Annual Energy Outlook 2018

with projections to 2050

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U.S. Energy Information Administration
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Overview/key takeaways

EIA's *Annual Energy Outlook* provides modeled projections of domestic energy markets through 2050, and it includes cases with different assumptions regarding macroeconomic growth, world oil prices, technological progress, and energy policies. Strong domestic production coupled with relatively flat energy demand allows the United States to become a net energy exporter over the projection period in most cases. In the Reference case, natural gas consumption grows the most on an absolute basis, and nonhydroelectric renewables grow the most on a percentage basis.

The Annual Energy Outlook provides long-term energy projections for the United States

- Projections in the *Annual Energy Outlook 2018* (AEO2018) are not predictions of what will happen, but rather modeled projections of what may happen given certain assumptions and methodologies.
- The AEO is developed using the National Energy Modeling System (NEMS), an integrated model that captures interactions of economic changes and energy supply, demand, and prices.
- Energy market projections are subject to much uncertainty, as many of the events that shape energy markets and future developments in technologies, demographics, and resources cannot be foreseen with certainty.
- More information about the assumptions used in developing these projections will be available shortly after the release of the AEO.
- The AEO is published pursuant to the Department of Energy Organization Act of 1977, which requires the U.S. Energy Information Administration (EIA) Administrator to prepare annual reports on trends and projections for energy use and supply.

What is the Reference case?

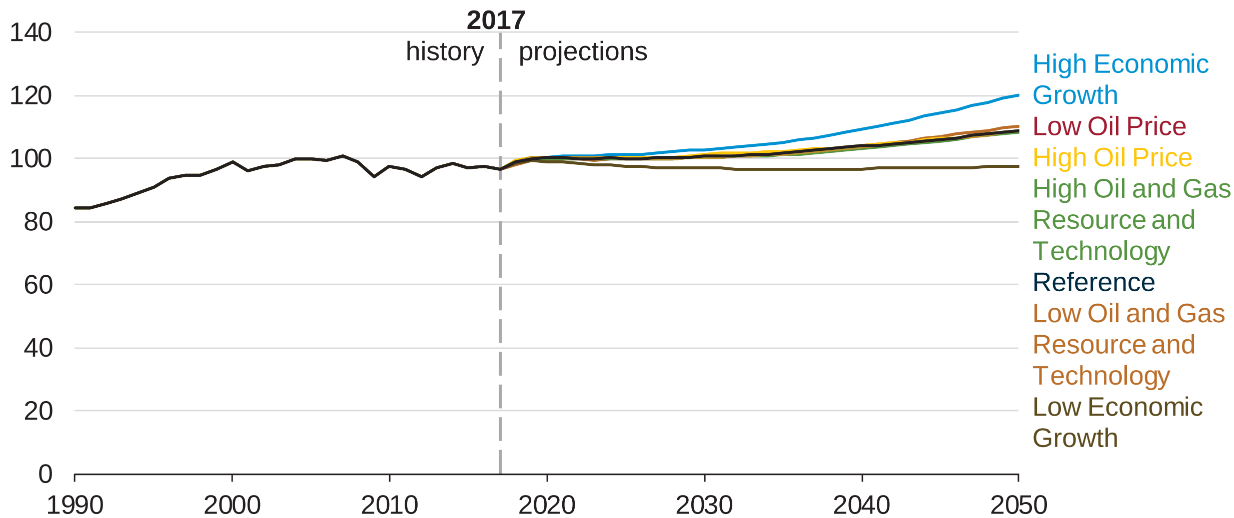
- The Reference case projection assumes trend improvement in known technologies along with a view of economic and demographic trends reflecting the current views of leading economic forecasters and demographers.
- The Reference case generally assumes that current laws and regulations affecting the energy sector, including sunset dates for laws that have them, are unchanged throughout the projection period.
- The potential impacts of proposed legislation, regulations, and standards are not included.
- EIA addresses the uncertainty inherent in energy projections by developing side cases with different assumptions of macroeconomic growth, world oil prices, technological progress, and energy policies.
- Projections in the AEO should be interpreted with a clear understanding of the assumptions that inform them and the limitations inherent in any modeling effort.

What are the side cases?

- Oil prices are driven by global market balances that are primarily influenced by factors external to the NEMS model. In the High Oil Price case, the price of Brent crude, in 2017 dollars, reaches $229 per barrel (b) by 2050, compared with $114/b in the Reference case and $52/b in the Low Oil Price case.
- In the High Oil and Gas Resource and Technology case, lower costs and higher resource availability than in the Reference case allow for higher production at lower prices. In the Low Oil and Gas Resource and Technology case, assumptions of lower resources and higher costs are applied.
- The effects of the economic assumptions on energy consumption are addressed in the High and Low Economic Growth cases, which assume compound annual growth rates for U.S. gross domestic product of 2.6% and 1.5%, respectively, from 2017–50, compared with 2.0%/year growth in the Reference case.
- Cases assuming the Clean Power Plan is implemented show how the presence of that policy could affect energy markets and emissions compared with the Reference, resource, economic, and oil price cases.
- AEO2018 will also include additional side cases—which are not discussed here—and will support a series of *Issues in Focus* articles that will be released in 2018.

Energy consumption is bounded by the High and Low Economic Growth cases—

Total energy consumption
quadrillion British thermal units

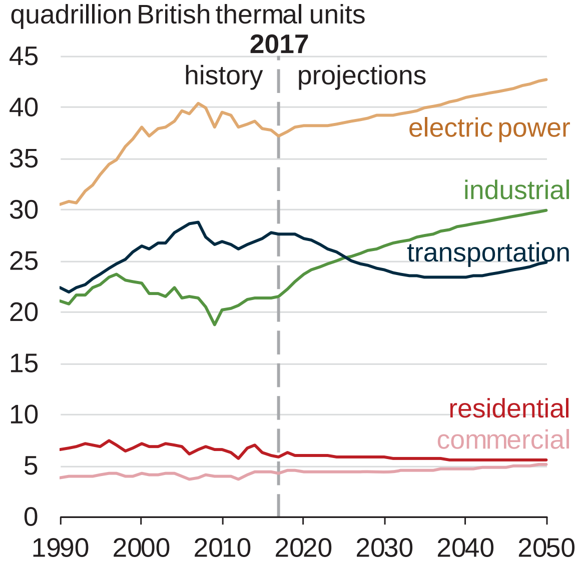


—and the spread of values increases in the last decade of the projection

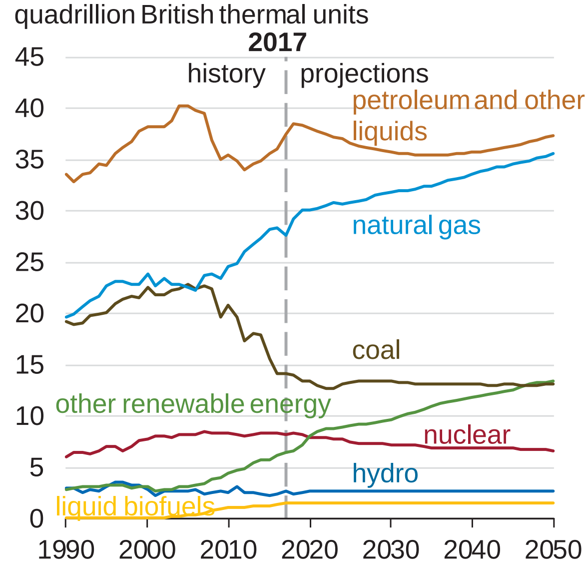
- In the Reference case, from 2017 to 2050, projected gross domestic product (GDP) grows annually at a rate of 2.0%, while projected energy consumption grows at 0.4%/year and surpasses its 2007 peak by 2033.
- In the High Economic Growth case, GDP grows by 2.6%/year from 2017 to 2050, while energy consumption grows by 0.7%. In the Low Economic Growth case, in which GDP grows 1.5% annually, energy consumption is essentially flat.
- By 2050, total energy consumption in the High Economic Growth case and Low Economic Growth case ranges from 10% more than and 10% less than, respectively, the Reference case.

The fuel mix of U.S. consumption changes over the projection period in the Reference case—

Energy consumption by sector (Reference case)
quadrillion British thermal units



Energy consumption by fuel (Reference case)
quadrillion British thermal units

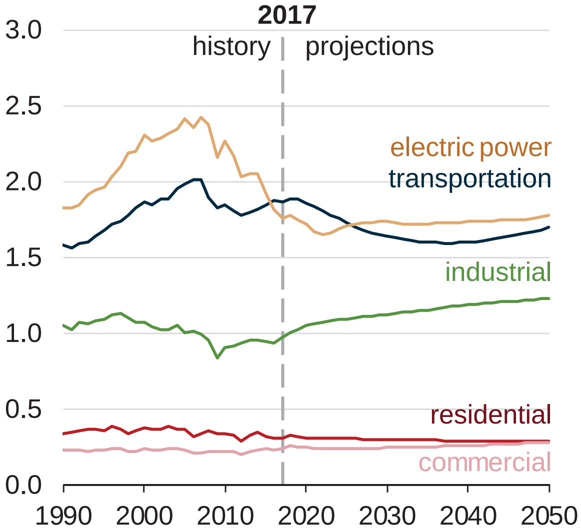


—with natural gas and renewables growing the most

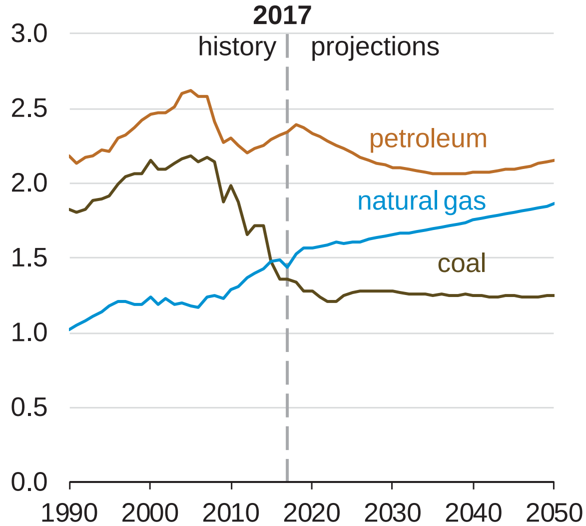
- Natural gas grows the most on an absolute basis in the Reference case projection and nonhydroelectric renewables grows the most on a percentage basis.
- The industrial sector accounts for the most growth in natural gas consumption, with expanding use in the chemical industries; for industrial heat and power; and for liquefied natural gas production. Natural gas consumption also increases significantly in the power sector as a result of the scheduled expiration of renewables tax credits in the mid-2020s.
- A combination of reductions in technology costs and implementation of policies that encourage the use of renewables at the state level (renewable portfolio standards) and at the federal level (production and investment tax credits) drives down the costs of renewables technologies (wind and solar photovoltaic), supporting their expanded adoption.

Energy-related carbon dioxide emissions mirror the trends in energy consumption across cases—

Energy-related carbon dioxide emissions by sector (Reference Case)
billion metric tons of carbon dioxide



Energy-related carbon dioxide emissions by fuel (Reference case)
billion metric tons of carbon dioxide



—and are essentially flat in the Reference case

- Energy-related CO2 emissions from the industrial sector grow the most on both an absolute and relative basis—0.6% annually—from 2017 to 2050 in the Reference case. Natural gas has the largest share of both energy and CO2 emissions in the industrial sector throughout the projection period. The relatively low cost of natural gas leads to further increases in usage and emissions.

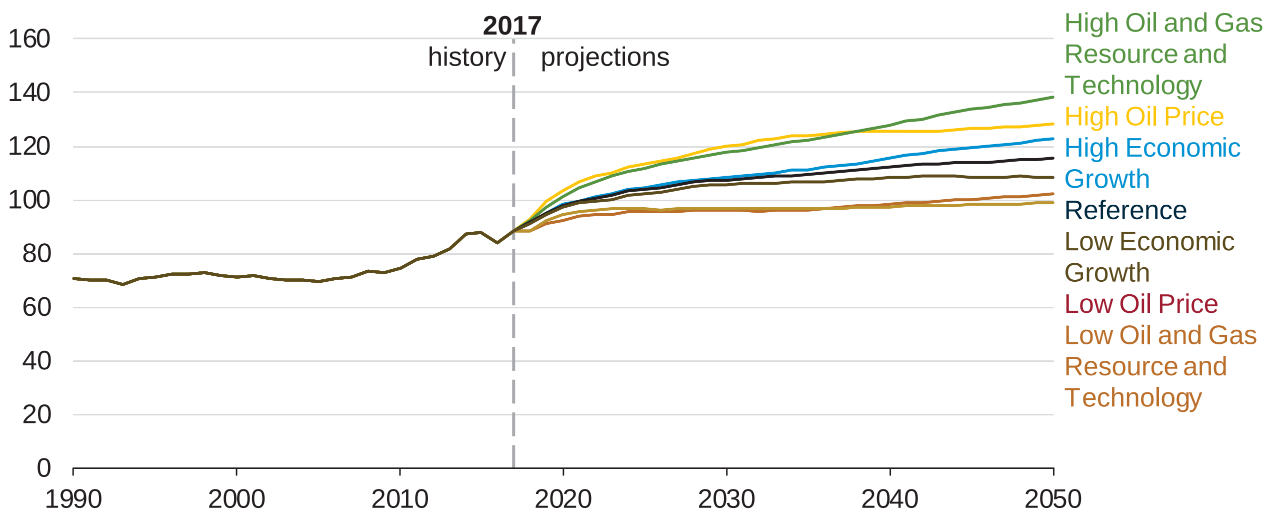
- Electric power sector CO2 emissions are relatively flat in the Reference case through 2050 as a result of favorable market conditions for natural gas and supportive policies for renewables compared with coal.

- Commercial sector emissions grow at a rate of 0.1% annually from 2017 to 2050, as higher energy use in the sector is only partially offset by efficiency gains. CO2 emissions in the residential and transportation sectors both decline by 0.2%/year over the projection period.

- Natural gas emissions grow at an annual rate of 0.8%, while petroleum and coal emissions decline at annual rates of 0.3% and 0.2%, respectively. Petroleum emissions rise in each of the final 13 years of the projection period, when increased vehicle usage outweighs efficiency gains.

Energy production growth depends on technology, resources, and market conditions—

Total energy production
quadrillion British thermal units

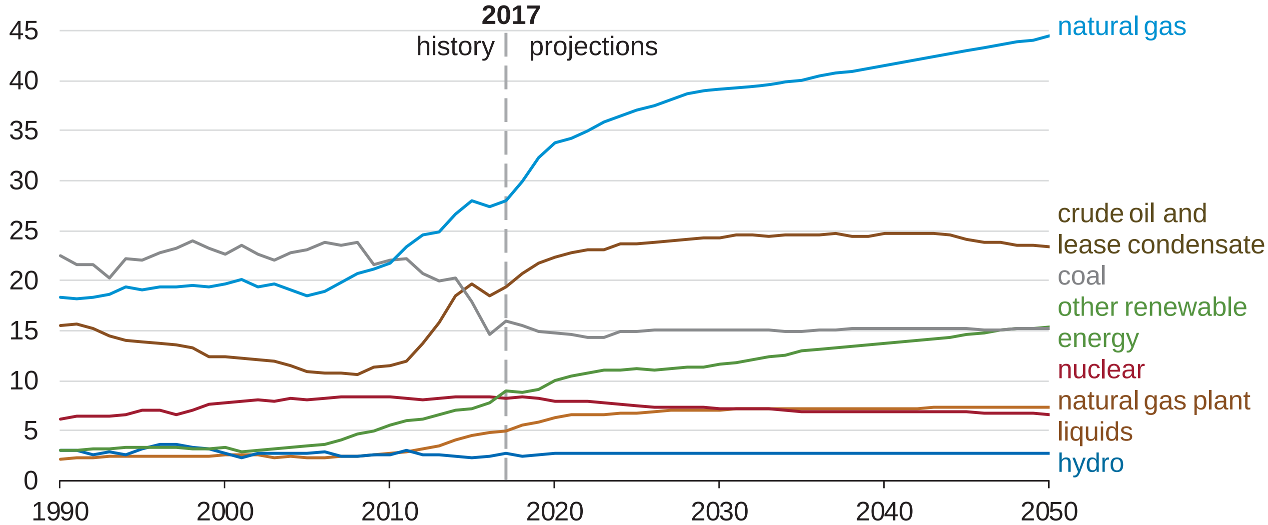


—making production more sensitive than consumption to side case assumptions

- Total U.S. energy production increases by about 31% from 2017 through 2050 in the Reference case, led by increases in the production of renewables other than hydropower, natural gas, and crude oil (although crude oil production only increases during the first 15 years of the projection period).
- Projected U.S. energy production is closely tied to assumptions about resources, technology, and prices, which is evident in side cases that vary these assumptions.
- The range of total production is bounded by the resource cases, which address the uncertainty in U.S. oil and natural gas resources and technology. The High Oil and Gas Resource and Technology case assumes higher estimates than the Reference case of unproved Alaska resources; offshore Lower 48 resources; and onshore Lower 48 tight oil, tight gas, and shale gas resources. This side case also assumes lower costs of producing these resources and faster technology improvement. The Low Oil and Gas Resource and Technology case assumes the opposite.
- The High Oil Price case reflects the impact of higher world demand for petroleum products, lower Organization of the Petroleum Exporting Countries (OPEC) upstream investment, and higher non-OPEC exploration and development costs. The Low Oil Price case assumes the opposite.

In the Reference case, natural gas accounts for the largest share of total energy production—

Energy production (Reference case)
quadrillion British thermal units



—while renewables other than hydropower grow the most on a percentage basis

- Natural gas production accounts for nearly 39% of U.S. energy production by 2050 in the Reference case. Production from shale gas and tight oil plays as a share of total U.S. natural gas production is projected to continue to grow because of the large size of the associated resources.

- Wind and solar generation leads the growth in renewables generation throughout the projection, accounting for 64% of the total electric generation growth in the Reference case through 2050. With a continued (but reduced) tax credit and declining capital costs, solar capacity continues to grow throughout the projection period, while tax credits that phase out for plants entering service through 2024 provide incentives for new wind capacity in the near term.

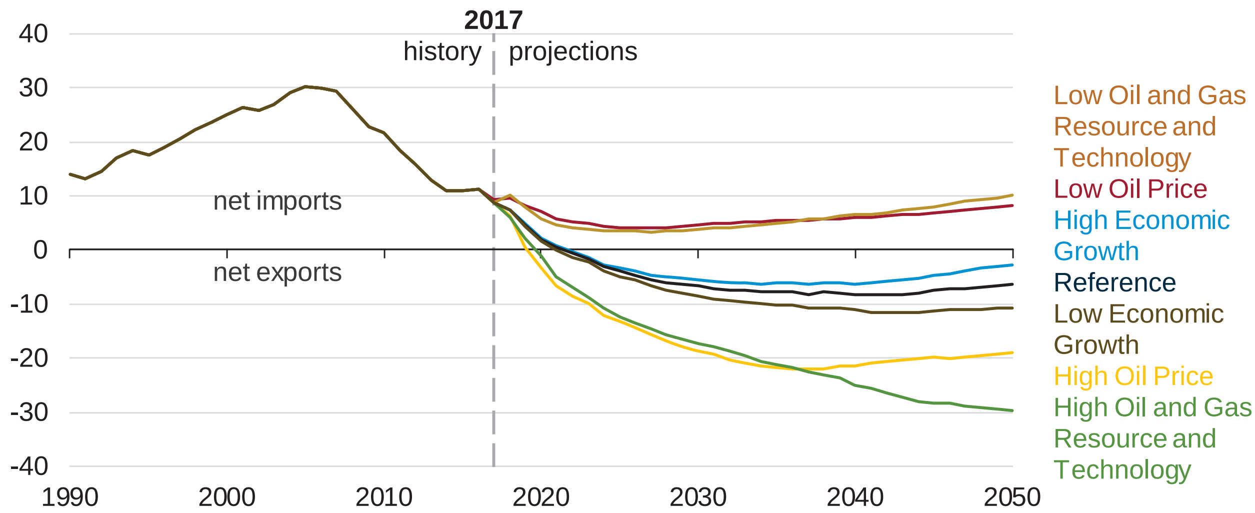
- In the Reference case, U.S. crude oil production in 2018 is projected to surpass the 9.6 million barrels per day (b/d) record set in 1970 and will plateau between 11.5 million b/d and 11.9 million b/d. The continued development of tight oil and shale gas resources supports growth in natural gas plant liquids production, which reaches 5.0 million b/d in 2023 in the Reference case—a nearly 35% increase from the 2017 level.

- Hydropower, nuclear power, and coal production are relatively flat in the Reference case through 2050, limited by slow growth in electricity demand as well as unfavorable economics and other considerations.

