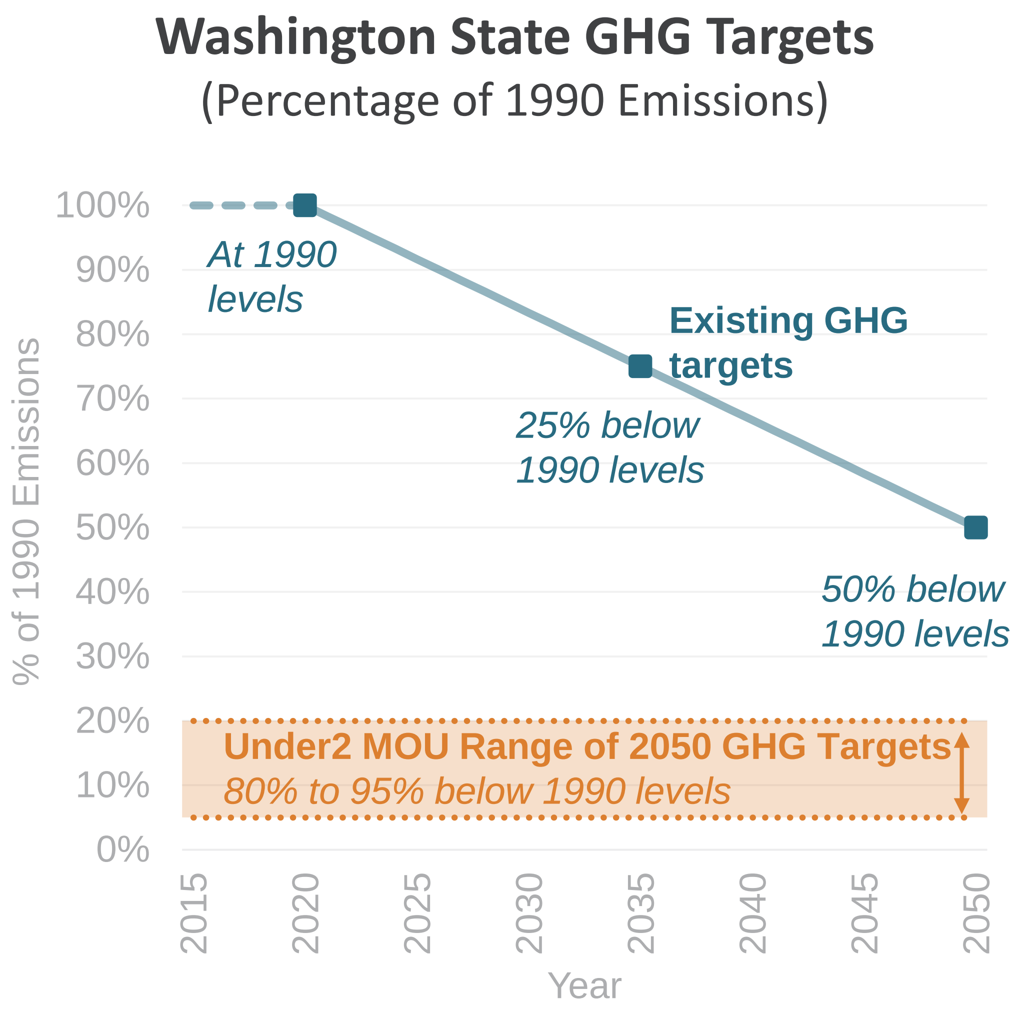
About Evolved Energy Research

- Energy consulting firm focused on analysis of deeply decarbonized energy systems
- Lead developers and maintainers of EnergyPATHWAYS, an open-source tool for developing rigorous and sophisticated bottom-up energy analyses
- Advise clients on issues of policy implementation and target-setting, R&D strategy, technology competitiveness and impact investing

Study Background

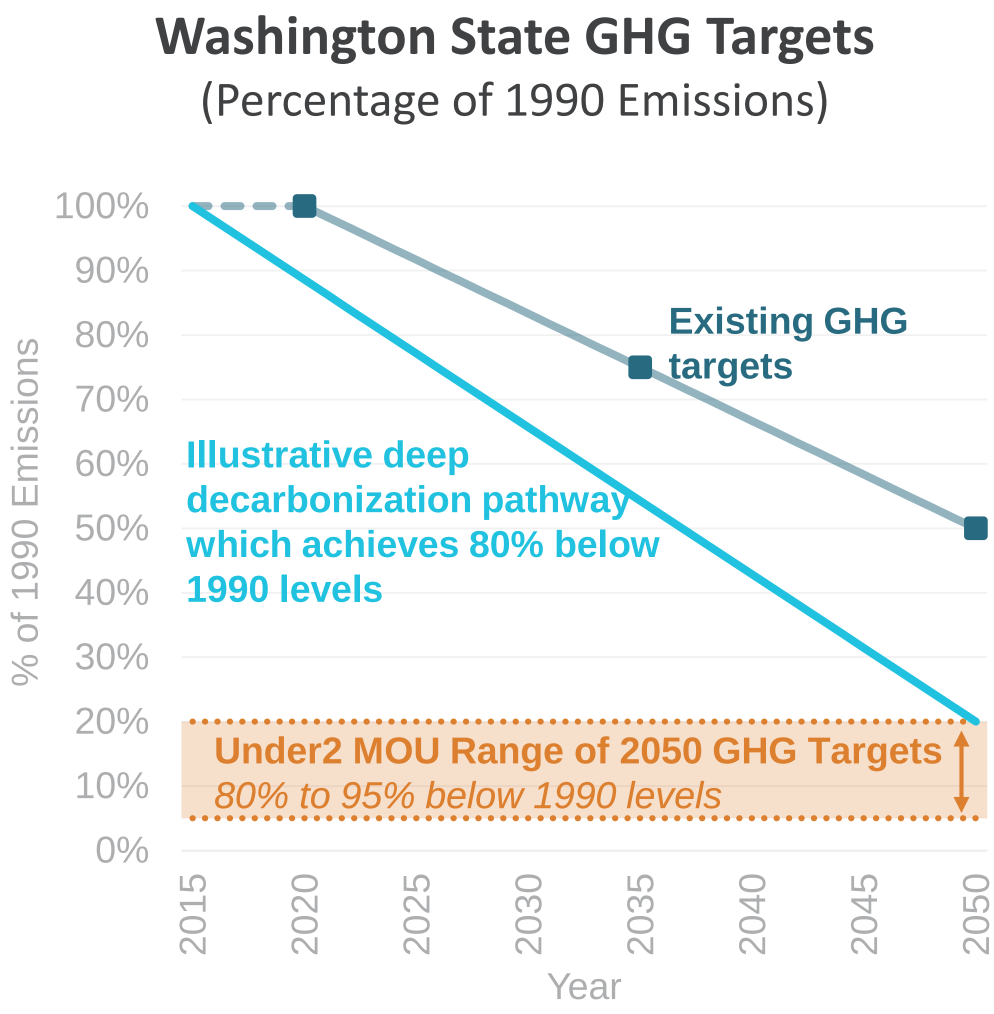
Context

- Washington State's existing greenhouse gas (GHG) limits require adjustments to align with the most recent scientific consensus and commitments
- **Existing limits** (below 1990 levels): 25% by 2035; 50% by 2050
- **Recent state, regional and global commitments** (below 1990 levels): 80% to 95% by 2050



Study Purpose

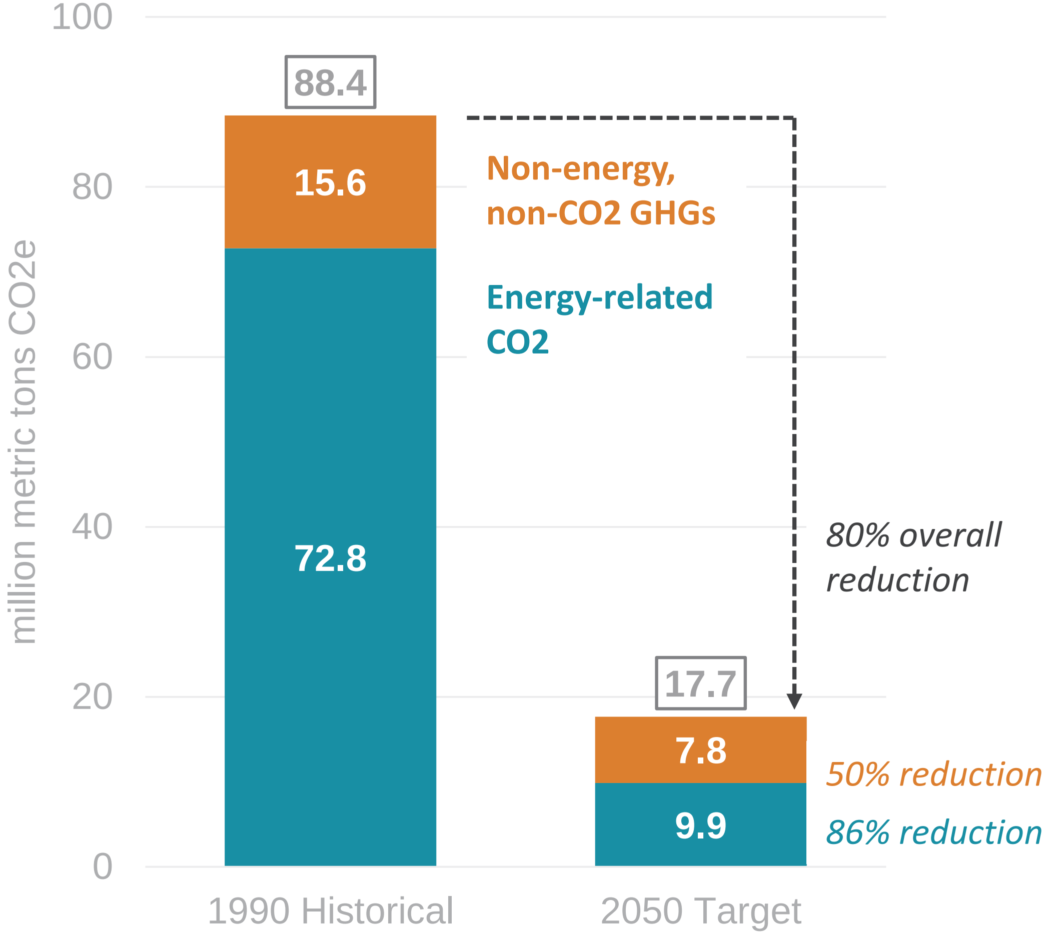
- Develop and evaluate technology pathways which achieve mid-century GHG emissions targets (“deep decarbonization pathways”, or “DDPs”)
- Quantify the magnitude, scope and timing of required changes to Washington State’s energy system in order to:
  - Support recommended changes in statutory GHG emission limits
  - Identify policies and investments consistent with adjusted emission limits
  - Facilitate a broader stakeholder discussion



Study's GHG Target

- For the purposes of this study, the GHG target is an 80 percent reduction below 1990 levels by 2050
  - Target is consistent with Washington State's Under2 MOU commitment
- Total permissible emissions budget in 2050 is 17.7 MMTCO2, which we allocate to:
  - Energy-related CO2
  - Non-energy CO2 and non-CO2 GHGs
- Study's focus is evaluating scenarios which achieve an 86 percent energy-related CO2 reduction below 1990 levels by 2050
  - Energy system emissions are below 9.9 MMTCO2 in 2050
- Additional detail on non-energy CO2 and non-CO2 GHGs in the Appendix

Washington State GHG Emissions
(1990 Historical and Study's 2050 Target)



Study Approach

Develop representation of WA State's current energy system
- Benchmark against historical energy use and emissions

Identify factors affecting future energy supply and demand
- Current policy and regulations
- Plausible mitigation options

Define scenarios
- Reference Case
- *Deep decarbonization pathways*
  - DDP Case 1
  - DDP Case 2
  - DDP Case 3

Model each scenario in EnergyPATHWAYS
- Energy Service Demand → Energy Supply → Results
  - Results: CO_2 emissions, final energy demand, energy system costs

Evaluate performance of each scenario
- GHG emissions consistent with target?
- Use a sustainable level of biomass?
- Realistic rate of energy system transformation?

Study Scope

- Scope of this project includes the design and evaluation of multiple deep decarbonization pathway scenarios, which each include alternative emission reduction strategies and technologies
- Scenarios are purposely designed as “bookend” cases to demonstrate multiple, distinctive ways of achieving the same GHG target
  - Commonalities exist among scenarios, but they’re defined by key differences
  - Robustness of results is prioritized over the design of a single “optimal” case
- Our scenarios are neither prescriptive nor exhaustive
  - Many additional pathways to deep decarbonization exist, which were not evaluated here

Design Principles Applied to All Scenarios

Design Principle	Implication
Economy and lifestyle similar to that of today	• Same level of energy service demands across cases
Use commercially demonstrated or near-commercial technologies	• No major breakthrough technologies (ex., nuclear fusion)
Infrastructure inertia	• Natural retirement of infrastructure • No early retirements
Electric reliability	• Ensure resource adequacy and flexibility
Environmental sustainability	• Limits on supply of biomass for energy use • Constraints on renewable energy and pumped hydro storage potential

Modeling Approach and Assumptions

Modeling Approach

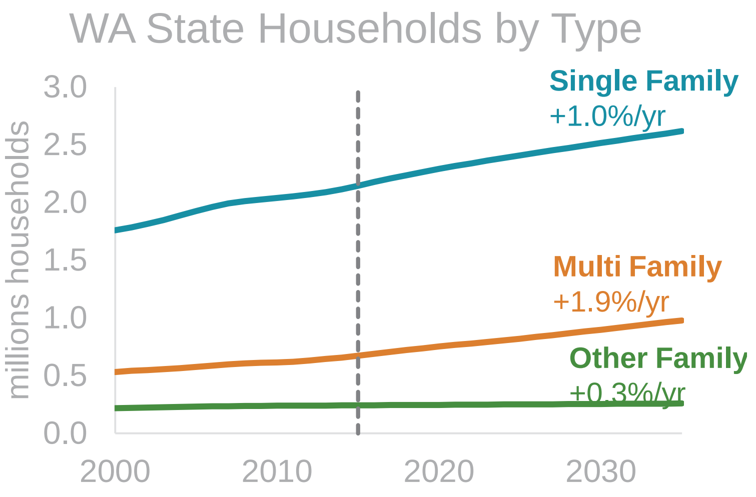
- We use EnergyPATHWAYS, an energy systems model, to evaluate deep decarbonization pathway cases for the state of Washington
  - Tracks all energy infrastructure, including its energy, CO_2 emissions and costs
  - Estimates energy demand from the “bottom-up”
  - Simulates power system operations though hourly electricity dispatch
- Scenarios include user-defined measures which change the composition of energy infrastructure over time

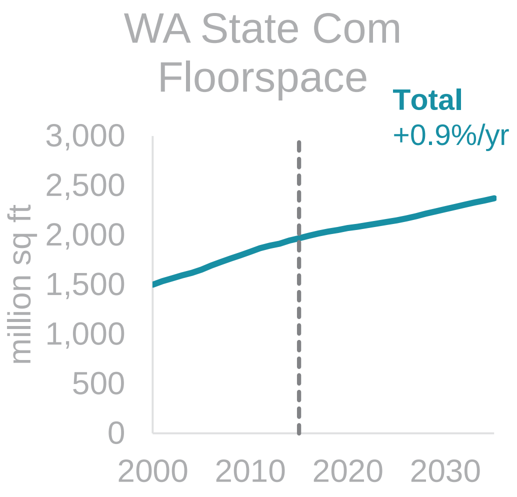
Modeling Boundary Conditions

- Analysis includes a detailed representation of Washington State's energy system supplemented by a high-level representation of energy infrastructure in other Western states
  - Energy infrastructure in other states included to capture petroleum, natural gas and biofuels imports and exports, as well as regional electricity dispatch
- Electricity dispatch occurs at a regional level to reflect:
  - Regional operational and planning activities (i.e., Northwest Power Pool and Northwest Power and Conservation Council)
  - Inter-dependency of the hydro system

Residential and Commercial Buildings Assumptions

- Households and commercial square footage data from Northwest Power and Conservation Council Seventh Northwest Power Plan
- Residential space heating, water heating and air conditioning stock data from Northwest Energy Efficiency Alliance





