Contents

Technical Modeling Appendix 2
- Methodology 2
- Scenarios 2
- Key Drivers and Demographics 4
- Assumptions by Sector 5
  - Buildings Sector 5
  - Transportation Sector 9
  - Industrial Sector 12
  - Oil & Gas Sector 14
  - Other Non-Combustion Emissions 17
  - Electricity Generation 19

Technical Modeling Appendix

Methodology

The Colorado PATHWAYS model is built using a "bottom-up" accounting of all energy-consuming devices and their emissions for key sectors of the economy along with a more general accounting of all energy demand and emissions for sectors where device-level data are not readily available. Scenarios are designed to test "what-if" questions and to provide a comparison of emissions reductions under a range of mitigation measures.

PATHWAYS captures interactions between demand- and supply-side variables (e.g. electrification of space heating leads to a reduction in natural gas demand and emissions in buildings and an increase in electricity supply and potentially emissions), with constraints and assumptions informed by existing analyses of resource availability, technology performance, and cost.

For key sectors like buildings and transportation, PATHWAYS uses a stock rollover approach primarily based on data from the EIA National Energy Modeling System (NEMS) that is validated through benchmarking to historical "top-down" energy consumption data for Colorado. For certain sectors like industry or off-road transportation where equipment stock data are not readily available, we benchmark directly to historical energy consumption data. Non-combustion emissions from sources like agricultural methane, industrial processes, and oil and gas extraction are benchmarked to a combination of federal and state data sources.

The study uses E3's PATHWAYS model to create strategically designed scenarios for how the state can reach its decarbonization goal. The PATHWAYS model is built using bottom-up data for all emissions produced and energy consumed within the State. It simulates the emissions from all sectors. To better understand the dynamic within the electricity sector, this study's modeling approach also incorporates detailed electricity sector representation using E3's RESOLVE model. RESOLVE is used to develop least-cost electricity generation portfolios that achieve Colorado's policy goals while maintaining reliability.

To populate the Colorado PATHWAYS model, we focused on in-state data sources where possible, supplementing with national data sets to fill remaining data gaps. Specific inputs are detailed in the sections that follow.

Scenarios

For this analysis, E3 developed three distinct scenarios: a Reference Scenario that reflects a "business-as-usual" projection of energy consumption and emissions under existing policies prior to the 2019 legislative sessions, a 2019 Action scenario that includes the impacts of policies and measures adopted in 2019, and a HB1261 targets scenario that is designed to meet the State's goals in 2025, 2030, and 2050.

- **Reference Scenario:** includes existing sector-specific policies adopted before the 2019, including the Renewable Energy Standard (RES) for electricity and federal CAFE standards for passenger vehicles.
- **2019 Action Scenario:** includes the impact of key policies adopted during 2019, such as electric sector GHG emissions targets (HB 1261), the incorporation of the social cost of carbon in electric sector planning (SB 236), increased efficiency standards for certain appliances (HB 1231), and the creation of a Zero Emission Vehicle (ZEV) program (EO B 2019 002).
- **HB 1261 Targets Scenario:** includes the impact of additional measures needed to reach the statewide goals to reduce 2025 greenhouse gas emissions by at least 26%, 2030 greenhouse gas

emissions by at least 50%, and 2050 greenhouse gas emissions by at least 90% relative to 2005 levels.

Table 1. Full list of mitigation measures by scenario

Sector	Strategy	Expressed as	Reference	2019 Action	HB 1261 Targets
Electricity	Clean Electricity	Required % reduction in emissions relative to 2005	None	80% by 2030, 95% by 2050	*Same as 2019 Action*
Buildings	Building Shell Efficiency	Efficient shell sales share	None	*Same as Ref.*	100% by 2030
	Building Electrification	Electric heat pump sales share	2%	*Same as Ref.*	60% by 2030, 95% by 2040
	Appliance Efficiency (non-HVAC)	Efficient appliance sales share	None	100% by 2021 for lighting, 100% by 2021 for com. cooking	100% by 2021 for lighting, 100% by 2030 for other appliances
Industry	Efficiency	Efficiency increase relative to baseline projection	None	*Same as Ref.*	20% by 2030, 40% by 2050
	Fuel Switching for Manufacturing	Share of natural gas demand electrified	None	*Same as Ref.*	17% by 2030, 32% by 2050
Transportation	CAFE Standards	LDV fuel economy	Extended 2021-2026	*Same as Ref.*	*Same as Ref.*
	VMT Reduction	LDV VMT reduction relative to Reference	None	*Same as Ref.*	10% reduction, beginning in 2020
	Vehicle Electrification	ZEV sales share	LDV: 9% by 2030 MDV/HDV: 0% Buses: 5% by 2030	LDV: 43% by 2030 MDV/HDV: 0% Buses: 5% by 2030	LDV: 70% by 2030, 100% by 2040 MDV/HDV: 40% by 2030, 100% by 2040 Buses: 100% by 2030
Oil & Gas	Leak Detection and Reduction	Catchall upstream leak rate	2.4%	1.5% by 2030, 1% by 2050	0.6% by 2030, 0.25% by 2050
	Fuel Switching	Share of diesel consumption electrified	None	*Same as Ref.*	100% by 2030
Other Non-Combustion	Soil Management	Amount of additional carbon sequestered	None	*Same as Ref.*	1 MMT by 2030, 3 MMT by 2050
	Enteric Methane Reduction	% reduction relative to Reference	None	*Same as Ref.*	25% by 2030
	HFC Phase Down	CO2e reduction in HFC emissions relative to Reference	None	*Same as Ref.*	1.7 MMT by 2030, 4 MMT by 2050

	Coal Mine Methane	% of abandoned mine methane emissions captured	None	*Same as Ref.*	38% by 2030
	Municipal Solid Waste	% of methane emissions captured	None	*Same as Ref.*	58% by 2030, 64% by 2050
	Wastewater Treatment	% of methane emissions captured	None	*Same as Ref.*	40% by 2030, 80% by 2050
Low Carbon Fuels	Conventional Biofuels	% of fuel demand met with conventional biofuels	7% ethanol blend for gasoline	*Same as Ref.*	15% ethanol blend by 2030, 20% biodiesel blend by 2030,
	Advanced Biofuels	% of fuel demand met with advanced biofuels	None	*Same as Ref.*	85% renewable gasoline blend by 2050, 80% renewable diesel blend by 2050, 1% renewable natural gas by 2030, 95% renewable natural gas by 2050, 97% renewable jet fuel by 2050
	Hydrogen	% of natural gas pipeline blend	None	*Same as Ref.*	5% blend by 2050
CCS	Industry CCS	Amount of CO2 captured and sequestered	None	*Same as Ref.*	2 MMT by 2030
	Direct Air Capture (DAC)	Amount of CO2 captured and sequestered	None	*Same as Ref.*	2.8 MMT by 2050

Key Drivers and Demographics

In 2015, Colorado had a population of 5.5 million people residing in 2.1 million households. In each sector of the economy, we create a representation of a base year (2015) of infrastructure and energy demand, and then identify key variables that drive activity change over the duration of each scenario (2015-2050). Table 2 shows the key drivers behind baseline projections of energy and emissions in each scenario.

Table 2. Key drivers of Reference Scenario energy consumption and emissions

Sector	Category	Annual Growth Rate	Source
Economy-Wide	Population Growth Rate	1.27%	State Demography Office
	GDP Growth Rate	1.9%	EIA Annual Energy Outlooks (AEO) 2019

Buildings	Households Growth Rate	1.33%	State Demography Office
	Commercial Sq. Footage	1.0%	EIA AEO 2019
Transportation	LDV VMT	1.49%	CDOT
	MDV VMT	1.3%	EIA AEO 2019
	HDV VMT	1.2%	EIA AEO 2019
Industry	Industry Fuel Use Growth Rate	Varies by Fuel	EIA AEO 2019
Electricity Generation	Electric Load Growth	Varies by Scenario	Bottom-up projection from electricity demands in buildings, transportation and industry in PATHWAYS
Oil & Gas	Oil Production	3% (2015-2030) -5% (2031-2050)	CDPHE Air Pollution Control Division
	Natural Gas Production	7% (2015-2030) -6% (2031-2050)	CDPHE Air Pollution Control Division
Waste and HFCs	Total Emissions	1.27%	Assumed to grow with population
Agriculture	Total Emissions	0%	Assumed to stay constant over the study period

Assumptions by Sector

Buildings Sector

Base Year

The Colorado LEAP model includes a stock-rollover representation of 17 residential and 10 commercial building subsectors, including space heating, water heating, and lighting. Sectoral energy demand is benchmarked to energy consumption by fuel from the EIA State Energy Data System (SEDS) for 2015 and is disaggregated by subsector based on the EIA National Energy Modeling System (NEMS) technology characterization. All residential and commercial subsectors are listed in Table 3.

Table 3. Representation of 2015 Building Energy Consumption by Subsector in Colorado

Sector	Subsector	Modeling Approach	Estimated Energy Use in 2015 [TBtu]	Estimated % of 2015 Energy Use [%]
Residential	Residential Central Air Conditioning	Stock Rollover	10	3%
	Residential Building Shell	Stock Rollover	-	0%

	Residential Clothes Drying	Stock Rollover	4	1%
	Residential Clothes Washing	Stock Rollover	0	0%
	Residential Cooking	Stock Rollover	3	1%
	Residential Dishwashing	Stock Rollover	2	0%
	Residential Freezing	Stock Rollover	1	0%
	Residential Reflector Lighting	Stock Rollover	1	0%
	Residential Room Air Conditioning	Stock Rollover	1	0%
	Residential General Service Lighting	Stock Rollover	5	1%
	Residential Exterior Lighting	Stock Rollover	1	0%
	Residential Linear Fluorescent Lighting	Stock Rollover	1	0%
	Residential SF SH	Stock Rollover	93	26%
	Residential MF SH	Stock Rollover	19	5%
	Residential Refrigeration	Stock Rollover	6	2%
	Residential Water Heating	Stock Rollover	31	9%
	Residential Other	Total Energy by Fuel	38	11%
Commercial	Commercial Air Conditioning	Stock Rollover	6	2%
	Commercial Cooking	Stock Rollover	5	1%
	Commercial High Intensity Discharge Lighting	Stock Rollover	0	0%
	Commercial Linear Fluorescent Lighting	Stock Rollover	6	2%
	Commercial General Service Lighting	Stock Rollover	2	1%
	Commercial Refrigeration	Stock Rollover	9	3%

	Commercial Space Heating	Stock Rollover	40	11%
	Commercial Ventilation	Stock Rollover	8	2%
	Commercial Water Heating	Stock Rollover	10	3%
	Commercial Other	Total Energy by Fuel	58	16%
All Building Sectors			**361**	**100%**

***Residential Other includes furnace fans, plug loads (e.g. computers, phones, speakers, printers), secondary heating, fireplaces, and outdoor grills. Commercial Other includes plug loads, office equipment, fireplaces, and outdoor grills.**

Reference Scenario

The Reference scenario does not include any incremental energy efficiency or fuel-switching measures. The existing market shares for energy-consuming appliances are assumed to hold constant throughout the study period, with the increase in total energy consumption in buildings being driven by growth in the number of households and commercial square footage in Colorado. Non-stock energy consumption in the Residential Other and Commercial Other subsectors is also assumed to grow at these rates.

2019 Action Scenario

The primary building sector measure in the 2019 Action scenario is the achievement of energy efficiency improvements. Energy efficiency in buildings is implemented in the PATHWAYS model in one of three ways:

1. As new appliance or lighting end use technology used in the residential and commercial sectors (e.g., a greater share of high efficiency appliances is assumed to be purchased). New equipment is typically assumed to replace existing equipment "on burn-out" at the end of the useful lifetime of existing equipment.
2. As a reduction in energy services demand, due to smart devices (e.g. programmable thermostats), conservation, or behavior change.
3. For the sectors that are not modeled using specific technology stocks (Residential Other and Commercial Other), energy efficiency is modeled as a reduction in total energy demand.

The full list of building sector measures and assumptions in the 2019 Action scenario is shown in Table 4.

Table 4. Building Sector Measures in the 2019 Action scenario

Category of Building Measures	2019 Action Scenario Assumption
Building retrofits for high efficiency building shells	None
New appliance sales	100% sales of efficient lighting and commercial cooking equipment by 2021 (represents HB 1231)
Building electrification	None
Behavioral conservation and smart devices	None
Other non-stock sectors	None

Since the model is based on a bottom-up forecast of technology stock changes in the residential and commercial sectors, the model does not use a single load forecast or energy efficiency savings forecast as a model input. It is important to note that the modeling assumptions used in this analysis may not reflect specific future energy efficiency programs or activities.

