Colorado's Clean Affordable Climate Pathways

Technical Report

December 2025

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Sustainability Solutions Group

Image at the cover and sub-cover: Panoramic view of Denver, Colorado. Photo by aphotostory/stock.adobe.com

Indian Peaks Wilderness, Colorado. Photo by John Fielder

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This analysis applies to the State of Colorado and cannot be applied to other jurisdictions without additional analysis. Any use by the project partners or any third party, or any reliance on, or decisions based on this document, are the responsibility of the user or third party.

Table of contents

Acknowledgements

The analysis and report was completed by:

- Chris Strashok, SSG
- Sebastien Bonelli, SSG
- Yuill Herbert, SSG

With supporting analysis from:

- Wendy Jaglom-Kurtz, RMI

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Acronyms

Acronym	Definition
ACS	American Community Survey
BAP	Business-as-Planned
CBECS	Commercial Buildings Energy Consumption Survey
DOE	US Department of Energy
ECMC	Colorado Energy & Carbon Management Commission
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GHG	Greenhouse gas
LC	Low carbon
LULUCF	Land Use, Land-Use Change, and Forestry
$MMTCO_2e$	Million metric tons of carbon dioxide equivalents
NASS	US Department of Agriculture, National Agricultural Statistics Service
NLCD	US Department of the Interior, Annual National Land Cover Database
NEI	EPA, National Emissions Inventory
OEERE	US Department of Energy, Office of Energy Efficiency and Renewable Energy
RECS	Residential Energy Consumption Survey
RC	Reference Case
SIT	EPA State Inventory Tool

Introduction

This project identifies sector-specific and economy-wide gaps that must be addressed to achieve Colorado's greenhouse gas (GHG) reduction targets. The project then evaluates pathways to achieve those emissions reductions and evaluates the financial costs and benefits, including the capital investments needed, the annual operating and maintenance costs or savings, and the impacts on energy affordability. In addition, the project evaluates changes in local air pollution emissions, such as precursors to ozone.

The analysis covers the 2023–2050 period. To achieve Colorado's statutory GHG emissions reduction goals over that period, numerous measures are assessed, many of which may be considered ambitious or technologically challenging today. This analysis does not specify the policies that should be used to implement the GHG reduction pathways; however, it provides insights into the costs and benefits of different options for achieving Colorado's goals and different types of policy approaches. Additionally, the analysis does not identify financing mechanisms. Investments in low-carbon technologies can be stimulated by incentives or regulations, can stem from private-sector investment or government funding, and can be financed up front or amortized over time through financing mechanisms such as a green bank. This analysis shows the net costs and benefits to residents and businesses of Colorado.

Methodology

The project involved three key steps:

1. **Calibrated baseline:** An energy and emissions model, ScenaEnergy, was used to represent activities that drive energy consumption in the state. The model was populated with data collected from a wide range of sources, as described in Appendix 1. The resulting energy consumption was then calibrated to align with observed energy consumption data for each sector. For this analysis, the baseline year is 2023.
2. **Future scenarios:** Scenarios were developed in consultation with expert advisors to represent different technological and policy pathways for Colorado.
3. **Modeling results:** Results were evaluated across multiple indicators, including energy, GHG emissions, local air pollution, capital and operating costs and savings, and new employment opportunities.

ScenaEnergy is a systems dynamics model that integrates fuels, sectors, and land use in order to enable bottom-up accounting for energy supply and demand. Energy and GHG emissions values are derived from a series of connected stock and flow models, which evolve based on current and future geographic and technology decisions/assumptions (e.g., electric vehicle [EV] uptake rates). ScenaEnergy accounts for physical flows (e.g., energy use, new vehicles by technology, vehicle miles traveled [VMT]) as determined by stocks (buildings, vehicles, heating equipment, etc.).

For any given year, ScenaEnergy traces the flows and transformations of energy from sources through energy currencies (e.g., gasoline, electricity, hydrogen) and end uses (e.g., personal vehicle use, space heating) to energy costs and GHG emissions. An energy balance is achieved by accounting for efficiencies, technology conversion, and trading losses at each stage of the journey from source to end use.

Costs are calculated by applying cost intensities for capital, maintenance, and energy costs to the stocks and flows in the model.

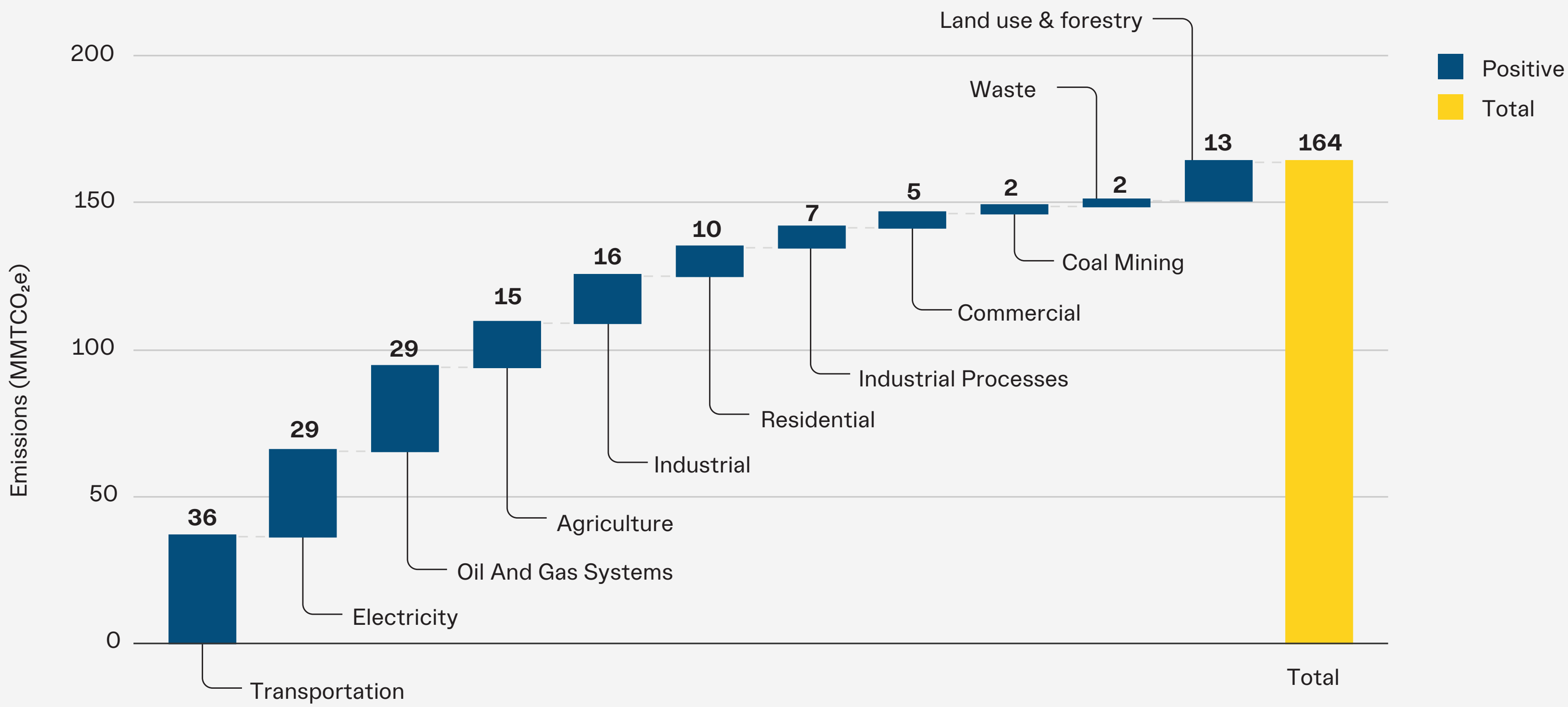
As this is an analysis of the energy system as a whole, the analysis did not evaluate hourly electricity demand and supply or transmission investments. As with other energy sources, electricity cost intensities are an input to the financial analysis, which, when combined with the model output for annual electricity consumption, result in annual energy costs. SSG used electricity cost projections published by the Energy Information Administration (EIA).[1] A separate spreadsheet analysis was undertaken to ensure that this assumption is reasonable. Appendix 8 describes this analysis.

1 Gagnon, Pieter; Pedro Andres Sanchez Perez; Julian Florez; James Morris; Marck Llerena Velasquez; and Jordan Eisenman. Cambium 2024 Data. National Renewable Energy Laboratory. https://scenarioviewer.nrel.gov and U.S. Energy Information Administration - EIA - Independent Statistics and Analysis, Table 54. Electric Power Projections by Electricity Market Module Region.

Calibrated Baseline

Prior to modeling future scenarios, SSG used reported energy data to calculate the emissions in 2023, the baseline year. Appendix 1 describes these data sources. GHG emissions in 2023 were 164 $MMTCO_2e$, including land use, land-use change, and forestry (LULUCF), and 151 $MMTCO_2e$, excluding LULUCF. The largest sources of emissions were transportation (22%), followed by electricity (18%) and oil and natural gas (18%) (Figure 1).

Figure 1.
Transportation, electricity, and oil and gas represent the largest sources of GHG emissions in Colorado in 2023, as estimated for this analysis.



Emissions from LULUCF totaled 13 $MMTCO_2e$ in 2023; however, the causes of these emissions (e.g., changes to the forest as a result of pine bark beetle infestations) and the strategies to mitigate them are uncertain. Subsequent charts and emissions estimates exclude these emissions. Future study is required to assess these emissions and the strategies to reduce them.

The 2023 estimated emissions are roughly equivalent to Colorado's 2005 emissions. For reference, the Colorado Greenhouse Gas Inventory estimated the state's emissions totaled 162 $MMTCO_2e$ in 2005, including LULUCF. Excluding LULUCF, Colorado's reported emissions were 153 $MMTCO_2e$ in 2005. Between 2005 and 2023, Colorado reduced emissions from the electric sector, but emissions in other sectors, particularly transportation, increased significantly. The estimated emissions in 2023 are also significantly higher than Colorado's reported emissions in 2020, the most recent emissions data available at the time of modeling, as reported in Colorado's Greenhouse Gas Inventory. This likely reflects that in 2020, as a result of COVID-19, transportation-related emissions sharply declined but rebounded by 2023 as COVID-era restrictions and driving behavior patterns returned to normal.

Future Scenarios

Six future scenarios were modeled, as described in Table 1. Appendix 2 describes the detailed assumptions for each scenario. The low-carbon (LC) scenarios were designed to explore pathways to achieve Colorado's statutory GHG emissions reduction targets (Appendix 3). The Reference Case (RC) Scenario reflects population growth and no further policy implementation and is designed to help stakeholders understand the implications of repealing existing clean energy policies. The Business-as-Planned (BAP) Scenario reflects existing enforceable policies, as assessed by the project team. Additionally, during the modeling process, Congress passed Congressional Review Act resolutions disapproving the waivers for Advanced Clean Cars II, Advanced Clean Trucks, and Low-NOx Omnibus regulations, which require vehicle manufacturers to meet emissions standards for new vehicles. This congressional action has been challenged by California and other states as unlawful and unconstitutional. As a result, these policies were excluded from the BAP Scenario because of the ongoing litigation related to the rules, and the levels of EV adoption anticipated under those policies are not included in the BAP Scenario.

Table 1.
SSG modeled six scenarios: one reference case, one business as planned, and four low-carbon scenarios illustrating different low-carbon pathways.

	Scenario	Description
RC	Reference Case	Extrapolation of current technologies and energy sources, scaled based on projected population growth
BAP	Business-as-Planned	Implementation of current policies
LC 1 (E&E)	Low-Carbon 1 (high efficiency & electrification)	Comprehensive efficiency, electrification, and accelerated ambition
LC 2 (LC fuels)	Low-Carbon 2 (low-carbon fuels)	High electrification with greater emphasis on low-carbon fuels/carbon capture and storage (CCS) technologies
LC 3 (least cost)	Low-Carbon 3 (least cost)	Prioritization of the lowest cost actions
LC 4 (sectors)	Low-Carbon 4 (sector-specific targets)	Implementation of sector-specific targets

The ambition level for measures in each scenario is represented in Table 2, where a darker shade indicates a higher ambition level. At a high level, LC 1 (E&E) includes a full suite of actions in every sector, identified through an extensive engagement process with project partners. LC 2 (LC fuels) narrows the number of actions and emphasizes renewable natural gas (RNG) and hydrogen in specific sectors and an increased reliance on carbon removal. LC 3 (least cost) further narrows the number of actions to focus on those with the lowest abatement cost, as calculated in LC 1 (E&E), and applies these to achieve GHG targets for the state as a whole. LC 4 (sectors) applies the constraint of achieving sector-specific targets[2] so that actions are accelerated in some sectors in comparison to LC 3 (least cost), ensuring that each sector meets its individual emission reduction targets. Appendix 5 describes the detailed assumptions for each scenario.

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2 Sector-specific targets were developed based on Colorado statutory requirements, the Air Quality Control Commission GHG resolution adopted in 2020, and the Greenhouse Gas Pollution Reduction Roadmap developed by the Colorado Energy Office in 2021.

The energy system was modeled with an annual time step in order to consider energy consumption for each sector and each source, with spatial resolution. A separate analysis was undertaken to evaluate the implications of each scenario for the electricity system. This analysis concluded that it was reasonable and conservative to assume that the LC scenarios need not result in higher per unit electricity costs than the BAP Scenario costs.[3]

Table 2.
Illustrative figure showing the inclusion and ambition of themes across scenarios, where darker colors = higher ambition and white = not included.

Theme	LC 1 (E&E)	LC 2 (LC fuels)	LC 3 (least cost)	LC 4 (sectors)
New building performance				
Retrofits				
Heat pumps				
Personal zero-emission vehicle (ZEV) adoption				
Mode shift				
Decentralized Photovoltaics (PV)				
Electric grid decarbonization				
Thermal energy networks				
Green H2 consumption				
Green H2 production				
Reducing emissions from oil and gas systems				
Supplying data centers with clean electricity				

3 The analysis is described in Appendix 8. The capital and operating costs of different capacity requirements were evaluated to assess the financial implications; the results indicated that low or zero carbon options had the lowest costs, while this analysis conservatively assumes cost parity. A more detailed hourly modeling analysis would be required to comprehensively evaluate the financial implications of decarbonising electricity generation.

GHG Emissions

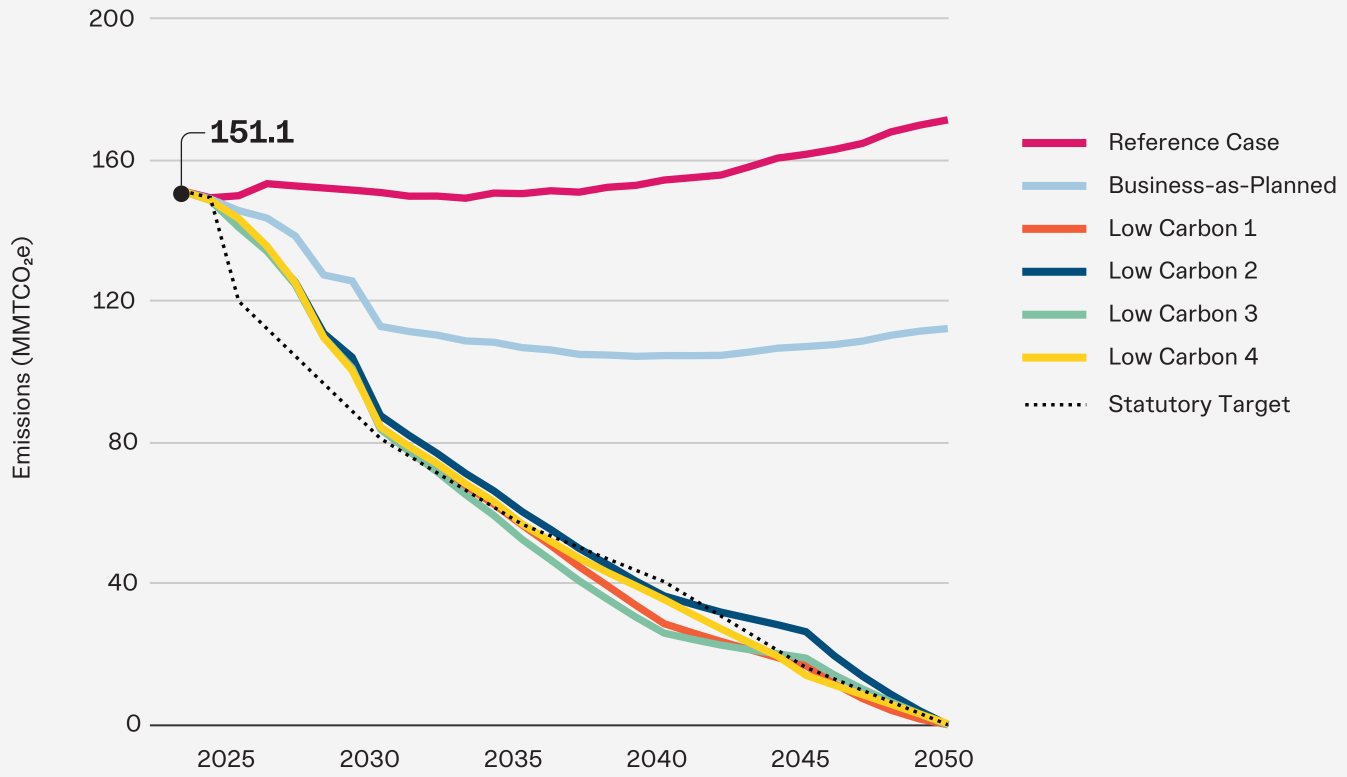
Observations

1. Colorado's current suite of climate policies does not achieve the State's GHG emissions reduction targets. As modeled in the Business-as-Planned Scenario, under current policy Colorado is forecasted to miss its climate targets by: 26 million $MTCO_2e$ in 2025, 32 million $MTCO_2e$ in 2030, 50 million $MTCO_2e$ in 2035, 64 million $MTCO_2e$ in 2040, 91 million $MTCO_2e$ in 2045, and 112 million $MTCO_2e$ in 2050.
2. Multiple scenarios were modeled to achieve Colorado's climate targets from 2030 through 2050, demonstrating different technological pathways for reducing GHG emissions in line with the State's targets.
3. Every low carbon scenario modeled achieves at least 1.5 billion $MtCO_2e$ in cumulative GHG emissions reductions relative to the BAP Scenario.
4. The shape of the GHG reduction curve influences the cumulative GHG emissions (2026–2050) for each Scenario. For example, LC 3 (least cost) reduces cumulative emissions by 144 million $MTCO_2e$ relative to LC 2 (LC fuels), 61 million $MTCO_2e$ relative to LC 4 (sectors), and 24 million $MTCO_2e$ relative to LC 1 (E&E). LC 3 (least cost), which was designed to meet Colorado's economy-wide climate targets at the least cost, reduces the most cumulative emissions out of all four low-carbon scenarios.

Downtown Denver overlooking highway I-25.
Photo by Jen Lobo/stock.adobe.com

Figure 2 illustrates the GHG emissions trajectory of each scenario. The dotted line represents Colorado's legislated GHG targets.

Figure 2.
Modeled emissions for each scenario show that emissions rise under the Reference Case Scenario, and under the Business-as-Planned Scenario, emissions decline in the near term but do not achieve Colorado's GHG goals. All low-carbon scenarios achieve or nearly achieve Colorado's goals between 2030 and 2050.



In the Reference Case Scenario, GHG emissions grow from 151 million $MTCO_2e$ in 2023 to 171 million $MTCO_2e$ in 2050 as a result of population growth and increased electricity consumption, assuming current mixes of generating capacity. Oil and gas production in the Reference Case Scenario follows the trajectory published in EIA's Annual Energy Outlook projection. Note that, as described above, the charts do not include GHG emissions associated with LULUCF unless otherwise indicated. See Appendix 2 for discussion on these emissions.

The BAP Scenario reduces emissions between 2023 and 2030, but after 2030, emissions remain relatively flat. The BAP Scenario does not achieve Colorado's statutory targets in any year, with a gap of 32 million $MTCO_2e$ by 2030 and 112 million $MTCO_2e$ by 2050. The BAP Scenario included actions that had a high certainty of being implemented either because of regulation, funding, or some other clear, enforceable mechanism.

LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors) are aligned with the State's targets beyond 2025, including in 2030. LC 2 (LC fuels) fell short in the last decade. In all low-carbon scenarios, carbon removal[4] was deployed between 2045 and 2050 to address residual emissions in hard-to-decarbonize sectors such as industrial processes. LC 2 (LC fuels), which relies on higher levels of low-carbon fuels, also deploys higher amounts of carbon removal than LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors).

The emissions reduction pathways for each scenario are illustrated by sector in Figure 3 and by energy source in Figure 4. GHG emissions are nearly phased out in each sector by 2050 across LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors). At the macro level, variations in each sector across the scenarios are minor, reflecting the requirement to reduce economy-wide emissions to zero by 2050 in alignment with the statutory targets. One notable variation is that LC 2 (LC fuels) retains higher levels of emissions from the oil and gas sector through 2045 in comparison to the other scenarios (due to continued future oil and gas production).

The low-carbon scenarios indicate an average annual decline in emissions of nearly 6 million $MTCO_2e$, with the reduction distribution varying amongst scenarios for each sector. For example, LC 4 (sectors) has greater cumulative reductions in the transportation, oil and gas, and industrial sectors and lower reductions in the agricultural sector compared to other scenarios.

4 Carbon removal is indicated as "Future Technologies" in the wedge diagrams, as the specific strategy is not specified.

Figure 3.
GHG emissions are flat in each sector in the RC Scenario. In the BAP Scenario, declines in GHG emissions are driven by the electricity sector. In the low-carbon scenarios, emissions decline in every sector.

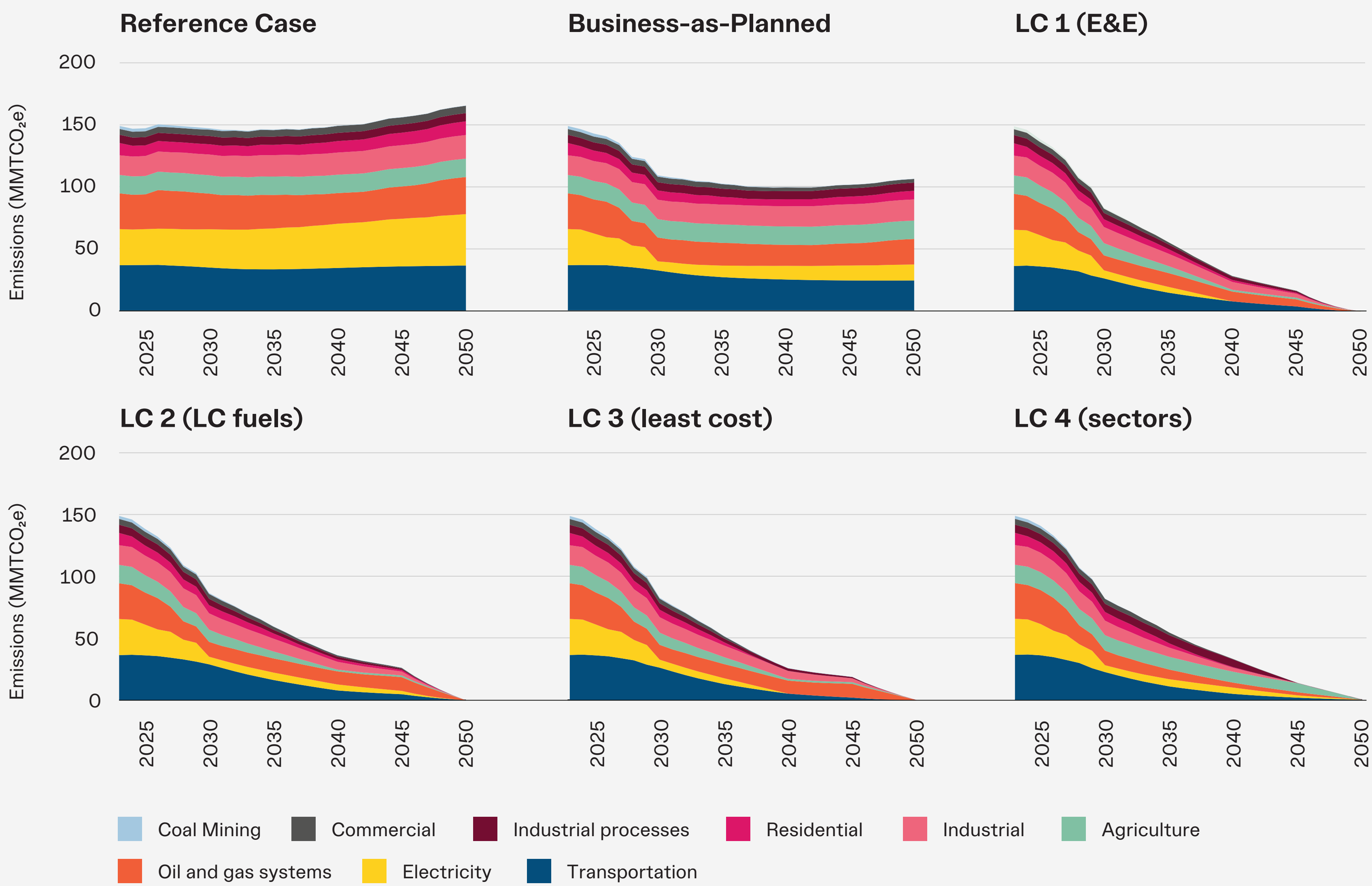
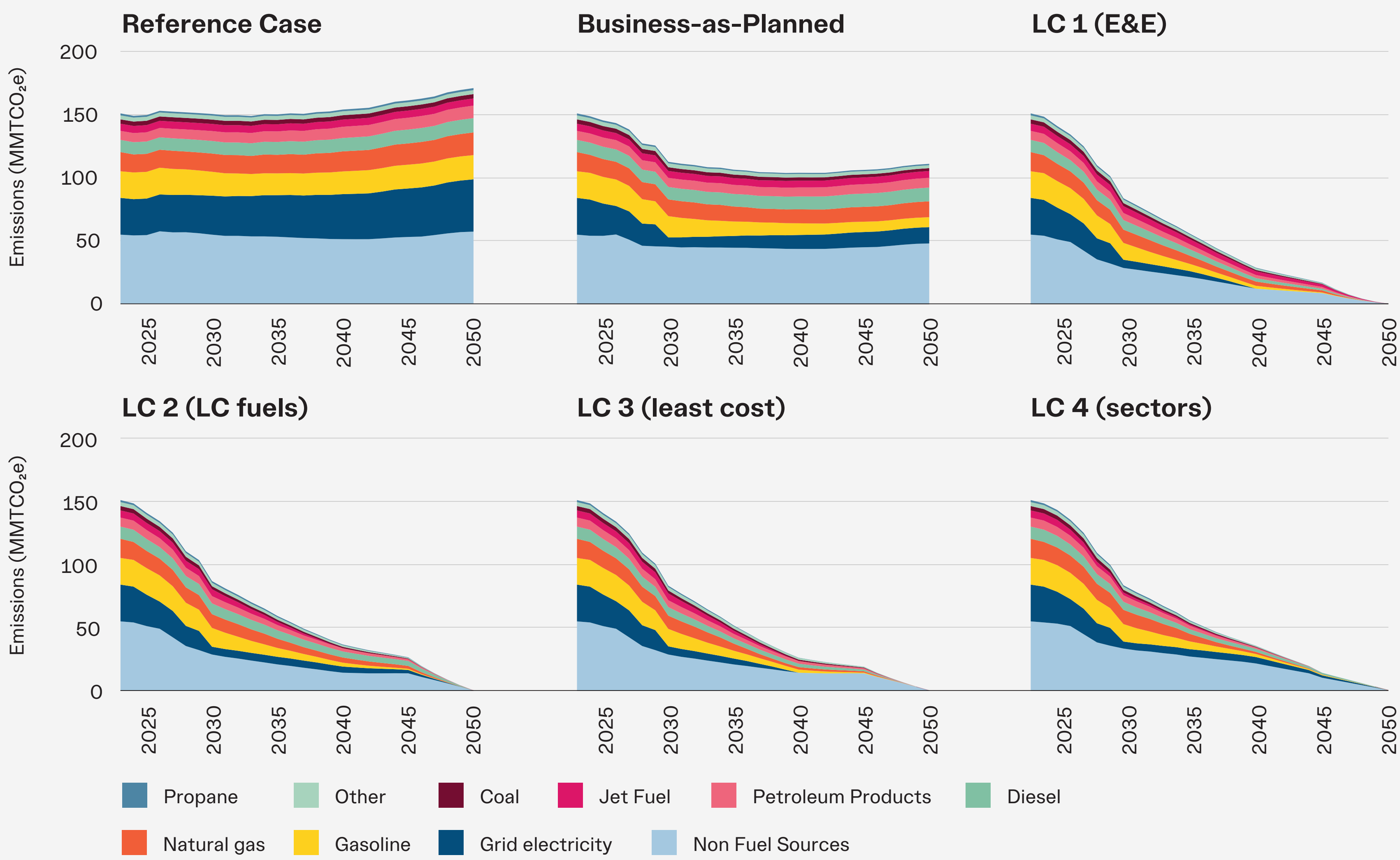


Figure 4.
Fuel emissions, which are broken down by type, are approximately two-thirds of the total emissions, and non-fuel emissions account for the remaining third (fugitive emissions, process emissions, agricultural emissions, and waste [landfill] emissions). Non-fuel emissions are persistent in the RC and BAP scenarios and remain the dominant source in the LC scenarios. Grid electricity emissions are reduced by 2030 in the BAP and LC scenarios, causing a steeper drop in emissions until 2030 in the LC scenarios, followed by a more gradual reduction until 2050.



The four low-carbon scenarios reduce cumulative GHG emissions by more than 40% relative to the BAP Scenario, saving more than 1.5 billion $MtCO_2e$ over the period (Figure 5).

Figure 6 illustrates how each sector's role varies across scenarios. Variation in reductions between the scenarios is a function of the shape of the curve for each sector, which is determined by which actions are implemented, when they are implemented, and the level of ambition with which they are implemented (Figure 6). Figure 7 illustrates variation in reductions between the scenarios for GHG emissions in the transportation sector, which can be as large as 88 million $MTCO_2e$ between LC 2 (LC fuels) and LC 4 (sectors) over the study period.

Figure 5.
Over the 2025–2050 time period, the cumulative GHG emissions are 1.5–1.6 billion tons less in the low-carbon scenarios compared with the Business-as-Planned Scenario. LC 3 (least cost) has the lowest cumulative emissions of any scenario.

