Independent Statistics and Analysis
U.S. Energy Information Administration

Annual Energy Outlook

AEO2023

The U.S. Energy Information Administration (EIA), the statistical and analytical agency within the U.S. Department of Energy (DOE), prepared this report. By law, our data, analyses, and forecasts are independent of approval by any other officer or employee of the U.S. Government. The views in this report do not represent those of DOE or any other federal agencies.

Table of Contents

Table of Figures

Administrator's Foreword

After a 23-year hiatus, I am reintroducing the Administrator's Foreword as part of the *Annual Energy Outlook* (AEO). The Foreword affords me an opportunity to provide context and outline future directions for one of our flagship products.

The U.S. energy system is rapidly changing. In recent years, technology innovation has accelerated the deployment of renewable energy, expanded markets for electric vehicles, and established record-high levels of petroleum and natural gas production. Heightened geopolitical risks have also influenced the energy system. And this year, recent federal legislation authorizes historic levels of investment in clean energy technology.

Ideally, we would model these dynamics to produce precise numerical forecasts that demonstrate how energy prices, technology deployment, and emissions will shift over time. Unfortunately, such precise forecasts are not possible. The 30-year decision landscape we model is too complex and uncertain. Thus, our objective must be to identify robust insights rather than precise numbers—think ranges and trends, not predictions and point estimates.

The AEO includes a series of projections—which we refer to as *cases*—each with different input assumptions that represent alternative views of how uncertainty may be resolved in the future. The Reference case represents our best guess under nominal conditions, which presumes no new policy or laws over the modeled time horizon. It's best to think of the Reference case as the experimental control: a baseline against which we can judge the other cases. Although the Reference case serves as an important benchmark, judgments about energy futures should never be based on a single projection. The AEO side cases represent plausible variations in key input assumptions that tend to drive the largest changes in projected outputs from the Reference case. This year's AEO narrative focuses on the full set of modeled cases in order to derive insights about our collective energy future.

Among the uncertainties we must confront, the timing, structure, and targets associated with yet-to-be-developed policy are the most uncertain. We only consider current laws and regulations across all modeled cases in this AEO. For some readers, this approach may be unsatisfying because policy rarely remains static for long periods. But this AEO should be considered part of an iterative policymaking process rather than apart from it; it gives decision-makers an opportunity to peer into a future without new policy. If the projected outcomes are undesirable from their viewpoint, they can effect change.

Changes to This Year's Edition

This year's edition of the *Annual Energy Outlook* includes three enhancements that improve the characterization of future uncertainty and provide more technical details on the model results.

Combination cases

Although the AEO core side cases address key uncertainties, each case represents a one-factor change to the Reference case. But, real energy markets often surprise us in more ways than one, particularly over the decades-long timeframes modeled in the AEO. In this year's edition, we include cases that combine assumptions from our macroeconomic and zero-carbon technology cost cases. These new cases reflect a combination of demand-side changes (macroeconomic growth affecting energy demand) and supply-side changes (renewables costs affecting generating capacity deployment) to expand the range of projections in the *Annual Energy Outlook*.

Visualizing uncertainty

Running a set of cases is not enough: how we present and discuss them within the report affects the insights that our readers draw from the analysis. Although the Reference case is an important benchmark, each case represents a possible alternative. So, in each of the figures in this report, you will see shaded areas that represent the range of results obtained across the modeled cases. Uncertainty can be characterized in many other ways beyond the analysis of multiple cases. One way, presented in the discussion section, uses deviations between realized and projected values drawn from previous AEO editions to derive a cone of uncertainty for future energy-related CO_2 emissions. Looking ahead, you should expect to see more innovation in how we treat uncertainty.

Technical notes

The narrative tends to focus on model-based results. We recognize that some readers want a deeper technical explanation around key issues. Although we describe our modeling approach elsewhere, how the model formulation and input assumptions influence the results is not always clear. To better explain key results, we included a series of technical notes in the narrative that focus on heat pump deployment, cost projections for renewables, electric vehicle deployment, and crude oil trade.

Future Work

At EIA, we are also pursuing broader changes to our long-term modeling efforts. I would like to highlight three such efforts.

Open-source code

One of our priorities at EIA is to make our data and model-based analysis as transparent and accessible as possible. We are working to make the National Energy Modeling System (NEMS) publicly available in GitHub under a permissive, open-source license, and we hope to complete this effort later this year. Making our models open source allows users to examine, reuse, and redistribute our code under clear legal guidelines. Giving you this kind of access is important to the learning and discovery process associated with energy modeling.

Expanded scenario range

Building on the combination cases in this year's AEO, we are expanding our capability to model a wider range of future scenarios using NEMS. In particular, decision makers need objective and rigorous assessments of net zero emissions pathways to inform ongoing policy discussions. We are working to incorporate novel fuel and technology pathways into NEMS and to appropriately treat uncertainty around technologies with limited commercial deployment.

A next-generation, open-source modeling framework

Although regularly updated, we have been using NEMS to produce the AEO since 1994—a span of nearly three decades that has born witness to significant changes in the real energy system, energy modeling methods, and software development practices. Moving forward, we need a flexible, next-generation modeling framework that can rapidly assess the cost, emissions, reliability, security, and community-level impacts associated with a number of contemporary energy issues. Some of these issues include pathways to a net-zero energy system, supply chain risks, rapid technology innovation, and shifting trade patterns. This modeling system will also be open source to promote transparency and encourage innovation within the modeling community. We've begun discussing this new framework, and I look forward to sharing our progress throughout my tenure as EIA Administrator.

In Closing

I'd like to thank our long-term modelers for their willingness to take on new directions and their tremendous effort to produce this year's AEO. I am very excited by the future work outlined above, and I feel privileged to help lead such a talented team of energy modelers.

Executive Summary

Our *Annual Energy Outlook* 2023 (AEO2023) explores long-term energy trends in the United States. Since last year's AEO, much has changed, most notably the passage of the Inflation Reduction Act (IRA), Public Law 117–169, which altered the policy landscape we use to develop our projections.

> Energy-related CO_2 emissions fall across all AEO2023 cases because of increased electrification, higher equipment efficiencies, and more zero-carbon electricity generation.

We project that U.S. energy-related CO_2 emissions drop 25% to 38% below the 2005 level by 2030. For reference, the United States' *nationally determined contribution* (NDC), submitted as part of the Paris Agreement, calls for a target of 50% to 52% of net greenhouse gas emissions below the 2005 level by 2030.[1] We only consider energy-related CO_2 emissions, which does not cover the full NDC scope. Total energy-related CO_2 emissions in 2050 declined by 17% in this year's Reference case compared with last year's. Some of the primary factors that contributed to the change in our base case include the IRA, updates to technology costs and performance across the energy system, and changes in the macroeconomic outlook. All AEO2023 cases assume current laws and regulations, and compared with last year's AEO, there is a significant shift toward lower future emissions. The IRA represents a complex piece of legislation, and we could not model all provisions given model structure and uncertainty over select implementation details. The appendix includes a detailed accounting of IRA provisions and how we addressed them. To further explore possible emissions reductions, we also derive a cone of uncertainty based on an empirical analysis of our past projections and find that the energy-related CO_2 emissions reduction can be as high as 38% below 2005 levels in 2030.

Overall, our lower projected U.S. energy-related CO_2 emissions is driven by increased electrification, equipment efficiency, and renewable technologies for electricity generation. However, emissions reductions are limited by longer-term growth in U.S. transportation and industrial activity. As a result, these projected emissions reductions are most sensitive to our assumptions regarding economic growth and the cost of zero-carbon generation technology.

---

[1] The *nationally determined contribution* (NDC) is a formal submission to the United Nations Framework Convention on Climate Change. The United States submitted, "To achieve an economy-wide target of reducing its net greenhouse gas emissions by 50-52 percent below 2005 levels in 2030."

In AEO2023, we see stable growth in U.S. electric power demand through 2050 in all cases we considered because of increasing electrification and ongoing economic growth. The combination of declining capital costs and government subsidies, including IRA initiatives, drive rising renewable technologies for electricity generation, such as solar and wind. Once built and when the resource is available, wind and solar are the least cost resources to operate to meet electricity demand because they have zero fuel costs. Over time, the combined investment and operating cost advantage increases the share of zero-carbon electricity generation. As a result, in AEO2023, we see renewable generating capacity growing in all regions of the United States in all cases. Across all cases, compared with 2022, solar generating capacity grows by about 325% to 1019% by 2050, and wind generating capacity grows by about 138% to 235%. We see growth in installed battery capacity in all cases to support this growth in renewables. Across the span of AEO cases, relative to 2022, natural gas generating capacity ranges from an increase of between 20% to 87% through 2050.

Renewable generating capacity grows in all regions of the United States in all AEO2023 cases, supported by growth in installed battery capacity.

Technological advancements and electrification drive projected decreases in demand-side energy intensity.

Not only is the U.S. electric power sector's composition changing, but we see increased electrification in the end-use sectors. We project more heat pumps and electric vehicles, as well as electric arc furnaces increasingly deployed in the iron and steel industry. In the residential and commercial sectors, higher equipment efficiencies and stricter building codes extend ongoing declines in energy intensity. Despite the growth in adopting heat pumps, natural gas-fired heating equipment, including furnaces and boilers, continue to account for the largest share of energy consumption for space heating in U.S. residential and commercial buildings across all cases through 2050. In the transportation sector, light-duty vehicle energy demand declines through 2045 as more electric vehicles are deployed and stricter Corporate Average Fuel Economy (CAFE) standards largely offset the continued growth in travel demand. The energy demand then increases as rising travel overcomes increasing efficiency. Across all cases, light-duty vehicle energy demand decreases by 3% to 28% in 2050 relative to 2022.

High international demand leads to continued growth in U.S. production, and combined with relatively little growth in domestic consumption, allows the United States to remain a net exporter of petroleum products and natural gas through 2050 in all AEO2023 cases.

Despite no significant change in domestic petroleum and other liquids consumption through 2040 across most AEO2023 cases, we expect U.S. production to remain historically high as exports of finished products grow in response to growing international demand. Despite the shift toward renewable sources and batteries in electricity generation, domestic natural gas consumption remains relatively stable—ending recent growth in most cases. Natural gas production, however, in some cases continues to grow in response to international demand for liquefied natural gas, supported by associated natural gas produced along with crude oil. Given the combination of relatively little growth in domestic consumption and continued growth in production, we project that the United States will remain a net exporter of petroleum products and natural gas through 2050 in all AEO2023 cases.

Introduction

The *Annual Energy Outlook* 2023 (AEO2023) explores long-term energy trends in the United States. Since we released the last AEO in early 2022, passage of the Inflation Reduction Act (IRA), Public Law 117–169, altered the policy landscape we use to develop our projections. The Appendix in this report explains our assumptions around IRA implementation and how we implemented the IRA in our AEO2023 cases. We are also releasing a separate *Issues in Focus* paper that explores how these assumptions affect our model-based projections. We have seen significant national and international short-term market volatility associated with economic growth as the world reemerges from the COVID-19 pandemic and political instability associated with Russia's full-scale invasion of Ukraine. We continuously monitor such developments and consider how they may affect our long-term projections.

AEO2023 includes a Reference case and 12 side cases that explore key areas of uncertainty about how energy markets will develop. We retooled our graphs to emphasize the range of results, denoted by shaded areas, across the full suite of modeled cases. We derive our key analytical insights by assessing the results across cases and examining how overall trends may vary under different assumptions. This year, we've added a discussion section focused on sources of uncertainty in the AEO2023 projections. We also now derive a cone of uncertainty associated with future energy-related CO_2 emissions using deviations between past projections and realized values.

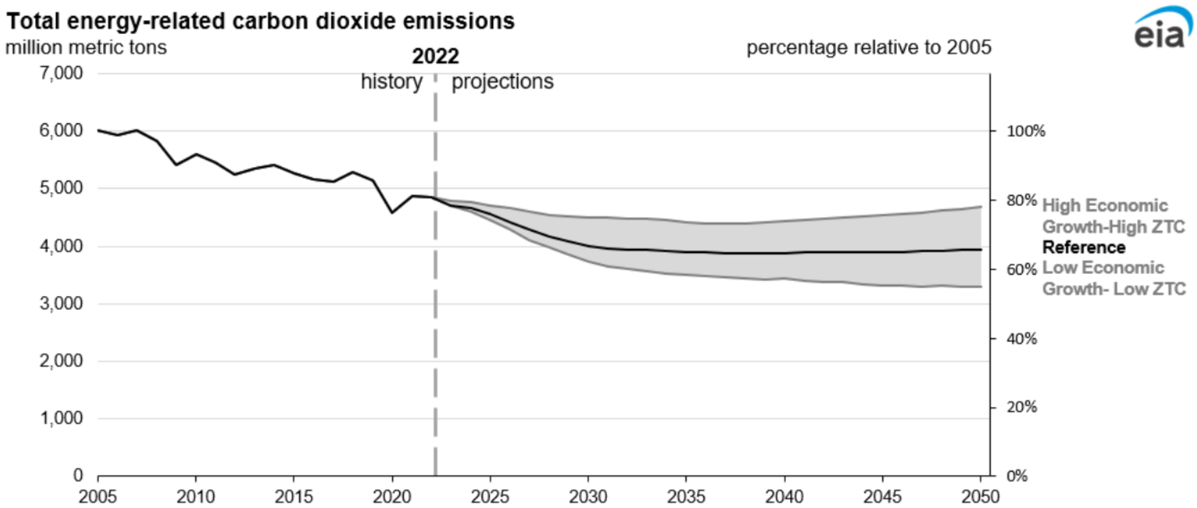
By 2030, energy-related CO_2 emissions fall 25% to 38% below 2005 levels, depending on case assumptions

Under the Paris Agreement, the United States set a goal to reduce economy-wide greenhouse gas emissions by 50% to 52% of 2005 levels by 2030. We only consider energy-related CO_2 emissions, which does not cover the full NDC scope. We project lower U.S. energy-related CO_2 emissions in 2030 relative to 2005 in the AEO2023 Reference case and all side cases (Figure 1). CO_2 emissions are most sensitive to economic growth and assumptions related to the cost of zero-carbon generation technology. Combinations of these two sets of assumptions form the upper and lower bounds of projected CO_2 emissions. Emissions decrease by 25% in 2030 relative to 2005 under the combined high economic growth and high zero-carbon technology cost assumptions and by as much as 38% under low economic growth and low zero-carbon technology cost assumptions. Both of these cases hinge on specific assumptions regarding the relationship between economic growth and zero-carbon technology development.[2] In the High Economic Growth case, emissions fall initially and then begin to increase

[2] The purpose of the combination cases was to explore a wider range of outcomes. We did not explicitly consider the correlation or interaction between zero-carbon technology costs and economic growth. The High Economic Growth and High Zero-Carbon Technology Cost case assume this higher growth rate takes place without declining zero-carbon technology costs. Similarly, slower economic growth accompanies declining technology costs in the Low Economic Growth and Low Zero-Carbon Technology Cost case.

again in 2040 as industrial activity and travel (measured in vehicle miles traveled) increase, surpassing emissions reductions from the electric power sector.