HB 1261 Targets Scenario

The HB 1261 Targets scenario includes electrification and more aggressive energy efficiency measures in buildings. Building electrification occurs primarily through the widespread adoption of electric heat pumps for space heating and water heating, while increased efficiency is achieved through sales of more efficient appliances, behavioral conservation, and building shell retrofits. The full list of building sector measures and assumptions in the HB 1261 Targets scenario is shown in Table 5.

Table 5. Building Sector Measures in the HB 1261 Targets scenario

Category of Building Measures	**HB 1261 Targets Scenario Assumption**
Building retrofits for high efficiency building shells	100% adoption of efficient building shells for new buildings and retrofits by 2030
New appliance sales	100% sales of efficient lighting and commercial cooking equipment by 2021 (represents HB 1231) 100% sales of all other appliances are efficient models by 2030
Building electrification	60% sales of electric heat pumps by 2030, 95% by 2050 for space heating and water heating
Behavioral conservation and smart devices	2% reduction in building energy demand by 2030, 4% by 2050
Other non-stock sectors	Full electrification of non-stock sector demand by 2050

A key assumption of the HB 1261 Targets scenario is the adoption of high efficiency electric heat pumps for space heating and water heating. According to a 2012 assessment of residential energy demand commissioned by CEO, heat pumps only make up around two percent of space heaters in Colorado[1]. The market share for heat pump water heaters was not reported but is assumed to be negligible.

In the HB 1261 Targets scenario we assume the shift to heat pumps displaces natural gas, LPG, and electric resistance space heating and water heating. Assumed equipment sales shares and the resulting stocks are shown in below.

[1] "Residential Energy-Use and Savings Potential Study for the Governor's Energy Office" E Source, 2012 https://www.colorado.gov/pacific/sites/default/files/atoms/files/Residential%20Energy-Use%20and%20Savings%20Potential%20Study.pdf

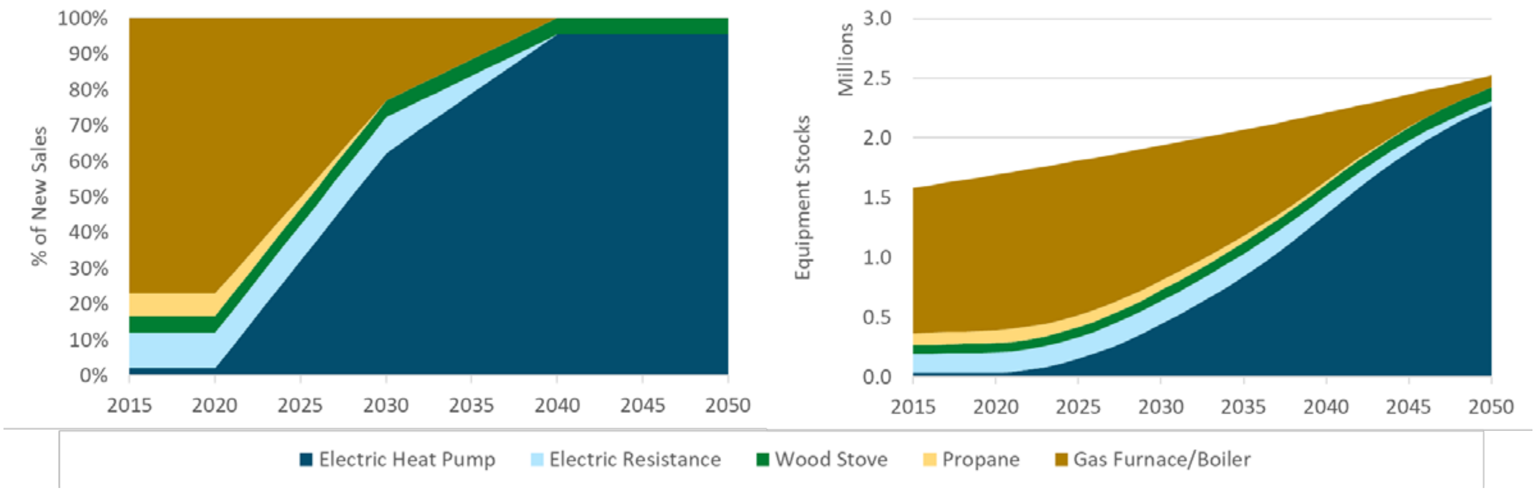

Figure 1. Annual equipment sales shares and stocks for residential space heating in the HB 1261 Targets scenario

Transportation Sector

Base Year

The Colorado PATHWAYS model includes a stock-rollover representation of five transportation subsectors and an energy representation of two subsectors. Sectoral energy demand is benchmarked to energy consumption from the EIA SEDS for 2015 and is disaggregated by subsector based on vehicle population and vehicle miles travelled (VMT) data provided by CDOT. All subsectors represented in the transportation sector are listed in Table 6.

Table 6. Representation of 2015 Transportation Energy Consumption by Subsector in Colorado

Sector	Subsector	Modeling Approach	Estimated Energy Use in 2015 [TBtu]	Estimated % of 2015 Energy Use [%]
Transportation	Transportation Short LDV	Stock Rollover	122	30%
	Transportation Long LDV	Stock Rollover	151	37%
	Transportation MDV	Stock Rollover	4	1%
	Transportation HDV	Stock Rollover	35	9%
	Transportation Buses	Stock Rollover	0	0%
	Transportation Aviation	Total Energy by Fuel	53	13%
	Transportation Other	Total Energy by Fuel	41	10%
All Transportation Sectors			**407**	**100%**

Reference Scenario

The Reference scenario includes in an increase in ZEV sales for light-duty vehicles and buses based on the reference forecasts from the 2018 EIA Annual Energy Outlook report. This does not include the impact of any Colorado state transportation policies. The details of these assumptions are shown in Table 7 below.

Table 7. Transportation sector measures in the Reference scenario

Category of Transportation Measures	Reference Scenario Assumption
LDV VMT Reduction	None
LDV ZEV Sales Share	9% sales by 2030
MDV ZEV Sales Share	None
HDV ZEV Sales Share	None
Bus ZEV Sales Share	5% sales by 2030
Transportation Other	AEO 2018 non-highway total fuel growth rates

2019 Action Scenario

The primary transportation sector measure in the 2019 Action scenario is an increase in ZEV sales for light-duty vehicles, which represents the implementation of Executive Order B 2019 002, "Supporting a Transition to Zero Emission Vehicles". Previous analysis performed by Navigant for CEO found that ZEVs would reach around 43% of new light-duty vehicles sales by 2030 in a "ZEV+" scenario designed to represent the impacts of a ZEV standard, continued vehicle tax credit, and continued charging infrastructure investment[2]. The light-duty vehicle sales shares in the 2019 Action scenario were aligned in PATHWAYS with the outputs from the Navigant ZEV+ scenario. The full list of assumptions for the transportation sector are shown in Table 8 below.

Table 8. Transportation sector measures in the 2019 Action scenario

Category of Transportation Measures	2019 Action Scenario Assumption
LDV VMT Reduction	None
LDV ZEV Sales Share	43% sales by 2030
MDV ZEV Sales Share	None
HDV ZEV Sales Share	None
Bus ZEV Sales Share	5% sales by 2030
Transportation Other	AEO 2018 non-highway total fuel growth rates

Assumptions for new light-duty vehicle sales and resulting vehicle stocks are shown in Figure 2.

[2] "Electric Vehicle Growth Analysis Results" Navigant, 2019
https://drive.google.com/file/d/1ulRw0Yfjz53nbvBjWQO14z_4jLsqzK4z/view

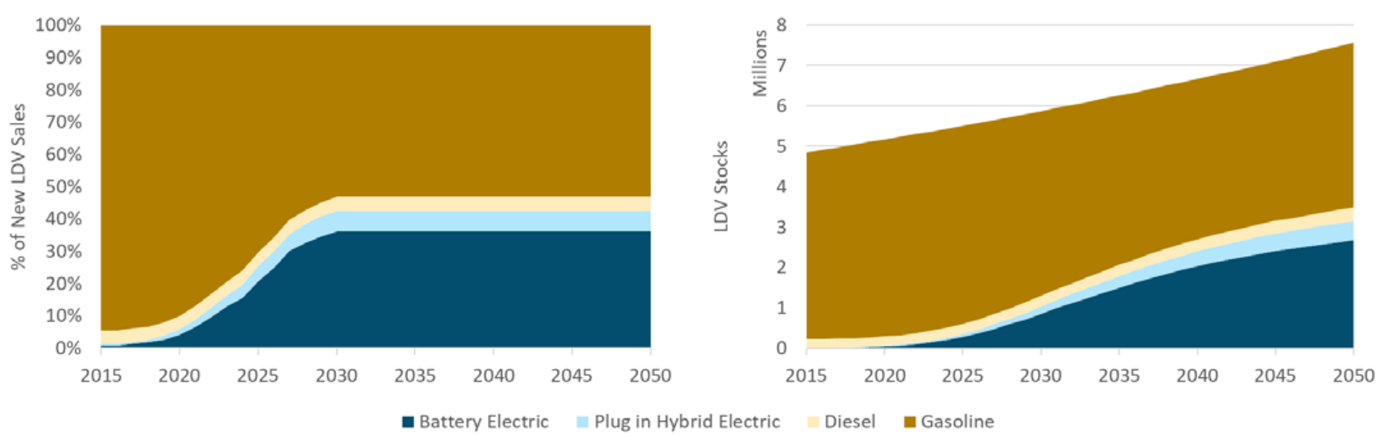

Figure 2. Annual light-duty vehicle sales shares and stocks in the 2019 Action scenario

HB 1261 Targets Scenario

The HB 1261 Targets scenario assumes aggressive levels of electrification for all vehicle classes along with VMT reductions for LDVs and increased use of low-carbon fuels for remaining non-electrified transportation. ZEV sales for LDVs go beyond what is included in the 2019 Action scenario, reaching 70% by 2030 and 100% by 2035, while ZEV sales for MDVs and HDVs reach 40% by 2030 and 100% by 2040. The full list of assumptions in the transportation sector are shown in Table 9 below, and assumptions for light-duty vehicle sales and resulting vehicle stocks are shown in Figure 3.

Table 9. Transportation sector measures in the HB 1261 Targets scenario

Category of Transportation Measures	2019 Action Scenario Assumption
LDV VMT Reduction	10% beginning in 2020 and held constant
LDV ZEV Sales Share	70% by 2030, 100% by 2040
MDV ZEV Sales Share	40% by 2030, 100% by 2040
HDV ZEV Sales Share	40% by 2030, 100% by 2040
Bus ZEV Sales Share	100% sales by 2030
Transportation Other	Low-carbon fuels meet 100% of demand by 2050

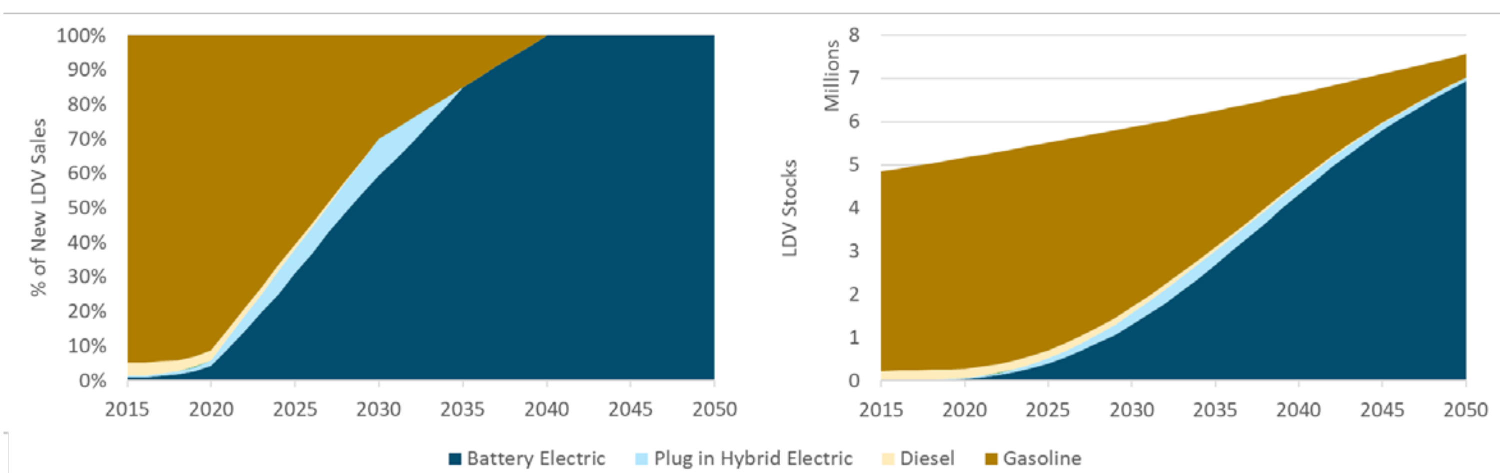

Figure 3. Annual light-duty vehicle sales shares and stocks in the HB 1261 Targets scenario

Industrial Sector

Base Year

The Colorado PATHWAYS model includes a representation of three industrial subsectors: Industry Manufacturing, Industry Oil & Gas, and Industry Other (includes agriculture, construction, mining, etc.) Total sectoral energy demand by fuel was benchmarked to EIA SEDS for 2015. For Industry Manufacturing, energy demand by fuel was estimated by allocating the total energy demand for each manufacturing subsector calculated in a 2017 CEO study to various fuels based on the energy consumption patterns reported for those subsectors national in the EIA Manufacturing Energy Consumption Survey (MECS). For Industry Oil & Gas, natural gas demand was benchmarked to the total Lease Fuel and Plant Fuel[3] consumption reported by EIA. Remaining energy demand by fuel from EIA SEDS was allocated to Industry Other, with the exception of diesel, which was split evenly between Industry Other and Industry Oil & Gas to account for diesel consumption used in oil & gas extraction. Final energy demand by subsector and fuel are shown in Table 10 below.