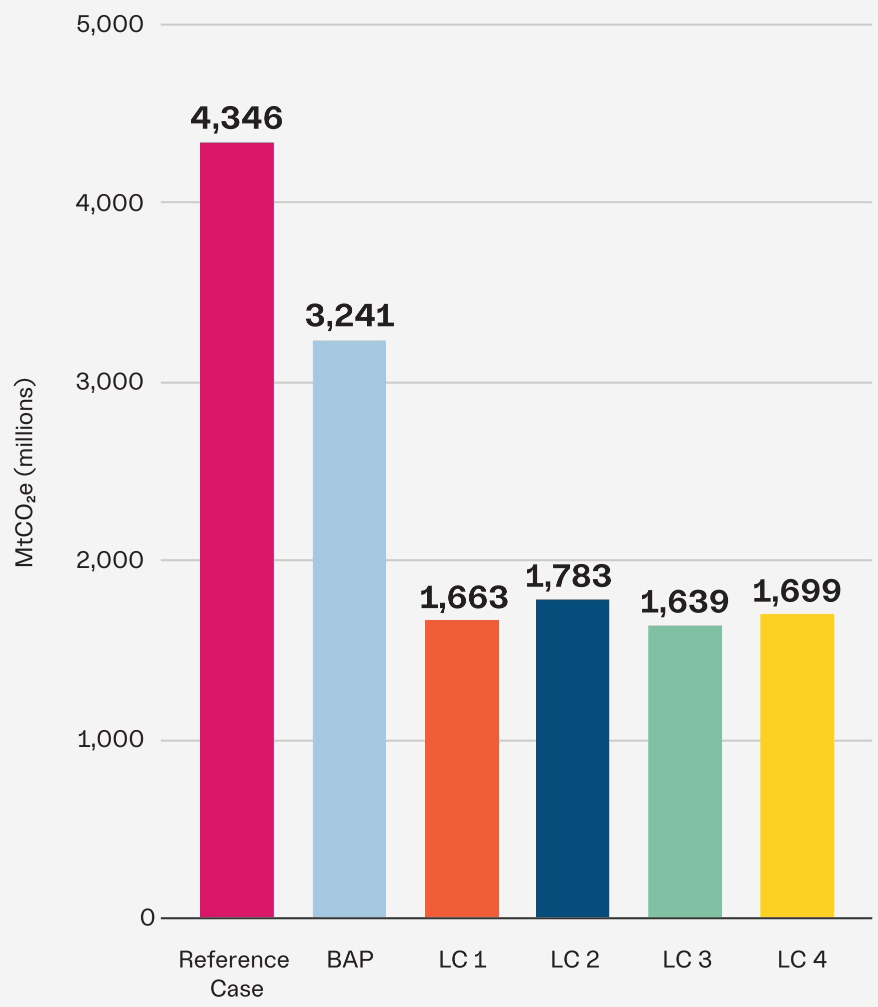


Figure 6.

The low-carbon scenarios prioritize different actions; as a result, cumulative GHG emissions reductions vary between sectors. For example, LC 3 (least cost) and LC 4 (sectors) achieve greater emissions reductions in the transportation sector than LC 2 (LC fuels). The emissions reductions shown are cumulative over the 2026–2050 period.

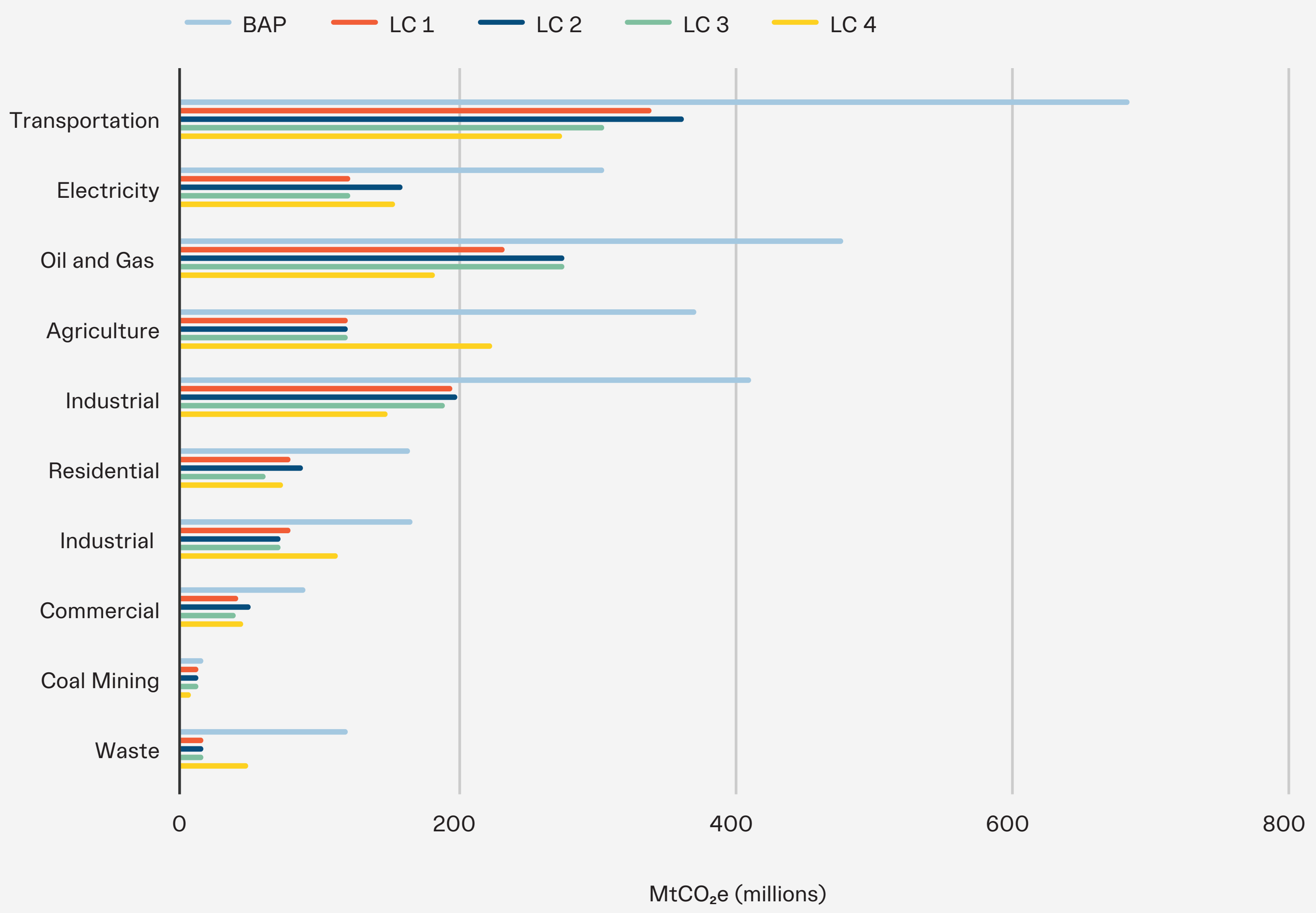
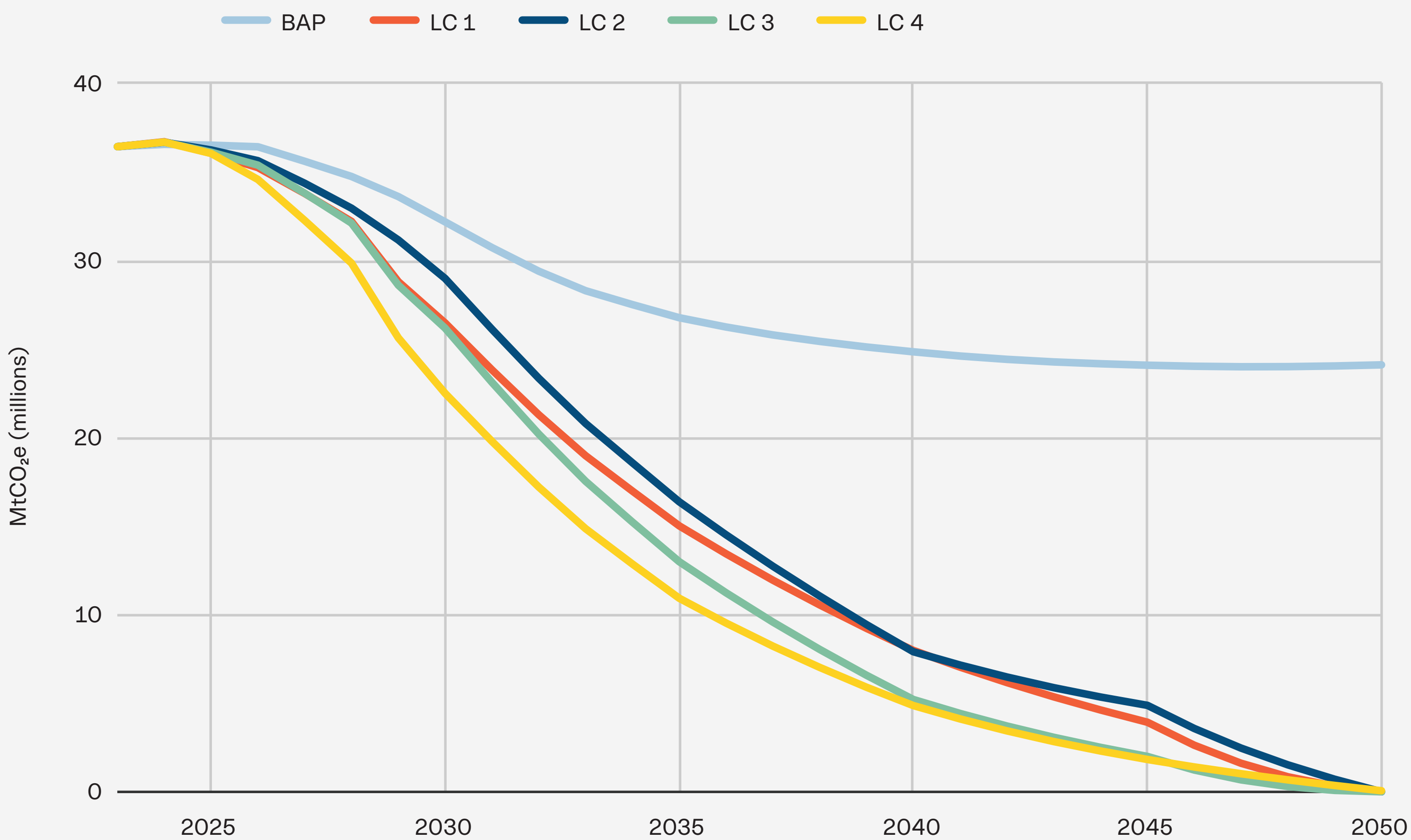


Figure 7.
All the low-carbon scenarios reduce more transportation emissions than the BAP Scenario.
LC 4 (sectors) and LC 3 (least cost) achieve the deepest reductions over the 2023–2050 period.



Energy

Observations

1. The LC energy system is a more efficient energy system. Total energy use (as measured in MMBTU) declines by nearly half (-38% to-46%) between 2023 and 2050 in the LC scenarios, even after accounting for population growth. Efficiency gains in LC 2 (LC fuels) are less than in the other LC scenarios (-38%).
2. The LC energy system is dominated by electricity. Electricity consumption nearly doubles in each scenario between 2023 and 2050 as electricity increasingly powers homes, businesses, and transportation.
3. Low-carbon actions unlock free sources of energy. Solar PV enables free solar energy harvesting. Heat pumps mobilize free energy from the ground and air, generating more than 100 million MMBTU by 2050.
4. Colorado has rich reserves of the energy sources on which the LC scenarios depend—solar, geothermal, wind. These reserves enable energy security and energy cost stability.
5. By 2050, LC 1 (E&E) reduces conversion losses by more than 50% relative to 2023, saving more than 200 million MMBTU per year. LC 1 (E&E) is the most efficient LC scenario, reducing electricity consumption and, in turn, electricity costs for customers.
6. Green hydrogen is used across all four LC scenarios, either only in the industrial sector (LC 1 [E&E]) or in the industrial and transportation sectors (LC 2 [LC fuels], LC 3 [least cost], and LC 4 [sectors]).

Wind Turbines on the Pawnee National Grasslands, Colorado. Photo by toroverde/stock.adobe.com

The LC scenarios have many common features. Overall, energy consumption declines significantly in the LC scenarios relative to 2023 and shifts primarily to electricity. As a result, electricity consumption doubles or nearly doubles by 2050 compared to today in each of the LC scenarios (for example, in 2050, electricity consumption is equal to 385 million MMBTU in LC 1 [E&E] versus 187 million MMBTU in 2023) (Figure 9). However, relative to the BAP Scenario, grid electricity consumption in LC scenarios decreases by 2050, including -8% LC 1 (E&E), -15% LC 2 (LC Fuel), -3% LC 3 (least cost) and -4% LC 4 (sectors).

Sources of the efficiency gains in the low-carbon scenarios include building retrofits, heat pumps, EVs, and mode shifting, which reduces VMT. For example, under the BAP Scenario, total VMT increases by 25% by 2050 as the population grows (Figure 11). LC 1 (E&E), which includes mode-share shifts, shows a 4% reduction in total VMT, while total VMT in LC 3 (least cost) and LC 4 (sectors) is flat between 2023 and 2050. Space and water heating is also more efficient under the low-carbon scenarios. Electricity is used to power heat pumps, which generate from 100 to 200 million MMBTU from ambient sources such as the air or water (Figure 8). For reference, 100 million MMBTU is roughly equivalent to the energy consumption of 500,000 people in Colorado in 2023, where each person consumes approximately 200 MMBTU per year.

Finally, across all the LC scenarios, fossil fuels are nearly phased out by 2050, except for small remnants in specific sectors.

The LC scenarios also illustrate several key differences.

LC 1 (E&E) is designed to prioritize investments in energy efficiency and electrification. LC 1 (E&E) includes substantial near-term investments in residential building retrofits to improve efficiency, along with significant investments in measures to electrify transportation and reduce vehicle miles traveled. LC 1 (E&E) is also the only scenario with district energy systems, which provide 6 million MMBTU in 2050. Relative to the other LC scenarios, LC 1 (E&E) is the most efficient scenario. LC 1 (E&E) reduces conversion losses by 100 million MBTU by 2050 relative to the other LC scenarios (Figure 10), approximately 14% of the total energy consumed. LC 1 (E&E) uses 22% less energy than LC 2 (LC fuels) and 12% less than LC 4 (sectors). In 2050, under the LC 1 (E&E) Scenario, Colorado saves 47% of the energy used in 2023, despite population growth.

In LC 1 (E&E), decentralized or behind-the-meter solar grows to between 30 and 40 million MMBTU by 2050. Note that across all four low-carbon scenarios, utility-scale solar is developed, but that is not explicitly differentiated from other zero-carbon types of electricity generation in the model.[5] Finally, LC 1 (E&E) is the only scenario that allows no new permits for oil and gas wells after 2030.

LC 2 (LC fuels) emphasizes investments in low-carbon fuels in addition to electrification and efficiency. For example, compared with LC 1 (E&E), LC 2 (LC fuels) has much lower levels of investment in residential building retrofits but comparable levels of investment in residential electric appliances. LC 2 (LC fuels) models lower investments in mode-shifting measures, such as passenger rail and e-bikes but does maintain investments in rural transit. As a result, electricity demand and VMT are notably higher under LC 2 (LC fuels) compared to the other low-carbon scenarios. In 2050, LC 2 (LC fuels) has the highest RNG consumption at 22 million MMBTU, which is used in residential and commercial buildings. LC 2 (LC fuels) also has the highest hydrogen consumption at 184 million MMBTU (used in the industrial and transportation sectors), whereas LC 1 (E&E) has the lowest hydrogen consumption at 94 million MMBTU, and it is used only in the industrial sector.

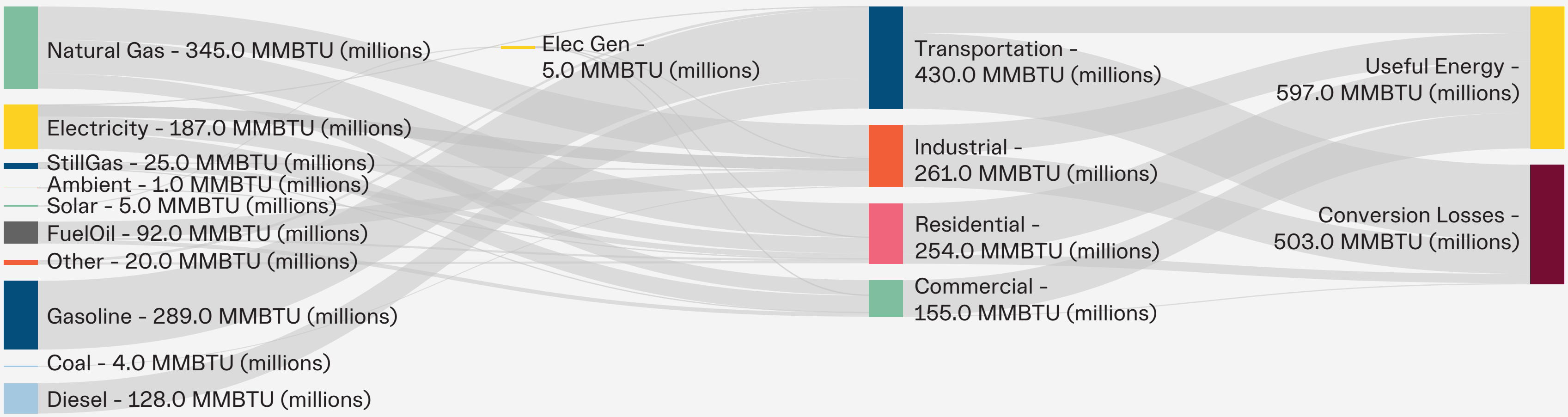
5 Additional analysis on electricity generation is included in Appendix 8.

LC 3 (least cost) prioritizes the lowest cost measures while ensuring the economy-wide GHG targets are met. LC 4 (sectors) sets sector-specific targets and deploys specific actions to ensure each sector meets its prescribed targets. In terms of energy use, LC 3 (least cost) and LC 4 (sectors) share many similarities with LC 1 (E&E), though neither scenario includes as much up-front investment in residential building retrofits.

To summarize, the energy systems pathways, illustrated by sector in Figure 12, show the energy transition over time. Electricity scales up from 2030 to 2040 and hydrogen growth is notable by 2040. Figure 13 is a snapshot of the energy system in 2050, illustrating the predominance of electricity across all sectors in the LC scenarios. These charts also show lower electricity consumption in LC 1 (E&E) and LC 3 (least cost) than in LC 2 (LC fuels) and LC 4 (sectors) due to efficiency gains. In LC 1 (E&E), the transportation sector is fully electrified, while hydrogen has a role in transportation in the other three scenarios. RNG is used in the residential and commercial buildings sectors in LC 1 (E&E), LC 2 (LC fuels), and LC 3 (least cost) but not in LC 4 (sectors).

Figure 8.
The Sankey diagrams are a snapshot of the energy system in 2023 and 2050 for the LC 3 (least cost) Scenario. In 2023, the primary sources of energy are natural gas (345 million MMBTU), gasoline (289 million MMBTU), and electricity (187 million MMBTU). Just over half of the energy consumption (597 million MMBTU) is used for its intended purpose, while 503 million MMBTU is expended as conversion losses. In comparison, by 2050 in the LC 3 (least cost) Scenario, electricity is the major source of energy (405 million MMBTU), followed by ambient energy used by heat pumps (205 million MMBTU), and hydrogen (135 million MMBTU). Of this, 480 million MMBTU is used for its intended purposes, while 324 million MMBTU is expended as losses, an improved ratio.

LC 3 (least cost) 2023



LC 3 (least cost) 2050

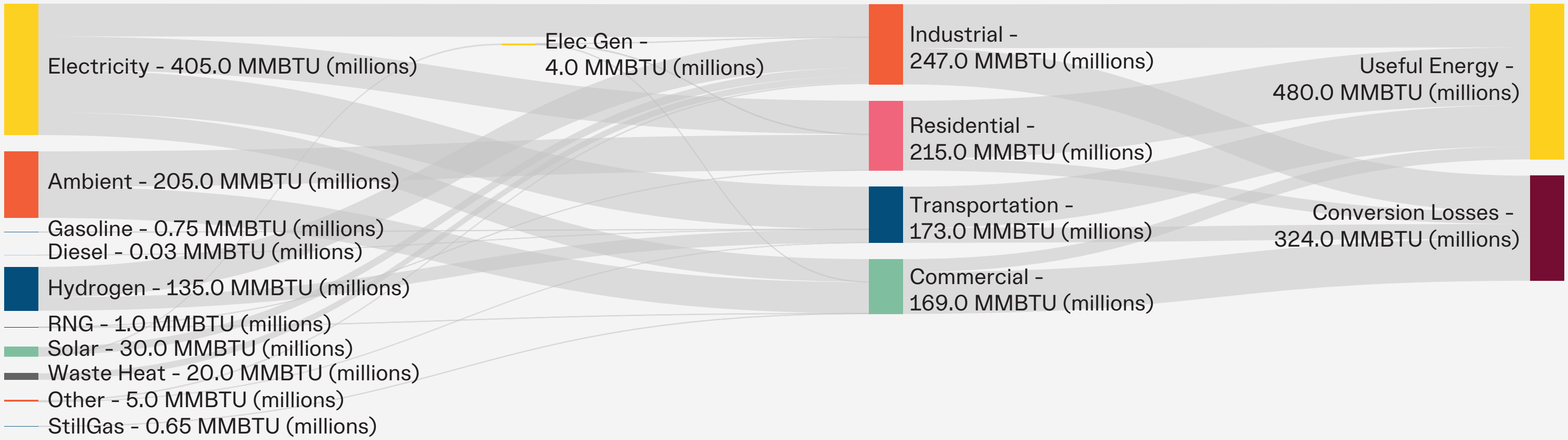


Figure 9.
Under the low-carbon scenarios, in 2050 end-use electricity consumption is between 2.7% and 14.9% higher than in the BAP Scenario.

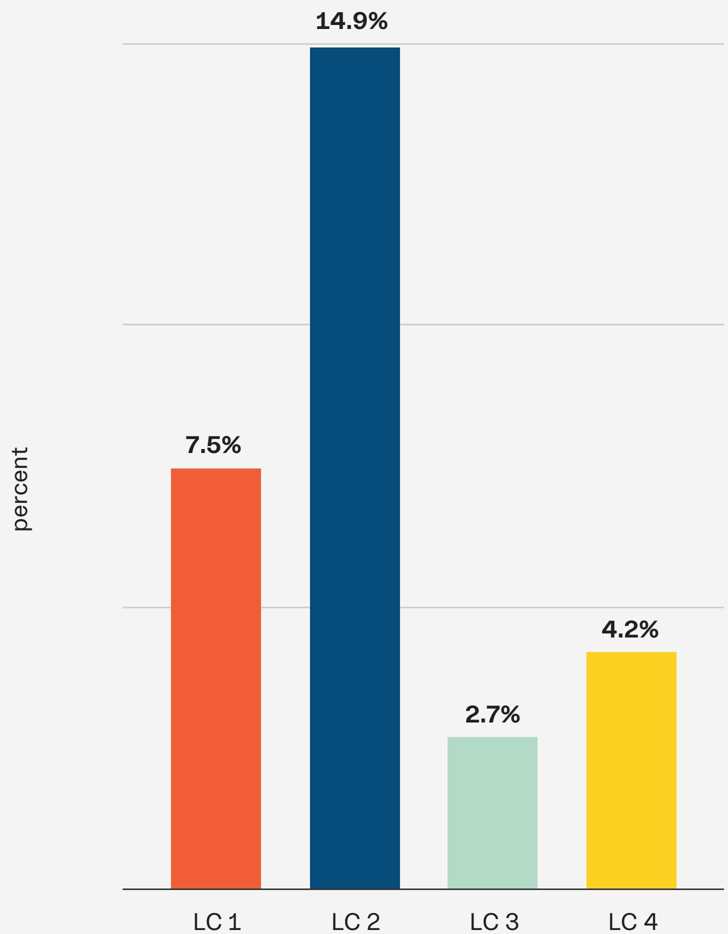


Figure 10.
Total energy consumption is much lower in the LC scenarios than in 2023 and the Reference Case and BAP scenarios. Additionally, in the LC scenarios, a higher share of the energy consumed is used for its intended purposes versus lost in conversion.

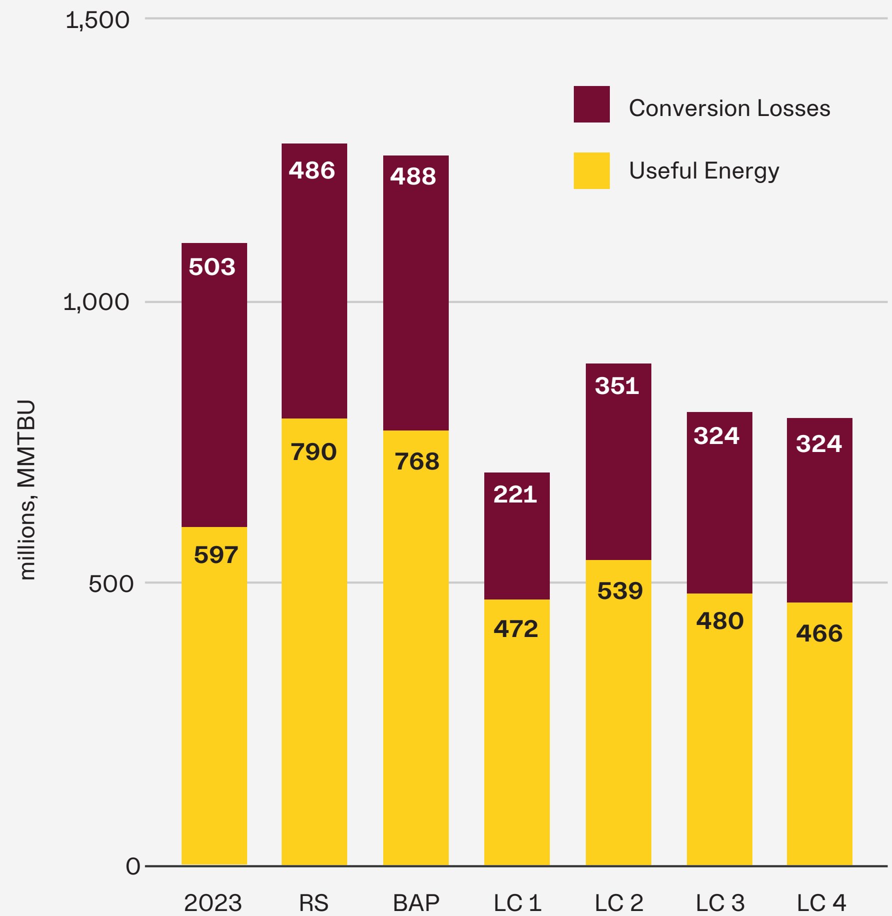


Figure 11.
Vehicle miles traveled in LC 2 (LC fuels) grows by 25% over 2023 levels as the population grows, with no constraining policies. VMT is flat in LC 3 (least cost) and LC 4 (sectors) despite population growth and declines in LC 1 (E&E), as LC 1 (E&E) places greater emphasis on policies that support mode shifting, including enhanced transit. Average annual change in VMT relative to 2023.

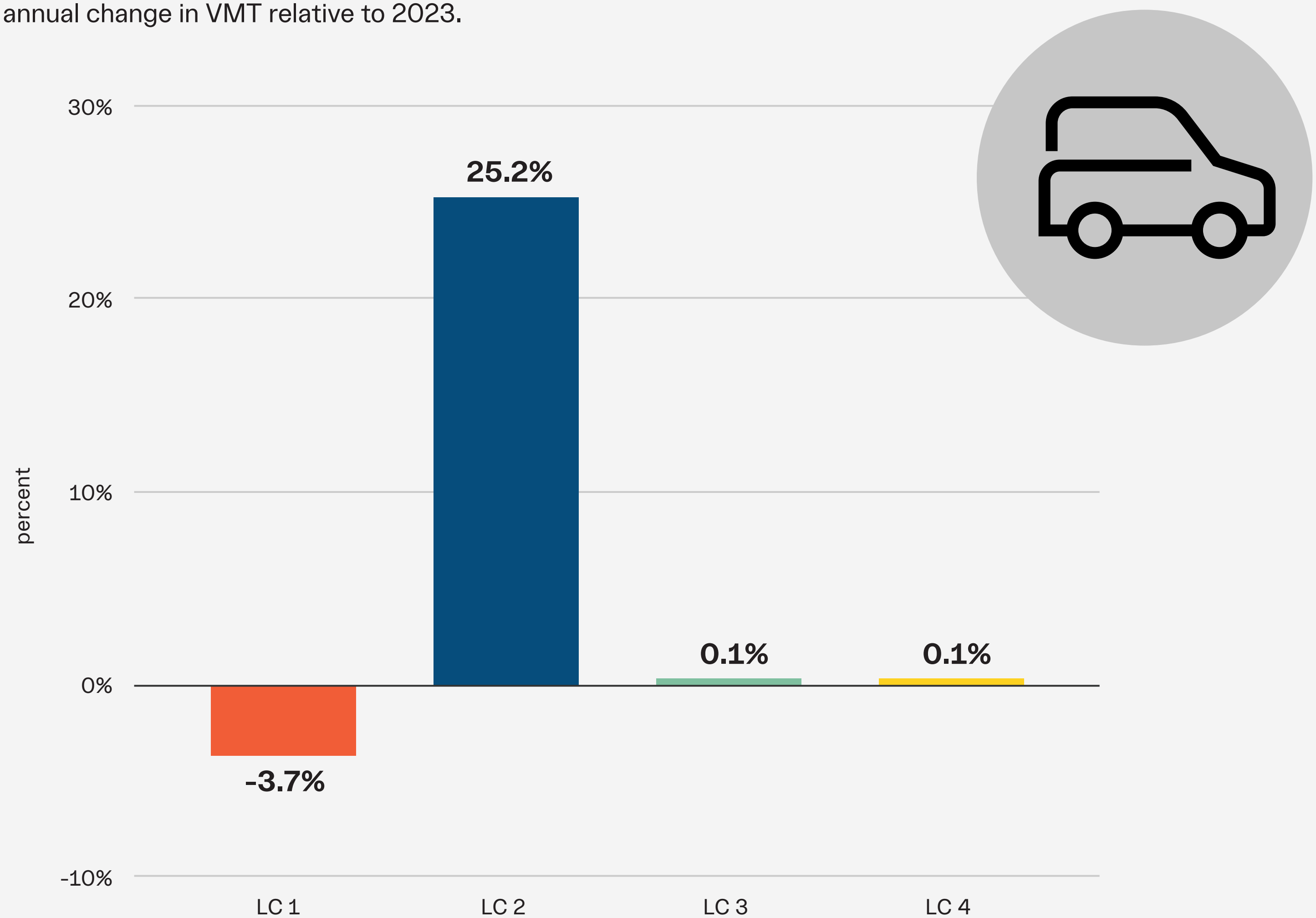


Figure 12.
The LC scenarios use less energy relative to the RC and BAP scenarios due to the efficiency of the technologies deployed, including heat pumps and electric vehicles. The curves and the mix of energy sources vary between the LC scenarios, with LC 1 (E&E) being the most energy efficient. The growth in electricity as the primary energy source (yellow) is evident in the LC scenarios, with greater or lesser amounts of green hydrogen (pink).