The United States is a net energy exporter in all but two cases—

Net energy trade

quadrillion British thermal units

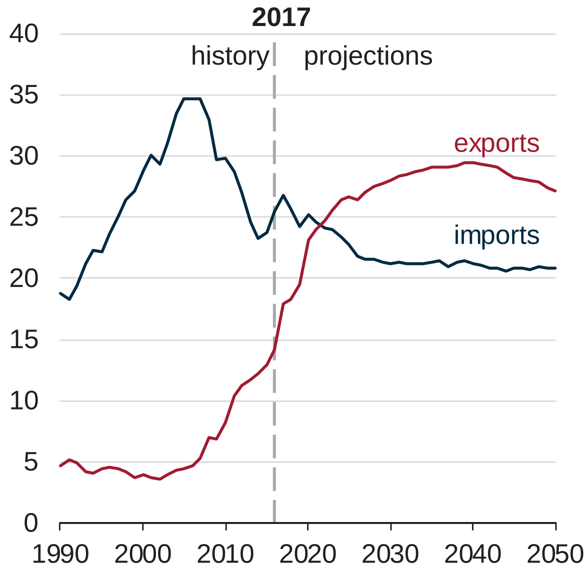


—and in the High Oil and Gas Resource and Technology case, net exports continue to increase through 2050

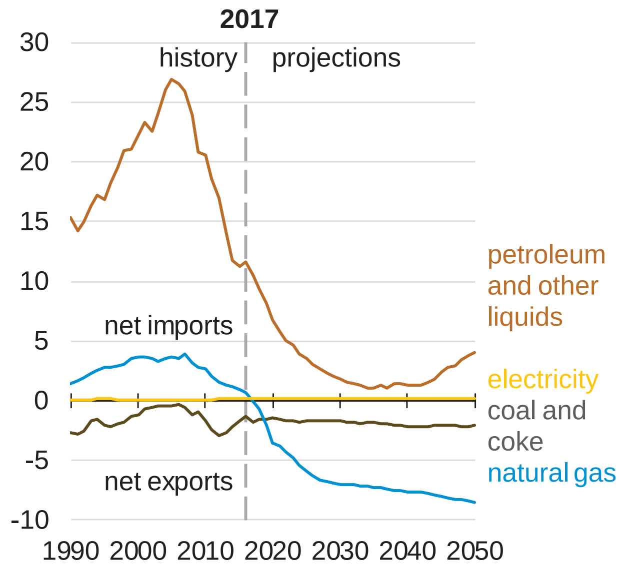
- The United States is projected to become a net energy exporter by 2022 in the Reference case projection, but the transition occurs earlier in three of the AEO2018 side cases.
- In the High Oil and Gas Resource and Technology case, favorable geology and technological developments lead to oil and natural gas production at lower prices, supporting exports that increase over time.
- In the High Oil Price case, before 2038, economic conditions are favorable for oil producers. Higher prices support higher levels of exports, but lower domestic consumption. After 2038, exports decline as a result of the lack of substantial improvements in technology, and production moves to less-productive regions.
- With less favorable geology and technology, as assumed in the Low Oil and Gas Resource and Technology case, and low world oil prices, as assumed in the Low Oil Price case, the United States remains a net energy importer.

Even though the United States becomes a net energy exporter in the Reference case—

Energy trade (Reference case)
quadrillion British thermal units



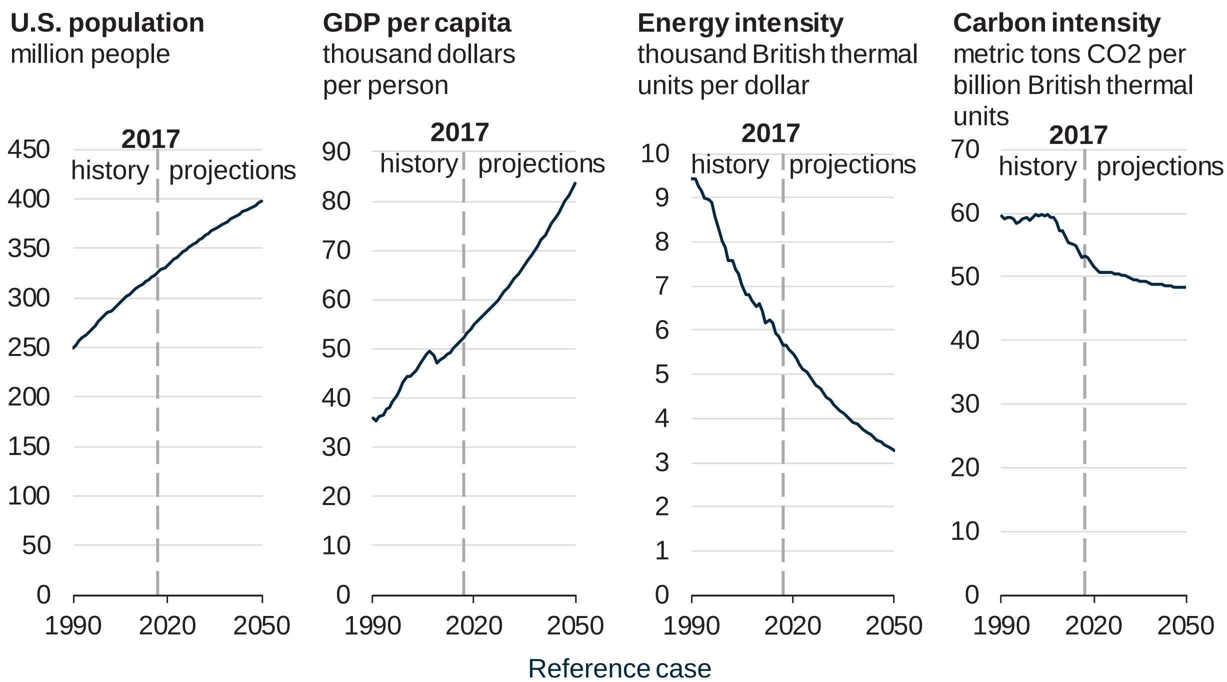
Net energy trade (Reference case)
quadrillion British thermal units



—both imports and exports continue through the projection period

- The United States has been a net energy importer since 1953, but declining energy imports and growing energy exports make the United States a net energy exporter by the early 2020s in the Reference case.
- Historically and in the projection, most U.S. energy trade is in crude oil and petroleum products. The United States remains both an importer and exporter of petroleum liquids, importing mostly crude oil and exporting mostly petroleum products such as gasoline and diesel through 2050 in the Reference case. The United States remains a net importer of petroleum and other liquids on an energy basis.
- U.S. natural gas trade, which historically was shipments by pipeline from Canada and to Mexico, is projected to be increasingly dominated by liquefied natural gas exports to more distant destinations.
- The United States continues to be a net exporter of coal (including coal coke) through 2050, but its export growth is not expected to increase significantly because of competition from other global suppliers closer to major markets.

Although population and economic output per capita continue rising in the Reference case—



—declines in energy intensity and carbon intensity mitigate emissions growth

- In the United States, the amount of energy used per unit of economic growth (energy intensity) has declined steadily for many years, while the amount of CO_2 emissions associated with energy consumption (carbon intensity) has generally declined since 2008.

- These trends are projected to continue as energy efficiency, fuel economy improvements, and structural changes in the economy all lower energy intensity.

- Carbon intensity declines as a result of changes in the U.S. energy mix that reduce the consumption of carbon-intensive fuels and increase the use of low- or no-carbon fuels.

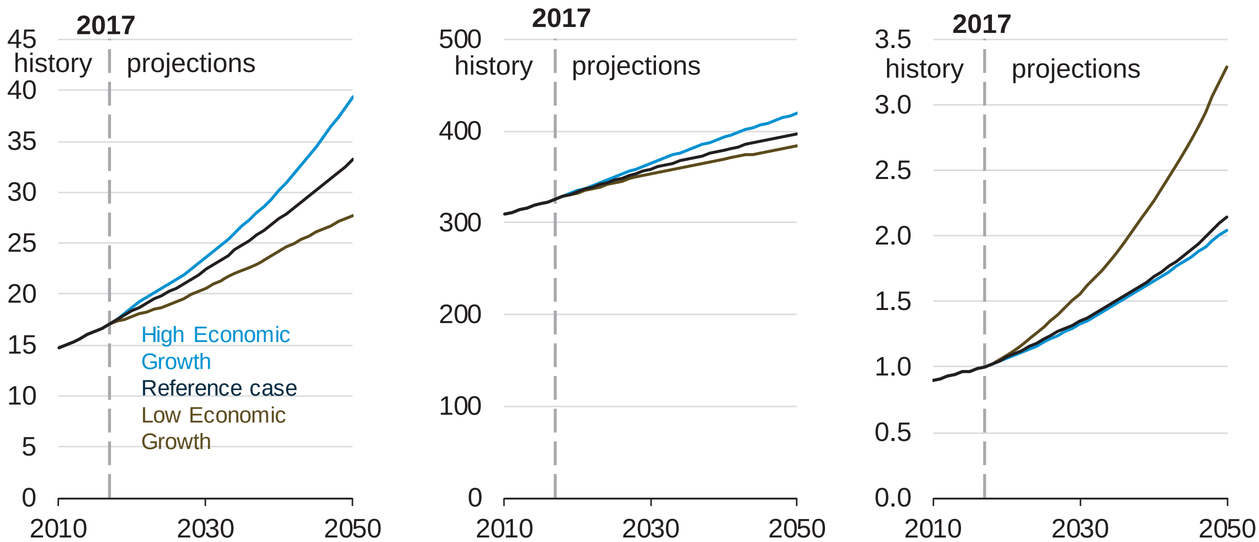
- By 2050, energy intensity and carbon intensity are 42% and 9% lower than their respective 2017 values in the Reference case, which assumes the laws and regulations currently in place.

Different macroeconomic assumptions address the energy implications of the uncertainty—

Gross domestic product
trillion 2009 dollars

Population
millions

Price index (2017 = 1.0)
GDP chain-type price index



—inherent in future economic growth trends

- The Reference, High Economic Growth, and Low Economic Growth cases illustrate three possible paths for U.S. economic growth. The High Economic Growth case assumes higher annual growth and lower annual inflation rates (2.6% and 2.2%, respectively) than in the Reference case (2.0% and 2.3%, respectively), while the Low Economic Growth case assumes lower annual growth and higher annual inflation rates (1.5% and 3.7%, respectively) than in the Reference case.

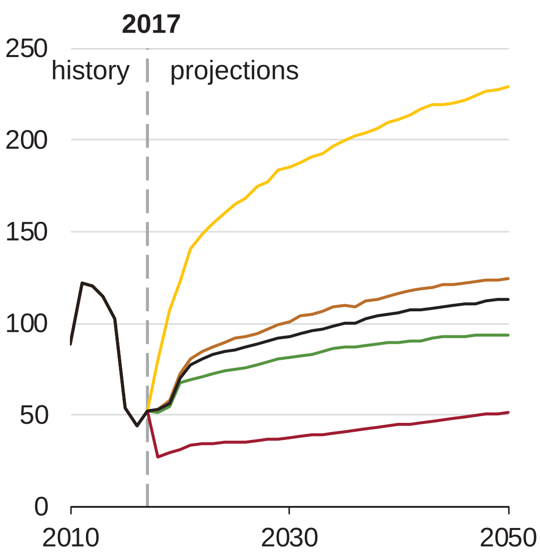
- In general, higher economic growth (as measured by gross domestic product) leads to greater investment, increased consumption of goods and services, more trade, and greater energy consumption.

- Differences among the cases reflect different expectations for growth in population, labor force, capital stock, and productivity. These changes affect growth rates in household formation, industrial activity, and amounts of travel, as well as investment decisions about energy production.

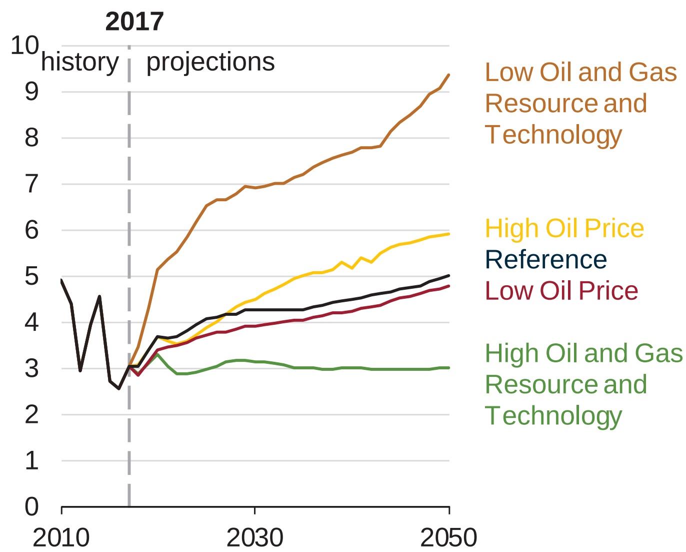
- All three economic growth cases assume smooth economic growth and do not anticipate business cycles or large economic shocks.

Assumptions about the size of U.S. resources and the improvement in technology affect domestic oil and natural gas prices—

North Sea Brent oil price
2017 dollars per barrel



Henry Hub natural gas price
2017 dollars per million Btu



—but global market conditions play a more significant role in oil price projections

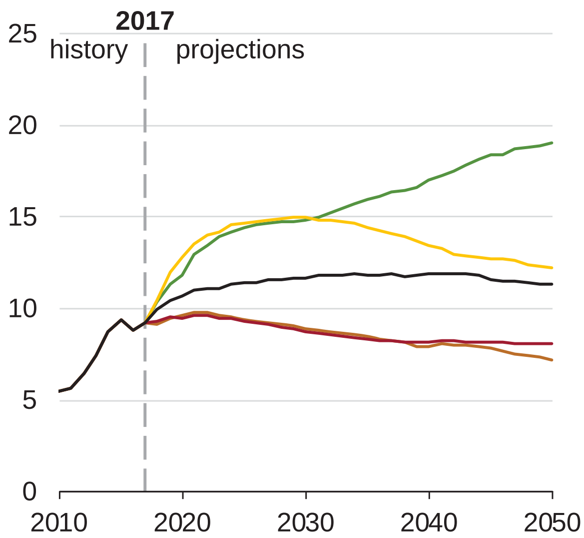
- In real terms, crude oil prices in 2016 (based on the global benchmark North Sea Brent) were at their lowest level since 2004, and natural gas prices (based on the domestic benchmark Henry Hub) were the lowest since before 1990. These prices increased modestly in 2017, and this trend continues over the projection period in all cases except the High Oil and Gas Resource and Technology case.

- Natural gas prices are highly sensitive to domestic resource and technology assumptions explored in the side cases. Across all cases, to satisfy the growing demand for natural gas, production expands into more expensive-to-produce areas, putting upward pressure on production costs and prices.

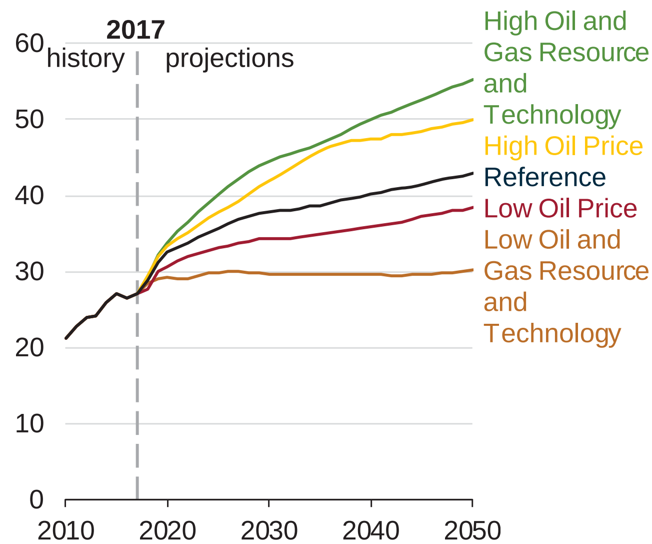
- Crude oil prices in the Reference case are projected to rise at a faster rate in the near term than in the long term because of weak near-term investment coupled with strong demand. At the same time, domestic and export market demand growth drives an increase in natural gas prices at the U.S. benchmark Henry Hub in the Reference case, despite technological advances supporting production.

Although world oil prices play a role in U.S. crude oil and natural gas production—

Crude oil production
million barrels per day



Dry natural gas production
trillion cubic feet



—resource availability and technological improvements are more significant determinants of domestic production levels

- Projections of tight oil and shale gas production are uncertain because large portions of the known formations have relatively little or no production history, and extraction technologies and practices continue to evolve rapidly. Continued high rates of drilling technology improvement could increase well productivity and reduce drilling, completion, and production costs.

- In the High Oil and Gas Resource and Technology case, crude oil and natural gas production both continue to grow through 2050.

- Crude oil prices affect natural gas production primarily through changes in global natural gas consumption, U.S. natural gas exports, and natural gas produced from oil formations (associated gas).

- In the High Oil Price case, the difference between crude oil and natural gas prices creates a greater incentive to consume natural gas in energy-intensive industries, for transportation, and to export overseas as liquefied natural gas, all of which drive U.S. production upward. Without the more favorable resources and technological developments in the High Oil and Gas Resource and Technology case, U.S. crude oil production begins to decline in the High Oil Price case in the early 2030s, and by 2050 crude oil production is nearly the same as in the Reference case.

Critical drivers and uncertainty

Various factors influence the model results in AEO2018, including: new and existing laws and regulations, updated data, and model improvements since AEO2017.

New laws and regulations reflected in the Reference Case

- The Clean Power Plan is not included in the *Annual Energy Outlook 2018* (AEO2018) Reference case, which changes the electricity generation mix. EIA will continue to monitor U.S. Environmental Protection Agency rulemaking and will include any final rules in subsequent AEOs.

- A number of current state and regional policies—including the Illinois Future Energy Jobs Act, the New York Clean Energy Standard, the Maryland Clean Energy Jobs Act, and the Regional Greenhouse Gas Initiative—affect the projected electric generation mix.

- Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL Convention), which limits emissions for ocean-going ships by 2020, was updated. This update affects the projected fuel mix for maritime transport.

Significant data updates

- U.S. Geological Survey resource assessments of the Wolfcamp and Spraberry formations, released in November 2016 and May 2017, respectively, were incorporated to update crude oil and natural gas resource assumptions for the Permian basin. This change mainly affects regional oil and natural gas production and related markets.

- EIA incorporated updates to natural gas plant liquids production based on EIA surveys of natural gas processing plants.

- EIA's 2014 Manufacturing Energy Consumption Survey, released in October 2017, resulted in revisions to estimates of industrial sector energy consumption.

- Higher-resolution solar resource data were introduced to better represent the diversity of solar generation opportunities within electricity market regions.

- Cost data from the Idaho National Laboratory report, *Economic and Market Challenges Facing the U.S. Nuclear Commercial Fleet*, published in September 2016, were used to update fixed operating and maintenance cost assumptions for single-reactor nuclear plants.

Model improvements—Liquids and Natural Gas

- EIA introduced a new Natural Gas Markets Module, which now balances supply and demand on a monthly basis across states rather than on a seasonal basis across regions. The new module also better reflects changing regional natural gas flows and pricing patterns, and it includes improved representations of Canadian and Mexican natural gas markets.

- The representation of technological and operational improvements in oil and natural gas production over the projection period was revised by increasing rates of technological progress during the early development of currently undeveloped resources to reflect industry-wide identification of the most productive areas and to select the best technologies for particular geologies (i.e., learning-by-doing).

Model improvements—Electric Power

- The capability to model energy storage on the electric grid with four-hour batteries was added to more effectively model electric grid operations, including the integration of wind and solar generation.

- The capability to model two distinct solar photovoltaic (PV) technologies was added to better account for the cost and value trade-offs between fixed-tilt and tracking-solar technologies. Both technologies have achieved significant market share as PV installations have increased.

- Wind plant dispatch decisions are now evaluated at a more granular time resolution to more accurately account for time-of-day and seasonal electricity demand.

- The representation of state-level Renewable Portfolio Standards was updated to include additional policy details such as set-aside targets to more specifically account for the effect of these standards on the electric generation mix.

Model improvements—Energy Consumption

- Credit banking associated with the Zero-Emission Vehicle program in California and the nine other states that chose to adopt California's vehicle emissions standard (a subset of the Clean Air Act Section 177 states) was added to account for the effects on the sales of electric and plug-in hybrid electric vehicles early in the projection period when vehicle manufacturers use banked over-compliance credits.

- Connected and automated light-duty vehicles were added, which includes technology-induced travel demand behavior specific to those vehicles, to account for the effects on travel demand for various modes of transit.