Figure 1.

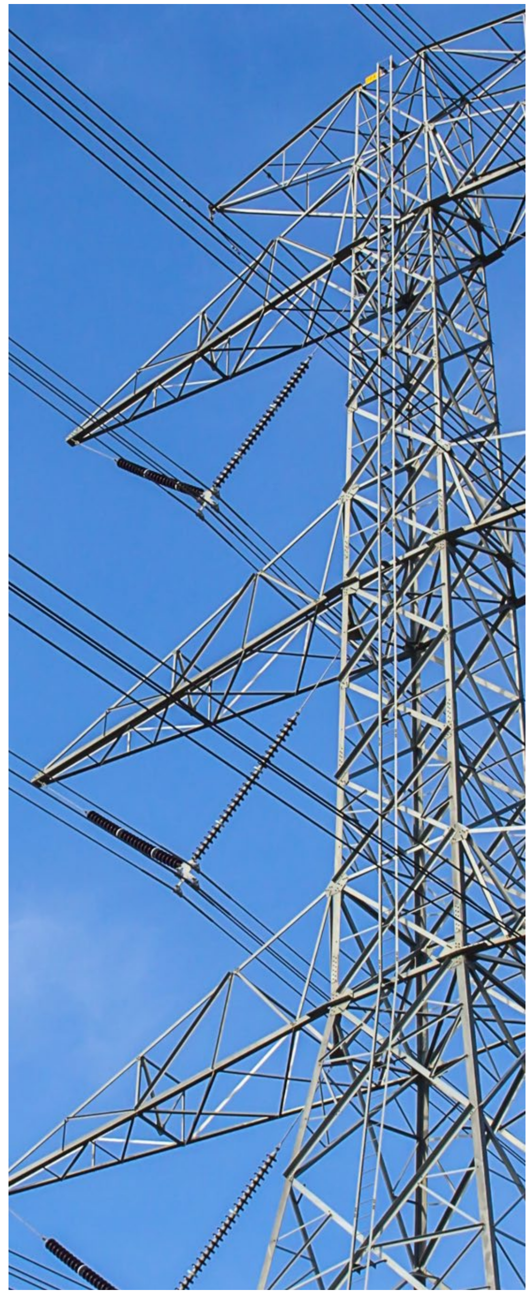


Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost.

The largest variations in projected U.S. CO_2 emissions across cases occur in the electric power, transportation, and industrial sectors. Although economic growth assumptions affect consumption and, in turn, projected CO_2 emissions in all sectors, different case-specific assumptions affect sectors differently. For example, emissions from the electric power sector are particularly responsive to assumptions about the cost of zero-carbon technologies, and transportation sector emissions are sensitive to assumptions about fossil fuel supply and cost, particularly oil and petroleum products.

1

The Electricity Mix in the United States Shifts from Fossil Fuels to Renewables



In this section, we discuss renewables displacing fossil fuels in the electric power sector.

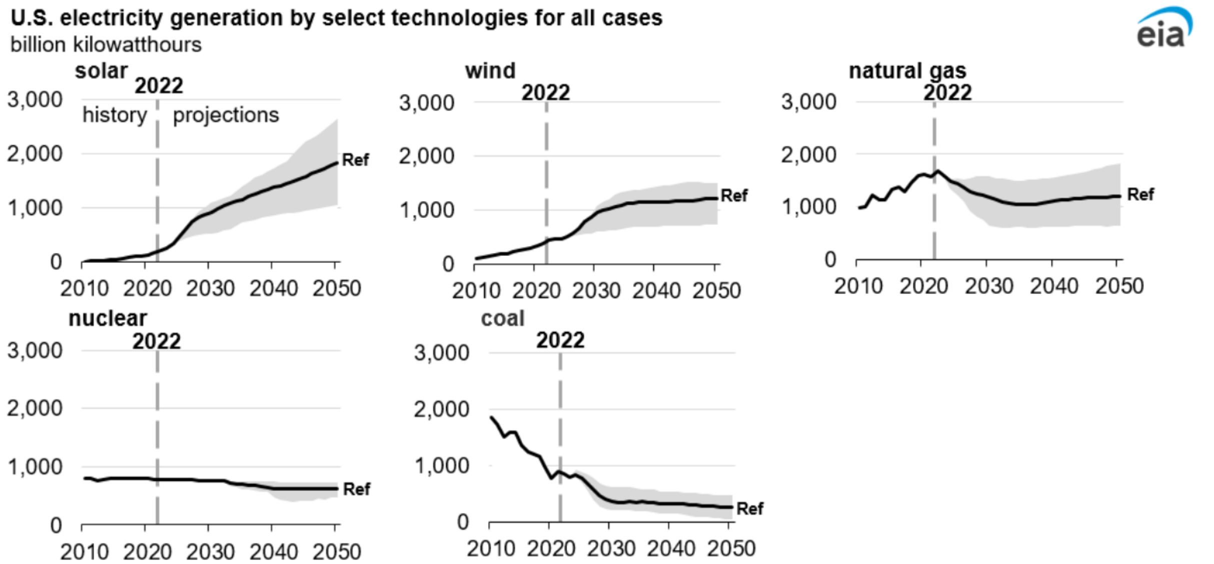
Renewables displace fossil fuels in the electric power sector due to declining renewable technology costs and rising subsidies for renewable power

Economic growth paired with increasing electrification in end-use sectors results in stable growth in U.S. electric power demand through 2050 in all cases. Declining capital costs for solar panels, wind turbines, and battery storage, as well as government subsidies such as those included in the IRA, result in renewables becoming increasingly cost effective compared with the alternatives when building new power capacity.

Power demand is increasingly met by renewables throughout the projection period.

Renewables are increasingly meeting power demand throughout the projection period (Figure 2). Natural gas, coal, and nuclear generation shares decline. Renewable power outcompetes nuclear power, even in the Low Zero-Carbon Technology Cost (ZTC) case, which evaluates the impact of more aggressive cost declines for nuclear and renewables than the Reference case. Most natural gas-fired generation comes from combined-cycled power plants as opposed to simple-cycle combustion turbines. Uncertainty in natural gas prices across cases leads to various projections for combined-cycle units in the short term, but in the long term, natural gas demand from the electric power sector stabilizes across all cases.

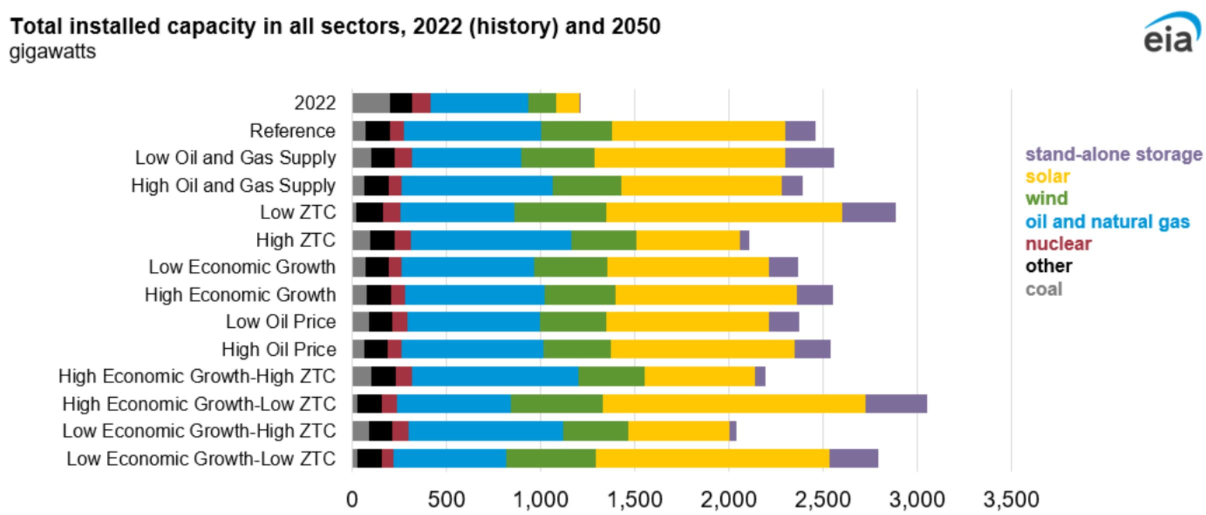
Figure 2.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. Ref=Reference case.

In order to meet increasing demand for electric power throughout the projection, total installed power capacity close to doubles across most cases, even in the Low Economic Growth case (Figure 3). Cases with a higher share of renewables in the generation mix have higher total grid capacity due to the inherently lower capacity factors of solar and wind compared with coal, nuclear, and combined-cycle plants.

Figure 3.

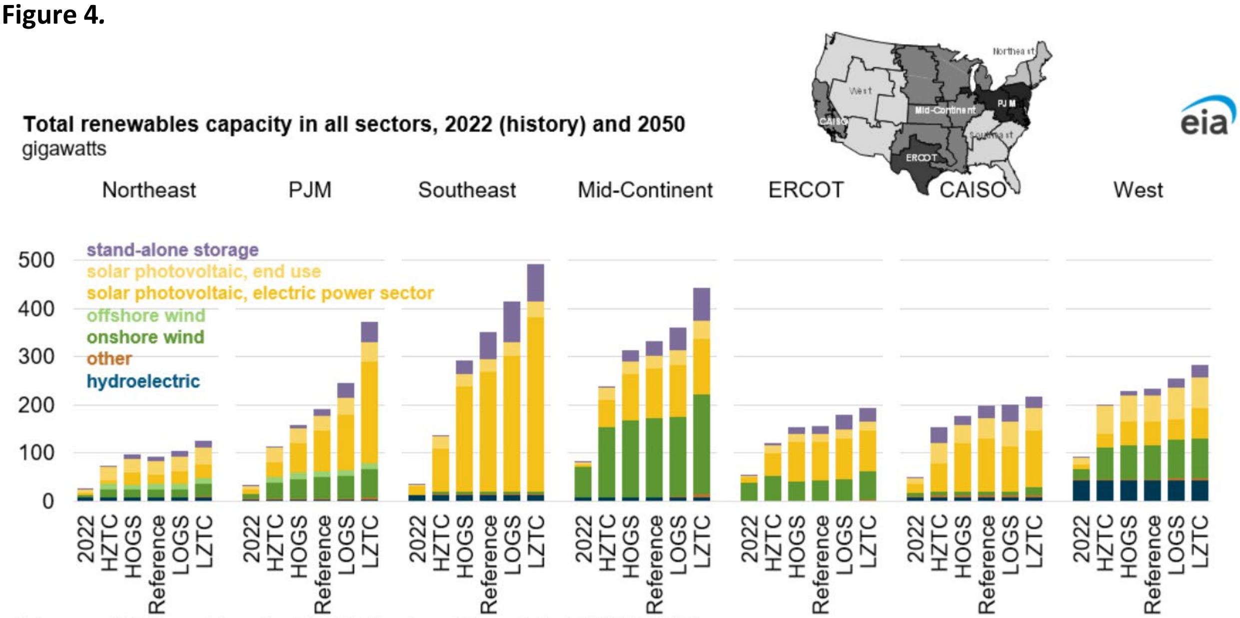


Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: ZTC=Zero-Carbon Technology Cost; other=geothermal, biomass, municipal waste, fuel cells, hydroelectric, pumped hydro storage.

We project that renewable power capacity will increase in all regions of the United States in all AEO2023 cases, although regional resource availability results in varying renewable resource mixes across regions (Figure 4). Across all cases, between 40%-60% of the renewable power capacity in the Mid-Continent region in 2050 comes from wind, and the Southeast and the region managed by the California

Independent System Operator (CAISO) have large shares of solar and a small amount of wind power capacity in all cases.