Table 10. Representation of 2015 Industry energy demand by subsector and fuel in Colorado

Fuel	Industry Manufacturing Demand [TBtu]	Industry Oil & Gas Demand [TBtu]	Industry Other Demand [TBtu]	Total Demand by Fuel [TBtu]
Electricity	30	0	22	**52**
Natural Gas	59	115	24	**197**
Coal	7	0	0	**7**
Diesel	1	12	12	**24**
Other Petroleum Products	10	0	6	**16**
Total Demand by Subsector	**106**	**127**	**63**	**296**

Reference Scenario

Industrial energy consumption in the Manufacturing and Other subsectors is assumed to grow at fuel-specific growth rates from the EIA Annual Energy Outlook. There are no energy efficiency, electrification, or low-carbon fuels measures assumed for industry in the Reference scenario. Energy consumption in the Oil & Gas subsector is assumed to grow and decline linearly with natural gas production. The natural gas production forecast used in this analysis is detailed further in the Oil & Gas Sector discussion.

2019 Action Scenario

There are no energy efficiency, electrification, or low-carbon fuels measures assumed for industry in the 2019 Action scenario. Energy consumption is assumed to grow at the same rates used in the Reference scenario.

HB 1261 Targets Scenario

[3] The EIA defines Lease Fuel and Plant Fuel as "Natural gas used in well, field, and lease operations, such as gas used in drilling operations, heaters, dehydrators, and field compressors" and "Natural gas used as fuel in natural gas processing plants", respectively

The HB 1261 Targets scenario includes aggressive energy efficiency, electrification, and low-carbon fuels measures for industry. A 20% reduction in energy service demand is assumed by 2030 for Industry Manufacturing and Industry Other, with that amount increasing to 40% by 2050. The 17% of fossil fuel consumption electrified by 2030 in Industry Manufacturing represents full electrification of facility HVAC and electrification of some low-temperature process heat, while the 32% of fossil fuel consumption electrified by 2050 represents additional electrification of process heating, along with a small amount of boiler electrification. CCS is assumed to be installed at all manufacturing facilities where coal is combusted by 2030, and a 90% capture rate is assumed. For Industry Oil & Gas, CCS equipment is assumed to be installed at all gas processing plants by 2050, also with a 90% capture rate. Remaining pipeline gas for Industry Manufacturing and Industry Other is assumed to have a 7% hydrogen blend by 2030, with the remaining 93% coming from biogas by 2050. The full list of industrial sector measures is shown in Table 11.

Table 11. Industrial sector measures in the HB 1261 Targets scenario

Category of Industrial Measures	Subsector(s) Affected	HB 1261 Targets Scenario Assumption
Energy Efficiency	Industry Manufacturing Industry Other	20% reduction in energy service demand by 2030, 40% by 2050
Electrification	Industry Manufacturing	17% of fossil fuel consumption is electrified by 2030, 32% by 2050
Electrification	Industry Oil & Gas	100% of diesel consumption is electrified by 2030
CCS	Industry Manufacturing	100% of coal consumption is assumed to have CCS installed by 2030 with a 90% capture rate
CCS	Industry Oil & Gas	16% and 32% of natural gas consumption is assumed to have CCS installed by 203 and 2050, respectively (90% capture rate)
Low-Carbon Fuels	Industry Manufacturing Industry Other	75% blend of renewable diesel by 2030, 100% by 2050 1% blend of renewable natural gas by 2030, 95% by 2050 5% blend of hydrogen for pipeline gas by 2030

Final energy demand by fuel is shown in Figure 4 below:

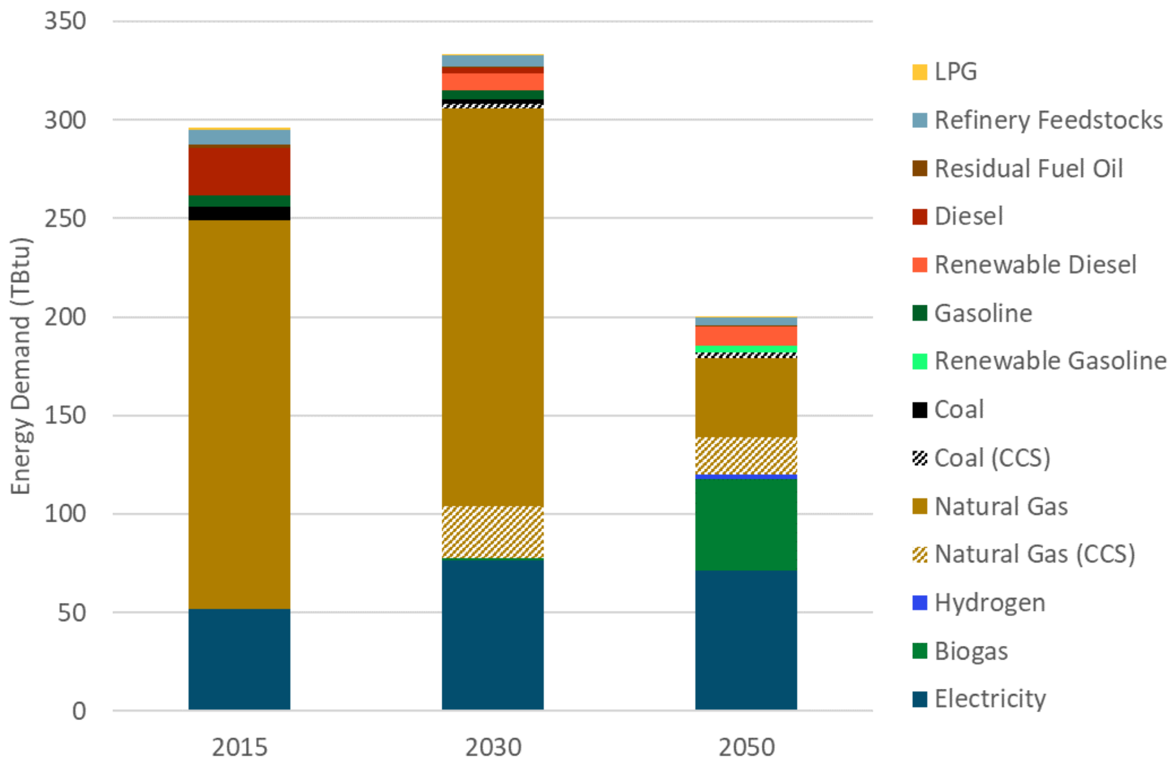

Figure 4. Final energy demand by fuel in the industrial sector for the HB 1261 Targets scenario

Oil & Gas Sector

Base Year

The Colorado PATHWAYS model includes fugitive methane and carbon dioxide emissions from in-state oil and gas production (energy combustion emissions associated with oil and gas production are addressed in the previous section). Historical and forecasted oil and gas production and emission values were provided to E3 by the Air Pollution Control Division (APCD) at the Colorado Department of Public Health and Environment. Base year production, leak rates and emission values are shown in Table 12.

Table 12. Representation of key indicators for the oil and gas sector in Colorado for 2015

Category	Subcategory	Value
Oil & Gas Production	Natural Gas (billion cubic feet)	1,691
	Crude Oil (million barrels)	123
Leak Rate	Upstream Operations Leak Rate	2.5%
	Downstream Distribution System Leak Rate	0.5%
Fugitive Emissions	Methane (MMT CO_2e)	19.4
	Carbon Dioxide (MMT)	0.3

Production Forecast

Natural gas and crude oil production forecasts are assumed to be the same across all three core scenarios and are shown below in Figure 5.

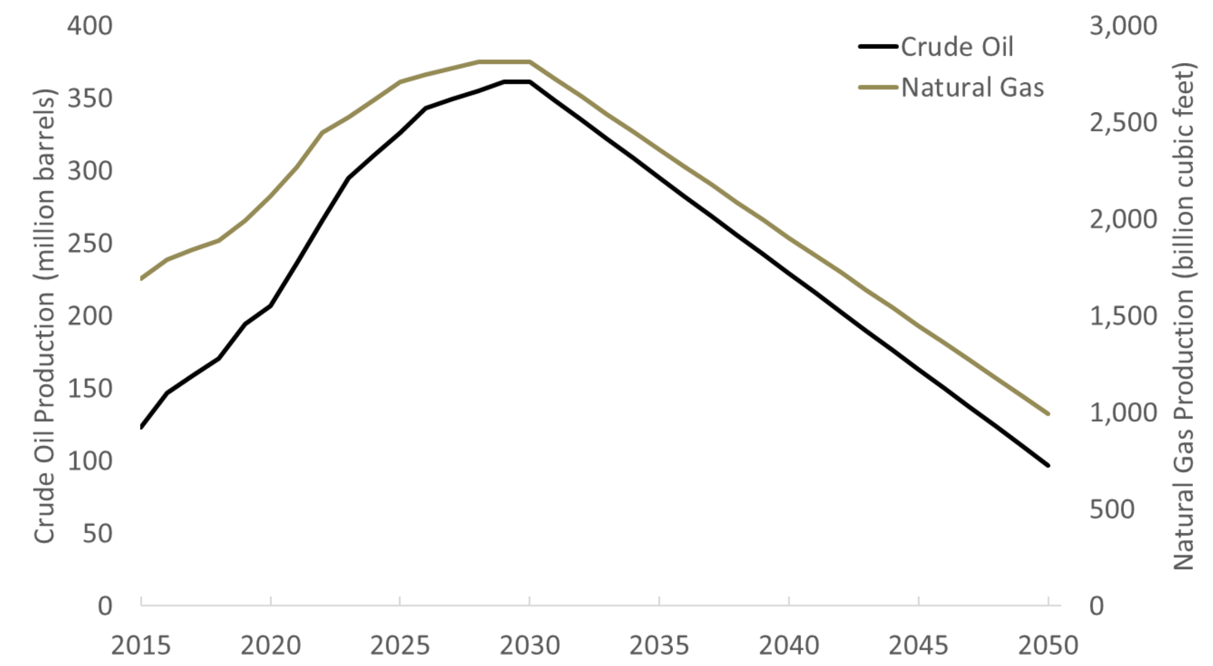

Figure 5. Forecasted crude oil and natural gas production from APCD

Leak Rate Forecast

Upstream and downstream leak rates are expected to hold constant in the Reference scenario. In the 2019 Action scenario, the full impact of recent oil and gas regulations is assumed to lead to a decline in both Upstream and Downstream leak rates between 2020 and 2030, with a more gradual decline continuing through 2050. This pattern is true for the HB 1261 Targets scenario as well, but incremental regulations are assumed to cause a larger drop in leak rates between 2020 and 2030. Leak rates by year for each scenario are shown in Figure 6 below.