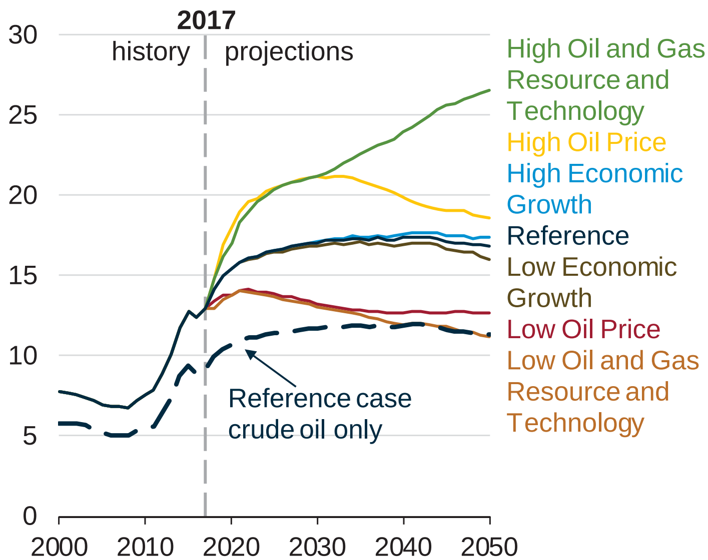
- Growth in commercial *other* electricity consumption (which includes such things as portable and plug-in devices) was indexed in AEO2018 to gross output of services, which results in slower increases in projected consumption than in AEO2017. Last year, it was indexed to expected growth in network and telecommunications equipment, which is now projected separately.

Petroleum and other liquids

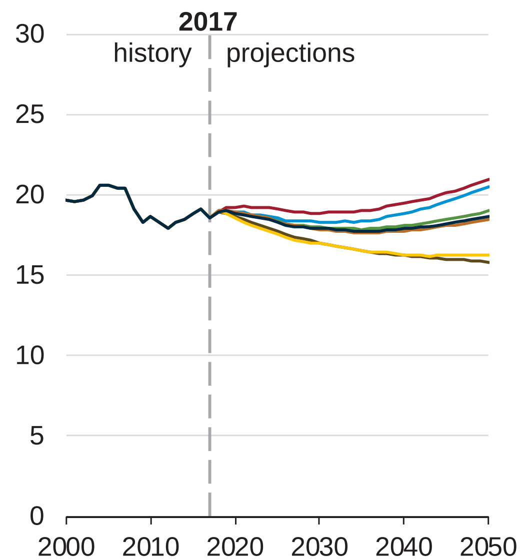
Growth in U.S. crude oil and natural gas plant liquids production generally continues through 2050 mainly as a result of the further development of tight oil resources. Over the same period, domestic consumption falls, making the United States a net exporter of liquid fuels in the Reference case and in a number of the side cases.

U.S. crude oil and natural gas plant liquids production grows to exceed its peak 1970 level—

U.S. crude oil and natural gas plant liquids production
million barrels per day



Petroleum product consumption
million barrels per day



—and consumption is lower than its 2004 peak level through 2050 in most cases

- In the Reference case, U.S. crude oil production in 2018 is projected to surpass the record of 9.6 million barrels per day (b/d) set in 1970 and will continue to grow as upstream producers increase output because of the combined effects of rising prices and production cost reductions.

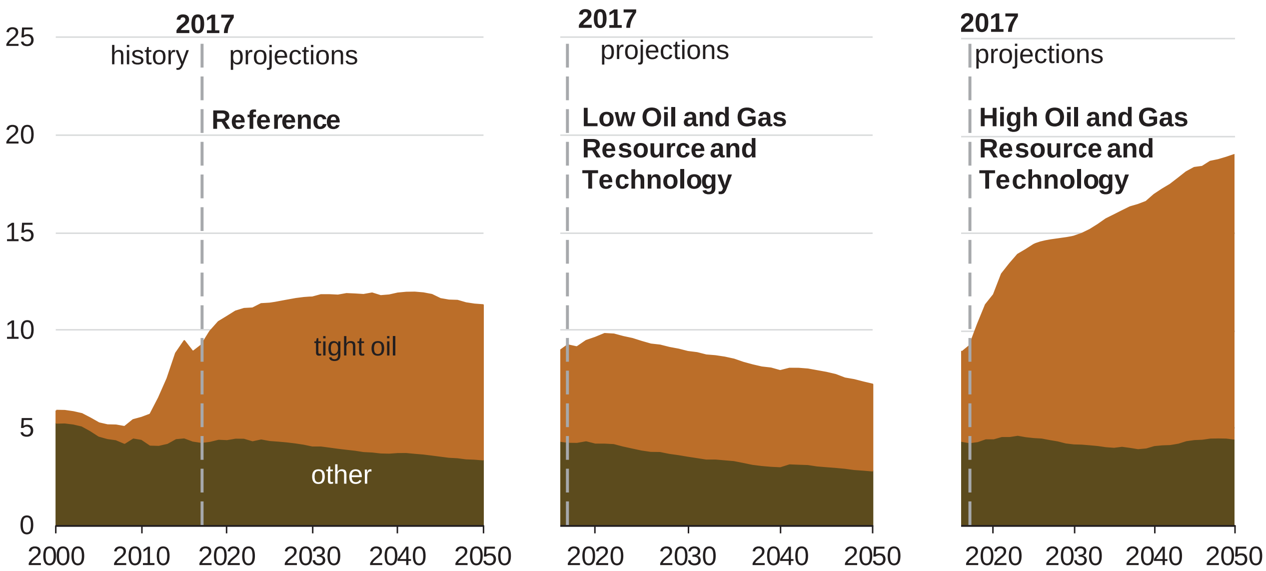
- With continued development of tight oil and shale gas resources, natural gas plant liquids production reaches 5.0 million b/d in 2023, nearly 35% above the 2017 level.

- Total liquids production varies widely under different assumptions about resources, technology, and oil prices. Production is less variable in the economic growth cases because domestic wellhead prices are less sensitive to macroeconomic growth assumptions.

- With higher levels of economic activity and relatively low oil prices, petroleum product consumption increases in the High Economic Growth and Low Oil Price cases, and it remains relatively flat or decreases in the other cases through 2050.

Tight oil production remains the leading source of U.S. crude oil production from 2017 to 2050 in the Reference case—

Crude oil production
million barrels per day



—a result that is consistent across all side cases

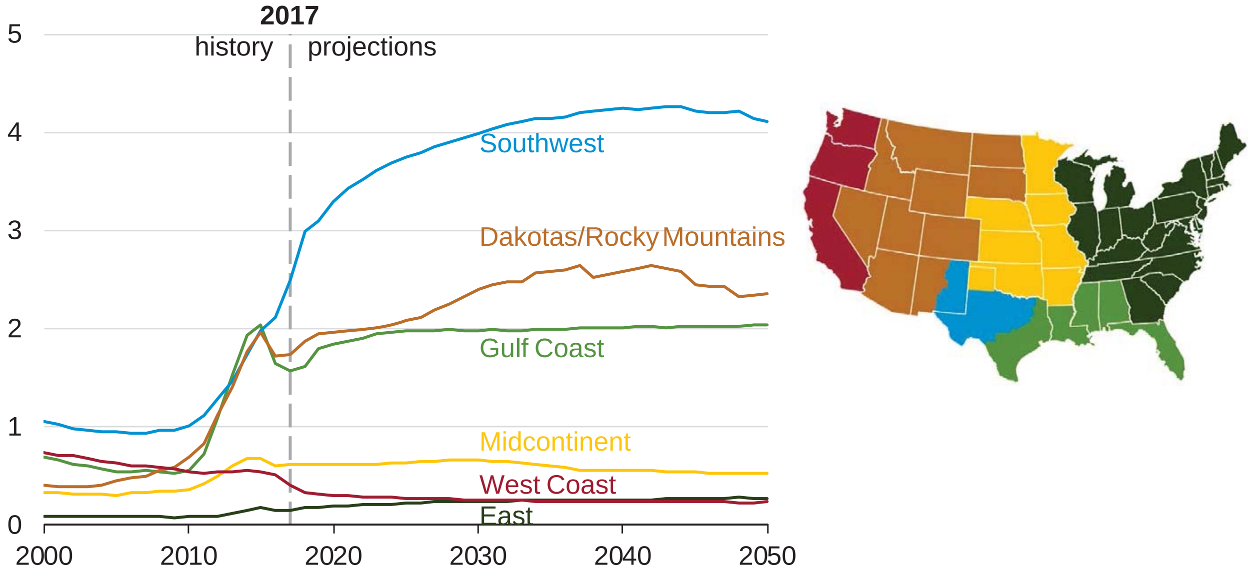
- Lower 48 onshore tight oil development continues to be the main driver of total U.S. crude oil production, accounting for about 65% of cumulative domestic production in the Reference case over the projection period 2017 to 2050.

- Despite rising oil prices, Reference case U.S. crude oil production levels off between 11 million and 12 million barrels per day as tight oil development moves into less productive areas and as well productivity declines.

- Previously announced deepwater discoveries in the Gulf of Mexico lead to increases in Lower 48 states offshore production through 2021. In the Reference case, offshore production then declines through 2035 and remains flat through 2050 as new discoveries offset declines in legacy fields.

The Southwest region leads growth in U.S. tight oil production in the Reference case—

Lower 48 onshore crude oil production by region (Reference case)
million barrels per day



—but the Gulf Coast and Dakotas/Rocky Mountains regions also remain important contributors to overall production

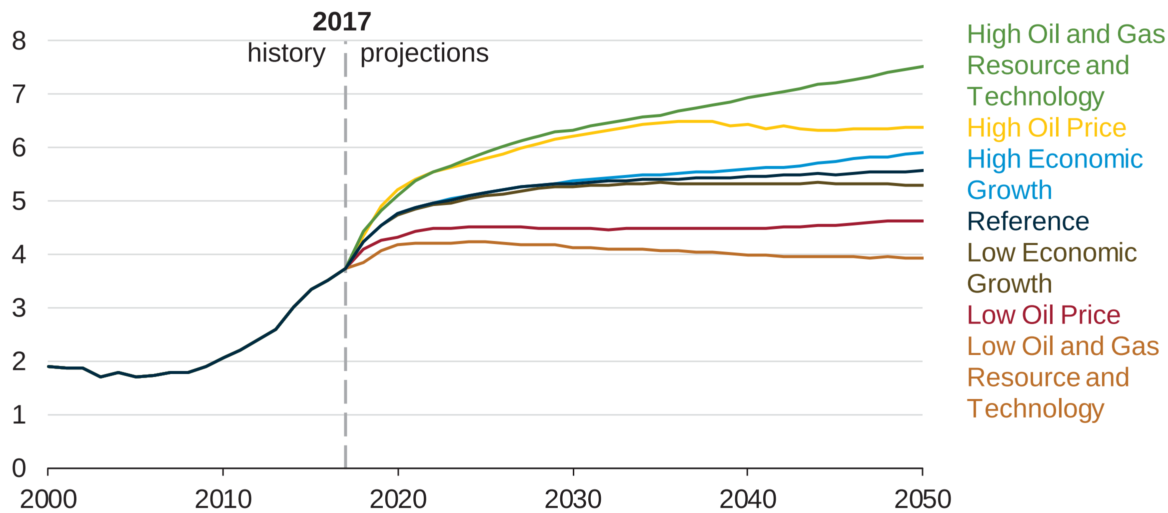
- Growth in Lower 48 onshore crude oil production occurs mainly in the Permian basin in the Southwest region. This basin includes many prolific tight oil plays with multiple layers, including Bone Spring, Spraberry, and Wolfcamp, making it one of the lower-cost areas to develop.

- Production growth in the Dakotas/Rocky Mountains region is driven by increases in production from the Bakken and Niobrara tight oil plays.

- Production in the Gulf Coast region increases through 2025 before flattening out as drilling in the Eagle Ford becomes less productive.

Natural gas plant liquids production increases from 2017 levels in all *Annual Energy Outlook* cases—

U.S. natural gas plant liquids production
million barrels per day



—driven by the higher price of oil relative to natural gas, liquids-rich natural gas formations, and growth in ethane demand

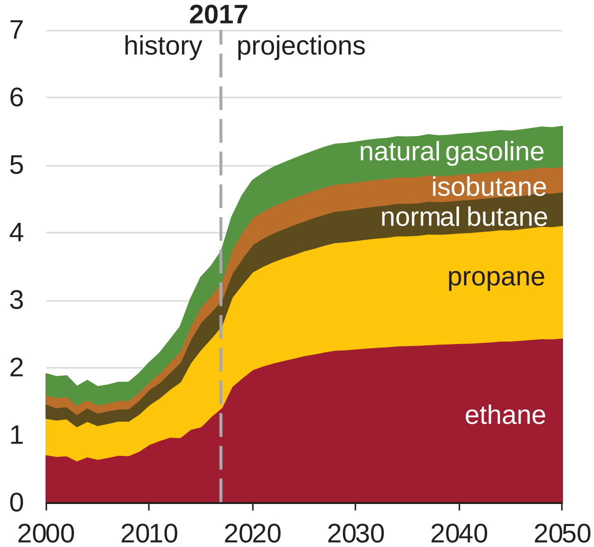
- In the Reference case, natural gas plant liquids (NGPL) production nearly doubles between 2017 and 2050, supported by an increase in global petrochemical industry demand.

- Most NGPL production growth in the Reference case occurs before 2025 when increased demand spurs higher ethane recovery and producers focus on natural gas liquids-rich plays, where NGPL-to-gas ratios are highest. After 2025, production migrates to areas where this ratio is lower.

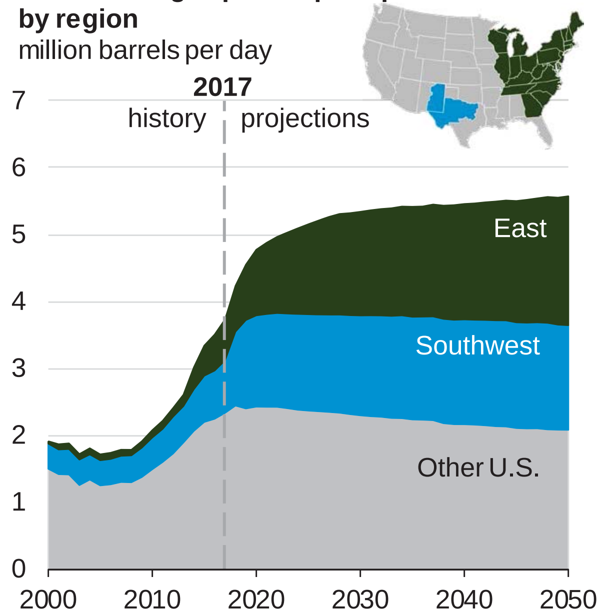
- NGPL production is projected to double in the High Oil and Gas Resource and Technology case and to remain nearly flat in the Low Oil and Gas Resource and the Technology case as a result of alternate resource and technology assumptions.

The East and Southwest regions lead the production of natural gas plant liquids in the Reference case—

U.S. natural gas plant liquids production by fuel
million barrels per day



U.S. natural gas plant liquids production by region
million barrels per day

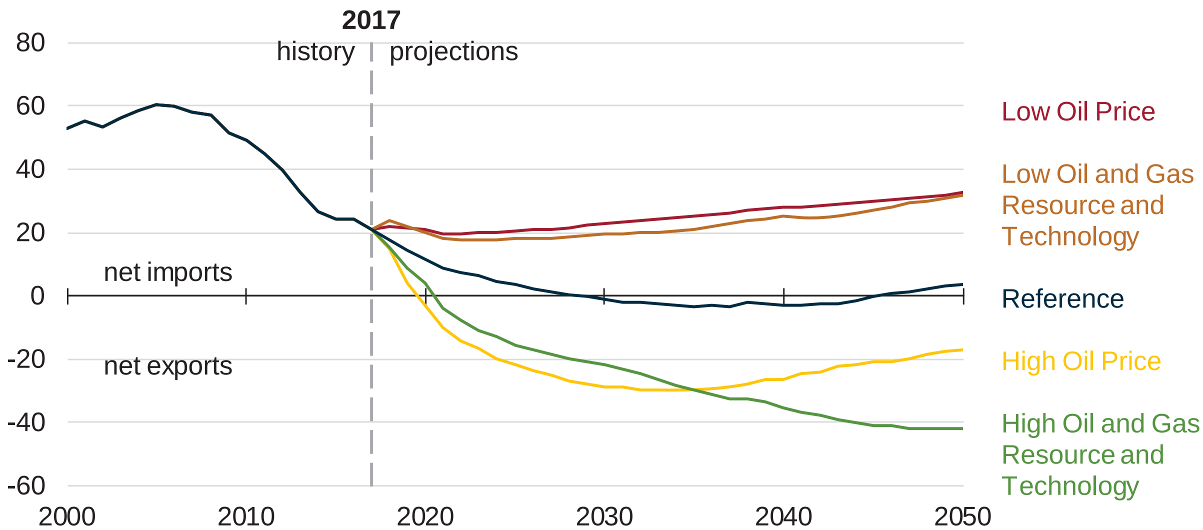


—as production focuses on tight plays with low production costs and easy access to markets

- Natural gas plant liquids (NGPL) are used in many different ways. Ethane is used almost exclusively for petrochemicals, while approximately 40% of propane is used for petrochemicals, and the remainder is used for heating, grain drying, and transportation. Approximately 60% of butanes and natural gasoline is used for blending with motor gasoline and fuel ethanol, and the remainder is used for petrochemicals and solvents.
- The shares of NGPL components in the Reference case are relatively stable over the entire projection period, with ethane and propane contributing about 44% and 30%, respectively, to the total volume.
- The large increase in NGPL production in the East (Marcellus and Utica plays) and Southwest (Permian plays) over the next 10 years is explained mainly by its close association with the development of crude oil and natural gas resources in those regions.
- By 2050, the East and Southwest regions account for more than 60% of total U.S. NGPL production.

In the Reference case, the United States is a modest net exporter of petroleum on a volume basis from 2029 to 2045—

Petroleum net imports/exports as a percentage of product supplied
percent



—but side case results vary significantly using different assumptions

- Net imports of crude oil and liquid fuels are projected to fall between 2017 and 2035 in the Reference case as strong production growth and decreasing domestic demand push the United States to net exporter status.

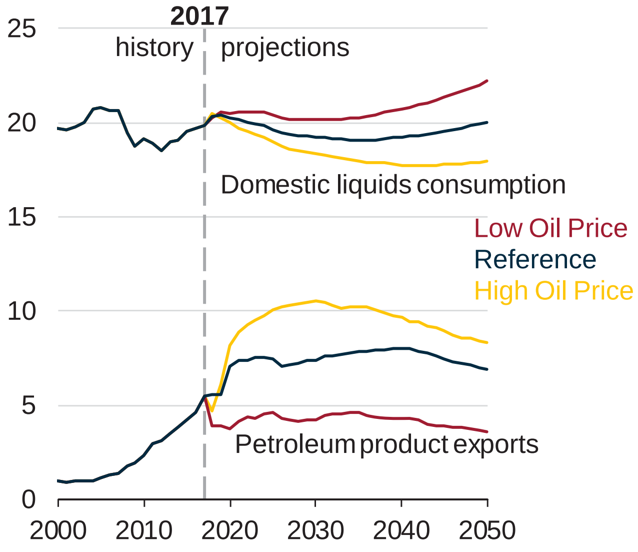
- In the Reference case, net exports from the United States as a percentage of product supplied (a proxy for domestic consumption) is projected to peak at more than 3% in 2037, before gradually reversing as domestic consumption rises. The United States returns to being a net petroleum importer in 2045 on a volume basis.

- Changes in net imports are larger across different price and resource scenarios as domestic crude oil production shifts. Net exports as a percentage of product supplied reaches a high of 30% in 2034 in the High Oil Price case. Conversely, low oil prices in the Low Oil Price case drive the net import share of product supplied up from 21% in 2017 to 32% in 2050.

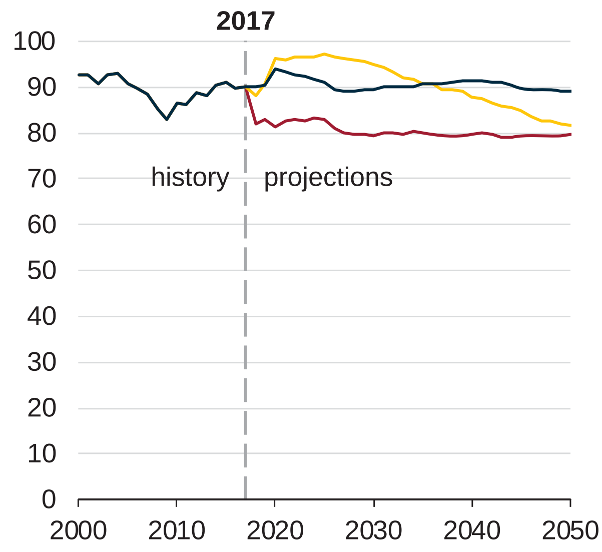
- The export share of petroleum product supplied continues to grow in the High Oil and Gas Resource and Technology case, reaching 42% by 2050.