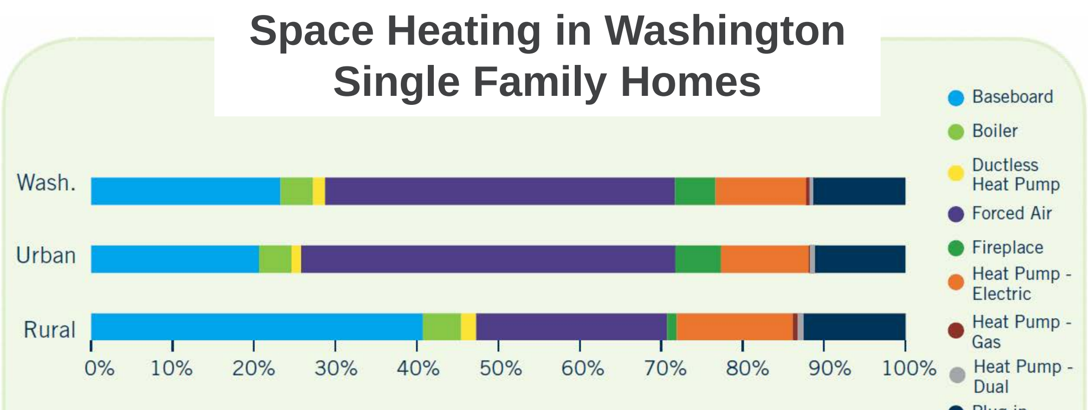
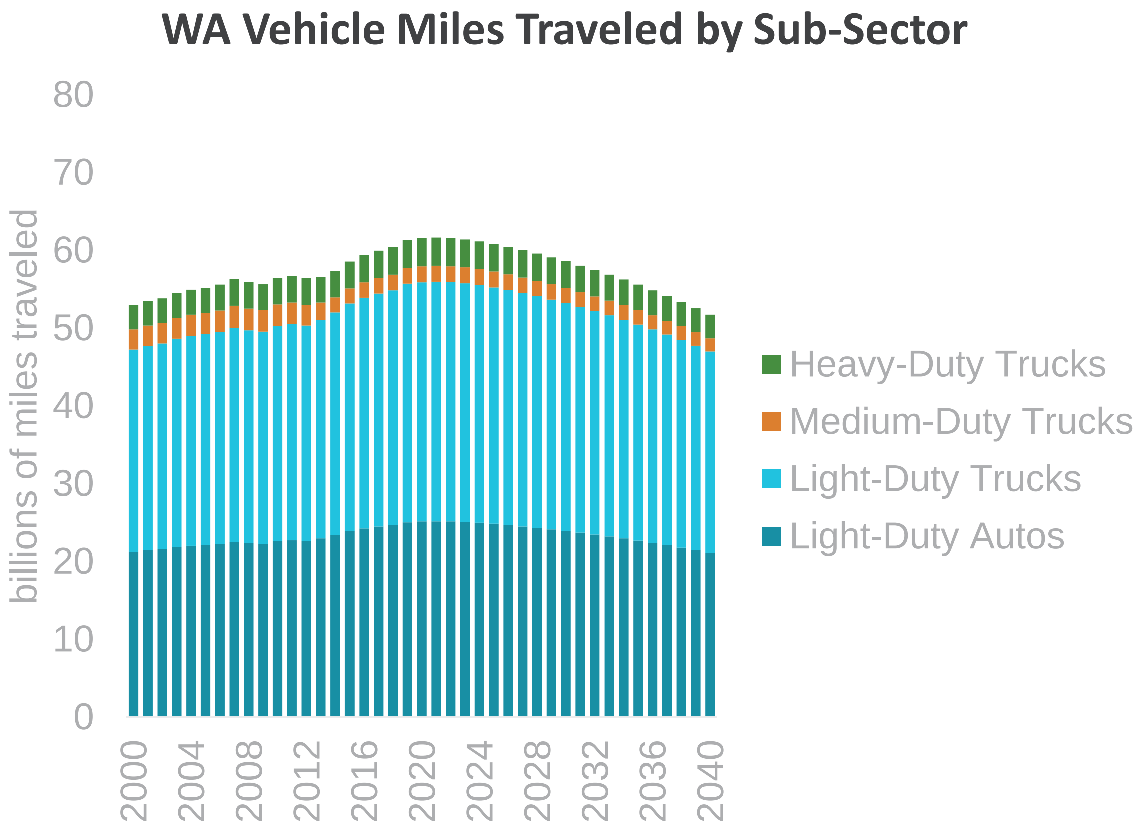


Figure from NEEA Residential Building Stock Assessment

Transportation Sector Assumptions

- Vehicle miles traveled (VMT) projection from Washington State Department of Transportation September 2016 forecast
- Sound Transit 3 is fully reflected by 2040
- Federal CAFE standards in place

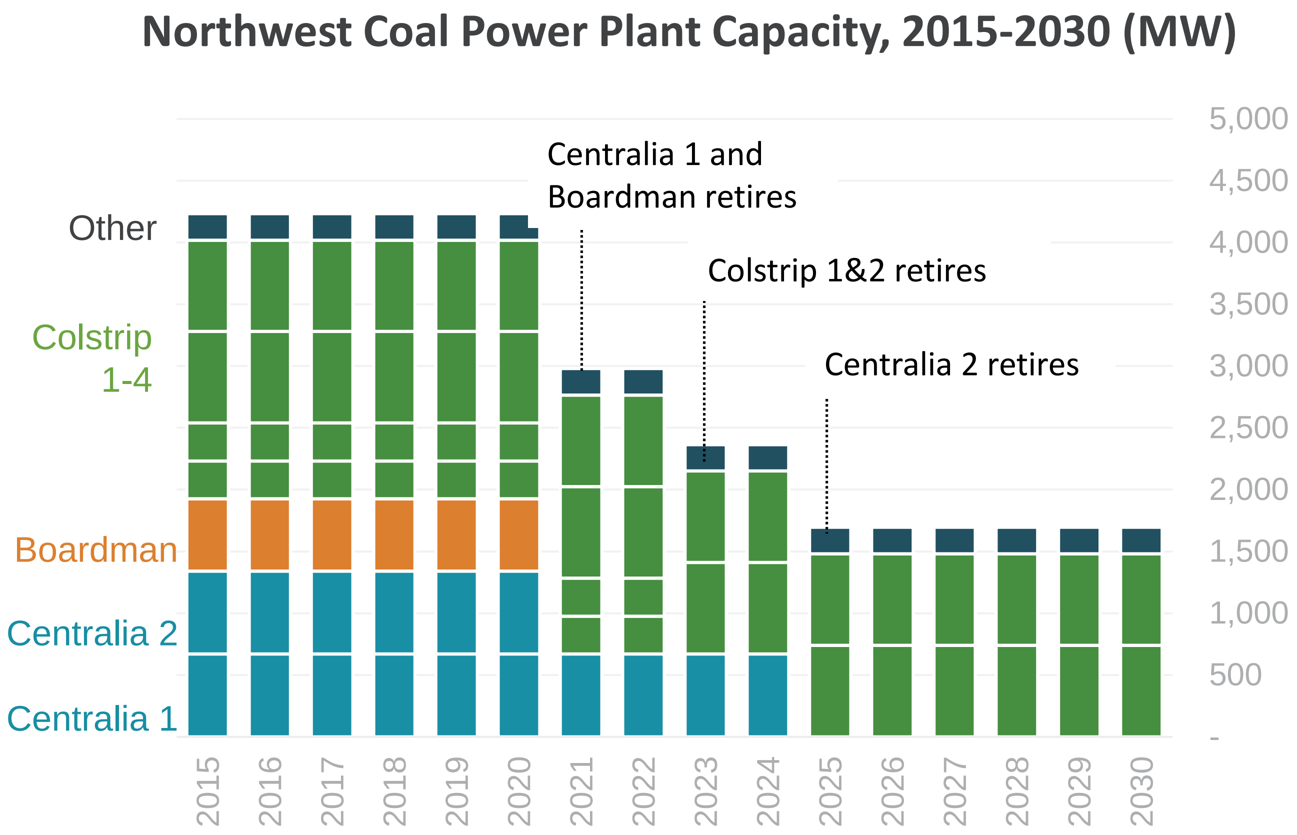


Industrial Sector

- Industrial sector energy demand driven by sector output (i.e., value of shipments)
- Census division-level projections for value of shipments are from the EIA's *Annual Energy Outlook*, which we further allocate to Washington State using historical state-level data on domestic freight shipments from the Bureau of Transportation Statistics

Electric Power Sector

- Generation resource data from U.S. Energy Information Administration and WECC's 2026 Common Case
- WECC Common Case reflects a trajectory of power plant changes over the coming decade
  - State RPS compliance
  - Coal plant retirements
  - Planned additions



Scenario Descriptions

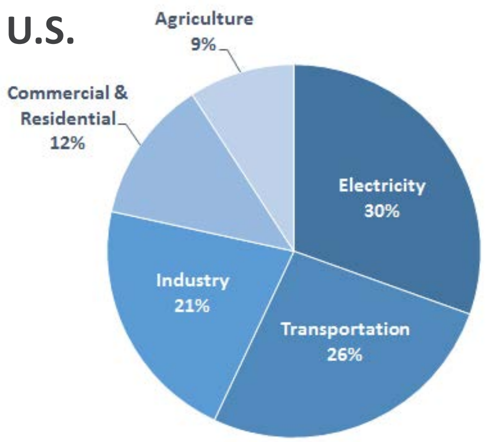
Overview

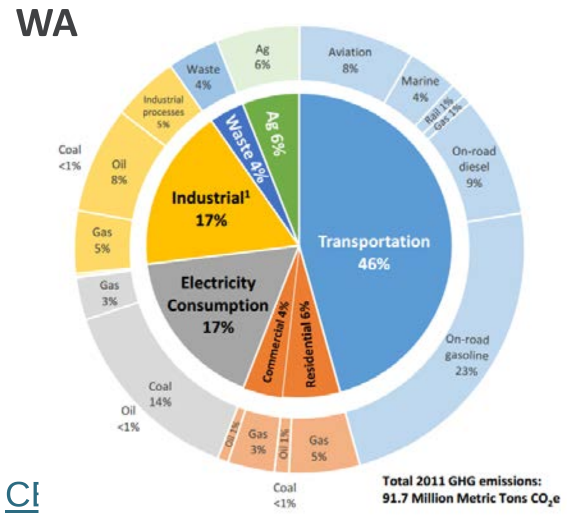
- We developed three deep decarbonization pathway cases which include alternative emission reduction strategies and technologies
- These cases were purposely designed as “bookend” cases to demonstrate multiple, distinctive ways of achieving the same GHG target, and the robustness of results was prioritized over the design of a single “optimal” case
- Three DDP cases are compared against a Reference Case reflecting current policy to demonstrate the scale of change needed to achieve energy-related CO_2 emissions below 9.9 $MMTCO_2$ in 2050

Considerations for Designing DDP Cases in Washington State

- Washington State is different from other regions of the U.S., so any energy system transformation must recognize the key differences to understand the advantages and disadvantages of various decarbonization options:
  - Electricity system dominated by hydro and highly interconnected with neighboring states/regions
  - Electricity already large source of home heating
  - Disproportionate share of emissions from the transportation sector

GHG Emissions by Sector





Sources: EPA and CI

Case Overview

DDP cases designed to achieve an 86% reduction in energy-related CO_2 emissions relative to 1990 levels by 2050

Reference

This scenario is a continuation of current and planned regulations, policies and infrastructure, including:

-Clean Air Rule
-Renewable Portfolio Standard
-Sound Transit 3

The case reflects existing energy policy. It is not designed to meet existing statewide GHG targets.

Electrification

This is a world where deep decarbonization is realized by electrifying end-uses to the extent possible and significantly reducing the consumption of pipeline gas in buildings. Liquid biofuels are deployed to decarbonize remaining fuel end-uses like freight trucks, marine vessels, and aviation.

The electricity sector adds significant new renewable resources largely balanced using existing and new pumped hydro storage and new battery energy storage resources.

Renewable Pipeline

In this world, buildings and industry continue to use a large share of pipeline gas, but the pipeline gas supply is decarbonized with a mix of biogas (primarily through gasification), synthetic natural gas and hydrogen. Decarbonized pipeline gas is also used in medium-duty and heavy-duty vehicles.

Power-to-gas facilities become a principal balancing resource in the electricity sector.

Innovation

In this world, policies of electrification are pursued and are aided by technology breakthroughs in vehicle electrification and hydrogen fuel cells. This allows further electrification of hard-to-decarbonize end-uses like trucking and a means to reduce biomass usage. Efforts to electrify the LDV fleet are aided by autonomous vehicle technology.

In the electricity sector, an additional breakthrough in wave technology results in the resource providing 5% of generation needs. Power-to-gas and electrolysis facilities are deployed for balancing.

Buildings and Industry Inputs

Primary equipment types by 2050

End - Uses	Electrification Case and Innovation Case	Renewable Pipeline Case
Space and Water Heating	Building shell efficiency; air source and geothermal heat pumps; electric resistance	Building shell efficiency; air source and geothermal heat pumps; electric resistance; high efficiency pipeline gas
Air Conditioning	Air source and geothermal heat pumps; high efficiency AC	Air source and geothermal heat pumps; high efficiency AC
Lighting	LED	LED
Appliances (clothes washers, clothes dryers, refrigerators, etc.)	Best available technology	Best available technology
Cooking	Electric	High efficiency/pipeline gas
Industry	20% reduction from baseline by 2050	20% reduction from baseline by 2050

Transportation Inputs

Primary vehicle types and energy intensity by 2050

	Electrification Case	Renewable Pipeline Case	Innovation Case
Light-duty vehicles	Electric vehicles	Electric vehicles	Shared autonomous electric vehicles
Medium-duty trucks	Combination of electric and hybrid diesel vehicles	Combination of electric and hybrid CNG vehicles	Electric vehicles
Heavy-duty trucks	High efficiency diesel vehicles	Combination of high efficiency diesel and LNG vehicles	Electric and hydrogen-fueled
Aviation	55% reduction in energy intensity	55% reduction in energy intensity	55% reduction in energy intensity
Marine Vessels	Minor electrification	Minor electrification	Electric and hydrogen-fueled

Electric Power Sector Assumptions

	Electrification Case	Renewable Pipeline Case	Innovation Case
Hydro	Consistent with TEPPC to 2035 and maintenance of generation capacity thereafter	Consistent with TEPPC to 2035 and maintenance of generation capacity thereafter	Consistent with TEPPC to 2035 and maintenance of generation capacity thereafter
Wind	45% onshore wind by 2050	45% onshore wind by 2050	40% onshore wind by 2050
Solar PV	10% grid-connected PV and 3800 MW Rooftop PV	10% grid-connected PV and 3800 MW rooftop PV	10% grid-connected PV and 3800 MW rooftop PV
Geothermal	3% by 2050	3% by 2050	3% by 2050
Biomass	Allow natural retirement of biomass capacity	Allow natural retirement of biomass capacity	Allow natural retirement of biomass capacity
Wave	n/a	n/a	5% by 2050
Nuclear	Maintenance of Columbia Generating Station through 2050	Maintenance of Columbia Generating Station through 2050	Maintenance of Columbia Generating Station through 2050
Coal	Retirement after 40-year life	Retirement after 40-year life	Retirement after 40-year life