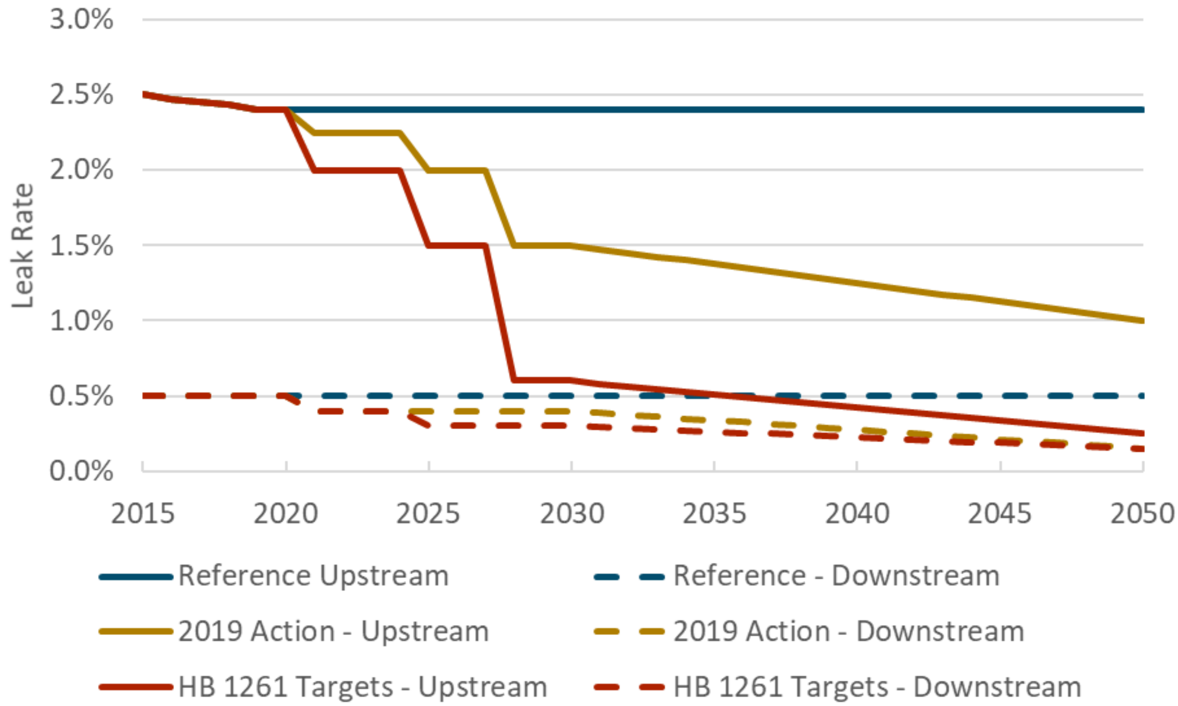

Figure 6. Forecasted leak rates by scenario for upstream and downstream oil and gas operations from APCD

Emissions Forecast
The upstream and downstream leak rate forecasts are applied to the crude oil and natural gas production forecasts as part of APCD's analysis to generate a forecast of fugitive emissions from the oil and gas sector. The results are shown in Figure 7 below.

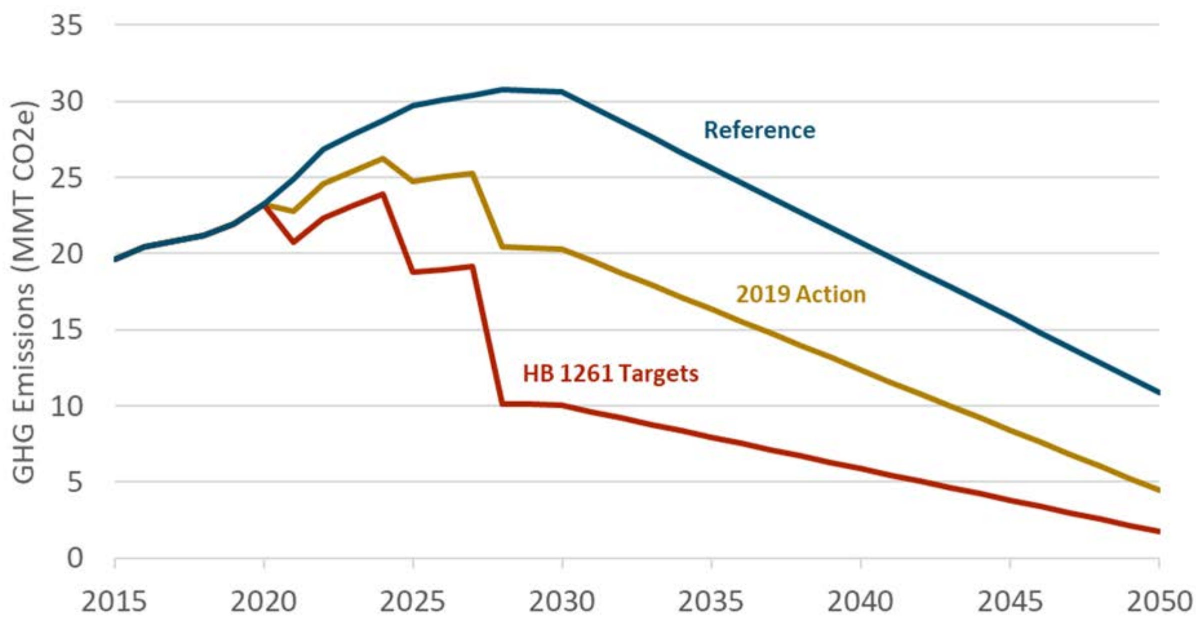

Figure 7. Forecasted oil and gas fugitive emissions by scenario from APCD

Other Non-Combustion Emissions

Base Year
In addition to fugitive emissions from the oil and gas sector, the Colorado PATHWAYS model includes non-combustion emissions from agriculture, coal mines, industrial processes, and waste management. Base year values were calculated using the EPA SIT with default inputs for Colorado. Base year emissions for each subsector are shown in Table 13.

Table 13. Representation of 2015 non-combustion emissions in Colorado (does not include oil and gas fugitive emissions)

Sector	Subsector	Estimated 2015 Emissions [MMT CO_2e]
Agriculture	Enteric Fermentation	6.9
	Manure Management	1.9
	Soil Management	2.3
Coal Mines	Abandoned Coal Mines	0.3
	Coal Mining	1.8
Industrial Processes*	Cement Manufacture	0.8
	Iron & Steel Production	0.3
	Lime Manufacture	0.4
	HFCs	2.9
	Semiconductor Manufacture	0.1
Waste Management	Municipal Solid Waste	3.9
	Wastewater Treatment	0.7
Total		**22.3**

**Does not includes Industrial Processes with less than 0.1 MMT of annual CO_2e emissions*

Reference Scenario

There are no non-combustion measures assumed in the Reference scenario.

2019 Action Scenario

There are no non-combustion measures assumed in the 2019 Action scenario.

HB 1261 Targets Scenario

The HB 1261 Targets scenario assumes aggressive non-combustion emissions reductions. In agriculture, changes in feeding practices are assumed to reduce enteric fermentation 25% by 2030, while incremental soil management practices are assumed to sequester an additional 1 MMT of CO_2 by 2030 and 3 MMT of CO_2 by 2050. For industrial process emissions, CCS equipment with a 90% capture rate is assumed to be installed at all cement and lime manufacturing facilities, and there is an HFC phase down in line with Kigali Amendment requirements. Emissions from active coal mining in Colorado are assumed to trend to zero by 2030, in line with electricity generation from coal in the HB 1261 Targets scenario, after which those mines are assumed to be sealed at an average seal rate of 80%. In addition, it is assumed that 38% of abandoned mine methane emissions are captured based on the feasibility assessment from a 2016 CEO market report on coal mine methane. For waste methane, it is assumed that all landfills deemed as “Candidates” by the EPA’s Landfill Methane Outreach Program (LMOP) are equipped with methane capture by 2030, with those deemed as “Potential” added by 2050. An assumed 40% capture of wastewater methane by 2030 and 80% by 2050 is based on previous state-level E3 PATHWAYS analysis. The total impact of these measures is a 54% reduction in non-combustion emissions by 2050, relative to the 2015 base year. Non-combustion emissions for 2015, 2030, and 2050 are shown in Figure 8 below.

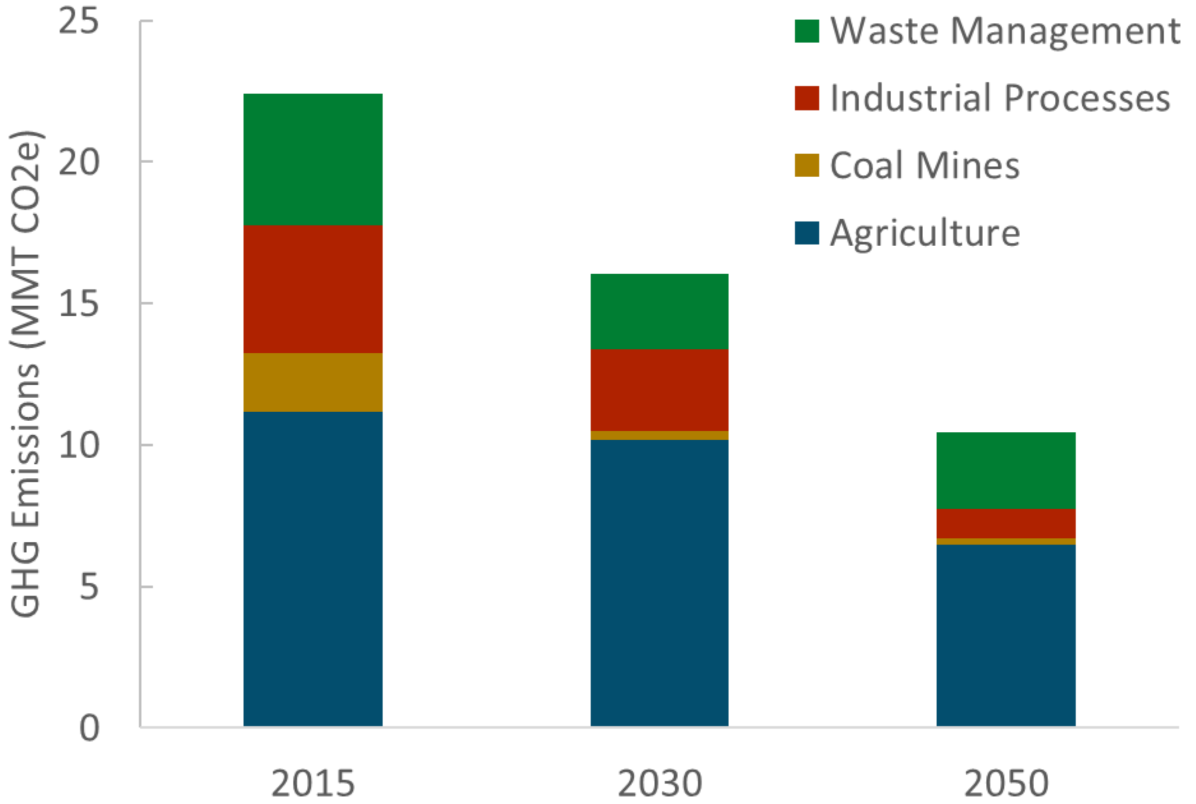

Figure 8. Non-combustion emissions by year for the HB 1261 Targets scenario

Electricity Generation

RESOLVE Methodology

E3 modeled electricity generation using the RESOLVE model. RESOLVE is a capacity expansion model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, technical, and policy constraints. Designed specifically to address the capacity expansion questions for systems seeking to integrate large quantities of variable resources, RESOLVE layers capacity expansion logic on top of a reduced-form production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment in which most new investments in the electric system have fixed costs significantly larger than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative scenarios. A graphic overview of the model is shown in Figure 9.

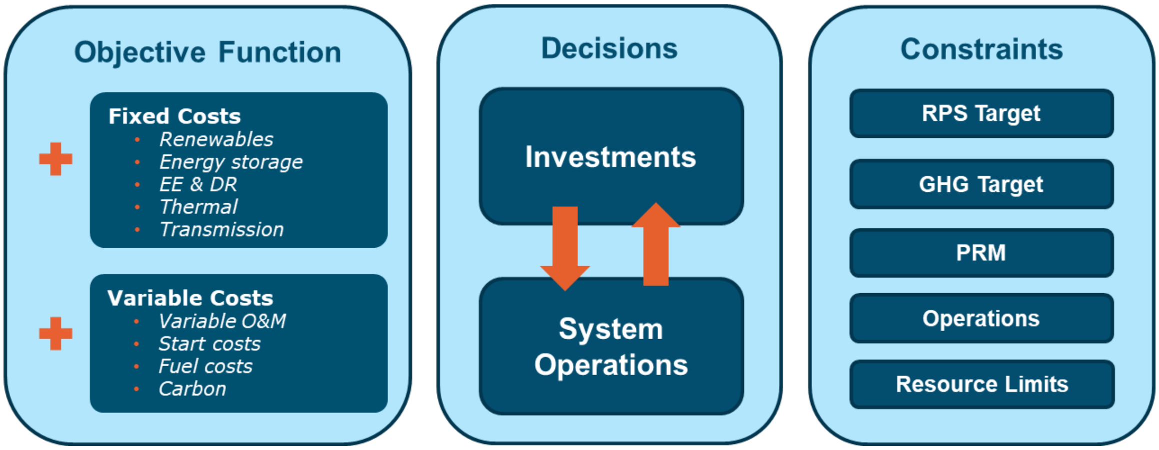

Figure 9: Overview of RESOLVE model architecture

RESOLVE's optimization capabilities allow it to select from among a wide range of potential new resources. The full range of resource options considered by RESOLVE in this study is shown in Table 14.