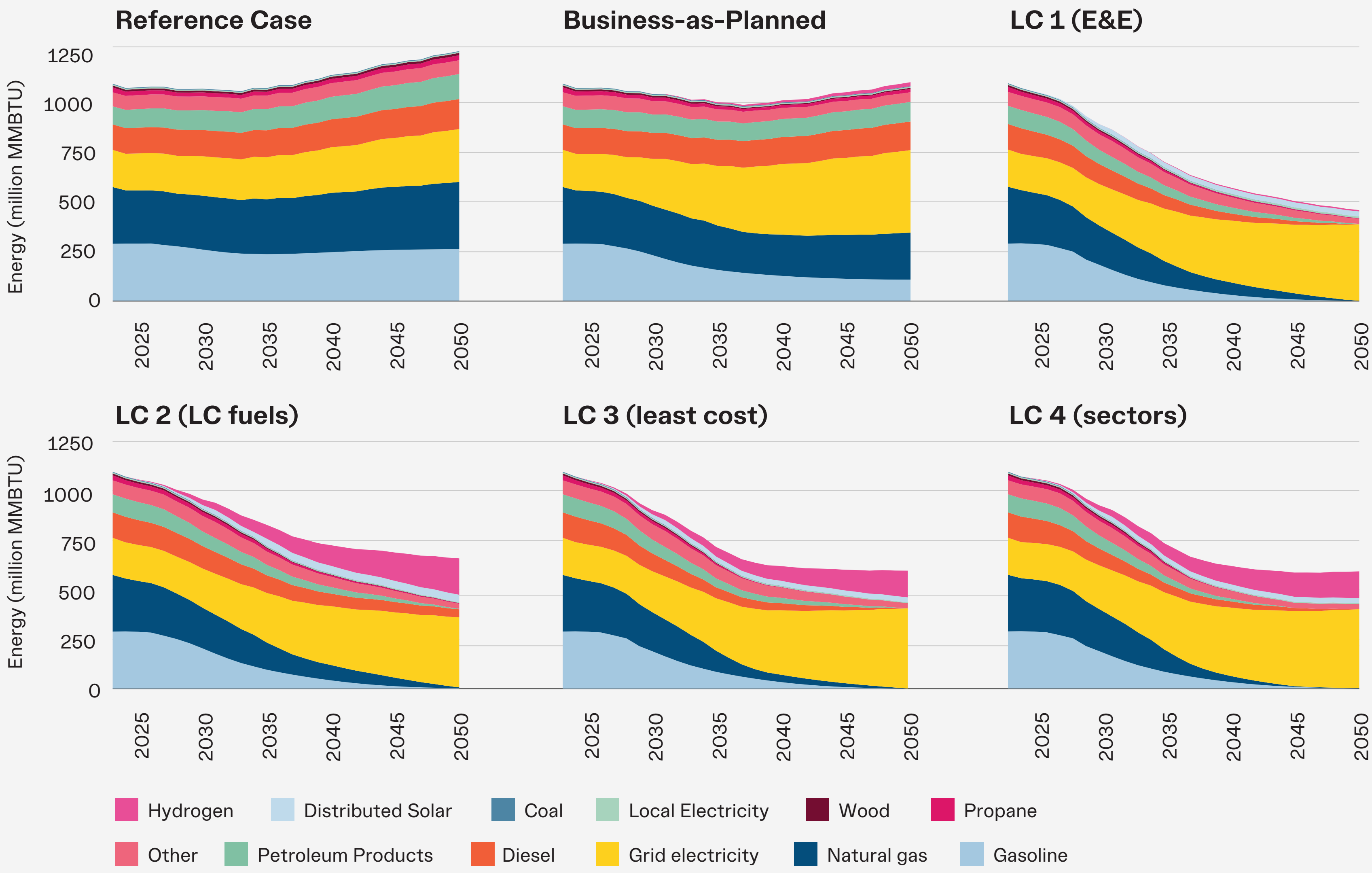
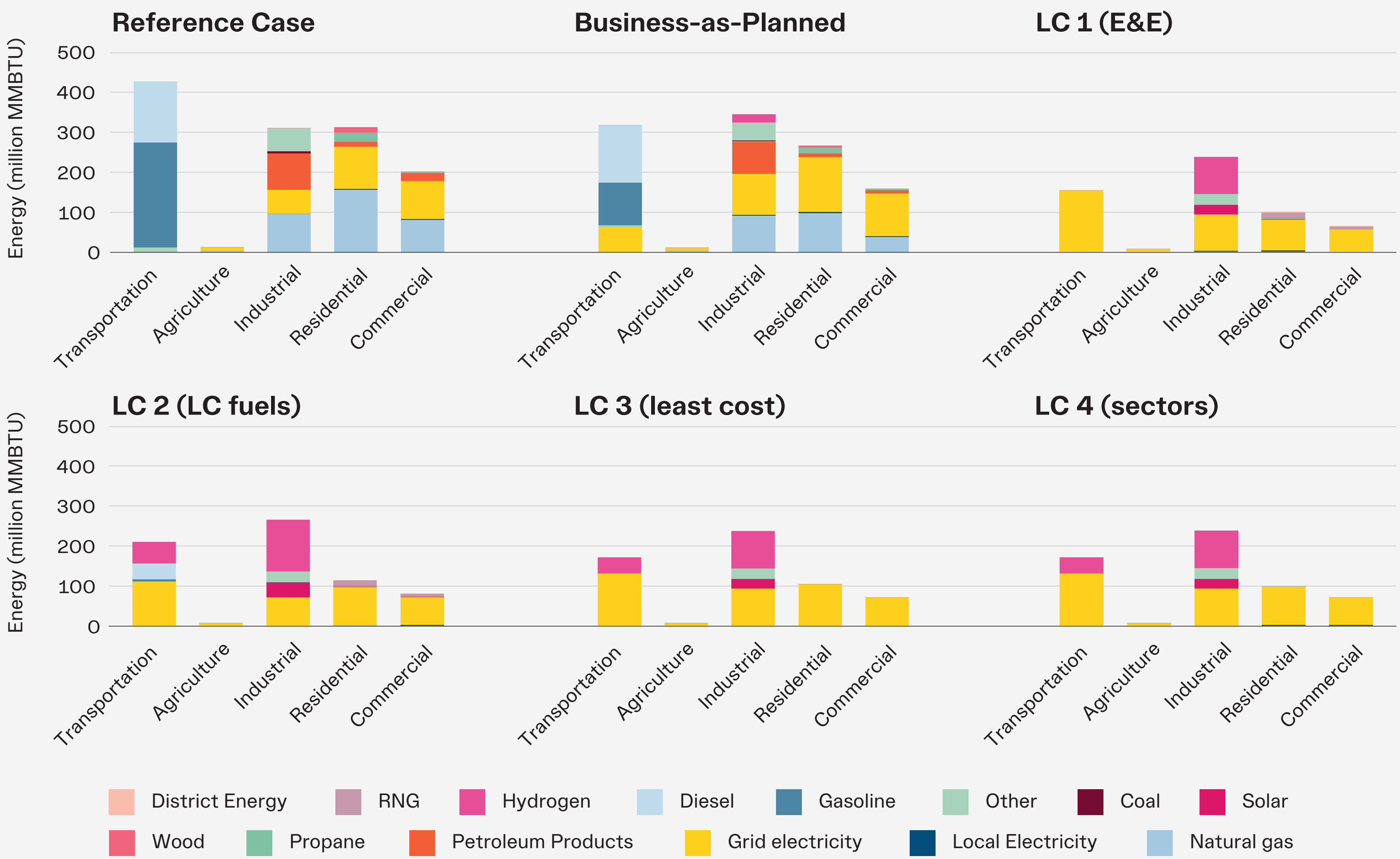


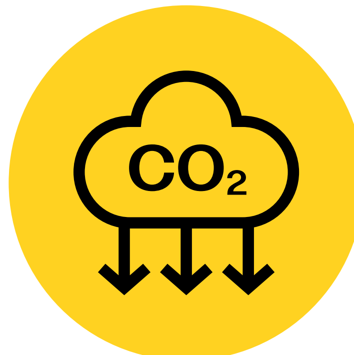
Figure 13.
In 2050, electricity is the primary energy source in each sector in the LC scenarios (yellow), which contrasts with the reliance on fossil fuels in the RC and BAP scenarios. Overall, energy consumption is noticeably lower in the LC scenarios compared to in the RC and BAP scenarios as a result of increased efficiency of technologies. Like all the LC scenarios, LC 2 (LC fuels) uses hydrogen in the industrial sector but also in transportation. Diesel consumption also remains in the transportation sector in LC 2 (LC fuels) but is displaced by electrification in the other LC scenarios. District energy is used in the residential and commercial sectors, as well as RNG, but these are thin slices in LC 1 (E&E) and LC 2 (LC fuels); district energy is constrained to areas with a high level of density, while RNG is constrained by supply.



GHG Reduction Actions

Observations

1. A core set of actions are critical to deep emissions reductions, irrespective of the LC Scenario.
2. Other actions are strategic, based on the co-benefits that result for different contexts.
3. If action to reduce GHG emissions is slower, Colorado will have to rely more on unproven or potentially costly technologies, such as carbon removal in the tail end of the study period, to meet the state’s target of net zero by 2050.
4. Carbon budgets can be identified for each sector for specific time steps (annual, biannual, etc.), based on the combination of actions in the scenario.



Wedge diagrams were generated for each of the scenarios. A wedge represents the size of the emissions reductions from a particular action. The wedges presentation is a simplifying picture and may not fully represent the impacts of certain actions, as there is feedback and dependencies between actions.

Under the BAP Scenario, the largest GHG reductions result from reducing emissions from electricity generation, followed by reduced oil and gas emissions. Figure 14 illustrates the impact of the actions in the BAP Scenario relative to Colorado’s GHG emissions reduction targets. Figure 15 shows emissions reductions from each of the actions modeled in LC 3 (least cost). The wedge at the top of the chart represents the actions in the BAP Scenario. A small number of actions generate most of the GHG reductions; for example, in LC 1 (E&E), 10 actions drive nearly 80% of the total emissions reductions from the scenario. These actions, which total 2.5 billion MTCO$_2$e in reductions between 2026 and 2050, include actions to eliminate emissions from electricity generation; improve industrial efficiency and enable fuel-switching; reduce, and ultimately eliminate, fugitive emissions from oil and gas operations; support mode shifting and electric vehicles in transportation; capture landfill gas; and reduce emissions from agriculture through various initiatives. The top 10 actions are similar in each LC scenario, although their respective contribution to emissions reductions, and therefore, order of priority, varies. Table 3 lists the key priority actions and the cumulative abatement modeled in LC 3 (least cost).

Figure 14.
GHG emissions reductions from the policies included in the BAP Scenario reduce GHG emissions but leave a significant gap to the State's targets. The reduction in electricity generation emissions resulting from HB21-1266 is the major source of savings in the BAP Scenario, with a smaller wedge from reduced oil and gas emissions.

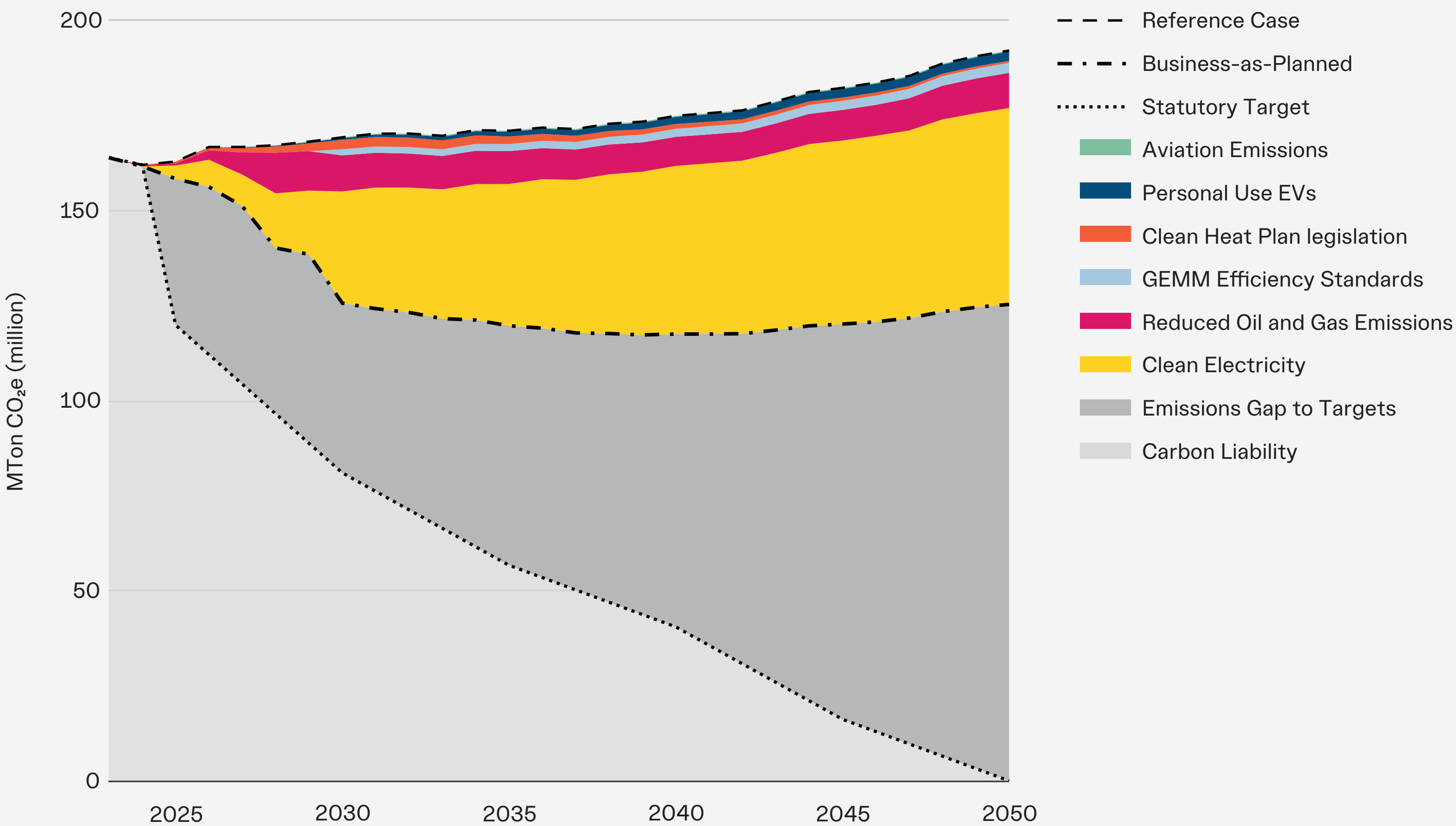


Figure 15.

Each wedge represents the impact of each of the actions modeled in LC 3 (least cost), where a larger wedge implies greater GHG emissions reductions. The wedge starting in 2045 is the additional reductions from carbon removal required to achieve the 2050 target.

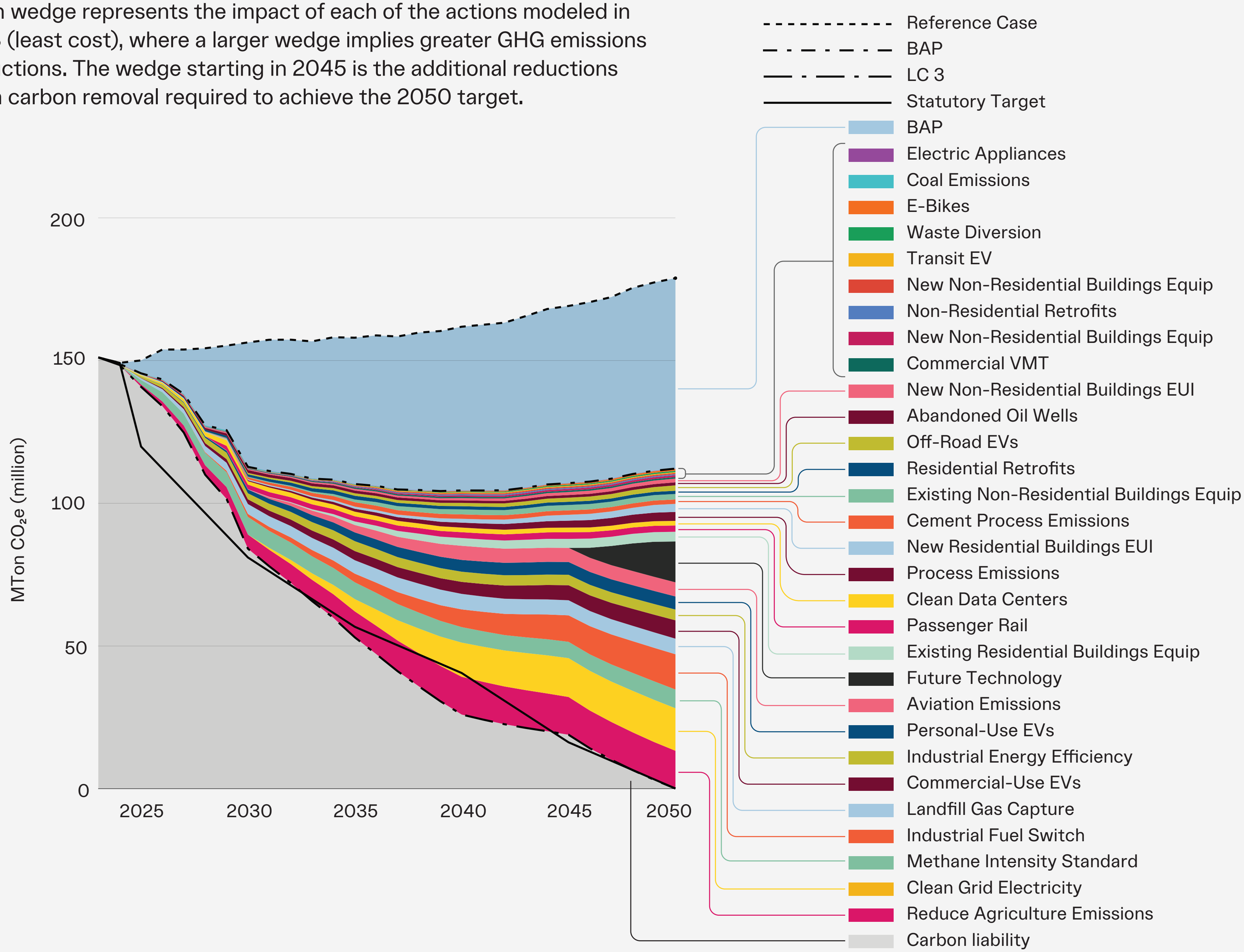


Table 3.
Key priority actions and the modeled $MMTCO_2e$ cumulative emissions reductions (2023–2050) for select measures under LC 3 (least cost).

Sector	Key Priority Actions	Cumulative Abatement (2023-2050) million $MTCO_2e$
Transportation	Electrify personal and commercial vehicles	169
	Reduce aviation emissions	78
	Promote alternative forms of transportation, including bus, train, and e-bikes	49
	Reduce vehicle miles traveled	10
Industry	Industrial fuel switch	133
	Industrial energy efficiency	79
	Process emissions	30
Agriculture	Emissions reductions from a combination of the following: ▪ No-till/reduced tillage ▪ Enhanced-efficiency fertilizers (EEFs)/4R nutrient management ▪ Manure digesters ▪ Enteric methane inhibitors (e.g., Bovaer, seaweed) ▪ Rotational improved grazing ▪ Agroforestry/tree planting (shelterbelts, riparian) ▪ Biochar soil amendment	245
Electricity	Decarbonize electricity generation	193
	Ensure new data centers are powered with clean energy	39
Residential and Commercial	Electrify end uses, including space and water heating	95
	Improve energy efficiency of existing buildings and establish rigorous efficiency standards for new buildings	83
Oil and Gas	Reduce methane leakage from oil and gas production	163
Waste	Divert waste and capture landfill gas	118

Figure 16 illustrates the wedges bundled by sector instead of by individual actions. The largest two reductions are in the electricity and transportation sectors, followed by the oil and gas sector. Note that the total reductions for agriculture include a combination of measures. Variation in the scenarios is evident by variation with respect to the dark black line, which represents Colorado's GHG targets.

Starting in 2045, carbon removal was applied to negate remaining emissions in each sector in order to achieve the net-zero target in 2050. For the purposes of this analysis, carbon removal serves as a proxy for different technologies or strategies that can remove carbon from the air and provide for long-term storage that keeps the captured carbon separate from the atmosphere. This may include technological strategies, such as direct air capture and storage, or nature-based strategies, such as those that enhance natural carbon sinks. Figure 17 illustrates the extent of carbon removal in each of the LC scenarios. LC 2 (LC fuels) requires more than three times the carbon removal than LC 1 (E&E), LC 3 (least cost), or LC 4 (sectors), indicating that there is a higher level of uncertainty in achieving the GHG targets with LC 2 (LC fuels) than with the other scenarios. LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors) each rely on carbon removal strategies to compensate for approximately 5-18 MMT of residual GHG emissions in 2050, while LC 2 (LC fuels) relies on nearly 20 MMT of carbon removal in 2050 in order to achieve net zero.

Dolores River Canyon in Montrose County, Colorado. Photo by John Fielder

Figure 4.
The trajectory of emissions reductions varies for each of the LC scenarios. In this illustration, emissions reductions for each sector are represented by solid colors and any remaining emissions are in faded colors. Colorado's targets are represented by the solid black line, and the BAP Scenario is represented by the dashed line. The line with dots and dashes represents the reductions from the LC Scenario, and it varies in its position relative to the solid line in each scenario. Consistent across each scenario are emissions reductions from electricity generation and transportation. Reductions in other sectors vary across the scenario both in timing and magnitude.

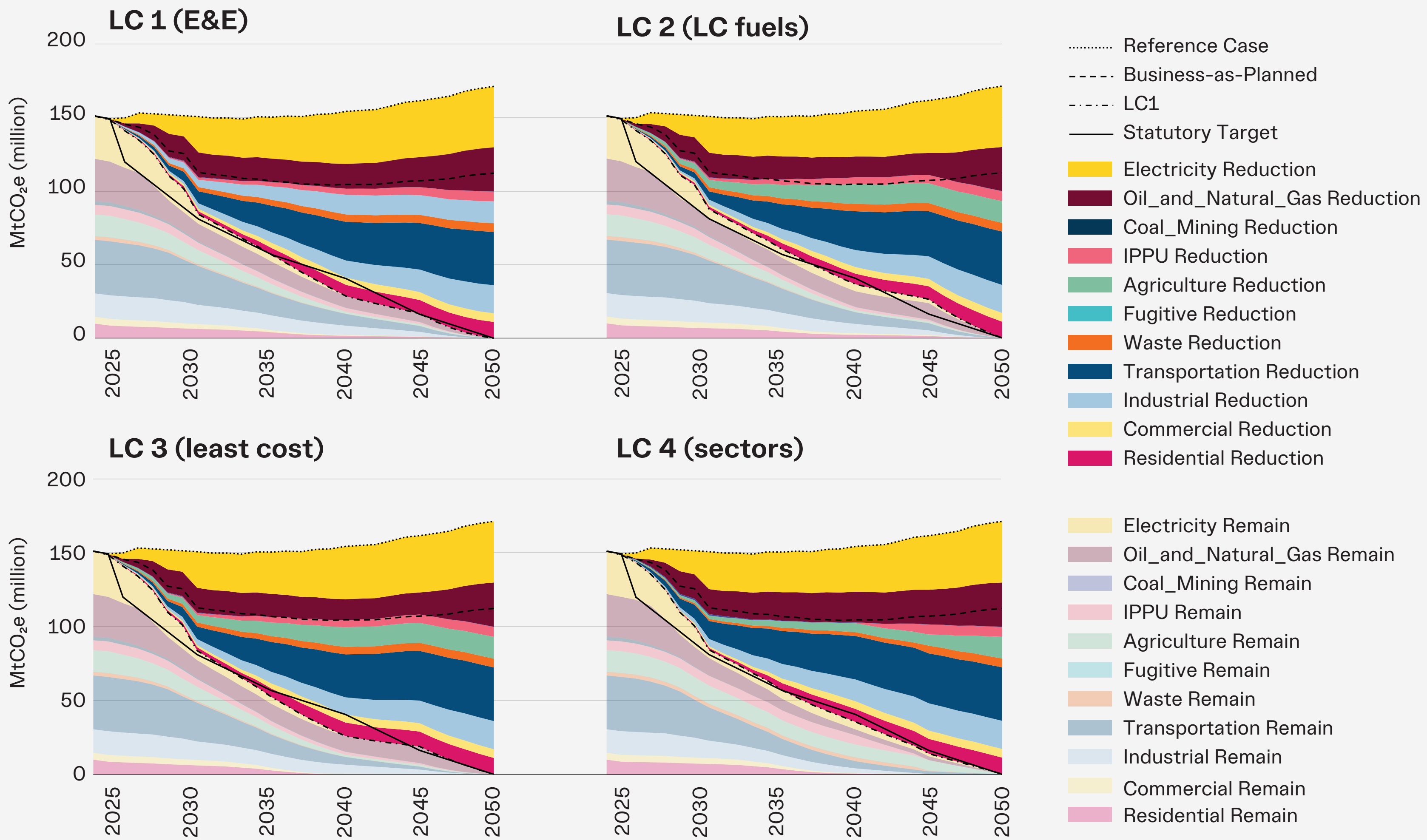
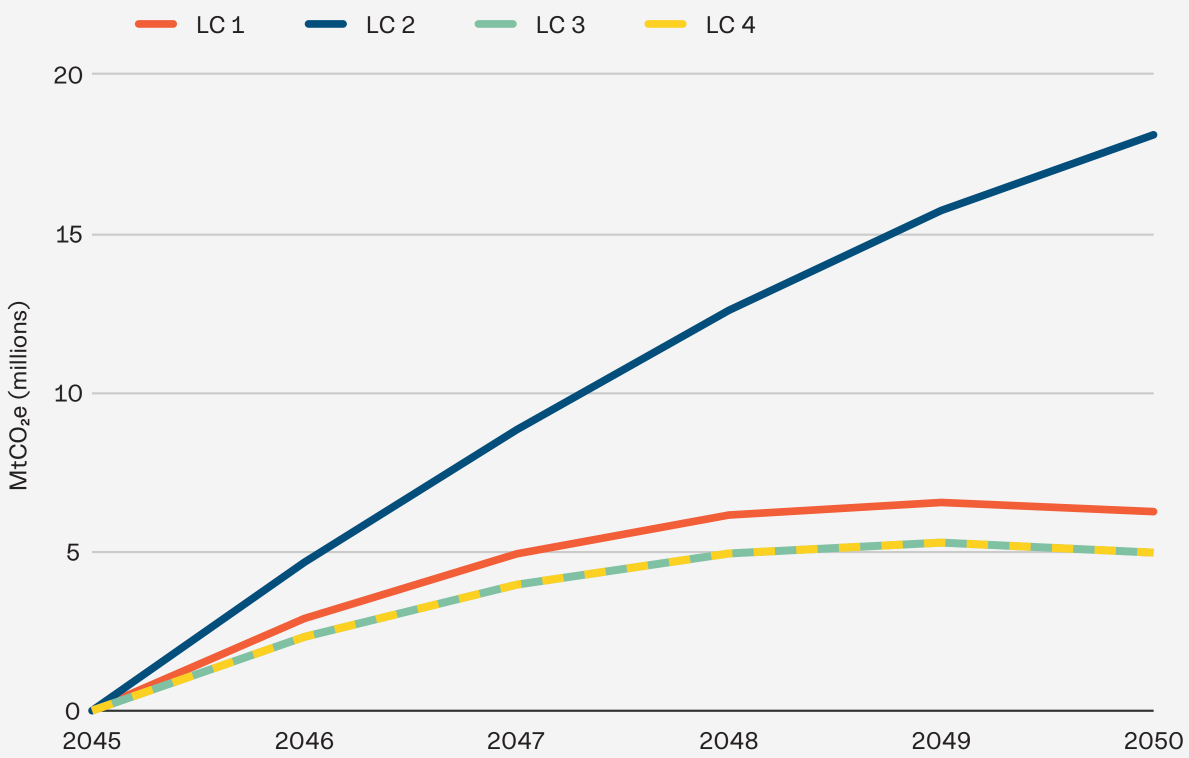


Figure 5.

Carbon removal is applied in each LC scenario to address the remaining emissions between 2045 and Colorado's net-zero 2050 target. LC 2 (LC fuels) has more remaining emissions and therefore requires more carbon removal, totaling 18 $MTCO_2e$ by 2050. The other three LC scenarios have similar trajectories; LC 3 (least cost) and LC 4 (sectors) nearly directly overlap, requiring removal of approximately 5 $MMTCO_2e$ by 2050.



Flat Tops Wilderness, Colorado.
Photo by John Fielder

Glenwood Springs, Colorado.
Photo by MaciejBledowski/stock.adobe.com

Economic Impacts

Observations

1. Households, businesses, and governments spend more than $20 billion on energy per year. Without accounting for price spikes, this total will increase as the population increases.
2. Compared to the BAP Scenario, the low-carbon scenarios save money for Colorado's people and businesses. For example, in 2030 in LC 1 (E&E), people and businesses in the state save $2.5 billion on energy costs relative to the BAP Scenario. By 2050, the savings climb to $8.8 billion.
3. Decarbonizing Colorado is a prosperity agenda, generating net economic benefits and new jobs and releasing capital that is locked up in unproductive energy expenditures.
4. All of the low-carbon scenarios result in net financial benefits for Colorado. The net present value (NPV) of LC 3 (least cost) when capital costs, energy, and operating costs are included is -$56 billion, the negative number indicating savings.
5. When climate change damages are included, the economic benefits are even more significant, with a net present value of -$752 billion (2026–2050) for LC 3 (least cost). As a reference, this exceeds Colorado's 2024 GDP.
6. LC 3 (least cost) has the best financial return, requiring half the capital investments of LC 1 (E&E) and resulting in twice the savings per $MTCO_2e$ of emissions reduced.
7. If the incremental capital cost is amortized, the actions will result in annual cost savings beginning in year one across the scenarios.
8. Reduced energy costs offer a disproportionate benefit for households experiencing energy poverty.
9. The low-carbon scenarios provide resilience against future price swings in energy costs.

In 2025, households, businesses, and governments in Colorado spent approximately $21 billion on energy across all energy types and sectors.[6] In the BAP Scenario, this climbs to $23.6 billion by 2050, while in the low-carbon scenarios, it declines to between $14.5 billion (LC 1 [E&E]) and $21.3 billion (LC 2 [LC fuels]) (Figure 18). Relative to the Reference Case Scenario, the BAP Scenario saves $25 billion in energy costs between 2025 and 2050, and the LC scenarios provide even greater savings. The scenario with the lowest energy costs, LC 1 (E&E), saves $166 billion relative to the Reference Case Scenario and $141 billion relative to the BAP Scenario. These energy cost savings can be used to finance the investments required to achieve the savings and to reduce energy costs in the state.

All four LC scenarios require capital investments. LC 1 (E&E) requires twice the average capital investment of the other scenarios, at just under $6 billion per year, whereas the other LC scenarios have average capital investments of approximately $3 billion per year (Figure 20). For comparison, Colorado's GDP was $553 billion in 2024; this level of investment is equivalent to between 0.5% and 1% of the 2024 GDP.

The increased investment in LC 1 (E&E) results in greater overall GHG savings than in LC 2 (LC fuels), but LC 3 (least cost) has the lowest abatement cost per ton of GHG emissions, as illustrated in Table 3 and Figure 21. Abatement costs are calculated by summing the costs and savings for each scenario, discounting the totals back to the present dollar using a discount rate of 3%, and dividing by the total GHG emissions reduction for that scenario. Table 4 illustrates the savings per ton of emissions reduced with and without the social cost of carbon.

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6 Energy costs by energy source are based on Gagnon, Pieter; Pedro Andres Sanchez Perez; Julian Florez; James Morris; Marck Llerena Velasquez; and Jordan Eisenman. Cambium 2024 Data. National Renewable Energy Laboratory. https://scenarioviewer.nrel.gov and U.S. Energy Information Administration - EIA - Independent Statistics and Analysis, Table 54. Electric Power Projections by Electricity Market Module Region, . Electricity unit costs are assumed to account for the required capacity additions and transmissions and distribution investments.

Table 4.
Cost (savings) associated with reducing GHG emissions under each low-carbon scenario. Negative costs represent savings. All figures are net present value calculated using a 3% discount rate.