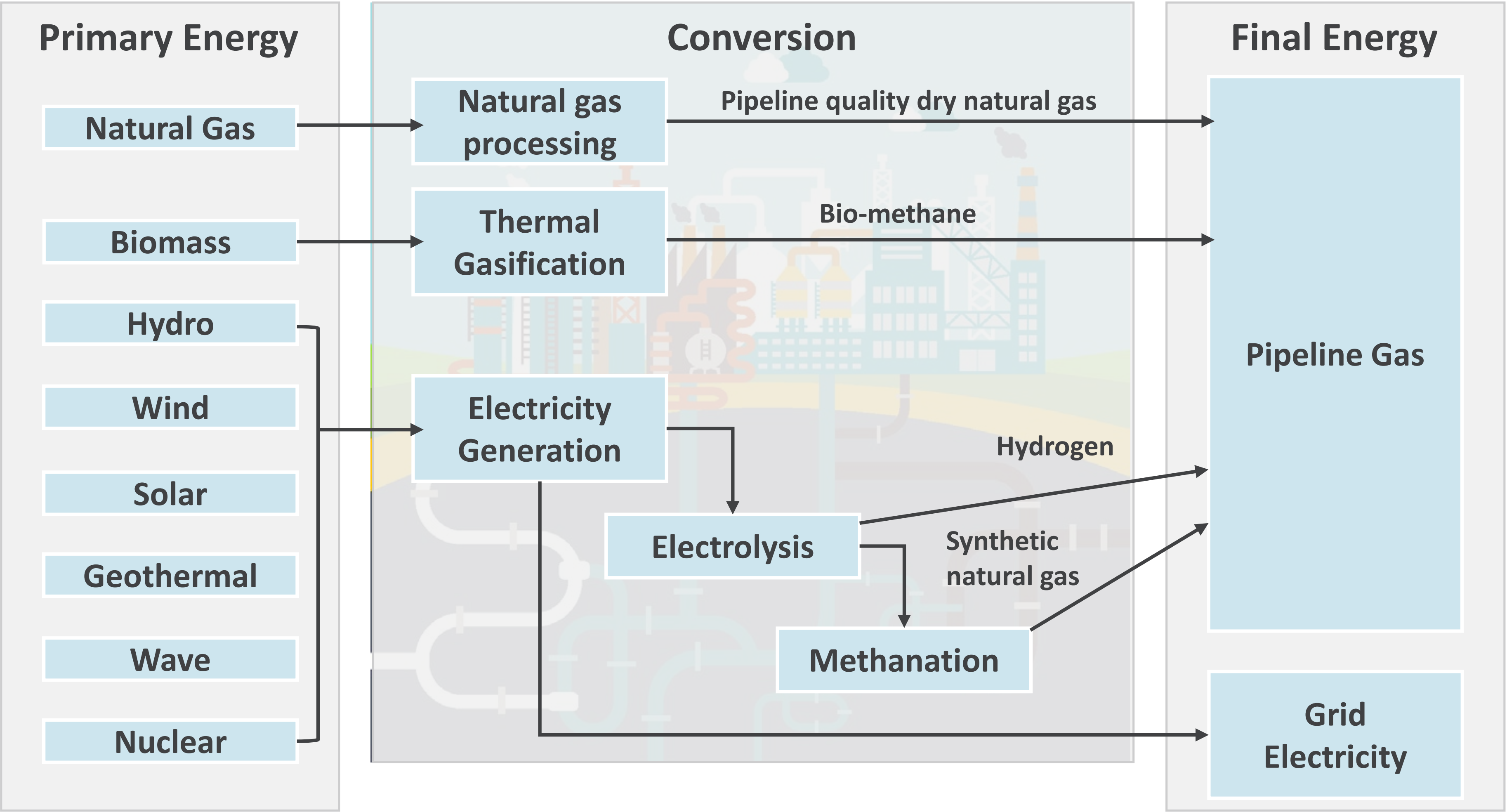
Innovation in the Electric Power Sector

- Onshore wind and solar PV, two mature renewable energy technologies, are key to decarbonizing the Northwest's electricity sector
- There is considerable value in deploying other low-carbon power generation technologies to complement onshore wind and solar PV which: (1) have relatively *low* output in the spring when hydro output is high and load is low; and (2) have relatively *high* output in the winter when loads peak
- In the Innovation Case, we use wave energy technology as a proxy resource since its output profile fits the characteristics described above
- However, other technologies may be suitable to capture this value, such as offshore wind

Decarbonizing Pipeline Gas and Liquid Fuels

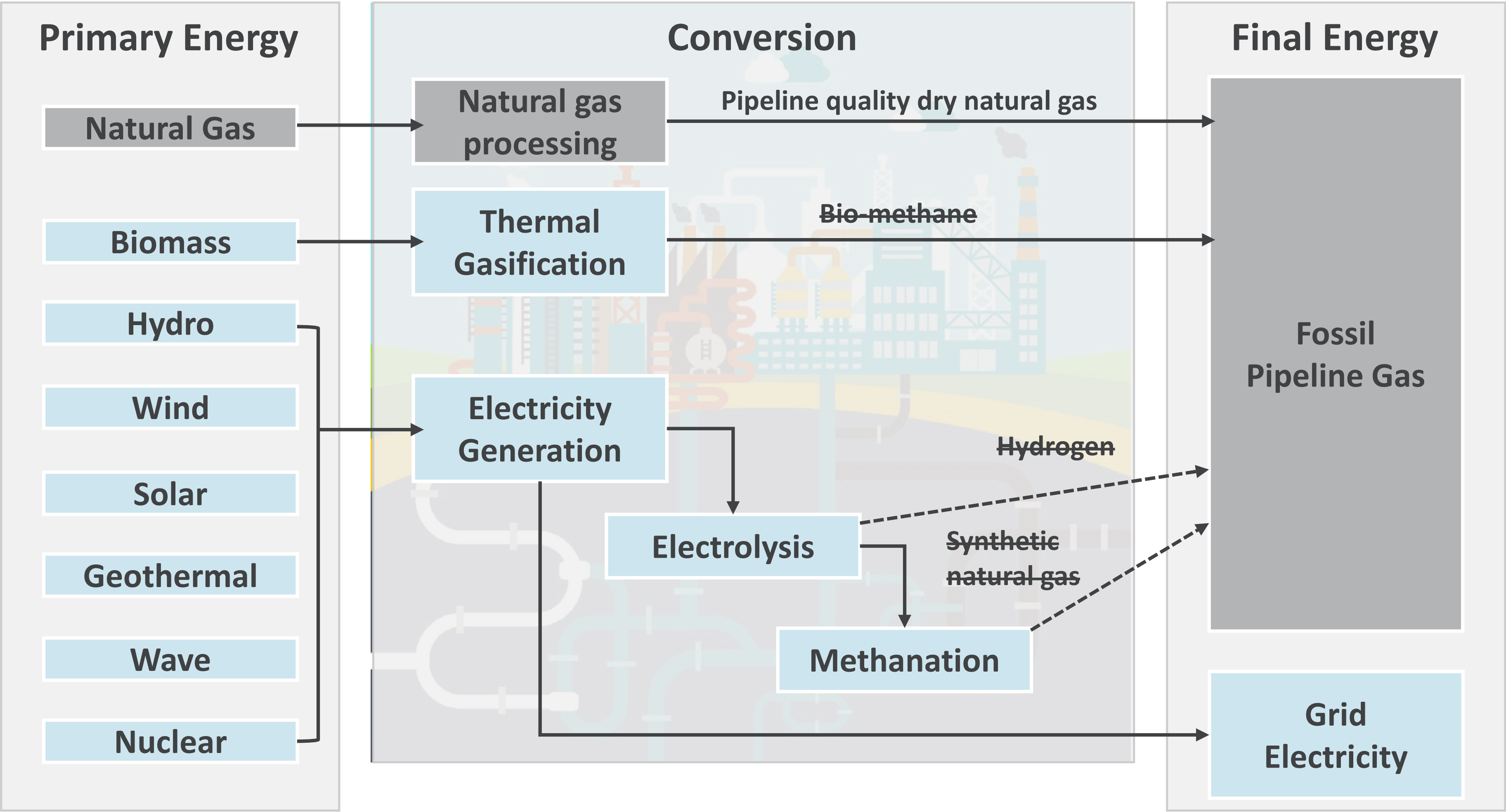
- In addition to reducing the emissions intensity of electricity generation with higher shares of renewable energy, the emissions intensity of pipeline gas and liquid fuels can be reduced by using biomass and low-carbon electricity as inputs to fuel production
  - Biomass is assumed to have a net CO2 emissions factor of zero
- Pipeline gas and liquid fuels can continue to be used in vehicles, water heaters and other equipment in a low-carbon energy system as long as they are “blended” with biomass- and electricity-derived inputs
- Following slides illustrate how the emissions intensity of pipeline gas can decrease to zero

Illustration of Pipeline Gas



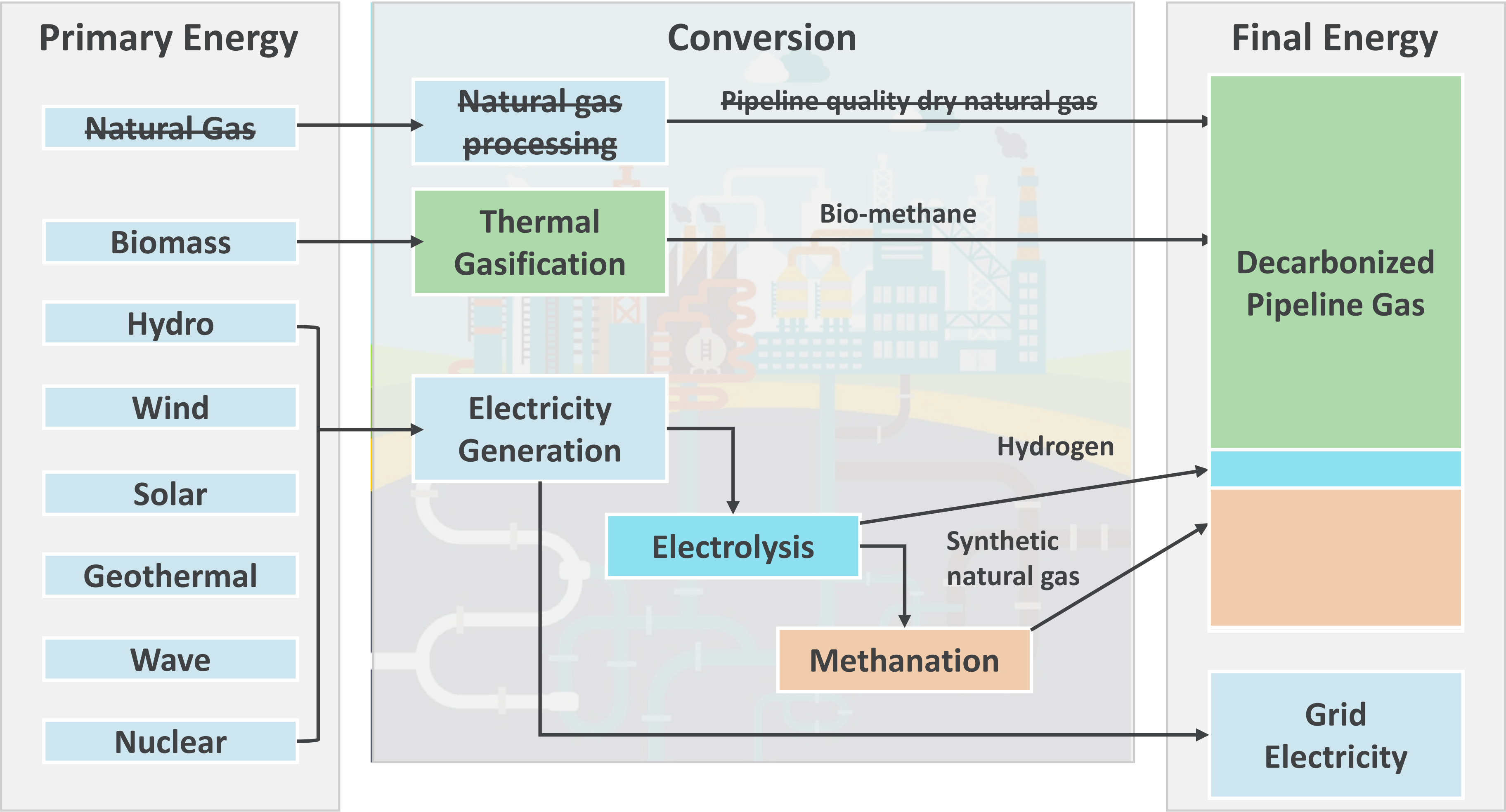
Note: note all final energy types shown. Size of arrows and box do not correspond to magnitude of energy flows or volume.

Illustration of Pipeline Gas Today



Note: note all final energy types shown. Size of arrows and box do not correspond to magnitude of energy flows or volume.

Illustration of Decarbonized Pipeline Gas



Note: note all final energy types shown. Size of arrows and box do not correspond to magnitude of energy flows or volume.

Key Fuel Blend Assumptions

Percent of fuel supply in 2050

- Constrained biomass resources allocated to various liquid and gas fuels

Focus on decarbonizing transportation fuels

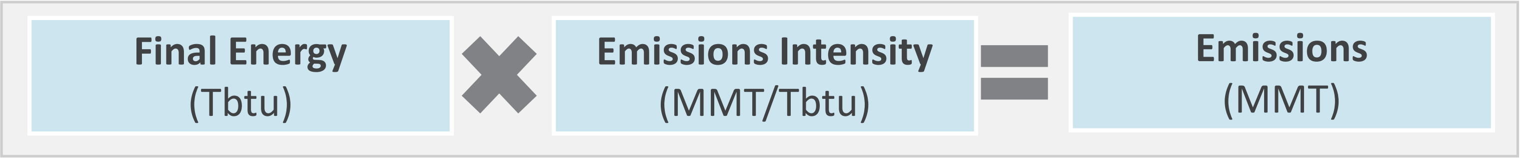
Decarbonize pipeline gas

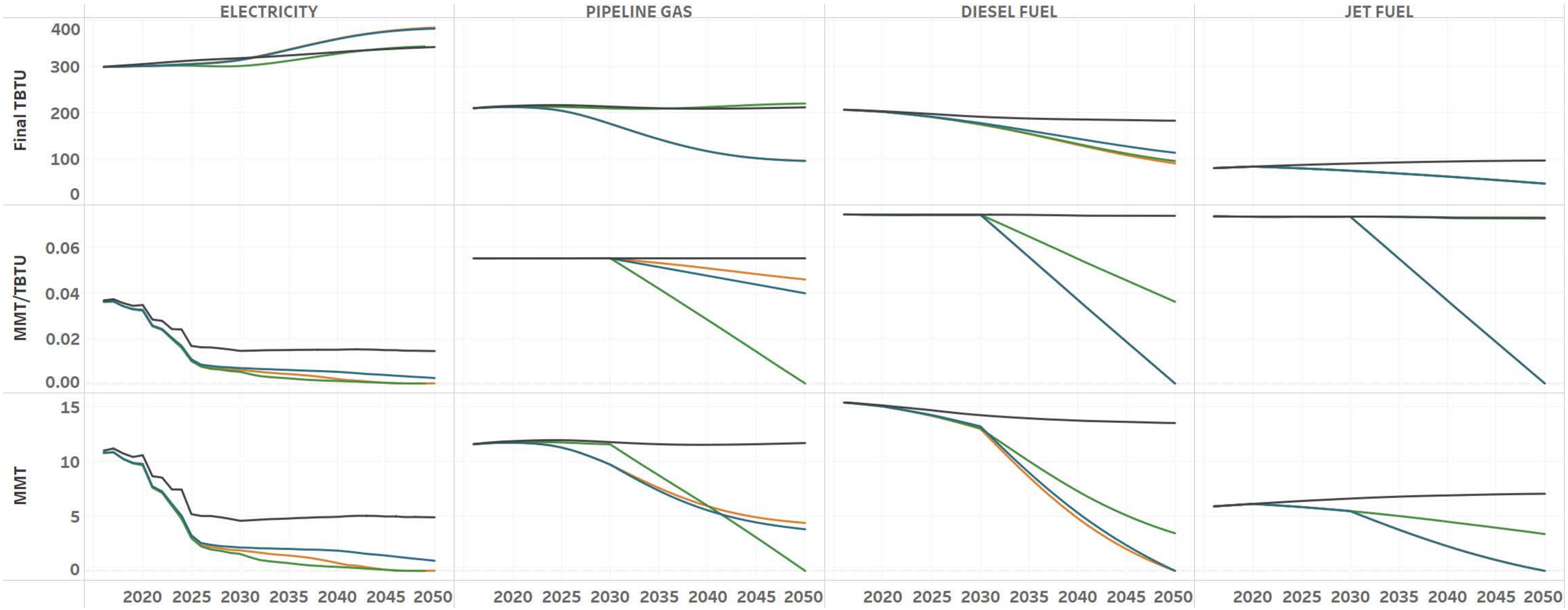
Type	Blend	Reference Case	Electrification Case	Renewable Pipeline Case	Innovation Case
Jet Fuel	Fossil jet fuel	100%	0%	100%	0%
	Renewable jet fuel	0%	100%	0%	100%
Diesel	Fossil diesel	100%	0%	60%	0%
	Renewable diesel	0%	100%	40%	100%
Pipeline Gas	Natural gas	100%	80%	0%	88%
	Biomethane	0%	20%	68%	0%
	Synthetic methane	0%	0%	25%	5%
	Hydrogen	0%	0%	7%	7%