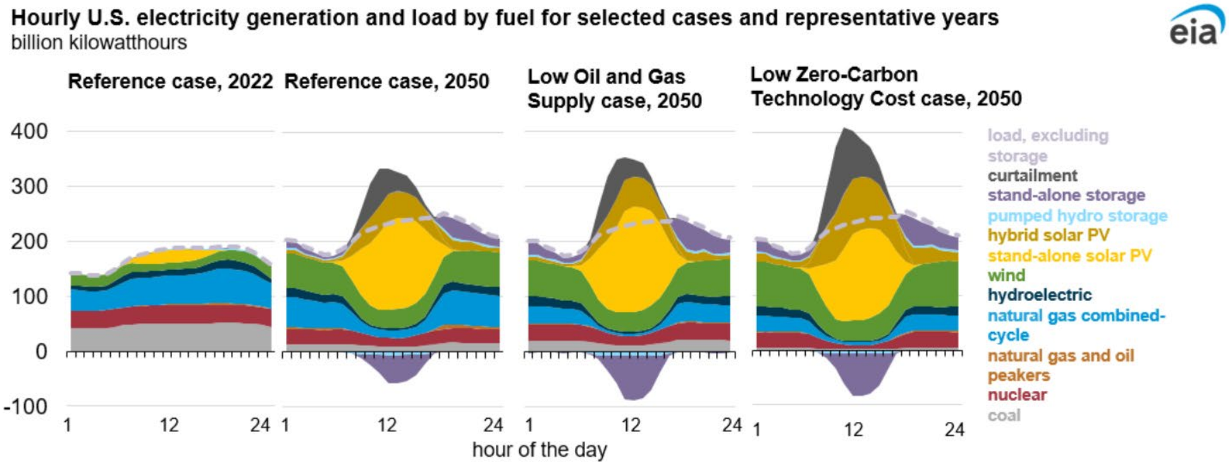
Figure 4.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: HZTC=High Zero-Carbon Technology Cost; LZTC=Low Zero-Carbon Technology Cost; HOGS=High Oil & Gas Supply; LOGS=Low Oil & Gas Supply; other=geothermal, biomass, municipal waste.

Once built and when the resource is available, wind and solar generation outcompete other technologies for system dispatch because they have zero fuel costs. Across all AEO2023 cases, some renewable generation is left unused and curtailed, typically midday when solar generation can exceed demand in some regions and seasons. Battery capacity is built in all cases to store and dispatch some of this otherwise unused generation in later hours, decreasing reliance on fossil fuel capacity, such as natural gas-fired peaking units or load-following combined-cycle units (Figure 5). Battery storage is also used to replace natural gas-fired capacity to provide reserve capacity. In the Reference case in 2050, 160 gigawatts (GW) of standalone battery storage capacity will be deployed, and deployment varies between 40 GW and 260 GW in the other cases.

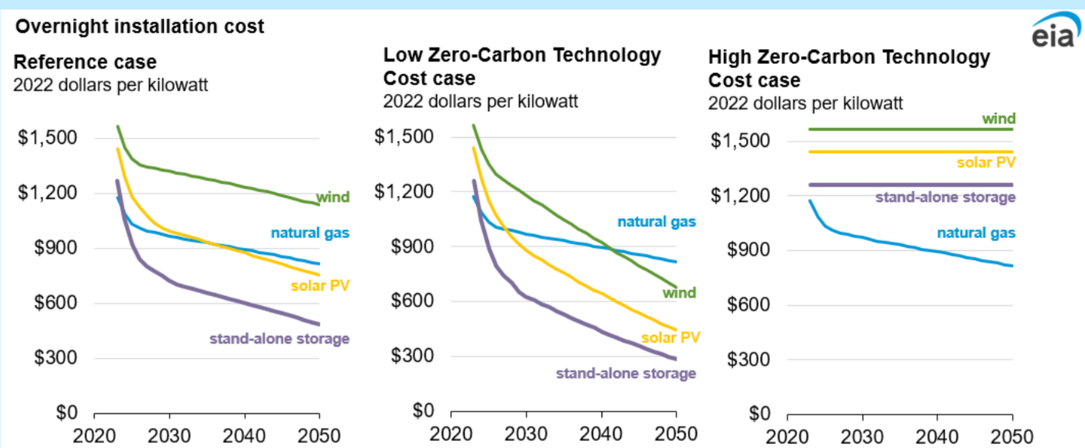
Figure 5.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Negative generation represents charging of energy storage technologies such as pumped hydro storage and battery storage. Hourly dispatch estimates are illustrative and are developed to determine curtailment and storage operations; final dispatch estimates are developed separately and may differ from total utilization as this figure shows. Standalone solar photovoltaic (PV) includes both utility-scale and end-use PV electricity generation.

Technical Note 1: Renewable costs and deployment

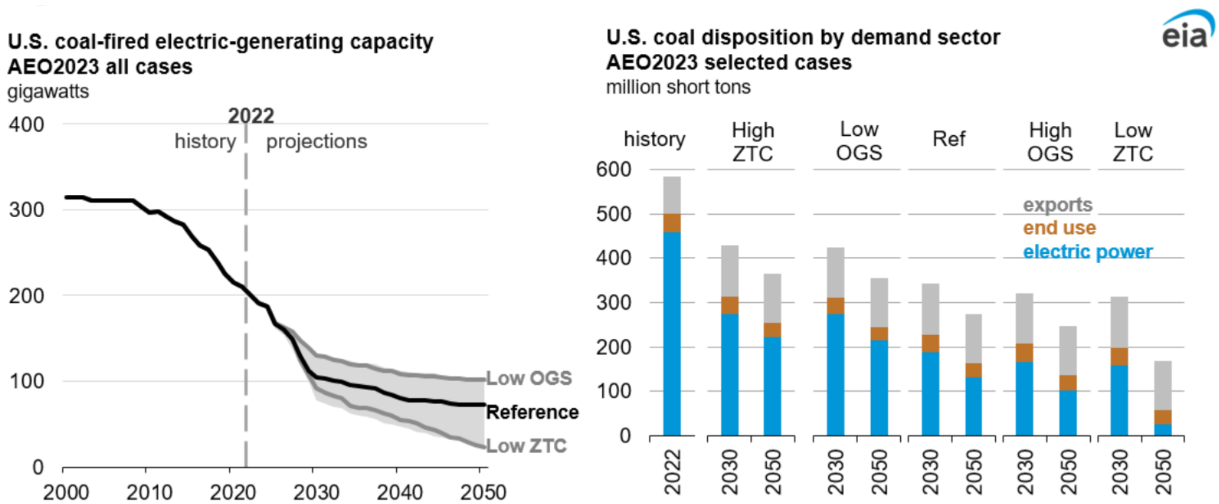
Continued decline of renewable technology costs relative to natural gas-fired generating technologies contributes to the change in generation mix in our projection period. In addition to recent policies that also favor renewables in the generation mix, we use learning factors to represent learning by doing, which reduces capital costs. Learning factors are calculated independently for each of the major design components of the technology, and they increase based on how much new capacity is deployed. For details on renewable costs in the ZTC cases, please see the Appendix. New, untested components decrease at a more rapid initial rate than mature components or conventional designs. More details can be found in the NEMS Electricity Market Module documentation.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Series in all charts begin in 2023. Overnight installation cost for natural gas refers to combined-cycle, multi-shaft technologies. Nuclear costs decline in the Reference and Low Zero-Carbon Technology cases, but they are not shown given the large differences in absolute cost compared with renewables. In the Reference case, nuclear begins at $7,900 per kilowatt (kW) and declines to $5,000/kW in 2050. In the Low Zero-Carbon Technology case, the cost of nuclear declines to $3,000/kW in 2050. Solar PV=stand-alone solar photovoltaic.

As a result of renewables growth, we project that U.S. coal-fired generation capacity will decline sharply by 2030 to about 50% of current levels (about 200 GW) with a more gradual decline thereafter. We project between 23 GW and 103 GW of coal-fired capacity operating in 2050 (Figure 6). The IRA provides additional incentives to wind and solar power generation, which accelerates the near-term decline of electric power sector coal-fired generating capacity and hastens the timeline for retirement in the U.S. coal fleet.

Figure 6.



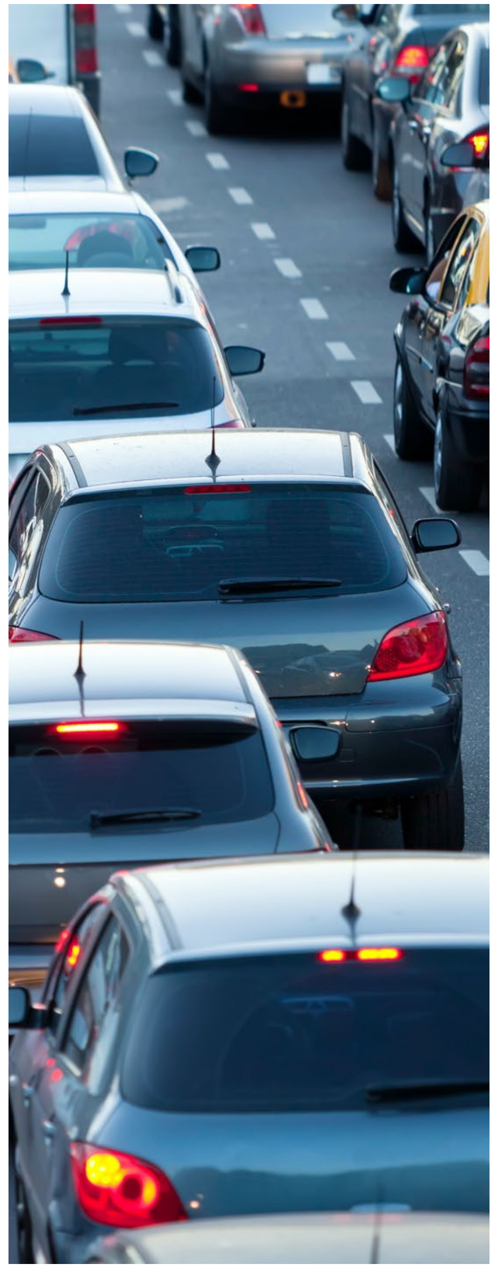
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.
ZTC=Zero-Carbon Technology Cost; Ref=Reference case; OGS=Oil and Gas Supply.

Coal consumption in the U.S. electric power sector in the Reference case drops to 189 million short tons (MMst) in 2030 and to 131 MMst in 2050 from 458 MMst in 2022. Coal disposition, which includes exports and consumption by the electric power sector and other end-use sectors, declines to a low of 170 MMst in 2050 in the Low ZTC case. In a high natural gas price environment, such as in the Low Oil and Gas Supply case, coal disposition could remain as high as 350 MMst in 2050. In all cases, annual coal exports average about 110 MMst in 2050, and end-use coal demand averages about 36 MMst. The ratio of coal exports to domestic coal consumption generally increases through the projection period in all cases. The majority of domestically produced coal is exported by 2050 in the Low ZTC case, 45% is exported in the High Oil and Gas supply case, which are the two cases that have the least coal demand from the electric power sector. Even in cases with more aggressive retirement of coal-fired power plants, such as the Low ZTC case, some of the relatively newer and more efficient coal power plants remain online across the United States because they can provide cheap dispatchable power to the grid.

The electric power sector is also decreasing its reliance on natural gas in favor of renewables, which we will discuss in Section 3.

2

Technological Advancements and Electrification Decrease Demand-Side Energy Intensity



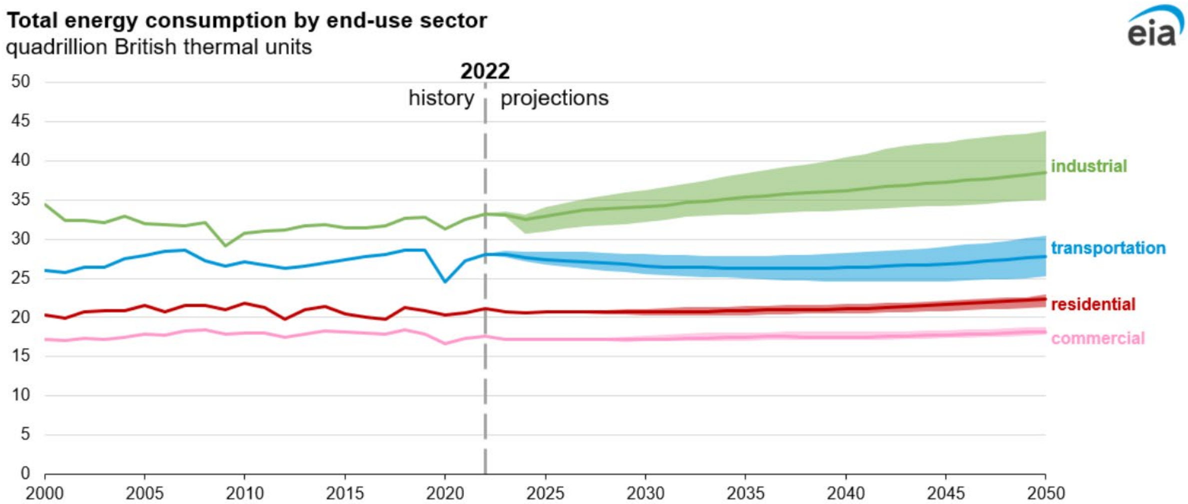
Moderate growth in U.S. energy consumption is the result of economic growth, population growth, and increased travel offsetting continued energy efficiency improvements. Demand-side energy intensity—the measure of energy consumed per household or per square foot of commercial floorspace—decreases as a result of changes in technology, policy, consumer behavior, demographics, and fuel mix. In this section, we quantify the decreases in CO_2 emissions intensity and demand-side energy intensity, and we discuss equipment changes in the buildings sector, electrification in iron and steel production, and technological advancements and government standards in the transportation sector.