Scenario	Net cost/savings per MTon of GHG ($/MTCO$_2$e) pollution reduced, relative to BAP (negative means savings)	
	Without Social Cost of Carbon	With Social Cost of Carbon
LC 1 (high efficiency, high electrification)	-$17	-$439
LC 2 (high low-carbon fuels)	-$14	-$423
LC 3 (least-cost strategies prioritized)	-$35	-$471
LC 4 (achieve sector-specific goals)	-$19	-$464

Figure 22 illustrates the present values of energy, maintenance, and operating and capital costs relative to the BAP Scenario, as well as the net present value of the scenario (dark blue). Negative values represent savings, while positive values indicate costs in the convention used in this analysis. A social discounting rate of 3% is used. Over the lifetime of the investment and physical stocks in the model, all LC scenarios result in net savings for Colorado: -$56 billion net cost savings in LC 3 (least cost) to -$27 billion net cost savings in LC 1 (E&E) and -$20 billion net cost savings in LC 2 (LC fuels). While LC 1 (E&E) has double the investment costs of the other scenarios, it also generates twice as much in gross annual cost savings. Where findings are represented in present dollars, a social discount rate of 3% was used, which is appropriate for an energy system analysis of this type.

Figure 23 illustrates the annual capital, energy, and maintenance costs and savings for each scenario, and the black line represents the annual net cost or savings. The point where the black line goes below the x-axis (negative) is a pivot point at which savings exceed costs on an annual basis. As most low-carbon scenarios are capital intensive early on, with increased savings later on, the earlier the pivot point, the greater return on the investment. In order of scenario, the pivot points when the scenario begins to provide annual net cost savings are 2038, 2041, 2034–2036, and 2039.

Figure 24 illustrates the impact of including cost savings from avoided climate damages, quantified using the social cost of carbon, into the economic analysis. When the analysis quantifies the economic benefits associated with avoided climate change impacts[7], pivot points move forward to 2030 for LC 1 (E&E) and 2026 for each of the following scenarios. The net present value of each scenario is -$690, -$611, -$752, and -$714 billion for LC 1 (E&E), LC 2 (LC fuels), LC 3 (least cost), and LC 4 (sectors), respectively—all representing substantial net cost savings. A net present value of -$690 billion translates into a benefit of -$115,000 per person in Colorado, assuming a population of 6 million people. The social cost of carbon represents global damages from climate change, so the benefits would not solely accrue to the people of Colorado, but the people of Colorado will also benefit from a more stable climate globally.

The low-carbon scenarios all require an incremental capital investment, but the analysis does not specify **which actor** provides the capital or the mechanism to drive that capital investment. Results are presented on a cash basis and amortized. When investments are amortized, the investments can be spread out over time to align with energy cost savings. For example, the incremental cost of performance improvements in a new home can be spread out over time so that the cost is equal to or less than the energy savings, including interest. A green bank is an example of a mechanism that can be used to amortize investments in many of the measures.[8] When amortized, each low-carbon scenario, except LC 4 (sectors), has net economic benefits from year one. Figure 25 illustrates the annualized capital costs, energy costs, and operation and maintenance costs for each scenario.

Figure 26 breaks down the capital investments in LC 3 (least cost) by action, where the capital cost or saving is incremental to the BAP Scenario. The burgundy bars are commercial EVs, which have an incremental capital cost relative to the diesel equivalent. The magenta bars represent an investment in passenger rail. The dark blue bars are residential retrofits, while the negative orange bars result from avoided vehicle purchases due to the introduction of e-bikes, recognizing that e-bikes reduce vehicle ownership not on a one-for-one basis.

Figure 27 provides a similar level of detail for energy costs, again calculating the incremental costs or savings relative to the BAP Scenario. Cost increases result from the introduction of more expensive energy sources, such as hydrogen or sustainable aviation fuels, or from fuel switching from natural gas to electricity, where the former is lower cost on a per unit of energy basis. Energy savings result from efficiency gains with new technologies such as heat pumps and from the use of EVs, which are more efficient than their gasoline or diesel counterparts.

Household energy expenditures decline in all four LC scenarios: by 22% in LC 1 (E&E) and LC 4 (sectors), by 10% in LC 2 (LC fuels), and by 19% in LC 3 (least cost) by 2050 (Figure 28). This decline in energy expenditures reduces the number of households in energy poverty by more than a quarter, except in LC 2 (LC fuels) (Figure 29).

7 U.S. Environmental Protection Agency. (2023). Report on the social cost of greenhouse gases: Estimates incorporating recent scientific advances. https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf

8 This analysis did not evaluate specific policy mechanisms for raising revenue consistent with requirements under Colorado's Taxpayer Bill of Rights.

The decline in energy costs is illustrated spatially in Figure 30, with overall decreases in every geographic zone. The impact of higher and lower fuel prices on household energy costs was also evaluated (Figure 31). Under the LC scenarios, household energy costs remain comparatively stable, insulating customers from the potential impacts of future energy cost increases.

The investments in the LC scenarios result in new job opportunities, which are quantified in Table 5 and Figure 32. LC 1 (E&E) results in an average of 24,600 jobs created per year, more than in LC 2 (LC fuels) (10,500), LC 3 (least cost) (16,100), and LC 4 (sectors) (17,100). The job projections are calculated based on the incremental increase in capital expenditures in each of the sectors.

Table 5.
Top sources of new employment opportunities in LC 1 (E&E).

Action	Cumulative Person-Years of Employment (2025–2050)
Residential Retrofits	155,958
Passenger Rail	127,800
Existing Residential Buildings Equip	90,395
Increase Active Modes	76,635
Industrial Energy Efficiency	60,511
Existing Non-Residential Buildings Equip	41,637
Non-Residential Retrofits	23,724

Figure 18.
Total energy expenditures in 2025 totaled $20.5 billion. In the Reference Case and BAP scenarios, these totals climb to $25 billion and $23.6 billion, respectively, by 2050. LC 1 (E&E) and LC 4 (sectors) have the lowest expenditures at $14.5 billion and $15.6 billion, respectively.

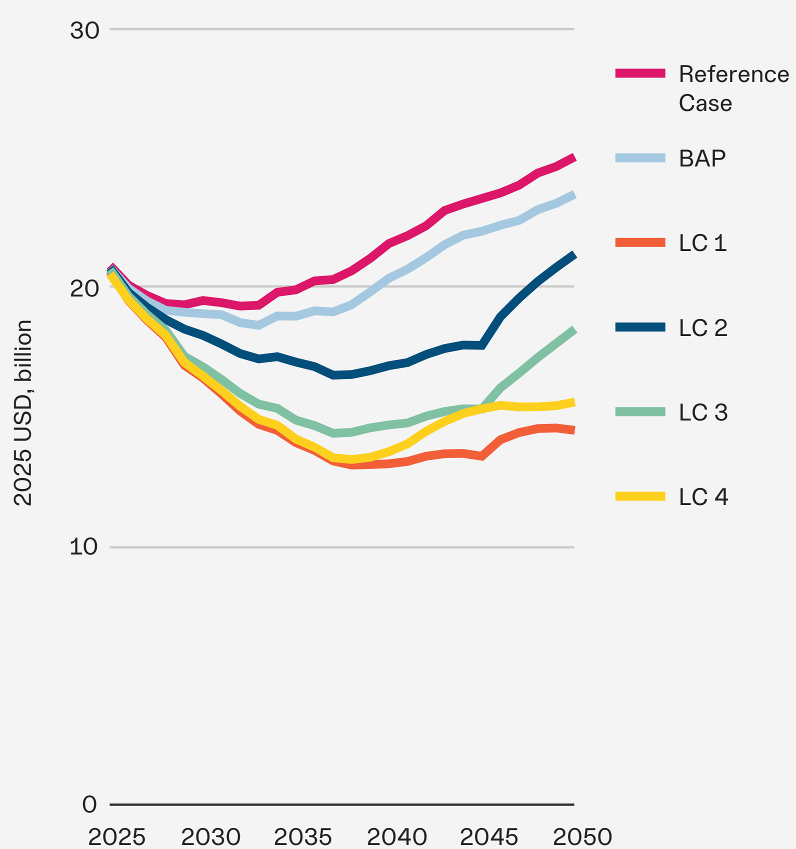


Figure 19.
Both the BAP and LC scenarios save billions in avoided energy costs relative to the Reference Case Scenario between 2026 and 2050. LC 1 (E&E) has the highest savings of $166 billion over the Reference Case Scenario, while LC 2 (LC fuels) has the lowest savings of $82 billion. These avoided energy costs can be a source of funding for the investments required to generate these savings.

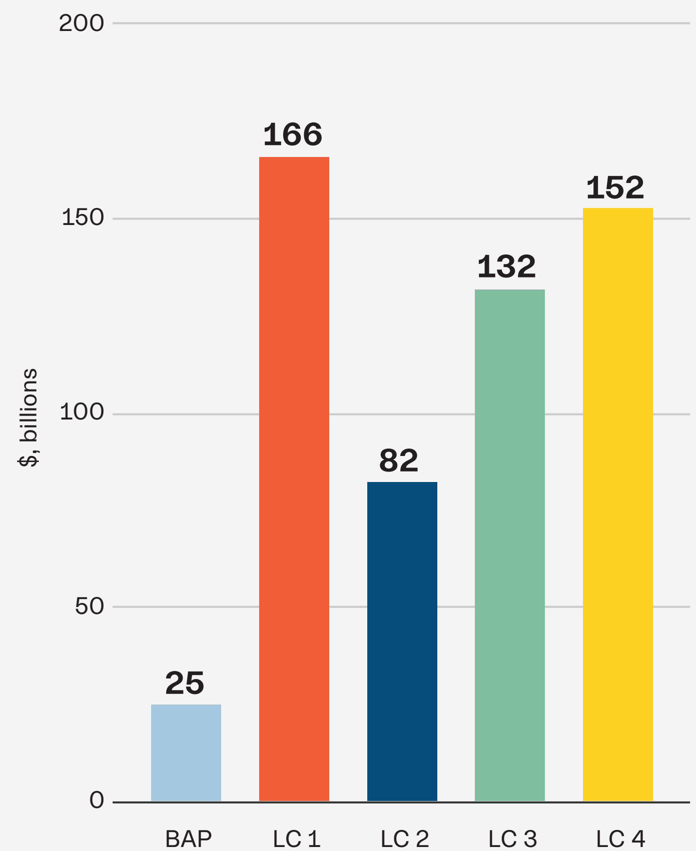


Figure 20.
LC 1 (E&E) has the highest average capital investment between 2025 and 2050 (nearly $6 billion), while LC 3 (least cost) has the lowest ($3 billion per year). These investments include the incremental capital costs relative to the BAP Scenario, including the additional cost of heat pumps relative to furnaces or EVs relative to gasoline vehicles, for each sector of the energy system.

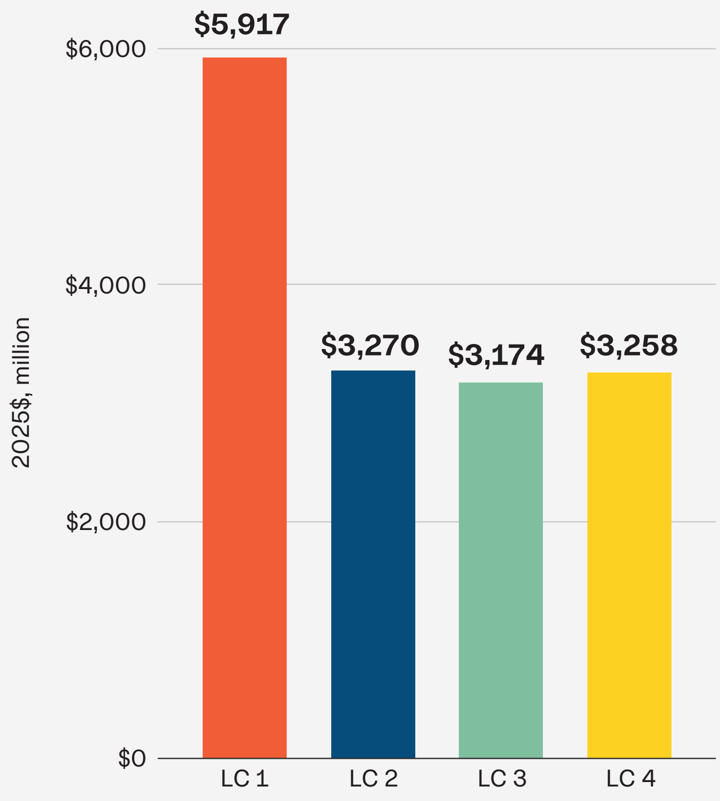


Figure 21.
The total capital costs and total savings are summed up, discounted back to $2025 with a 3% discounting rate, and then divided by the total GHG emissions reductions for the period from 2025 to 2050. The result is the net present value of each tCO_2e of emissions reductions for each LC scenario. As the number is negative, Colorado saves money for each tCO_2e of savings achieved across all LC scenarios. LC 3 (least cost) saves the most (-$35/$tCO_2e$), while LC 2 (LC fuels) saves the least (-$14/$tCO_2e$).

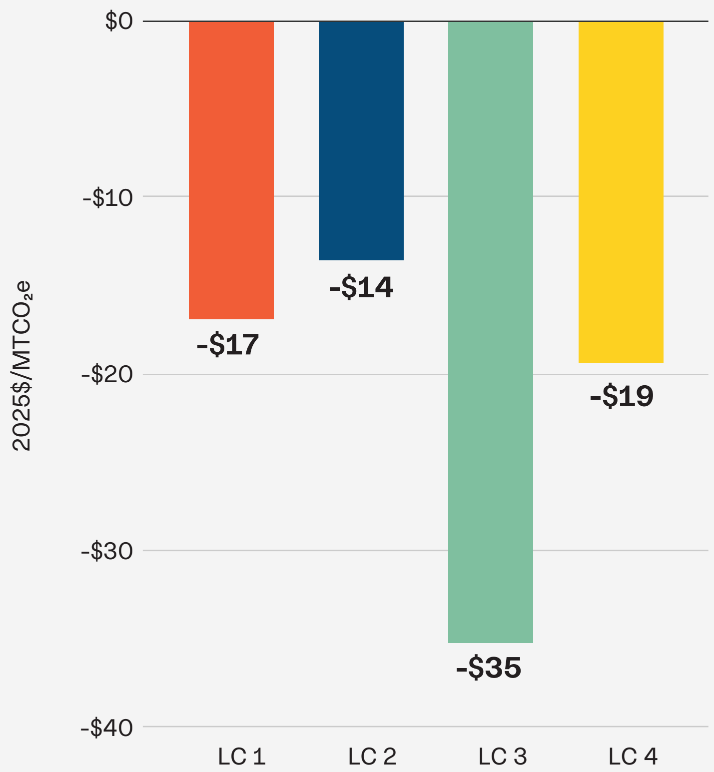
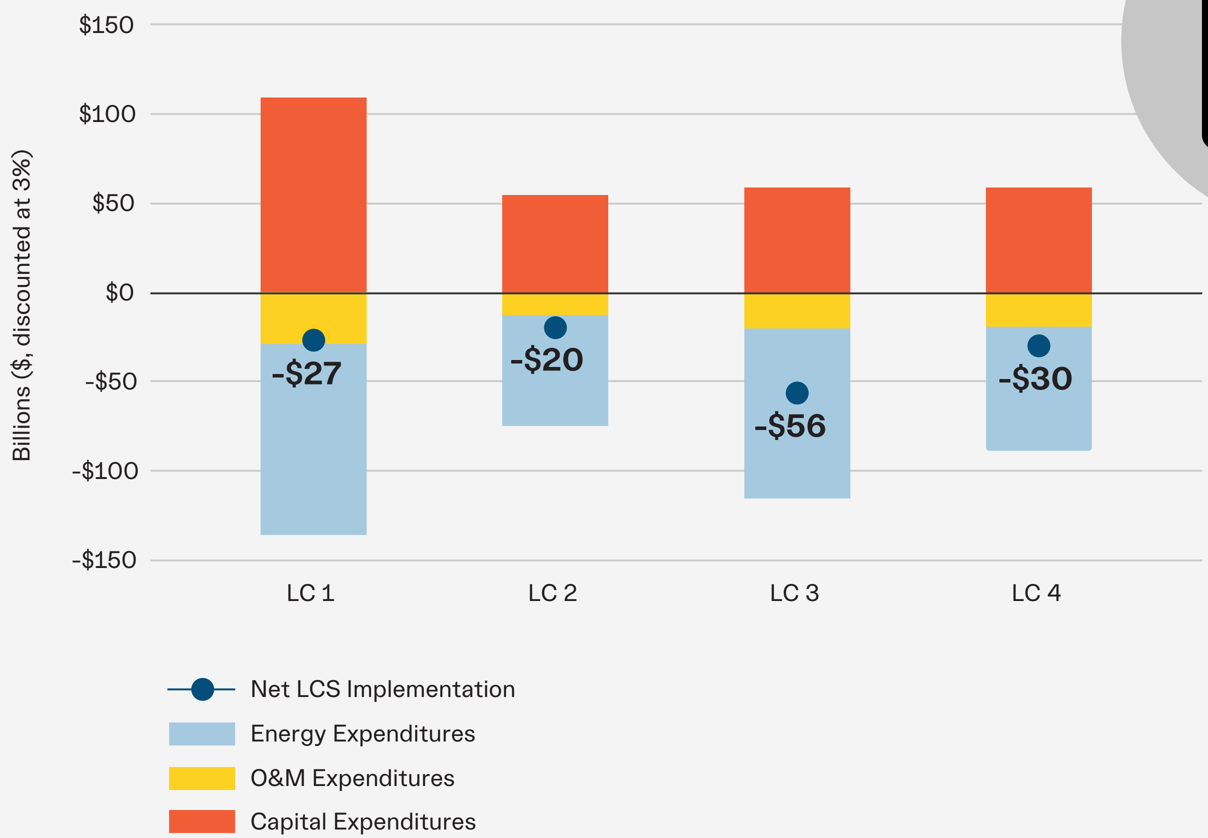


Figure 22.
The energy, maintenance, and capital expenditures were summed up between 2025 and 2050 and discounted back to $2025 using a 3% discounting rate. All LC scenarios result in net savings. LC 1 (E&E) has the highest investments (~$100 billion) but also the highest maintenance and energy savings (~$125 billion). LC 3 (least cost) has the highest net savings of the four scenarios (-$56 billion).



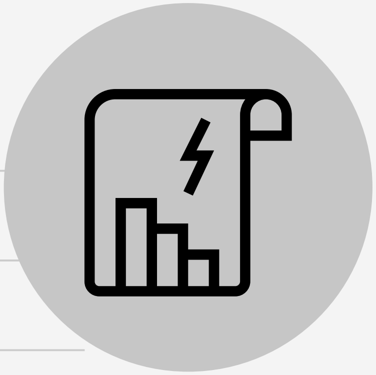


Figure 23.
The annual distribution of incremental capital costs, operating savings, and energy savings relative to the BAP Scenario shows a pattern of up-front capital costs followed by increasing energy cost savings at the end of the time period. Therefore, discounting weighs the capital costs more than the energy cost savings because of where they fall on the timescale. The black line indicates the annual net cost (sum of capital costs, energy costs, and maintenance costs). Where the black line is negative, savings exceed costs on an annual basis, the "pivot point." LC 3 (least cost) has the earliest pivot point in 2034, while the other LC scenarios' pivot points occur in the late 2030s or early 2040. The positive energy costs in LC 4 (sectors) are due to having to achieve the sector-based targets, accelerating investments or costs in sectors such as off-road vehicles and aviation.

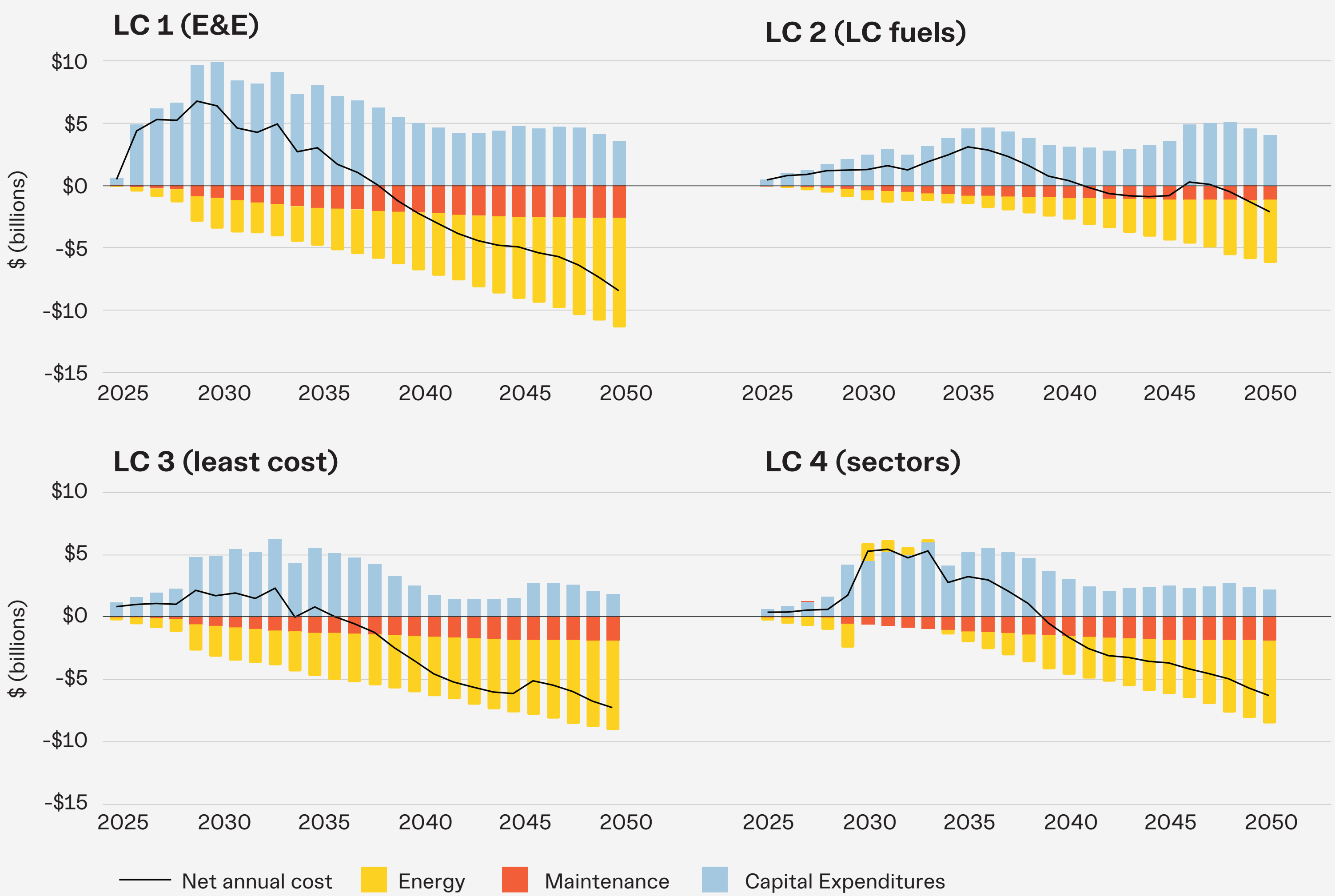


Figure 24.
When the cost of climate change is added to economic analysis (as represented by the social cost of carbon), all LC scenarios except LC 1 (E&E) are negative in year one. Savings from avoided climate change damages are multiples of either the incremental costs or savings in each of the LC scenarios.

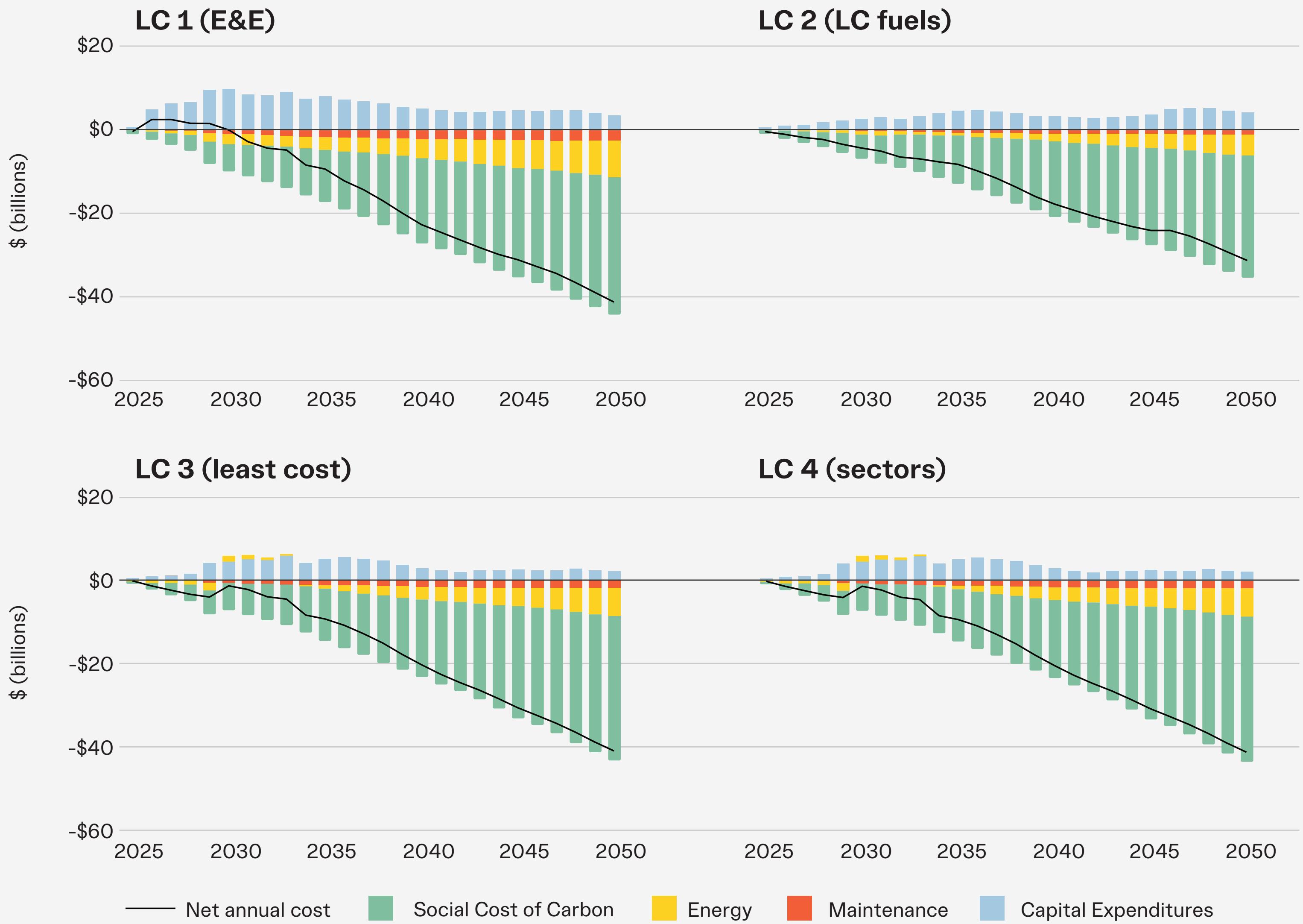


Figure 25.
Most of the investments in the LC scenarios would not be paid for on a cash basis but would be financed. For example, most electric cars or solar systems are financed. In terms of the financial analysis, this has the effect of spreading out the capital cost over time, as well as adding an interest cost. If the investments are financed, the financing costs can be balanced with the savings. The impact of amortizing the capital investments is that there are annual savings for all of the LC scenarios except LC 4 (sectors). Note that the payments and energy savings extend beyond the 2050 study period.

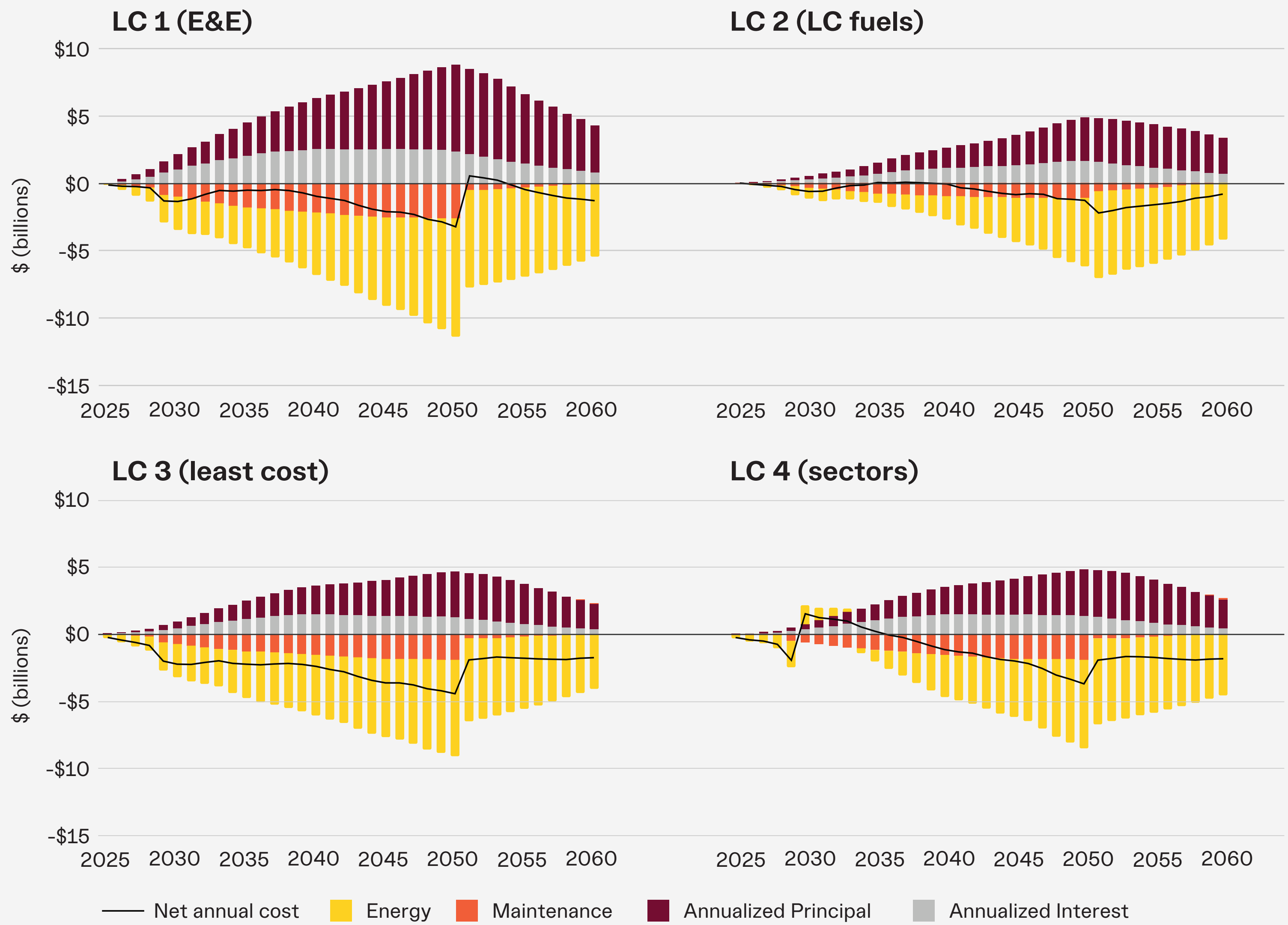


Figure 26.