Table 14. Eligible resources for RESOLVE capacity expansion function

Resource Type	Available Options
Natural Gas Generation	• Simple cycle combustion turbines (CTs) • Combined cycle gas turbines (CCGTs) • CCGTs with carbon capture & sequestration
Renewable Generation	• Solar PV • Onshore Wind
Energy Storage	• Lithium ion batteries

To identify optimal investments in the electric sector, maintaining a robust representation of prospective resources' impact on system operations is fundamental to ensuring that the value each resource provides to the system is captured accurately. At the same time, the addition of investment decisions across multiple periods to a traditional unit commitment problem increases its computational complexity significantly. RESOLVE's simulation of operations has therefore been carefully designed to simplify a traditional unit commitment problem where possible while maintaining a level of detail sufficient to provide a reasonable valuation of potential new resources. The key attributes of RESOLVE's operational simulation are enumerated below:

- **Hourly chronological simulation of operations**: RESOLVE's representation of system operations uses an hourly resolution to capture the intraday variability of load and renewable generation.
- **Planning reserve margin requirement**: When making investment decisions, RESOLVE requires the portfolio to include enough firm capacity to meet coincident system peak plus additional 16.3% of planning reserve margin (PRM) requirement. This value is chosen based on PSCO's 2016 IRP[4]. The contribution of each resource type towards this requirement depends on its attributes and varies by type: for instance, variable renewables are discounted compared to thermal generators because of limitations on their availability to produce energy during peak hours.

[4] https://www.xcelenergy.com/company/rates_and_regulations/resource_plans/2016_psco_electric_resource_plan

- **Greenhouse gas cap**: RESOLVE also allows users to specify and enforce a greenhouse gas constraint on the resource portfolio for a region. As the name suggests, the emission cap requires that annual emission generated in the entire system to be less than or equal to the designed maximum emission cap. As it designs future portfolios, RESOLVE chooses both (1) how to dispatch new and existing resources to meet the goal (e.g. displacing output from existing coal plants with increased natural gas generation) and (2) what additional investments are needed to further reduce carbon in the system.

Representing the Colorado Electricity System

Colorado is represented as a single zone in RESOLVE. The study assumes no transmission or distribution constraint within the state. For further simplification, the study also assumes the Colorado system is islanded without electricity traded and transferred between Colorado and other states given the transmission capability between Colorado and other states is limited. However, wind from southern and eastern Wyoming are included as new resource options due to their proximity to Colorado's border and high wind quality.

GHG reduction target for the electricity sector is summarized in the table below. GHG targets for milestone years like 2030, 2040, and 2050 are calculated based on the announcement by the state or by utilities. Targets for the years between the goals are interpolated linearly. **Error! Reference source not found.** shows the GHG reduction target over the analysis horizon under the 2019 Action and HB1261 scenarios. Even though the GHG targets are calculated based on each utility's announcement individually, the GHG constraints are enforced for the state aggregately without differentiating the utility service territories.

Table 15. Electric sector GHG targets

Reference	2019 Action	HB 1261 Targets
Existing RPS policy, no additional GHG reduction target	- 80% statewide emissions reduction by 2030, - Tri-state's 100% clean energy in Colorado by 2040, and - Xcel's 100% reduction by 2050 (Represents Xcel & Tri-State commitments + HB 1261)	*Same as 2019 Action*

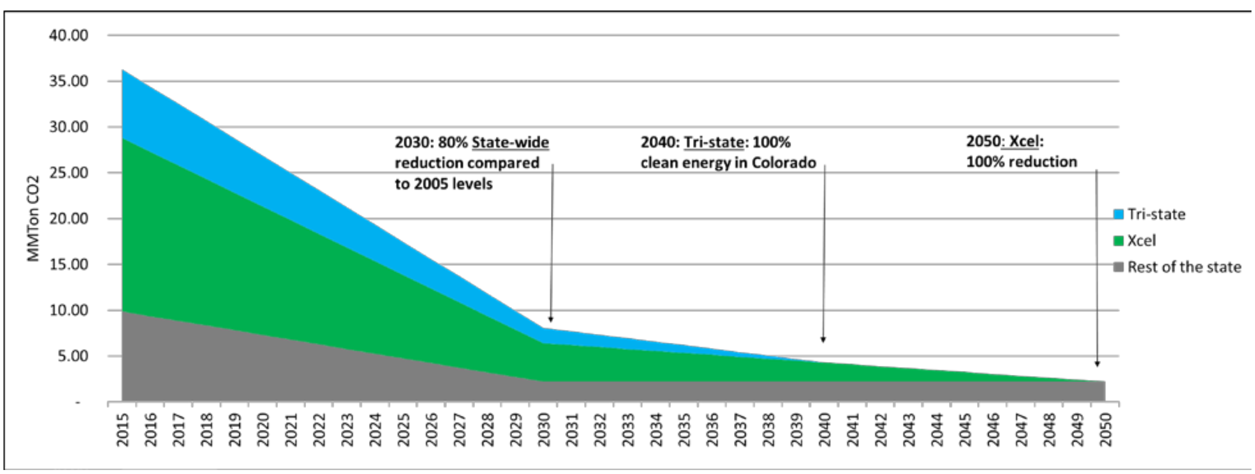

Figure 10. GHG reduction targets in 2019 Action and HB 1261 Target scenarios

The GHG emissions for the electricity sector are calculated based on generators that are physically located in Colorado. Therefore, RESOLVE is set up consistently to represent the GHG constraints. This means the total load modeled in RESOLVE is the load served by in-state generators, which is equal to

- + the Colorado loads
- - the Colorado loads that are served by out-of-state generators
- + the out-of-state loads that are served by Colorado generators

Inputs and Assumptions

This study relies on a wide range of inputs and assumptions to populate the RESOLVE model. Data is obtained from publicly available information. The key categories of inputs and assumptions are summarized in Table 16. Additional detail on each specific input is included in subsequent sections. We also have a separate input spreadsheet that contains inputs used in the model and data sources.

Table 16. Key inputs and sources for RESOLVE model

Input Category	Source	Description
Demand forecast	PATHWAYS Study	Annual demand and peak forecast for the state of Colorado
Existing resources	WECC 2026 TEPPC Common Case + recent utility announcement	Capacity, commission dates, retirement dates and operating characteristics for all existing and planned resources within the state of Colorado
New resources	WECC 2019 Generator Capital Cost Tool	Costs and performance for candidate resources considered in the portfolio optimization
Hourly profiles	NREL Wind Toolkit & NREL's National Solar Radiation Database (NSRDB)	Hourly profiles for all the components of demand; hourly generation profiles for solar and wind resources
Fuel price forecast	Market Forward price & EIA AEO Forecast	Fuel price forecast data for all thermal resources

Existing Resources

Existing and planned resources represent what utilities have planned to build or retire in the future. Assuming utilities' plan will be executed, RESOLVE makes additional resource investment to meet the future load and policy targets while minimizing the overall investment and operating costs.

The primary source for operating characteristics and costs on existing and planned generation is the WECC 2026 TEPPC Common Case. After consolidating the existing fleet information from the WECC common case, this study adjusted the coal retirement schedule based on the recent utility announcements. The study also includes renewable additions announced by utilities as part of the planned resource additions. Coal retirement schedule for each scenario is summarized in the Table 17 below.

Table 17. Coal retirement schedule by scenario

Plant Name	Size (MW)	Reference	2019 Action	HB 1261 Targets
Comanche 1	325	*12/31/2022*	*12/31/2022*	*12/31/2022*
Comanche 2	335	*12/31/2025*	*12/31/2025*	*12/31/2025*
Comanche 3	766	*12/31/2069*	*12/31/2069*	*12/31/2069*
Craig 1	428	*12/31/2025*	*12/31/2025*	*12/31/2025*
Craig 2	428	*12/31/2034*	9/30/2028	9/30/2028
Craig 3	448	*12/31/2044*	12/31/2029	12/31/2029
Hayden 1	212	*12/31/2030*	*12/31/2030*	*12/31/2030*
Hayden 2	286	*12/31/2036*	*12/31/2036*	*12/31/2036*
Martin Drake 6	83	*12/31/2035*	12/31/2022	12/31/2022
Martin Drake 7	141	*12/31/2035*	12/31/2022	12/31/2022
Pawnee 1	505	*12/31/2041*	*12/31/2041*	*12/31/2041*
Rawhide 1	280	*12/31/2050*	12/31/2029	12/31/2029
Ray D Nixon 1	208	*12/31/2050*	12/31/2029	12/31/2029

To accurately capture the coal retirement schedule, each coal plant unit is modeled separately. Existing gas and fuel oil plants are, on the other hand, modeled by plants. The composition of existing fleet for the reference case is shown in F. The final retirement schedule decided by RESOLVE might be different from the planned retirement schedule since RESOLVE can choose to retirement more coal plants earlier if it is economic to do so.

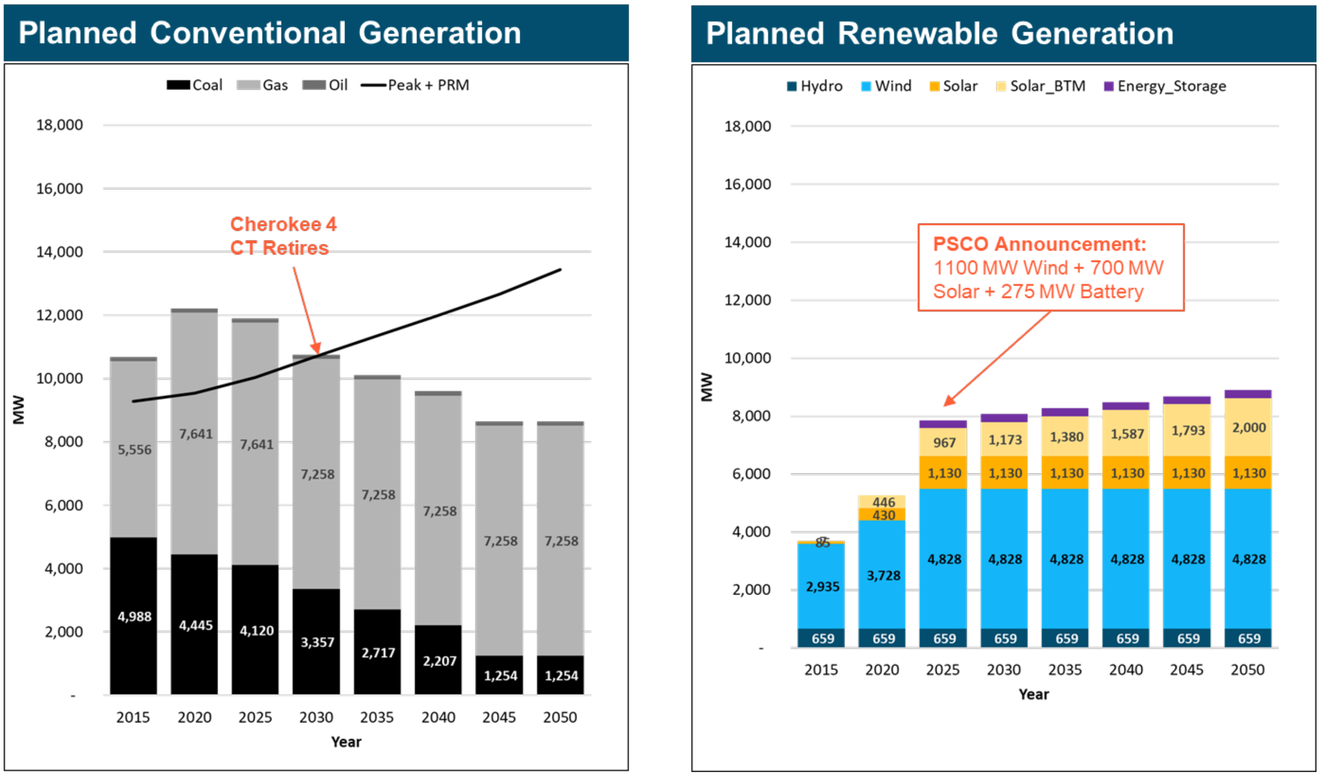

Figure 11. Planned conventional and renewable generation for the reference case

New Resource Options

A broad range of new resources options are considered as candidates in the portfolio optimization process. These options include new gas, renewable, storage, and new gas with carbon capture. The study includes biofuel as an alternative fuel to use. This section summarizes general assumptions on resource cost and performance used to characterize each of these options.

