Independent Statistics & Analysis
U.S. Energy Information Administration

Annual Energy Outlook 2021

with projections to 2050

Narrative

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The *Annual Energy Outlook* explores long-term energy trends in the United States

- Projections in the *Annual Energy Outlook 2021* (AEO2021) are not predictions of what will happen, but rather, they are modeled projections of what may happen given certain assumptions and methodologies. By varying those assumptions and methodologies, AEO2021 can illustrate important factors in future energy production and use in the United States.
- Energy market projections are uncertain because many of the events that shape energy markets—as well as future developments in technologies, demographics, and resources—cannot be foreseen with certainty. To illustrate the importance of key assumptions, AEO2021 includes a Reference case and side cases that systematically vary important underlying assumptions.
- The U.S. Energy Information Administration (EIA) develops the AEO by using the National Energy Modeling System (NEMS), an integrated model that captures interactions of economic changes and energy supply, demand, and prices.
- The AEO is published to satisfy the Department of Energy Organization Act of 1977, which requires EIA's Administrator to prepare annual reports on trends and projections for energy use and supply.

What is the AEO2021 Reference case?

- The AEO2021 Reference case represents EIA's best assessment of how U.S. and world energy markets will operate through 2050, based on key assumptions intended to provide a baseline for exploring long-term trends.
- The Reference case serves as a reasonable baseline case that can be compared with the side cases that include alternative assumptions.
- EIA based the economic and demographic trends reflected in the Reference case on the current views of leading economic forecasters and demographers. For example, the Reference case projection assumes improvement in known energy production, delivery, and consumption technologies.
- The Reference case generally assumes that current laws and regulations that affect the energy sector, including laws that have end dates, remain unchanged throughout the projection period. This assumption enables EIA to use the Reference case as a benchmark to compare with alternative policy-based cases.
- The potential effects of proposed legislation, regulations, or standards are not included in the AEO2021 cases.

What are the side cases?

- Global market balances, primarily influenced by factors that are not modeled in NEMS, will drive future oil prices. In the AEO2021 High Oil Price case, the price of Brent crude oil, in 2020 dollars, reaches $173 per barrel (b) by 2050, compared with $95/b in the Reference case and $48/b in the Low Oil Price case.

- Compared with the Reference case, the High Oil and Gas Supply case reflects lower costs and greater resource availability for oil and natural gas in the United States, which allows for more production at lower prices. The Low Oil and Gas Supply case assumes fewer resources and higher costs.

- The High Economic Growth case and Low Economic Growth case address the effects of economic assumptions on the energy consumption modeled in the AEO2021. The two cases assume compound annual growth rates for U.S. gross domestic product of 2.6% and 1.6%, respectively, from 2020 to 2050, compared with 2.1% per year growth in the Reference case.

- The High Renewables Cost case and the Low Renewables Cost case examine the sensitivities surrounding capital costs for renewable electric power generating technologies. Capital cost reduction for an electric power generating technology is assumed to occur from learning by doing. The High Renewables Cost case assumes no cost reduction from learning for any renewable technologies. The Low Renewables Cost case assumes higher learning rates for renewable technologies through 2050, resulting in a cost reduction of about 40% from the Reference case by 2050.

Takeaways from the Reference and side cases

Returning to 2019 levels of US energy consumption takes years; energy related carbon dioxide emissions fall further before leveling off or rising

- Energy consumption fell faster than gross domestic product in 2020, and the pace at which both will return to 2019 levels remains uncertain.
- Petroleum remains the most-consumed fuel in the United States, as energy-related carbon dioxide emissions dip through 2035 before climbing in later years.
- The energy intensity of the U.S. economy continues to fall as end-use sector intensities decline at varying rates.

Renewable energy incentives and falling technology costs support robust competition with natural gas as coal and nuclear power decrease in the electricity mix

- Electricity demand grows at a modest rate throughout the projection period.
- As coal and nuclear generating capacity retires, new capacity additions come largely from natural gas and renewable technologies.
- Renewable electricity generation increases more rapidly than overall electricity demand through 2050.
- The cost-competiveness of solar photovoltaic and natural gas combined-cycle units leads to capacity additions.

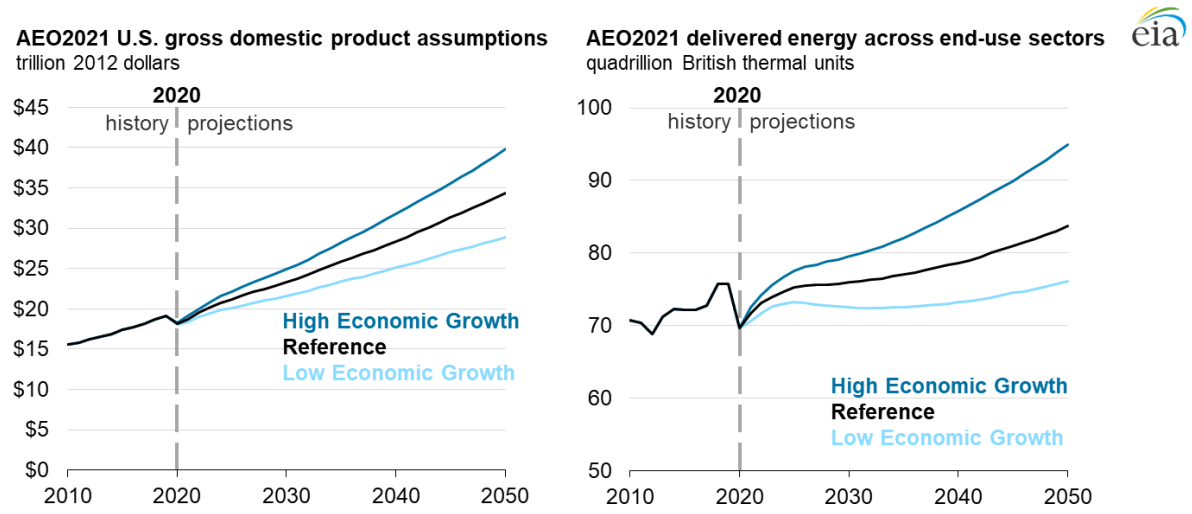
Continuing record-high domestic energy production supports natural gas exports but does not necessarily mean growth in the US trade balance in petroleum products

- Amid uncertainty, the United States continues to be an important global supplier of crude oil and natural gas.
- Motor gasoline remains predominant despite a growing mix of technologies in passenger vehicles.
- Natural gas consumption growth between 2020 and 2050 is concentrated in two areas: exports and industrial use.
- The amount of crude oil processed at U.S. refineries decreased in 2020 because of lower demand for transportation fuels, but it returns to 2019 levels by 2025.
- Consumption of biofuels as a share of the domestic fuel mix increases in AEO2021.

Energy consumption fell faster than gross domestic product in 2020, and the pace at which both will return to 2019 levels remains uncertain

Delivered energy consumption and gross domestic product decreased in 2020

Figure 1.

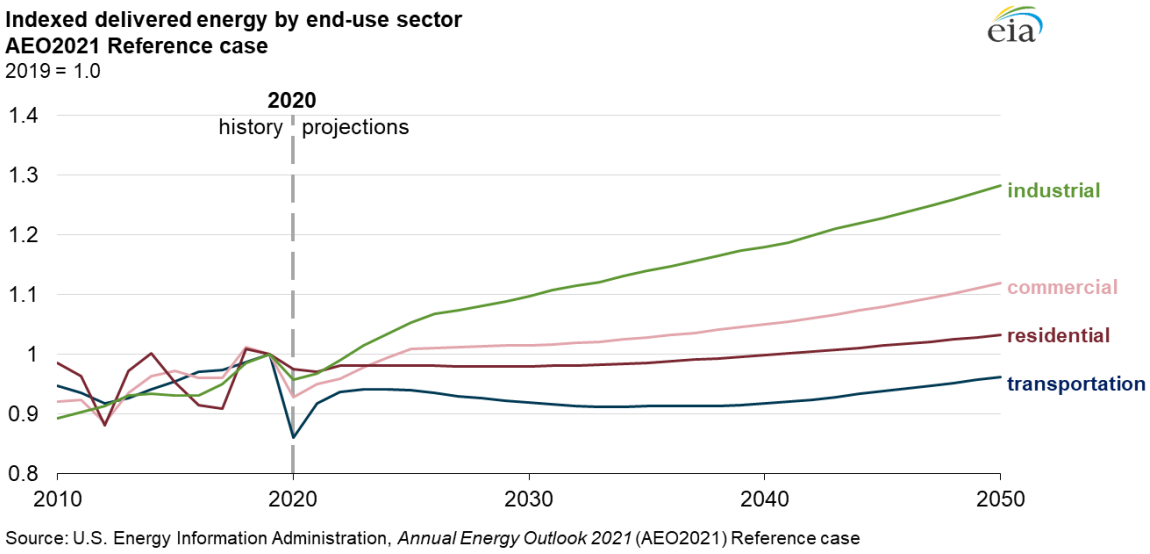


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Economic Growth, and Low Economic Growth cases

The 2020 downturn in the U.S. economy stems from a series of demand shocks, both direct and indirect, that have resulted in large part from responses to the COVID-19 pandemic. Demand for energy delivered to the four U.S. end-use sectors (residential, commercial, transportation, and industrial) decreased to 90% of its 2019 level in 2020; a steeper decline than seen in real GDP. Compared with the financial crisis of 2008, the COVID-19-related decline in the total demand for delivered energy is about 70% larger. In the AEO2021 Reference case, EIA projects that U.S. energy demand takes until 2029 to return to 2019 levels.

Projections in AEO2021 focus on key factors driving longer-term demand for energy: growing economy and population; increasing use of renewables; increasing consumption of natural gas and electricity; and changing technology, behavior, and policy that affects energy efficiency in vehicles, end-use equipment, and lighting. These factors extend beyond the uncertainty resulting from the COVID-19 pandemic. The AEO2021 economic growth side cases provide alternative assumptions that reflect the uncertainties in the future growth of the U.S. economy. The economic growth cases also show the fastest and slowest rates of return to the 2019 level of total U.S. energy demand: in 2024 in the High Economic Growth case and in 2050 in the Low Economic Growth case, compared with 2029 in the Reference case.