U.S. energy consumption increases through 2050, and electricity plays an increasingly large role

U.S. energy consumption increases in many end-use sectors across all AEO2023 cases. Total energy consumption, including electricity use and electricity-related losses, increases by as much as 15% from 2022 to 2050 across the AEO2023 Reference case and side cases (Figure 7). The largest increases, in percentage terms, are in the industrial sector where energy consumption increases as much as 32% and in the transportation sector where energy consumption increases as much as 8%. Energy consumption in the residential and commercial sectors are the least sensitive to changes in assumptions across cases.

Total energy consumption, including electricity use and electricity-related losses, increases by as much as 15% from 2022 to 2050 across the AEO2023 Reference case and side cases.

Figure 7.



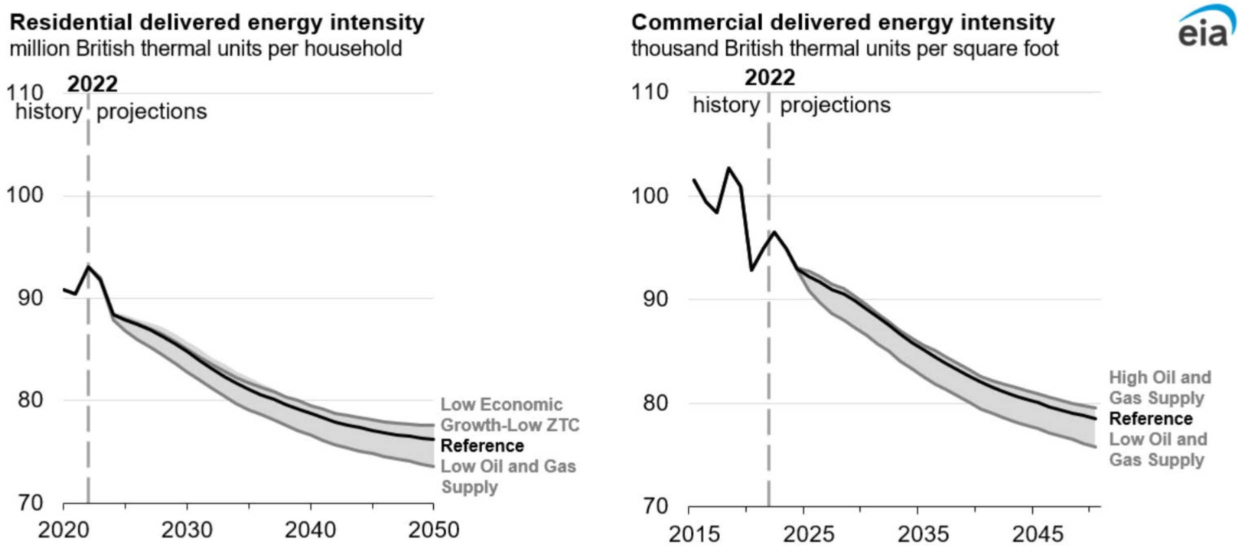
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Total consumption in end-use sectors includes purchased electricity and electricity-related losses. Each line represents AEO2023 Reference case projections. Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.

In addition to macroeconomic growth assumptions, which affect energy consumption in all sectors, many sectors are also highly responsive to zero-carbon technology cost assumptions. Increasing energy consumption, improving end-use and electric power sector technology and efficiency, and declining costs for zero-carbon generation technologies, which, in turn, leads to cheaper electricity, all lead to increased electrification in the end-use sectors. The share of electricity in the residential and transportation sectors increase the most as demand for space cooling increases and electric vehicles gain a larger market share. The residential sector purchased 5.1 quadrillion British thermal units (quads) of electricity in 2022, and residential consumption of purchased electricity increases between about 14% and 22% from 2022 to 2050 across all cases, reaching between 5.9 and 6.3 quads. Electricity purchased for transportation reaches between about 0.6 quads and 1.3 quads in 2050, from 0.1 quads of purchased electricity in 2022, an increase of between 892% and 2,038% across all cases. Electricity purchased in the industrial sector is most influenced by economic growth assumptions, increasing by about 3%, from 3.5 quads in 2022 to about 3.6 quads in 2050 in low economic growth cases and by about 36% to 38%, to about 4.7 quads, in high economic growth cases.

Greater heating equipment efficiency reduces fossil fuel use in buildings

Despite modest growth in total energy consumption in the residential and commercial sectors, due to a growing number of households and expanding commercial floorspace, average energy intensity declines through 2050 across all cases (Figure 7 and Figure 8). Building envelope efficiency improves as states and localities adopt newer building energy codes and some existing households and commercial spaces receive additional insulation, air sealing, and other weatherization upgrades.

Figure 8.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.
ZTC=Zero-Carbon Technology Cost.

An established trend toward warmer winters and population shifts toward warmer and drier areas of the United States reduce energy consumption for space heating in all cases. At the same time, the established trend toward warmer summers leads to increasing electricity consumption for space cooling.

Technical Note 2: Modeling growth in residential heat pump installations

Our projections of residential heat pumps, like all major end-use equipment, begin with the census division-level stocks from our 2015 Residential Energy Consumption Survey *(RECS). We use data from the most recent U.S. Census Bureau's* Survey of Construction *to further align recent space heating equipment shares in newly built housing units. Equipment purchase decisions account for federal and non-federal subsidies that further reduce installed costs of high-efficiency equipment such as air- and ground-source heat pumps or high-efficiency natural gas furnaces. These subsidies include national tax credits extended by the Inflation Reduction Act (IRA) and utility rebates to end users at the census-division level. Technology performance and energy prices are considered as well. Some provisions of the IRA—such as those targeting low-income households—are not explicitly included in our modeling. Refer to the Appendix for additional details.*

Natural gas-fired heating equipment, including furnaces and boilers, continue to account for the largest share of energy consumption for space heating in U.S. residential and commercial buildings across all cases throughout the projection period. Over time, older heating equipment is replaced by newer, more efficient equipment that meets updated federal minimum energy efficiency standards.

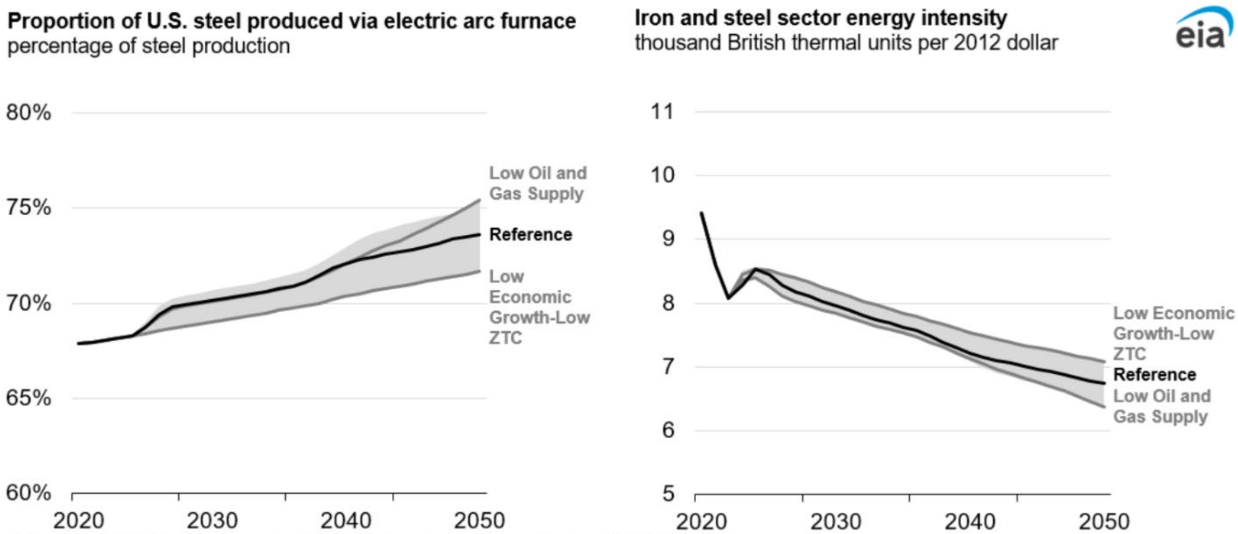
Federal and non-federal subsidies both encourage homes and businesses to adopt high-efficiency natural gas and electric equipment, including heat pumps. Electric heat pumps, including ground-source heat pumps, gain market share over the projection period, increasing from 11% of households in 2022 to between 14% and 15% of households in 2050 across all cases; however, their growth is limited by:

- A large existing market share for non-heat pump equipment that lasts a long time
- The high cost of purchasing and switching technologies, including electrical upgrades to accommodate electric heating and cooling and new ductwork when replacing boilers
- The higher price of electricity versus natural gas per million British thermal units, despite heat pump efficiency that may be multiple times higher than fossil fuel-fired equipment
- Reduced overall demand for space heating as building efficiency improves and heating degree days decrease

Electricity increasingly powers production in the iron and steel industry, decreasing energy intensity and CO_2 emissions

Steel production is an energy-intensive industry, but the choice of production technology significantly affects its energy and emission intensity. U.S. manufacturers continue to transition away from the combustion-powered, integrated steel mill process to steel produced by electric-arc furnaces, which have a lower energy intensity and make up about 68% of U.S. steel produced in 2022. Over the projection period, the share of U.S. steel produced by the electric-arc furnace process increases by 4% to 7% across the range of cases (Figure 9). The energy intensity of U.S. steel production continues to fall across all cases, declining between 12% and 21% across all cases (Figure 9). In 2018, steel production accounted for 1.3% of U.S. energy demand, and we project total energy demand for iron and steel production to fall relative to total U.S. energy demand, after peaking in 2027.

Figure 9.

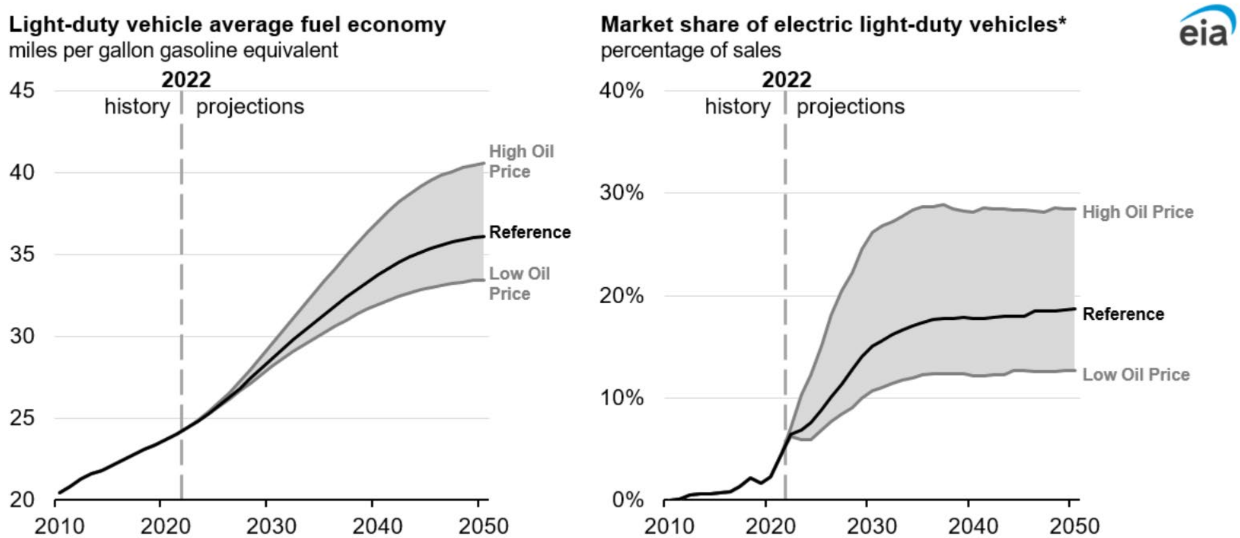


Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: All displayed data are projections. Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost.

Technological advancements, including electrification, for light-duty vehicles reduce energy intensity and fossil fuel use

In the transportation sector, light-duty vehicle (LDV) fuel economy increases due to rising Corporate Average Fuel Economy (CAFE) standards and electric vehicle (EV) sales. In addition to required fuel economy increases, consumer purchase decisions are also influenced by fuel prices. Consumer interest in EVs, which are significantly more efficient than internal combustion engine vehicles, and the impact EV adoption has on average light-duty vehicle fuel economy are sensitive to the price of gasoline (Figure 10).

Figure 10.