Natural gas

Two generic gas generation resources are included as options for additional capacity:

- Advanced CCGT: a generic new combined cycle plant that reflects both capital costs and the ongoing costs of operating the plant.
- Frame CT: frame CTs are available as resource options. As with the advanced CCGT, the capacity potential is uncapped.

The levelized fixed costs associated with each generic gas resource in this analysis was based on the WECC 2019 Generator Capital Cost Tool[5]. As shown in Figure 12, the fixed cost per kW of CCGT is higher than the cost of new combustion turbines. Gas-fired resources costs are expected to remain relatively constant in real terms through 2050.

---

[5] https://www.wecc.org/Administrative/E3-WECC%20Resource%20Cost%20Update-201905%20RAC%20DS%20Presentation.pdf

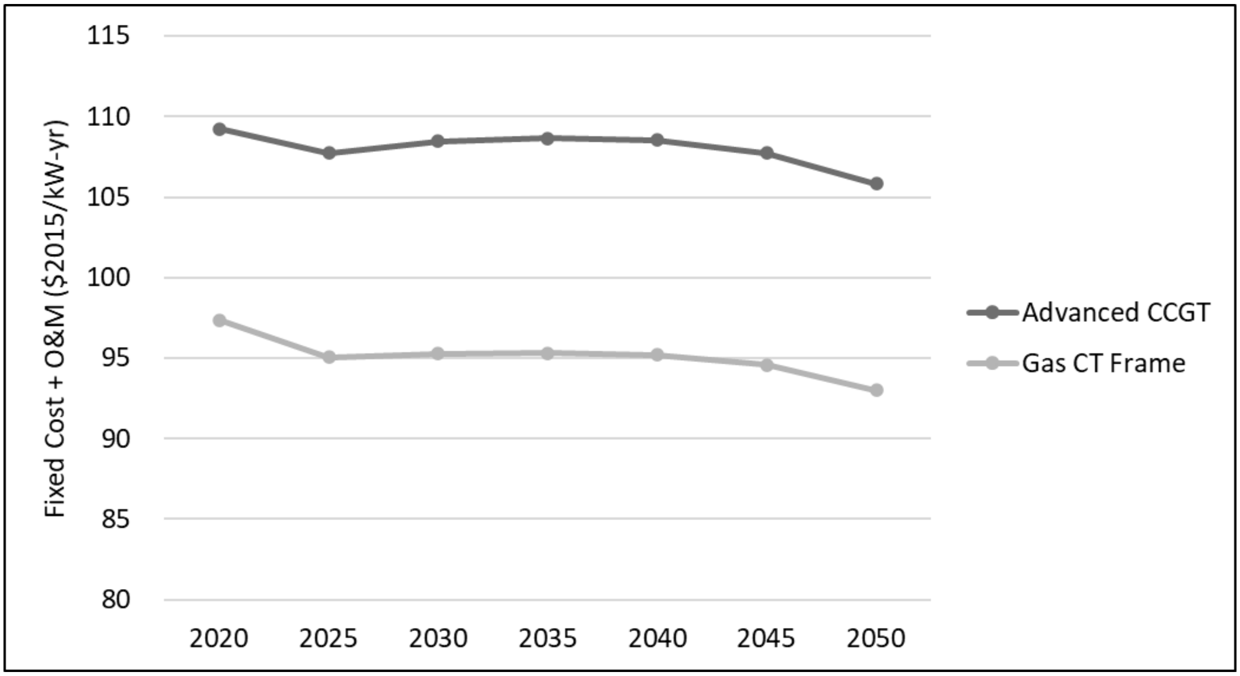

Figure 12. Levelized fixed costs for new gas generation resources

The study also included natural gas combined cycle power plants with carbon capture and storage (CCS) as a candidate resource. CCS is a new emerging technology, and thus there are many uncertainties around the future cost and performance. The operating characteristics and the cost estimates for candidate natural gas CCGTs are based on the Pathways to Deep Decarbonization in New York State report[6]. The CCS cost estimates for upstate New York are used as a proxy for Colorado.

Renewables

Renewable resources candidates are shown in Figure 13 and are developed based on the Western Renewable Energy Zones[7].

[6] Available online: https://climate.ny.gov/-/media/CLCPA/Files/2020-06-24-NYS-Decarbonization-Pathways-App-A.pdf

[7] Available online: https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/WREZ_Report.pdf

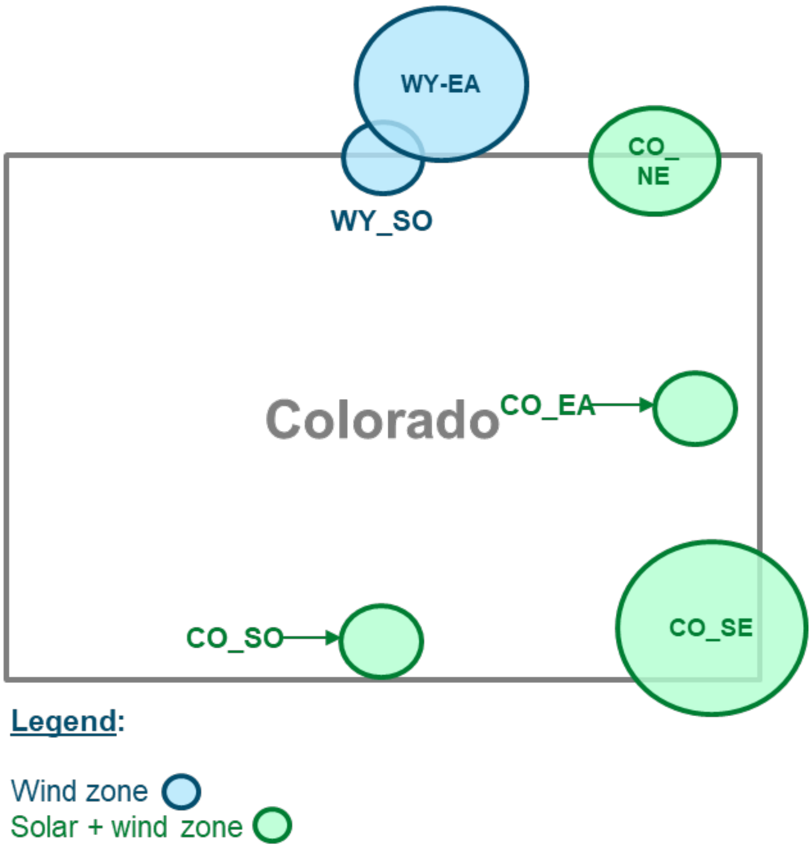

Figure 13. Renewable Resource Candidates

Colorado has significant quality renewable resources, and the wind and solar potentials in Colorado are both above 100 GW[8]. As a result, the study does not specify a limit for the wind and solar resources' technical potentials in RESOLVE. Even without the technical potential limits, RESOLVE won't build an unreasonable amount of renewables because the model also considers the economics. The study checks results for each scenario to make sure the renewable builds are within a reasonable range. On the other hand, RESOLVE does consider the differences in capacity factors for renewables in each region. Capacity factors for each candidate resource are summarized in the table below.

Table 18. Renewable Candidates and Capacity Factors

Renewable Candidates	Capacity Factor
Wind (WY_EA)	45%
Wind (WY_SO)	44%
Wind (CO_NE)	37%
Wind (CO_EA)	41%
Wind (CO_SE)	42%
Wind (CO_SO)	41%
Solar (CO_NE)	29%
Solar (CO_EA)	32%
Solar (CO_SE)	32%

[8] Based on the Renewable Energy Deployment in Colorado and the West: A Modeling Sensitivity and GIS Analysis report by Clayton Barrows, Trieu Mai, Scott Haase, Jennifer Melius, and Meghan Mooney from National Renewable Energy Laboratory

Solar (CO_SO)	33%

Cost assumptions for new renewable resources in this study are also based on the WECC 2019 Generator Capital Cost Tool. This study translates the capital and fixed O&M cost assumptions for wind and solar PV (single-axis tracking) technologies into a levelized cost of energy (LCOE) metric for each type of resource that reflects an proxy for the price at which an independent developer might offer the resource to a credit-worthy utility through a long-term power purchase agreement (PPA). LCOEs for each resource vary through time due to assumed changes in technology cost, financing costs, and federal tax credits.

The LCOEs for new renewable resources also include a component to capture the transmission upgrades needed to ensure that resources can be delivered to loads. Transmission costs are additive to the capital cost of the resource itself and are estimated based on the distance between the location of the resources and the load center (Denver)

Figure 14 below shows the average LCOE for solar and wind candidates over time. Near-term wind costs are relatively low—in large part, due to the effect of the Federal Production Tax Credit (PTC); in the long run, the LCOE of wind is assumed to increase from today's level due to the expiration of the PTC, an effect that is partially offset by some improvements in capital costs. The near-term trajectory of costs is heavily shaped by the expiration of the PTC, which results in a near-term cost increase; in the long run, the LCOE for new wind resources declines slightly in real terms as technology continues to improve at a modest pace. While the Federal Investment Tax Credit (ITC) available to solar resources today is scheduled to revert to a lower level of 10% in the next few years, continued anticipated cost reductions in capital costs over time helps to offset the effect of the sunsetting ITC on the resulting LCOEs for solar resources.

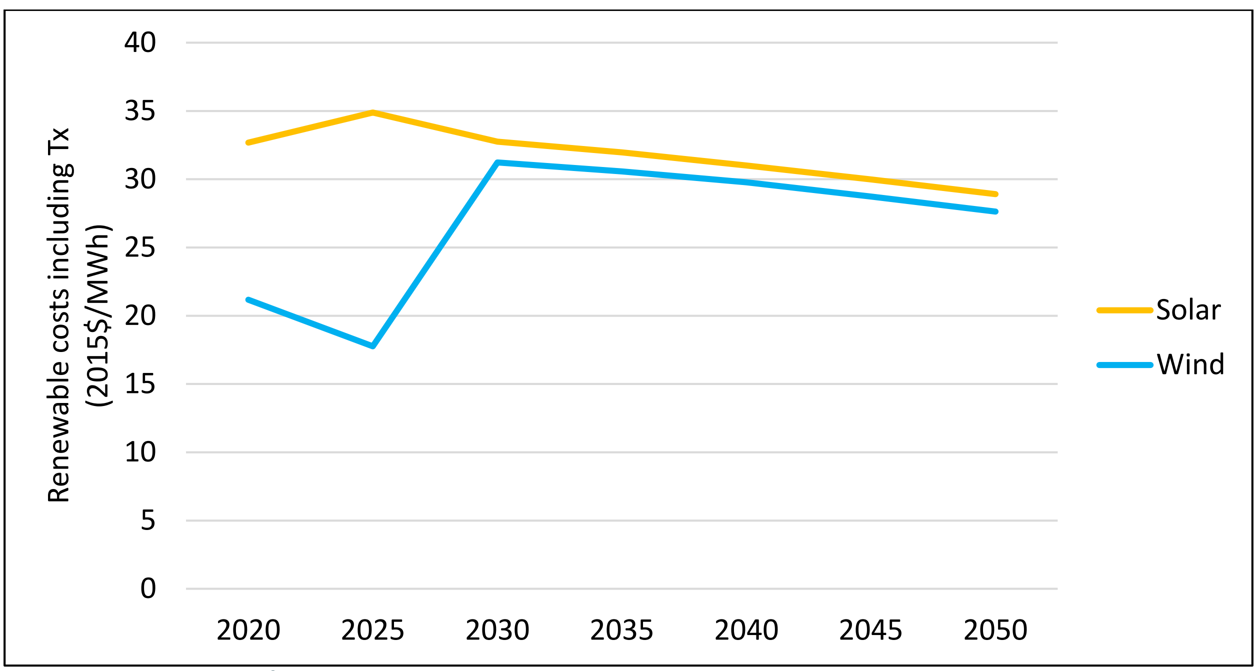

Figure 14. Average LCOE for Solar and Wind Candidates by Years

LCOE for each renewable candidate in 2030 is shown in the Figure 15 below. The LCOE is broken into the transmission cost and the capital and other costs. Wind in South Wyoming and South Colorado have the cheapest LCOE due to its high capacity factors and proximity to the load pocket.