Figure 2.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Responses to the pandemic decreased energy consumption in the transportation sector more than in the other end-use sectors

In the Reference case, energy consumption in the transportation sector remains lower than its 2019 level for the entire projection period because travel greatly decreased in 2020 as a result of lockdowns, and assumed improvements in fuel economy offset projected resumed travel growth. Responses to the COVID-19 pandemic including mobility restrictions, limitations on nonessential travel, and increased working from home greatly reduced long- and short-distance U.S. travel demands in 2020 compared with 2019. In the Reference case, U.S. passenger air travel demand decreases by nearly two-thirds in 2020 and returns in 2025 to 2019 levels; bus passenger travel demand decreases by nearly half in 2020 and returns in 2031 to 2019 levels; and light-duty vehicle (LDV) travel returns to 2019 levels by 2024.

As rising economic activity results in increased travel demands that surpass 2019 levels, energy consumption in aviation (excluding military use) to move passengers and goods across the world returns to its 2019 levels by 2030. However, energy consumption by light-duty and heavy-duty vehicles remains lower than 2019 levels for the entire projection period. Although travel demands increase for most modes, assumptions of increasing fuel efficiency slow growth in energy consumption. Energy consumption decreases in the Reference case because of the market-based adoption of energy efficiency technologies in new vehicles and the increasingly stringent federal fuel economy standards through for new light-duty vehicles (through 2026) and heavy-duty vehicles (through 2027). Efficiency improvements fully offset the consumption growth from LDV travel growth through 2043 and partially offset the consumption growth from heavy-duty vehicle travel growth through 2036. Continued growth of on-road travel increases energy use later in the projection period because the travel demand for both light- and heavy-duty vehicles outpaces fuel economy improvements.

Industrial energy consumption is projected to return to 2019 levels more rapidly than in other sectors

By 2025, industrial output in the United States returns to 2019 levels in the Reference case, although EIA projects that specific industries will return to 2019 levels at different rates. Industrial energy

consumption also declined in 2020, but EIA projects it to return to its 2019 levels by 2023, which is even faster than output growth and yields an increase in energy intensity in the near term. The U.S. industrial sector consumes more energy than any other end-use sector, and its energy use is projected to grow nearly twice as fast as any other end-use sector between 2020 and 2050. Metal-based durables, primary metals, and refining, all sensitive to net exports, contributed significantly to the 2020 decline in delivered energy consumption, while energy-intensive manufacturing and non-manufacturing industries drive the return to 2019 levels.

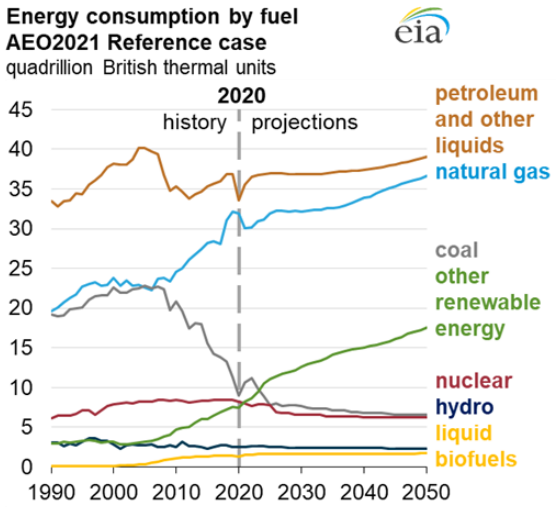
Energy consumption in buildings is least affected

Consumption of energy in commercial buildings declined in 2020, resulting in the largest single-year decline in buildings sector delivered energy consumption since 2012. However, in the Reference Case, energy consumption in commercial buildings returns to 2019 levels by 2025. Commercial and residential energy intensities—the ratio of delivered energy consumption to floorspace or building counts—suggest shifts in demand from increased working from home and videoconferencing in 2020 compared with 2019, although the increase in demand for energy by the residential sector is tempered by lower space heating needs resulting from a relatively warm 2019–2020 winter.

Consumption of energy in residential buildings remains stable through the short term because because working from home is moderating the effects of the economic downturn. Although Reference case energy consumption grows more slowly in residential buildings than in any other end-use sector between 2020 and 2050, increases in residential demand for cooling and electronic equipment offset efficiency improvements in many types of equipment, resulting in small increases in delivered energy consumption.

Petroleum remains the most-consumed fuel in the United States, as energy-related carbon dioxide emissions dip through 2035 before climbing in later years

Figure 3.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Vehicles and industrial processes are the main petroleum consumers in the Reference Case

Petroleum and other liquids remain the most-consumed fuel in the AEO2021 Reference case. The transportation sector is the largest consumer of petroleum and other liquids, particularly motor gasoline and distillate fuel oil. In the Reference Case, EIA assumes that current fuel economy standards stop requiring additional efficiency increases in 2026 for light-duty vehicles and in 2027 for heavy-duty vehicles. As travel continues to increase, consumption of petroleum and other liquids increases later in the projection period.

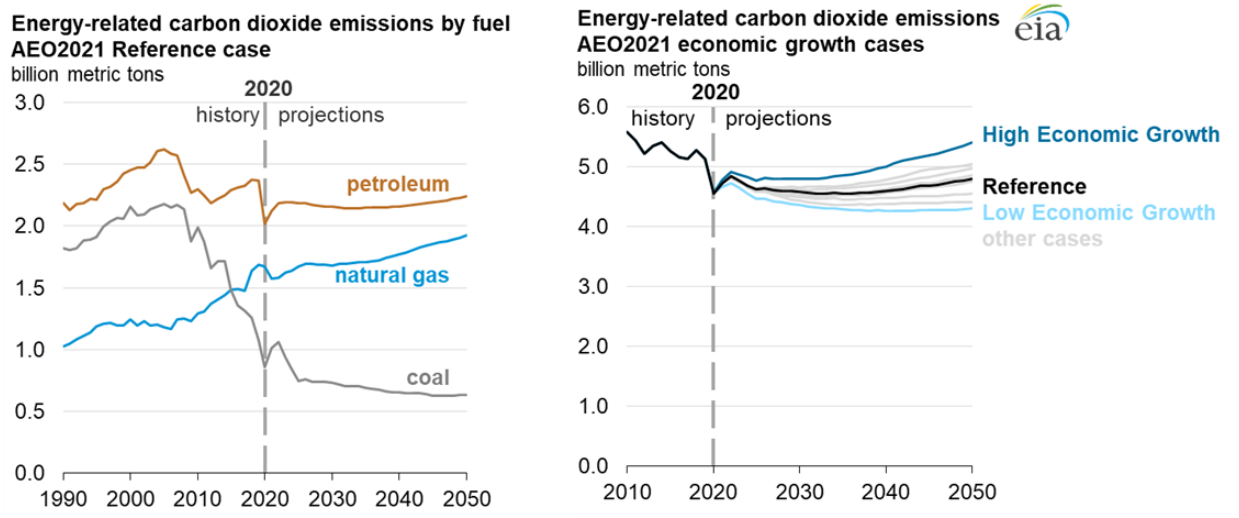
For industrial uses, petroleum remains the primary fuel for refining processes and for agriculture.

Coal continues a steady decline, as solar, wind, and natural gas use increases

In all cases, consumption of non-hydroelectric renewable energy is projected to be the fastest growing energy source. Policies at the state and federal level have encouraged significant investment in renewable resources for electricity generation and transportation fuels. New technologies have driven down the cost to install wind and solar generation, further increasing their competitiveness in the electricity market even as policy effects moderate over time. Federal regulation continues to encourage the use of biofuels, primarily ethanol, in the projection period. However, relatively modest increases in overall electricity and liquid fuel demand slow the projected growth of renewable energy in the Reference case.

EIA projects that consumption of natural gas will keep growing as well, driven by expectations that natural gas prices will remain low compared with historical levels. In the Reference case, the industrial sector becomes the largest consumer of natural gas starting in the early 2020s. This sector will expand the use of natural gas as a feedstock in the chemical industries, as well as for industrial heat and power.

Figure 4.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Economic Growth, and Low Economic Growth cases

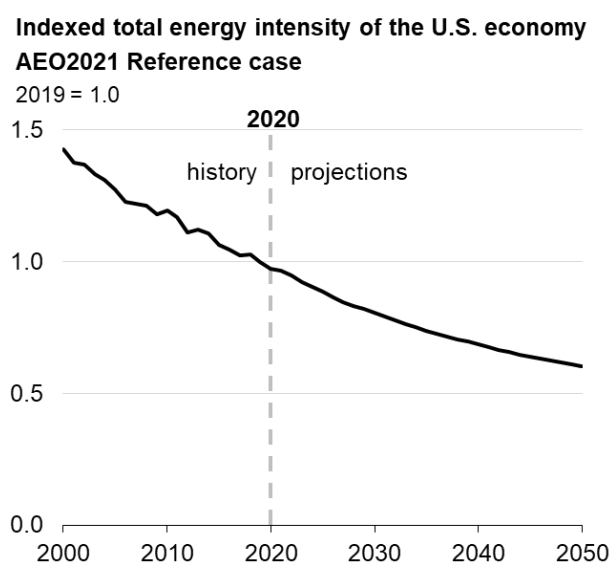
Coal use through 2050 generally declines with the retirement of coal-fired electricity generating units in the United States. In 2020, all power generation types, including coal, saw a decline in power demand because of COVID-19 response measures, but the decline in power demand affected coal to a greater extent because the annual average natural gas price fell to its lowest level in more than 20 years and as a result coal-fired generation was displaced by natural gas-fired generation.

Changes in fuel mix reduce Reference case emissions through 2035

Changes over time in carbon dioxide (CO2) emissions in the Reference case reflect the shift in fuel consumption: emissions decrease from 2023 to 2035 as a result of a transition away from more emission-intensive coal and a rise in the use of natural gas and renewable energy. After 2035, U.S. emissions begin to trend upward, reflecting the overall increase in the use of energy as a result of increasing population and economic growth. This trend holds true in all AEO2021 side cases. The High Economic Growth case has the largest increase in emissions, and the Low Economic Growth case has the lowest. Reductions in both energy intensity (energy consumption per gross domestic product) and carbon intensity (CO2 per energy consumption) both lessen the effects of economic growth. Even in the High Economic Growth case, energy-related CO2 emissions remain lower than the 2007 peak of 6 billion metric tons through 2050.

The energy intensity of the U.S. economy continues to fall as end-use sector intensities decline at varying rates

Figure 5.