No biomass for pipeline gas

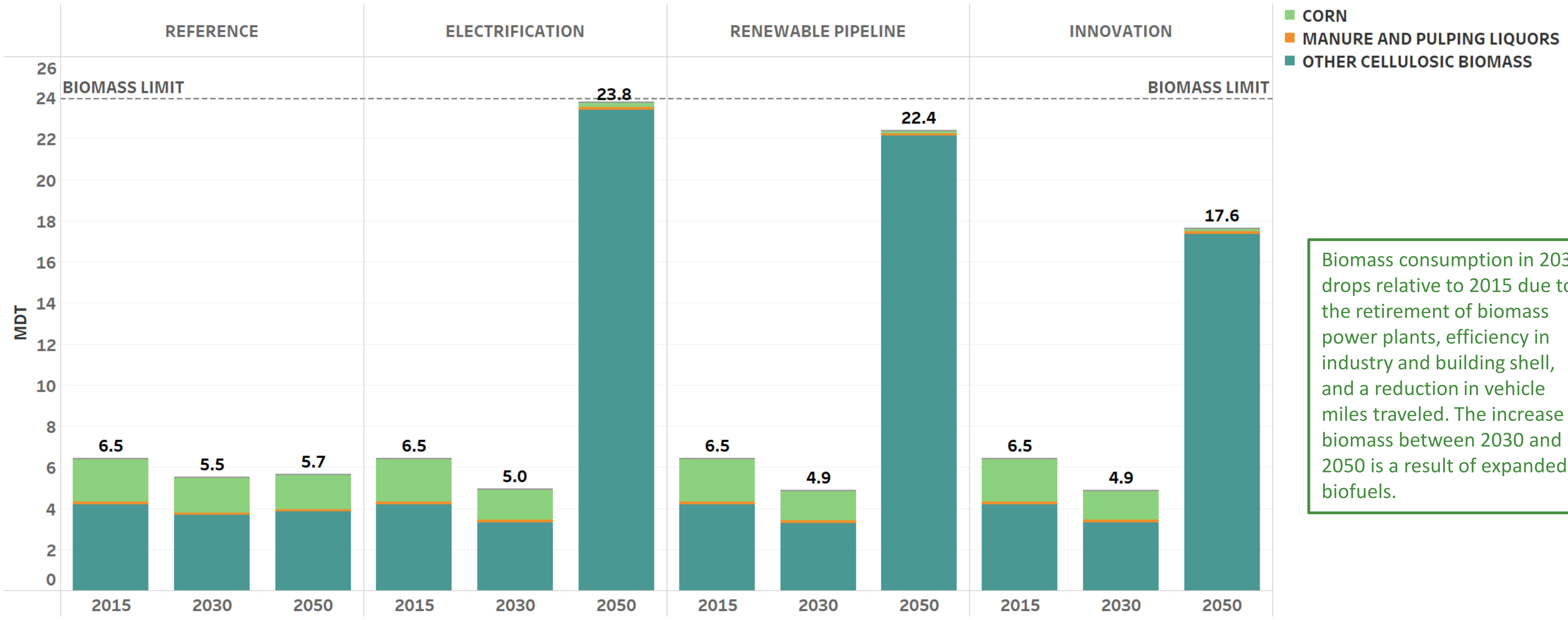
Fuel Comparison

All Cases





Biomass Assumptions



Biomass consumption in 2030 drops relative to 2015 due to the retirement of biomass power plants, efficiency in industry and building shell, and a reduction in vehicle miles traveled. The increase in biomass between 2030 and 2050 is a result of expanded biofuels.

Results

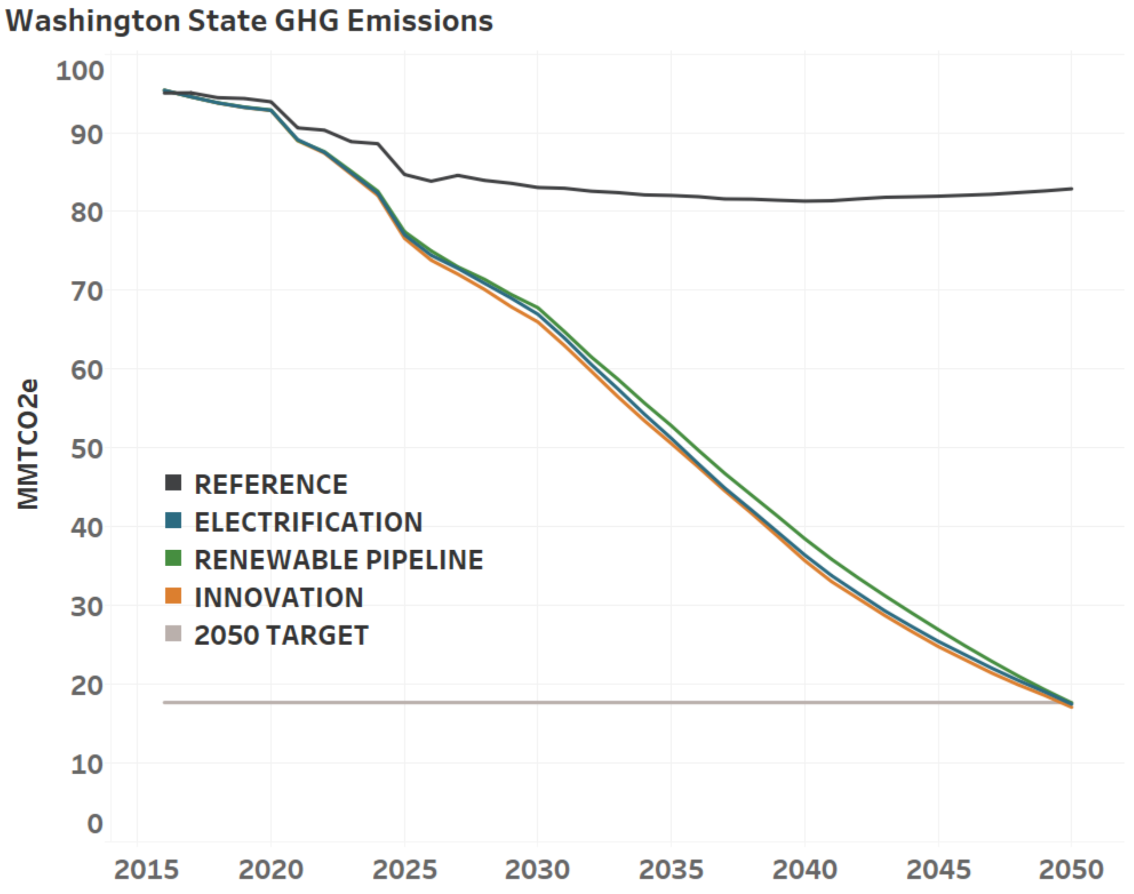
Emissions and Final Energy Demand

Interpreting the Results

- Cases are **not forecasts**, but rather represent “what if” scenarios
- Each case is created using expert judgement to demonstrate how a future deeply decarbonized energy system could operate, but they are not explicitly designed to minimize cost for a given emissions target
- Costs and technology performance are projected based on high quality public sources, but have significant uncertainty
  - Long-term planning processes that adapt to new information is valuable

Washington State GHG Emissions Summary

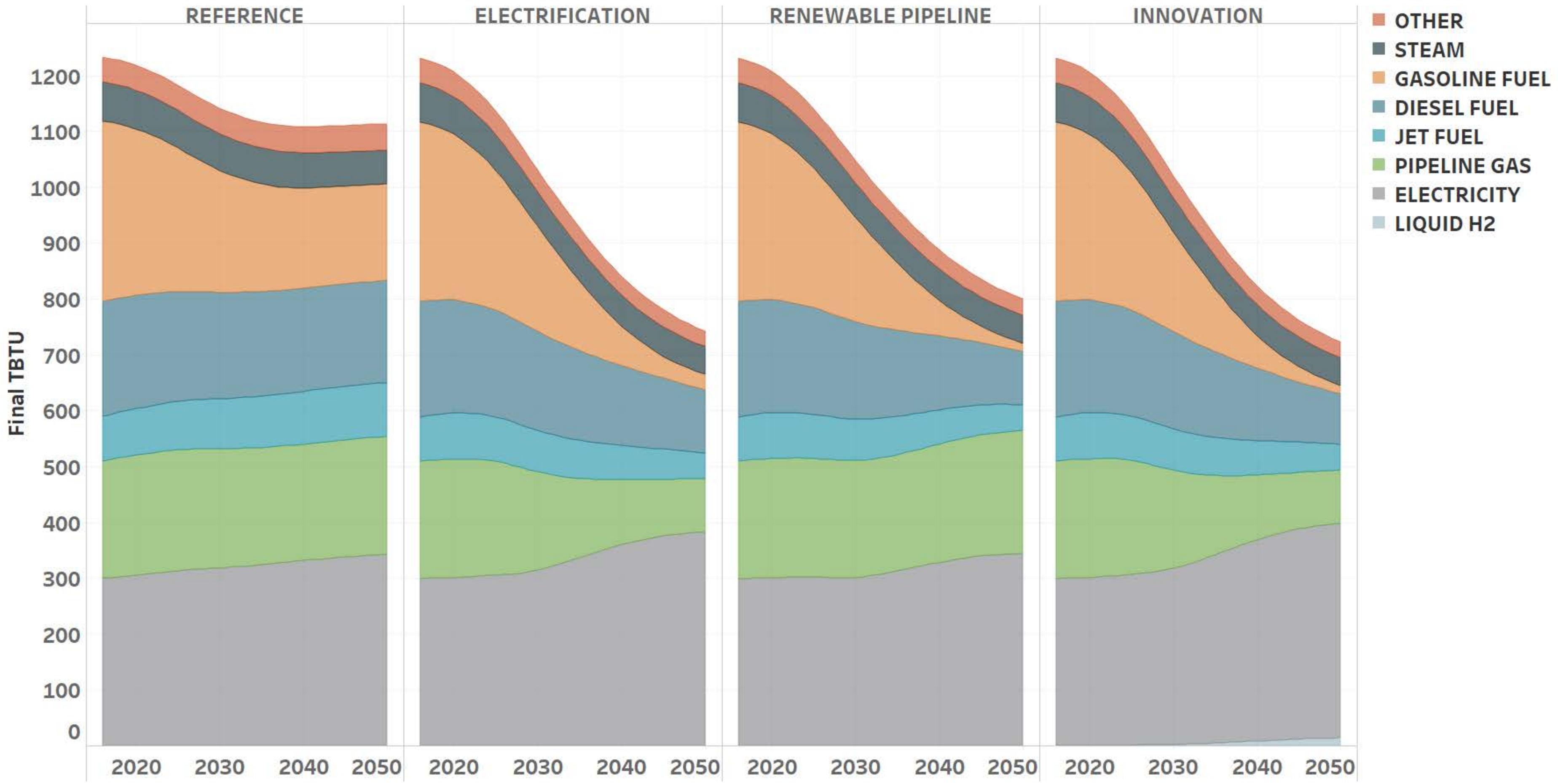
- Reference Case GHG emissions decrease but fall substantially short of 2050 target
  - Energy CO2 emission reductions offset by growth in non-energy, non-CO2 emissions
- All DDP cases reach GHG emissions below 17.7 MMTCO2e using alternative technologies and approaches



Note: GHG emissions include both energy-related CO2 and non-energy, non-CO2 GHGs

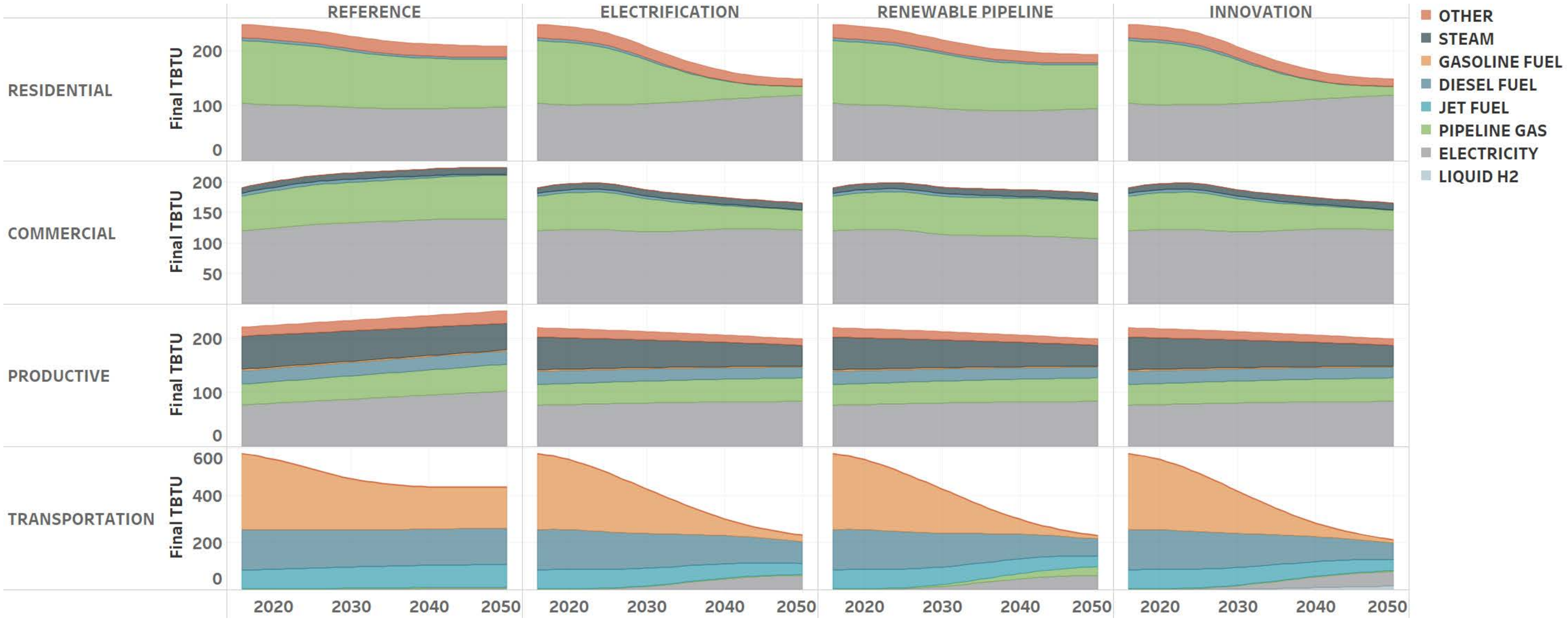
Final Energy Demand

All Cases and Sectors



Sectoral Final Energy Demand

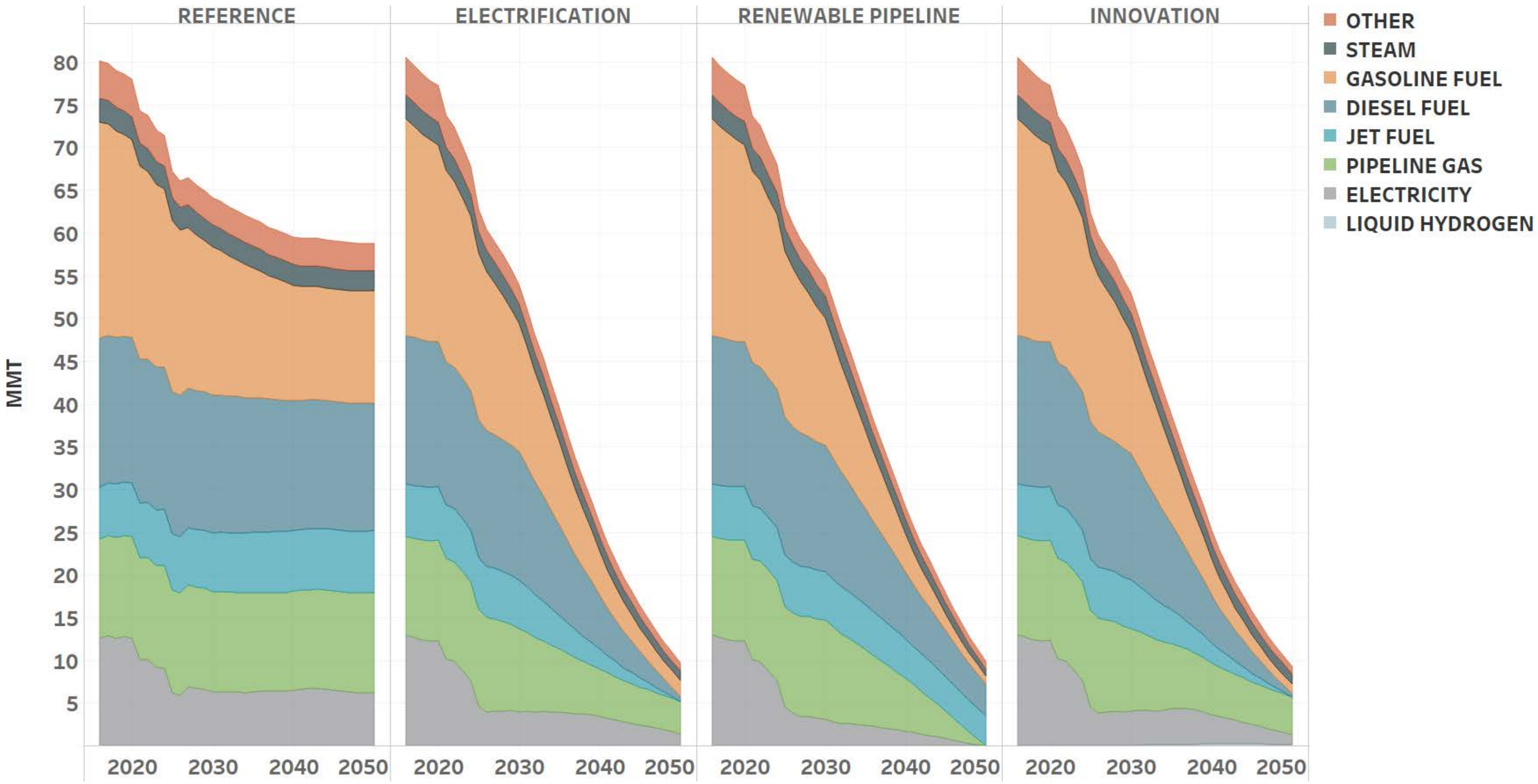
All Cases



Note: Productive sector includes the agriculture sector and industrial sectors except those that are part of the energy supply chain (i.e., refining).