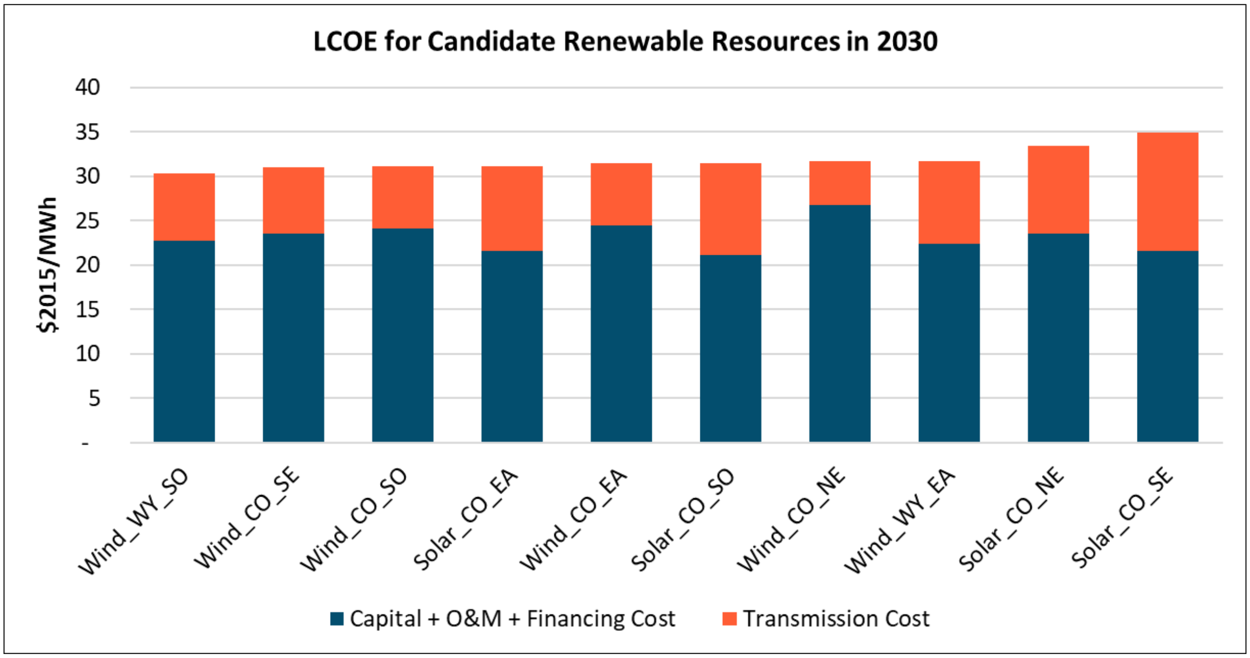

Figure 15. LCOE for Candidate Resources in 2030

Energy storage

4-hour Li-ion battery with 85% round-trip efficiency is included as one of the candidate resources in the study. Cost assumptions for new energy storage are also based on WECC 2019 Generator Capital Cost Tool. This study relies upon WECC's characterization of a utility-scale battery system with four hours of duration. Figure 16 shows the levelized fixed cost assumptions for battery storage across the analysis horizon.

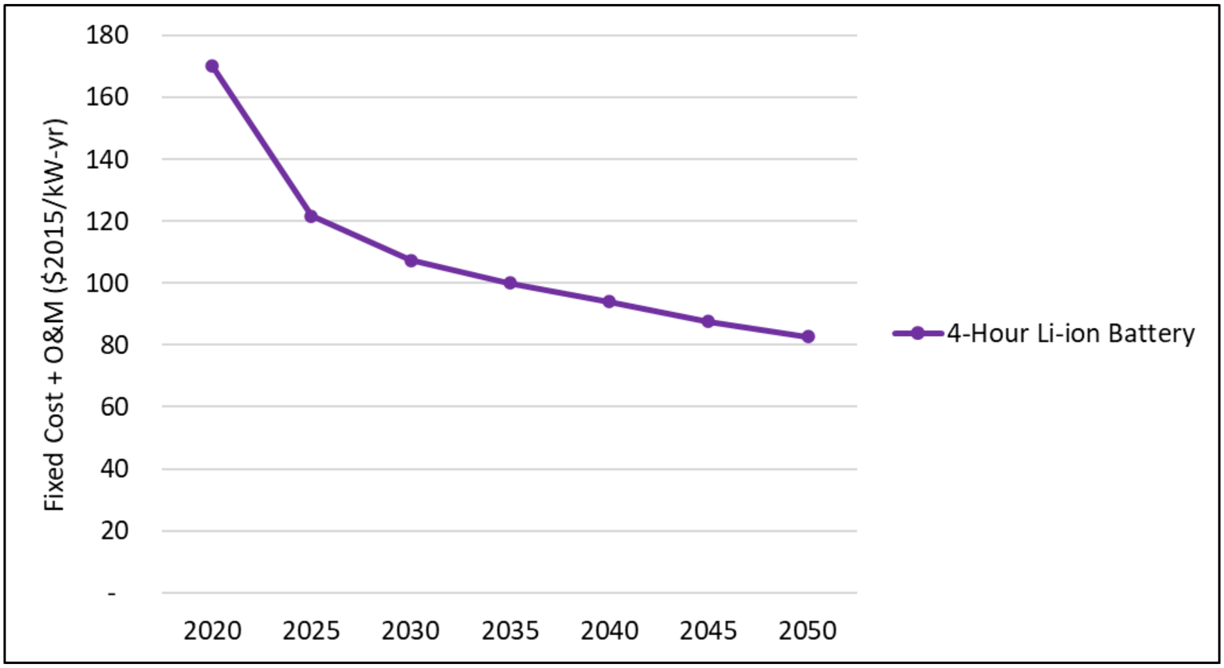

Figure 16. Levelized cost projections for new storage resources

Hourly Profiles

Hourly profiles for load and wind and solar resources are key inputs to this study. Load, wind, and solar each vary on an hourly, daily, and seasonal basis, and their variations are often correlated due to underlying meteorological phenomena that affect all three. Capturing these patterns in a statistically rigorous manner is crucial to enable planning of a system that can operate efficiently on a day-to-day basis and is resilient in spite of an increasingly intermittent and variable energy supply.

This study relies on a library of hourly load, wind, and solar profiles that reflect the meteorological conditions across the three-year time span from 2010 through 2012. Developing profiles that are weather-matched and time-synchronized in this manner ensures consistency across the data set, preserving the key underlying correlations among the variables. The hourly profiles for this study are based on the following sources:

- Load profiles are based on the historical hourly profiles from the WECC 2026 TEPPC Common Case
- Load shapes for end uses that may be electrified in the future (e.g. space heating, water heating, electric vehicle) are developed through E3's RESHAPE tool[9]; RESHAPE is designed to capture the diversity of space heating and transportation loads under higher levels of electrification. The tool does this by representing a diverse housing stock, including geographically explicit weather data, and using empirical estimates of hourly energy usage where possible. RESHAPE includes modules for both transportation and buildings.
- Wind profiles are developed for the same period using data from NREL's WIND Toolkit, which provides detailed geospatial simulations of wind speed and generation profiles for a large number of sites throughout the United States

- Solar PV profiles are simulated using NREL's System Advisor Model (SAM) and solar irradiance data from the National Solar Radiation Database (NSRDB) for a variety of plausible locations throughout the state

A representative subset of 40 days is sampled to reflect representative combinations of loads and associated renewable production profiles from the time series described. The reduced representative days enable portfolio optimization across multiple decades within a reasonable solving time.

Effective Load Carrying Capability

Capacity accreditation for variable and use-limited resources under a PRM framework requires an estimate of "effective load carrying capability," which captures limitations of each resource to meet reliability needs. The effective load carrying capability represents the amount of firm capacity that can be provided by the resource. The firm capacity is then counted toward the planning resource margin requirement in modeling. The assumed ELCC for each resource category are summarized in the table below. For thermal resources, the study uses the weighted average ELCC for each thermal resource category in PSCO's 2016 IRP as the ELCC for current and future thermal resources.

Table 19. Effective Load Carrying Capability Summary

Resource Category	ELCC (% of Nameplate)	Sources
Coal	93%	PSCO 2016 IRP
Natural Gas	92%	PSCO 2016 IRP
Oil	93%	PSCO 2016 IRP
Wind	Varies by installed capacity	E3's estimate
Solar	Varies by installed capacity	E3's estimate
4-hour Li-ion Battery	Varies by installed capacity	E3's estimate & NREL's report[10]

In this model, ELCCs for renewables are estimated based on their respective impacts on the net peak demand across the top 100 hours of the year. As illustrated in the Figure 17 below, renewable ELCCs are estimated based on the achieved peak load reduction provided by the renewable resource when it is stacked against the system load shape.

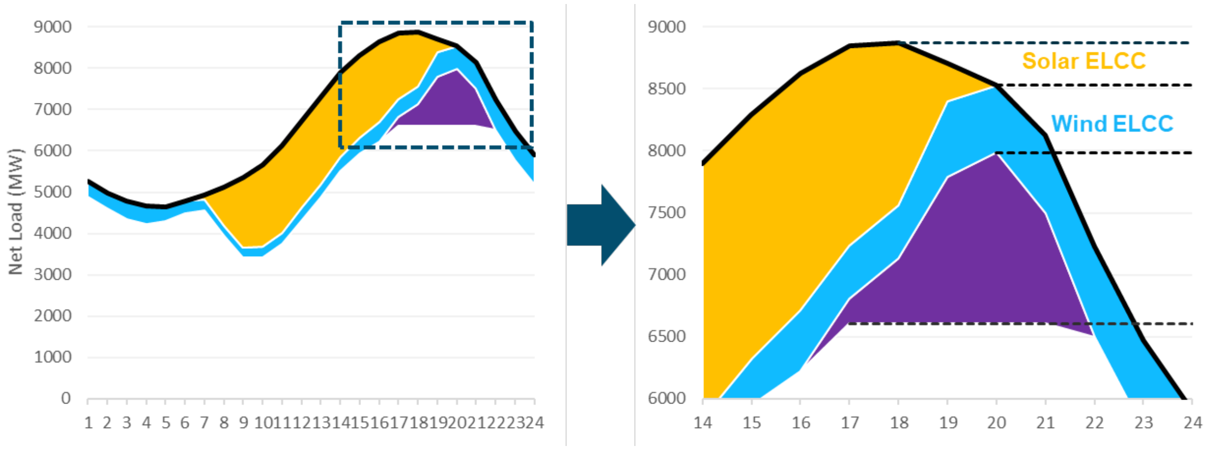

Figure 17. Illustration of the ELCC methodology

---

[10] NREL: The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States: https://www.nrel.gov/docs/fy19osti/74184.pdf

Based on the estimation method described above, the estimated average ELCCs for wind and solar combined is shown in the figure below. The average ELCC is shown based on the wind and solar penetrations in the system. Wind and solar penetrations are calculated as % of annual energy. The red dots represent how the average ELCC changes when solar penetration level is fixed at 10% and wind penetration level varies from 0% to 60%. More specifically, for the red dot on the right, of which the x axis is 60% and the y axis is 20%, it means that when solar penetration 10% and wind penetration is 60%, solar and wind combined provide a firm capacity equal to 20% of the system peak.