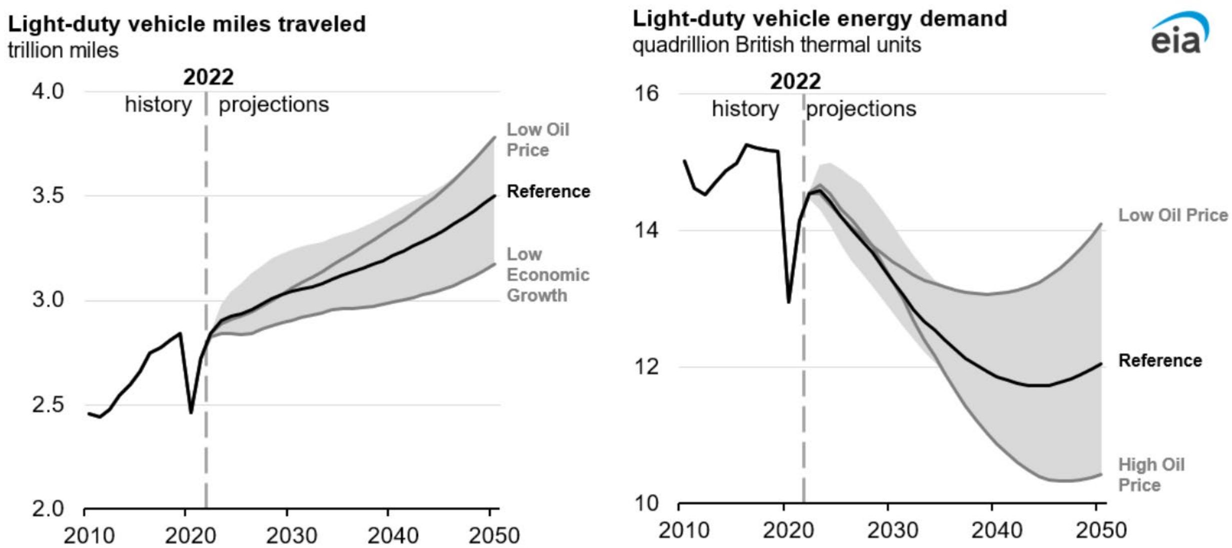
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: *Includes battery electric and plug-in hybrid electric vehicles. Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.

The updated CAFE standard, which applies to model years 2024 through 2026, significantly increases average new vehicle fuel economy requirements. By 2026, the updated CAFE standard is 28% higher than the Safer Affordable Fuel-Efficient (SAFE) standard for new vehicles it replaced, resulting in an increase from 37 miles per gallon (mpg) to 47 mpg by 2026. In addition to improved conventional vehicle fuel efficiency, EV sales increase through 2050, increasing EVs on the road. The CAFE standard, which offers credits to EV manufacturers, and decreasing battery prices help drive this increase in EV sales.

U.S. passenger vehicle-miles traveled increases steadily with population and income throughout the projection period, growing between 12% and 33% across all cases. In the Reference case, 23% more vehicle miles are traveled in 2050 than in 2022 (Figure 11). We project LDV energy consumption to fall through the early 2040s as a result of fuel economy improvements but then to rise due to increasing vehicle miles traveled for the remainder of the projection period (Figure 11).

We project LDV energy consumption to fall through the early 2040s as a result of fuel economy improvements but then to rise due to increasing vehicle miles traveled for the remainder of the projection period.

Figure 11.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. Right hand chart includes delivered energy, specifically energy consumed on board the vehicle; it does not include losses between car and charger.

Technical Note 3: Electric vehicle (EV) deployments

Projected declines in EV vehicle component costs, along with federal and state policies that provide incentives for EV purchases or require minimum sales, drive EV sales growth in our model projection. We derive cost declines for EV powertrain components and batteries by using learning rates based on cumulative production, resulting in increased projected driving range and a continual decline in EV prices over the projection period. We derive EV sales shares at the census-division level using a consumer choice model based on preference data and calibrated to align with historical sales data. In addition to other vehicle attributes, our consumer choice model captures the impact of vehicle price, cost to drive, access to refueling, and the effect that availability of vehicle propulsion options has on consumer purchase decisions. All of these factors contribute to the attractiveness of EVs to consumers and increases EV deployment relative to internal combustion engine vehicles. We assume Corporate Average Fuel Economy standards result in technological improvements and increased EV adoption because of declining cost and favorable fuel economy credits. The clean vehicle credit in the 2022 Inflation Reduction Act, which varies from $3,750 to $7,500 per vehicle, drives additional EV sales. Our Transportation Demand Model also ensures legally enforceable state minimum EV sales requirements are met in each census division and EV prices adjust to account for tax credits at purchase. In addition, other factors, such as a rising number of charging stations, affect our EV sales projections. We base our model projections on these data, assumptions, and current enforceable laws and regulations and do not assume that state and federal stated goals for EV sales are met. These details are available in our model documentation.

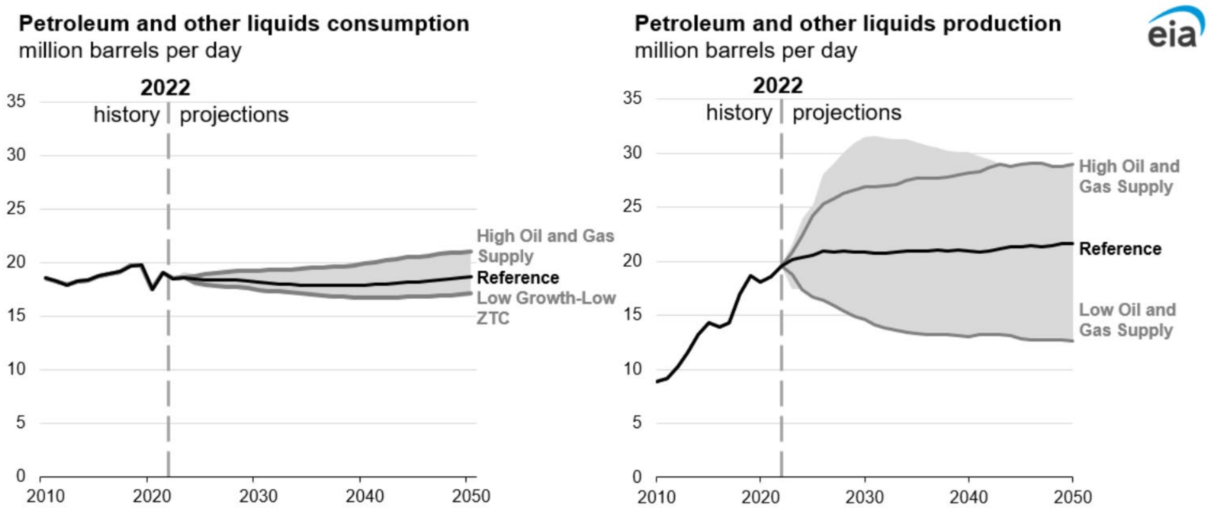
3

International Demand for Petroleum and Natural Gas Drives U.S. Production, While Domestic Consumption Either Grows Slowly or Decreases

Although U.S. consumption of petroleum products remains relatively flat, international demand supports U.S. exports of petroleum and other liquids (Figure 12). The dynamics of international trade affect domestic production of natural gas and of petroleum and other liquids.

International demand drives petroleum and other liquids production

Figure 12.



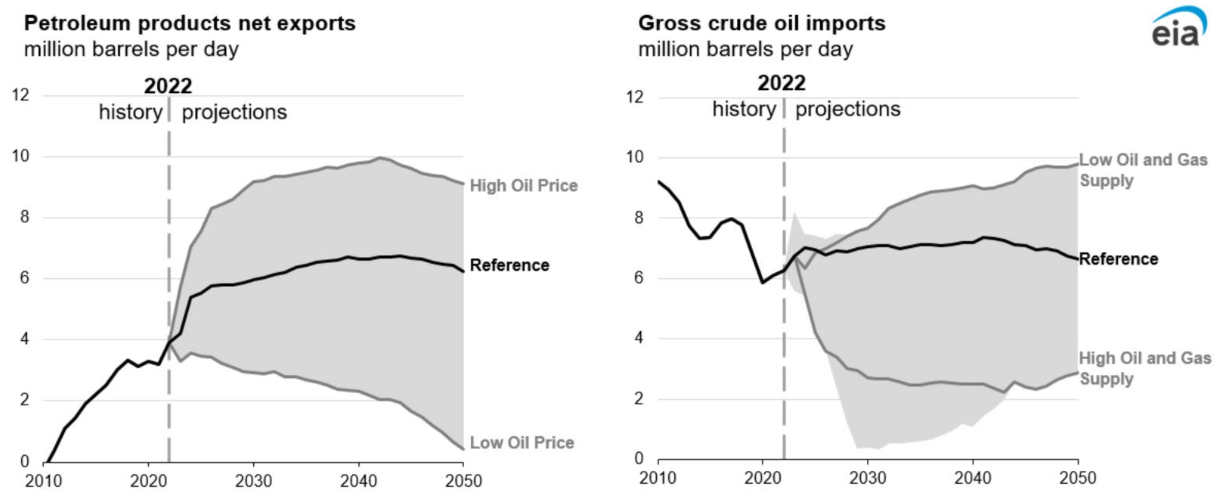
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Biofuels are not included in *petroleum and other liquids* production or consumption. Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost.

In all cases, we project that the United States will remain a net exporter of petroleum products through 2050.

Although domestic consumption of petroleum and other liquids does not increase through 2040 across most cases, U.S. petroleum and other liquids production remains high because of increased exports of finished products in response to growing international demand (Figure 13). In all cases, we project that the United States will remain a net exporter of petroleum products through 2050. In the High Oil Price case, increased production leads to the most exports among all cases over the projection period. The Low Oil Price case shows the opposite: decreased production along with the lowest export volumes.

Crude oil imports remain relatively flat in the Reference case but vary widely in the side cases (Figure 13); the Low Oil and Gas Supply case leads to the greatest level of imports throughout the forecast period while the and High Oil and Gas Supply case leads to the lowest imports (Figure 13). This wide range in imports is mainly due to the tradeoff between domestic production and imports. In the Low Oil and Gas Supply case, crude oil imports increase significantly, partially to account for falling domestic crude oil production. The opposite occurs in the High Oil and Gas Supply case, in which increased domestic production balances lower crude oil imports.

Figure 13.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.

In the High Oil Price case, U.S. crude oil imports initially decline but begin to increase starting in 2030 because of changing trends in domestic crude oil production. In the early years, domestic crude oil production increases rapidly due to high prices. However, crude oil production begins to fall after 2030 because wells are drilled increasingly close to one another, resulting in well productivity declines. As wells are drilled closer together, they produce less crude oil and eventually become unprofitable, at which point new drilling stops. Crude oil imports decline early in the High Oil Price case as crude oil production increases; imports increase after 2030 as well productivity and crude oil production declines.

Because international demand for finished petroleum products keeps exports high, U.S. refinery runs remain strong as the U.S. refinery sector remains competitive in the global market through 2050. Refinery capacity remains relatively constant through 2050, and refinery capacity utilization remains high, at around 90% or higher, under favorable economic conditions.

Technical Note 4: Crude oil trade dynamics

Crude oil is a global commodity, and the United States participates in the global market as both an importer and exporter of crude oil and its associated products. Because of logistical, regulatory, and quality considerations, both exporting and importing petroleum often makes economic sense. For example, a refiner in the Gulf Coast may find it more profitable to export motor gasoline to Mexico rather than shipping it to the East Coast because cheaper gasoline imports from Europe may be available to the East Coast.

The chemical makeup of the imported or exported product also affects crude oil trade. The type of crude oil—light or heavy, low-sulfur (sweet) or high-sulfur (sour)—helps determine the processes that refine it into a petroleum product such as distillate fuel oil or propane. In short, the United States imports different types of crude oil to optimize production across its various refineries.

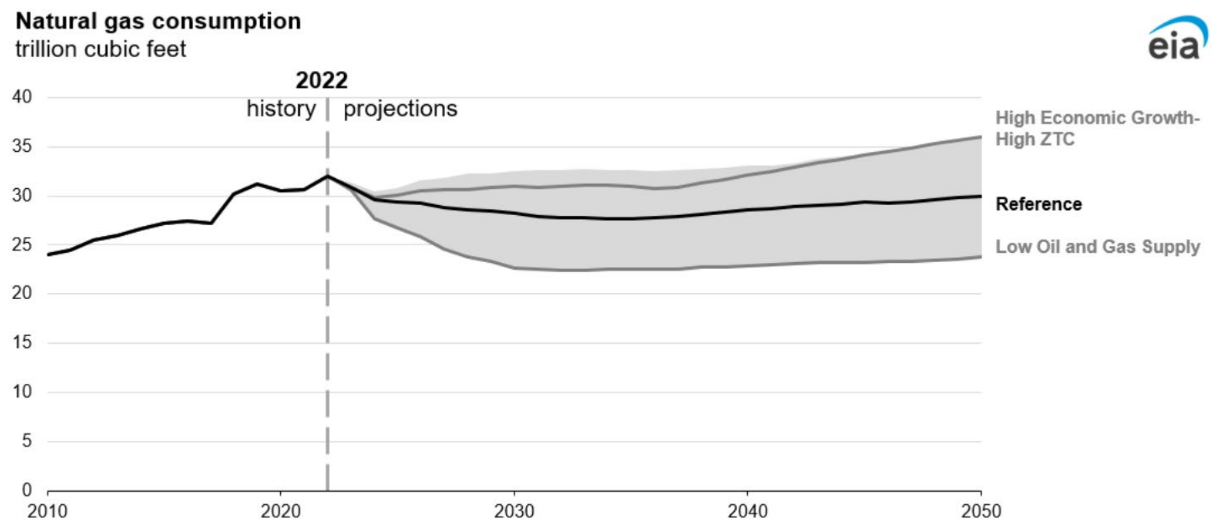
The World Oil Price path is an exogenous assumption to the model and affects domestic crude oil production and international trade. For each year of the projection period, NEMS computes the Brent crude oil price, provides a supply curve of world crude oil-like liquids, and provides supply curves for each foreign crude oil type considered. NEMS also provides, for each year of the projection period, exogenous supply and demand curves for U.S. import and export of petroleum products.