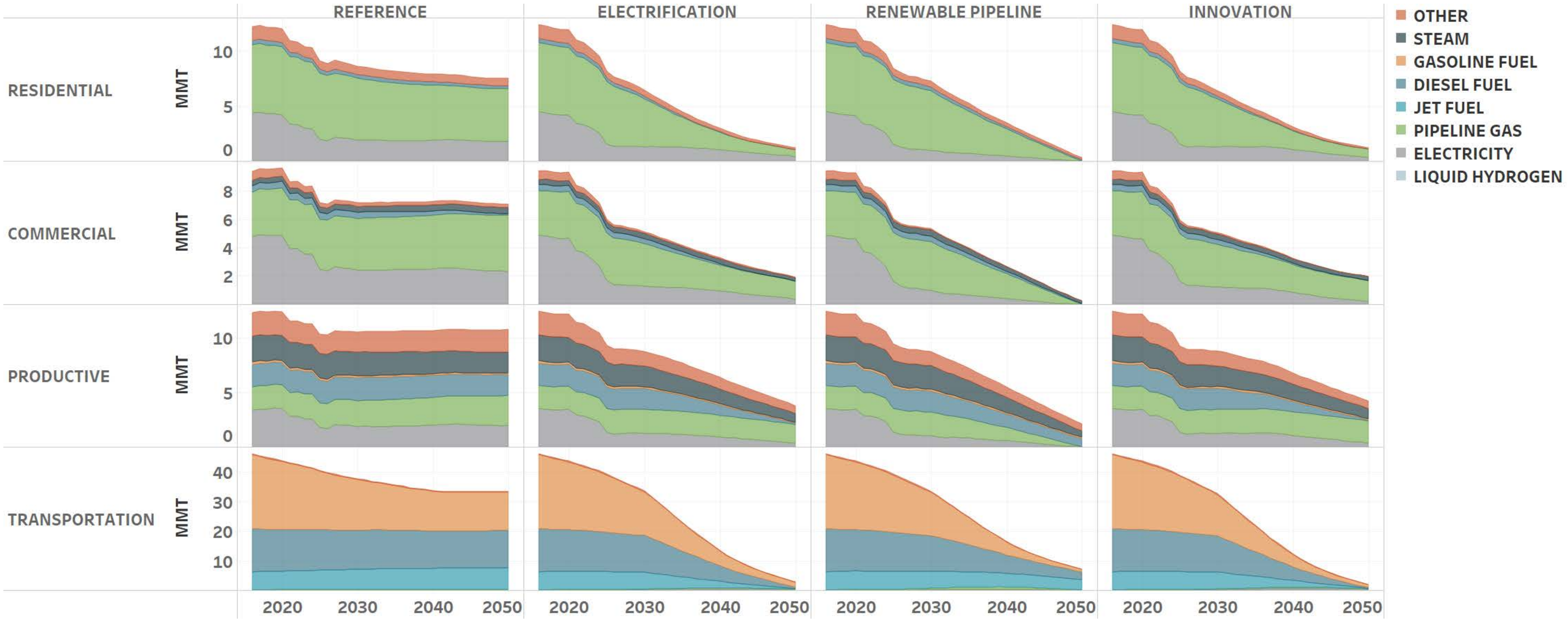
Energy-Related CO2 Emissions

All Cases

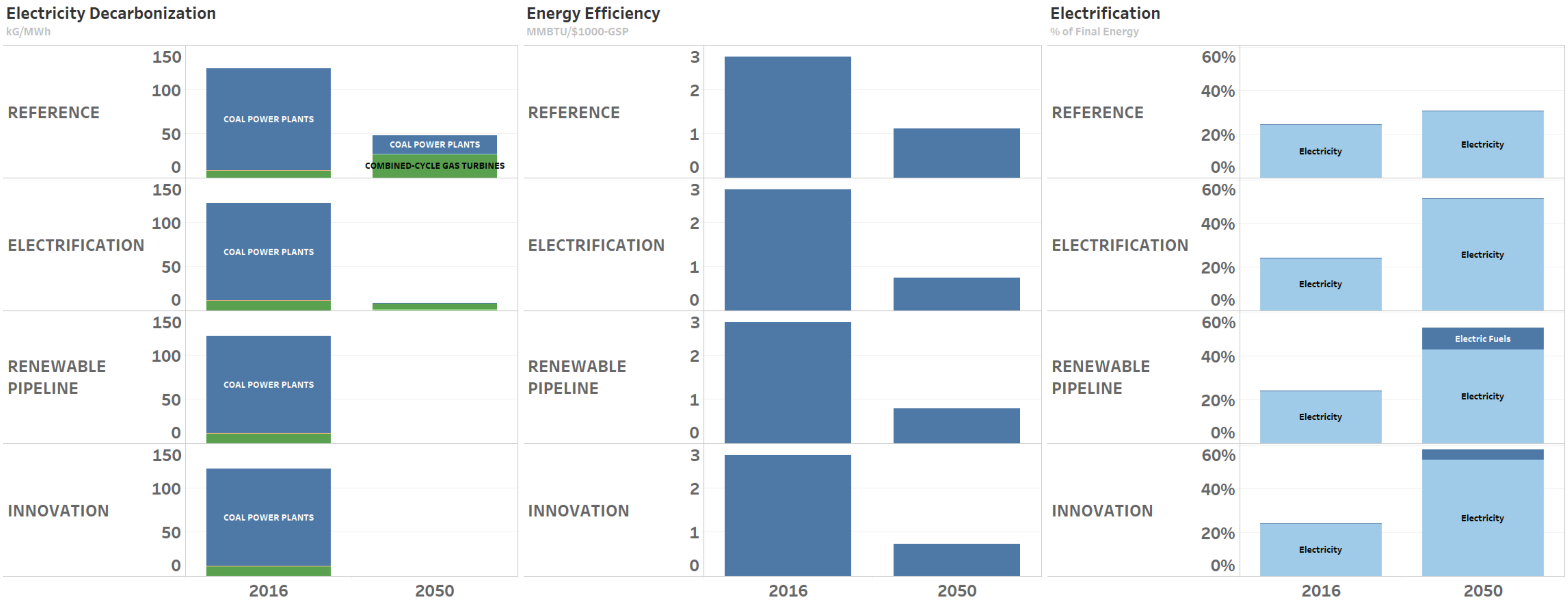


Sectoral Energy-Related CO2 Emissions

All Cases



Three Pillars



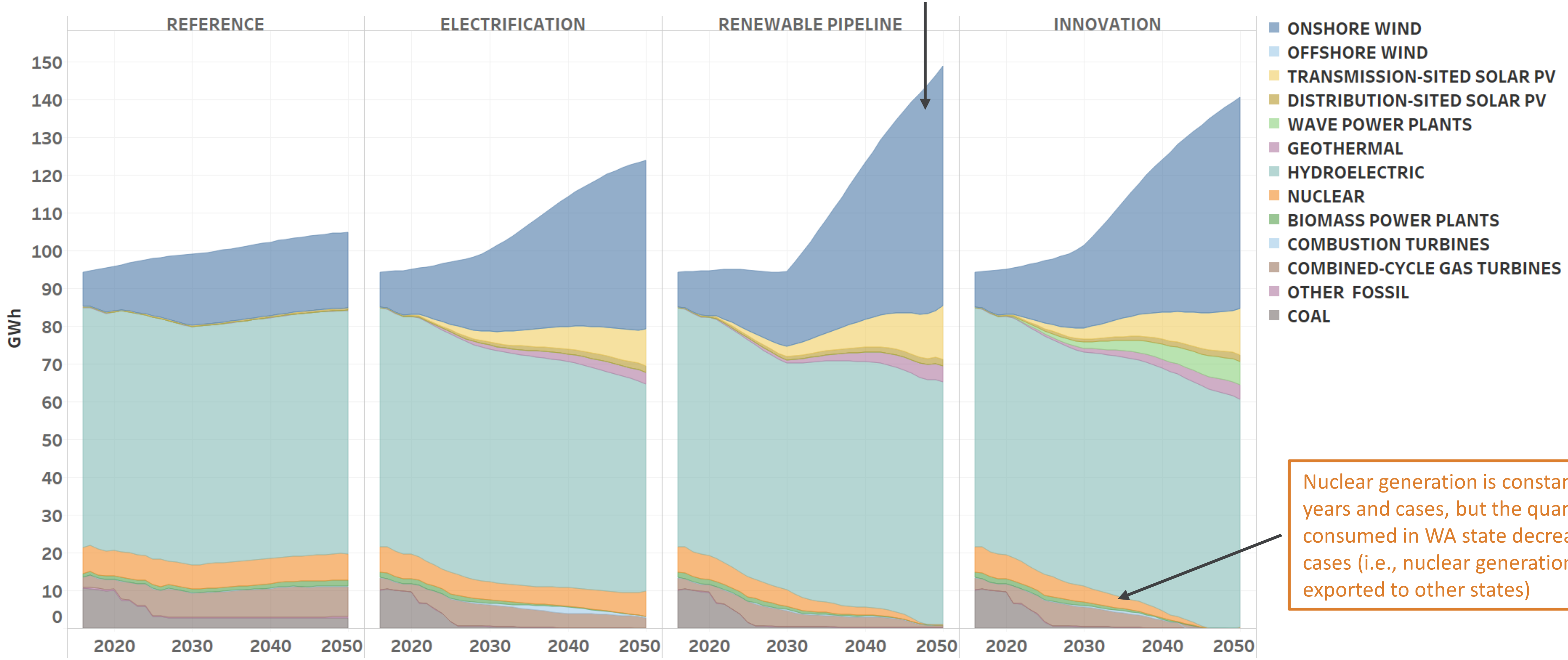
Results

Electric Power Sector

Electricity Generation Consumed in Washington State

All Cases

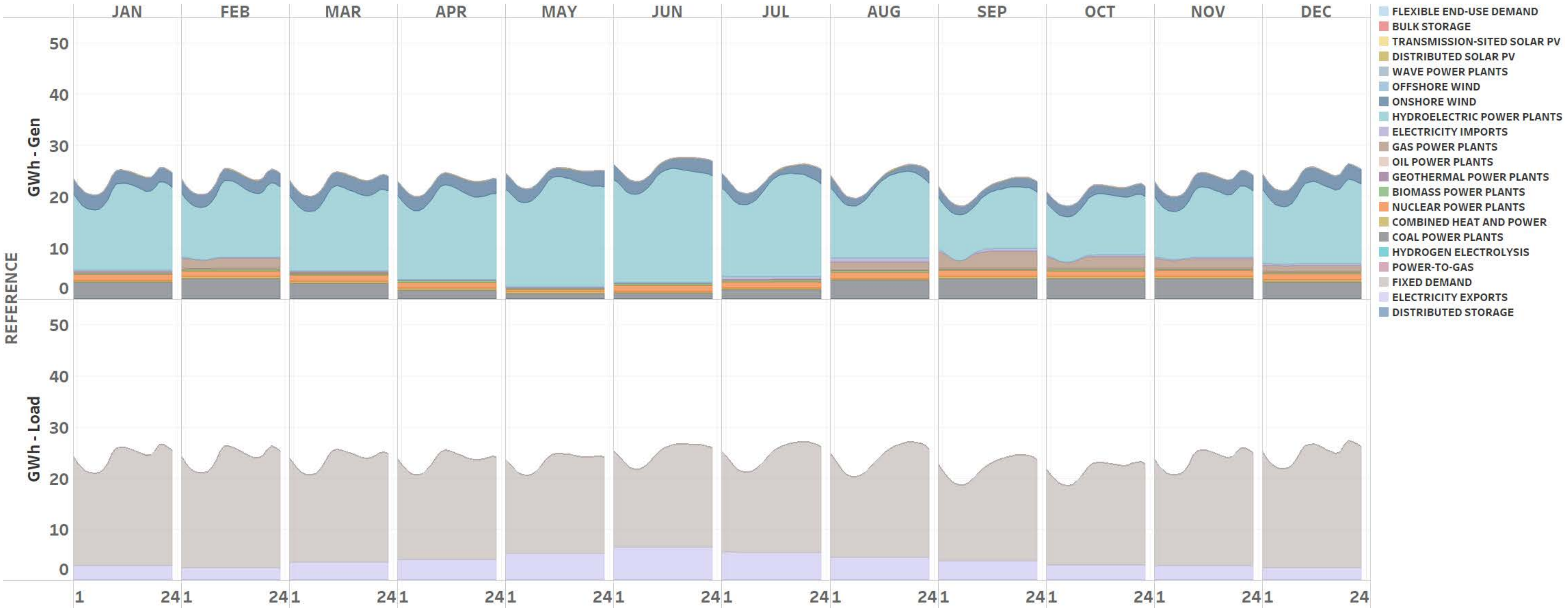
Production of electric fuels for gas pipeline results in highest electricity generation requirement despite lower end-use electrification



Nuclear generation is constant across years and cases, but the quantity consumed in WA state decreases in some cases (i.e., nuclear generation is exported to other states)