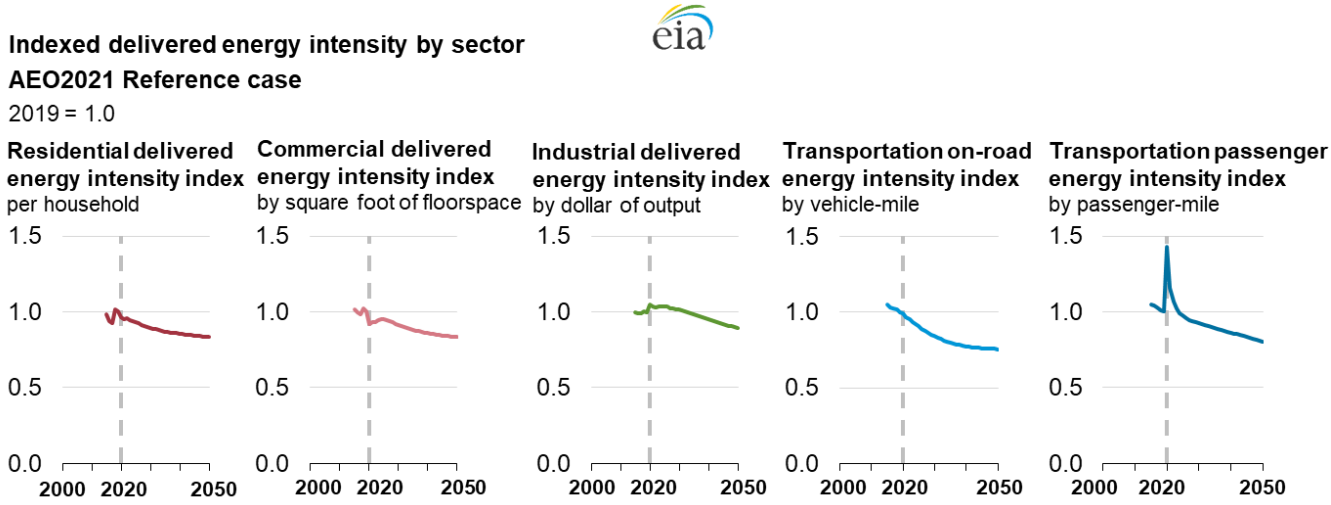


Note: Total energy intensity calculation reflects primary energy, which includes electricity losses.
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Energy intensity declines across the entire economy

Total U.S. energy intensity—measured as the amount of primary energy consumed per dollar of GDP—continues to decrease slowly in the Reference case as real GDP increases faster than total energy consumption. In 2020, U.S. energy intensity is about half of what it was in 1990. In 2050, the ratio is about two-thirds of what it was in 2020. The U.S. economy becomes steadily less energy-intensive, although the rate of decrease is slower relative to recent history.

Figure 6.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Declines in energy intensity occur in each end-use sector

Energy is used in the economy to provide specific end-use services. Activities that consume energy provide indicators of efficiency (energy intensity) for each economic sector in the United States and vary in the Reference case projection as sectoral activity, technology choice, and utilization interact.

Industrial sector

Energy intensity in the U.S. industrial sector—measured as the amount of energy consumed by industry per dollar of industrial gross output—generally declines at nearly the same annual rate between 1990 and 2050 because of a continuing shift toward less energy-intensive manufacturing industries. Energy intensity increases in 2020 in response to lower utilization, but thereafter returns to a steady decline.

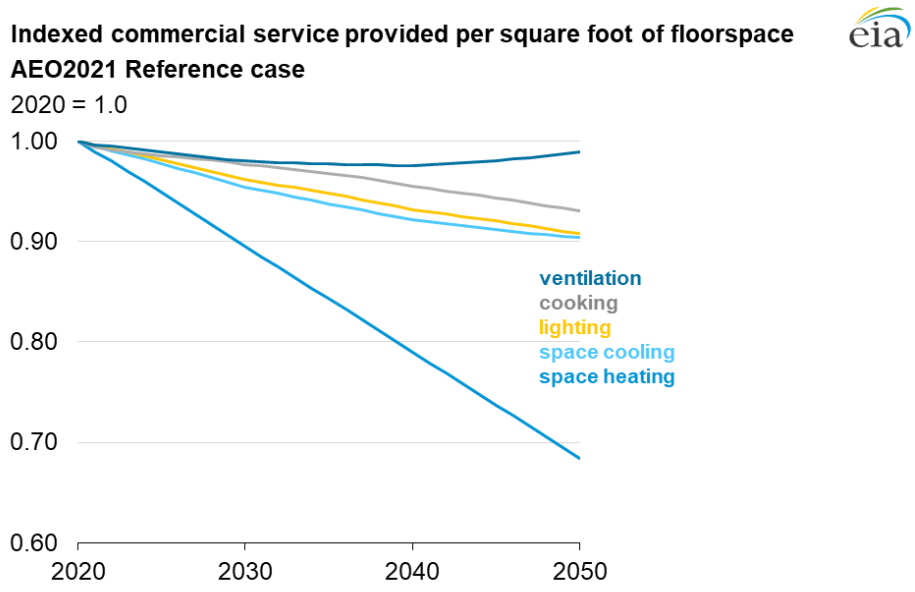
Transportation sector

Energy intensities in the U.S. transportation sector—measured as the amount of energy consumed in transportation per passenger-mile traveled for rail, air, and bus modes and per vehicle mile traveled for light-and heavy-duty vehicle modes—have different pathways in the short term. The collapse in passenger traffic arising from the pandemic, as measured by average load factors, results in an increasing amount of energy per passenger-mile: an energy intensity spike in the short term. After air load factors return to 2019 levels in 2024, the trend in energy intensity per passenger mile returns to a steady decline as rail, air, and bus modes adopt energy-efficient technologies and practices. After 2020, the combined energy intensity for light- and heavy-duty vehicles declines throughout the projection period because combined travel growth is fully offset by increases in fuel economy. The rate of decrease slows toward the end of the projection period because current fuel efficiency regulations require no additional increases in fuel economy for new light-duty vehicles after 2026 or for new heavy-duty vehicles after 2027.

Commercial and residential buildings sectors

EIA calculates energy intensity in the U.S. buildings sector as either the amount of energy consumed in buildings per square foot of commercial floorspace or the amount of energy consumed per residential household. Currently established increases in efficiency standards, building codes, and incentives lead to energy efficiency improvements, especially those attributed to energy management controls and sensors associated with space heating. These improvements, along with growth in distributed electricity generation including onsite solar—partially offset the effects of growth in the U.S. population, households, and commercial floorspace, which decreases energy intensity.

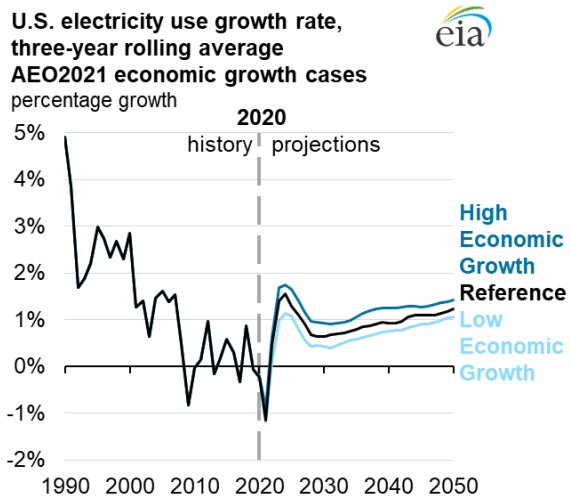
Figure 7.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Electricity demand grows at a modest rate throughout the projection period

Figure 8.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Economic Growth, and Low Economic Growth cases

Annual average electricity growth rate is less than 1% from 2020 to 2050 in the Reference case

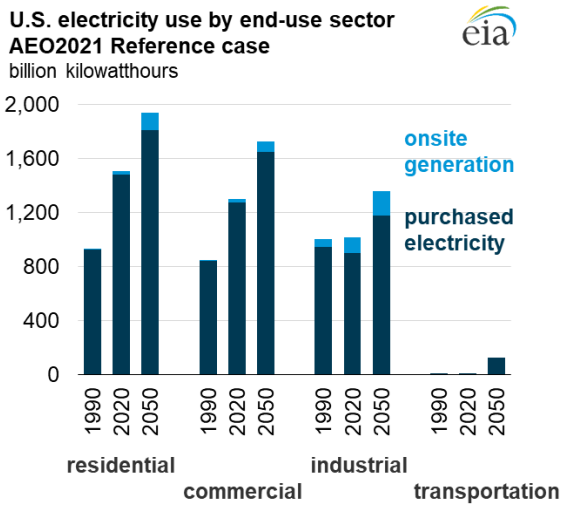
In the short term, demand for electricity may fluctuate as a result of year-to-year weather changes, but EIA projects that longer-term trends in electricity demand are driven by economic growth, and are somewhat offset by efficiency improvements. In the AEO2021 Reference case, after electricity demand returns to 2019 levels (following the impacts of COVID-19) in 2022, the average annual growth rate surpasses 1% only toward the end of the projection period. EIA projects electricity demand in the AEO2021 High Economic Growth case to grow at about one-quarter of a percentage point faster than in the Reference case, and it projects electricitiy demand in the Low Economic Growth case to grow at about one-quarter of a percentage point slower than in the Reference case.

COVID-19's projected impacts on electricity demand are short term in the Reference case

Although shifting weather patterns and efficiency improvements explain some of the near-term changes in electricity demand, the COVID-19 pandemic and associated economic downturn has a role as well, resulting in a near-term decline in electricity demand. EIA does not project long-term structural changes in electricity demand resulting from the pandemic, and the AEO2021 Reference case projects that demand largely returns to 2019 levels by 2025. Before 2025, higher residential sector demand partially offsets lower electricity demand from the commercial and industrial sectors.

The share of onsite electricity generation increases across non-transportation sectors

Figure 9.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

The growth in electricity sales from vendors is lessened by significant growth in onsite generation in the residential, commercial, and industrial sectors. Installation of rooftop photovoltaic (PV) systems, primarily on residential and commercial buildings, and combined-heat-and-power systems in industrial and some commercial applications, will account for more than 7% of total electricity generation by 2050, almost doubling the 2020 share of onsite power generators.