In response to Russia's full-scale invasion of Ukraine in early 2022, the United States banned petroleum imports from Russia. AEO2023 projections reflect this policy change. However, we assume that equivalent imports from other countries substitute for U.S. crude oil imports (especially unfinished oil imports) from Russia, minimizing effects on domestic markets.

Natural gas consumption in end-use sectors is variable

In the United States, electrification is displacing combustion fuels in the demand sectors. As electricity generation shifts to using more renewable and battery sources, domestic natural gas consumption for electricity generation is likely to decrease by 2050 relative to 2022, which contrasts with relatively stable growth over the past decade (Figure 14).

Figure 14.



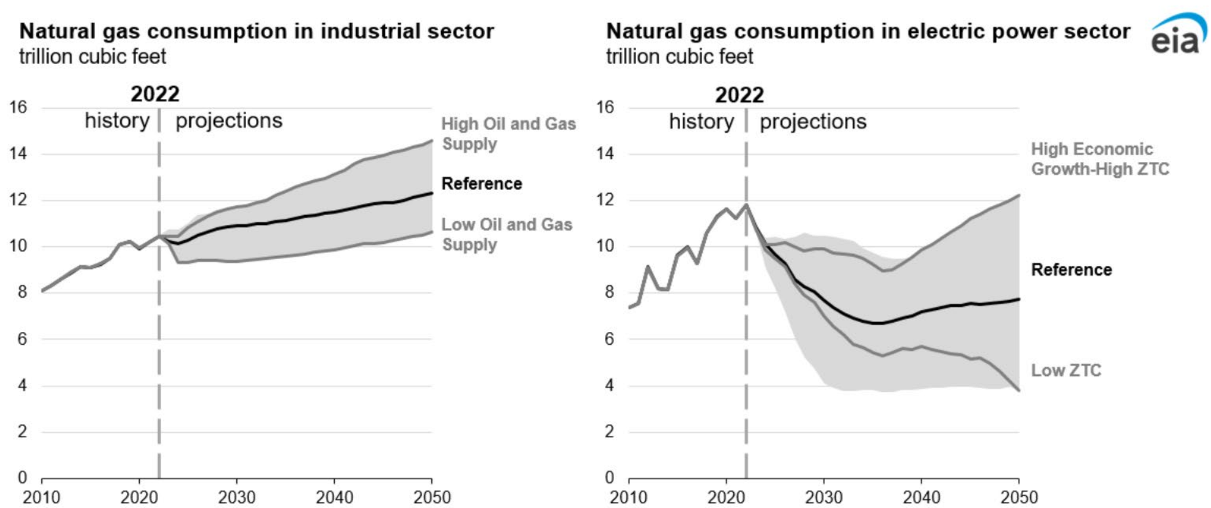
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost.

More natural gas is consumed in the industrial or electric power sectors than in any other sectors of the U.S. economy. Projected consumption in both sectors is very sensitive to changes in our side case assumptions, particularly in the Oil and Gas Supply cases (Figure 15). These cases, which result in the most and the least natural gas consumption in the industrial sector, vary widely due to differences in resource extraction assumptions. By 2050, natural gas consumption in the industrial sector diverges from the Reference case by 14% in the Low Oil and Gas Supply case and 18% in the High Oil and Gas Supply case.

In the electric power sector, our projections for natural gas consumption generally fall but range widely, with consumption in 2050 diverging from the Reference case by over 50% in the bounding cases.

In the electric power sector, our projections for natural gas consumption generally fall but range widely, with consumption in 2050 diverging from the Reference case by over 50% in the bounding cases (Figure 15). Natural gas consumption remains below the peak in 2022, at nearly 12 trillion cubic feet, through 2050 across all side cases except the High Economic Growth and High ZTC case. In the Low ZTC case, lower costs for renewables makes natural gas less competitive, resulting in a larger decrease in natural gas consumption compared with the Reference case. In the High Economic Growth and High ZTC case, increased economic activity drives increased end-use demand, which results in more natural gas consumption. Higher costs for renewables make natural gas a more competitive option in that case, further increasing natural gas consumption in the electric power sector.

Figure 15.

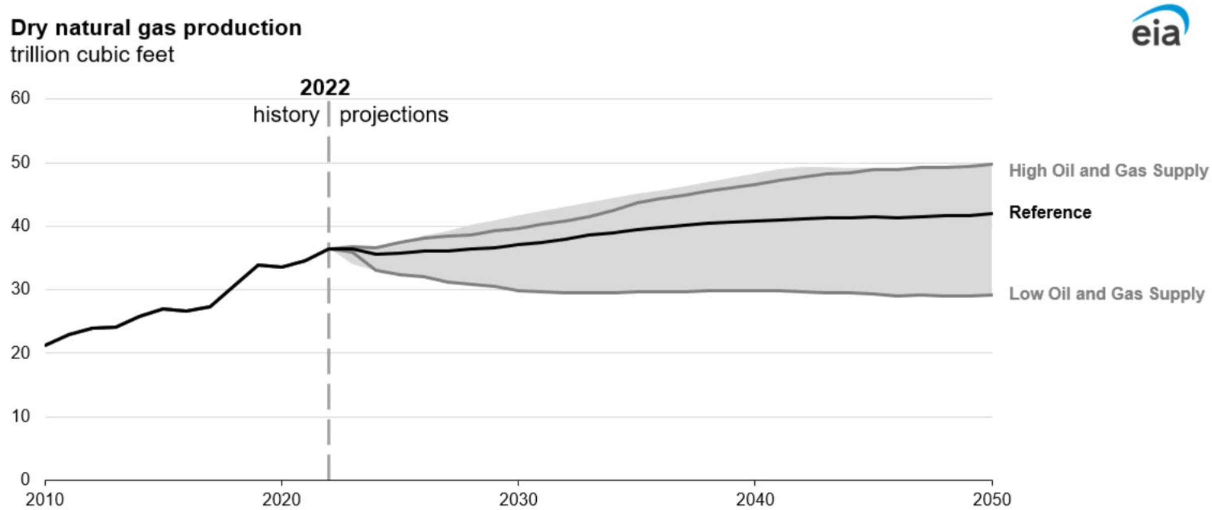


Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost.

Under favorable economic, supply, and oil price assumptions, U.S. natural gas production continues to grow

In the Reference case, U.S. natural gas production increases by 15% from 2022 to 2050, and consumption decreases by 6% from its peak in 2022 (Figure 16). Across all cases, domestic production outpaces domestic consumption; production increases across all side cases except in the Low Oil and Gas Supply case and the Low Oil Price case.

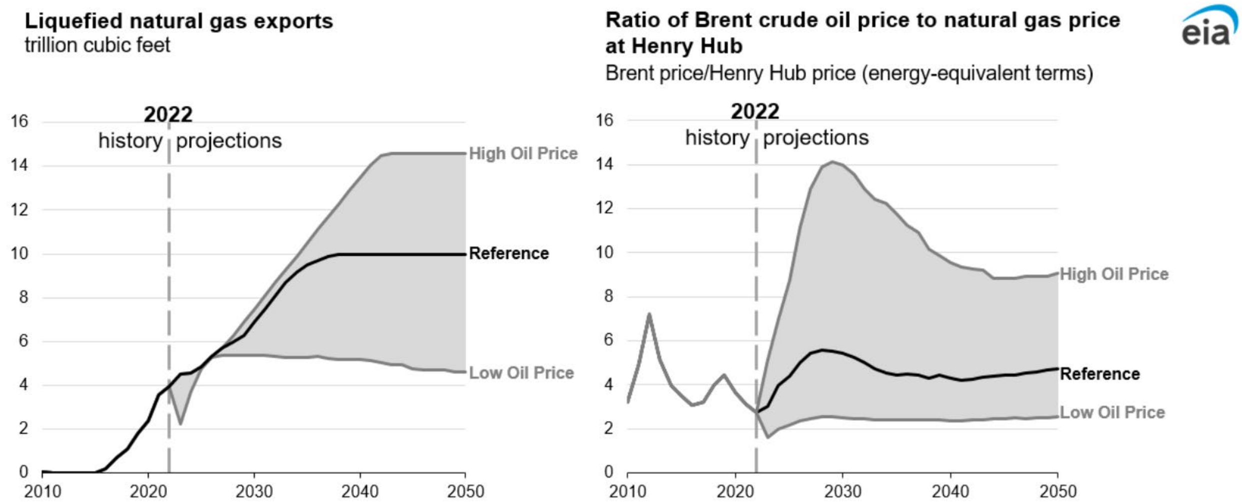
Figure 16.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.

In some cases, exports to satisfy growing international demand for natural gas encourage growth in domestic natural gas production. A significant portion of production growth is due to liquefied natural gas (LNG) export demand, which drives the overall increase in natural gas exports (Figure 17).

Figure 17.

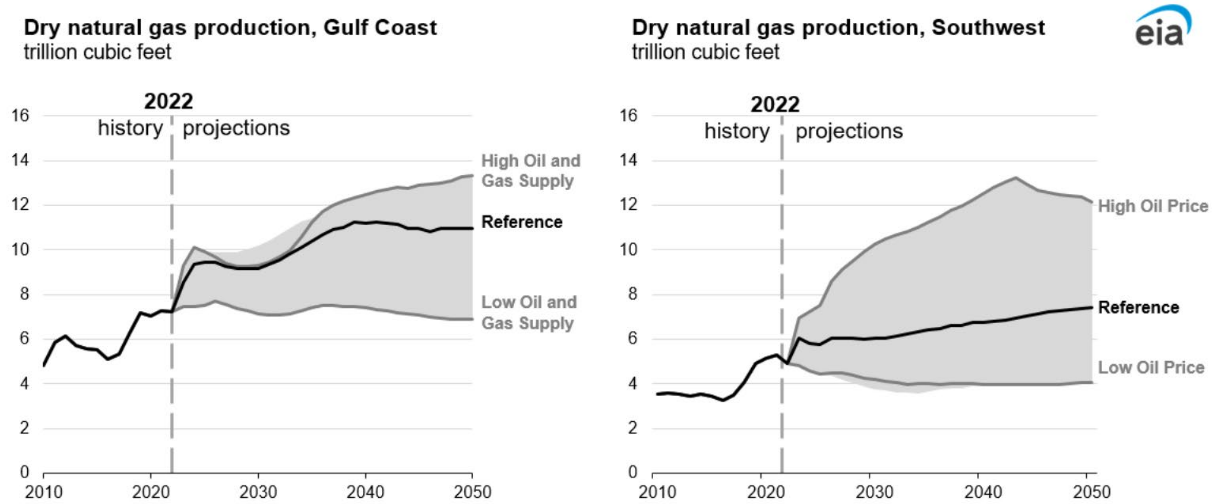


Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.

Historically, most LNG was traded under long-term, oil price-linked contracts because a global LNG price benchmark did not exist and because oil could substitute for natural gas in industry and for power generation, which was especially common in Asia. These factors supported highly correlated international natural gas and oil prices. With growth in more market based-LNG, the strength of the relationship between international natural gas prices and oil prices has eroded. However, we expect that future oil prices will still affect additional LNG export capacity and overall export levels. When the Brent price is high relative to the U.S. Henry Hub price, like in the High Oil Price case, building more LNG export capacity and exporting LNG are more economical than when the Brent price is lower relative to Henry Hub. In the Low Oil Price case, the Brent price is lower, and the Henry Hub price is higher, which curtails LNG exports to below current volumes in the near term and causes LNG capacity to be underutilized near the end of the projection period.

International demand for LNG exports results in rising natural gas production, favoring areas that have better access to terminals. In AEO2023, dry natural gas production grows in the Southwest, which has easy pipeline transport to the Gulf Coast, where LNG is exported. Production in the Gulf Coast also generally increases across the projection period, due to its proximity to LNG export terminals, in all cases except the Low Oil and Gas Supply case (Figure 18).

Figure 18.



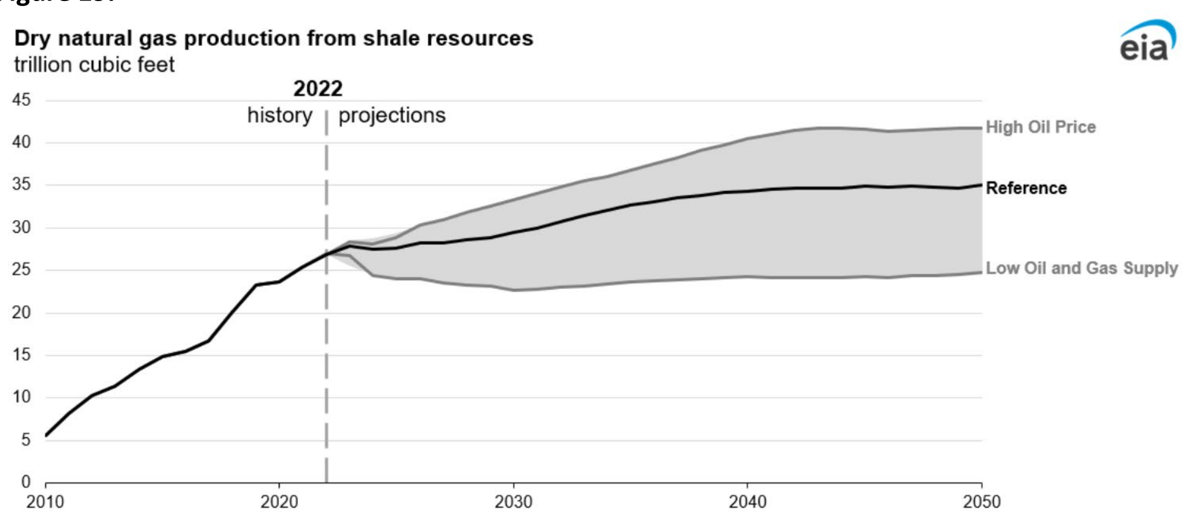
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.