Capital investments are tracked for sector and sub-sectors as incremental to the BAP Scenario, as is illustrated for LC 3 (least cost). In a few cases, the LC scenarios result in lower levels of investment than in the BAP Scenario. For example, investments in e-bikes in LC 3 (least cost) results in reduced vehicle ownership but not on a one-for-one basis. The timing of the investments is the result of the implementation schedule of the policy.

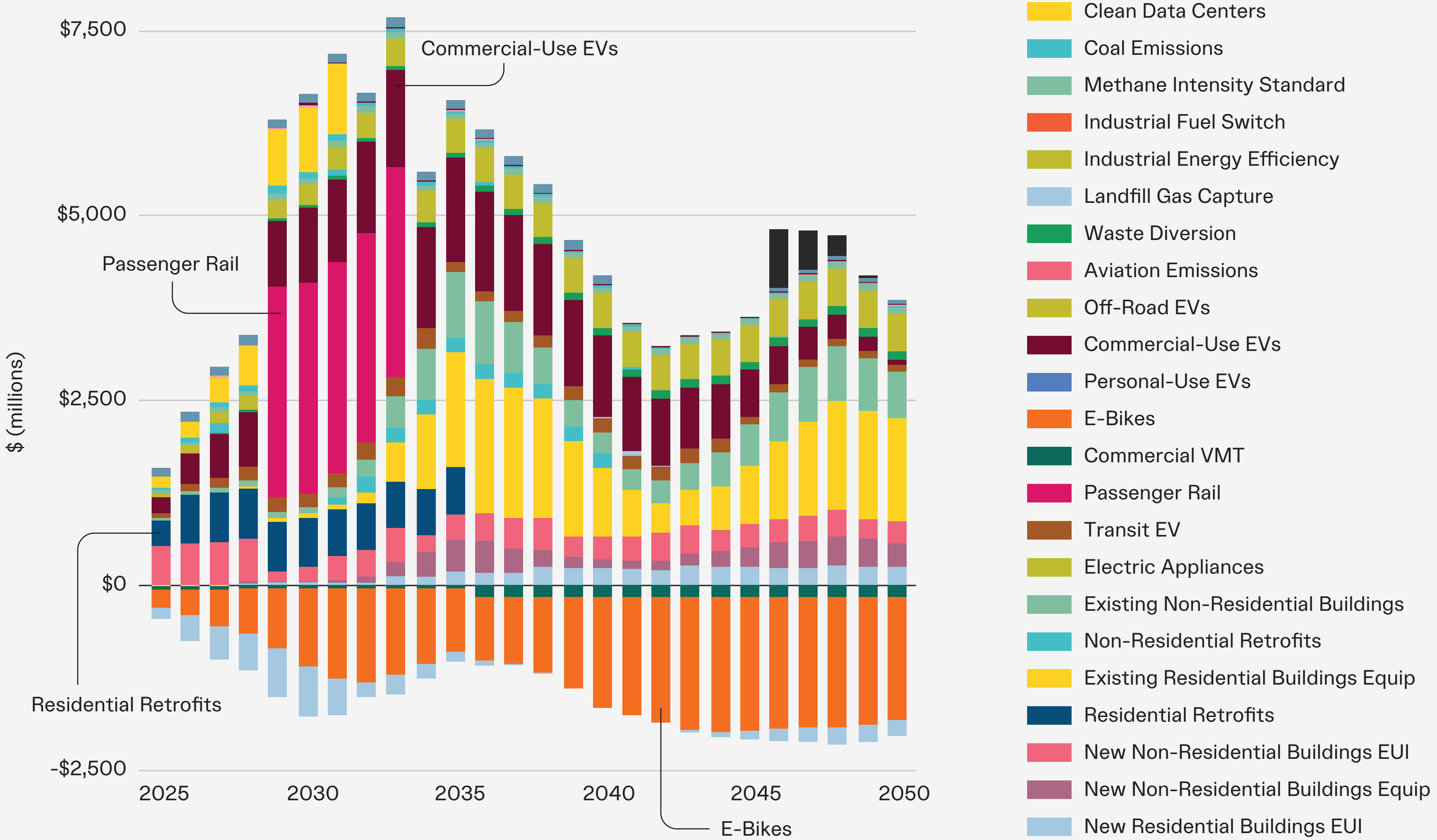


Figure 27.
Energy costs are tracked by sector and sub-sector, as is illustrated for LC 3 (least cost). Most policies result in energy savings because either the per unit energy cost is lower or efficiency gains more than compensate for increased per unit energy costs. Fuel switching in some sectors increases energy costs where fuel switching increases costs—or example, switching to sustainable aviation fuel or electrifying processes in industry.

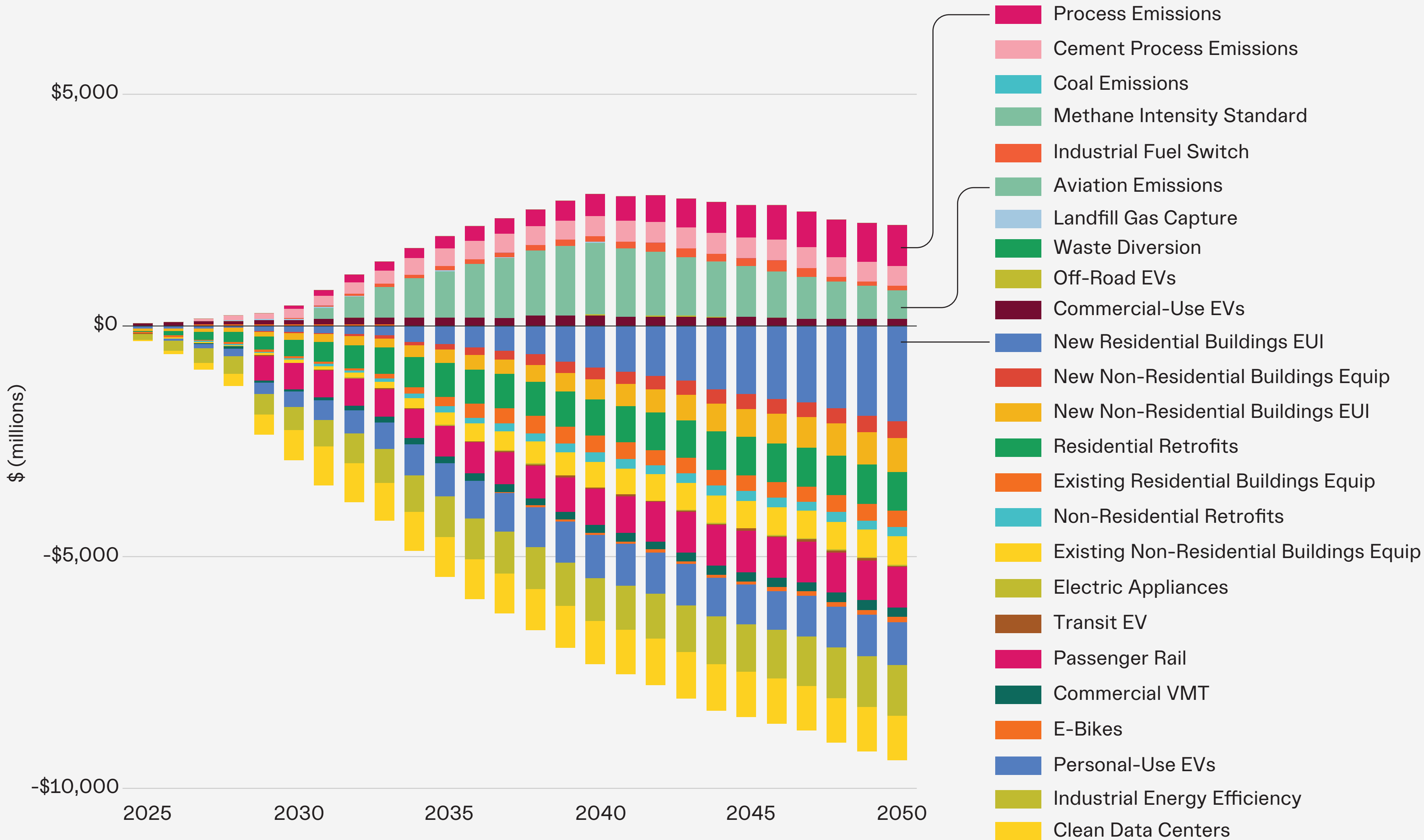


Figure 28.
Household energy costs decline in all LC scenarios over 2025 expenditures, with the highest declines in LC 1 (E&E) and LC 4 (sectors) (-22%). LC 2 (LC fuels) has the lowest decline (-9%).

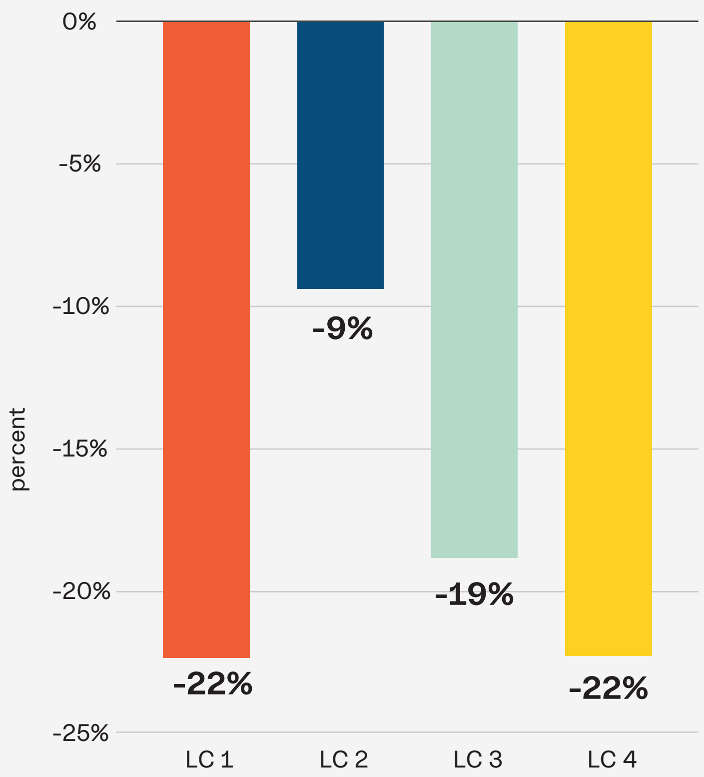


Figure 29.
Reduction in household energy costs also reduces the number of homes that are energy burdened. Energy burden represents a range; therefore, the decrease in household energy costs in LC 2 (LC fuels) does not move households out of the energy-burdened category, even though household energy expenditures decline.

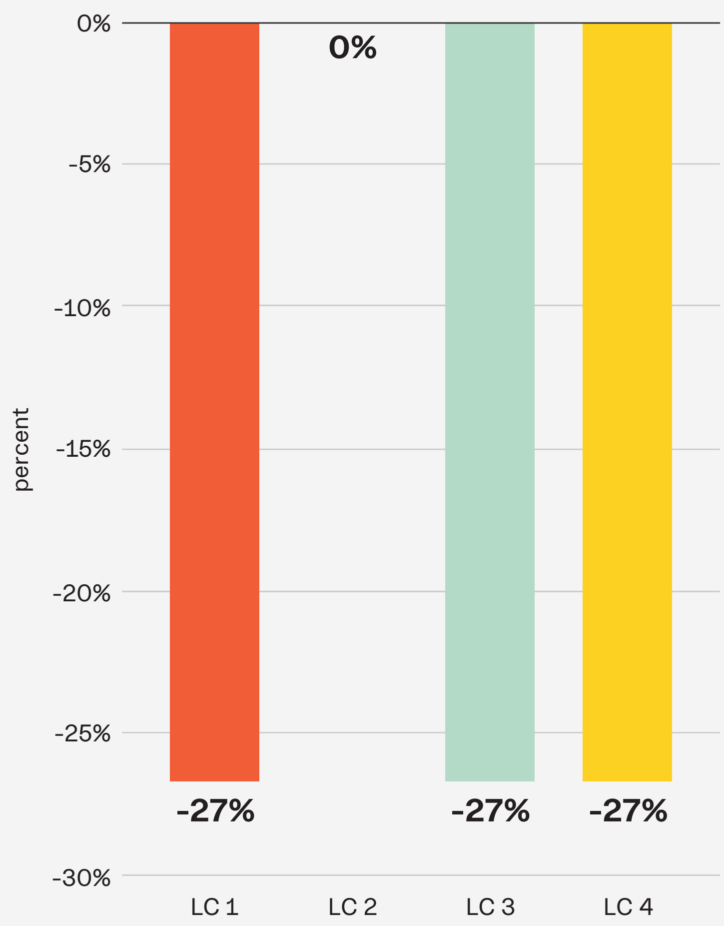


Figure 30.
The spatial distribution of household energy expenditures varies across the geography, with higher expenditures being represented by darker colors. By 2050 in the BAP Scenario, household energy costs decline in most places, particularly in the urban context. In the LC 1 (E&E) and LC 3 (least cost), energy costs per household decline across the board.

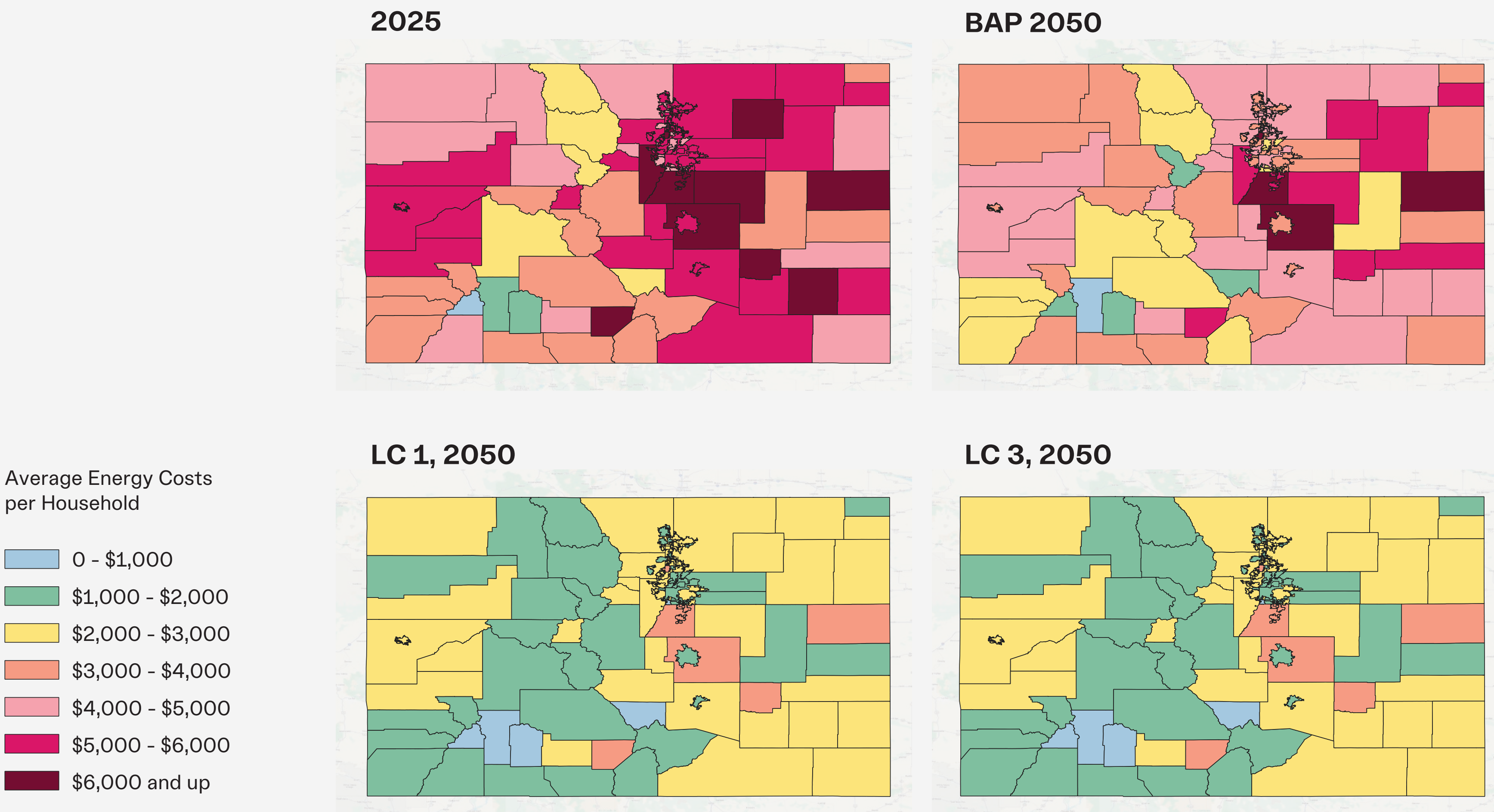


Figure 31.
In order to evaluate the sensitivity of the household energy cost, adjustments were made to the projected energy cost intensities. In (1), electricity and natural gas cost intensities are halved; in (2), costs represent the intensities used in the analysis; and in (3), cost intensities are doubled. In each of these cases, household energy costs are lower than in the BAP Scenario, indicating that the LC scenarios are more resilient to future energy cost changes.

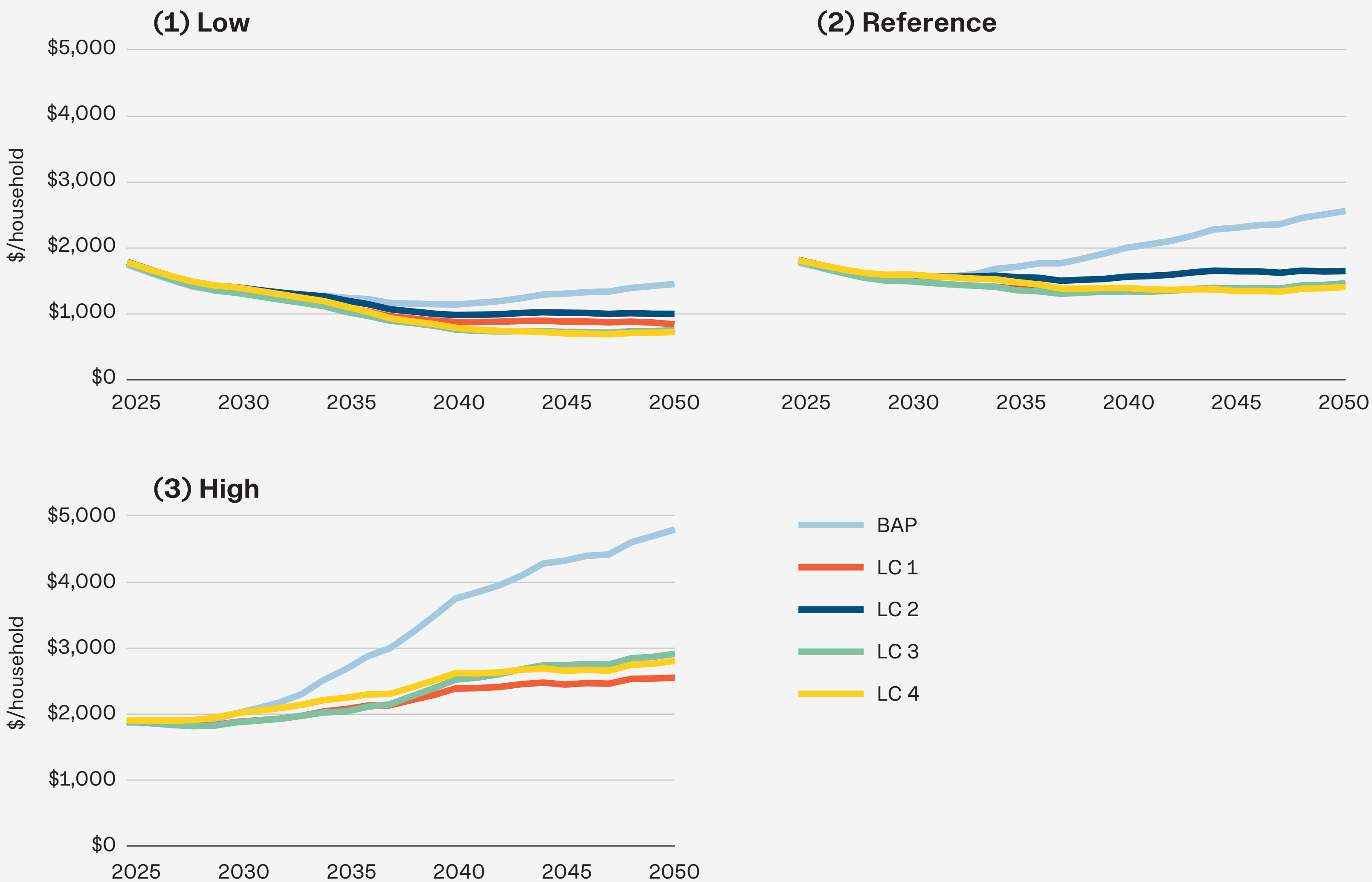


Figure 32.
Capital investments result in job opportunities, which are calculated based on employment multipliers for each sector. Residential retrofits are a major source of employment in LC 1 (E&E) but have a much smaller impact in the other LC scenarios. There is a major spike in employment in LC 1 (E&E) and LC 3 (least cost) from 2029 to 2033 due to the expansion of passenger rail.