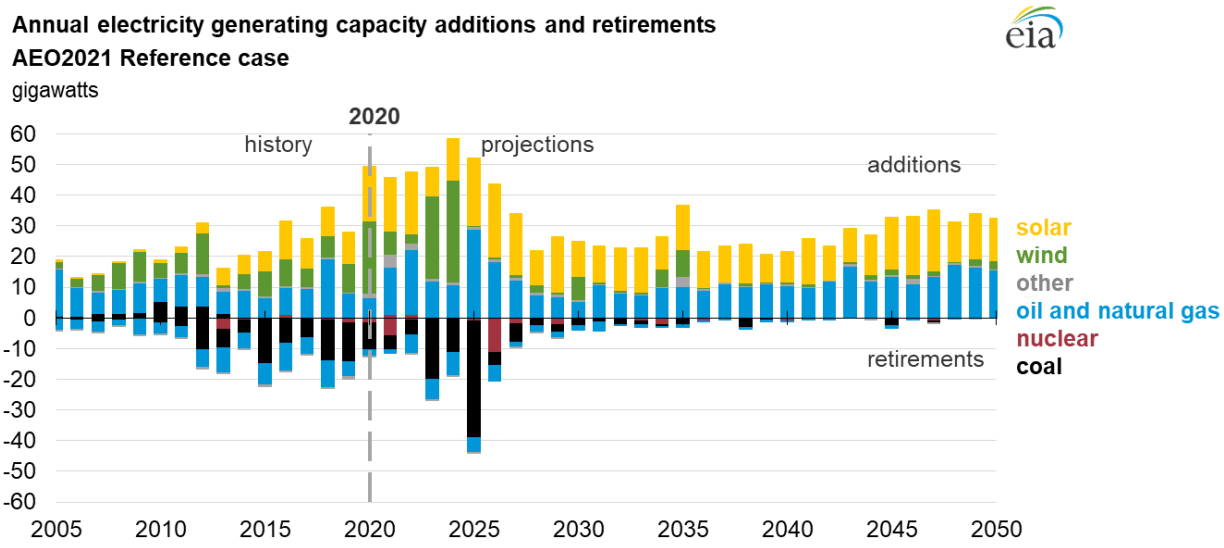
Electricity demand in transportation remains low

Although the greatest potential for increased electricity demand is within the transportation sector, electricity demand from this sector remains less than 3% of economy-wide electricity demand throughout the projection period. Current laws and regulations are not projected to induce much market growth, despite continuing improvements in electric vehicles (EVs) through evolutionary market developments. Both vehicle sales and utilization (miles driven) would need to increase substantially for EVs to raise electric power demand growth rates by more than a fraction of a percentage point per year.

As coal and nuclear generating capacity retires, new capacity additions come largely from natural gas and renewable technologies

Renewable technologies account for the majority of the projected capacity additions

Figure 10.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case and July 2020 Form EIA-860M

Renewable electric generating technologies account for almost 60% of the approximately 1,000 gigawatts of cumulative capacity additions projected in the AEO2021 Reference case from 2020 to 2050. The large share is a result of declining capital costs but is also a result of increasing renewable portfolio standard (RPS) targets and tax credits. Although wind contributes to renewable electric generating capacity additions, it is on a much smaller scale compared with solar capacity, which builds steadily throughout the projection period.

Wind additions are largely tied to policy

The projection now assumes the production tax credit (PTC) for wind runs for an extra year, or through 2024, following a one-year extension under the Taxpayer Certainty and Disaster Tax Relief Act of 2019, Division Q of the Further Consolidated Appropriations Act of 2020 passed in December 2019 and under the Internal Revenue Service's Notice 2020-41 issued in May 2020. Although capital costs for both wind and solar continue to decline throughout the projection period, without additional policy intervention, wind is not as cost-competitive as solar. More than two-thirds of cumulative wind capacity additions from 2020 to 2050 occur before the PTC expires at the end of 2024. The steadier pace of solar additions in part reflects the continued availability of a 10% investment tax credit (ITC), which continues in perpetuity after 2023 when the current 30% phases out.

Natural gas continues to be the fuel of choice for fossil-fuel capacity additions

Although renewable electric generating technologies account for about 60% of cumulative capacity additions throughout the projection period in the AEO2021 Reference case, natural gas-fired generators account for almost the entire remaining balance of additions—about 40% through 2050. These natural gas-fired generator additions are almost evenly split between combined-cycle technologies and

combustion turbines, which both provide energy and help balance the intermittent output from wind and solar generators.

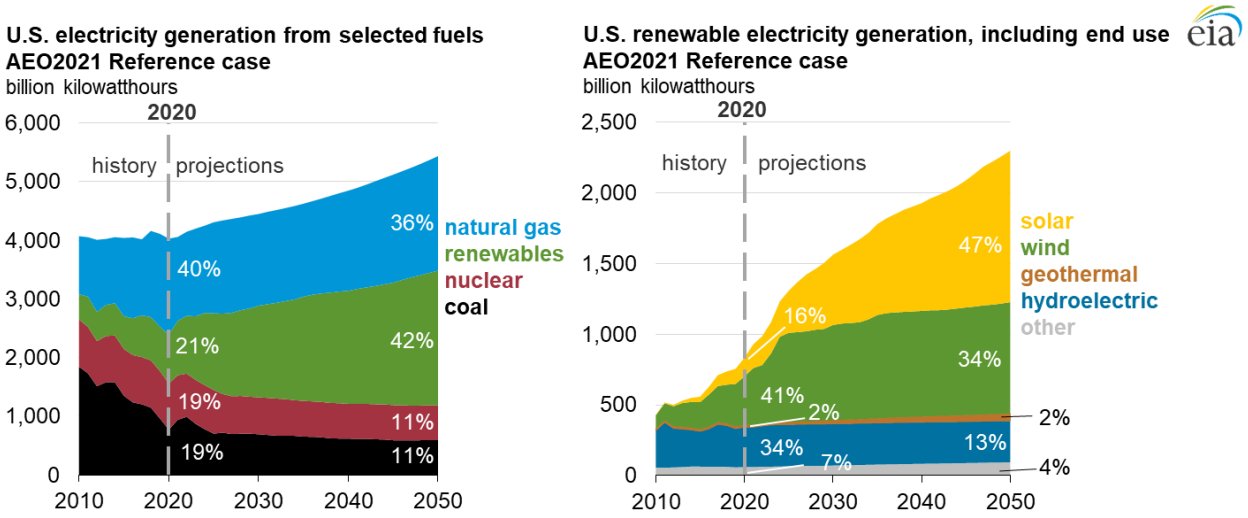
Coal-fired generating unit retirements largely take place by 2025

Most of the coal-fired generating capacity retirements assumed in the AEO2021 Reference case occur by 2025. The Reference case includes legislation and regulation as of September 2020, and so incorporated the EPA's Affordable Clean Energy (ACE) rule (84 FR 32520), which was vacated in the United States Court of Appeals for the District of Columbia Circuit on January 19, 2021. In AEO2021, the coal-fired plants remaining after ACE takes effect are more efficient and continue to operate throughout the projection period. Low natural gas prices in the early years of the projection period also contribute to the retirements of coal-fired and nuclear plants because both coal and nuclear generators are less profitable in these years, because natural gas generation generally sets power prices in wholesale electricity markets.

Renewable electricity generation increases more rapidly than overall electricity demand through 2050

Sustained low natural gas prices do not result in significant increases in the share of natural gas generation in the Reference case

Figure 11.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

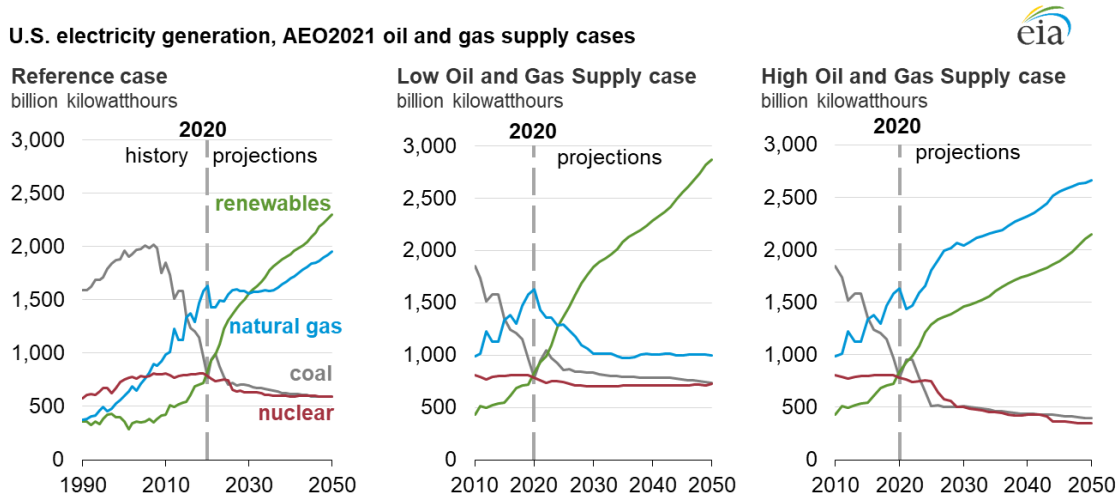
The share of natural gas in the generation mix remains flat, hovering at about one-third from 2020 to 2050. The share remains the same even though natural gas prices remain low (at or lower than $3.50 per million British thermal units) for most of the projection period, despite significant coal and nuclear generating unit retirements resulting from market competition, as regulatory and market factors induce more renewable electric generation.

Renewable electric generation is used to meet an increasing share of additional demand

As the share of natural gas-fired generation remains relatively flat, and as the contribution from the coal and nuclear fleets drops by half, the renewables' share of the electricity generation mix more than doubles from 2020 to 2050. Wind is responsible for most of the growth in renewables generation from 2020 through 2024, accounting for more than two-thirds of those increases in electricity generation during that period. After the production tax credit (PTC) for wind phases out at the end of 2024, solar generation is responsible for almost three-quarters of the increase in renewables generation. EIA assumes solar receives a 30% investment tax credit (ITC) through 2023, which is then reduced to a permanent value of 10% in 2024 and forward.

Impacts of COVID-19 on natural gas prices led to near-term trade-offs between coal and natural gas generation

Figure 12.