Associated natural gas is a major source of natural gas production

In AEO2023, shale gas and associated dissolved natural gas from oil formations are the primary sources of long-term growth of domestic natural gas production through 2050. Increased production wells in the Permian Basin (Southwest region) is the primary driver behind associated dissolved natural gas growth. Increases in shale gas production mainly comes from the Texas-Louisiana Salt Basin (Gulf Coast Region) and the Appalachian Basin (East Region).

In the High Oil Price case and High Oil and Gas Supply case, oil production growth leads to increased associated dissolved natural gas and shale production (Figure 19). The opposite occurs in the Low Oil Price case and Low Oil and Gas Supply case.

Figure 19.



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.

Discussion

Sources of uncertainty

Energy market projections are inherently uncertain because many of the events that will shape future energy markets—including developments in policy, technology, demographics, and resources—are not known. To illustrate the role of uncertainty, AEO2023 includes a baseline Reference case and several side cases that systematically vary important underlying assumptions. Many sources of uncertainty exist beyond the ones we test explicitly, including new policy, unforeseen geopolitical events, and rapid technology innovation, particularly around technologies that are in the earliest stages of development.

Policy

Our key assumptions in the Reference case provide a baseline for exploring long-term trends, based on current laws and regulations as of November 2022. These assumptions include provisions of the IRA; however, we were unable to model all provisions, as indicated in the appendix. Any future legislation would further affect technology trajectories and emissions pathways. We publish the current laws and regulations considered in the AEO2023 on the AEO website.

Geopolitical events

We account for current events that affect the energy markets with the information available at the time we prepare this publication. However, we cannot foresee future events such as wars, supply disruptions, pandemics, or other such issues that could having lasting impacts on the U.S. energy system.

Rapid technology innovation

The technologies considered in the AEO2023 include only well-documented trends in energy innovation. Additional breakthroughs not considered here might occur. Examples of the kind of breakthrough we don't consider include early-developmental-stage technologies such as hydrogen, enhanced geothermal, and fusion, as well as other technologies currently unknown or not well characterized.

Quantifying uncertainty using statistical errors from past projections

The sources of uncertainty described above, among others, result in observed values that are different than our projected values. To explore some key uncertainties, we include a number of side cases that incorporate plausible alternatives to assumptions in the Reference case. We can also develop a sense of future uncertainty by calculating the differences (or *statistical errors*[3]) between realized values and our Reference case projections from previous AEO editions. Given constantly evolving modeling techniques and a dynamic energy landscape replete with non-linear relationships, statistical errors from past projections will not necessarily provide an accurate basis for estimating uncertainty in current projections. Nevertheless, using statistical errors from past projections implicitly captures real world factors that were difficult to anticipate in past AEO editions.

[3] Here we use "error" in a statistical sense to denote the difference between projected and real-world values. Because our Reference case is not intended to serve as a forecast, deviations from reality should not be interpreted as errors.

In the 2022 edition of our *Annual Energy Outlook Retrospective Review* (AEO Retrospective), we quantified the statistical errors associated with past Reference cases over several key output metrics and projection timeframes, ranging from 1 to 15 years. Building on the work from the AEO Retrospective and following the NP2 method (a methodology detailed in a 2017 paper by researchers Lynn H. Kaack, Jay Apt, M. Granger Morgan, and Patrick McSharry), we can use statistical errors from past projections to develop a *cone of uncertainty*—similar to those used by the National Oceanic and Atmospheric Administration (NOAA) to produce hurricane path cones—which we can apply to the AEO2023 projections. Employing statistical errors from past projections along with side case projections can help us better assess the possible range of uncertainty in the AEO results.

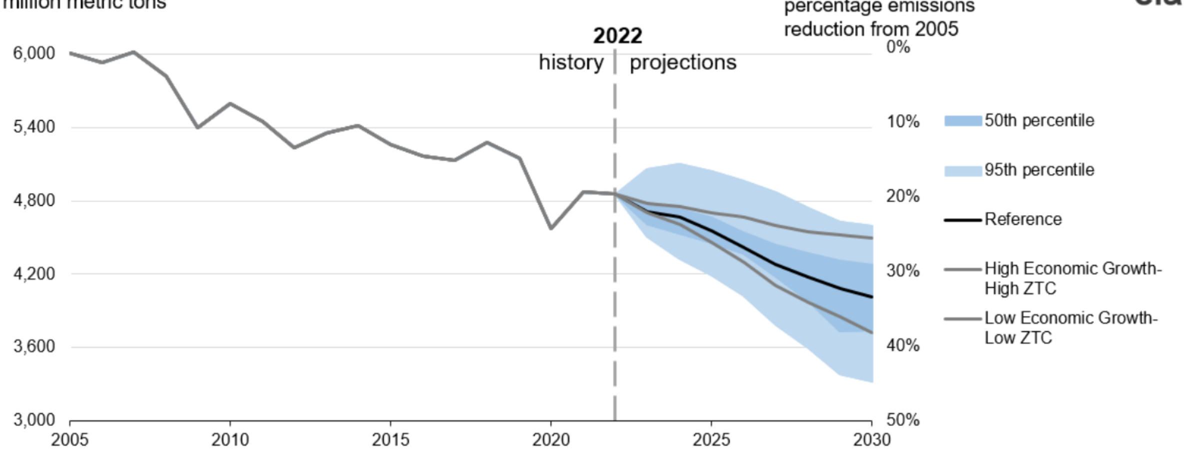
For example, we can use the statistical errors from past AEO Reference case projections to project future uncertainty in U.S. energy-related CO_2 emissions produced by the AEO2023 Reference case until 2030 (Figure 20). Figure 20 includes two uncertainty cones for total energy-related CO_2 emissions, representing statistical error estimations where the narrower and wider cones capture 50% and 95% of the historical projection errors around the Reference case, respectively. Our Reference case projection has a wide range of future uncertainty in total energy-related CO_2 emissions, which in some instances goes beyond the bounds explored in our most extreme side cases.

Because the AEO Reference case includes only laws and regulations current at the time it is developed, past Reference case projections of total energy-related CO_2 emissions tend to be higher than actual because they don't include subsequent public policies that further reduce emissions. The uncertainty cones capture these over-projected statistical errors in total energy-related CO_2 emissions and show the possibility for lower emissions compared with our most extreme side case with the lowest total energy-related CO_2 emissions. We see the possibility of total energy-related CO_2 emissions increasing in the short term before falling in the long term, both in our High Economic Growth and High Zero-Carbon Technology Cost case and the upper 95th percentile of statistical errors from past projections.

We will continue to explore our use of this technique, as well as other ways to quantify uncertainty, in future analyses.

Figure 20.

Total energy-related carbon dioxide emissions
million metric tons



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Cone of uncertainty associated with total energy-related CO_2 emissions using empirical projection intervals. Historical values and AEO2023 Reference case are displayed as solid black line. The projection error density forecast by blue shaded areas. The different shades correspond to the 50th and 95th percentiles. AEO2023 envelope side cases are in solid grey lines. ZTC=Zero-Carbon Technology Cost.

Appendix

Case Descriptions

AEO2023 Reference Case

In the AEO2023 Reference case, we assess how U.S. and world energy markets would operate through 2050 under current laws and regulations as of November 2022 under evolutionary technological growth assumptions. Our key assumptions in the Reference case provide a baseline, or experimental control, for exploring long-term trends. An overview of the laws and regulations included in AEO2023 is available on the AEO website. This Appendix addresses the Inflation Reduction Act and how we incorporated it into the Reference case and side cases.

High and Low Oil Price cases

Global market balances, primarily international supply and demand factors, will drive future crude oil prices. To account for these factors, oil prices are an exogenous assumption in our analysis. In the AEO2023 High Oil Price case, the price of Brent crude oil, in 2022 dollars, reaches $190 per barrel (b) by 2050, compared with $101/b in the Reference case and $51/b in the Low Oil Price case.

High and Low Oil and Gas Supply cases

Compared with the Reference case, the High Oil and Gas Supply case assumes that the estimated ultimate recovery per well for tight oil, tight gas, or shale gas in the United States is 50% higher. Similarly, this case assumes that undiscovered resources in Alaska and the offshore Lower 48 states are 50% greater than assumed in the Reference case. Technological improvement rates that reduce costs and increase productivity of oil and natural gas production in the United States are also 50% higher than assumed in the Reference case. Conversely, the Low Oil and Gas Supply case assumes that the estimated ultimate recovery per well for tight oil, tight gas, or shale gas in the United States; the undiscovered resources in Alaska and the offshore Lower 48 states; and rates of technological improvement are all 50% lower than assumed in the Reference case.

High and Low Zero-Carbon Technology Cost cases

The High Zero-Carbon Technology Cost case and the Low Zero-Carbon Technology Cost case examine the sensitivities around capital costs for electricity-generating technologies that produce zero emissions, which include renewables, nuclear (a zero-carbon technology included in these cases for the first time in this AEO), and diurnal storage technologies. We assume capital costs decline over time from learning by doing as commercialization expands and construction and manufacturing experience accelerates. The High Zero-Carbon Technology Cost case assumes no cost reductions from learning by doing. The Low Zero-Carbon Technology Cost case assumes faster, exogenously determined technology cost declines through 2050, resulting in about a 40% cost reduction by 2050 compared with the Reference case for each zero-carbon technology. In addition, we assume fixed operating and maintenance costs will decline along with the capital cost from technology improvement. These cases replace the Low and High

Renewable Cost cases from prior AEOs and now reflect the zero-carbon technology suite, as represented in our models, which is targeted by incentives in the Inflation Reduction Act.

High and Low Economic Growth cases

The High Economic Growth case and Low Economic Growth case address the effects of economic assumptions on energy consumption modeled in the AEO2023. From 2022 to 2050, the High Economic Growth case assumes the compound annual growth rate for U.S. GDP is 2.3%, and the Low Economic Growth case assumes a 1.4% rate. By contrast, the Reference case assumes the U.S. GDP annual growth rate is 1.9% over the projection period.

Economic Growth and Zero-Carbon Technology Cost Combination cases

In addition to our eight standard core cases, we have added four combination cases for AEO2023. These cases simultaneously vary economic growth and zero-carbon technology cost assumptions. The four combinations are:

- High Economic Growth and High Zero-Carbon Technology Cost
- High Economic Growth and Low Zero-Carbon Technology Cost
- Low Economic Growth and High Zero-Carbon Technology Cost
- Low Economic Growth and Low Zero-Carbon Technology Cost

Inflation Reduction Act assumptions in the Reference case and core side cases

The Inflation Reduction Act (IRA), or Public Law 117-169, that took effect on August 16, 2022, includes energy- and climate-related provisions.[4] We reviewed the law for directives that would influence energy consumption, production, and trade in the U.S. economy as modeled in NEMS. We incorporated provisions of this law into the Reference case and side cases, unless otherwise noted. Case assumptions were frozen in mid-November 2022, and AEO2023 does not include regulatory guidance or provisions issued after that time.

This document summarizes the energy- and climate-related provisions from the IRA as incorporated into the AEO2023 Reference and side cases. This document does not cover details about provisions included in the Low and High Uptake cases, which vary the number of bonus tax credits and incentives applied to eligible technologies. Those case definitions and results are discussed in the *Issues in Focus: Inflation Reduction Act Cases in the AEO2023*. Further details about how we modeled the IRA provisions are also in the NEMS Assumptions documents. The No IRA case assumes the same economic outlook as the Reference case but excludes the IRA provisions.

All cases use the macroeconomic outlook from S&P Global IHS Markit as of September 2022.

Although all provisions of the IRA are current law, some are not explicitly included in the NEMS version used for AEO2023. We did not include these provisions for one of three reasons:

1. Guidance is not yet available on how federal agencies will implement some provisions, and without that guidance, we lack the details to analyze their effect. We will analyze these provisions in the future as we receive more clarity.
2. A number of provisions require significant modifications to NEMS that were not possible in this timeframe, and we will consider ways to include these provisions in a future outlook to the extent possible.
3. Other provisions do not align with our analytic resolution. For instance, NEMS does not model individual electricity transmission lines, and therefore, we do not model the IRA-driven impacts related to the planning or construction of transmission lines through financial appropriations in the form of assistance or loans.

Some provisions are not listed in the following table because they are not relevant to this analysis or had minor impacts to the energy system. In the *Excluded* column of Table 1, the numbers in bold correspond to one or more of the reasons listed above. The use of -- indicates that a certain column is not applicable.

[4] Inflation Reduction Act, Public Law 117-169, (August 16, 2022), https://www.congress.gov/bill/117th-congress/house-bill/5376.