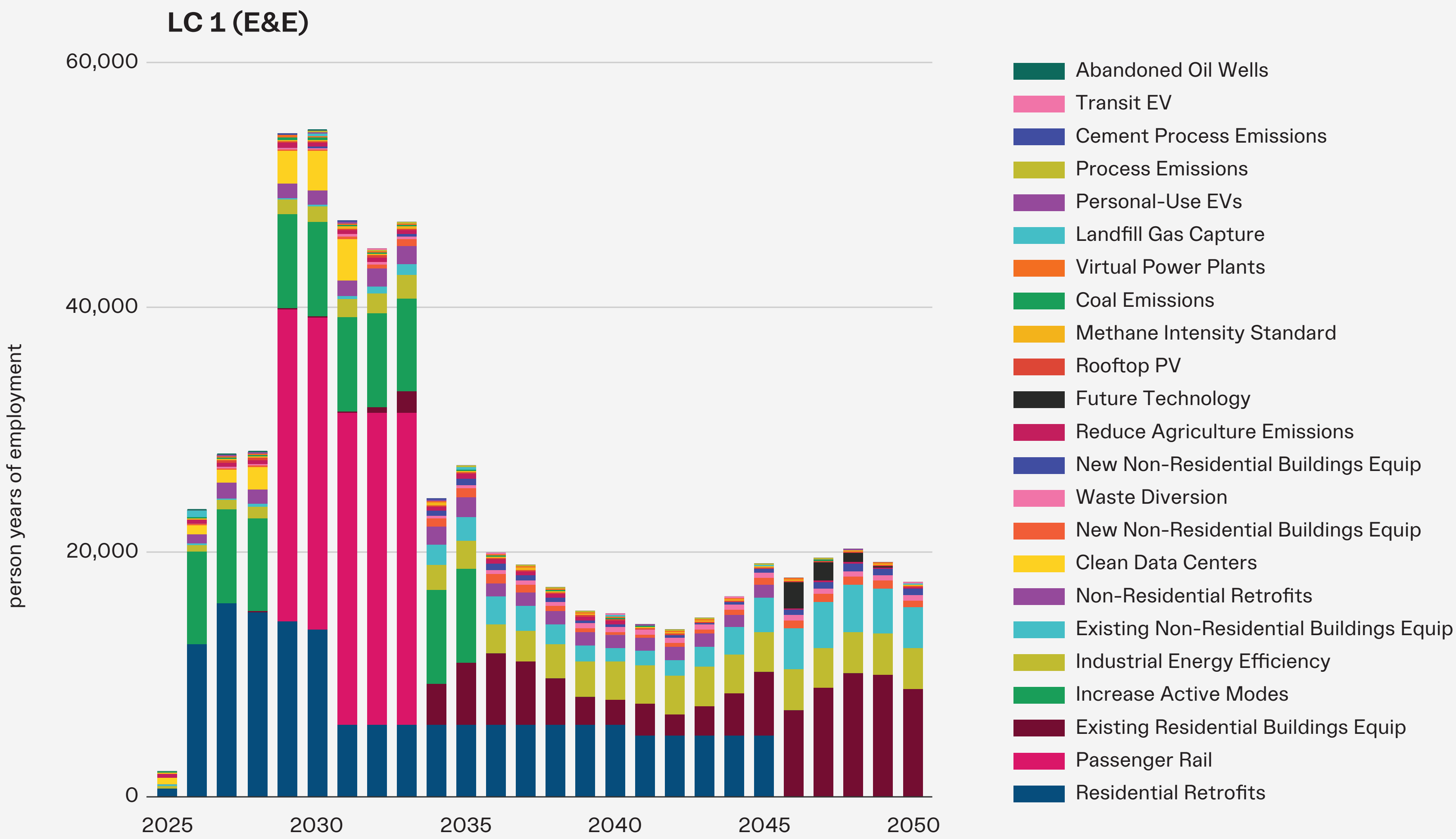


Figure 32. *(continued)*

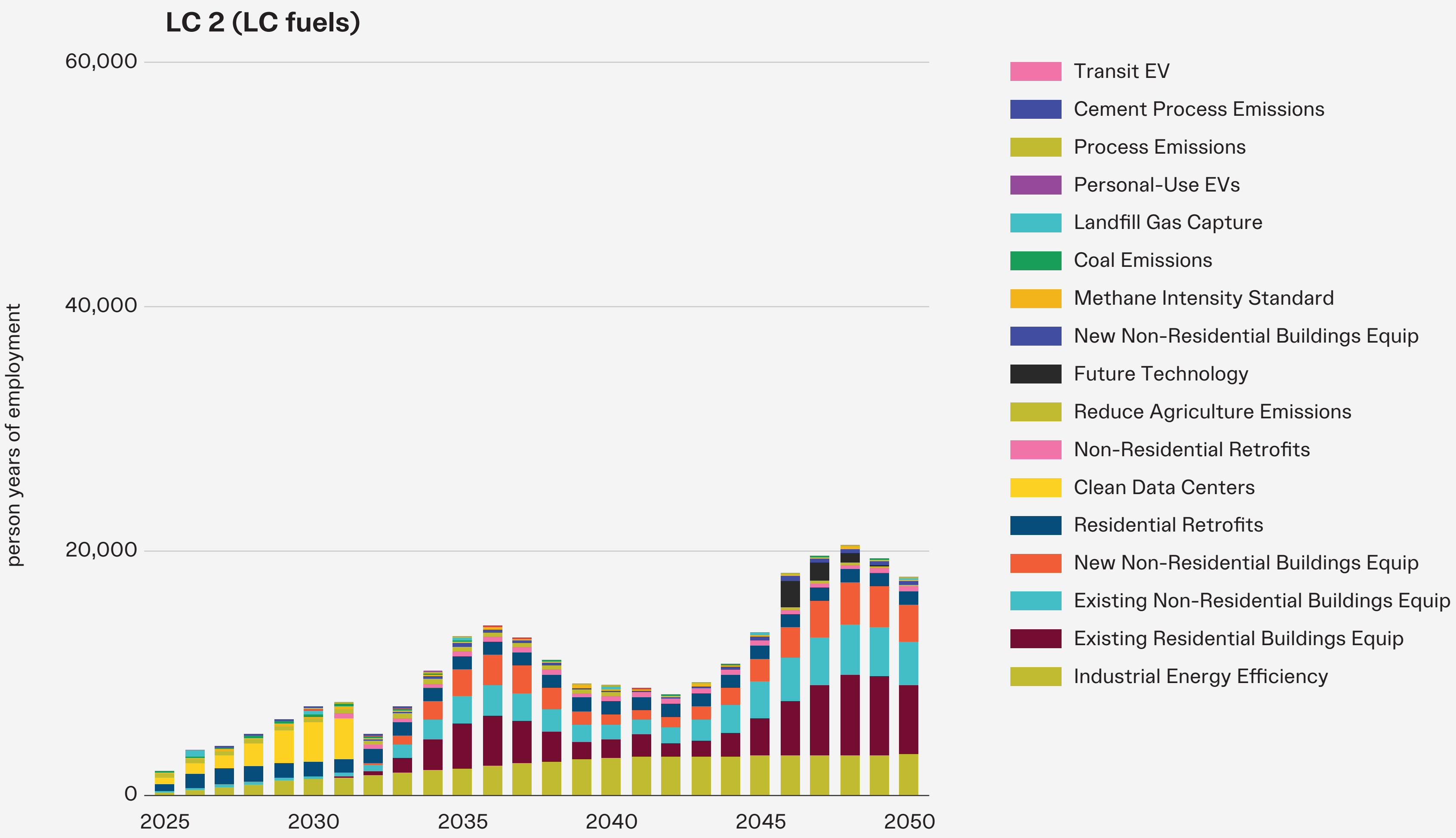


Figure 32. *(continued)*

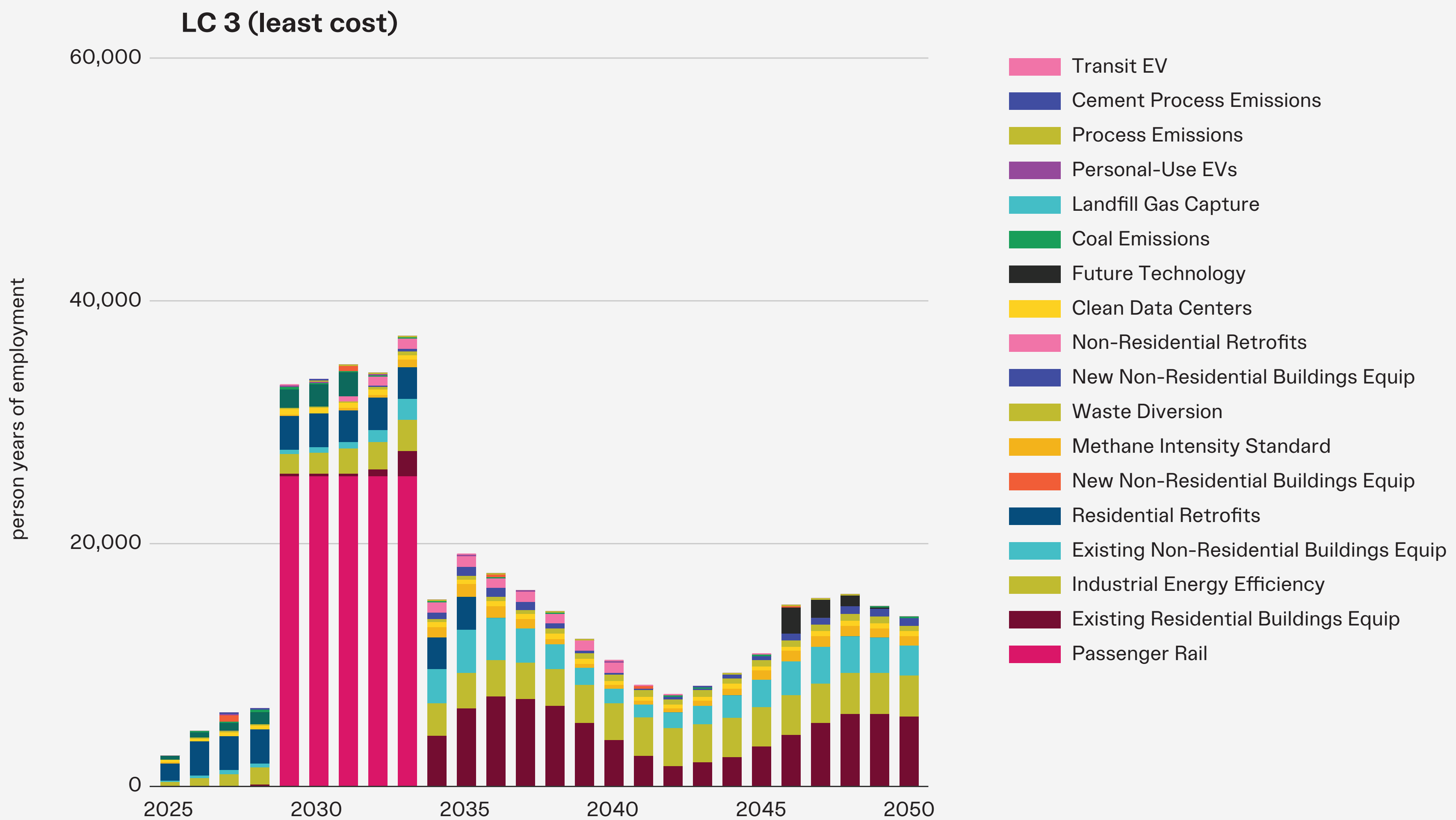
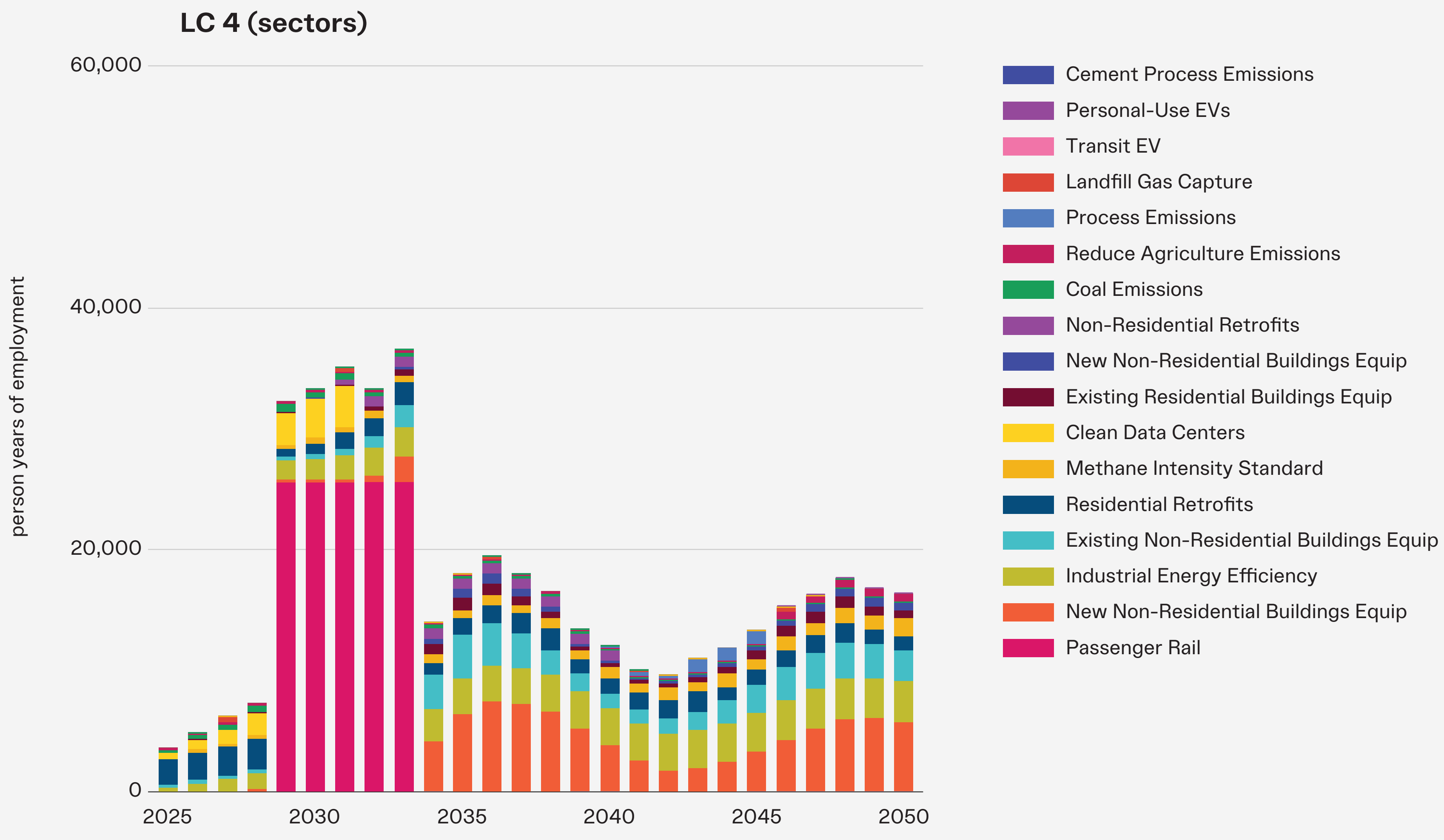


Figure 32. *(continued)*



Air Pollution

Local air pollution impacts public health and the environment and is largely a function of combusting fossil fuels. Pollutants include carbon monoxide, NOx, SO2, particulate matter, ozone, and lead. Volatile organic compounds (VOCs) and hydrocarbons are precursors to ground-level ozone (smog), which can cause health impacts such as asthma, particularly in vulnerable populations. In 2025, large portions of the Colorado Front Range did not comply with federal air quality standards for ozone.

All four low-carbon scenarios result in significant reductions in local air pollutants compared to projected pollution levels under the BAP Scenario. In scenarios LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors), local air pollutants are sharply reduced by 2040 and virtually eliminated by 2050 (Tables 6 and 7). In LC 2 (LC fuels), local air pollution is reduced relative to the BAP Scenario but remains in both 2040 and 2050 because the scenario includes higher levels of combustion of RNG in the transportation sector and in the residential and commercial sectors. Figure 33 illustrates the statewide emissions of local air pollutants in order to provide a high-level comparison between low-carbon scenarios. However, Figure 34 shows the local air pollution by county, which provides important insight into the public health impacts (benefits) of different low-carbon scenarios, with blue indicating lower levels and red representing higher levels of pollution.

Colorado's I-70 through Denver. Photo by Kristina Blokhin/stock.adobe.com

Table 6.
Local air pollutants (Mtons) by scenario in 2040. Hydrocarbons (HC) and volatile organic compounds are included as they are precursors to ozone. Ozone formation was not modeled.

	CO	HC	NOx	PM 10	PM 2_5	SO_2	VOC
BAP	445,525	10,302	86,365	21,148	13,355	4,222	41,136
LC 1	132,307	2,185	22,966	6,918	4,976	404	12,957
LC 2	299,468	2,792	35,033	10,065	7,272	1,884	26,452
LC 3	116,678	2,340	19,979	4,449	2,261	338	10,250
LC 4	90,534	2,340	18,211	4,240	2,031	1,719	8,054

Table 7.
Local air pollutants (Mtons) by scenario in 2050.

	CO	HC	NOx	PM10	PM2_5	SO_2	VOC
BAP	441,200	9,472	92,424	22,080	14,634	4,768	41,865
LC 1	10,377	39	1,935	2,551	2,347	178	2,371
LC 2	241,759	60	13,329	5,605	4,847	299	20,638
LC 3	2,183	43	844	1,345	942	147	1,048
LC 4	2,207	43	884	1,345	942	147	1,050

At large industrial facilities, greenhouse gas emissions and criteria pollutants are driven down as a result of converting fossil-fuel-based processes to electricity and green hydrogen or relying on carbon capture and sequestration. Even if industrial facilities export their products (e.g., refined petroleum) to other states, criteria pollution is almost eliminated by 2050 under LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors). However, as with all actions in the low-carbon scenarios, state policies will need to ensure that these reductions in local air pollutants are realized.

Figure 33.

Local air pollutants decline in all the LC scenarios, nearly to zero in LC 1 (E&E). The decline in LC 2 (LC fuels) is less, as it relies on alternative fuels, which result in combustion, whereas in LC 1 (E&E), these fuels are phased out. Reductions in local air pollution in LC 3 and LC 4 are similar to LC 1.

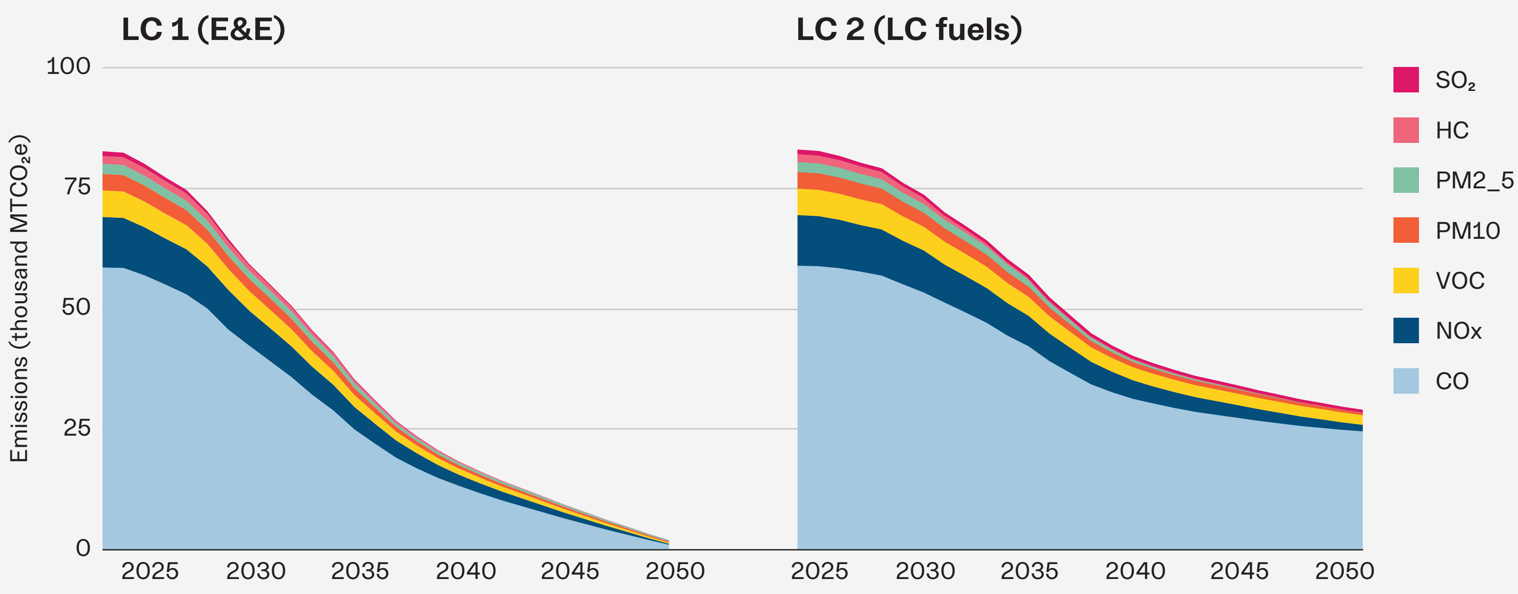
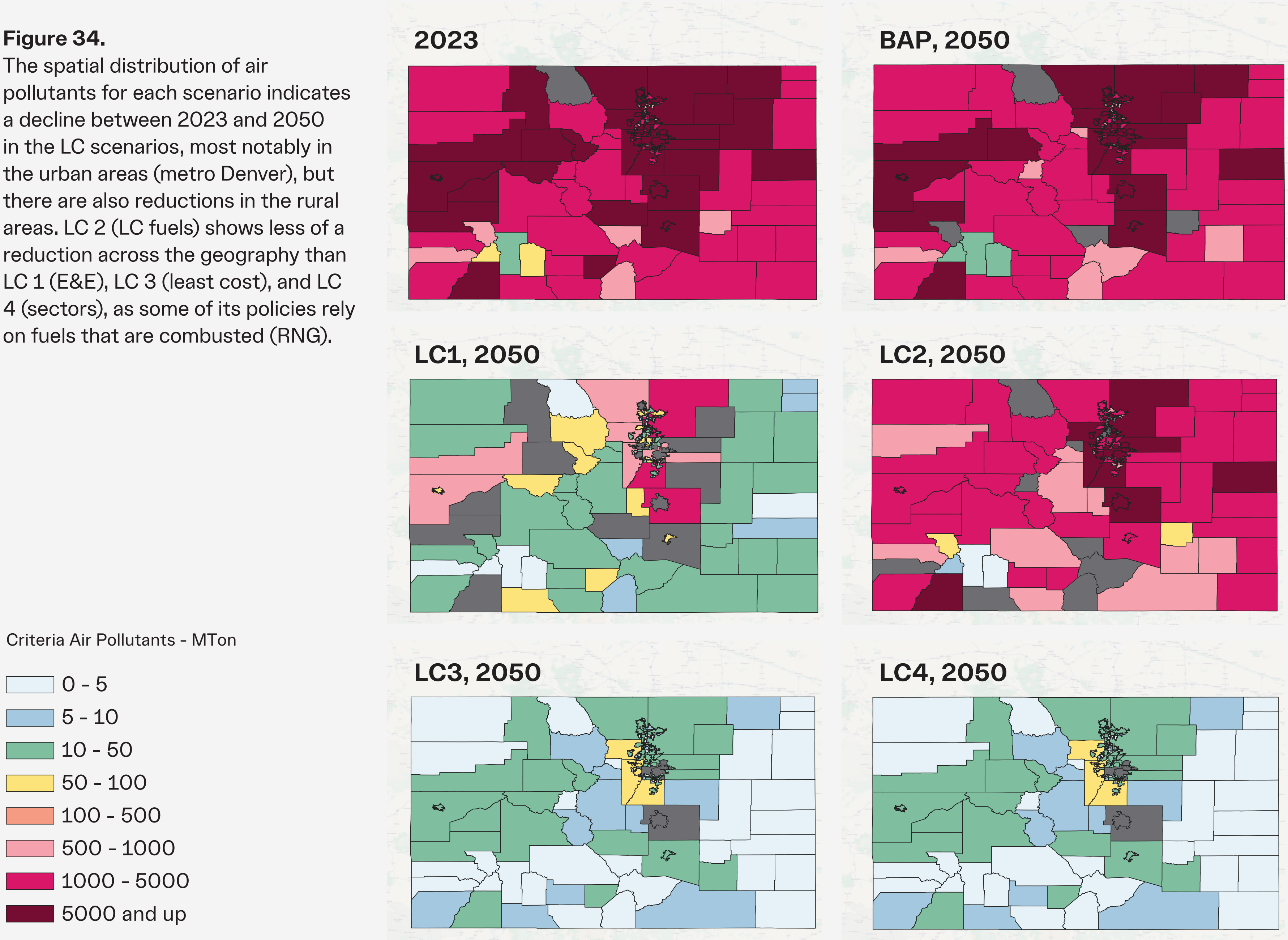


Figure 34.
The spatial distribution of air pollutants for each scenario indicates a decline between 2023 and 2050 in the LC scenarios, most notably in the urban areas (metro Denver), but there are also reductions in the rural areas. LC 2 (LC fuels) shows less of a reduction across the geography than LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors), as some of its policies rely on fuels that are combusted (RNG).



Based on the reduction in local air pollutants, annual avoided health costs were determined using the Environmental Protection Agency's (EPA) Co-Benefits Risk Assessment (COBRA)[9] model (Table 8). All four scenarios show substantial savings in health costs. Many of these costs are borne by individuals living in high-pollution areas and disproportionately impacted communities (DICs).

Table 8.
Average annual avoided health costs (million USD, 2025–2050) by scenario.

	LC 1	LC 2	LC 3	LC 4
Avoided Health Costs	$2,100	$1,980	$2,230	$2,160

9 EPA's CO–Benefits Risk Assessment (COBRA) screening model explores how changes in air pollution from clean energy policies and programs, including energy efficiency and renewable energy, can affect human health at the county, state, regional, or national levels - What is COBRA? | US EPA.

Implementation

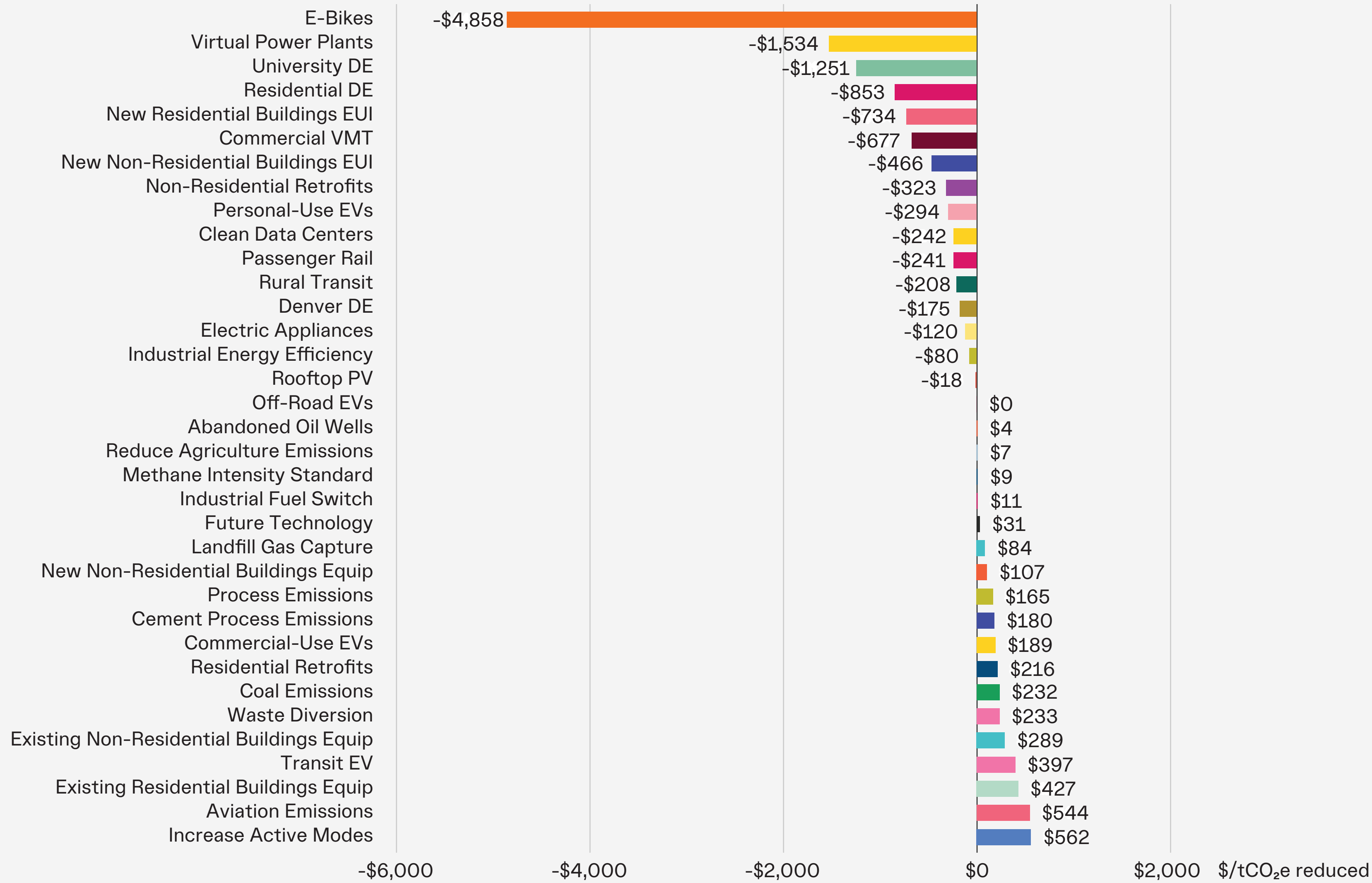
Many actions to reduce GHG emissions provide cost savings, while others incur net costs. The abatement cost curves provide insight on each of the possible actions (Figure 35).

- Negative or low-cost measures (strongly negative): "No-regret" or economically beneficial may not require additional intervention.
- Moderate-cost measures: Feasible but require incentives or regulation.
- High-cost measures (strongly positive): May need strong policy or technology innovation support.

However, there may be additional barriers to the deployment of an action, including informational, workforce, supply chain, or market lock-in, that require some type of policy intervention. A further consideration is that the abatement savings may be compelling, but the potential for reducing GHG emissions from that action is limited, so consideration of the abatement and GHG abatement potential for each action informs the priority of that action. Appendix 5 includes abatement costs for each of the actions.

Figure 35.

The abatement costs represent the total capital and operating costs of an action, discounted back to $2025 to calculate the net present value. The NPV is divided by the total GHG reduction to calculate the $/tCO₂e. Actions with negative numbers save money for every tCO₂e reduced, while actions with positive values cost money. Policy interventions can be mapped to different measures according to their abatement cost. If they cost money, the action may require subsidies, research, or innovation; if they save money, regulation can unlock emissions reductions and cost savings.



Conclusions

1. A low-carbon future for Colorado includes many upsides: increased affordability for households and businesses, more predictable energy pricing, cleaner and healthier air, new job opportunities, new business opportunities, and a healthier population. The scenarios modeled in this analysis show there are multiple pathways to put Colorado on track to reduce GHG emissions in line with its climate targets while providing net economic benefits and cost savings to Colorado households, dramatically reducing air pollution, and creating thousands of jobs as Colorado builds a cleaner economy.
2. In the big picture, low-carbon scenarios are fundamentally about unlocking free energy in a variety of forms.
3. New capital deployment or reallocation will be critical to achieving the State's climate targets. The capital investments necessary to implement the modeled low-carbon scenarios are equivalent to approximately 1% or less of Colorado's economy. The State may raise revenue to fund this investment through a program that levies a tax or fee on pollution, or it may implement emissions regulations that stimulate private investment in pollution reductions. This investment pays dividends in reducing customers' energy bills, reducing the number of households that are energy burdened, and providing overall net economic benefits.
4. Colorado should establish policies to stimulate investments into clean energy solutions, raise revenue to help meet the State's climate targets, and ensure that consumers see an immediate economic benefit from low-carbon investments.
5. LC 3 (least cost) is the lowest capital cost pathway to achieving Colorado's GHG targets and provides the greatest net cost savings out of all scenarios modeled. By achieving Colorado's climate targets in the least cost manner, LC 3 (least cost) reduces the greatest cumulative GHG emissions out of the four low-carbon scenarios and reduces criteria air pollutants on par with LC 1 (E&E) and LC 4 (sectors). LC 3 (least cost) also provides affordability and job creation benefits, though not at the same levels as LC 1 (E&E).
6. The Sector-Specific-Targets Scenario, as defined by LC 4 (sectors), is limited by delaying emissions reductions that are beneficial in the short term (e.g., landfill gas capture) and accelerating emissions reductions that may be more expensive on a cost-per-ton basis (e.g., sustainable aviation fuels). As a result, the modeling indicates this sector-by-sector approach limits Colorado's ability to minimize climate and other air pollution and limits economic benefits.

7. As illustrated in LC 2 (LC fuels), there are downsides to alternative fuels in terms of affordability, GHG reductions, job creation, and air pollution. However, RNG may be useful for transitioning from natural gas in the near term, while H2 will likely be critical in the industrial and transportation sectors in the mid to long term.
8. Clean electricity is foundational to all of the low-carbon scenarios.
9. In addition to clean electricity, four industries headline Colorado's decarbonization future: heat pumps, EVs, clean industry, and reducing fugitive emissions from oil and gas. Various measures must be deployed to reduce emissions from agriculture. Additionally, as illustrated in LC 1 (E&E), weatherization or retrofits of existing buildings require an up-front capital investment and provide valuable benefits, such as reduced energy costs, but are not critical.
10. GHG reductions from land use, land-use change, and forests are uncertain and require additional investigation.
11. Carbon removal, or an equivalent, will be required to absorb remaining GHG emissions in order to achieve Colorado's target of net-zero GHG emissions by 2050; however, this is a medium-to long-term strategy.

Colorado Springs, Colorado. Photo by Neil/stock.adobe.com

US I-70 near Mountain Garfield Palisade, Mesa County, Colorado.
Photo by ssmalomuzh/stock.adobe.com

Landscape of Grand Junction, Colorado
Photo by Tomasz Zajda/stock.adobe.com

Appendices

Appendix 1. Calibration Data Assumptions

Data	Source	Use
Population by county, age, sex	US Census—2023 American Community Survey (ACS)	Calibration target
Natural gas, electricity, and other fuel use by county	EIA, State Energy Data System (SEDS) Department of Energy (DOE) and State and Local Planning for Energy (SLOPE) Platform	Calibration target
Residential buildings by county, type, and year built	US Census—2023 ACS FEMA, Hazus Program	Input assumption
Non-residential buildings by type	FEMA, Hazus Program DOE, city and county commercial building inventories	Input assumption
Residential and non-residential end-use equipment fuel shares	Residential Energy Consumption Survey (RECS) Commercial Buildings Energy Consumption Survey (CBECS) Office of Energy Efficiency and Renewable Energy (OEERE)	Input assumption
Industrial large emitters	EPA, Flight	Calibration target
Oil, gas, and coal production	Colorado Energy and Carbon Management Commission (ECMC) SEDS	Input assumption
Personal-use vehicles	DOE, vehicle registration counts by state DOE, city and county vehicle inventories	Input assumption
Personal-use vehicle trips	Replica OD trip data	Calibration target

Data	Source	Use
Personal, commercial, and transit vehicle miles traveled	Federal Highway Administration (FHWA) Highway Statistics, VM-2 vehicle miles of travel, by functional system United States. Federal Highway Administration. Office of Highway Policy Information FHWA Highway Statistics, VM-4 Distribution of Annual Vehicle Distance Traveled United States. Federal Highway Administration. Office of Highway Policy Information EPA State Inventory Tool (SIT)	Calibration target
Gasoline and diesel fuel use by county	EIA, SEDS DOE, SLOPE Platform	Calibration target
Off-Road fuel use	SIT	Calibration target
Aviation fuel use	EIA, SEDS	Calibration target
Rooftop solar	EIA, Electric Power Annual—Small-scale capacity	Input assumption
Waste and waste water	National Emissions Inventory (NEI)	Calibration target
Agriculture, forestry, and land use (AFOLU)	National Agricultural Statistics Service (NASS) National Land Cover Database (NLCD) NEI	Calibration target
Heating and cooling degree days by county	U.S. Climate Resilience Toolkit Climate Explore (Version 3.1)	Input assumption

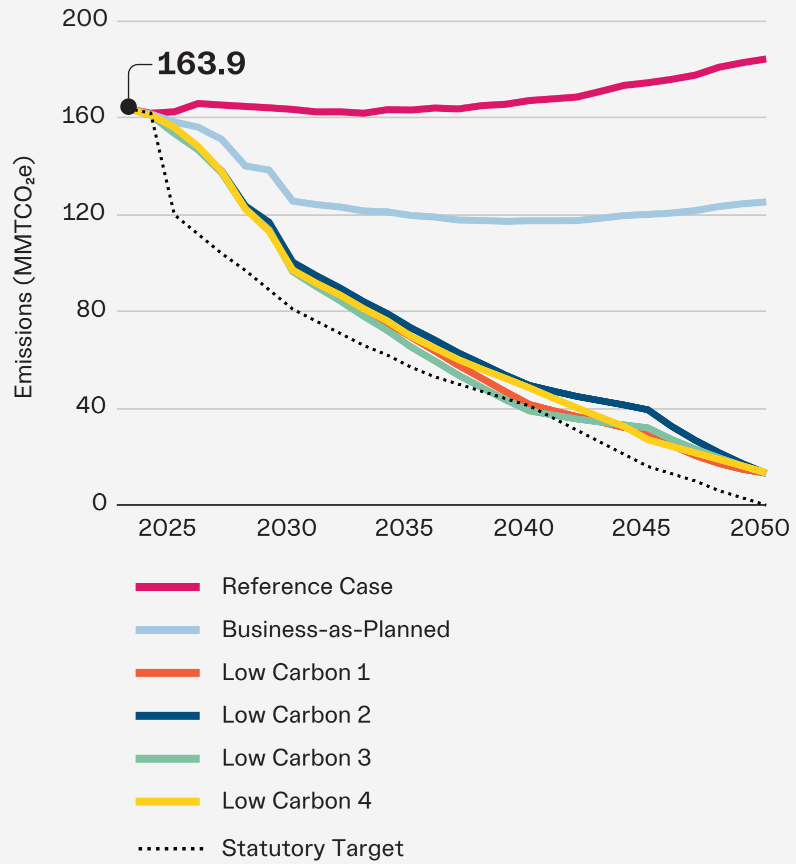
Appendix 2. Land-Use Implications

Greenhouse gas emissions resulting from land use, land-use change, and forests are predominantly from changes in forest cover or other disturbances (insects, fire). Due to uncertainty with respect to the scale of future LULUCF emissions and available mitigation actions, no actions were measured for this sector.

Figure 2.1 illustrates the pathways by sector for each scenario, including land-use GHG emissions. GHG emissions are nearly phased out in each sector by 2050 across LC 1 (E&E), LC 3 (least cost), and LC 4 (sectors), except in the LULUCF sector for the reason described above (13 million $MTCO_2e$ remaining).

Additional research is required to identify the GHG emissions source from LULUCF, as well as effective actions to mitigate it.

Figure 2.1.
Results of the scenario analysis, including GHG emissions from LULUCF.



Appendix 3.
Colorado's GHG Targets

	Baseline (Net GHG Emissions, CO_2e)	Reduction Target Relative to Baseline (%)	Target Emissions Level (Net GHG Emissions, CO_2e)
2005	162		
2025		26%	120
2030		50%	81
2035		65%	57
2040		75%	41
2045		90%	16
2050		100%	0

Appendix 4. Scenario Summaries

The scenario results presented for each LC scenario below are relative to the BAP Scenario.