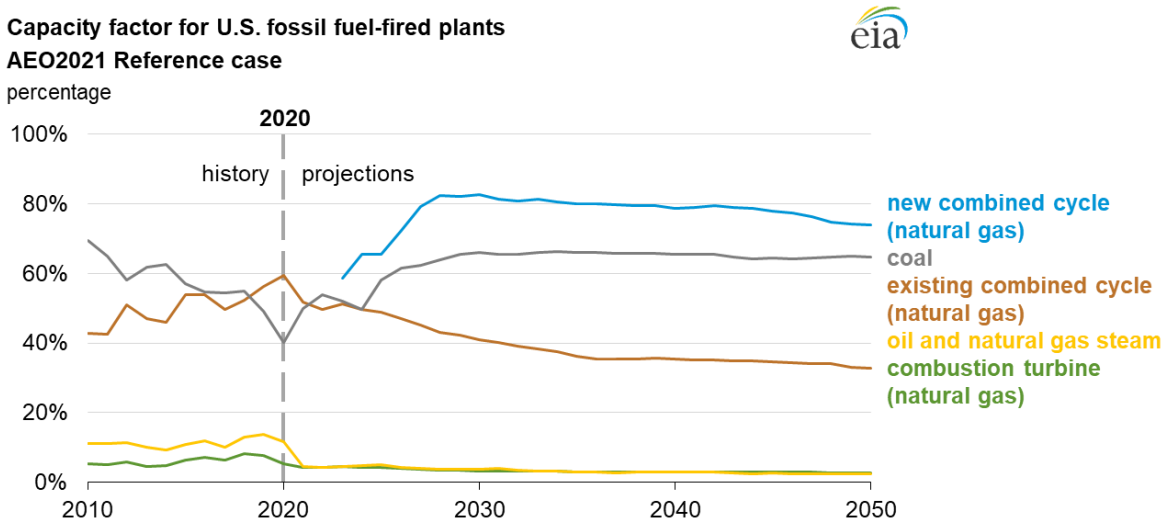


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, and Low Oil and Gas Supply cases

In 2020, low heating demand early in the year because of warmer-than-normal weather, along with COVID 19-related demand reductions, led to natural gas production outpacing demand. The oversupply of natural gas led to the lowest natural gas prices since the 1990s. In addition, responses to the pandemic caused disruptions in the coal supply chain as mines temporarily closed to limit the spread of the virus. COVID 19-related impacts to the coal supply chain, as well as the lowest natural gas prices in a few decades, caused the projected share of coal-fired generation to decrease by over 4% in 2020 (from 23% in 2019 to 19% in 2020). At the same time, the share of natural gas-fired generation increased by about half that amount (from 38% in 2019 to 40% in 2020). EIA projects natural gas prices to increase by more than one-half in 2021 as the natural gas share of the generation mix returns to pre-COVID-19 levels and maintains that share through 2050. Similarly, coal generation in 2022 also increases with electricity demand and the rising natural gas prices before returning to its longer-term structural decline.

As more solar and wind energy is integrated into the electricity grid, natural gas-fired generating unit capacity factors steadily decrease

Figure 13.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

As a result of faster growing natural gas-fired generating capacity than natural gas-fired generation from 2020 to 2050, capacity factors for natural gas units decline steadily across all plant technology types. As more wind and solar capacity is added that displaces generation from both existing and new natural gas-fired generators, capacity factors for existing combined-cycle units will drop by nearly half from a peak of 60% in 2020. Natural gas accounts for over 40% of cumulative capacity additions from 2020 to 2050. About half of these additions are low-utilization combustion turbines, which are economically attractive when mostly used to provide infrequent peaking capacity. Energy storage systems, such as stand-alone batteries or solar/battery hybrid systems, are used as an arbitrage tool to move solar and other generation from periods of high supply and low demand to periods of low supply and high demand.

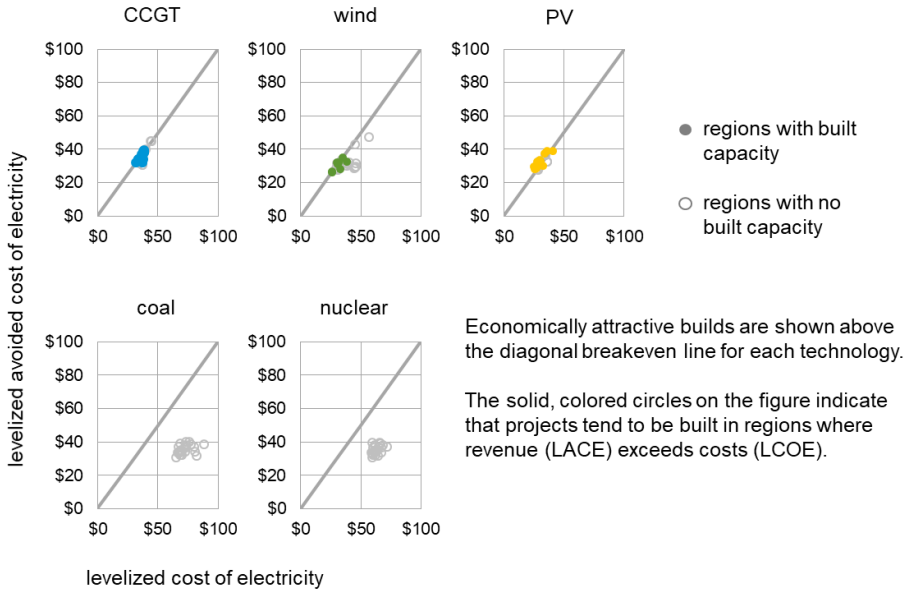
The cost-competiveness of solar photovoltaic and natural gas combined-cycle units leads to capacity additions

Declining costs of intermittent renewable technologies, particularly solar photovoltaic, make solar cost-competitive with natural gas combined cycle

Figure 14.

Levelized avoided cost of electricity (LACE) and levelized cost of electricity (LCOE) by technology, 2026 online year, AEO2021 Reference case

2020 dollars per megawatthour



Note: CCGT = natural gas combined cycle, PV = solar photovoltaic
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

In the AEO2021 Reference case, natural gas-fired combined-cycle and solar photovoltaic generators are the most economically attractive generating technologies when considering the overall cost to build and operate, as well as the value of the plant to the grid.

The levelized cost of electricity (LCOE) reflects the cost to build and operate a power plant per unit of generation, annualized over a cost-recovery period. The levelized avoided cost of electricity (LACE) represents a power plant's value to the grid, which is a proxy for a plant's potential revenues from the sales of electricity generated from displacing another marginal asset.

Both the levelized cost and levelized avoided cost of electricity, when used together, simplify the factors contributing to the capacity expansion decisions modeled. The value-cost-ratio (the ratio of LACE-to-LCOE) shows combined cycle and solar photovoltaic are the most economically competitive generating technologies.

In the AEO2021 Reference case, expected revenues from electricity generated from both natural gas-fired combined-cycle units and solar photovoltaic with single axis tracking units are generally greater than or equal to their respective projected costs across most of the electricity market regions in 2026.

Correspondingly, these two technologies show the greatest projected growth throughout the projection period. The value of wind approaches its cost in several regions. These regions see new wind capacity builds in the AEO2021 Reference case, primarily in advance of the phaseout of the production tax credit (PTC).

LACE accounts for both the variation in daily and seasonal electricity demand in the region where a new project is under consideration and the characteristics of the existing generation fleet where the new generating capacity will be added. The prospective new generation resource is compared with the mix of new and existing generation and capacity that it would displace. For example, a wind resource that would primarily displace existing natural gas-fired generation will usually have a different value than one that would displace existing coal-fired generation.

Amid uncertainty, the United States continues to be an important global supplier of crude oil and natural gas

Oil price is the primary driver of drilling and production

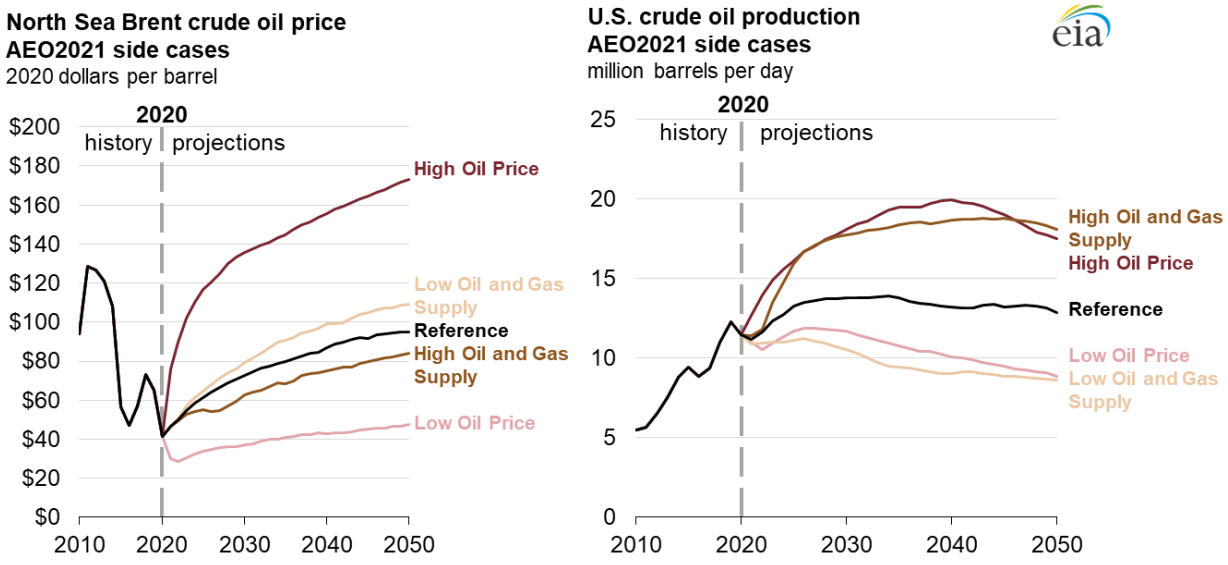
For both liquid fuels and natural gas, the effects of COVID-19 are primarily a short-term demand-side shock. Uncertainty surrounding post-pandemic expectations for oil and natural gas demand translates to uncertainties in supply through prices.

In AEO2021, the oil price is the primary driver of projected drilling activity and accompanying U.S. crude oil production rates. Thus, given the current economic downturn, EIA expects a lower price path in the short and medium term to decrease U.S. oil production rates compared with AEO2020.