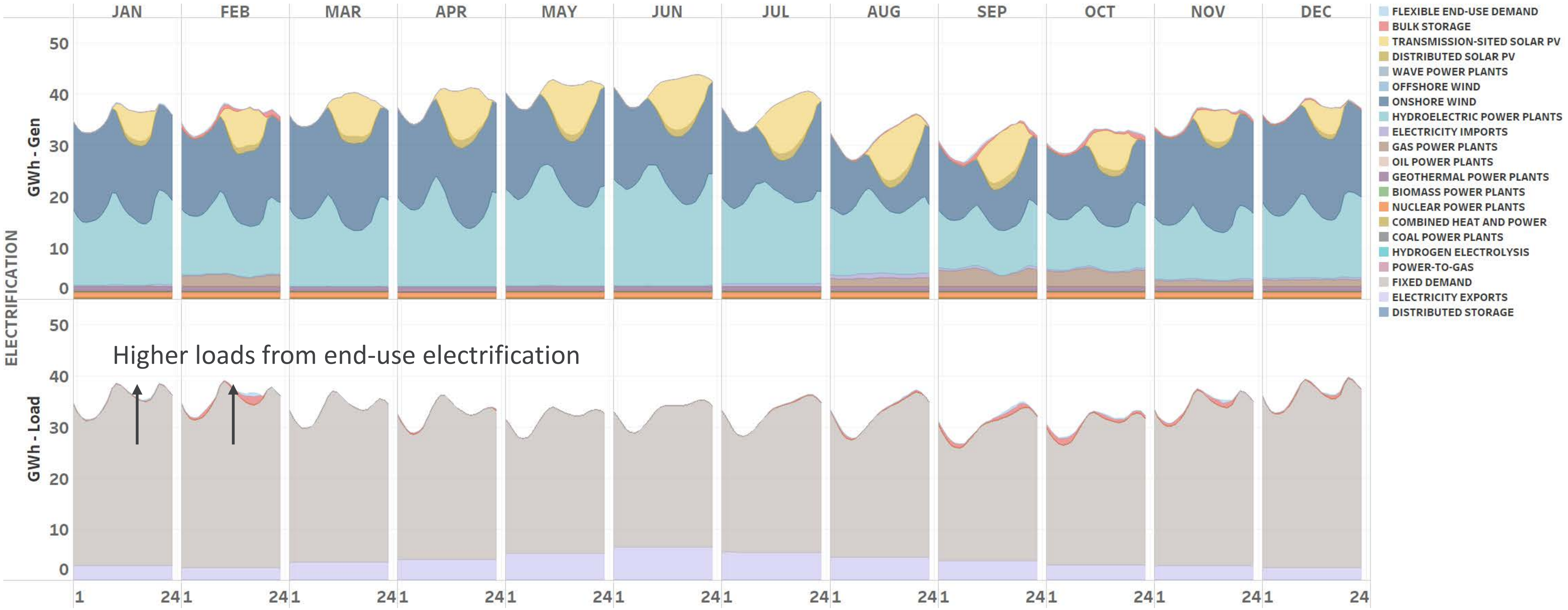
2015 Month-Hour Generation and Load

Reference Case



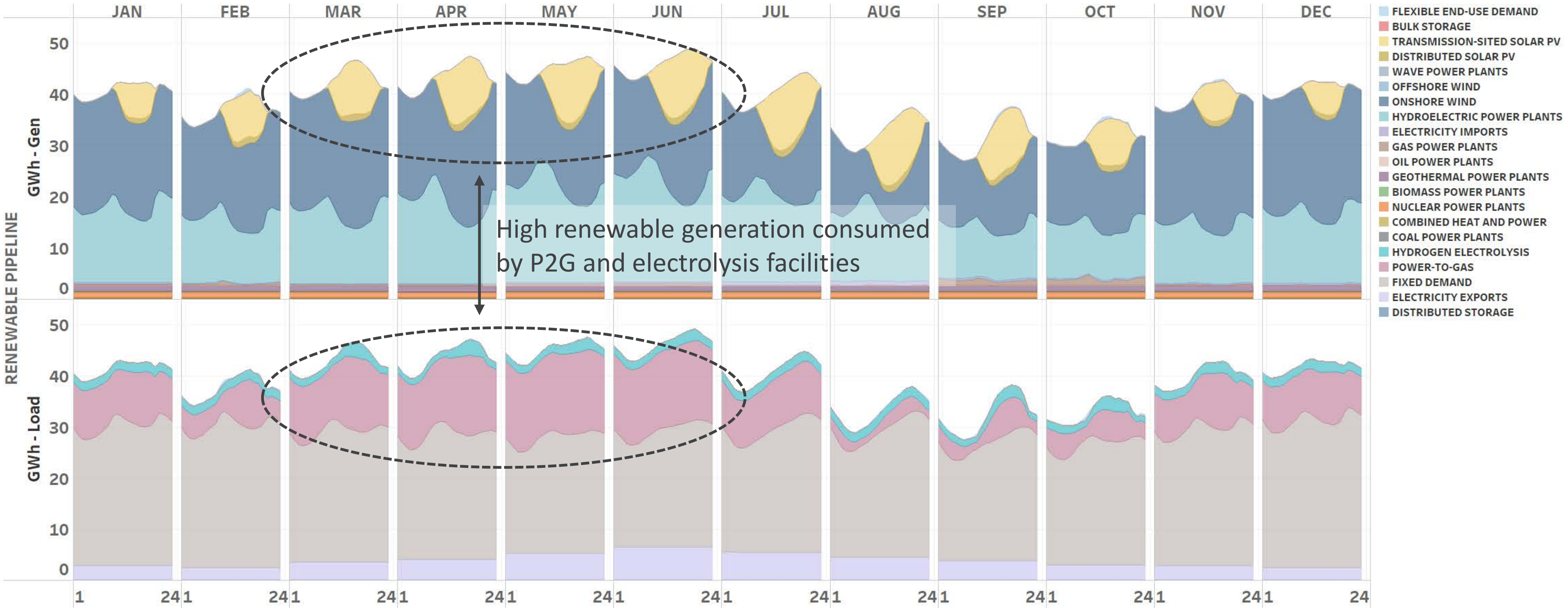
2050 Month-Hour Generation and Load

Electrification Case



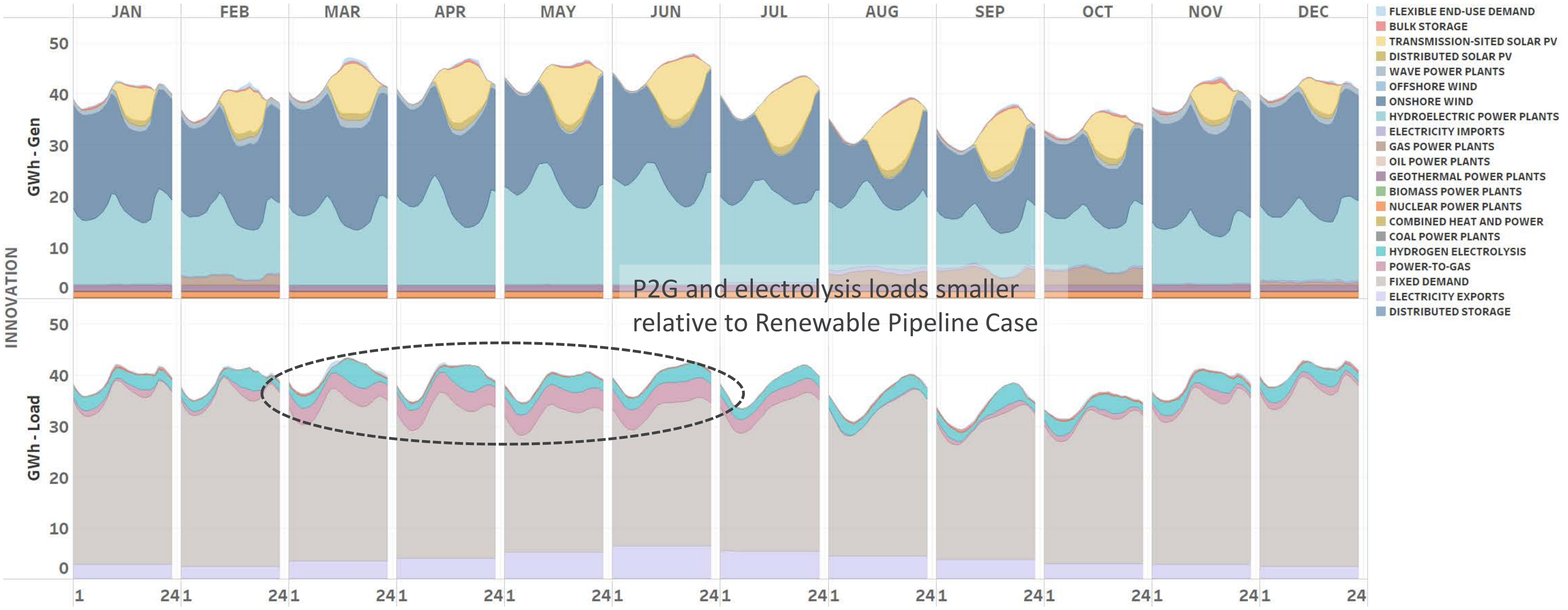
2050 Month-Hour Generation and Load

Renewable Pipeline Case



2050 Month-Hour Generation and Load

Innovation Case

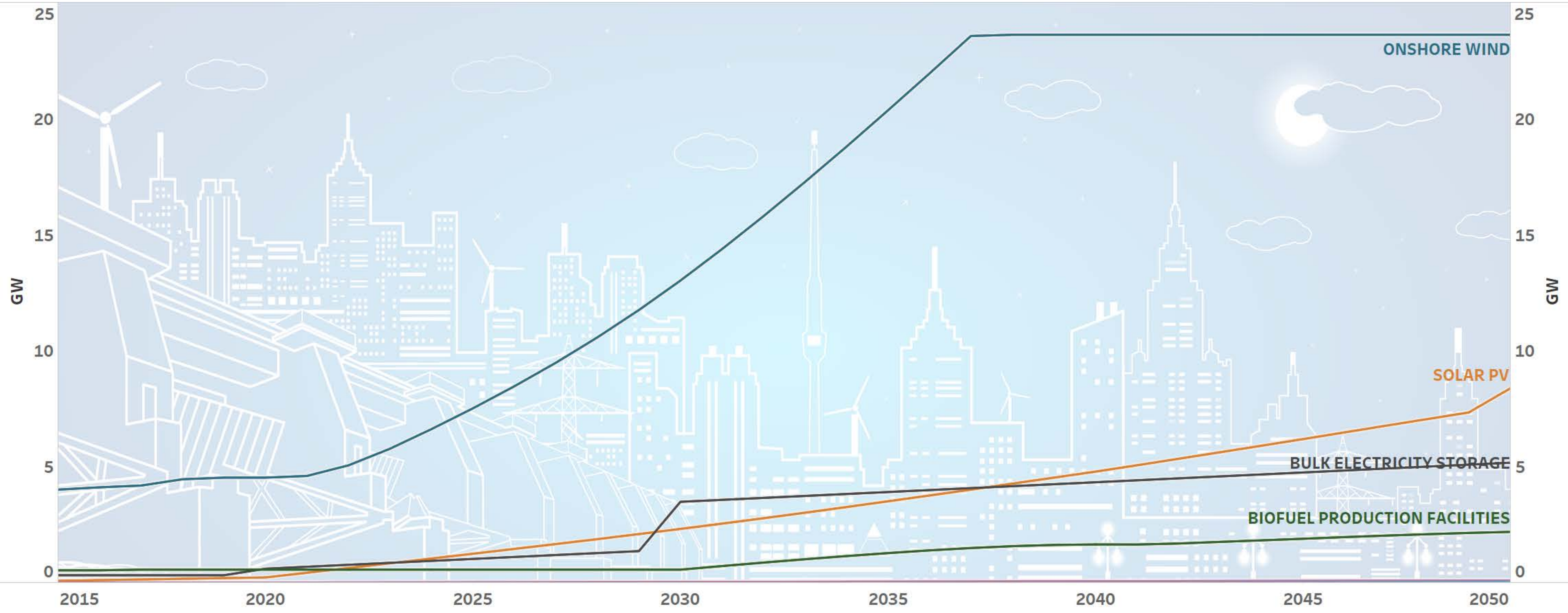


Results

Infrastructure

New Energy Supply Infrastructure

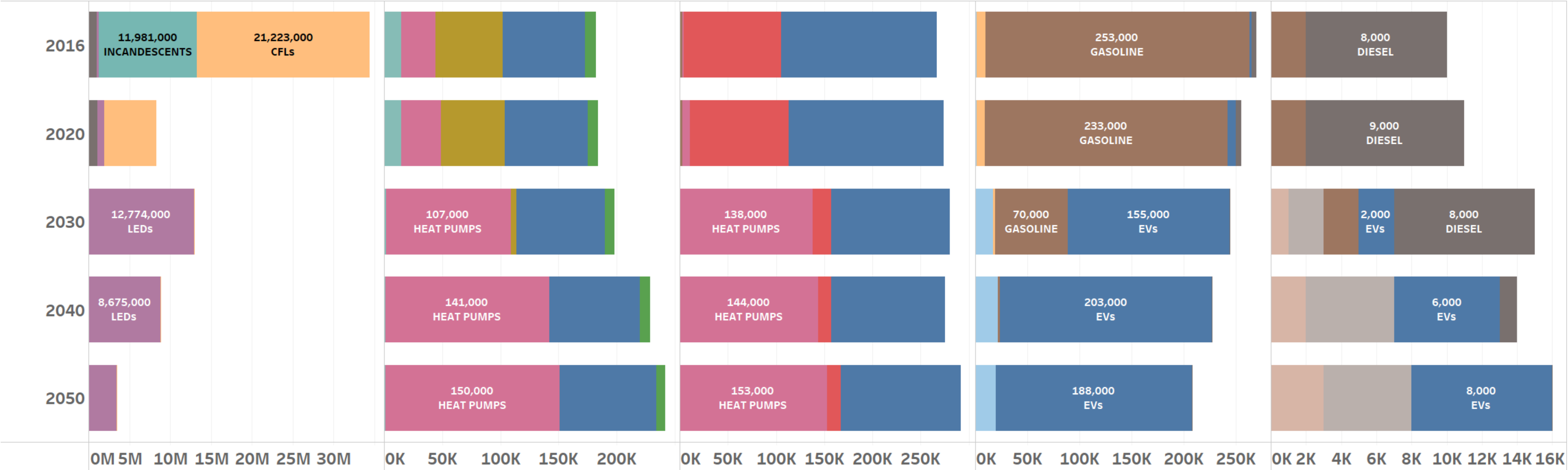
Electrification Case



Note: onshore wind and pumped hydro storage build constrained by potential constraints.

Demand-Side Equipment Sales Targets

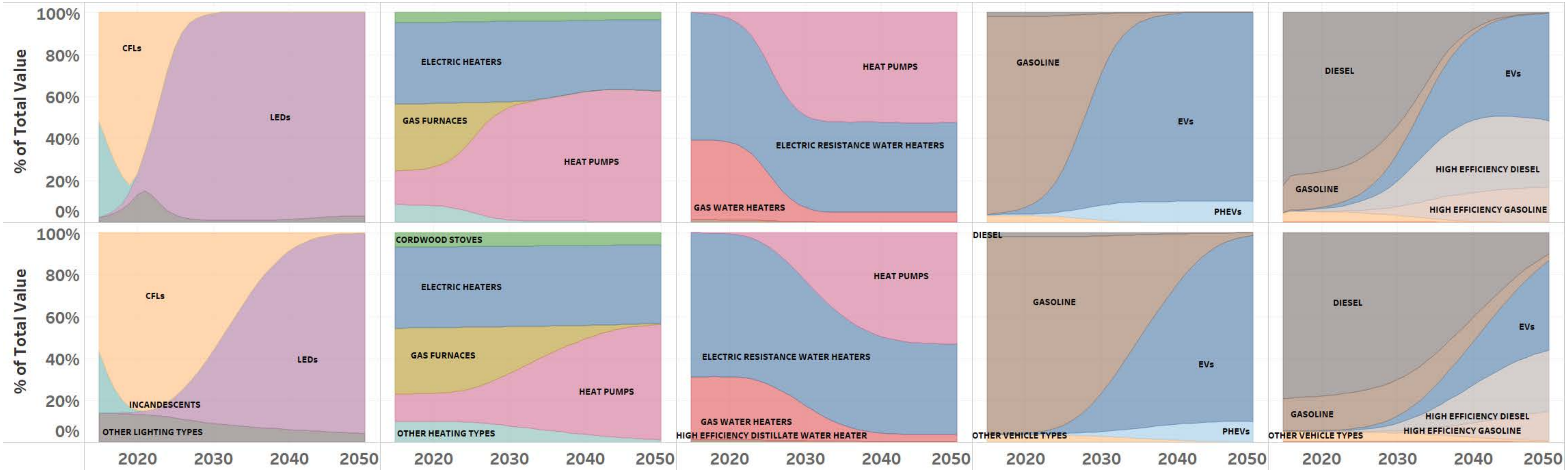
Electrification Case



**Residential lighting, residential space heating, residential water heating, light duty vehicles, medium & heavy-duty vehicles*

Demand-Side Equipment Sales (Top) and Stocks (Bottom)

Electrification Case



Residential lighting, residential space heating, residential water heating, light duty vehicles, medium & heavy-duty vehicles

Results

Cost Impacts

Overview

- The scope of costs in our analysis is limited to **energy system costs**, which includes:
  - Annualized capital costs of demand- and supply-side energy equipment
  - Variable fuel costs
  - Fixed and variable operations and maintenance costs
- This is the annual cost of producing, distributing and consuming energy in Washington State
- Our analysis **does not** include costs outside of the energy system or benefits from avoiding climate change and air pollution
- **All costs are in 2014 dollars**