LC 1 (E&E)	
↓ **Emissions**	**60** **million $MTCO_2e$** Average annual avoided GHG emissions (2025–2050)
↑ **Capital expenditure**	**$5,917** **million** Average annual capital expenditure (undiscounted) (2025–2050)
↓ **Saves money per ton of emissions reduced**	**-$17** **$/$MTCO_2e$** Net present value of a metric ton of avoided GHG emissions with a 3% discount rate
↓ **Energy consumption**	**$21,570** **million MMBTU** Average annual avoided energy consumption (2025–2050)
↑ **Electricity consumption**	**7%** Change in electricity consumption relative to the Business-as-Planned Scenario in 2050

LC 1 (E&E)	
↑ **RNG consumed**	**14 million MMBTU** Cumulative amount of renewable natural gas consumed (2025–2050)
↑ **Green hydrogen consumed**	**38 million MMBTU** Cumulative amount of green hydrogen consumed (2025-2050)
↓ **Criteria air pollutants**	**530 thousand MTon** Average annual avoided CAP emissions (2025–2050)
↓ **Health care costs**	**$2,100 million** Average annual avoided health costs (2025–2050)
↓ **Decrease household energy expenditures**	**-22%** Change in household energy expenditures between 2023 and 2050
↓ **Decrease energy burdened households**	**-27%** Change in number of energy-burdened households between 2023 and 2050
↓ **Decreases the social cost of carbon**	**-$16 billion** Average annual avoided damage from climate change globally (2023–2050)

LC 1 (E&E)	
↓ **Decreases vehicle miles travelled**	**-3.7%** Percent change in personal vehicle miles traveled (2023–2050)
↑ **Increase in active trips**	**80 million trips/household** Average annual active trips per household (2023–2050)
↑ **Increase in active mode share**	**65%** Change in share of trips that are active between 2023 and 2050
↑ **Reliance on carbon capture**	**875,359 $MTCO_2e$** Average annual GHG emissions captured (2025–2050)
↑ **Carbon capture investment**	**$63 million** Average annual capital expenditure (undiscounted) for captured GHG emissions (2025–2050)

LC 2 (LC fuels)	
↓ **Emissions**	**56** **million $MTCO_2e$** Average annual avoided GHG emissions (2025–2050)
↑ **Capital expenditure**	**$3,270** **million** Average annual capital expenditure (undiscounted) (2025–2050)
↓ **Saves money per ton of emissions reduced**	**-$14** **$/$MTCO_2e$** Net present value of a metric ton of avoided GHG emissions with a 3% discount rate
↓ **Energy consumption**	**$23,738** **million MMBTU** Average annual avoided energy consumption (2025–2050)
↑ **Electricity consumption**	**15%** Change in electricity consumption relative to the Business-as-Planned Scenario in 2050
↑ **RNG consumed**	**15** **million MMBTU** Cumulative amount of renewable natural gas consumed (2025–2050)

LC 2 (LC fuels)	
↑ **Green hydrogen consumed**	**81** **million MMBTU** Cumulative amount of green hydrogen consumed (2025-2050)
↓ **Criteria air pollutants**	**380** **thousand MTon** Average annual avoided CAP emissions (2025–2050)
↓ **Health care costs**	**$1,980** **million** Average annual avoided health costs (2025–2050)
↓ **Decrease household energy expenditures**	**-9%** Change in household energy expenditures between 2023 and 2050
↓ **Decrease energy burdened households**	**0%** Change in number of energy-burdened households between 2023 and 2050
↓ **Decreases the social cost of carbon**	**-$15** **billion** Average annual avoided damage from climate change globally (2023–2050)

LC 2 (LC fuels)	
↑ **Increases vehicle miles travelled**	**25%** Percent change in personal vehicle miles traveled (2023–2050)
↑ **Increase in active trips**	**64 million trips/household** Average annual active trips per household (2023–2050)
↓ **Decrease in active mode share**	**-3%** Change in share of trips that are active between 2023 and 2050
↑ **Reliance on carbon capture**	**2,197,376 $MTCO_2e$** Average annual GHG emissions captured (2025–2050)
↑ **Carbon capture investment**	**$172 million** Average annual capital expenditure (undiscounted) for captured GHG emissions (2025–2050)

LC 3 (least cost)	
↓ Emissions	**61** **million $MTCO_2e$** Average annual avoided GHG emissions (2025–2050)
↑ Capital expenditure	**$3,174** **million** Average annual capital expenditure (undiscounted) (2025–2050)
↓ Saves money per ton of emissions reduced	**-$35** **$/$MTCO_2e$** Net present value of a metric ton of avoided GHG emissions with a 3% discount rate
↓ Energy consumption	**$21,611** **million MMBTU** Average annual avoided energy consumption (2025–2050)
↑ Electricity consumption	**3%** Change in electricity consumption relative to the Business-as-Planned Scenario in 2050
↑ RNG consumed	**9** **million MMBTU** Cumulative amount of renewable natural gas consumed (2025–2050)

LC 3 (least cost)	
↑ **Green hydrogen consumed**	**58 million MMBTU** Cumulative amount of green hydrogen consumed (2025-2050)
↓ **Criteria air pollutants**	**550 thousand MTon** Average annual avoided CAP emissions (2025–2050)
↓ **Health care costs**	**$2,230 million** Average annual avoided health costs (2025–2050)
↓ **Decrease household energy expenditures**	**-19%** Change in household energy expenditures between 2023 and 2050
↓ **Decrease energy burdened households**	**-27%** Change in number of energy-burdened households between 2023 and 2050
↓ **Decreases the social cost of carbon**	**-$17 billion** Average annual avoided damage from climate change globally (2023–2050)

LC 3 (least cost)	
– **no change vehicle miles travelled**	**0.1%** Percent change in personal vehicle miles traveled (2023–2050)
↑ **Increase in active trips**	**56 million trips/household** Average annual active trips per household (2023–2050)
↓ **Decrease in active mode share**	**-4%** Change in share of trips that are active between 2023 and 2050
↑ **Reliance on carbon capture**	**671,197 $MTCO_2e$** Average annual GHG emissions captured (2025–2050)
↑ **Carbon capture investment**	**$49 million** Average annual capital expenditure (undiscounted) for captured GHG emissions (2025–2050)

LC 4 (sectors)	
↓ **Emissions**	**59 million $MTCO_2e$** Average annual avoided GHG emissions (2025–2050)
↑ **Capital expenditure**	**$3,258 million** Average annual capital expenditure (undiscounted) (2025–2050)
↓ **Costs money per ton of emissions reduced**	**-$19 $/$MTCO_2e$** Net present value of a metric ton of avoided GHG emissions with a 3% discount rate
↓ **Energy consumption**	**$21,537 million MMBTU** Average annual avoided energy consumption (2025–2050)
↑ **Electricity consumption**	**4%** Change in electricity consumption relative to the Business-as-Planned Scenario in 2050
↑ **RNG consumed**	**0 million MMBTU** Cumulative amount of renewable natural gas consumed (2025–2050)

LC 4 (sectors)	
↑ **Green hydrogen consumed**	**68** **million MMBTU** Cumulative amount of green hydrogen consumed (2025-2050)
↓ **Criteria air pollutants**	**570** **thousand MTon** Average annual avoided CAP emissions (2025–2050)
↓ **Health care costs**	**$2,160** **million** Average annual avoided health costs (2025–2050)
↓ **Decrease household energy expenditures**	**-22%** Change in household energy expenditures between 2023 and 2050
↓ **Decrease energy burdened households**	**-27%** Change in number of energy-burdened households between 2023 and 2050
↓ **Decreases the social cost of carbon**	**-$16** **billion** Average annual avoided damage from climate change globally (2023–2050)

LC 4 (sectors)

- **no change vehicle miles travelled**	**0.1%** Percent change in personal vehicle miles traveled (2023–2050)
↑ **Increase in active trips**	**56 million trips/household** Average annual active trips per household (2023–2050)
↓ **Decrease in active mode share**	**-4%** Change in share of trips that are active between 2023 and 2050
↑ **Reliance on carbon capture**	**253,074 $MTCO_2e$** Average annual GHG emissions captured (2025–2050)
↑ **Carbon capture investment**	**$51 million** Average annual capital expenditure (undiscounted) for captured GHG emissions (2025–2050)

Appendix 5. Scenario Assumptions

Reference Case

Theme	Description
Population Growth	Population grows from 5.81 million in 2023 to 7.35 million in 2050, Colorado Department of Labor and Employment. Housing needs grow in proportion to population.
Employment Growth	Employment grows from 9.24 million in 2023 to 13.11 million in 2050, Colorado Department of Labor and Employment. Non-residential building grows in proportion to employment. Employment represents total employment available in Colorado, including people living outside of the state.
Oil, Gas and Coal Production	Production follows EIA's Annual Energy Outlook projection for the state, with emission factors based on the state's inventory.
Electricity Generation	Assume no changes to how grid electricity is generated.
Industrial Activity	Assume no change to heavy industrial activity; light industry grows proportionate to population growth.
Heating and Cooling Degree Days	Projections provided by U.S. Climate Resilience Toolkit Climate Explore (Version 3.1).
Land Use	Assume no land-use change.

BAP	
Theme	**Description**
Cleaner Electricity Grid	Emissions from electricity generation are reduced to 80% by 2030, achieving HB21-1266 targets. After 2030, emission factors for electricity generation are held constant.
Buildings	GHG emissions from gas consumption in existing and new residential and commercial buildings are reduced by 22% by 2030 relative to 2015, as proposed by the Clean Heat Plan legislation, SB21-264. After 2030, GHG emissions intensities are held constant.
Low-Emission Aviation	Assumes a 5% reduction of aviation emissions by 2032, as a result of the HB23-1272 tax credit for sustainable aviation fuel. The reduction is based on a finding in the Colorado Energy Policy Simulator.[10]

10 Energy Innovation LLC and RMI (2023). Colorado Energy Policy Simulator. Retrieved from: https://docs.energypolicy.solutions/models/colorado

BAP	
Theme	**Description**
Oil and Gas Emissions	Reduce sector emissions by 30–35% relative to 2023 levels by 2036, accounting for the impact of direct regulations, based on separate modeling by Environmental Defense Fund (EDF). SSG modeled future oil and gas sector methane emissions in the Business-as-Planned Scenario by applying year-over-year percent changes to a topline, sector-level emissions factor for oil and gas based on EDF modeling of current state and federal direct regulations through 2038.[11] For example, EDF estimated the Colorado sector-level emissions factor to be reduced by an average of approximately 5% annually from 2024 to 2027, driven by OOOOb regulations and state-level regulations such as the zero-bleed pneumatic controller standard. Note that these projections do not reflect EPA's recently released final rule delaying parts of OOOOb and the entirety of OOOOc standards,[12] as this action is currently being litigated.[13] In addition, these projections only evaluate the impact of direct regulations and do not reflect additional reductions that may be achieved as a result of Colorado's Greenhouse Gas Intensity Standard for oil and gas. While the Greenhouse Gas Intensity Standard will likely achieve additional reductions, compliance with this standard was uncertain at the time of modeling since 2025 is the first reporting year of the Greenhouse Gas Intensity Standard. Time will be needed to evaluate regulatory compliance with the measurement and reporting requirements and a full accounting of emissions reductions due to the intensity standards themselves. SSG modeled compliance with the standard as a component of the low-carbon scenarios rather than the Business-as-Planned Scenario.

11 EDF estimated a 2023 oil and gas methane emissions total for Colorado using the EI-ME model, a measurement-based, spatially explicit inventory of US oil and gas methane emissions, combined with 2023 measurement data from MethaneAIR, a specially equipped jet aircraft chartered by EDF. Emissions were broken out by source category and segment and estimated for future years using projected energy growth rates from Rystad. From this baseline emissions projection, regulatory scenarios can be modeled. EDF modeled emissions under all current direct regulations (state and federal) through 2038. Using projected production and modeled emissions over time, EDF estimated a growth trajectory for a sector-wide oil and gas emissions factor.

12 Extension of Deadlines in Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review Final Rule, 90 Fed. Reg. 35,966 (Jul. 31, 2015).

13 Groups File Lawsuit Challenging Trump EPA's Delay of Protections Against Oil and Gas Methane Pollution - Earthjustice

BAP	
Theme	**Description**
Industrial Emissions	Industrial and manufacturing sector emissions are projected to decline 16% below 2015 levels by 2030 under the Business-as-Planned scenario. This represents the potential impact of Colorado's GEMM I, GEMM II, and midstream oil and gas emissions regulations, which collectively cover approximately 50% of the sector's emissions, combined with projected increases in emissions from the other half of sector-wide emissions that are unregulated.
Vehicle Adoption	EV uptake climbs to 60% new light-duty vehicle sales by 2035, at which point it is held constant.[14] The fleet composition for medium-and heavy-duty vehicles is unchanged. Vehicle miles traveled grows as commercial floor space grows.
Data Centers	Data-center-driven load growth assumed to be in line with Xcel Energy's updated new large load base forecast. Assumes 929 MW by 2031. No new loads added after 2031.

14 U.S. Energy Information Administration, July 17, 2025, Table 38. Light-Duty Vehicle Sales by Technology Type, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=48-AEO2025&region=1-8&cases=ref2025&start=2023&end=2050&f=A&linechart=ref2025-d032025a.4-48-AEO2025.1-8&map=ref2025-d032025a.4-48-AEO2025.1-8&ctype=map&sourcekey=0

LC 1 (E&E)	
Theme	**Description**
New Building Performance	New Residential and Non-Residential Buildings ▪ Zero operational carbon used in buildings by 2030. 100% electrification. ▪ Split 20/80 between ground-source and air-source space conditioning heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Existing Buildings	Residential Buildings ▪ 50% of existing buildings are retrofitted by 2035 and 100% by 2045. ▪ Deep retrofits reduce energy use by 50% for space-conditioning load and 50% for non-space conditioning load. ▪ Space heating is split 20/80 between ground-source and air-source space-conditioning heat pumps. ▪ Water heating is split 50/50 between air-source heat pumps and electric resistance hot water heaters.
Existing Buildings	Non-Residential Buildings ▪ 50% of existing buildings are retrofitted by 2035 and 100% by 2045. ▪ Deep retrofits reduce energy use by 50% for space-conditioning load and 50% for non-space-conditioning load. ▪ Space heating is split 20/80 between ground-source and air-source space-conditioning heat pumps. ▪ Water heating is split 50/50 between air-source heat pumps and electric resistance hot water heaters.

LC 1 (E&E)	
Theme	**Description**
Existing Buildings	Municipal, University, School, and Hospital (MUSH) Buildings ▪ 90% of MUSH buildings are electrified by 2035, with deep energy retrofits reducing energy use by 50%. ▪ 90% of MUSH buildings have solar and storage installed by 2040. ▪ Space heating is split 20/80 between ground-source and air-source space-conditioning heat pumps. ▪ Water heating is split 50/50 between air-source heat pumps and electric hot water heaters.
Building Equipment	Cooking: Scale up to 90% of new purchases being induction by 2030.
Thermal Energy Networks	University District Energy ▪ Zero-emissions district energy for the four public universities and 14,000 homes by 2035.
Thermal Energy Networks	Denver District Energy ▪ New zero-emissions district energy systems in high-density commercial areas—pproximately 22 million sq ft of floor area are connected to district energy systems by 2040 (geothermal heat pumps, waste heat).
Rooftop PV	30 MW of solar added per year.
Virtual Power Plants	225 MW of solar+storage by 2035. No additional solar added after 2035.
Zero-Emissions Transit	Scale up to electrify 100% of transit by 2040.
Passenger Rail	Reduction of 63 million VMT (three trips per person) per year starting in 2029, scaling from three trips/person/year to 10 trips/person/year by 2045.

LC 1 (E&E)

Theme	Description
Rural Transit	Scale up to 5–10% VMT reduction in rural counties by investing in on-demand transit and improved intercity transit connections through enhanced Bustang services by 2035.
Mode Shift	Double the share of non-car travel (transit, biking, walking) from 9.6% to 19.2% by 2035. This includes an assumption of increased transit service to cities over 100,000
Commercial VMT Reduction	Reduce VMT trip generation by 25% for new warehouse buildings in major cities by 2035. VMT trip generation rate is flat after 2035.
E-Bikes	E-bike adoption climbs to 10%[15] of new vehicle sales by 2035 for equity-seeking populations (adults only). Assumes 20% mode share for e-bikes.
Personal-Use ZEV Adoption	Adopt the following ZEV/PHEV new vehicle sales requirements under Advanced Clean Cars II ▪ 2026 35% ▪ 2030 68% ▪ 2035 100%
Commercial-Use ZEV Adoption	ZEV (100% electric) adoption in 2035 of 75% for Class 4–8 trucks, 55% for Class 2b–3 trucks, and 40% for Class 7–8 tractor trucks. 100% by 2050. Requires transportation network companies and potentially other high-mileage fleets to achieve 80% electric vehicle stock by 2030 and 100% by 2035.

15 National Renewable Energy Laboratory, April 2021, The CanBikeCO Mini Pilot: Preliminary Results and Lessons Learned, The CanBikeCO Mini Pilot: Preliminary Results and Lessons Learned

LC 1 (E&E)

Theme	Description
Off-Road Emissions	Scale up to 100% of new vehicles purchased by 2035 are zero emissions.
Electric Aviation	Scale up to 100% electric for trips of less than 600 miles by 2040.
Sustainable Aviation Fuel	Starting in 2030, sustainable aviation fuel (biofuels) is increasingly introduced, scaling up to 80% by 2050.
Diversion From Landfill	Scale up to 60% waste diversion from landfills by 2040.
Landfill Methane Emissions	Scaling up to major landfills having a landfill capture efficiency of 70% by 2030, producing biomethane (RNG).
Industrial Efficiency	Scale up to 50% efficiency across industry by 2040.
Industrial Energy Use	Scale up to 50% of industrial processes converted to green H2 and 50% electrified by 2050.
No New Oil and Gas Permits	No new permits beginning in 2030.
Plug Gas Wells	Scale up to 661 plugged orphan wells (leaking wells) by 2030.
Oil and Gas Emissions	Model compliance with the HB 21-1266 target for the oil and gas sector to reduce emissions 36% by 2025 and 60% by 2030, below 2005 levels. This reduction is held constant after 2030.
Clean Data Centers	100% of data centers use net new 24/7 carbon-free electricity (similar to Google's commitment).

LC 1 (E&E)

Theme	Description
Methane Capture From Coal Mining	Scale up to a 70% emissions reduction by 2030 and 100% by 2050.
Cement Process Emissions	Scale up to a 50% reduction by 2030 and 90% by 2050 from concrete in Colorado.
Industrial Process Emissions	Scale up to 444,000 tCO_2e reduction per year by 2030; remaining non-industrial emissions scale up to 100% carbon capture by 2050.
Cleaner Electricity Grid	Require 95% emissions reductions by 2035 and 100% clean electricity by 2040; applied to all utilities.
Reduce Agriculture Emissions	Scale up to 80% reductions by 2040 by applying a combination of the following: ▪ No-till/reduced tillage ▪ Enhanced-efficiency fertilizers /4R nutrient mgmt ▪ Manure digesters ▪ Enteric methane inhibitors (e.g., Bovaer, seaweed) ▪ Rotational/improved grazing ▪ Agroforestry/tree planting (shelterbelts, riparian) ▪ Biochar soil amendment
Carbon Removal	Remaining emissions (22.8 $MMTCO_2e$) are removed between 2045 and 2050 to reach the 2050 target.

LC 2 (LC fuels)

Theme	Description
New Building Performance	New Residential and Non-Residential Buildings ▪ Zero operational carbon by 2035 across all building types: 50% electrification; 50% RNG. ▪ Split electrification 20/80 between ground-source and air-source space-conditioning heat pumps, and the remaining 50% are natural gas heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Existing Buildings	Residential Buildings ▪ 50% of existing buildings are retrofitted by 2035 and 100% by 2045. ▪ Deep retrofits with savings of 30% for space-conditioning load and 30% non-space-conditioning load. ▪ Split electrification 20/80 between ground-source and air-source space-conditioning heat pumps, and the remaining 50% are natural gas heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Existing Buildings	Non-Residential Buildings ▪ 50% of existing buildings are retrofitted by 2035 and 100% by 2045. ▪ Deep retrofits with savings of 30% for space-conditioning load and 30% for non-space-conditioning load. ▪ Split electrification 20/80 between ground-source and air-source space-conditioning heat pumps, and the remaining 50% are natural gas heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Building Equipment	Cooking: Scale up to 40% of new purchases being induction by 2035.
Zero-Emissions Transit	Scale up to 50% electricity and 50% green H2 for transit by 2040.
Rural Transit	Scale up to 5–10% VMT reduction in rural counties by investing in on-demand transit and improved intercity transit connections through enhanced Bustang services by 2035.

LC 2 (LC fuels)	
Theme	**Description**
Commercial VMT Reduction	Reduce VMT trip generation by 25% by 2035 for new warehouse buildings in major cities. VMT trip generation rate is flat after 2035.
Personal-Use ZEV Adoption	Adopt the following ZEV/PHEV new vehicle requirements under Advanced Clean Cars III: ▪ 2026 35% ▪ 2030 68% ▪ 2035 100%
Commercial-Use ZEV Adoption	ZEV (75% hydrogen/25% electric) adoption in 2035 of 75% for Class 4–8 trucks, 55% for Class 2b–3 trucks, and 40% for Class 7–8 tractor trucks. 100% by 2050. Requires transportation network companies, and potentially other high-mileage fleets, to achieve 80% electric vehicle stock by 2030 and 100% by 2035.
Electric Aviation	Scale up to 100% electric for trips of less than 600 miles by 2040.
Sustainable Aviation Fuel	Starting in 2030, sustainable aviation fuel (biofuels) is increasingly introduced, scaling up to 100% by 2040.
Landfill Methane Emissions	Scaling up to major landfills having a landfill capture efficiency of 90% by 2030, producing biomethane (RNG).
Industrial Efficiency	Scale up to 50% efficiency across industry by 2040.
Industrial Energy Use	Scale up to 75% of industrial processes converted to green H2 and 25% electrified by 2050.
Plug Gas Wells	Scale up to 661 plugged orphan wells (leaking wells) by 2030.

LC 2 (LC fuels)

Theme	Description
Oil and Gas Emissions	Model compliance with the HB 1266 target for the oil and gas sector to reduce emissions 36% by 2025 and 60% by 2030, below 2005 levels. This reduction is held constant after 2030.
Clean Data Centers	100% of data centers use net new 24/7 carbon-free electricity (similar to Google's commitment).
Methane Capture From Coal Mining	Reduce emissions by 70% by 2030 and 100% by 2050.
Cement Process Emissions	Scale up to a 90% reduction by 2035 from concrete in Colorado.
Industrial Process Emissions	Scale up to 444,000 tCO_2e reduction per year by 2030; remaining non-industrial emissions scale up to 100% carbon capture by 2050.
Green Hydrogen	Scale up to in-state production of 67,000 MT by 2035.
Cleaner Electricity Grid	Require 95% emissions reductions by 2035 and 100% clean electricity by 2050; applied to all utilities.
Reduce Agriculture Emissions	Scale up to 80% reductions by 2040 by applying a combination of following: ▪ No-till/reduced tillage ▪ Enhanced-efficiency fertilizers/4R nutrient management ▪ Manure digesters ▪ Enteric methane inhibitors (e.g., Bovaer, seaweed) ▪ Rotational/improved grazing ▪ Agroforestry/tree planting (shelterbelts, riparian) ▪ Biochar soil amendment

LC 2 (LC fuels)

Theme	Description
Carbon Removal	Remaining emissions (57.1 $MMTCO_2e$) are removed between 2045 and 2050to reach the 2050 target.

LC 3 (least cost)

Theme	Description
New Building Performance	New Residential and Non-Residential Buildings ▪ Zero operational carbon in buildings by 2035. 100% electrification. ▪ 100% air-source space-conditioning heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Existing Buildings	Residential Buildings ▪ 50% of existing buildings are retrofitted by 2030, and 100% by 2035. ▪ Deep retrofits with savings of 30% for space-conditioning load and 30% non-space-conditioning load. ▪ 100% air-source space-conditioning heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Existing Buildings	Non-Residential Buildings ▪ 50% of existing buildings are retrofitted by 2030, and 100% by 2035. ▪ Deep retrofits with savings of 30% for space-conditioning load and 30% non-space-conditioning load. ▪ 100% air-source space-conditioning heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.

LC 3 (least cost)

Theme	Description
Building Equipment	Cooking: Scale up to 90% of new purchases being induction by 2030.
Zero-Emissions Transit	Scale up to 50% electricity and 50% green H2 for transit by 2040.
Passenger Rail	Reduction of 63 million VMT (three trips per person) per year starting in 2029, scaling from three trips to 10 trips by 2045.
Commercial VMT Reduction	Reduce VMT trip generation by 25% by 2035 for new warehouse buildings in major cities. VMT trip generation rate is flat after 2035.
E-Bikes	E-bike adoption climbs to 10% of new vehicle sales by 2035 for equity-seeking populations (adults only). Assumes 20% mode share for e-bikes.
Personal-Use ZEV Adoption	Adopt the following ZEV/PHEV new vehicle requirements under Advanced Clean Cars III: ▪ 2026 35% ▪ 2030 68% ▪ 2035 100%
Commercial-Use ZEV Adoption	ZEV (75% hydrogen/25% electric) adoption in 2035 of 75% for Class 4–8 trucks, 55% for Class 2b–3 trucks, and 40% for Class 7–8 tractor trucks. 100% by 2050. Requires transportation network companies and potentially other high-mileage fleets to achieve 80% electric vehicle stock by 2030 and 100% by 2035.
Off-Road Emissions	Scale up to 100% of new purchases being zero-emission by 2035.
Electric Aviation	Scale up to 100% electric for trips of less than 372 miles by 2040.

LC 3 (least cost)	
Theme	**Description**
Sustainable Aviation Fuel	Starting in 2030, sustainable aviation fuel (biofuels) is increasingly introduced, scaling up to 100% by 2040.
Diversion From Landfill	Scale up to 60% waste diversion from landfills by 2040.
Landfill Methane Emissions	Scaling up to major landfills having a landfill capture efficiency of 90% by 2030, producing biomethane (RNG).
Industrial Efficiency	Scale up to 50% efficiency across industry by 2035.
Industrial Energy Use	Scale up to 50% of industrial processes converted to green H2 and 50% electrified by 2050.
Plug Gas Wells	Scale up to 661 plugged orphan wells (leaking wells) by 2030.
Oil and Gas Emissions	Model compliance with the HB 1266 target for the oil and gas sector to reduce emissions 36% by 2025 and 60% by 2030, below 2005 levels. This reduction is held constant after 2030.
Clean Data Centers	100% of data centers use net new 24/7 carbon-free electricity (similar to Google's commitment).
Methane Capture From Coal Mining	Scale up to a 70% reduction by 2030 and 100% by 2050.
Cement Process Emissions	Scale up to a 90% reduction by 2035 from concrete in Colorado.
Industrial Process Emissions	Scale up to 444,000 tCO_2e reduction per year by 2030; remaining non-industrial emissions scale up to 100% carbon capture by 2050.

LC 3 (least cost)	
Theme	**Description**
Cleaner Electricity Grid	Require 95% emissions reductions by 2035 and 100% clean electricity by 2040; applied to all utilities.
Reduce Agriculture Emissions	Scale up to 80% reductions by 2040 by applying a combination of the following: ▪ No-till/reduced tillage ▪ Enhanced-efficiency fertilizers /4R nutrient management ▪ Manure digesters ▪ Enteric methane inhibitors (e.g., Bovaer, seaweed) ▪ Rotational/improved grazing ▪ Agroforestry/tree planting (shelterbelts, riparian) ▪ Biochar soil amendment
Carbon Removal	Remaining emissions (17.5 $MMTCO_2e$) are removed between 2045 and 2050to reach the 2050 target.

LC 4 (sectors)

Theme	Description
New Building Performance	New Residential and Non-Residential Buildings ▪ Zero operational carbon in buildings by 2030. 100% electrification. ▪ 100% air-source space-conditioning heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Existing Buildings	Residential Buildings ▪ 50% of existing buildings are retrofitted by 2035 and 100% by 2045. ▪ Deep retrofits with savings of 30% for space-conditioning load and 30% non-space-conditioning load. ▪ 100% air-source space-conditioning heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Existing Buildings	Non-Residential Buildings ▪ 50% of existing buildings are retrofitted by 2035 and 100% by 2045. ▪ Deep retrofits with savings of 30% for space-conditioning load and 30% non-space-conditioning load. ▪ 100% air-source space-conditioning heat pumps. ▪ Split 50/50 between air-source heat pumps and electric hot water heaters.
Building Equipment	Cooking: Scale up to 90% of new purchases being induction by 2030.
Zero-Emissions Transit	Scale up to 50% electricity and 50% green H2 for transit by 2040.
Passenger Rail	Reduction of 63 million VMT (three trips per person) per year starting in 2029, scaling from three trips to 10 trips by 2045.

LC 4 (sectors)

Theme	Description
Commercial VMT Reduction	Reduce VMT trip generation by 25% by 2035 for new warehouse buildings in major cities.
E-Bikes	E-bike adoption climbs to 10% of new vehicle sales by 2035 for equity-seeking populations (adults only). Assumes 20% mode share for e-bikes.
Personal-Use ZEV Adoption	Adopt the following ZEV/PHEV new vehicle requirements under Advanced Clean Cars III: ▪ 2026 35% ▪ 2030 68% ▪ 2035 100%
Commercial-Use ZEV Adoption	ZEV (75% hydrogen/25% electric) adoption in 2035 of 75% for Class 4–8 trucks, 55% for Class 2b–3 trucks, and 40% for Class 7–8 tractor trucks. 100% by 2050. Requires transportation network companies and potentially other high mileage fleets to achieve 80% electric vehicle stock by 2030 and 100% by 2035
Off-Road Emissions	Scale up to 100% of new purchases by 2050.
Electric Aviation	Scale up to 100% electric for trips of less than 370 miles by 2040.
Sustainable Aviation Fuel	Scale up to 40% sustainable aviation fuel (biofuels) by 2030 and to 100% by 2040.
Diversion From Landfill	Scale up to 60% waste diversion from landfills by 2040.

LC 4 (sectors)

Theme	Description
Landfill Methane Emissions	Scaling up to 2040, major landfills and waste water treatment facilities have a gas capture efficiency of 100% by 2050, producing biomethane (RNG).
Industrial Efficiency	Scale up to 50% efficiency across industry by 2035.
Industrial Energy Use	Scale up to 50% of industrial processes converted to green H2 and 50% electrified by 2045.
Plug Gas Wells	Plug 661 orphan wells (leaking wells) by 2030.
Oil and Gas Emissions	Reduce emissions 35% by 2030, 55% by 2035, 75% by 2040, 85% by 2045, and 100% by 2050.
Clean Data Centers	Ensure 100% of data centers use net new 24/7 carbon-free electricity (similar to Google's commitment).
Methane Capture From Coal Mining	Scale up to an 80% emissions reduction by 2030 and 100% by 2050.
Cement Process Emissions	Starting in 2045, scale up to reducing 100% of emissions by 2050.
Industrial Process Emissions	Starting in 2040, scale up to reducing 100% of emissions by 2050.
Cleaner Electricity Grid	Require 95% emissions reductions by 2035 and 100% clean electricity by 2050; applied to all utilities.

LC 4 (sectors)

Theme	Description
Reduce Agriculture Emissions	Scale up to 20% reductions by 2030, 30% reductions by 2035, 40% reductions by 2040, 50% reductions by 2045, and 80% reductions by 2050 by applying a combination of the following options: ▪ No-till/reduced tillage ▪ Enhanced-efficiency fertilizers / 4R nutrient management ▪ Manure digesters ▪ Enteric methane inhibitors (e.g., Bovaer, seaweed) ▪ Rotational/improved grazing ▪ Agroforestry/tree planting (shelterbelts, riparian) ▪ Biochar soil amendment
Carbon Removal	Remaining emissions (17.5 $MMTCO_2e$) are removed between 2045 and 2050 to reach the 2050 target.

Appendix 6. Emissions Reductions by Action

The scenario results presented are cumulative emissions reductions relative to the BAP Scenario over the 2023–2050 period for each of the actions in the LC scenarios.