In the Reference case, petroleum product exports increase as domestic consumption decreases—

U.S. liquids consumption and petroleum product exports
million barrerls per day



U.S. refinery utilization
percent



— and refinery utilization rates remain relatively stable

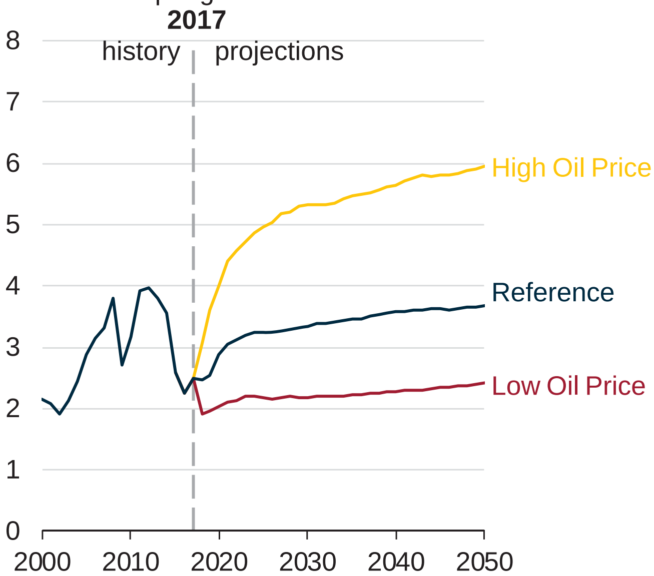
- In the Reference case, domestic consumption of petroleum products generally decreases through 2035, mainly because of vehicle fuel efficiency gains, and petroleum product exports generally increase through 2040. Domestic liquids consumption and petroleum product exports are two of the main drivers for refinery utilization both historically and through the projection period.

- In the Low Oil Price case, lower global demand for petroleum products leads to lower levels of petroleum product exports and refinery utilization in the United States. Refinery utilization stays relatively stable at slightly below 80% through most of the projection period.

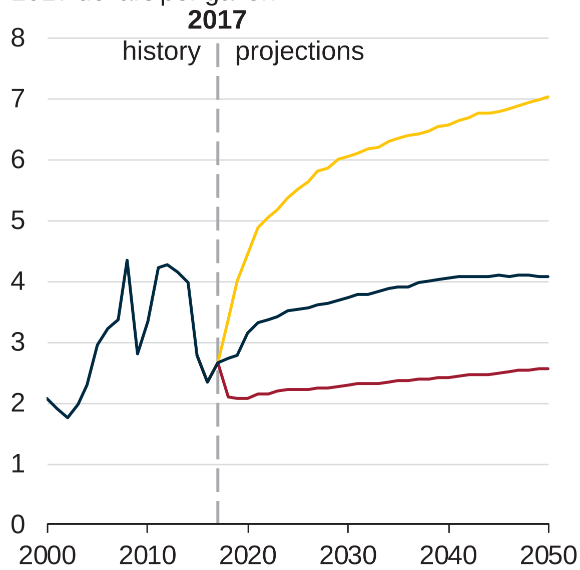
- In the early years of the projection, the elevated international demand in the High Oil Price case leads to higher U.S. petroleum product exports and, initially, higher U.S refinery utilization. Refinery utilization drops gradually as U.S. domestic consumption declines in response to high oil prices.

In the Reference case, motor gasoline and diesel fuel prices rise after 2018 through the projection period—

Motor gasoline retail prices
2017 dollars per gallon



Diesel retail prices
2017 dollars per gallon



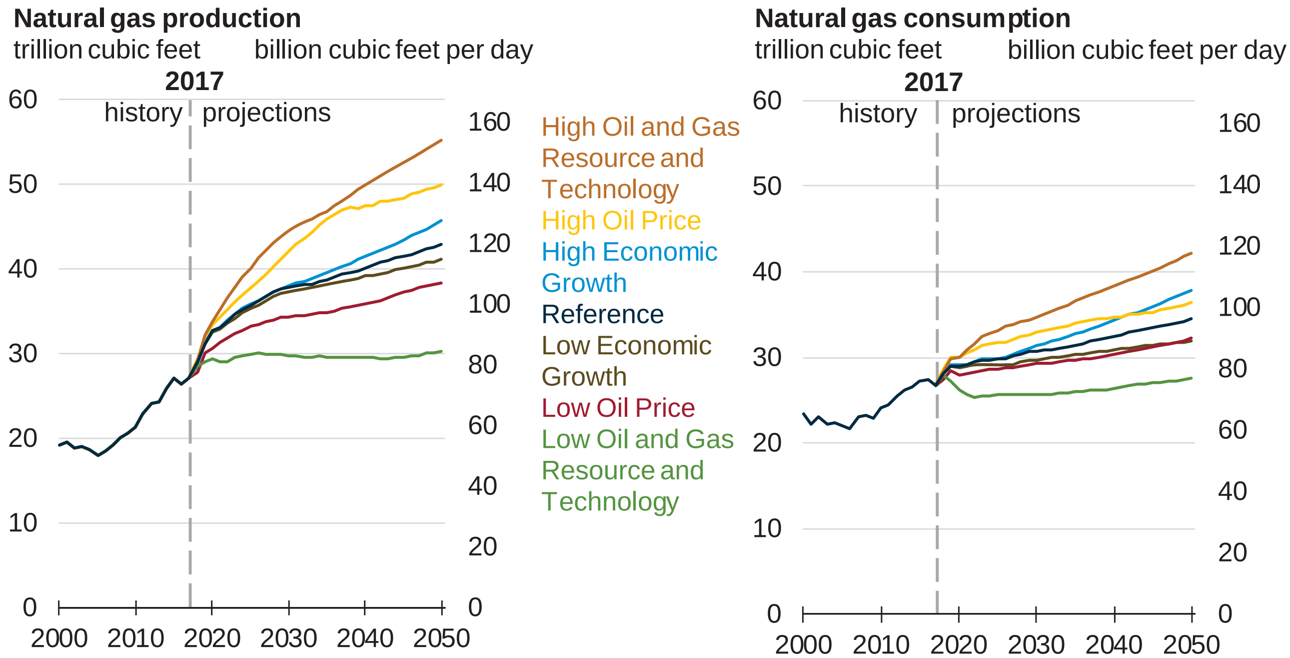
—but neither price returns to its previous peak

- Retail prices of motor gasoline and diesel fuel are projected to increase from 2018 to 2050 in the Reference case, largely because of expected increases in crude oil prices.
- Although the spread between diesel fuel and motor gasoline retail prices has tightened on a volume basis in recent years, this trend reverses through 2041 because of strong growth in global diesel demand for use in transportation and industry.
- Motor gasoline and diesel fuel retail prices move in the same direction as crude oil prices in the High and Low Oil Price cases. Motor gasoline retail prices in 2050 range from $5.95 per gallon (gal) in the High Oil Price case to $2.41/gal in the Low Oil Price case. Diesel fuel retail prices range from $7.02/gal in the High Oil Price case to $2.56/gal in the Low Oil Price case in 2050.

Natural gas

Natural gas production increases in every case, supporting higher levels of domestic consumption and natural gas exports. However, these projections are sensitive to resource and technology assumptions.

U.S. natural gas consumption and production increase in all cases—



—with production growth outpacing natural gas consumption in all cases

- Natural gas production in the Reference case grows 6%/year from 2017 to 2020, which is greater than the 4%/year average growth rate from 2005 to 2015. However, after 2020, it slows to less than 1%/year for the remainder of the projection.

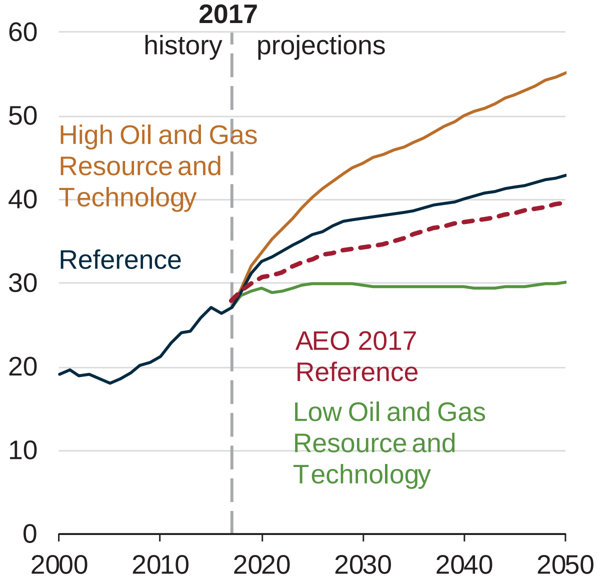
- Near-term production growth across all cases is supported by growing demand from large natural gas-intensive, capital-intensive chemical projects and from the development of liquefaction export terminals in an environment of low natural gas prices.

- After 2020, production grows at a higher rate than consumption in all cases except in the Low Oil and Gas Resource and Technology case, where production and consumption remain relatively flat as a result of higher production costs.

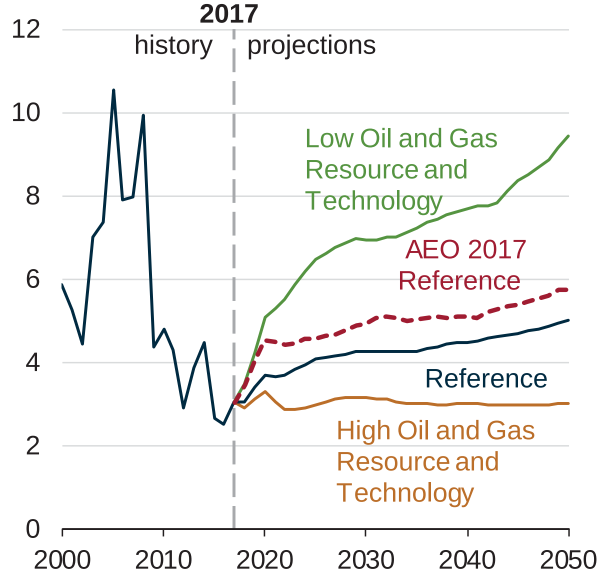
- In all cases other than the Low Oil and Gas Resource and Technology case, U.S. natural gas consumption increases over the entire projection period.

Natural gas prices across cases are dependent on resource and technology assumptions—

Dry natural gas production
trillion cubic feet



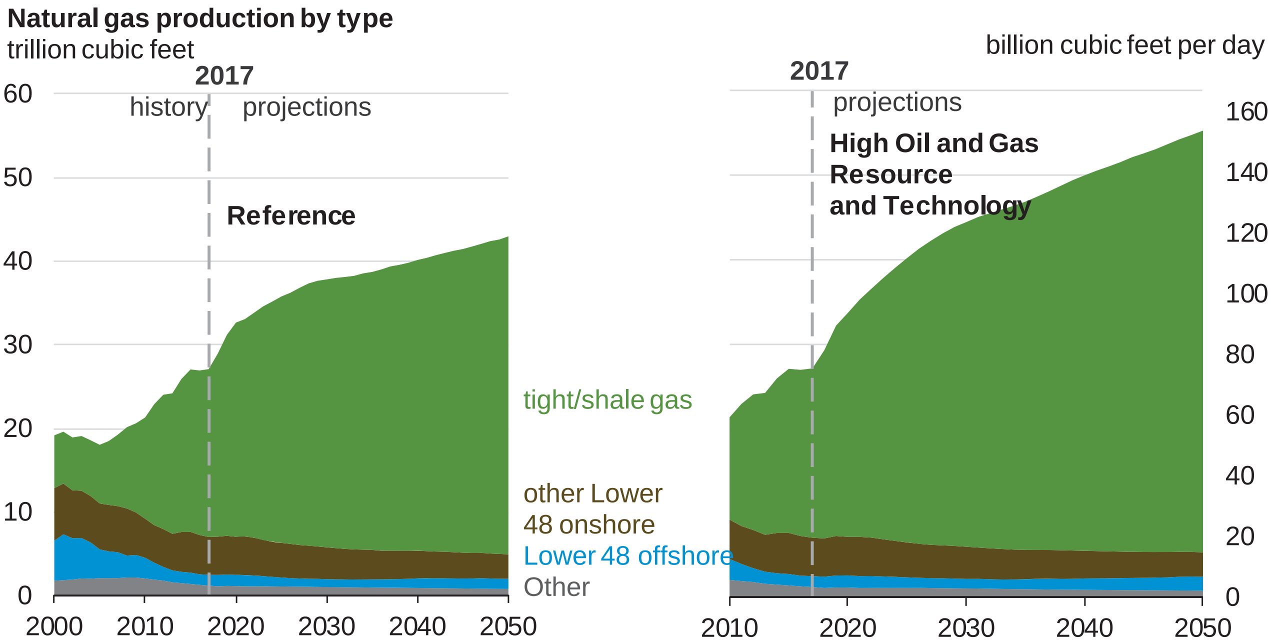
Natural gas spot price at Henry Hub
2017 dollars per million British thermal units



—and Henry Hub prices in the AEO2018 Reference case are 14% lower on average through 2050 than in AEO2017

- Growing demand in domestic and export markets leads to increasing natural gas spot prices over the projection period at the U.S. benchmark Henry Hub in the Reference case despite continued technological advances that support increased production.
- To satisfy the growing demand for natural gas, production must expand into less prolific and more expensive-to-produce areas, which will put upward pressure on production costs.
- The High Oil and Gas Resource and Technology case, which reflects lower costs and higher resource availability, shows an increase in production and lower prices relative to the Reference case. In the Low Oil and Gas Resource and Technology case, high prices, which result from higher costs and fewer available resources, result in lower domestic consumption and lower exports over the projection period.
- Natural gas prices in the AEO2018 Reference case are lower than in the AEO2017 Reference case because of an estimated increase in lower-cost resources, primarily in the Permian and Appalachian basins, which support higher production levels at lower prices over the projection period.

Increased U.S. natural gas production is the result of continued development of shale gas and tight oil plays—



Note: Other includes Alaska and coalbed methane

—which account for more than three-quarters of natural gas production by 2050

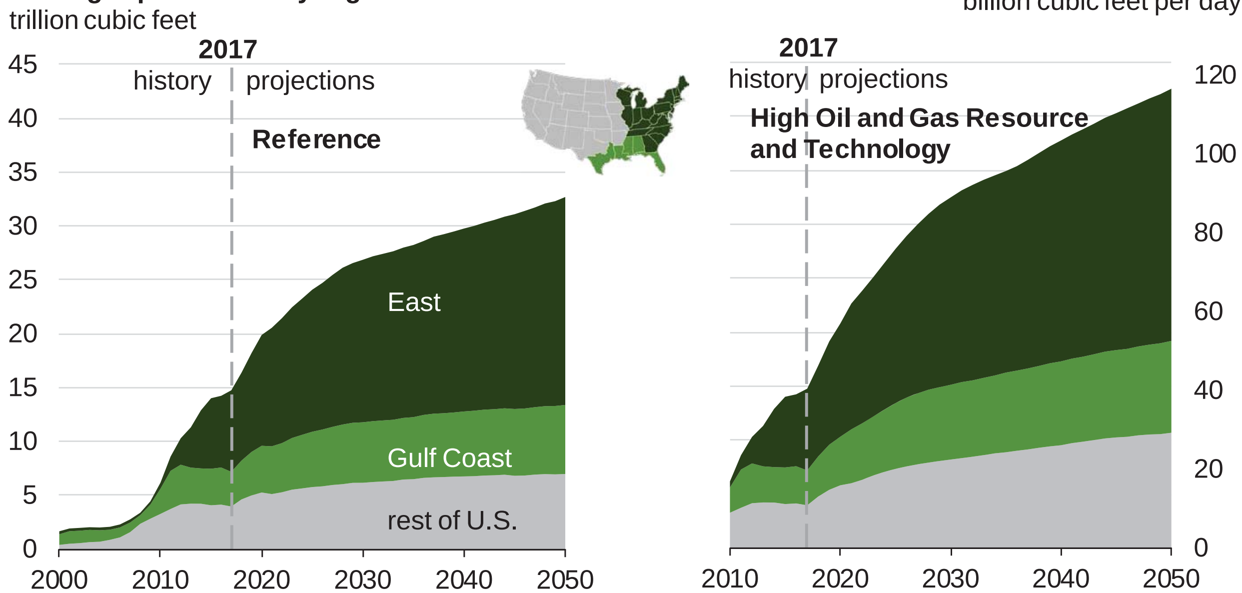
- Natural gas production from shale gas and tight oil plays as a share of total U.S. natural gas production is projected to continue to grow in both share and absolute volume because of the large size of the associated resources, which extend over more than 500,000 square miles.

- Offshore natural gas production in the United States stays nearly flat over the projection period as production from new discoveries generally offsets declines in legacy fields.

- Production of coalbed methane gas generally continues to decline through 2050 because of unfavorable economic conditions for producing that resource.

Plays in the East lead production of U.S. natural gas from shale resources in the Reference case—

Shale gas production by region



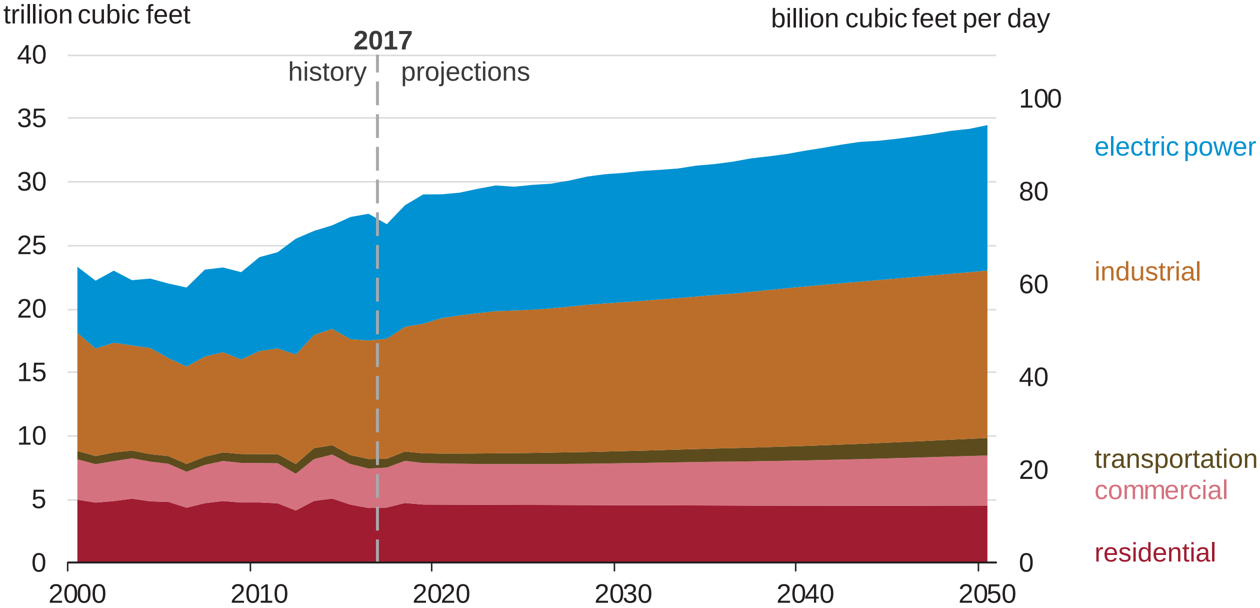
—followed by growth in Gulf Coast onshore production

- Continued development of the Marcellus and Utica plays in the East is the main driver of growth in total U.S. shale gas production across most cases and the main source of total U.S. dry natural gas production.
- Production from the Eagle Ford and Haynesville plays in the Gulf Coast region is a secondary source to domestic dry natural gas, with production largely leveling off after 2028.
- Associated natural gas production from tight oil production in the Permian basin grows strongly through the projection period.
- Continued technological advancements and improvements in industry practices are expected to lower costs and to increase the volume of oil and natural gas recovery per well. These advancements have a significant cumulative effect in plays that extend over wide areas and that have large undeveloped resources (Marcellus, Utica, and Haynesville).

Industrial and electric power demand drives natural gas consumption growth—

Natural gas consumption by sector

trillion cubic feet



—as consumption in the residential and commercial sectors remains relatively flat over the projection period in the Reference case

- The industrial sector is the largest consumer of natural gas in the Reference case. Major natural gas consumers in this sector include the chemical industry (where natural gas is used as a feedstock in the production of methanol and ammonia), industrial heat and power, and liquefied natural gas export facilities.