Producers are more dependent on capital from cash flow

The oil and natural gas industry was already headed toward relying on capital from cash flow instead of debt and equity. COVID-19 has accelerated this trend, leaving producers more dependent on internal sources of cash flow because outside funding sources are less available or require higher rates of return. AEO2021 reflects these trends, with model changes including reducing drilling responsiveness to price increases in the short term and increasing the hurdle rate of return. Oil prices remain the most significant determining factor in oil production, and so if oil prices rapidly rise, as is seen in the High Oil Price case scenario, then production would follow suit.

Figure 15.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, Low Oil and Gas Supply, High Oil Price, and Low Oil Price cases

Reference case crude oil production remains at record-high levels for the next 30 years

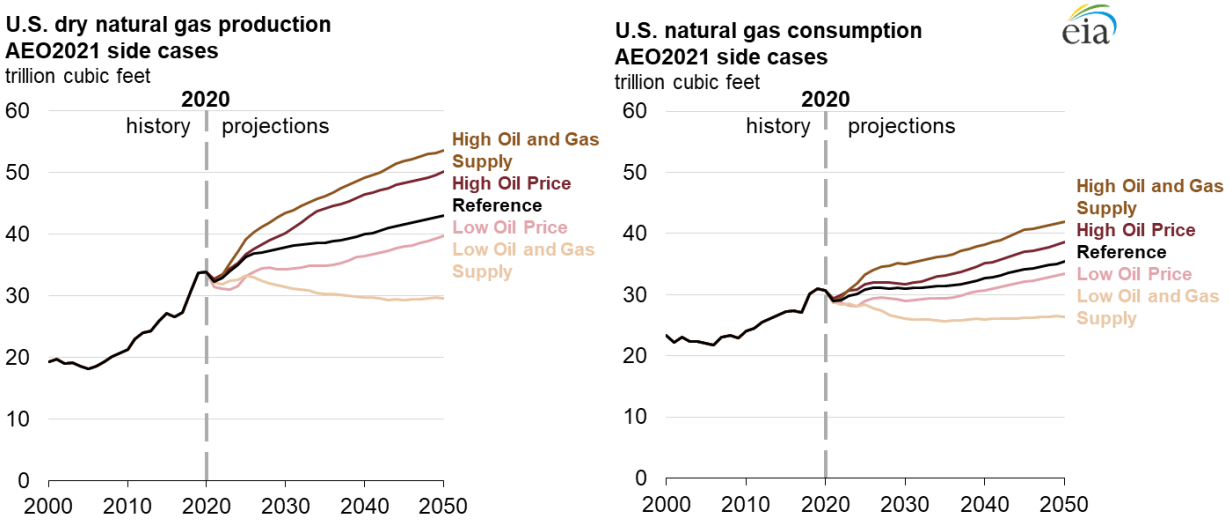
Starting in 2023, oil and natural gas production in the Reference case remains at historically high levels through 2050. The United States continues to be an integral part of global oil and natural gas markets and a significant source of global supply.

Domestic crude oil production in the Reference case returns to 2019 levels starting in 2023. In the long term, production continues to grow, generally plateauing in the later years of the projection period. The Brent crude oil price returns to 2019 levels after 2025 in the Reference case. Where the prices return quickly to pre-COVID-19 levels, as they do in the High Oil Price case, then crude oil production returns to 2019 levels more quickly. However, in the Low Oil Price case where oil prices are much lower than recent historical levels seen during the past 10 years, production never returns to pre-pandemic levels.

Tight oil is primarily driving the growth in the oil production outlook, followed by offshore resources. Tight oil production from the Wolfcamp play in the Permian Basin (Southwest region) and the Bakken play in the Williston Basin (Northern Great Plains region) leads the growth in U.S. tight oil production. However, estimates of technically recoverable tight or shale crude oil and natural gas resources are uncertain. The high and low oil and gas supply cases explore the impact of higher and lower resource supply levels on domestic production, including tight oil.

Natural gas production continues to grow, and end-use consumption and liquefied natural gas (LNG) trade remains uncertain

Figure 16.



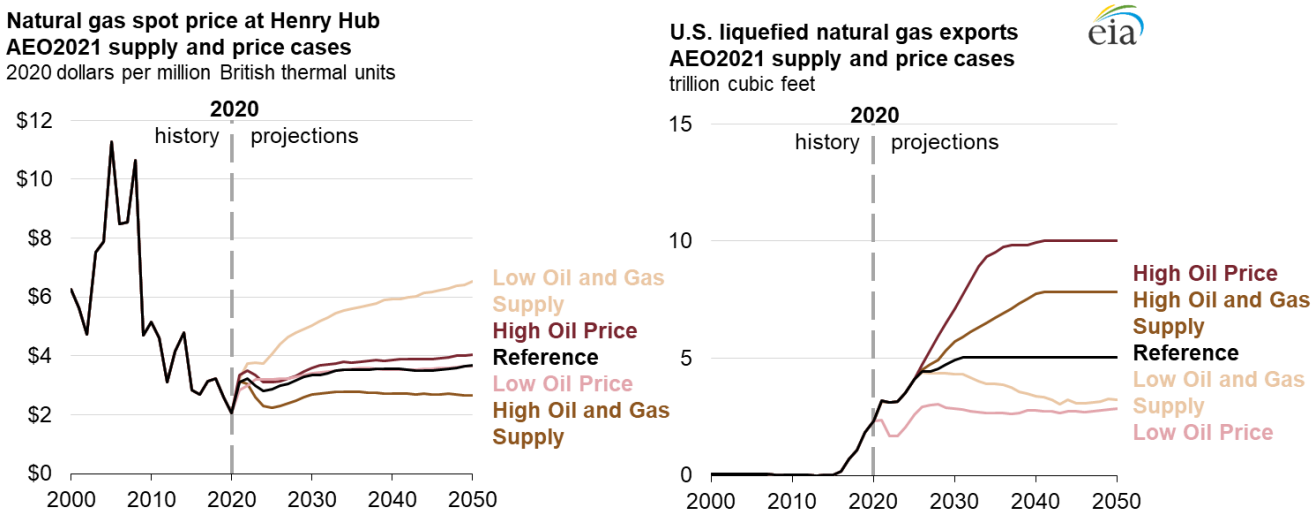
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Domestic natural gas production in the Reference case also returns to pre-pandemic levels starting in 2023. In the long term, production continues to grow during the entire projection period, driven by end-use consumption and opportunities to sell natural gas internationally through LNG exports.

Shale gas and associated natural gas from oil plays are the primary contributors to this long-term growth. In the Reference case, more than half of the growth in shale gas production between 2020 and 2050 comes from shale gas plays in the Appalachian Basin in the East region, and most of the remaining growth comes from plays in the Gulf Coast and Southwest regions. Due to the drop in crude oil production, associated natural gas (natural gas produced in primarily oil formations) also decreased in 2020 because of the relatively low crude oil and natural gas prices. EIA projects associated natural gas

will return to 2019 levels in 2024 and then steadily increase at a modest rate through 2050, primarily driven by increased drilling in the Permian Basin.

Figure 17.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, Low Oil and Gas Supply, High Oil Price, and Low Oil Price cases

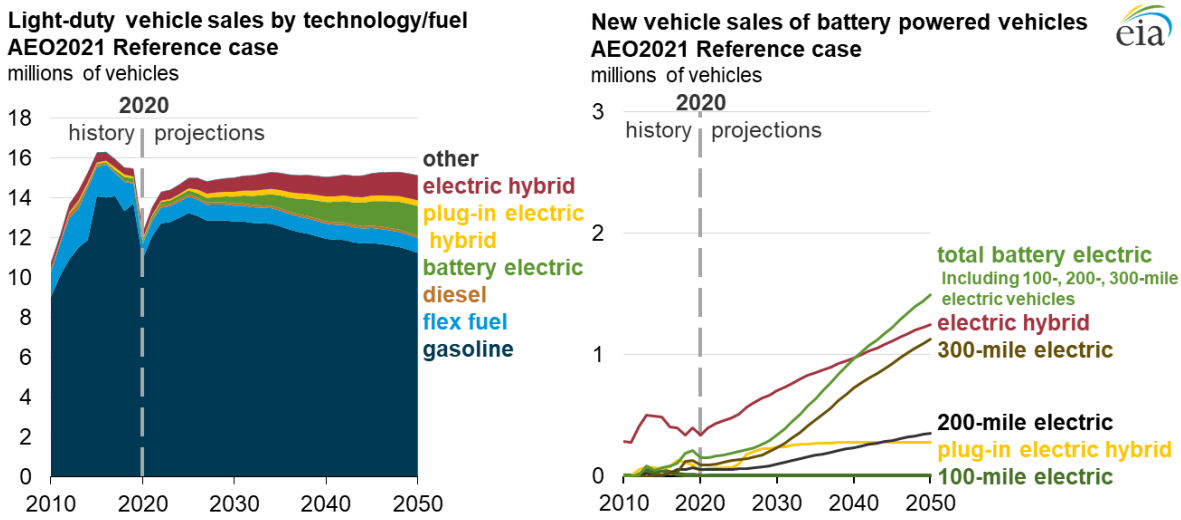
In the long term, because of expected increases in international demand for natural gas, EIA expects U.S. LNG exports to more than double between 2020 and 2029 in the Reference case.

The side cases display the uncertainty in international demand for and competitiveness of U.S. supply. Oil prices, which are traditionally used as a basis for global LNG price contracts, and U.S. natural gas prices both drive how competitive U.S. LNG exports are in global markets. The Oil and Gas Supply cases define the range of projected U.S. natural gas supply prices in the AEO 2021. Henry Hub natural gas spot prices remain below $3 per million British thermal units (MMBtu) in the High Oil and Gas Supply case and exceed $6/MMBtu by 2050 in the Low Oil and Gas Supply case.

With higher oil prices or lower U.S. natural gas domestic prices, LNG exports are much higher than in the Reference case, while the opposite occurs with lower oil prices or higher U.S. natural gas domestic prices.