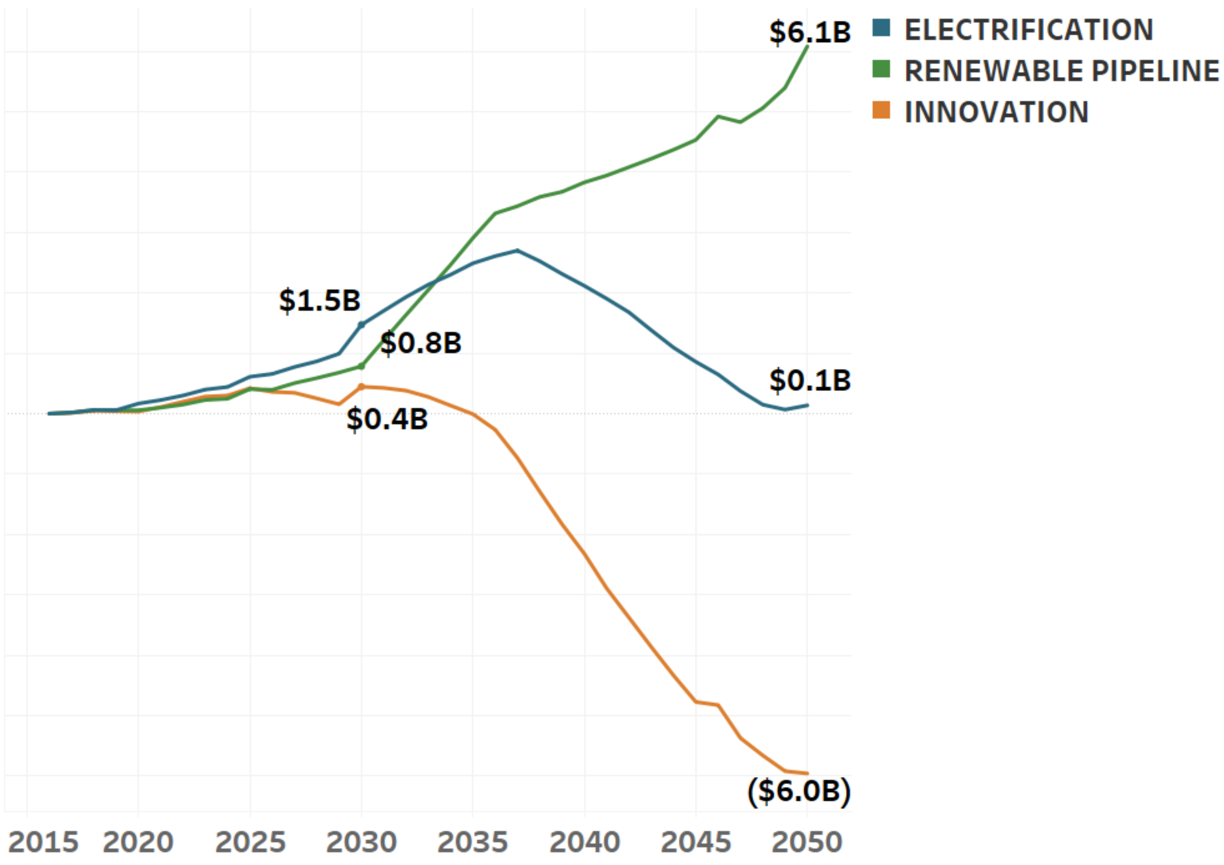
Cost of Deep Decarbonization

- Our primary metric to evaluate the cost of decarbonizing the energy system is “net energy system cost”, which is the additional cost of investment in low-carbon and efficient equipment and infrastructure less the savings from avoided fossil fuel purchases

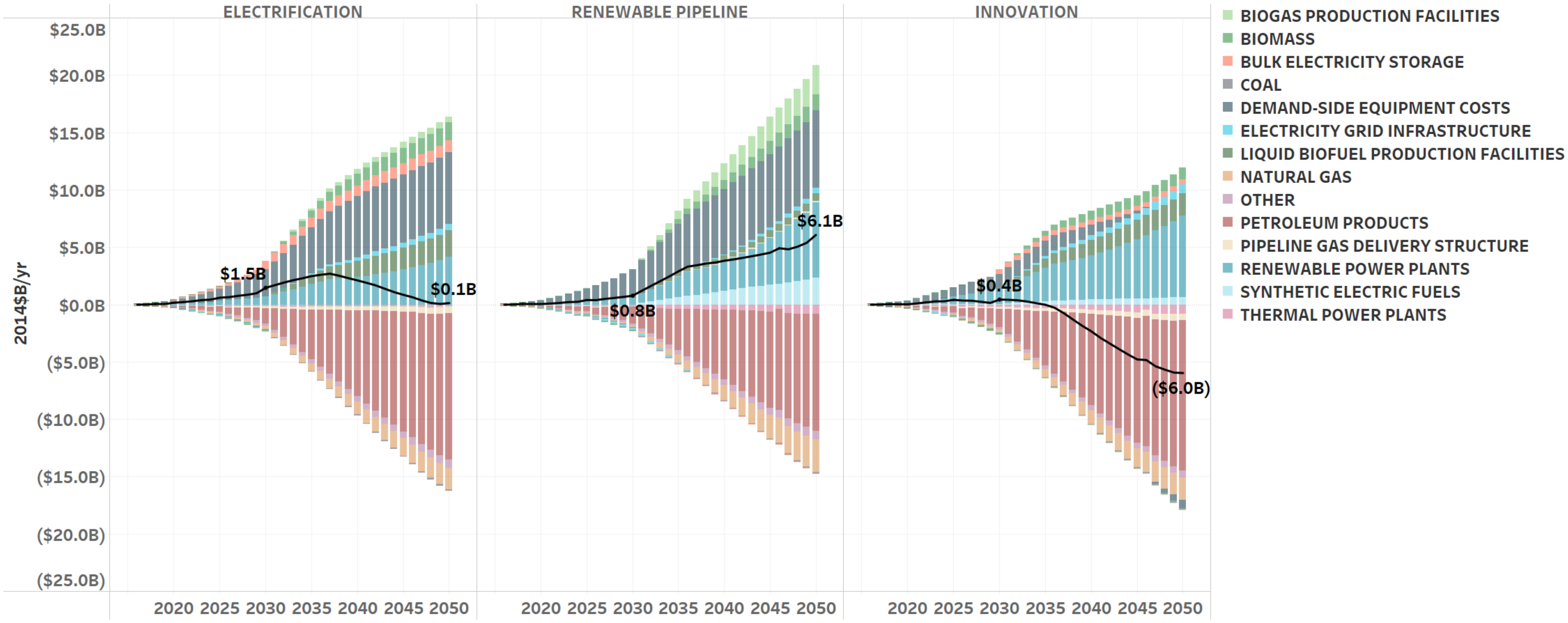
Net Energy System Cost

DDP Case Energy System Cost **−** Reference Case Energy System Cost

WA Net Energy System Cost (2014$B/yr)

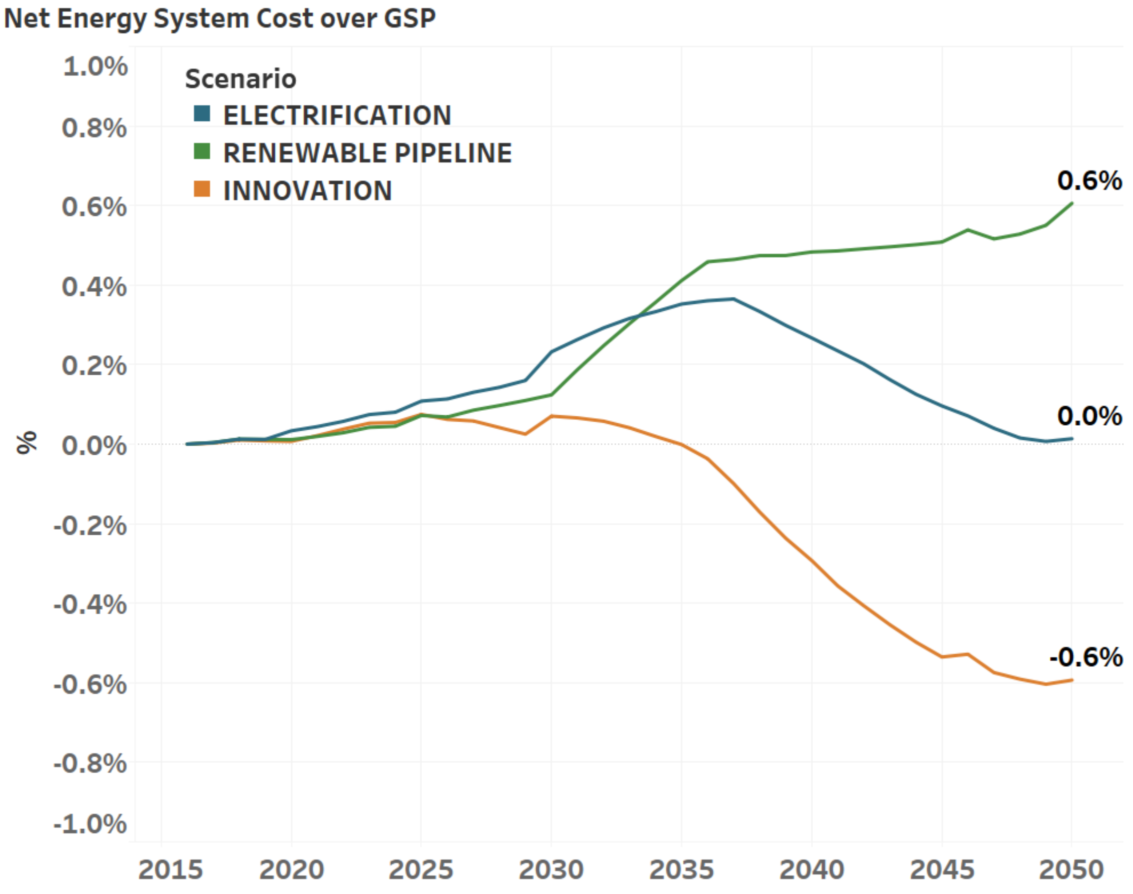


Decomposing the Cost of Deep Decarbonization



Putting the Costs in Context

- Magnitude of net energy system costs are small relative to the projected size of Washington's economy
- DDP Cases show a wide range of outcomes, illustrating that GHG targets can be achieved without excessive costs and even cost savings
- Analysis does not incorporate any macro-economic feedbacks from energy infrastructure changes

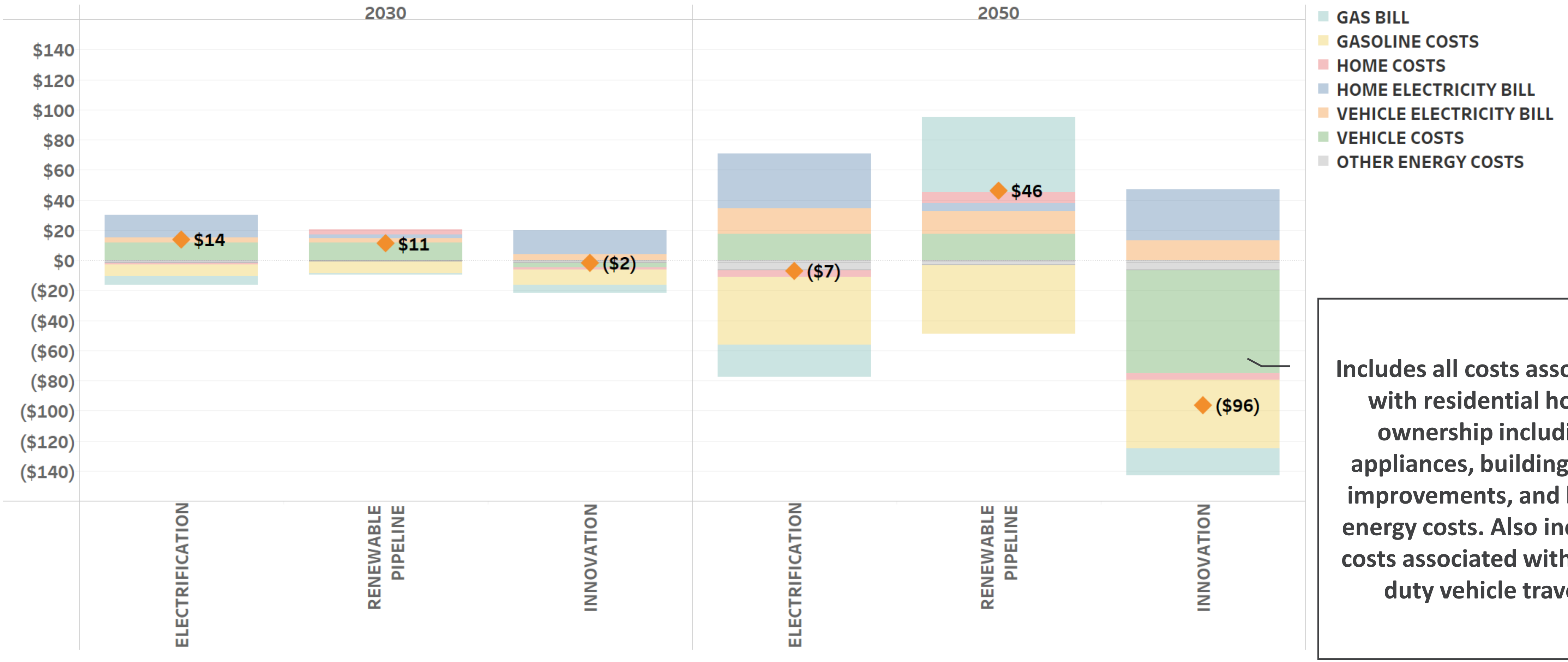


Note: Washington GDP forecast is based on 2015 estimate of $439 billion (2014 dollars) increasing at a real growth rate of 2.4%/yr, the Pacific census division growth rate from EIA AEO2015.

Interpreting Cost Savings from the Innovation Case

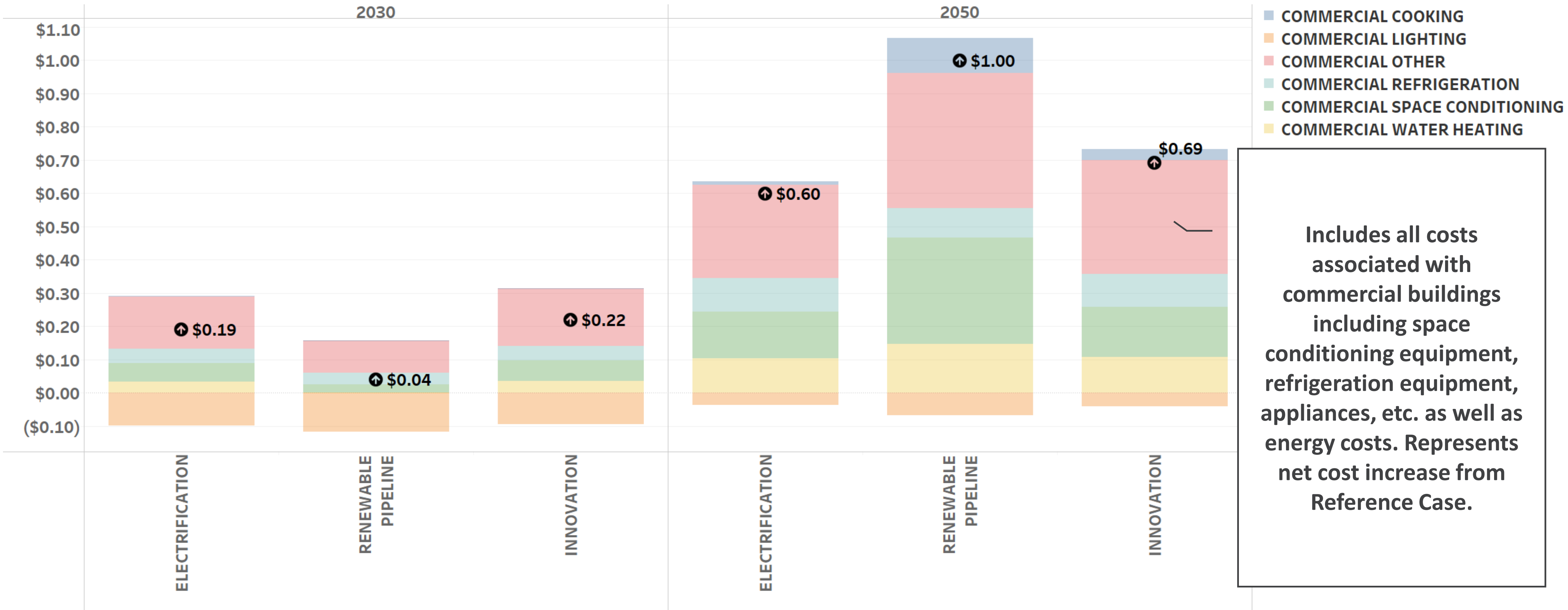
- Cost savings realized in the Innovation Case are largely due to the introduction of shared autonomous electric vehicles (SAEVs) in the passenger transportation sector
- SAEVs reduce costs, because they would be driven more frequently than personally-owned EVs
  - Fewer light-duty vehicles are required to meet travel demand (i.e., the stock is lower)
  - Higher utilization is assumed to reduce a SAEV's lifetime and its financing period, resulting in more frequent turnover and lower interest payments
- Since the Reference Case does not incorporate autonomous vehicle (AV) technology, then comparability is made more difficult since not all of the cost savings are directly attributable to the decision to decarbonize the energy system
- However, separate analysis shows that AV technology reduces the per-mile cost of electric vehicles, which should help facilitate the transition away from conventional internal combustion engines