Table 1. Included and excluded Inflation Reduction Act (IRA) provisions in NEMS

Section	Provision	Description	Included	Excluded
Title I Committee on Finance				
13101 and 13102	Extension and Modification of Credits Produced from Certain Renewable Resources Extension and Modification of Energy Tax Credit	These provisions include extensions of the Internal Revenue Service Code Section 45[i] production tax credit (PTC) and Section 48[ii] investment tax credit (ITC) for certain energy properties.	We assume the tax credit extensions and modified tax credit values. We also assume the prevailing wage and apprenticeship requirements are met by the most eligible technologies, except certain combined-heat-and-power systems, and the domestic content requirements are met by certain technologies.	We exclude certain technologies such as small-scale energy storage (called behind-the-meter storage). Further details about the technologies we model are in the NEMS Assumptions documents. We exclude the *energy communities* bonus credit. **(1,2,3)**
13103	Increase in Energy Credit for Solar and Wind Facilities Placed in Service in Connection with Low-Income Communities	This provision allows qualified solar and wind projects located in low-income communities to qualify for *environmental justice solar and wind capacity* credits.	--	**(1,3)**
13104	Extension and Modification of Credit for Carbon Oxide Sequestration	This provision extends the carbon oxide capture credit under IRS section 45Q.[iii]	We assume the tax credit extensions and modified tax credit values. We also assume the prevailing wage and apprenticeship requirements are met.	We exclude the new tax credit for direct air capture (DAC). **(2)**

Section	Provision	Description	Included	Excluded
13105	Zero-Emission Nuclear Power Production Credit	This provision creates a production credit for qualified nuclear power generation.	We assume the prevailing wage requirements are met.	--
13201	Extension of Incentives For Biodiesel, Renewable Diesel and Alternative Fuels	This provision extends the biodiesel and renewable diesel credit and an alternative fuel credit.	We extended the existing biomass-based diesel credit through 2027.	--
13202	Extension of Second Generation Biofuel Incentives	This provision extends a tax credit for second-generation biofuel production.	We extended the credit through 2027.	--
13203	Sustainable Aviation Fuel Credit	This provision creates a sustainable aviation fuel credit equal to $1.25 per gallon.	We implemented a simplified version of this credit that extends the credit through 2027	We did not assume the supplementary amount when the fuel meets certain lifecycle greenhouse gas (GHG) requirements. **(2)**
13204	Clean Hydrogen	This provision creates a new tax credit for the qualified production of clean hydrogen.	--	**(2)**
13301	Extension, Increase, and Modifications of Nonbusiness Energy Property Credit	This provision extends tax credits under IRS Section 25C[iv] for home energy efficiency improvements and modifies the tax credit for qualified energy efficiency improvements.	We assume the tax credit extensions and modified tax credit values through 2032.	We do not explicitly model service panel replacement, wiring upgrades, or home energy audits. **(3)**
13302	Residential Clean Energy Credit	This provision extends the credit under IRS Section 25D[v] for the cost of qualified residential energy efficiency expenditures and projects.	We assume the tax credit extensions and modified tax credit values, including phaseout, through 2034.	We do not explicitly model residential clean energy technologies such as residential battery storage. Further details about the

Section	Provision	Description	Included	Excluded
				technologies we model are in the NEMS Assumptions documents. **(2,3)**
13303	Energy Efficient Commercial Buildings Deduction	This provision amends IRS Section 179D[vi] and allows expenses associated with qualifying commercial building efficiency costs to be deductible expenses if they meet certain requirements.	--	**(1,3)**
13304	Extension, Increase, and Modifications of New Energy Efficient Home Credit	This provision extends Section 45L[vii] credits for new energy-efficient homes through December 31, 2032, and increases the credit if qualified projects meet prevailing wage and apprenticeship requirements.	We assume a $500–$2,500 tax credit for new properties meeting or exceeding ENERGY STAR specifications.	We do not explicitly model zero-energy ready homes ($5,000 credit), and we exclude the *energy communities* bonus credit. **(1,3)**
13401	Clean Vehicle Credit	This provision extends the Section 30D[viii] vehicle tax credit through December 31, 2032, and updates the credit value. This provision also contains vehicle assembly requirements, battery component requirements, vehicle price limits, and income limits for vehicle buyers.	We do not explicitly model this provision, but we assume the total number of vehicles that qualify for the clean vehicle tax credit based on an analysis of official U.S. government IRA expenditure estimates from the Congressional Budget Office.[ix]	--
13402	Credit for Previously-Owned Clean Vehicles	This section creates a new tax credit for used clean vehicles.	--	**(1,3)**

Section	Provision	Description	Included	Excluded
13403	Qualified Commercial Clean Vehicles	This provision provides a clean vehicle credit for vehicles not powered by internal combustion engines.	--	**(1,3)**
13404	Alternative Fuel Refueling Property Credit	This section extends and modifies a tax credit for qualified alternative-fuel refueling properties.	--	**(1,3)**
13501	Extension of the Advanced Energy Project Credit	This provision funds qualifying investments in advanced energy projects, such as facilities that manufacture electric vehicles.	--	**(1,3)**
13502	Advanced Manufacturing Production Credit	This provision provides production credits for domestic manufacturing of key components for clean energy technologies.	--	**(1,2)**
13701	Clean Electricity Production Credit	This provision creates a new production tax credit for qualified domestically produced electricity that does not emit GHG emissions.	We assume the prevailing wage and apprenticeship requirements and the domestic content requirements are met by certain technologies.	We exclude the bonus credits for qualified projects located in an *energy community*. **(1,2)**
13702	Clean Electricity Investment Credit	This provision creates a new investment tax credit for eligible clean energy technologies.	We assume the prevailing wage and apprenticeship requirements and the domestic content requirements are met by certain technologies.	We exclude the bonus credits for qualified projects located in an *energy community*. We do not model certain technologies, such as small-scale energy storage projects (called behind-the-meter storage). Further details

Section	Provision	Description	Included	Excluded
				about the technologies we model are in the NEMS Assumptions documents. **(1,2)**
13703	Cost Recovery for Qualified Facilities, Qualified Property, and Energy Storage Technology	The provision updates the definition of a *five-year property* to include facilities that qualify for the clean electricity production credit, property that qualifies for the clean energy investment tax credit, and any energy storage technology for accelerated cost recovery.	We assume the extension of the modified accelerated cost recovery system, or MACRS, for certain commercial end-use equipment and for applicable technologies in the electric power sector.	We do not explicitly model energy storage in the residential and commercial buildings sectors. Further details about the technologies we model are in the NEMS Assumptions documents. **(2,3)**
13704	Clean Fuel Production Tax Credit	This provision creates a tax credit for domestic clean fuel production, including a credit for sustainable aviation fuel, produced after December 1, 2024, and sold before December 31, 2027.	We implemented a simplified version of this credit for certain qualified fuels.	We did not model the credit values based on the lifecycle carbon emissions or emissions factor associated with qualified fuels. **(2,3)**
Part 8 13801–13802	Credit Monetization and Appropriations	These sections include provisions[x] that allow a taxpayer to transfer eligible credits to another taxpayer.	--	**(3)**
Title II Committee on Agriculture, Nutrition, and Forestry				
20001– 23005	Subtitles A–D	These sections fund the U.S. Department Forestry and U.S. Department of Agriculture for climate mitigation and restoration projects. Section 22003 focuses on	--	**(1,3)**

Section	Provision	Description	Included	Excluded
		biofuel infrastructure and agriculture product market expansion.		
Title III Committee on Banking, Housing, and Urban Affairs				
30001	Enhanced Use of Defense Production Act of 1950	This provision funds the acceleration of domestic production of clean energy technologies.	--	**(1,3)**
30002	Improving Energy Efficiency or Water Efficiency or Climate Resilience of Affordable Housing	This section funds projects that improve energy efficiency, water efficiency, or climate resilience for eligible properties.	--	**(1,3)**
Title IV Committee on Commerce, Science, and Transportation				
40007	Alternative Fuel and Low-Emission Aviation Technology Program	This section funds grants issued by the U.S. Department of Transportation for projects that produce, transport, blend, or store sustainable aviation fuel or that develop, demonstrate, or apply low-emission aviation technologies.	--	**(1)**
Title V Committee on Energy and Natural Resources				
50121	Home Energy Performance-Based, Whole-House Rebates	This section funds DOE's grants to state energy offices for rebates called Home Owner Managing Energy Savings, or HOMES.	--	**(1)**
50122	High-Efficiency Electric Home Rebate Program	This section funds DOE's financial support for state energy offices' and	--	**(1)**

Section	Provision	Description	Included	Excluded
		tribal governments' high-efficiency electric home rebate programs.		
50123	State-Based Home Energy Efficiency Contractor Training Grants	This section funds education and training for energy efficiency contractors.	--	**(3)**
50131	Assistance for Latest and Zero Building Energy Code Adoption	This section pays states and local governments to adopt the latest residential and commercial building energy codes and adopt residential and commercial building energy codes that exceed specific industry standards.	--	**(1)**
50141	Funding for DOE Loan Programs Office	This section raises the loan guarantee commitment authority to $40 billion for the DOE Title XVII Innovative Technology Loan Guarantee Program.	--	**(1)**
50142	Advanced Technology Vehicle Manufacturing	This section funds DOE's direct loans for establishing or expanding domestic manufacturing facilities for low- or no-emitting vehicles.	--	**(1)**
50143	Domestic Manufacturing Conversion Grants	This section provides grants for domestic production of electric vehicles and hydrogen fuel cell vehicles.	--	**(1)**

Section	Provision	Description	Included	Excluded
50144	Energy Infrastructure Reinvestment Financing	This section provides additional loan guarantee authority under the Energy Policy Act of 2005 for energy infrastructure that reduces air pollution.	--	**(1)**
50145	Tribal Energy Loan Guarantee Program	This provision funds the DOE's Tribal Loan Guarantee Program.	--	**(1,3)**
Part 5 50151–50153	Electric Transmission	These provisions fund DOE programs that facilitate certain transmission lines or transmission siting and planning.	--	**(1,3)**
50161	Advanced Industrial Facilities Deployment Program	This section makes about $5.8 billion available to DOE's Office of Clean Energy Demonstrations for advanced industrial technologies.	--	**(1,3)**
Part 7 50171–50173	Other Energy Matters	These sections fund the DOE laboratory infrastructure and the fabrication and enrichment facilities for special nuclear material.	--	**(1)**
50251	Leasing on the Outer Continental Shelf	This provision authorizes the U.S. Department of Interior (DOI) to conduct wind lease sales in the Outer Continental Shelf and in areas within an exclusive economic zone.	--	**(1,3)**
50261	Offshore Oil and Gas Royalty Rate	This provision increases the minimum royalty rate for new offshore fossil fuel leases.	We assume the updates to the minimum royalty rates.	--

Section	Provision	Description	Included	Excluded
50262	Mineral Leasing Act Modernization	This provision updates the onshore oil and natural gas royalty rates.	We assume the updates to the onshore oil and natural gas production royalty rates.	We exclude the adjustments to federal leases. **(3)**
50263	Royalties on All Extracted Methane	This provision modifies the royalties paid for natural gas produced on federal land and on the Outer Continental Shelf, including natural gas lost through upstream equipment.	--	**(3)**
50264	Lease Sales Under the 2017–2022 Outer Continental Shelf Leasing Program	This provision requires the completion of the 2017–2022 Outer Continental Shelf leasing program.	We assume the Outer Continental Shelf Leasing Program is completed.	--
50265	Ensuring Energy Security	This provision requires the DOI to conduct oil and natural gas lease sales annually for 10 years prior to issuing leases or rights-of-way for any new solar or wind energy projects.	--	**(3)**
Title VI Committee on Environment and Public Works				
60101	Clean Heavy-Duty Vehicles	This provision funds communities to help them replace eligible vehicles with zero-emission vehicles.	--	**(1,3)**
60103	Greenhouse Gas Reduction Fund	This section funds deployment of zero-emission technologies in low-	--	**(1,3)**

Section	Provision	Description	Included	Excluded
		income and disadvantaged communities.		
60104	Diesel Emissions Reductions	This section provides funding to identify and reduce diesel emissions from *goods movement facilities*.	--	**(1,3)**
60113	Methane Emissions Reduction Program	This section creates a methane emissions charge for qualified petroleum and natural gas systems.	--	**(1,3)**
60114	Climate Pollution Reduction Grants	This section funds the EPA's GHG air pollution implementation grants and GHG air pollution planning and implementation	--	**(1,3)**
Subtitle E 60501–60506	Transportation and Infrastructure	These sections include assistance for using low-carbon materials for constructing or altering federal buildings; for low-carbon transportation materials grants; and for a neighborhood access and equity grant program.	--	**(3)**
Title VII Committee on Homeland Security and Governmental Affairs				
70006	FEMA Building Materials Program	This section funds the Federal Emergency Management Agency's (FEMA) costs for low-carbon materials and incentives for net-zero energy projects.	--	**(3)**
Title VIII Committee on Indian Affairs				

Section	Provision	Description	Included	Excluded
80001	Tribal Climate Resilience	This section adds funds to the Bureau of Indian Affairs (BIA) for tribal climate resilience and adaptation programs.	--	**(1,3)**

[i] Electricity produced from certain renewable resources, etc., 26 U.S. Code § 45 (2022)
[ii] Energy credit, 26 U.S. Code § 48 (2022)
[iii] Credit for carbon oxide sequestration, 26 U.S. Code § 45Q (2022)
[iv] Energy efficient home improvement credit, 26 U.S. Code § 25C (2022)
[v] Residential clean energy credit, 26 U.S. Code § 25D (2022)
[vi] Energy efficient commercial buildings deduction, 26 U.S. Code § 179D (2022)
[vii] New energy efficient home credit, 26 U.S. Code § 45L (2022)
[viii] Clean vehicle credit, 26 U.S. Code § 30D (2022)
[ix] U.S. Congressional Budget Office, "Summary Estimated Budgetary Effects of H.R. 5376, the Inflation Reduction Act of 2022," August 5, 2022, https://www.cbo.gov/system/files/2022-08/hr5376_IR_Act_8-3-22.pdf
[x] Front Matter, 26 U.S. Code Chapter 65 § 6418 (2022)