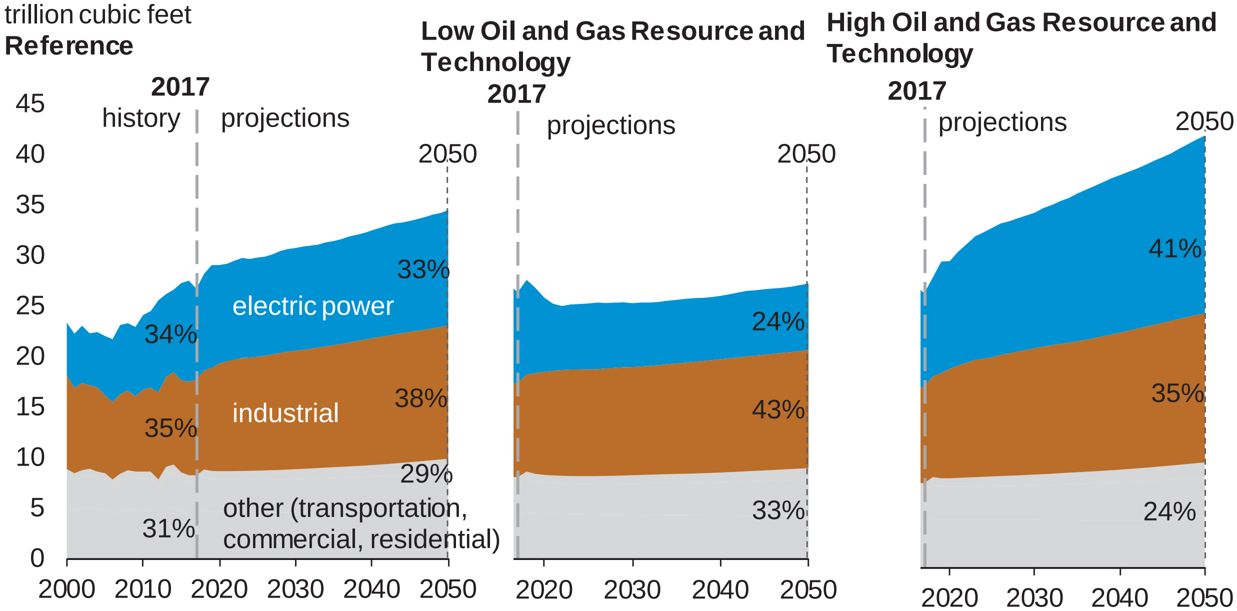
- Natural gas used for electric power generation generally increases over the projection period but at a slower rate than in the industrial sector. This growth is supported by the scheduled expiration of renewable tax credits in the mid-2020s.

- Natural gas consumption in the residential and commercial sectors remains largely flat because of efficiency gains and population shifts that counterbalance demand growth.

- Although natural gas use rises in the transportation sector, particularly for freight and marine shipping, it remains a small share of total natural gas consumption, and natural gas remains a small share of transportation fuel demand.

Natural gas supply assumptions that affect prices result in significant changes in natural gas consumption—

U.S. natural gas consumption by sector
trillion cubic feet



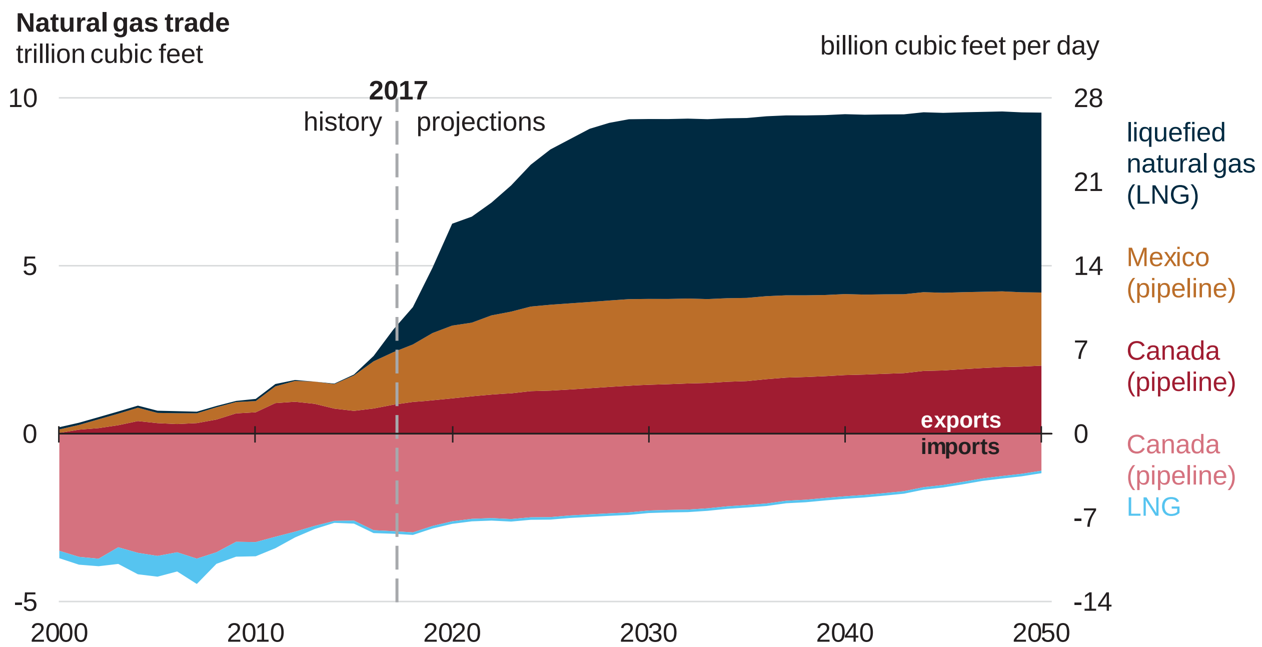
—particularly in the electric power sector as natural gas prices across cases change its competitiveness with other generation fuels

- Between the two largest sectors of natural gas consumption—industrial and electric power—the electric power sector is more responsive to prices. In the short term, electric generators can react quickly to take advantage of changes in relative fuel costs and generally have more fuel options than the industrial sector. In contrast, although energy costs are considered when making long-term decisions about the number, siting, and types of industrial facilities, these costs are only one of many factors.

- The industrial sector is projected to be the largest natural gas-consuming sector in the Reference case, accounting for 38% of the domestic market in 2050. However, in the High Oil and Gas Resource and Technology case, the electric power sector is the largest natural gas consumer. Because Henry Hub spot prices remain lower than $3.50 per million British thermal units (MMBtu) in that case through the entire projection period, natural gas is more competitive with renewables and coal. By 2050, natural gas use in the electric power sector is 41% of total U.S. domestic natural gas consumption in that case.

- Conversely, in the Low Oil and Gas Resource and Technology case, the electric power sector only accounts for an average 25% of U.S. natural gas use from 2020 to 2050 because of higher natural gas prices—Henry Hub natural gas prices reach $6.50/MMBtu by 2025 and more than $9.40/MMBtu by 2050. The industrial sector accounts for 42% of the domestic natural gas market from 2020–2050 in that case.

The United States is a net natural gas exporter in the Reference case because of near-term export growth and continued import decline —

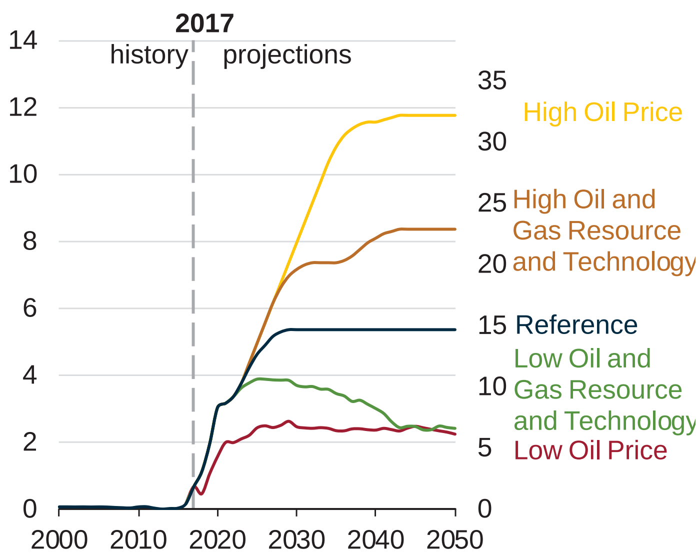


—as liquefied natural gas export facilities allow domestic production to reach global markets

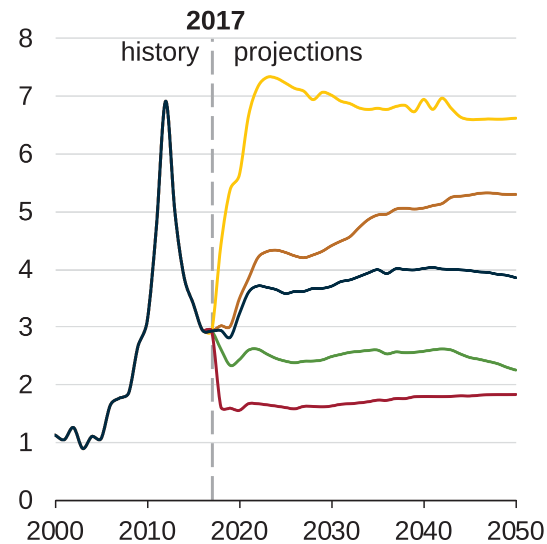
- In the Reference case, pipeline exports to Mexico and liquefied natural gas (LNG) exports increase until 2020. Through 2030, pipeline export growth to Mexico slows, and LNG exports grow rapidly.
- Increasing natural gas exports to Mexico are the result of more pipeline infrastructure to and within that country, allowing for increased natural gas-fired power generation. By the mid-2020s, Mexican domestic natural gas production begins to displace U.S. exports.
- One LNG export facility currently operates in the Lower 48 states with a second facility expected to be operating in March 2018. After the five U.S. LNG export facilities currently under construction are completed by 2021, LNG export capacity is projected to increase as Asian demand grows and U.S. natural gas prices remain competitive. As U.S.-sourced LNG becomes less competitive, export volumes remain constant during the later years of the projection.
- U.S. imports of natural gas from Canada, primarily from its prolific Western region, remain relatively stable for the next few years before declining from historically high levels. U.S. exports of natural gas to Eastern Canada continue to increase because of Eastern Canada’s proximity to U.S. natural gas resources in the Marcellus and Utica plays.

U.S. liquefied natural gas exports are sensitive to both oil and natural gas prices—

Liquefied natural gas exports
trillion cubic feet   billion cubic feet per day



Oil-to-natural gas price ratio
energy-equivalent terms



—resulting in a wide range of expected U.S. liquefied natural gas export levels across cases

- Historically, most liquefied natural gas (LNG) was traded under long-term, oil price-linked contracts, in part because oil could substitute for natural gas in industry and for power generation. However, as the LNG market expands, contracts are expected to change with weaker ties to oil prices.

- When the oil-to-natural gas price ratio is highest, as in the High Oil Price case, U.S. LNG exports are at their highest levels. Demand for LNG increases as consumers move away from petroleum products. U.S. LNG supplies have the advantage of being priced based on relatively low domestic spot prices instead of on oil-linked contracts.

- In the High Oil and Gas Resource and Technology case, low U.S. natural gas prices make U.S. LNG exports competitive relative to other suppliers. Conversely, higher U.S. natural gas prices in the Low Oil and Gas Resource and Technology case result in lower U.S. LNG exports.

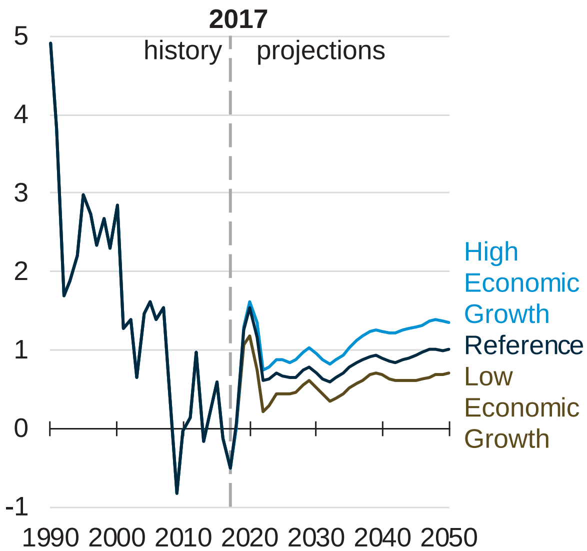
- As more natural gas is traded via short-term contracts or traded on the spot market, the link between LNG and oil prices is projected to weaken over time, making U.S. LNG exports less sensitive to the oil-to-natural gas price ratio and resulting in slower growth in U.S. LNG exports in all cases.

Electricity

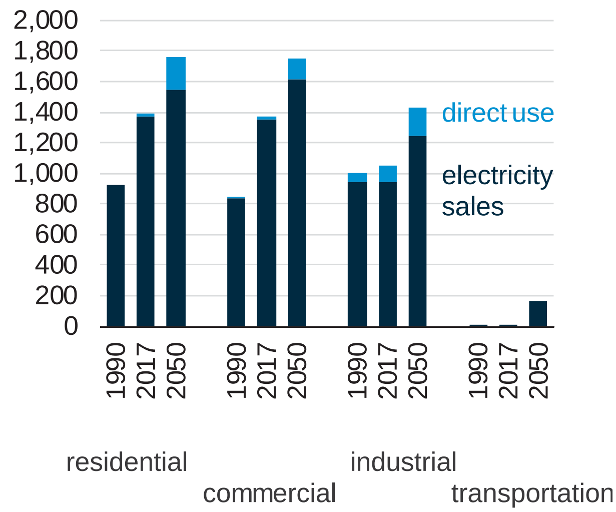
As electricity demand grows modestly, the primary drivers for new capacity in the Reference case are the retirements of older, less-efficient fossil fuel units, the near-term availability of renewable energy tax credits, and the continued decline in the capital cost of renewables, especially solar photovoltaic. Low natural gas prices and favorable costs for renewables result in natural gas and renewables as the primary sources of new generation capacity. The future generation mix is sensitive to the price of natural gas and the growth in electricity demand.

After decades of slowing growth, electricity use is expected to grow steadily through 2050—

Electricity use growth rate
percent growth (three-year rolling average)



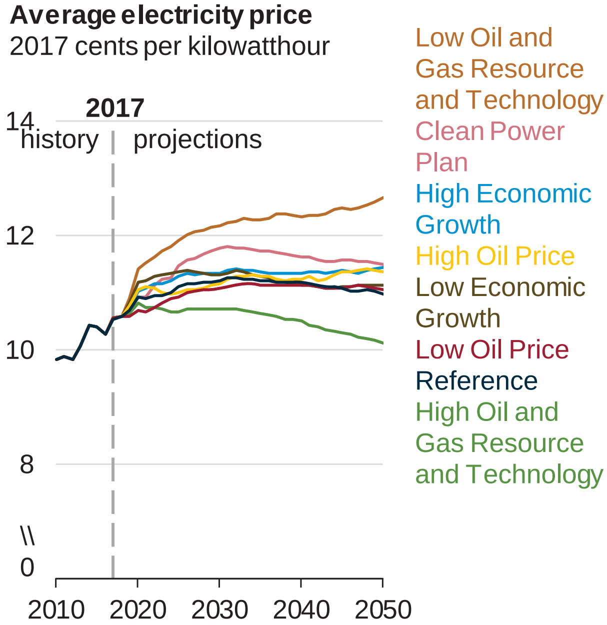
Electricity use by end-use demand sector
billion kilowatthours

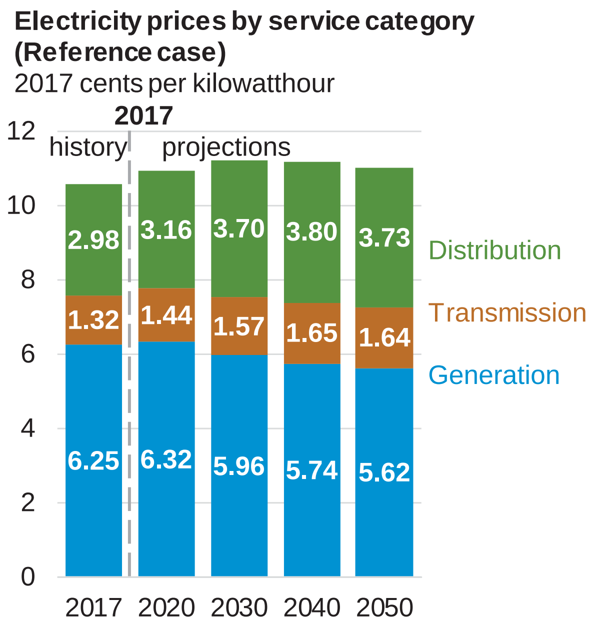


—with growth projected in all demand sectors

- Electricity demand is driven by economic growth and increasing efficiency. Historical electricity demand growth rates slowed as older, less-efficient end-use equipment was replaced with newer, more-efficient stock even as the economy continued to grow.
- Electricity demand growth was negative in 2017, but it is projected to rise slowly through 2050. From 2017–2050, the average annual growth in electricity demand reaches about 0.9% in the AEO2018 Reference case.
- Through the projection period, the average electricity growth rates in the High and Low Economic Growth cases deviate from the Reference case the most—where the High Economic Growth case is about 0.3 percentage points higher than in the Reference case, and electricity growth in the Low Economic Growth case is about 0.3 percentage points lower than in the Reference case.
- Growth in direct-use generation outpaces the growth in retail sales as a result of the adoption of rooftop photovoltaic and natural gas-fired combined heat and power.

Reference case electricity prices remain flat, with falling generation costs offset by increasing transmission and distribution costs—





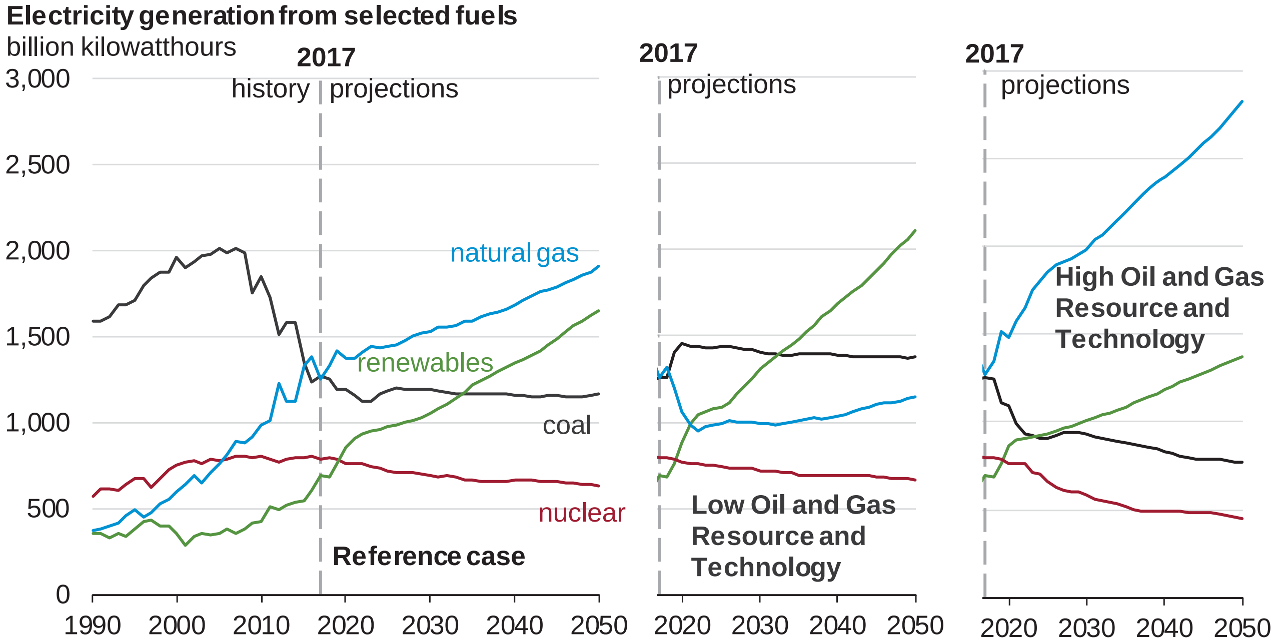
—with significant price differences through 2050 across scenarios depending on natural gas prices

- Average electricity prices are projected to remain relatively flat—ranging between 10.6 and 11.8 cents per kilowatthour (kWh)—through the projection period in the Reference case and the side cases (except for the Low and High Oil and Gas Resource and Technology cases). By 2050, prices rise to 12.7 cents/kWh in the Low Oil and Gas Resource and Technology case and fall to 10.1 cents/kWh in the High Oil and Gas Resource and Technology case.

- The generation cost represents the largest share of the price of electricity, and it is projected to decrease by 10% from 2017 to 2050 in the Reference case in response to continued low natural gas prices and increased generation from renewables.

- The transmission cost component is projected to increase by 24% over the forecast period, and the distribution cost component is expected to increase by 25%—reflecting the need to replace aging infrastructure and upgrade the grid to accommodate changing reliability standards.