Motor gasoline remains predominant despite a growing mix of technologies in passenger vehicles

Figure 18.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

The majority of new vehicles are powered by liquid fuels

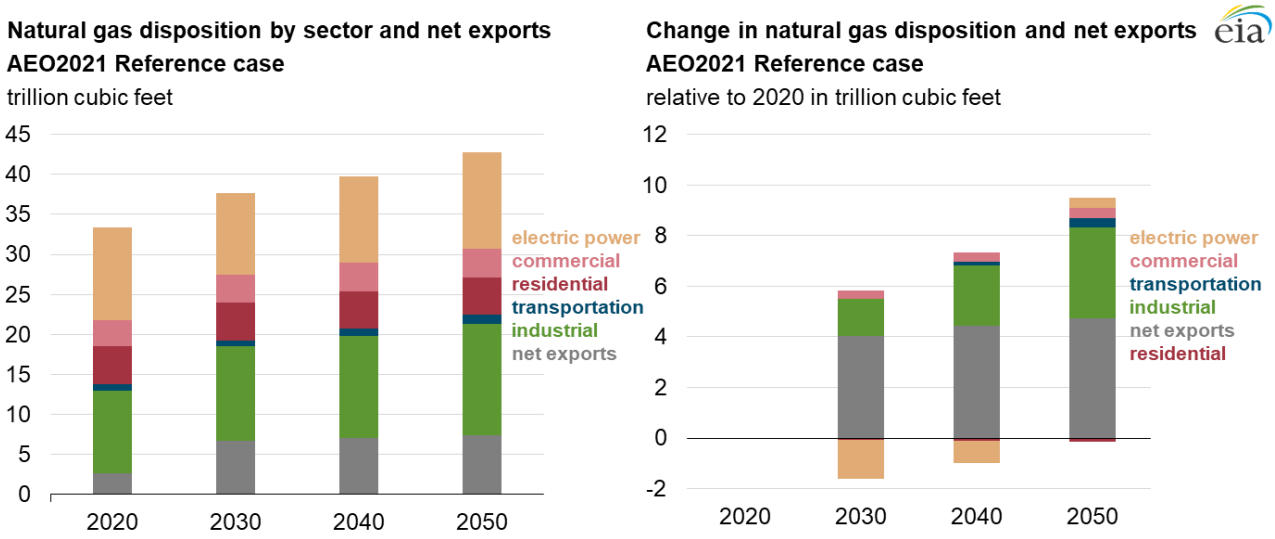
Spurred by rising incomes, increases in employment rates, and population growth, total annual sales of new light-duty vehicles (LDVs) in the United States in the Reference Case increase after the 2020 economic downturn before leveling off after 2025. EIA projects fewer sales of new LDVs in every year in the projection period than in 2019, although the market continues to grow for alternative technologies, particularly battery electric vehicles (BEVs). Gasoline and flex-fuel vehicles—which may use gasoline blended with up to 85% ethanol—accounted for 95% of the new LDV market in 2020, but their share of new-vehicle sales decreases to 79% in 2050. Both BEVs and electric hybrids increase their market shares of annual new LDV sales.

Motor gasoline consumption in U.S. transportation sector peaks in 2022

Because most light-duty vehicles have internal combustion engines, motor gasoline remains the major transportation fuel through 2050 as personal travel returns to pre-pandemic per-driver levels in the longer term. After pandemic response-related demand losses in 2020, consumption of motor gasoline in transportation peaks in about 2022 as fuel economy improvements partially offset travel growth. Motor gasoline use slowly trends lower thereafter as a result of further fuel economy improvements in new LDVs relative to travel growth, as well as increasing sales of energy-efficient alternative-fueled vehicles that further displace motor gasoline use.

Natural gas consumption growth between 2020 and 2050 is concentrated in two areas: exports and industrial use

Figure 19.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Natural gas production continues to grow during the entire projection period, driven by end-use consumption and opportunities to sell natural gas through LNG exports for international consumption. Large amounts of natural gas are consumed in the United States for various uses, for example space heating in buildings, thermal and feedstock requirements in industrial processes, and natural gas-fired electricity generation that is subsequently delivered as purchased electricity. Natural gas consumption growth between 2020 and 2050 is concentrated in two areas: exports and industrial use. All sectors in the United States are projected to increase natural gas consumption in 2050 relative to 2020 in the Reference case, except the residential sector.

The U.S. industrial sector leads future increases in domestic natural gas consumption

In the AEO2021 Reference case, the industrial sector is responsible for more of the growth in domestic natural gas consumption than any other U.S. sector because of the economic growth driving increased U.S. industrial output, coupled with a limited economic fuel-switching capability. Industrial firms are very price sensitive and tend to continue using natural gas as ample supply keeps industrial pricing attractive in the Reference case projection.

Although natural gas is consumed across the entire U.S. industrial sector, increased production of natural gas as well as low natural gas prices will especially benefit the chemical industry because of its requirements for raw material (feedstocks) and heat and power inputs. The bulk chemical industry, which includes production of organic chemicals (including petrochemicals), inorganic chemicals, resins, and agricultural chemicals, is responsible for almost half of the growth in industrial natural gas demand, including growth in both heat and power and feedstock used in producing methanol, nitrogenous fertilizers, and hydrogen. Most of this growth in liquid feedstock consumption is for hydrocarbon gas liquids (HGL), of which ethane and propane from the natural gas stream are the main components.

Natural gas-fired combined heat and power adds to industrial demand for natural gas

Taking advantage of combined-heat-and-power (CHP) technologies, the bulk chemical, refining, and paper industries use the most CHP in the United States because these large industries have high, well-defined heating needs, and therefore, process steam is readily available onsite to use for electricity generation. Low natural gas prices contribute to the increasing use of natural gas-fired CHP technology in the projections. Furthermore, paper and refining also use byproducts of their manufacturing processes as CHP fuel, so use of CHP in these industries tends to increase with output.

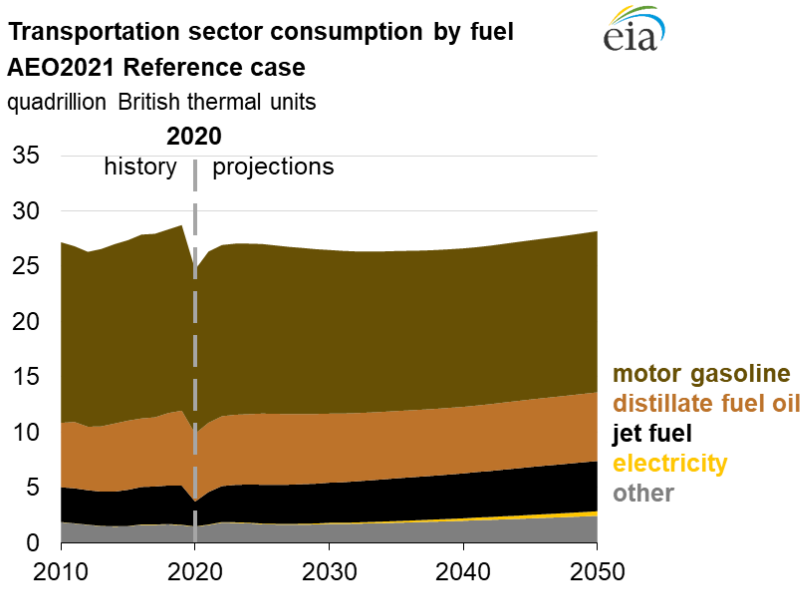
Consumption of natural gas in other sectors grows slowly

In the AEO2021 Reference case, power sector demand for natural gas-fired electricity generation increases at a much slower rate than either exports or industrial demand between 2020 and 2050. Even as natural gas-fired generation increases during the projection period, increased fleet efficiency from natural gas-fired generator additions of new combined-cycle electric generating technologies that operate at high usage levels—coupled with existing, less-efficient natural gas-fired technologies declining in use or retiring from the fleet—slow growth in natural gas consumption. Use of natural gas for transportation steadily increases through 2050 because of the improved economics of natural gas as a fuel for heavy-duty vehicles, but it remains at relatively low levels. The residential sector's consumption of natural gas is nearly flat, and commercial buildings show low-to-moderate growth, both as a result of final demand growth being tempered by energy efficiency improvements (particularly energy management controls and sensors) in space heating.

The amount of crude oil processed at U.S. refineries decreased in 2020 because of lower demand for transportation fuels, but it returns to 2019 levels by 2025

Lower refinery throughput in 2020

Figure 20.

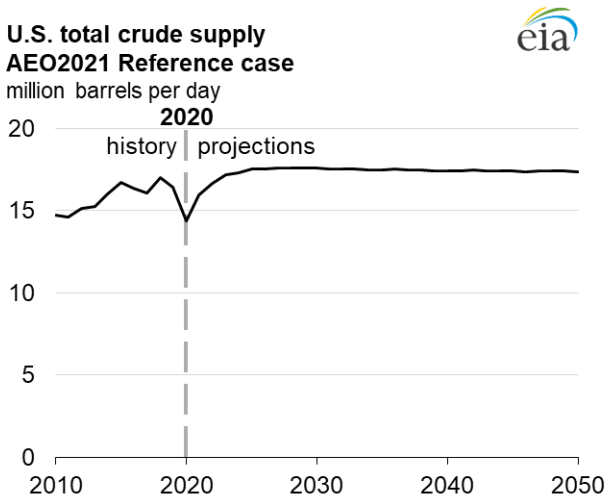


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

As people stayed home and avoided nonessential travel during the pandemic, domestic (and global) demand for transportation fuels in 2020 decreased. Weekly U.S. consumption estimates for motor gasoline in particular recorded their lowest levels since January 1994. In response, U.S. refineries altered their operations to adjust to less end-use product demand, and total refinery throughput decreased in 2020.

Refineries can change their petroleum product output by changing how often and in what manner the downstream that processes the output from distillation units are run. Beginning in late March of 2020, because of responses aimed at slowing the spread of COVID-19, refinery yields for liquid fuels began to fall, as did refinery utilization. Crude oil throughput, or the amount of crude oil processed at refineries, decreased in 2020. In the Reference case, however, total refinery throughput returns to pre-COVID levels in about 2025, and utilization returns to pre-COVID levels sooner because of the permanent closures of some refining capacity.

Figure 21.