Household Cost Impacts - $ per month



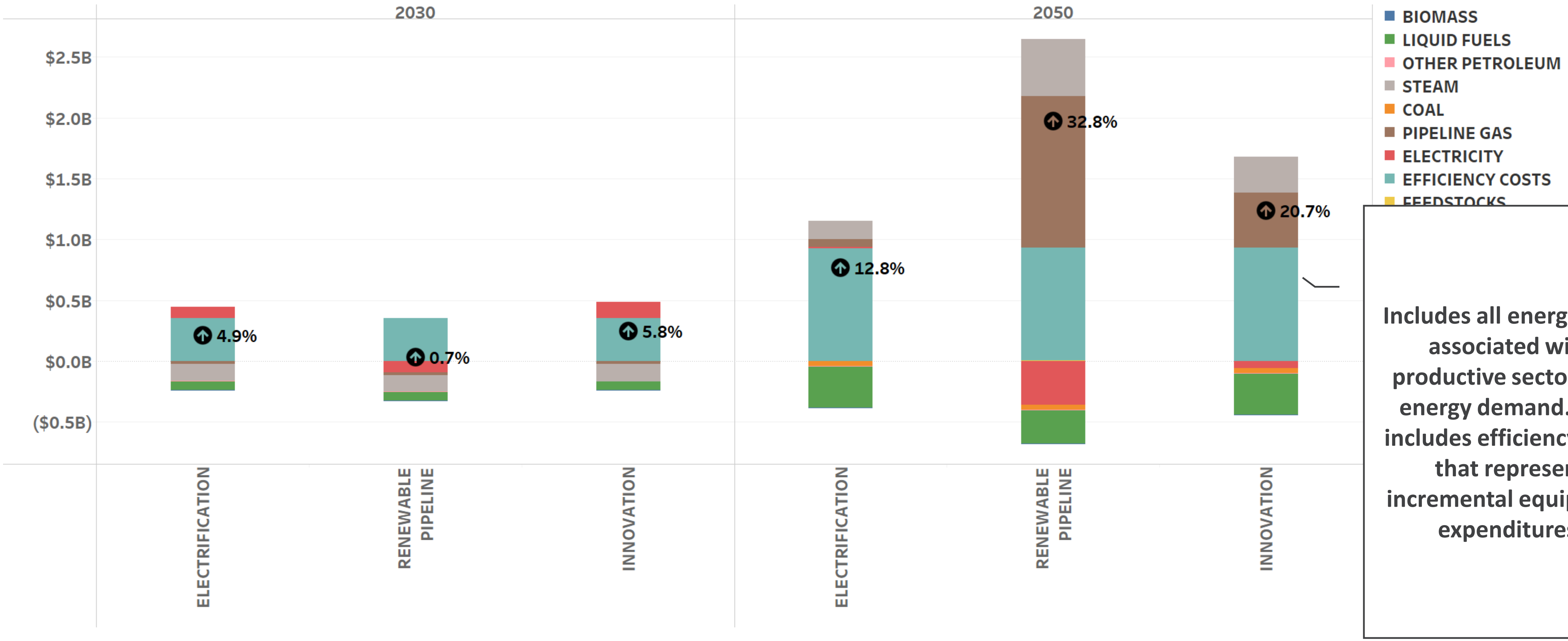
Includes all costs associated with residential home ownership including appliances, building shell improvements, and home energy costs. Also includes costs associated with light-duty vehicle travel.

Commercial Building Cost Impacts - $ per square foot



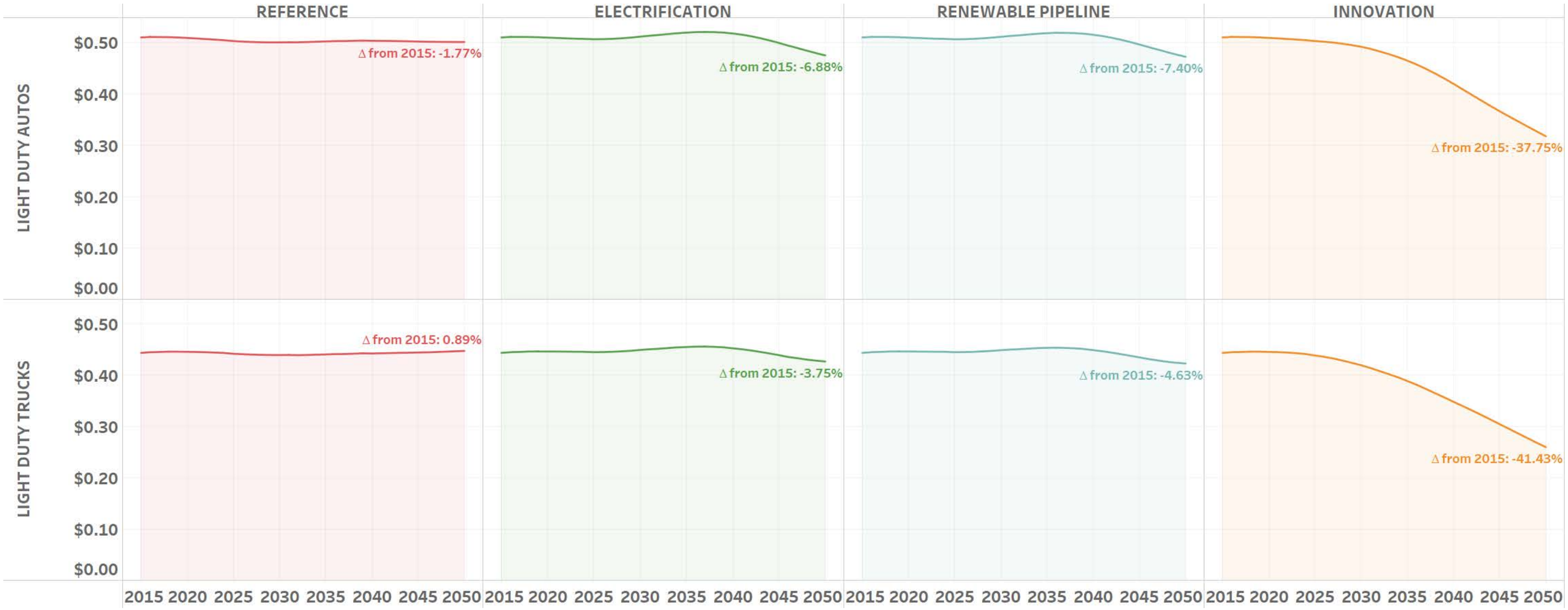
Includes all costs associated with commercial buildings including space conditioning equipment, refrigeration equipment, appliances, etc. as well as energy costs. Represents net cost increase from Reference Case.

Productive Sector Cost Impacts - $B

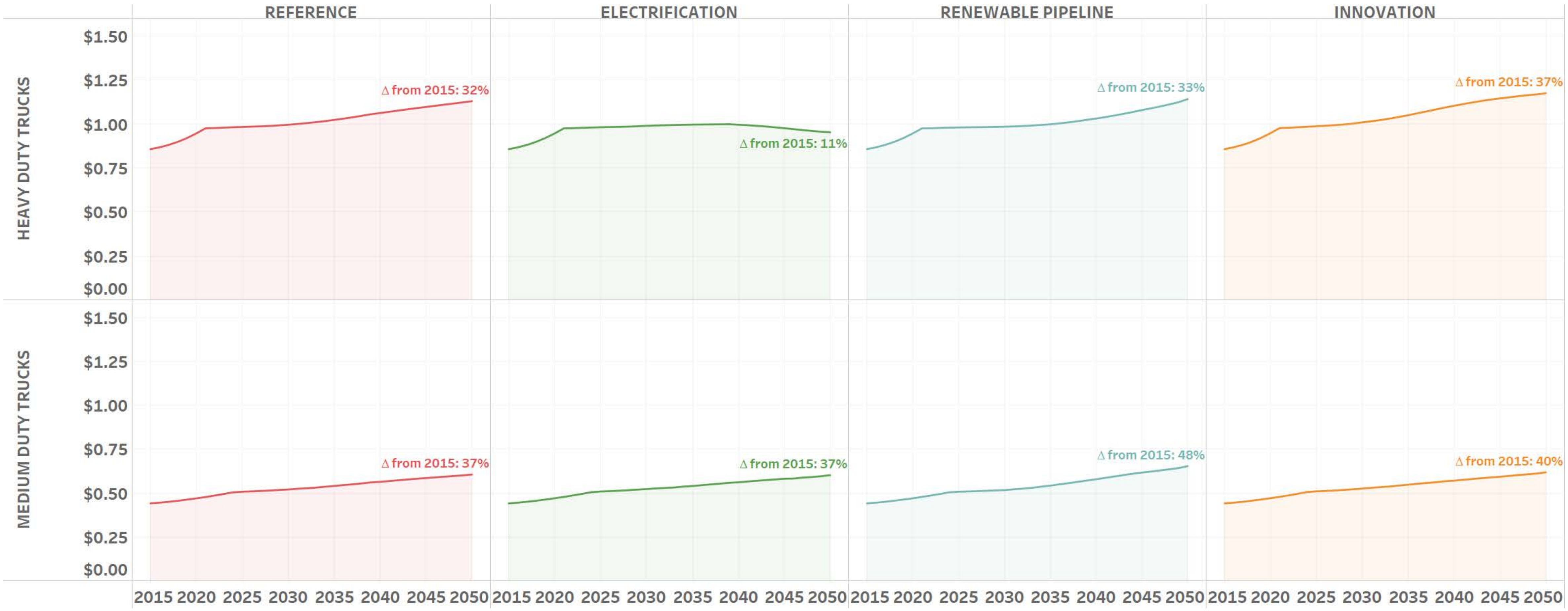


Includes all energy costs associated with productive sector final energy demand. Also includes efficiency costs that represent incremental equipment expenditures.

Light-Duty Vehicle Cost Impacts - $/Mile



Trucking Cost Impacts - $/Mile



Summary

Key Takeaways

- Decarbonizing Washington's energy system commensurate with an economy-wide goal of 80% GHG reductions by 2050 can be achieved
  - At reasonable cost;
  - Without early retirement of existing infrastructure; and
  - Without the need for technology that has not yet been demonstrated
- Achieving deep decarbonization in Washington State will include reliance on the three pillars of energy system transformation
  - Energy efficiency
  - Electrification of end-uses
  - Decarbonization of electricity generation
- In the long-run, costs are likely to fall on difficult-to-electrify sectors like industry and heavy-duty trucking
  - Mitigation of these costs may come from unmodeled strategies like mode-shifting in freight, industrial fuel switching/deeper energy efficiency reductions, or explicit policies that help share the cost burden between sectors

Key Takeaways Continued

- Reducing emissions from the transportation and refining of fossil fuels is critical to achieving the target
  - If unaddressed, refinery emissions would represent the majority of 2050 CO_2 emissions
  - New coal or LNG export terminals could also make hitting the target difficult
  - Deep decarbonization will not be pursued alone, and the economic incentive to continue to sell fossil fuels externally will create conflict with Washington's own GHG targets
- Continue phase-out of coal generation in electricity
- Pursue electrification policy wherever possible
- Consider the economic future of distribution gas pipeline
- Explore opportunities for regional cooperation
  - Electricity sector operations and planning
  - Biofuels development and trade
  - Petroleum refining future

Conclusions

- It's possible to develop a system at a reasonable cost that meets GHG mitigation goals, but it does require significant foresight to manage anticipated challenges
  - Gas pipeline (potential business model challenges)
  - Electric vehicle deployment (overcoming first-cost barriers)
  - Electricity balancing (to manage curtailment); and
  - Biofuels development (cost and sustainability)
- Washington has a unique opportunity to lead the transition with its industry (Boeing), technology (Microsoft, Amazon and Google), and academic and research institutions (WSU, UW, PNNL) all positioned to play key roles

Further Research

- Investigate the potential for managed land-use activities to contribute to the emissions reduction target in Washington State
- Analyze the benefits to Washington State of acting with regional partners
- Examine additional co-benefits of different pathways, specifically reduced local air pollution
- Evaluate the ability of the energy system to manage energy “surpluses” and “droughts” across different weather years given that supply becomes increasingly dependent on resources driven by weather (i.e., water, wind and solar) and end-uses are electrified
  - Our analysis is based on “normal” weather conditions

Appendix

Acronyms

- **AEO**: Annual Energy Outlook
- **AV**: Autonomous Vehicle
- **CAFE**: Corporate Average Fuel Economy
- **CNG**: Compressed Natural Gas
- **EIA**: U.S. Energy Information Administration
- **EV**: Electric Vehicle
- **GDP**: Gross Domestic Product
- **GHG**: Greenhouse Gas
- **GSP**: Gross State Product
- **HDV**: Heavy-Duty Vehicle
- **ICE**: Internal Combustion Engine
- **LDV**: Light-duty Vehicle
- **LED**: Light Emitting Diode
- **LNG**: Liquefied Natural Gas
- **NWPCC**: Northwest Power and Conservation Council
- **NWPP**: Northwest Power Pool
- **ODS**: Ozone Depleting Substances
- **P2G**: Power-to-Gas
- **PHEV**: Plug-in Hybrid Electric Vehicle
- **RPS**: Renewable Portfolio Standard
- **SAEV**: Shared Autonomous Electric Vehicle
- **SNG**: Synthetic Natural Gas
- **ST3**. Sound Transit 3
- **TEPPC**: Transmission Expansion Planning Policy Committee
- **VMT**: Vehicle Miles Traveled
- **WECC**: Western Electricity Coordinating Council

GHG Target Methodology

- We determined the permissible emissions budget in 2050 for energy-related CO2 and non-energy, non-CO2 GHGs using the following steps
  - First, we surveyed the literature for non-energy CO2 and non-CO2 GHGs mitigation options by source
  - Next, we applied plausible reduction potential by source to baseline non-energy CO2 and non-CO2 GHG emissions to estimate its budget in 2050
  - Finally, we estimated the energy-related CO2 budget by taking the difference between the total permissible GHG budget (17.7 MMT) and the non-energy, non-CO2 GHG budget (7.8 MMT), which equals 9.9 MMT
- Sources for mitigation options
  - EPA's (2014) *Mitigation of Non-CO2 Greenhouse Gases in the United States: 2010 to 2030*
  - California State Agencies' (2015) PATHWAYS Project technical appendix
  - Recent amendment to Montreal Protocol to eliminate hydrofluorocarbons

Non-energy CO2 and non-CO2 GHGs

		Non-energy, non-CO2 GHG Emissions				2050 Mitigation Case		
		Historic		Baseline Projection		Reduction	Emissions	Source
		1990	2012	2020	2050			
		MtCO2e	MtCO2e	MtCO2e	MtCO2e	%	MtCO2e	
Industrial Processes	Cement Manufacture (CO2)	0.2	0.3	0.3	0.3	20%	0.2	CA PATHWAYS
	Aluminum Production (CO2, PFC)	5.9	0.7	0.4	0.3	58%	0.1	EPA
	Limestone and Dolomite Use (CO2)	0.0	0.0	0.0	0.0	0%	0.0	n/a
	Soda Ash (CO2)	0.1	0.1	0.1	0.1	0%	0.1	n/a
	ODS Substitutes (HFC, PFC and SF6)	0.0	3.2	4.5	9.8	100%	0.0	HFC treaty
	Semiconductor Mfg. (HFC, PFC and SF6)	0.0	0.1	0.1	0.2	20%	0.2	EPA
	Electric Power Transmission/Distribution (SF6)	0.8	0.2	0.3	0.2	58%	0.1	EPA
Fossil Fuel Industry	Natural Gas Industry (CH4)	0.4	0.7	0.7	0.9	45%	0.5	EPA
	Coal Mining (CH4)	0.0	0.0	0.0	0.0	0%	0.0	n/a
	Petroleum Industry (CH4)	0.0	0.0	0.0	0.0	0%	0.0	n/a
Waste Management	Solid Waste Management	1.0	2.8	3.6	5.1	50%	2.5	CA PATHWAYS
	Wastewater Management	0.5	0.7	0.8	1.2	48%	0.6	EPA
Agriculture	Enteric Fermentation	2.0	2.1	2.0	1.9	23%	1.5	EPA
	Manure Management	0.7	1.2	1.3	2.0	62%	0.8	CA PATHWAYS
	Agriculture Soils	3.7	1.7	2.0	1.8	52%	0.9	CA PATHWAYS
Res/Com/Ind (RCI)	Wood (CH4 and N2O)	0.2	0.2	0.3	0.3	0%	0.3	n/a
Total		**15.5**	**14.0**	**16.4**	**24.1**		**7.8**	

50% below 1990 levels;
2/3 below 2050 baseline