The projected mix of electricity generation technologies varies widely across cases—

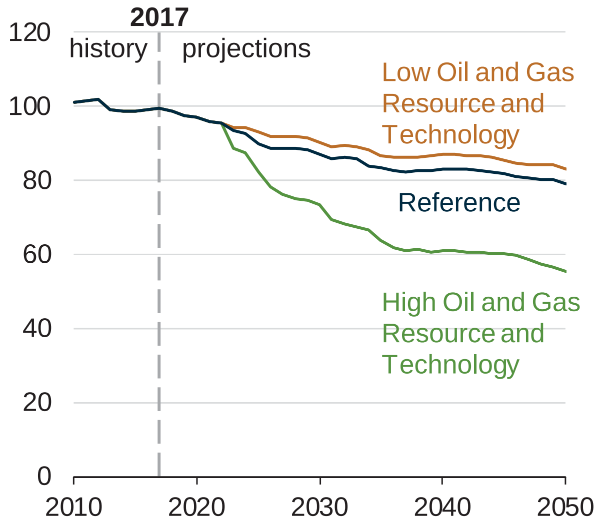


—as differences in fuel prices result in significant substitution

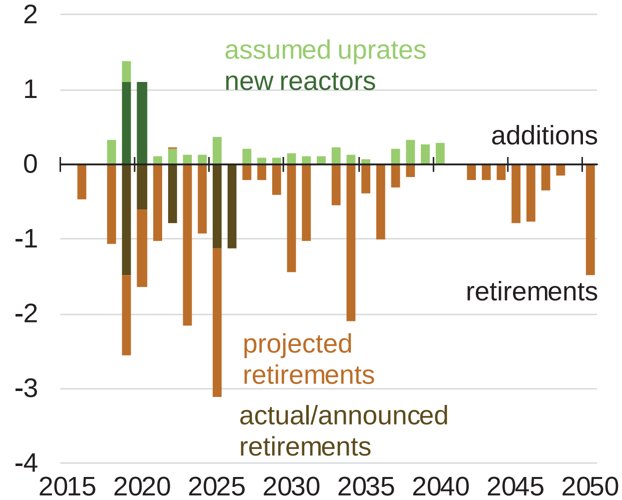
- Fuel prices in the near term drive the share of natural gas-fired and coal-fired generation. In the longer term, the relatively low cost of coal moderates the decline in coal-fired generation in the Reference case.
- Federal tax credits drive near-term growth in renewables generation, moderating growth in natural gas-fired electricity generation except with in the High Oil and Gas Resource and Technology case, which projects very low natural gas prices.
- Lower natural gas prices in the High Oil and Gas Resource and Technology case support significantly higher natural gas-fired generation, with less growth in renewables generation than in the Reference case and declining coal-fired generation from 2017 through 2050.
- Higher natural gas prices in the Low Oil and Gas Resource and Technology case lead to higher levels of coal-fired generation compared with the Reference case, with 460 billion kilowatthours more renewables generation in 2050 than in the Reference case.

Nuclear capacity retires as natural gas prices decrease—

Nuclear electricity generating capacity
gigawatts



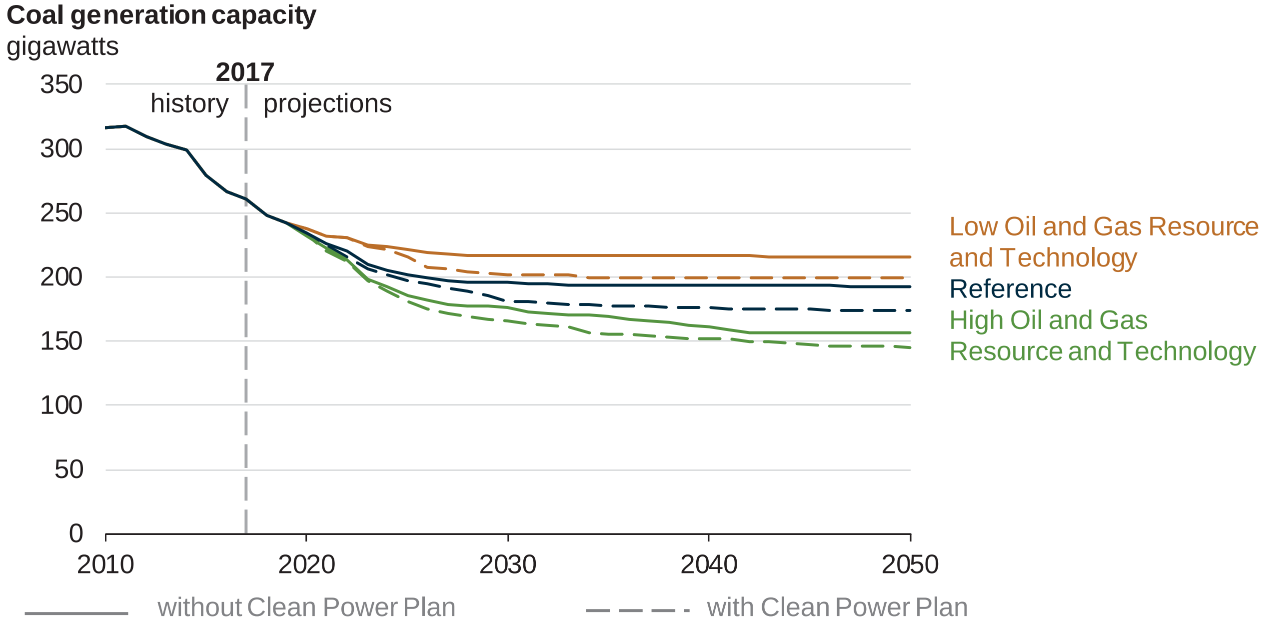
Year-over-year nuclear capacity changes (Reference case)
gigawatts



—because of lower revenues in competitive power markets

- The Reference case projects a steady decline in nuclear electric generating capacity—from 99 gigawatts (GW) in 2017 to 79 GW in 2050 (a 20% decline)—with no new plant additions beyond 2020.
- Lower natural gas prices in the High Oil and Gas Resource and Technology case lead to lower wholesale power market revenues for nuclear power plant operators, accelerating the closure of an additional 24 GW of nuclear capacity by 2050 compared with the level in the Reference case.
- Higher natural gas prices in the Low Oil and Gas Resource and Technology case decrease the financial risks to nuclear power plant operators, resulting in fewer retirements of nuclear capacity (4 GW) through 2050 compared with the Reference case.

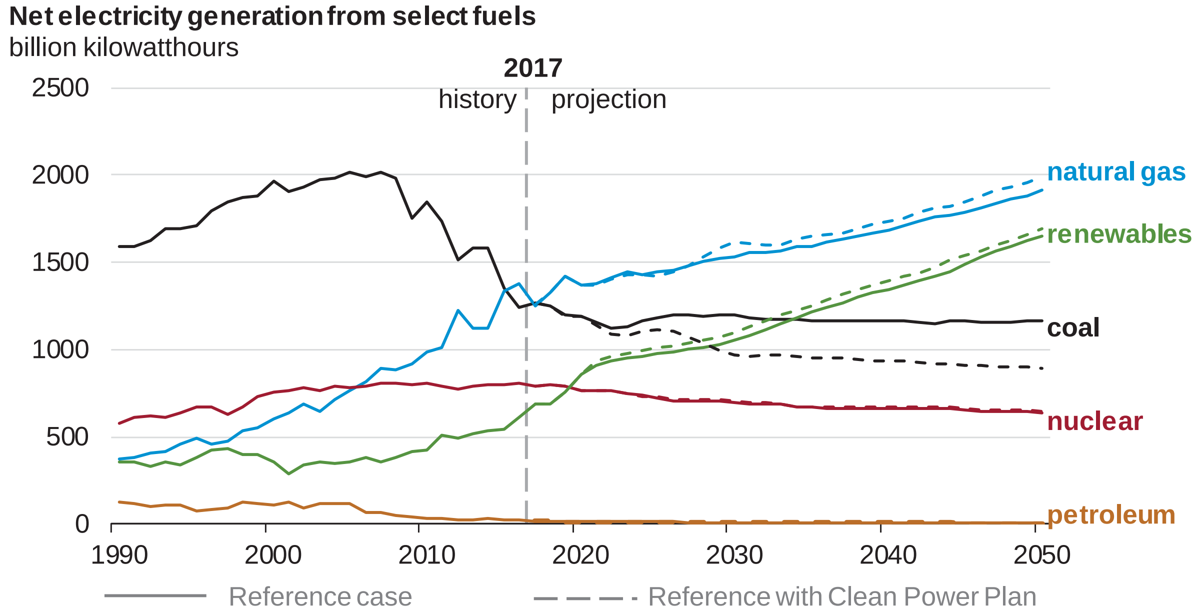
Coal-fired electric generating capacity decreases through 2030, even without the Clean Power Plan or lower natural gas prices—



—while lower natural gas prices would result in additional reductions in projected coal-fired electric generating capacity

- Between 2011 and 2016, net coal capacity decreased by nearly 60 gigawatts (GW), partly as a result of compliance with the U.S. Environmental Protection Agency's Mercury and Air Toxics Standards.
- Coal-fired generating capacity decreases by an additional 65 GW between 2017 and 2030 as a result of competitively priced natural gas and increasing renewables generation, before leveling off near 190 GW in the Reference case through 2050.
- Higher natural gas prices in the Low Oil and Gas Resource and Technology case slow the pace of coal power plant retirements by approximately 20 GW in 2030 versus the Reference case. Conversely, lower natural gas prices in the High Oil and Gas Resource and Technology case increase coal power plant retirements by 19 GW in 2030, with 157 GW of coal capacity remaining by 2050.
- Adoption of the Clean Power Plan or similar greenhouse gas emission restrictions by regional or state authorities results in 15 GW of additional coal power plant retirements by 2030 and 19 GW by 2050 in the Reference case.

Coal-fired electricity generation remains at a higher level in the Reference case than in the Clean Power Plan case—



—but growth in natural gas and renewables generation capacity dampens coal's growth

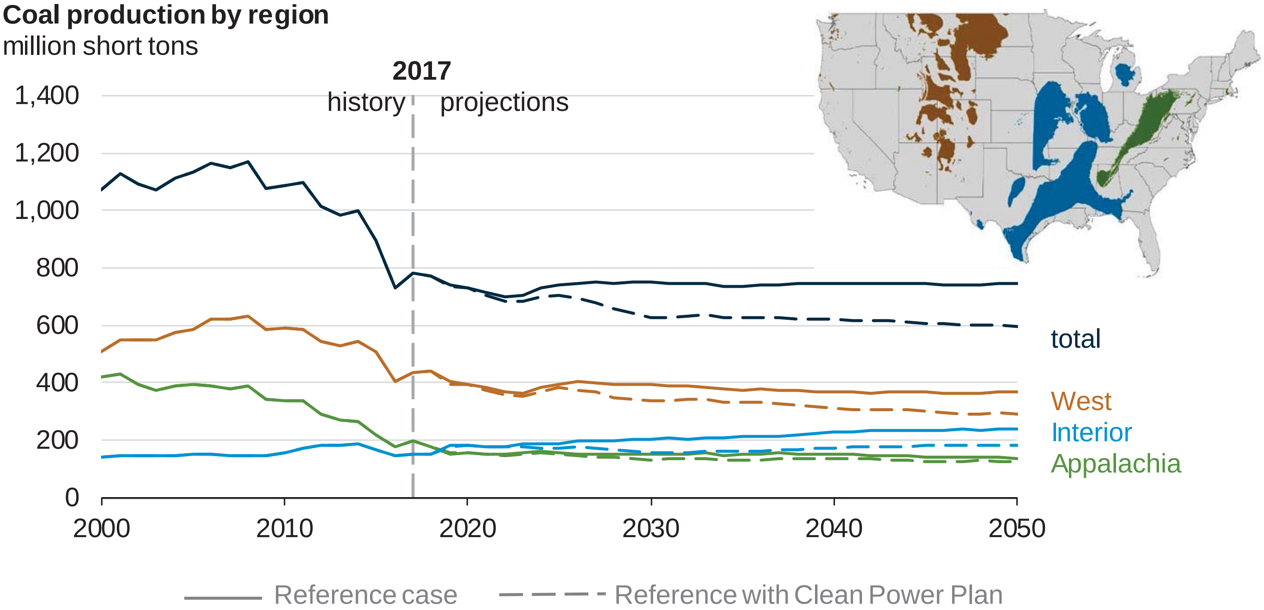
- In the Reference case, near-term coal power plant retirements and competition with natural gas-fired electricity generation result in a slight decline in coal-fired generation through 2022 before stabilizing at about 1,200 billion kilowatthours (BkWh) through 2050. In the Clean Power Plan (CPP) case, coal-fired electricity generation continues to decline through 2030 to about 1,000 BkWh, then declines very gradually through 2050.

- Natural gas-fired generation steadily increases its market share of total electricity generation relative to coal through 2050, and it grows at about the same rate in the Reference and CPP cases.

- Federal tax credits lead to a significant increase in renewable electricity generation through the early 2020s in both the Reference and CPP cases. Continued favorable economics relative to other generating technologies result in a more than doubling of renewables generation between 2017 and 2050, with an average annual growth rate of 2.8% in both the Reference case and the CPP case.

Coal production decreases through 2022 because of retirements of coal-fired electric generating capacity—

Coal production by region
million short tons

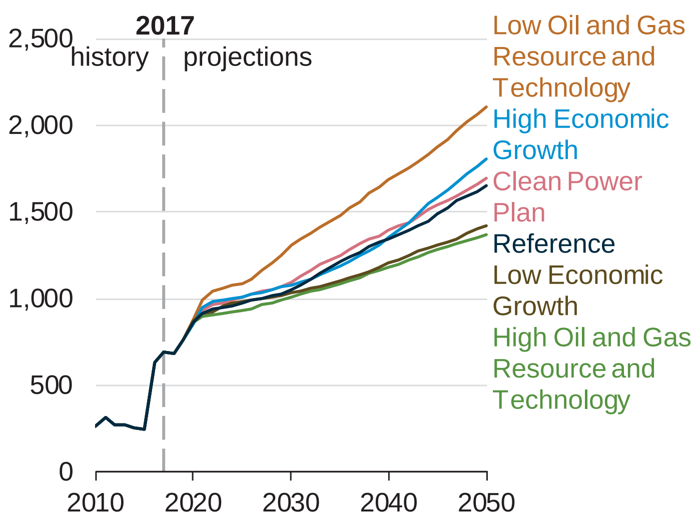


—before stabilizing as natural gas prices increase through 2050

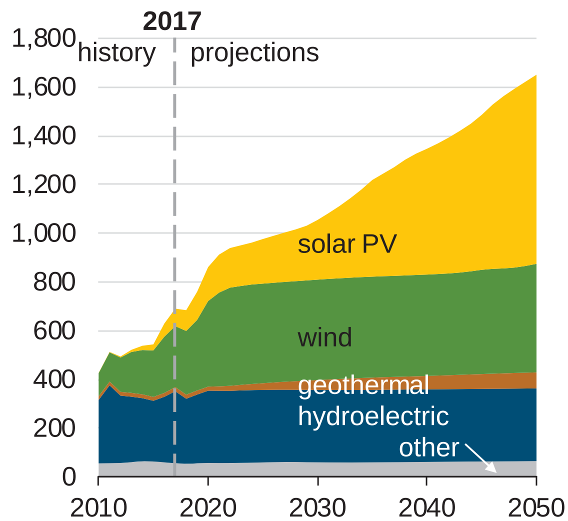
- Coal production in the Reference case continues to decline, from 784 million short tons (MMst) in 2017 to 699 MMst in 2022, in response to retirements of coal-fired electric power plants and competitive price pressure from natural gas and renewables.
- In the Reference case, coal production rises slightly in the mid-2020s, rising to 750 MMst in 2030 before decreasing slightly as natural gas prices increase and as renewable capacity additions slow with the expiration of the production tax credit for wind installations.
- In the Reference case, coal production in the Interior region grows by about 90 MMst between 2017 and 2050, while production in the Appalachia and the West regions declines by 58 MMst and 69 MMst, respectively, in part as a result of expected improvements in labor productivity for the Interior region compared with gradual declines in other regions.
- Under the Clean Power Plan, coal production is projected to decrease to 629 MMst by 2030 and to decline gradually thereafter.

Generation from renewable sources grows across all cases, led by growth in wind and solar photovoltaic generation—

Total renewables generation, including end-use generation
billion kilowatthours



Renewable electricity generation, including end-use generation (Reference case)
billion kilowatthours



—even in cases with relatively low electricity demand or low natural gas prices

- In the Reference case, renewable generation is projected to increase 139% through the end of the projection period, reaching 1,650 billion kilowatthours (BkWh) by 2050.

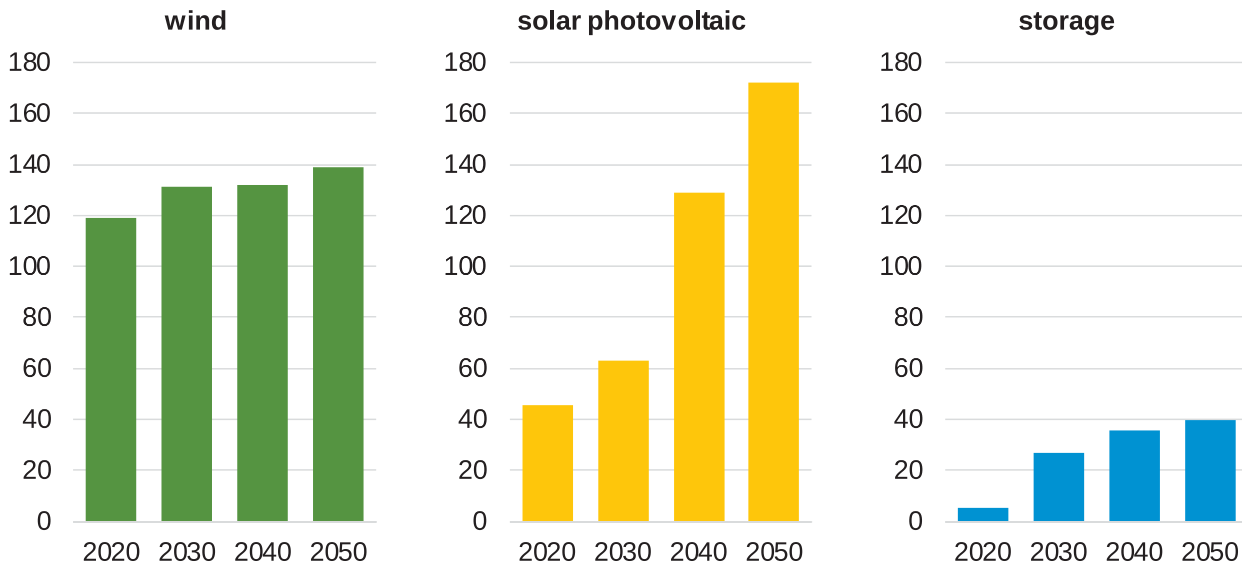
- The increase in wind and solar generation leads the growth in renewable generation through the projection period, accounting for nearly 900 BkWh (94%) of the total growth in the Reference case. The extended tax credits account for much of the accelerated growth in the near term. Solar photovoltaic (PV) growth continues through the projection period as solar PV costs continue to decrease.

- In the High Oil and Gas Resource and Technology case, low natural gas prices limit the growth of renewables in favor of additional natural gas-fired generation. Renewables generation is 277 BkWh lower than Reference case levels in 2050, although this level still represents a near doubling from 2017 levels.

- In the Low Economic Growth case, electricity demand is lower than in the Reference case. Because renewables are a marginal source of new generation, this lower level of demand results in 228 BkWh less renewable generation in 2050 compared with the Reference case.

Increasing wind and solar capacity additions in the Reference case—

Utility-scale wind, solar, and storage operating capacity
gigawatts

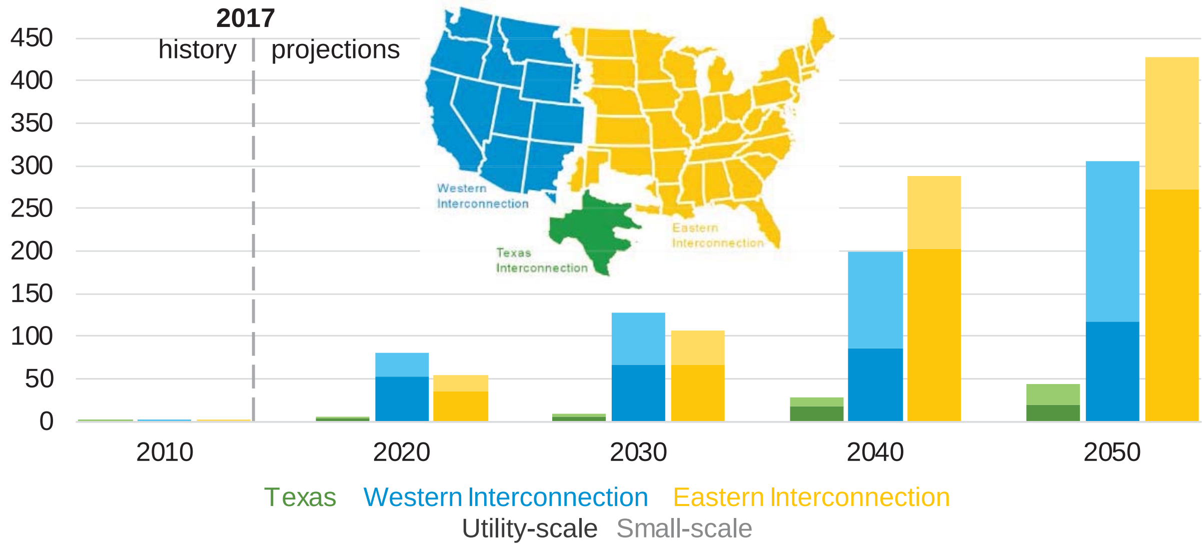


—support growth of energy storage capacity

- From 2020 to 2050, utility-scale wind capacity is projected to grow by 20 gigawatts (GW), and utility-scale solar photovoltaic capacity is projected to grow by 127 GW. Over this same period, utility-scale storage capacity is projected to grow by 34 GW.
- Battery-based storage costs are expected to continue to decline as utility-scale energy storage markets grow.
- Policies such as storage mandates in California and market participation rules in the PJM electricity market support near-term growth in storage systems to stabilize grid operations, improve utilization of existing generators, and integrate intermittent technologies such as wind and solar into the grid.
- In the longer term, wind and solar growth are projected to support economic opportunities for storage systems that can provide several hours of storage and enable renewables generation produced during the hours with high wind or solar output to supply electricity at times of peak electricity demand.