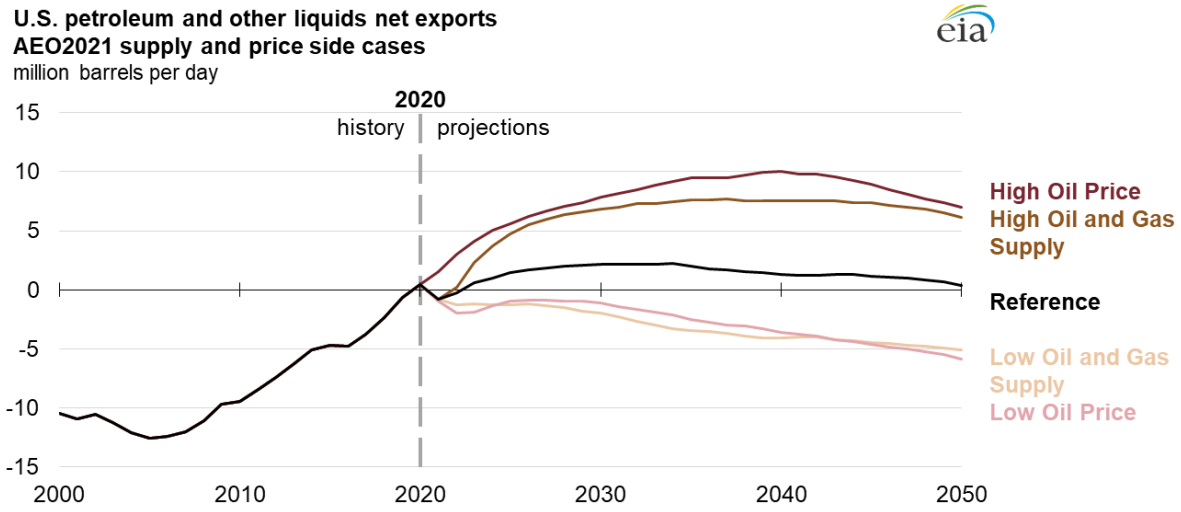


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Petroleum trade

In addition, refineries have lower capacity as a result of several closures and conversions of refineries in 2020. This factor puts further downward pressure on total crude processing, resulting in less petroleum product and more crude to be exported. The projected increase in domestic crude oil production, recovery in global liquid fuels demand, and increase in U.S. refinery inputs means the U.S. returns to net petroleum exporter status, on a volume basis, by 2024.

Figure 22.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, Low Oil and Gas Supply, High Oil Price, and Low Oil Price cases

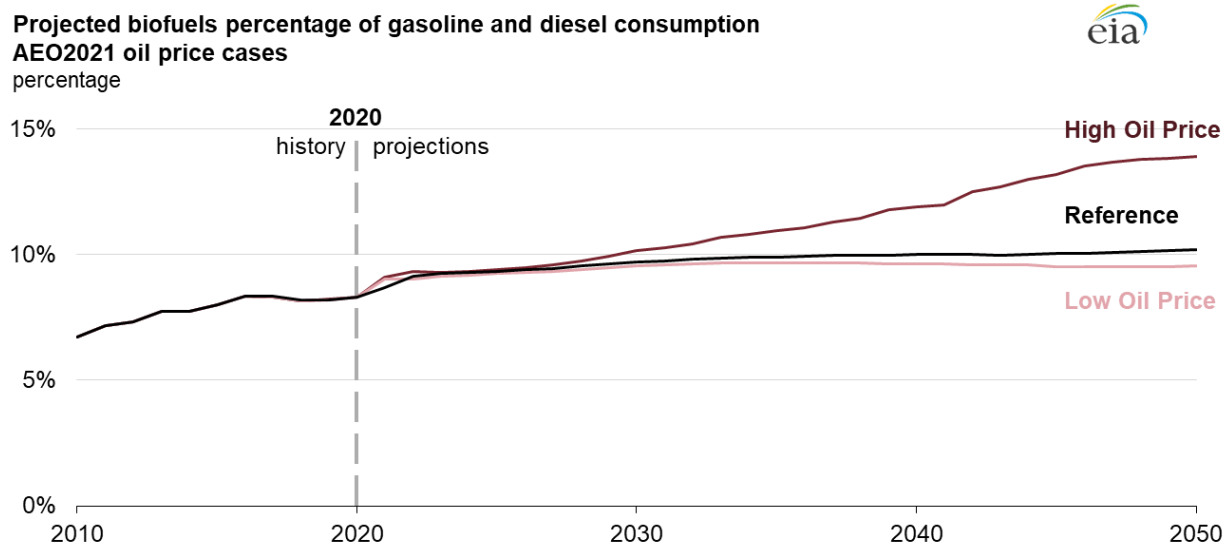
In the Reference case, the United States is both an importer and exporter of petroleum liquids, importing mostly heavy crude oil and exporting mostly petroleum products such as gasoline and diesel. Even though product exports in 2020 were lower than previous years, the AEO2021 Reference case projects relatively high levels of exports for petroleum and other liquids exports through 2050.

These high export levels are primarily a result of less consumption of liquid fuels in the United States and, to a lesser extent, a result because of domestic production of crude oil that cannot be processed economically domestically and is more valuable when exported. Net exports of petroleum and other liquids hold steady in the Reference case and stay in a similar range for the rest of the projection period.

The side cases illustrate the variable nature of U.S. petroleum trade. In the High Oil and Gas Supply side case, more resources and more availability result in increased domestic production and net exports. The High Oil Price case shows similar results: high production levels and accompanying exports. Whether it be higher supply or higher price, the effect is the same—the United States remains a net exporter during the entire projection period for those two cases. The opposite occurs in the Low Oil and Gas Supply case and Low Oil Price case. Generally, as a result of many possible oil price paths, production and throughput remain significantly uncertain.

Consumption of biofuels as a share of the domestic fuel mix increases in AEO2021

Figure 23.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil Price, and Low Oil Price cases

Biofuels consumption decreases less than petroleum consumption

Although response to the COVID-19 pandemic affected demand for all liquid fuels in 2020, biofuel consumption has not decreased as much as petroleum-based fuels. AEO2021's Reference case shows biofuels production returning to 2019 levels in 2021, slightly faster than petroleum-based transportation fuels (motor gasoline and diesel), contributing to an increasing share of biofuels in the domestic fuel mix.

Biofuels consumption is supported by regulation

Biofuels consumption returns to 2019 levels faster than petroleum-based fuels mainly because of regulatory support, such as the federal Renewable Fuel Standard (RFS) program, which is administered by the U.S. Environmental Protection Agency (EPA) and is used to set annual U.S. renewable fuel volume targets. In the model, the RFS is a minimum level that must be met, so even when total transportation fuel demand drops, the RFS still requires a certain level of renewable fuel. State policy such as California's Low Carbon Fuel Standard (LCFS) is also designed to encourage domestic biofuels production.

Biofuels use increases as a share of the total in the Reference case

In this year's Reference case, EIA projects that the percentage of biofuels (including, ethanol, biodiesel, and other biomass) blended into the U.S. fuel pool (gasoline and diesel) will increase and slowly grow across the entire projection period. In the High Oil Price case, the share of biofuels consumed in the United States rises to a greater percentage as higher prices for gasoline and diesel make biofuels more competitive. The share of biofuels in the Low Oil Price case remains relatively unchanged when compared with the Reference case because of regulations like those previously mentioned. For example,

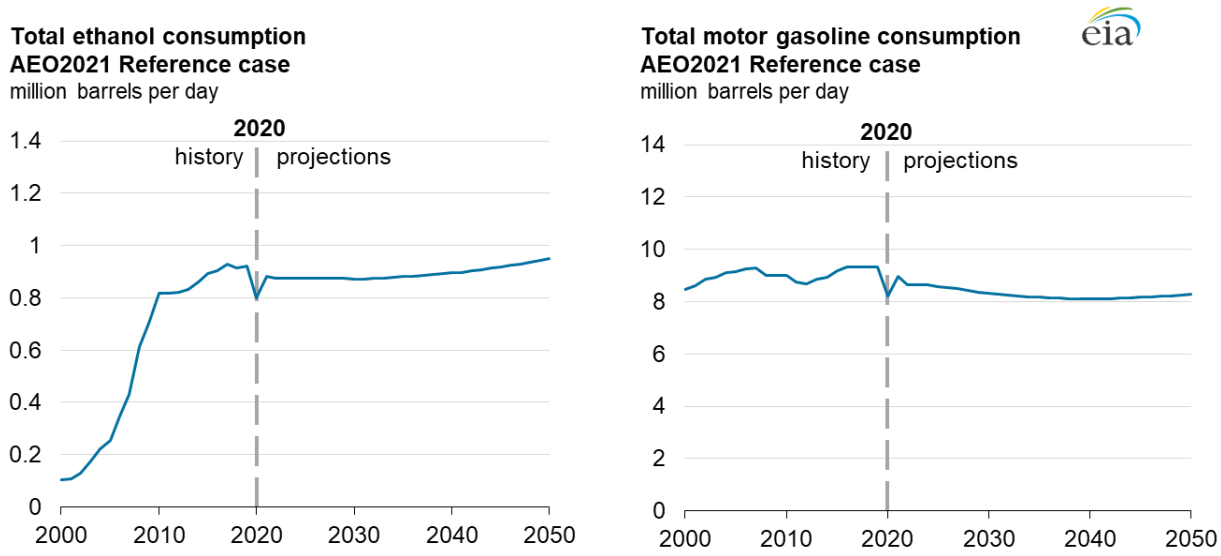
the LCFS encourages the use of biomass-based diesel because renewable diesel has one of the lowest carbon intensities of the approved pathways for LCFS compliance.

Individual biofuels supply

Biomass-based diesel, for the most part, tracks overall diesel demand. Biomass-based diesel is supported by policy including the renewed biodiesel mixture tax credit, and so it is likely to continue to gain market share through 2050. EIA projects diesel demand in the Reference case to almost return to pre-COVID levels in 2021, but never quite reach 2019's peak. EIA expects biodiesel to grow slightly, maintaining a steady level of production through 2050.

Several new renewable diesel plants have been announced this year, both domestically and overseas. A few domestic refineries have shuttered to convert to renewable diesel production, or they have made plans to do so in the near future, contributing to projected increases in renewable diesel supply.

Figure 24.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

For ethanol, because almost all finished motor gasoline sold in the United States is blended with 10% ethanol (E10), reductions in gasoline demand have driven similar decreases in fuel ethanol demand, and, correspondingly, fuel ethanol production. Consumption of both ethanol and gasoline in 2020 have dropped by more than 10%, and both return in 2021 to almost reach 2019 levels at a similar pace. After this near-term return to 2019 levels, motor gasoline and diesel follow a pattern of general decrease, never fully returning to pre-COVID levels. On the other hand, ethanol does return to pre-COVID levels in the later years of the projection period, steadily growing through 2050 because of higher ethanol blends making their way into the on-road transportation pool.