LC 1 (E&E)			
Action Title	**Annual Emissions Reduced ($MMTCO_2e$)**	**Percent of Total**	**Cumulative Percent of Total**
Reduce Agriculture Emissions	277.98	17.32%	17.23%
Clean Grid Electricity	183.74	11.45%	28.62%
Industrial Fuel Switch	134.08	8.35%	36.93%
Landfill Gas Capture	121.27	7.55%	44.45%
No New O&G permits	109.58	6.83%	51.24%
Methane Intensity Standard	106.18	6.61%	57.83%
Commercial-Use EVs	82.48	5.14%	62.94%
Personal-Use EVs	72.71	4.53%	67.45%
Industrial Energy Efficiency	70.65	4.40%	71.83%
Passenger Rail	43.87	2.73%	74.55%

LC 1 (E&E)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Aviation Emissions	41.91	2.61%	77.14%
Clean Data Centers	39.00	2.43%	79.56%
Process Emissions	36.26	2.26%	81.81%
New Residential Buildings EUI	35.85	2.23%	84.03%
Residential Retrofits	33.80	2.11%	86.13%
Future Technology	26.78	1.67%	87.79%
Non-Residential Retrofits	26.52	1.65%	89.43%
Cement Process Emissions	24.68	1.54%	90.96%
Off-Road EVs	23.21	1.45%	92.40%
Existing Residential Buildings Equip	22.83	1.42%	93.82%
New Non-Residential Buildings EUI	22.21	1.38%	95.19%
Abandoned Oil Wells	16.35	1.02%	96.21%
Existing Non-Residential Buildings Equip	10.83	0.67%	96.88%
Commercial VMT	9.56	0.60%	97.47%

LC 1 (E&E)			
Action Title	**Annual Emissions Reduced ($MMTCO_2e$)**	**Percent of Total**	**Cumulative Percent of Total**
Increase Active Modes	6.56	0.41%	97.88%
Transit EV	5.18	0.32%	98.20%
Waste Diversion	5.15	0.32%	98.52%
New Non-Residential Buildings Equip	4.41	0.27%	98.79%
E-Bikes	4.37	0.27%	99.06%
Coal Emissions	3.54	0.22%	99.28%
New Non-Residential Buildings Equip	2.76	0.17%	99.45%
Increase Transit Use	1.79	0.11%	99.56%
University DE	1.77	0.11%	99.67%
Residential DE	1.63	0.10%	99.78%
Electric Appliances	1.28	0.08%	99.85%
Virtual Power Plants	1.07	0.07%	99.92%
Rooftop PV	0.80	0.05%	99.97%
Denver DE	0.47	0.03%	100.00%

LC 1 (E&E)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Rural Transit	-7.80	-0.49%	100.00%
Total	1,605	100%	100%

LC 2 (LC fuels)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Reduce Agriculture Emissions	244.89	16.95%	16.89%
Methane Intensity Standard	141.56	9.80%	26.66%
Industrial Fuel Switch	139.34	9.64%	36.27%
Landfill Gas Capture	127.81	8.85%	45.08%
Clean Grid Electricity	123.89	8.57%	53.63%
Personal-Use EVs	100.86	6.98%	60.58%
Commercial-Use EVs	90.89	6.29%	66.85%
Aviation Emissions	77.52	5.37%	72.20%
Industrial Energy Efficiency	70.65	4.89%	77.07%

LC 2 (LC fuels)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Future Technology	59.92	4.15%	81.21%
Clean Data Centers	39.00	2.70%	83.90%
Process Emissions	36.26	2.51%	86.40%
New Residential Buildings EUI	30.85	2.13%	88.52%
Cement Process Emissions	30.20	2.09%	90.61%
Existing Residential Buildings Equip	25.73	1.78%	92.38%
Abandoned Oil Wells	22.09	1.53%	93.91%
New Non-Residential Buildings EUI	18.53	1.28%	95.18%
Existing Non-Residential Buildings Equip	18.43	1.28%	96.46%
Residential Retrofits	16.33	1.13%	97.58%
Commercial VMT	9.56	0.66%	98.24%
New Non-Residential Buildings Equip	6.14	0.43%	98.66%
Non-Residential Retrofits	5.57	0.39%	99.05%
Transit EV	5.53	0.38%	99.43%

LC 2 (LC fuels)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Coal Emissions	3.54	0.25%	99.67%
Electric Appliances	2.41	0.17%	99.84%
New Non-Residential Buildings Equip	2.32	0.16%	100.00%
Rooftop PV	-0.01	0.00%	100.00%
Rural Transit	-4.88	-0.34%	100.00%
Total	1,445	100%	100%

LC 3 (least cost)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Reduce Agriculture Emissions	244.89	15.34%	15.34%
Clean Grid Electricity	193.03	12.09%	27.43%
Methane Intensity Standard	141.37	8.86%	36.29%
Industrial Fuel Switch	132.98	8.33%	44.62%
Landfill Gas Capture	112.81	7.07%	51.69%

LC 3 (least cost)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Commercial-Use EVs	90.89	5.69%	57.38%
Industrial Energy Efficiency	78.79	4.94%	62.32%
Personal-Use EVs	78.49	4.92%	67.24%
Aviation Emissions	77.52	4.86%	72.09%
Future Technology	46.53	2.92%	75.01%
Existing Residential Buildings Equip	46.47	2.91%	77.92%
Passenger Rail	43.87	2.75%	80.67%
Clean Data Centers	39.00	2.44%	83.11%
Process Emissions	36.26	2.27%	85.38%
New Residential Buildings EUI	30.85	1.93%	87.31%
Cement Process Emissions	30.20	1.89%	89.21%
Existing Non-Residential Buildings Equip	29.96	1.88%	91.08%
Residential Retrofits	26.34	1.65%	92.73%
Off-Road EVs	23.21	1.45%	94.19%

LC 3 (least cost)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Abandoned Oil Wells	22.09	1.38%	95.57%
New Non-Residential Buildings EUI	18.53	1.16%	96.73%
Commercial VMT	9.56	0.60%	97.33%
New Non-Residential Buildings Equip	8.70	0.54%	97.88%
Non-Residential Retrofits	7.08	0.44%	98.32%
New Non-Residential Buildings Equip	6.42	0.40%	98.72%
Transit EV	5.53	0.35%	99.07%
Waste Diversion	5.15	0.32%	99.39%
E-Bikes	4.77	0.30%	99.69%
Coal Emissions	3.54	0.22%	99.91%
Electric Appliances	1.43	0.09%	100.00%
Total	1,596	100%	100%

LC 4 (sectors)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Methane Intensity Standard	269.38	17.50%	17.50%
Industrial Fuel Switch	172.43	11.20%	28.70%
Clean Grid Electricity	164.33	10.68%	39.38%
Reduce Agriculture Emissions	142.97	9.29%	48.66%
Aviation Emissions	101.57	6.60%	55.26%
Commercial-Use EVs	90.89	5.90%	61.17%
Industrial Energy Efficiency	78.79	5.12%	66.29%
Personal-Use EVs	78.49	5.10%	71.38%
Landfill Gas Capture	66.78	4.34%	75.72%
New Non-Residential Buildings Equip	46.14	3.00%	78.72%
Passenger Rail	43.87	2.85%	81.57%
Clean Data Centers	39.01	2.53%	84.10%
New Residential Buildings EUI	35.85	2.33%	86.43%
Process Emissions	33.81	2.20%	88.63%
Existing Non-Residential Buildings Equip	29.96	1.95%	90.58%

LC 4 (sectors)

Action Title	Annual Emissions Reduced ($MMTCO_2e$)	Percent of Total	Cumulative Percent of Total
Off-Road EVs	26.21	1.70%	92.28%
Abandoned Oil Wells	22.09	1.43%	93.71%
Residential Retrofits	18.53	1.20%	94.92%
New Non-Residential Buildings EUI	15.26	0.99%	95.91%
Coal Emissions	10.03	0.65%	96.56%
Commercial VMT	9.56	0.62%	97.18%
New Non-Residential Buildings Equip	8.33	0.54%	97.72%
Non-Residential Retrofits	7.08	0.46%	98.18%
Existing Residential Buildings Equip	6.42	0.42%	98.60%
Transit EV	5.53	0.36%	98.96%
Waste Diversion	5.15	0.33%	99.29%
E-Bikes	4.77	0.31%	99.60%
Cement Process Emissions	4.65	0.30%	99.90%
Electric Appliances	1.47	0.10%	100.00%
Total	1,539	100%	100%

Appendix 7. Abatement Costs

Abatement costs are the net present value of the investment, energy costs or savings, and maintenance costs or savings divided by the GHG emissions reduction between 2025 and 2050.

LC 1	$/tCO₂e reduced	LC 2	$/tCO₂e reduced	LC 3	$/tCO₂e reduced	LC 4	$/tCO₂e reduced
E-Bikes	-$4,858	Rural Transit	-$1,600	E-Bikes	-$4,474	E-Bikes	-$4,474
Virtual Power Plants	-$1,534	New Residential Buildings EUI	-$748	New Residential Buildings EUI	-$745	New Residential Buildings EUI	-$739
University DE	-$1,251	Commercial VMT	-$579	Commercial VMT	-$548	Commercial VMT	-$553
Residential DE	-$853	New Non-Residential Buildings EUI	-$472	Residential Retrofits	-$329	New Non-Residential Buildings EUI	-$446
New Residential Buildings EUI	-$734	Residential Retrofits	-$397	Non-Residential Retrofits	-$329	Non-Residential Retrofits	-$329
Commercial VMT	-$677	Non-Residential Retrofits	-$379	Personal-Use EVs	-$289	Personal-Use EVs	-$289
New Non-Residential Buildings EUI	-$466	Electric Appliances	-$307	New Non-Residential Buildings EUI	-$272	Residential Retrofits	-$272
Non-Residential Retrofits	-$323	Personal-Use EVs	-$307	Clean Data Centers	-$242	Clean Data Centers	-$243
Personal-Use EVs	-$294	Clean Data Centers	-$242	Passenger Rail	-$241	Passenger Rail	-$241
Clean Data Centers	-$242	Industrial Energy Efficiency	-$80	Electric Appliances	-$119	Electric Appliances	-$119

LC 1	$/tCO₂e reduced	LC 2	$/tCO₂e reduced	LC 3	$/tCO₂e reduced	LC 4	$/tCO₂e reduced
Passenger Rail	-$241	Abandoned Oil Wells	$3	Industrial Energy Efficiency	-$80	Industrial Energy Efficiency	-$81
Rural Transit	-$208	Reduce Agriculture Emissions	$7	New Non-Residential Buildings Equip	-$28	Off-Road EVs	$0
Denver DE	-$175	Methane Intensity Standard	$9	Off-Road EVs	$0	Abandoned Oil Wells	$3
Electric Appliances	-$120	Industrial Fuel Switch	$12	Abandoned Oil Wells	$3	Existing Non-Residential Buildings Equip	$6
Industrial Energy Efficiency	-$80	Future Technology	$14	Existing Non-Residential Buildings Equip	$6	Methane Intensity Standard	$8
Rooftop PV	-$18	Landfill Gas Capture	$80	Reduce Agriculture Emissions	$7	Reduce Agriculture Emissions	$9
Off-Road EVs	$0	Existing Non-Residential Buildings Equip	$123	Methane Intensity Standard	$9	Industrial Fuel Switch	$13
Abandoned Oil Wells	$4	New Non-Residential Buildings Equip	$137	Landfill Gas Capture	$9	Landfill Gas Capture	$13
Reduce Agriculture Emissions	$6	Existing Residential Buildings Equip	$152	Industrial Fuel Switch	$11	Existing Residential Buildings Equip	$66
Methane Intensity Standard	$9	Aviation Emissions	$164	Future Technology	$18	New Non-Residential Buildings Equip	$151
Industrial Fuel Switch	$11	Process Emissions	$165	Aviation Emissions	$164	Cement Process Emissions	$156
Future Technology	$31	Commercial-Use EVs	$176	Process Emissions	$165	Process Emissions	$172

LC 1	$/tCO₂e reduced	LC 2	$/tCO₂e reduced	LC 3	$/tCO₂e reduced	LC 4	$/tCO₂e reduced
Landfill Gas Capture	$84	Cement Process Emissions	$178	Commercial-Use EVs	$176	Commercial-Use EVs	$176
New Non-Residential Buildings Equip	$107	Coal Emissions	$232	Cement Process Emissions	$178	Coal Emissions	$230
Process Emissions	$165	Transit EV	$292	Existing Residential Buildings Equip	$189	Waste Diversion	$233
Cement Process Emissions	$180			Coal Emissions	$232	Transit EV	$292
Commercial-Use EVs	$189			Waste Diversion	$233	Aviation Emissions	$429
Residential Retrofits	$216			Transit EV	$292		
Coal Emissions	$232						
Waste Diversion	$233						
Existing Non-Residential Buildings Equip	$289						
Transit EV	$397						
Existing Residential Buildings Equip	$427						
Aviation Emissions	$544						
Increase Active Modes	$562						

Appendix 8. Electricity System Analysis

SSG completed a high-level analysis to evaluate the financial impact of decarbonizing the electricity system. The method involved applying shares derived from electricity generation technologies in EIA's Electric Power Projections scenarios[16] to the annual electricity consumption results from ScenaEnergy. Table 8.1 describes the consumption and supply assumptions for each scenario.

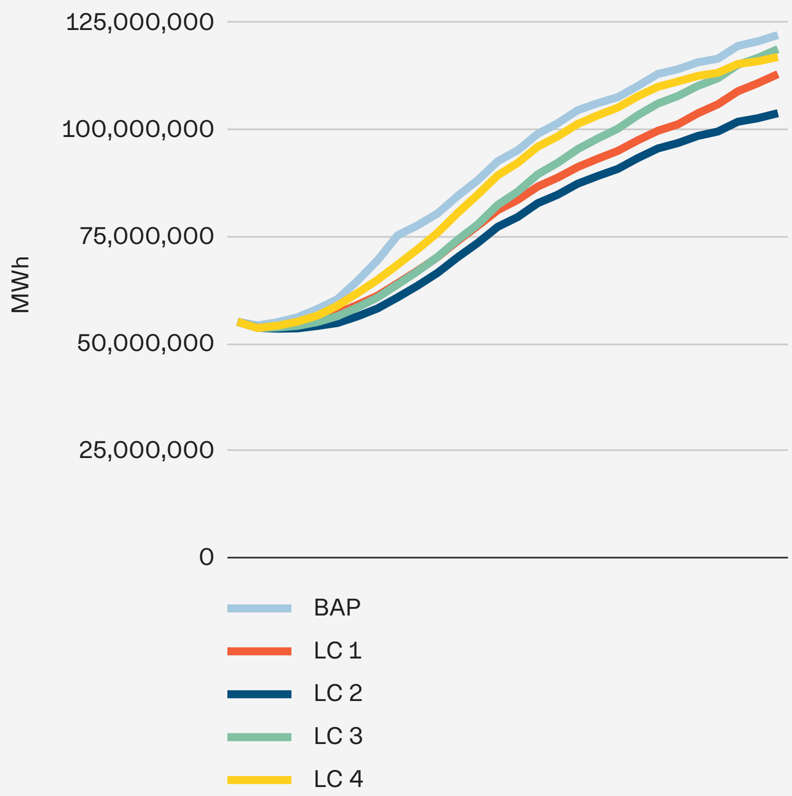
Two variations of the BAP Scenario are evaluated, one in which the current generation mix is held constant and one in which the generation mix evolves according to EIA's reference scenario to enable an assessment of the impact of maintaining coal generation in the generation mix.

16 U.S. Energy Information Administration (2025). Table 54. Electric Power Projections by Electricity Market Module Region Reference case and Low Zero-Carbon Technology Cost projections. Retrieved from: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2025&region=5-3&cases=ref2025~lowZTC&start=2023&end=2050&f=A&sourcekey=0

Table 8.1.
Basis for the electricity generation capacity assumptions

Scenario	Electricity Consumption	Electricity Generation Mix
BAP with current generation mix	BAP	EIA Reference case new capacity demand served by coal instead of renewables.
BAP	BAP	EIA Reference case projection.
LC 1, LC 3	LC 1, LC 3	Starting in 2030, EIA Low Zero-Carbon Technology and all natural gas generation is transferred to renewable energy by 2040.
LC 2, LC 4	LC 2, LC 4	Starting in 2030, EIA Low Zero-Carbon Technology and all natural gas generation is transferred to renewable energy by 2050.
Nuclear	BAP	EIA Reference case projection—Starting in 2030, natural gas is replaced by nuclear by 2050.

Figure 8.1.
Grid electricity consumption grows across all the scenarios. LC 2 has the lowest electricity consumption, as it relies on alternative fuels. LC 1 has the second lowest electricity consumption due to its emphasis on energy efficiency. Lower electricity consumption does not necessarily translate into lower capacity additions because each generation form has a different capacity factor.



Generation by technology was then converted to capacity using capacity factors (calculated from each EIA scenario reported capacity and generation) for each of the scenarios. Figure 8.2 illustrates the annual incremental capacity added for each scenario. This is in addition to an assumed base capacity of 14.8 GW (coal-3.60 GW, gas-4.4 GW, solar-2.0. GW wind-4.7. GW) installed in 2024. Total capacity added between 2025 and 2050 ranges from 27.3 GW (LC 2) to 35.3 GW (LC 4).[17]

17 In comparison, a study analyzing Colorado's electricity supply forecast capacity additions of 25 GW by 2045. As this study did not include a detailed projection of the demand side of the energy system, it is difficult to directly compare the rationale for the capacity projections. These numbers are also influenced by the type of capacity and the related capacity factors. However, in terms of trajectory, there is general alignment. See: Energy Strategies (2024). Transmission Capacity Expansion Study for Colorado. Retrieved from: https://content.leg.colorado.gov/sites/default/files/images/ceta_transmission_study_final_report.pdf#page=17.17.

Figure 8.2.
Incremental capacity added to the electricity generation system for each scenario to address the annual electricity consumption requirements modeled in ScenaEnergy, while also decreasing the GHG intensity of electricity. In each of the LC scenarios, gas capacity comes online to remove coal generation in 2030. In LC 1 and LC 3, gas generation is phased out by 2040. In LC 2 and LC 4, gas generation is phased out by 2050. In the nuclear scenario, nuclear capacity is added starting in 2031 alongside wind and solar to replace natural gas capacity.

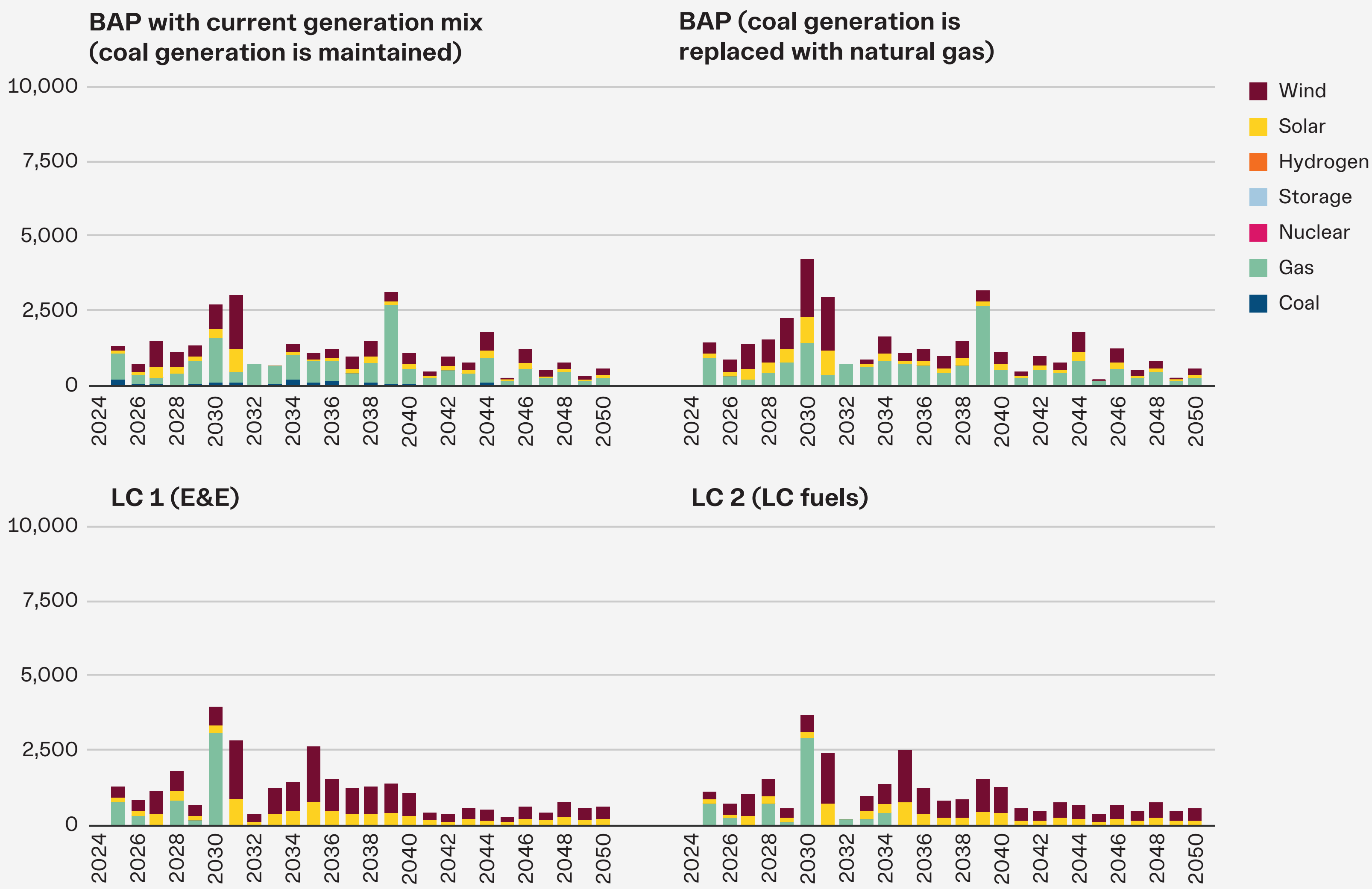
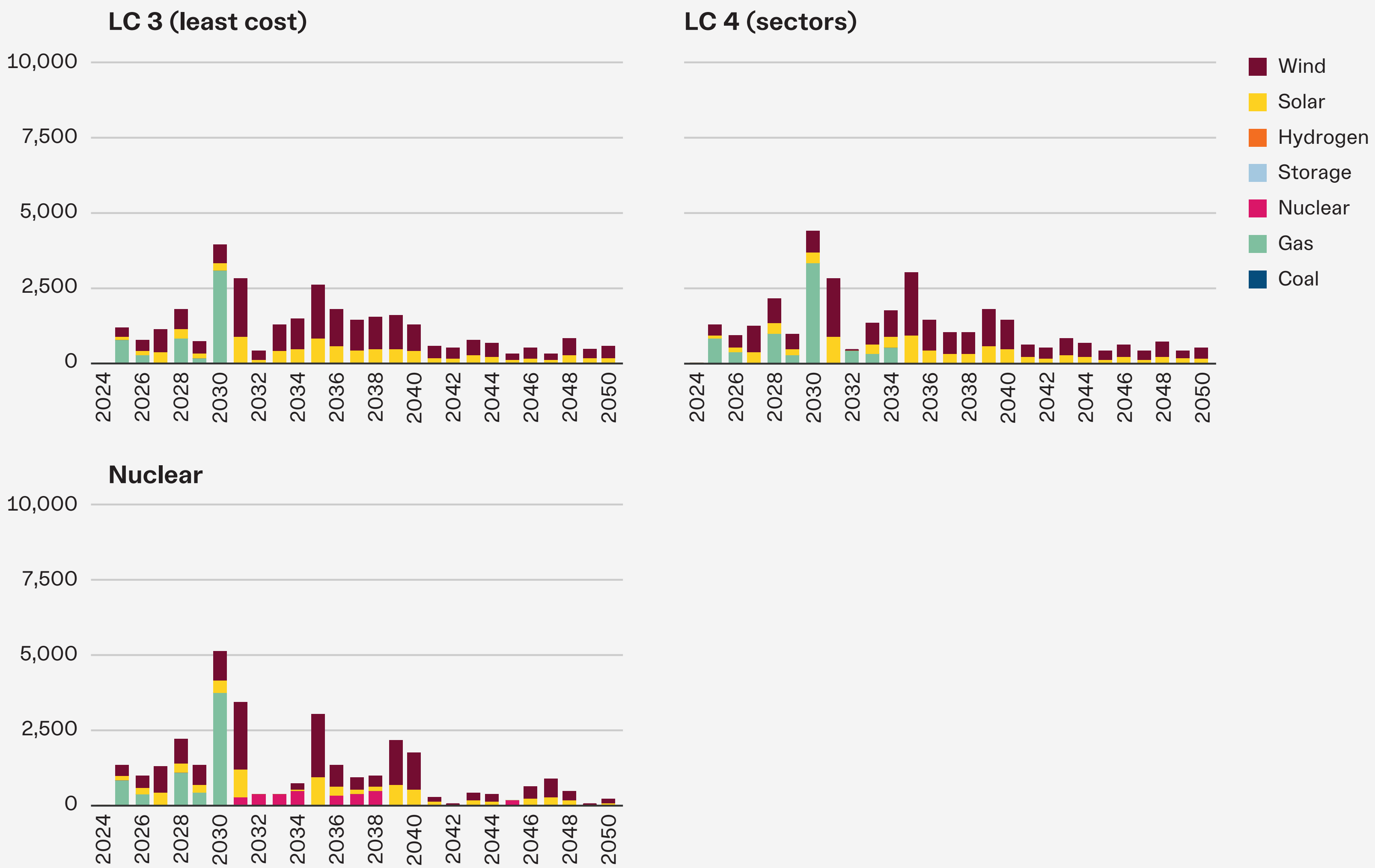


Figure 8.2. *(continued)*



Capital cost intensities were applied to the capacities by technology and variable non-fuel and operations and maintenance intensities were applied to generation totals,[18] and the annual totals were discounted back to $2025 with a 3% discounting rate.[19]

The results (Figure 8.3) provide a number of insights:

- Phasing out coal as currently planned (BAP Scenario) reduces capital investment costs relative to maintaining coal generation (BAP Scenario with current generation mix), however operation and maintenance costs are increased.
- The primary objective of this analysis was to consider whether decarbonizing electricity in the context of the LC scenarios would cause an increase in electricity prices, as the analysis assumes a consistent electricity cost intensity projection across the scenarios. This analysis indicates that this assumption is likely conservative, and it is possible that transitioning the electricity system to zero emissions could be lower cost than one which relies on gas or nuclear power (LC 1's total cost is $39 billion versus $46 billion in the BAP Scenario, for example). In part, this is because electricity consumption is lower in the LC scenarios than in the BAP Scenario.
- While these results are indicative, a more comprehensive analysis (hourly modeling) of the electricity system would be required to evaluate variations in peak electricity demand across the scenarios, temporal availability of supply to consider variability and storage requirements, the impact of decentralized electricity resources, and the implications for transmission and distribution.
- Enhanced geothermal electricity generation was not evaluated, but it has the potential to provide firm generation and grid stability services at a lower cost than nuclear.[20]
- Given that electricity consumption is higher in the BAP Scenario than in the LC scenarios, it is not conclusive that these costs will be higher in a decarbonized electricity system than in a BAP electricity system.
- A study of transmission expansion costs for Colorado found that the transmission investments could be between $4.5 billion (Reference Case Scenario) and $8.7 billion (high-demand scenario),[21] costs which would be on top of the numbers included in Figure 8.3. However, growth in electricity consumption across all the scenarios indicates that transmission investments will be required irrespective of the decarbonization objectives.

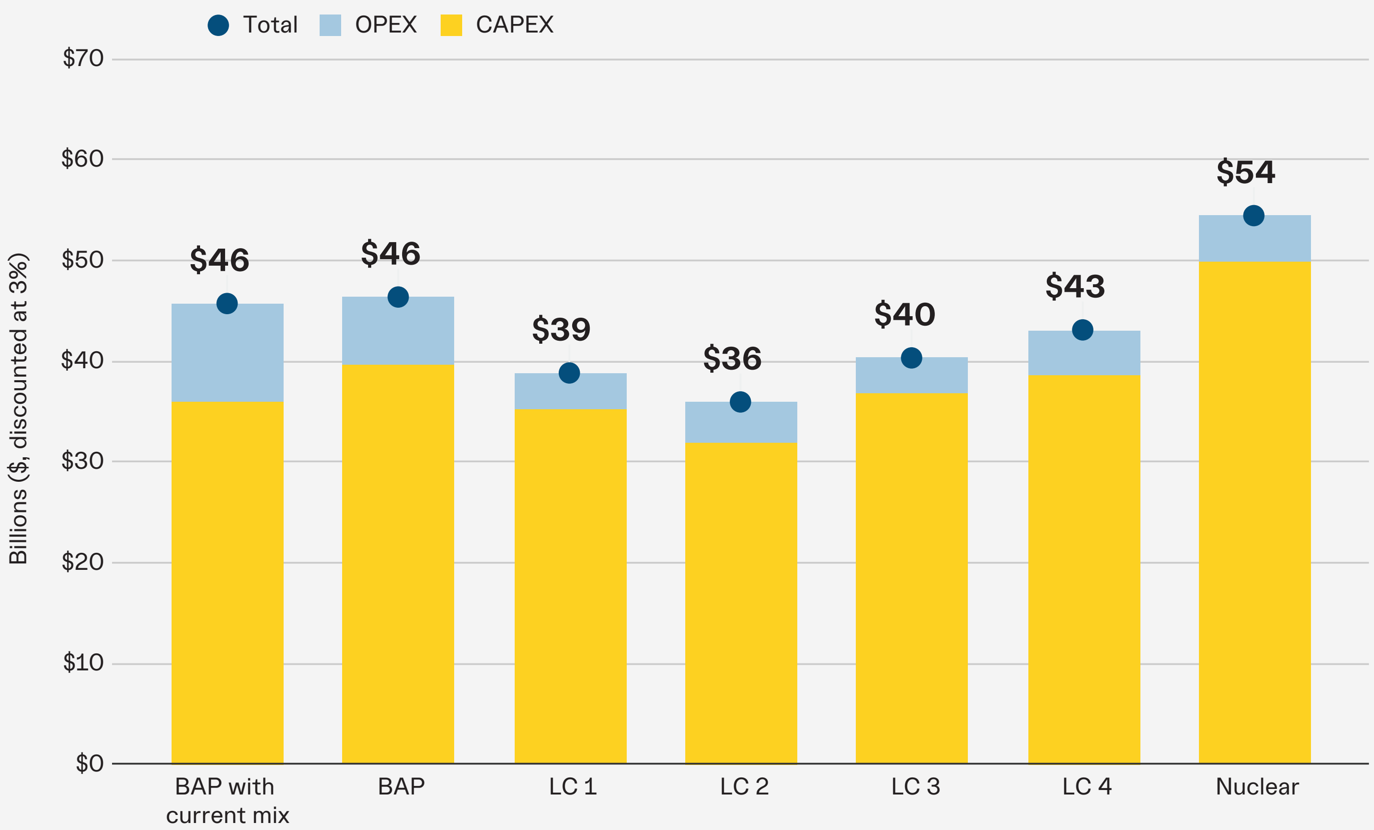
18 NREL (2024).Electricity Annual Technology Baseline (ATB). Retrieved from: https://atb.nrel.gov/electricity/2024/data

19 A social discount rate of 3% is consistent with values used in major climate-economic analyses. See, for example: Organisation for Economic Co-operation and Development (OECD). (2018). Cost-benefit analysis and the environment: Further developments. OECD Publishing. https://doi.org/10.1787/9789264085169-en

20 Horne, R., Genter, A., McClure, M., Ellsworth, W., Norbeck, J., & Schill, E. (2025). Enhanced geothermal systems for clean firm energy generation. Nature Reviews Clean Technology, 1(2), 148-160.

21 Energy Strategies (2024). Transmission Capacity Expansion Study for Colorado. Retrieved from: https://content.leg.colorado.gov/sites/default/files/images/ceta_transmission_study_final_report.pdf#page=17.17.

Figure 8.3
The total CAPEX and OPEX for the electricity system under each of the scenarios. The BAP Scenario with current generation mix has the same electricity consumption as the BAP Scenario, indicating that maintaining coal generation increases electricity system costs. LC 2 has lower electricity consumption than the other LC scenarios, as it relies on alternative fuels. LC 1 and LC 3 phase out natural gas generation by 2040, while LC 2 and LC 4 phase out natural gas generation by 2050. The introduction of nuclear generation increases electricity system costs.



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Technical Report

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