Projected solar PV cost competitiveness results in growth of solar generation in the Reference case in all interconnection regions—

Solar photovoltaic electricity generation by region (Reference case)
billion kilowatthours

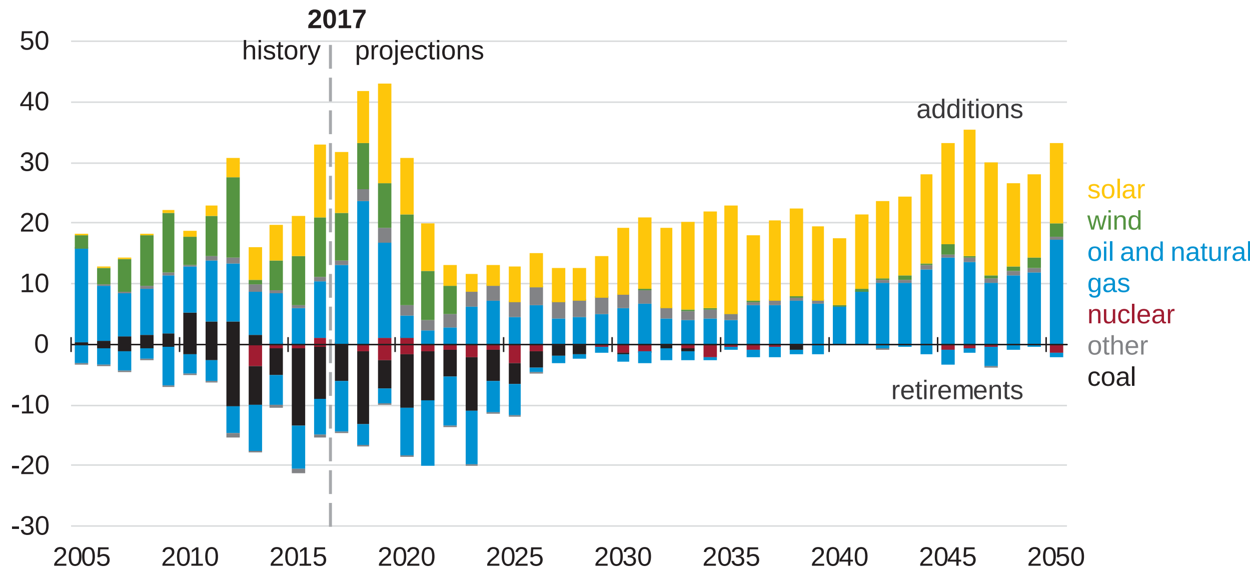


—for both utility-scale and small-scale systems

- Electricity generation from solar photovoltaic (PV) facilities in all sectors is projected to reach 14% of total electricity generation by 2050 in the Reference case, with 53% of the total from utility-scale systems and 47% from small-scale systems.
- In the Western Interconnection, growth in solar PV generation comes primarily from small-scale systems such as roof-top PV. In the Eastern Interconnection, solar PV generation is produced mostly from utility-scale systems through the projection period.
- The share of the Western Interconnection's solar PV generation to the U.S. total generally decreases over the projection period, from 66% in 2017 to 39% in 2050, as the penetration of solar PV installations increases in the Texas and Eastern Interconnections. By 2032, the Eastern Interconnection is projected to have the largest share of U.S. solar PV generation (49%) and that share increases through the projection period to 55% by 2050. Texas is estimated to generate about 6% of solar PV generation by 2050.

Renewables and natural gas comprise most of the capacity additions through the projection period in the Reference case—

Annual electricity generating capacity additions and retirements (Reference case)
gigawatts



—with tax credit phase-outs and coal plant retirements accelerating additions of near-term renewables and natural gas-fired capacity

- Most electric generation capacity retirements occur by 2025, when natural gas prices are lower. They taper off in the later years of the projection period.

- In the Reference case, 80 gigawatts (GW) of new wind and solar photovoltaic (PV) capacity are added from 2018–2021, motivated by declining capital costs and the availability of tax credits.

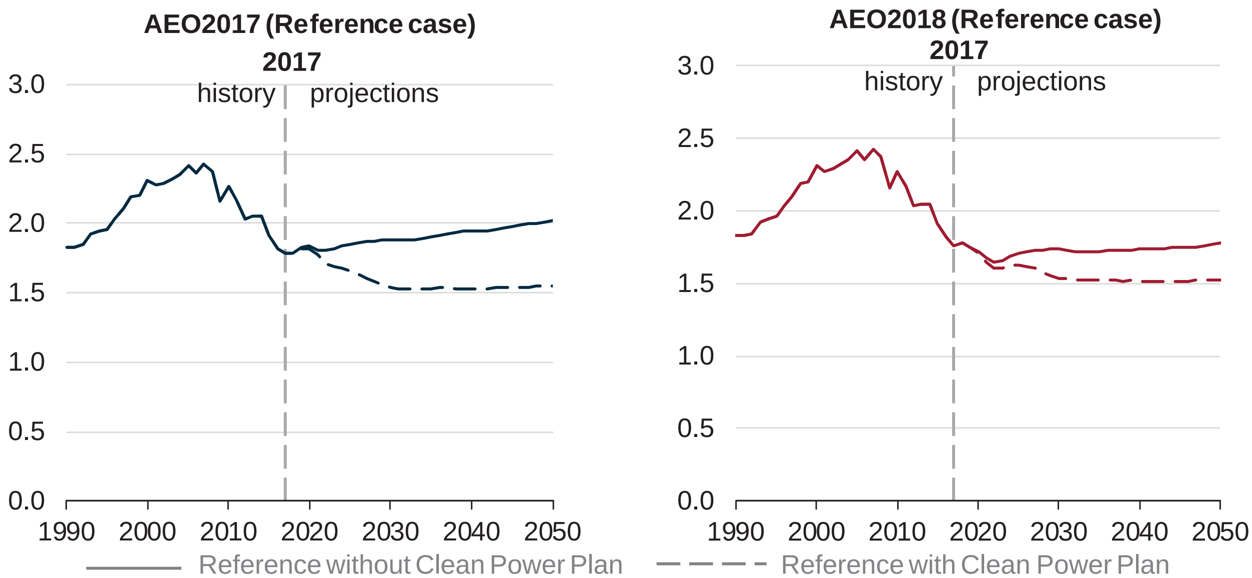
- New wind capacity additions continue at much lower levels after the expiration of production tax credits in the early 2020s. Although the commercial solar investment tax credits (ITC) are reduced and the ITC for residential-owned systems expires, the growth in solar PV capacity continues through 2050 for both the utility-scale and small-scale applications.

- New natural gas-fired capacity is also added steadily through 2050 to meet growing electricity demand.

The projected effect of the Clean Power Plan on carbon dioxide emissions is smaller in AEO2018 than it was in AEO2017—

Electricity-related carbon dioxide emissions
billion metric tons of carbon dioxide

Electricity-related carbon dioxide emissions
billion metric tons of carbon dioxide



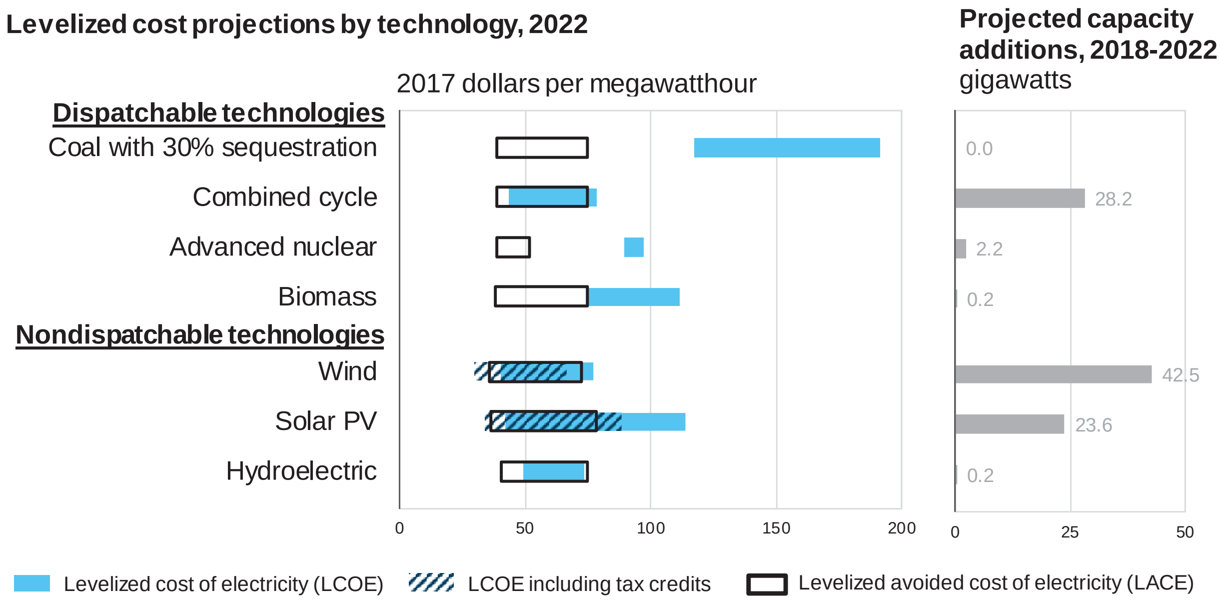
—because of lower projected levels for coal-fired generation even without the Clean Power Plan policy

- In the near term, the cumulative effect of increased coal plant retirements, lower natural gas prices, and lower electricity demand in the AEO2018 Reference case is a reduction in the projected carbon dioxide (CO2) emissions from electric generators, even without the Clean Power Plan (CPP). In 2020, projected electric power sector CO2 emissions are 1.72 billion metric tons, which is 120 million metric tons (7%) lower than the projected level of CO2 emissions in the AEO2017 Reference case without the CPP.

- By 2030, most of the additional planned coal unit retirements have occurred, and in the absence of the CPP, projected CO2 emissions stabilize in the Reference case at about 1.71 billion metric tons, which is 143 million metric tons (8%) below the AEO2017 Reference case without the CPP for that year.

- Over the long term, greater renewables growth in the AEO2018 Reference case results in electric power sector emissions growing at a slower rate, reaching 1.78 billion metric tons in 2050, which is 242 million metric tons (12%) below the level for that year in the AEO2017 Reference case without the CPP.

Combined cycle, wind, and solar photovoltaic generation have the most favorable cost characteristics—



—when the levelized cost and levelized avoided cost of electricity are considered together

- Comparisons of levelized cost of electricity (LCOE) across technologies can be misleading because different technologies serve different market segments.
- The levelized avoided cost of electricity (LACE) is a measure of what it would cost to generate the electricity that is otherwise displaced by a new generation project.
- Overlap in the levelized cost and levelized avoided cost indicates favorable economics for new builds for that technology.
- Wind plants entering service in 2022 that started construction in 2018 will receive an inflation-adjusted federal production tax credit of $14/megawatthour; solar plants entering service in 2022 will receive a 26% federal investment tax credit, assuming a two-year construction lead time.

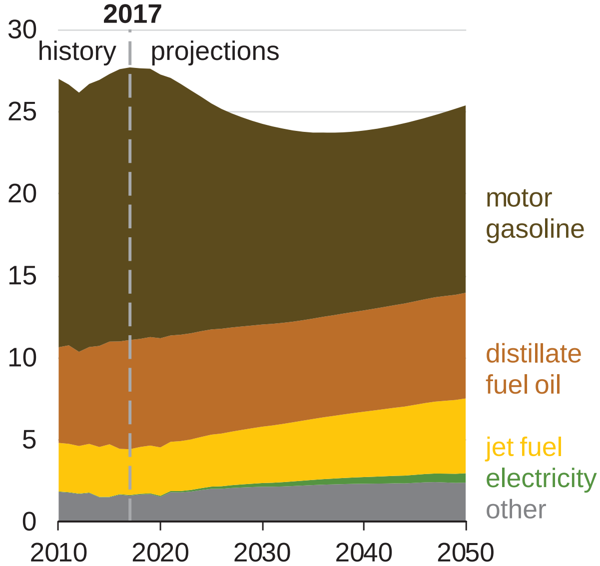
See more information in EIA's LCOE/LACE report on EIA's website.

Transportation

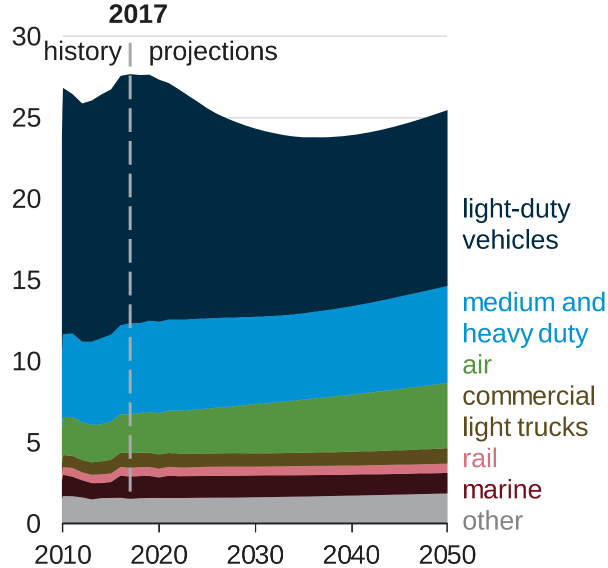
Transportation energy consumption peaks in 2017 in the Reference case because rising fuel efficiency outweighs increases in total travel and freight movements, but the trend begins to reverse in the second half of the projection period.

Transportation energy consumption declines between 2019 and 2035 in the Reference case—

Transportation sector consumption by fuel type
quadrillion British thermal units



Energy consumption by travel mode
quadrillion British thermal units

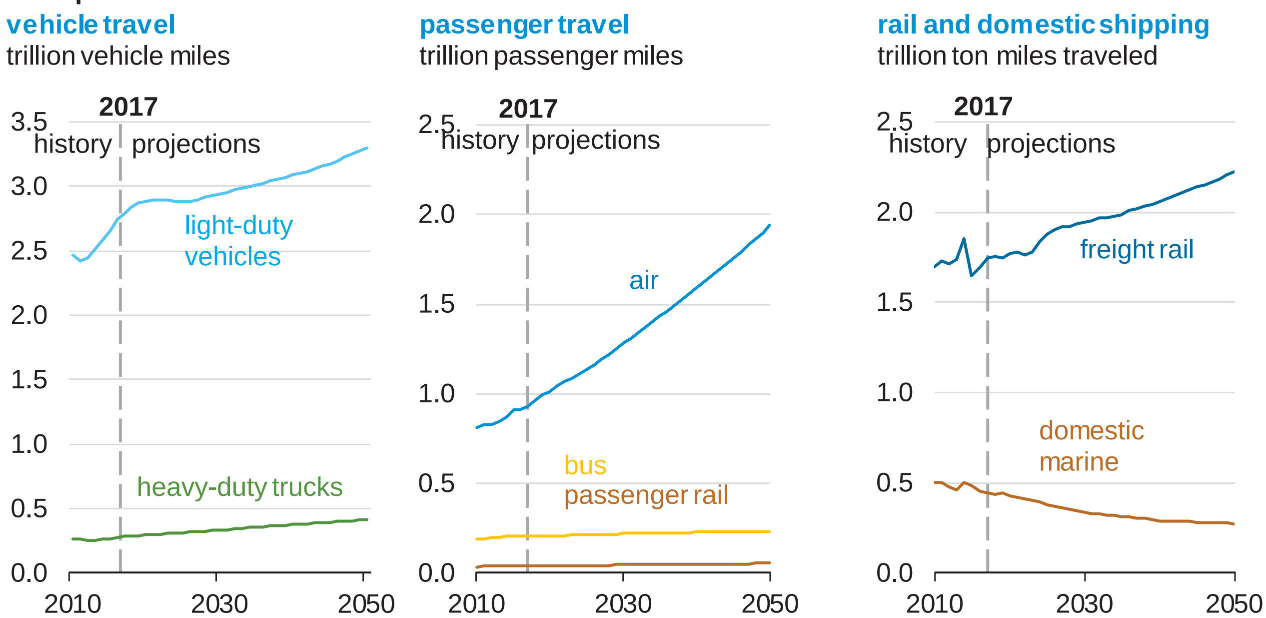


—because increases in fuel economy more than offset growth in vehicle miles traveled

- Increases in fuel economy standards temper growth in motor gasoline consumption, which decreases by 31% between 2017 and 2050.
- Increases in fuel economy standards result in heavy-duty vehicle energy consumption and related diesel use ending at approximately the same level in 2050 as in 2017, despite rising economic activity that increases the demand for freight truck travel.
- Excluding electricity and other transportation fuels, which are at comparatively low levels in 2017, jet fuel consumption grows more than any other transportation fuel over the projection period, rising 64% from 2017 to 2050, as growth in air transportation outpaces increases in aircraft energy efficiency.
- Motor gasoline and distillate fuel oil's combined share of total transportation energy consumption decreases from 84% in 2017 to about 70% in 2050 as the use of alternative fuels increases.
- Continued growth in on-road travel demand increases energy consumption later in the projection period, because current fuel economy and greenhouse gas standards require no additional efficiency increases for new vehicles after 2025 for light-duty vehicles and after 2027 for heavy-duty vehicles.

Passenger travel increases across all transportation modes in the Reference case through 2050—

Transportation travel statistics



—and total freight movement increases

- Light-duty vehicle miles traveled increase by 18% in the Reference case, growing from 2.8 trillion miles in 2017 to 3.3 trillion miles in 2050 as a result of rising incomes and growing population.

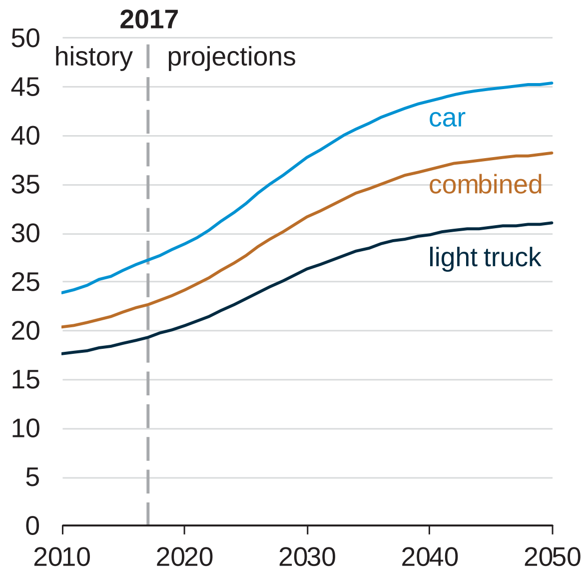
- Truck vehicle miles traveled, the dominant mode of freight movement, grow by nearly 50%, from 384 billion miles in 2017 to 569 billion miles in 2050 as a result of increased economic activity. Freight rail ton miles grow by 27% over the same period, led primarily by rising industrial output. However, U.S. coal shipments, which are mainly via rail, remain relatively flat.

- Air travel doubles from 0.9 trillion revenue passenger miles to 1.9 trillion revenue passenger miles between 2017 and 2050 in the Reference case because of an increased demand for personal travel.