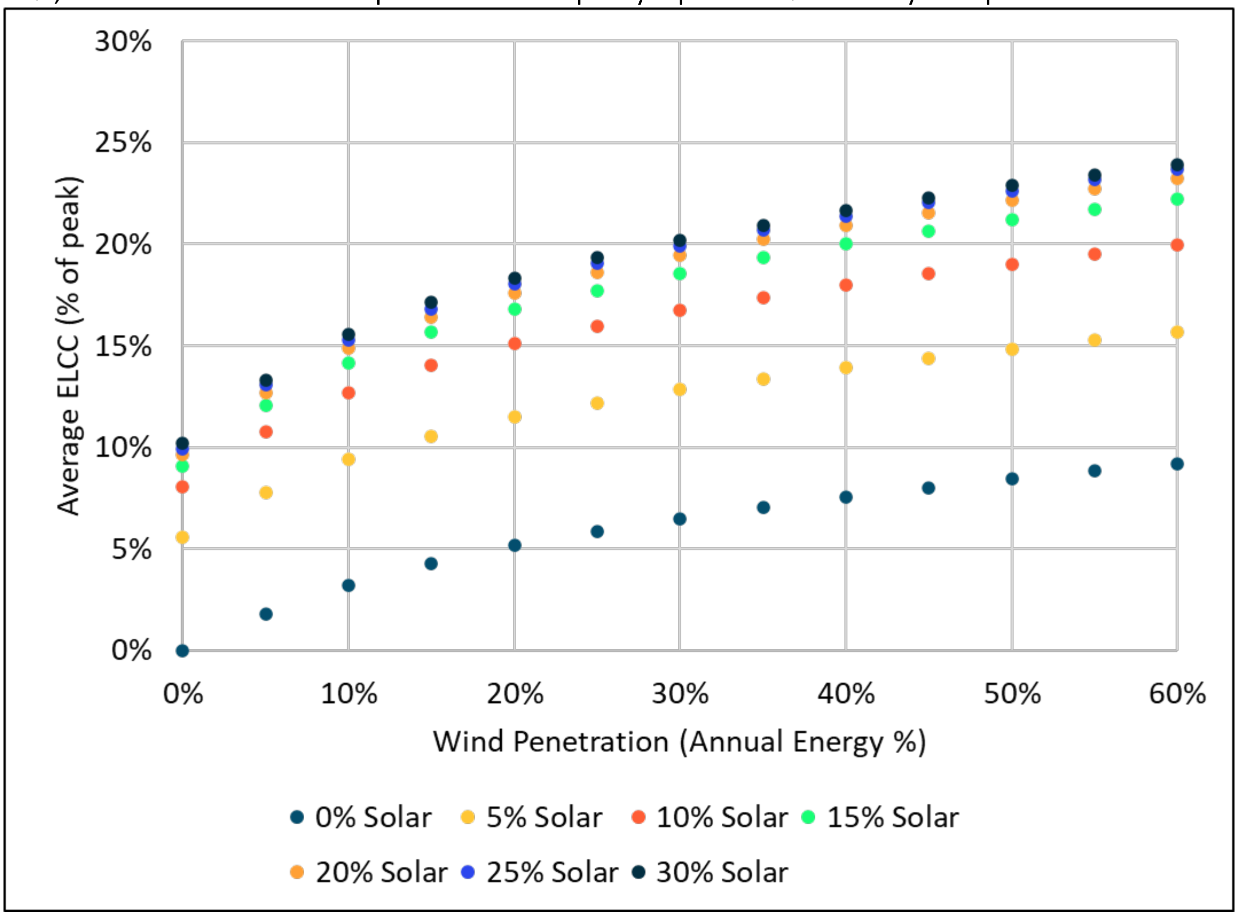

Figure 18. Estimated ELCC for wind and solar

The ELCC for 4-hour Li-ion storage is estimated based on the previous studies E3 conducted in Northwest Region[11], Xcel Minnesota[12], and a Small Northeast utility[13]. Based on these three studies, E3 summarizes the relationship between incremental ELCC and total installed battery capacity in the system and applies that relationship to Colorado. The nameplate capacity threshold for first trench with 100% incremental ELCC is based on the NREL study[10]. Li-ion batteries' incremental ELCC decrease as the total battery installed capacity increases. With more Li-ion batteries in the system, system peak is

[11] Northwest Region: Resource Adequacy in the Pacific Northwest
[12] Xcel Minnesota: Upper Midwest 2019 IRP Support
[13] Small Northeast Utility: confidential internal analysis

flatter, and it becomes more difficult for the new 4-hour battery to provide capacity during the longer peak period.

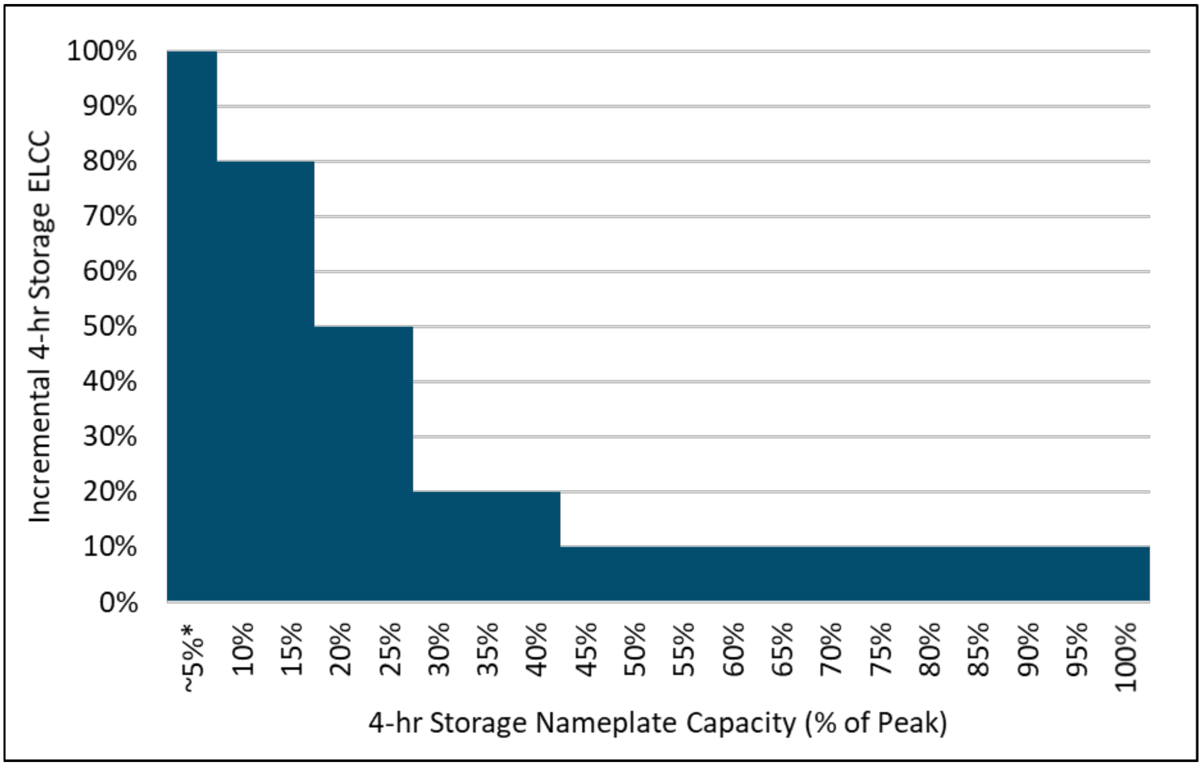

Figure 19. 4-hr Storage ELCC

Fuel Price Forecasts

Natural gas prices forecasts are based on the Market Forward prices for the near term (2020-2022) and EIA AEO Forecast[14] for the long term (2040-2050). Prices are interpolated linearly for the years in between (2022–2040).

Coal prices are assumed to stay the same in the real term for future years. Coal plants are grouped into two groups given there are significant differences in historical fuel prices among coal plants in the state as shown in Figure 20. The future coal prices for each group are assumed to be the same as the weighted average 2019 historical coal prices in real term. The two groups are:

- Uinta basin: Craig, Hayden, and Nucla
- Southern powder river basin: Cherokee, Martin Drake, Ray D Nixon, Rawhide, Pawnee, and Comanche

[14] https://www.eia.gov/outlooks/aeo/

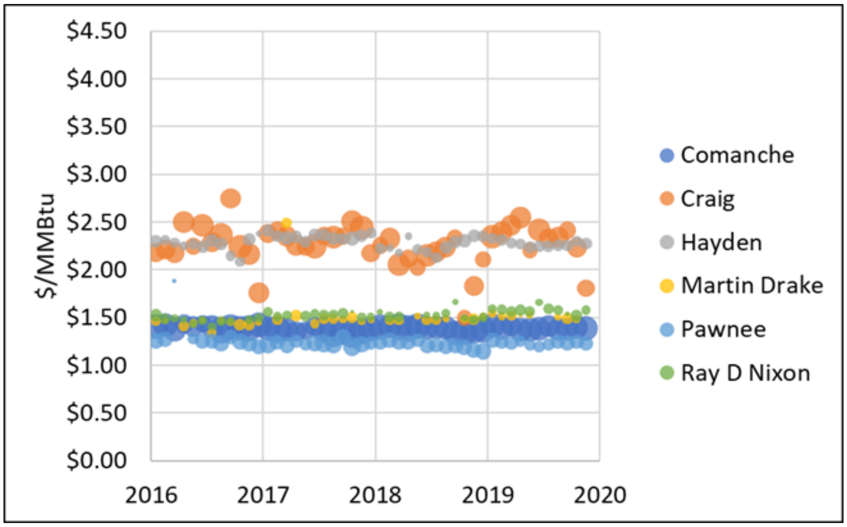

Figure 20. Historical Coal Prices by Plants

Fuel price projections used in this study are summarized in Figures 21 and 22. Natural gas and fuel oil are expected increase in price.

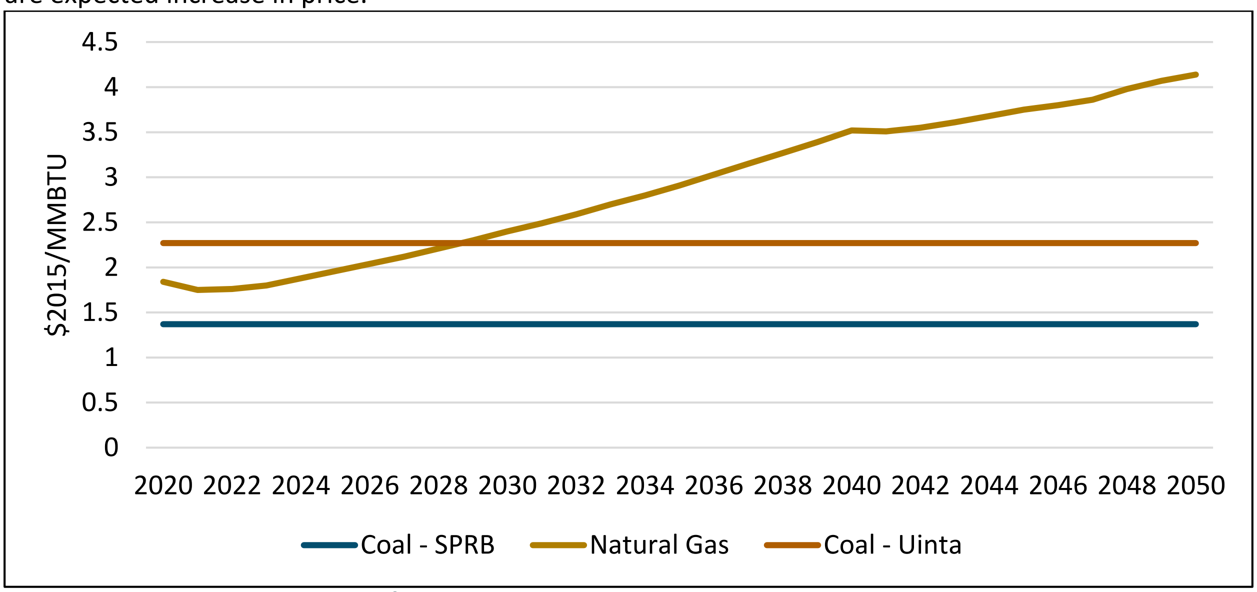

Figure 21. Coal and Natural Gas price forecast

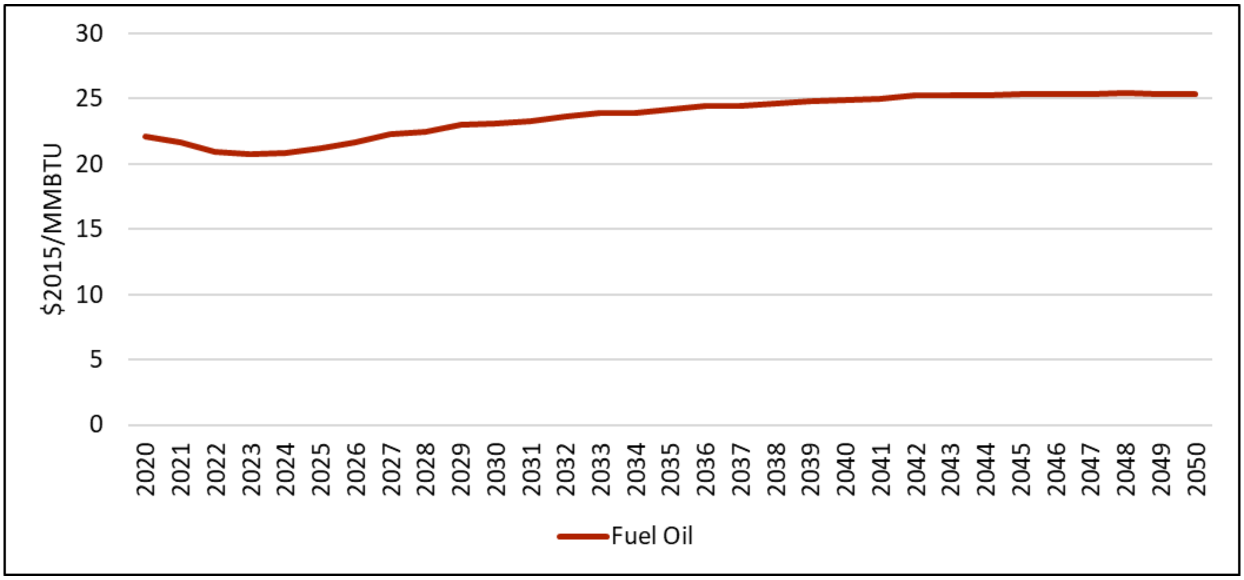

Figure 22. Diesel Fuel Oil Price Forecast