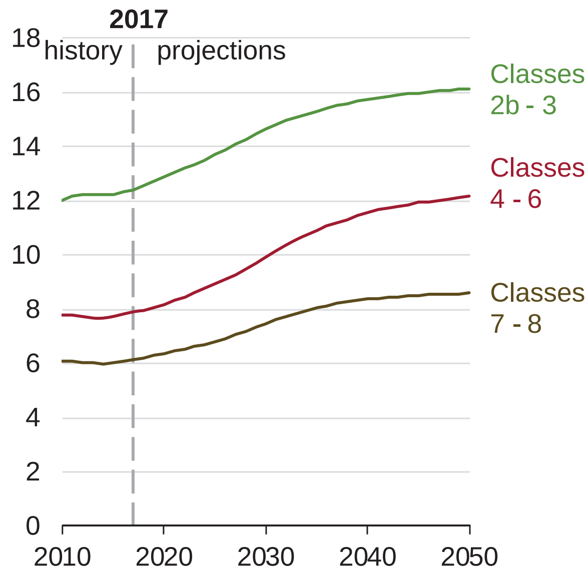
- Domestic marine shipments decline modestly over the projection period, continuing a historical trend related to logistical and economic competition with other freight modes.

Fuel economy of all on-road vehicles increases in the Reference case—

Light-duty vehicle stock fuel economy
miles per gallon



Heavy-duty vehicle stock fuel economy
miles per gallon



—across all vehicle types through the projection period

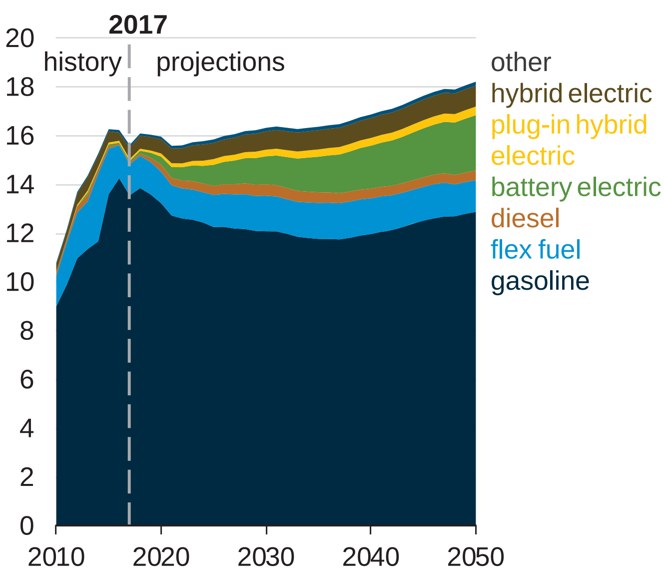
- Fuel economy of light-duty vehicles from 2017 to 2050 increases by 66% for cars and by 60% for light trucks. The combined fuel efficiency increases by 68% by 2050 as newer, more fuel-efficient vehicles enter the market, including a higher share of cars, which are more efficient than light trucks.

- Fuel economy of the heavy-duty vehicles improves across all weight classes as the second phase of heavy-duty vehicle efficiency and greenhouse gas standards takes full effect in 2027.

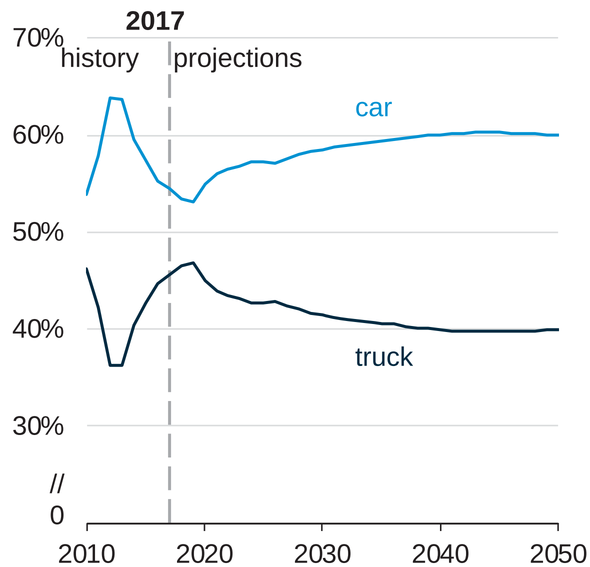
- Gains in fuel economy offset increases in on-road travel for both light-duty and heavy-duty vehicles. These gains keep heavy-duty vehicle energy consumption relatively flat and decrease light-duty vehicle energy consumption. After 2039, increasing vehicle travel outweighs fuel economy improvements, leading to increases in fuel demand.

Light-duty vehicle fuel economy improves as sales of more fuel-efficient cars grow and as electrified powertrains gain market share—

Light-duty vehicle sales by fuel type
millions of vehicles



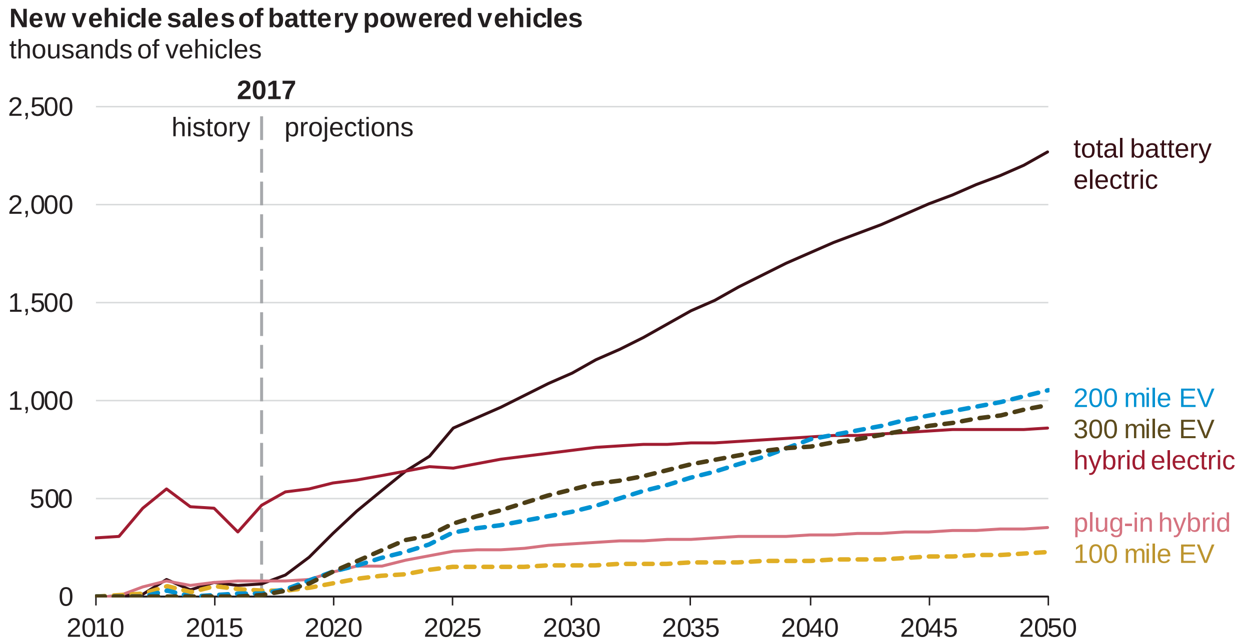
Light-duty vehicle sales shares
percent



—but gasoline vehicles remain the dominant vehicle type through 2050 in the Reference case

- Combined sales of new electric, plug-in hybrid electric, and hybrid vehicles grow in market share from 4% in 2017 to 19% in 2050 in the Reference case.
- The combined share of sales attributable to gasoline and flex-fuel vehicles (which use gasoline blended with up to 85% ethanol) declines from 95% in 2017 to 78% in 2050 because of the growth in the sales of electric vehicles.
- Passenger cars gain market share relative to light-duty trucks because of their higher fuel efficiency in periods when motor gasoline prices are projected to increase and because crossover vehicles, often classified as passenger cars, increase in availability and popularity.
- New vehicles of all fuel types show significant improvements in fuel economy because of compliance with increasing fuel economy standards. New vehicle fuel economy rises by 45% from 2017 to 2050.

Sales of electric and plug-in hybrid electric light-duty vehicles increase in the Reference case—

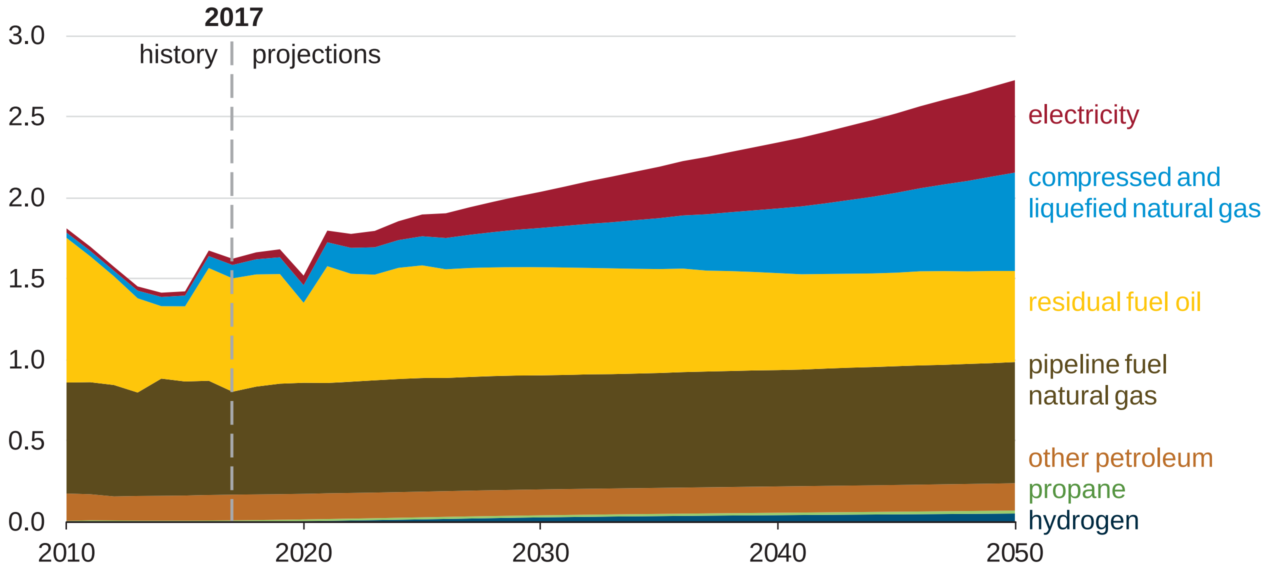


—driven by state policies, more models offering longer driving-range capabilities, and battery cost reductions

- Battery-electric vehicle (BEV) sales increase from less than 1% of total U.S. vehicle sales in 2017 to 12% in 2050. Plug-in hybrid electric vehicle (PHEV) sales increase from less than 1% to 2% over the same period.
- California's Zero-Emission Vehicle regulation, which has been adopted by nine additional states, requires a minimum percentage of vehicle sales of electric and plug-in hybrid vehicles. In 2025, the year the regulation and new federal fuel economy standards go into full effect, projected sales of BEV and PHEV vehicles reach 1.1 million, or about 7% of projected total vehicle sales in the Reference case.
- Sales of the longer-ranged 200- and 300-mile electric vehicles grow over the entire projection period, tempering sales of the shorter-range 100-mile electric vehicles and plug-in hybrid electric vehicles.

Consumption of total non-major transportation fuels grows considerably in the Reference case between 2017 and 2050—

Transportation sector consumption of non-major petroleum and alternative fuels
quadrillion British thermal units



—because of the increased use of electricity and natural gas

- Electricity use in the transportation sector increases sharply after 2020 in the Reference case because of the projected rise in the sale of new light-duty vehicles that are electric and plug-in hybrid-electric.
- Natural gas consumption increases over the entire projection period because of growing use in heavy-duty vehicles and freight rail.
- New limits on the air pollutants associated with the International Convention for the Prevention of Pollution by Ships (MARPOL) lead to some switching from residual fuel oil to liquefied natural gas in maritime vessels during later years of the projection period.

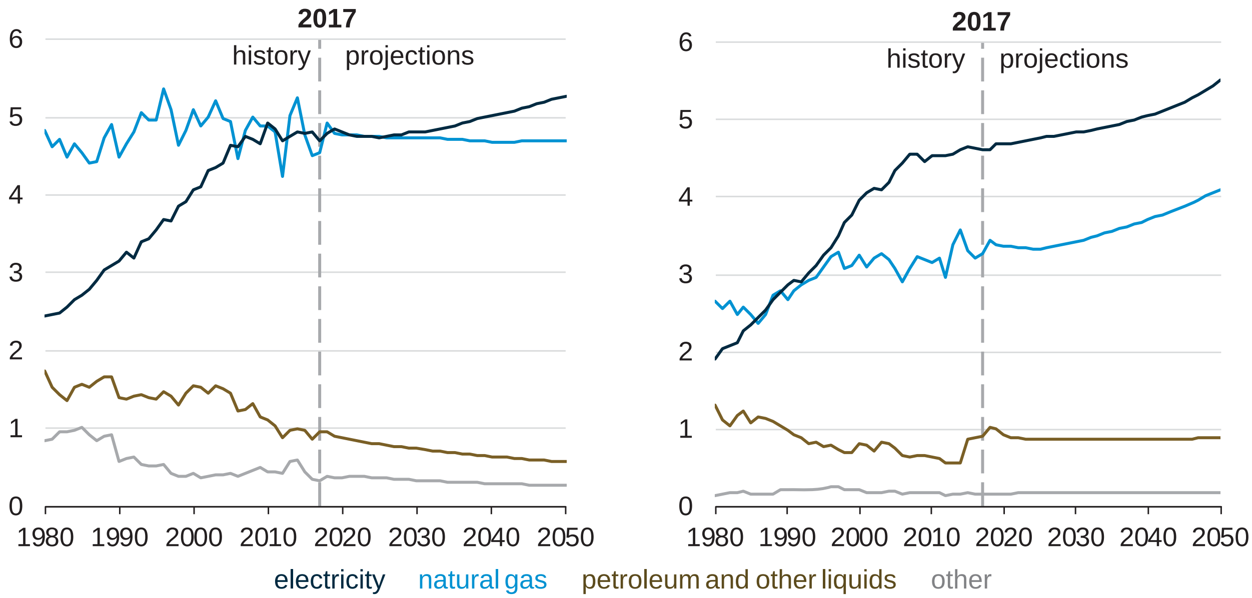
Buildings

Delivered energy consumption in the buildings sector is expected to grow gradually from 2017 to 2050 in the Reference case based in part on currently established efficiency standards and incentives. Distributed solar capacity is anticipated to grow throughout the projection period based on near-term incentives, declining costs, and demographic factors.

Residential and commercial energy consumption grows gradually from 2017 to 2050—

Residential sector energy consumption
quadrillion British thermal units

Commercial sector energy consumption
quadrillion British thermal units

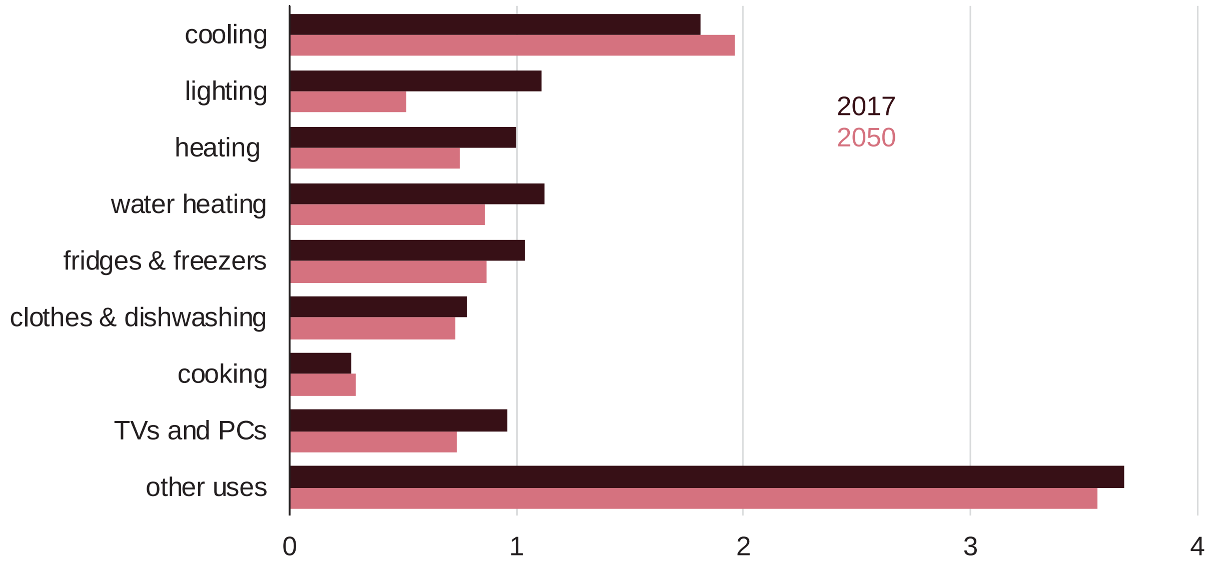


—led by modest electricity consumption growth in the residential and commercial sectors

- Energy delivered to the buildings sector (residential and commercial) grows 0.3%/year from 2017 to 2050 in the Reference case, accounting for 27% of total U.S. delivered energy in 2017 and 26% in 2050.
- In the buildings sector, efficiency gains, increases in distributed generation, and regional shifts in the population partially offset the impacts of growth in population, number of households, and commercial floorspace.
- Electricity accounts for most of U.S. buildings energy consumption growth in all AEO2018 cases, followed by natural gas. Consumption of delivered electricity would be even higher if not for the expected growth in distributed generation sources, particularly rooftop solar panels.
- Growth in commercial sector natural gas use later in the projection period reflects increased use of combined heat and power in the sector.

Residential electricity use per household decreases for most end uses—

Use of purchased electricity per household
thousand kilowatthours per household

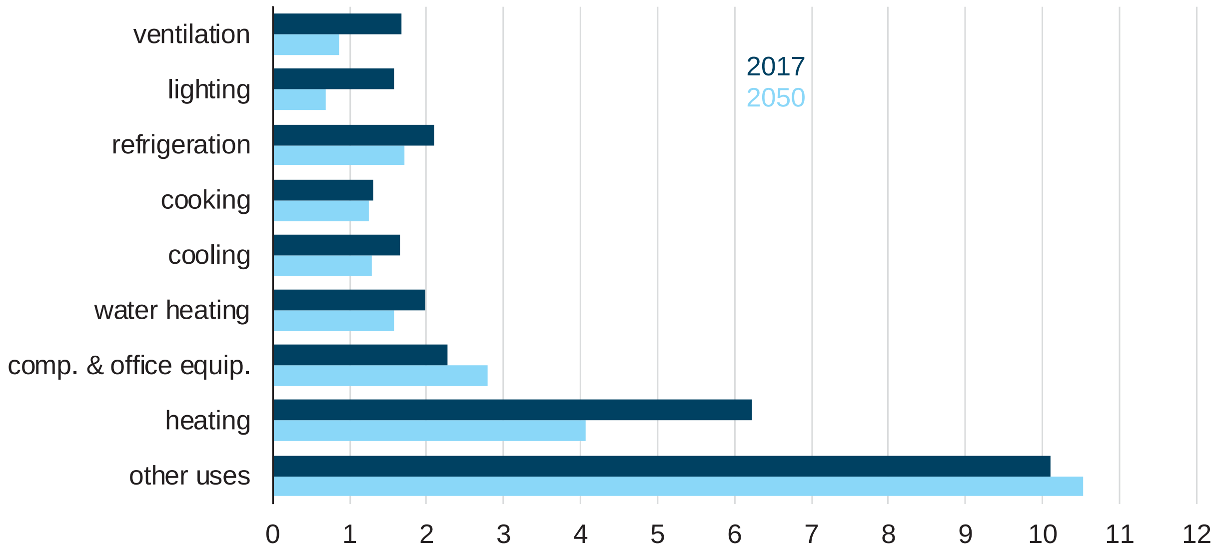


—as a result of increases in appliance energy efficiency standards and building energy codes

- Electricity use per household decreases in the Reference case through 2050, even as the number of homes grows 0.8%/year and the average size of homes grows 0.4%/year. In total, the use of purchased electricity per household decreases from 12,000 kilowatthours (kWh) in 2017 to 10,000 kWh in 2050.
- Continued population shifts to warmer parts of the United States lower heating demand and increase cooling demand in all cases in the residential sector. Heating and cooling demand are also affected by efficiency improvements.
- By 2050, the average household uses less than half as much electricity for lighting as it did in 2017, as more energy-efficient, light-emitting diodes replace incandescent bulbs and compact fluorescent lamps.
- Energy efficiency standards tighten for other uses, such as dehumidifiers, ceiling fans, pool pumps, and other miscellaneous loads, which lowers energy consumption per household in these end uses. However, increased adoption of electronic devices contributes to growth in residential use of electricity.
- Residential on-site electricity generation, mostly from photovoltaic solar panels, lowers total delivered electricity purchased from the electric grid over the projection period.

Commercial electricity use per square foot of commercial floorspace falls—

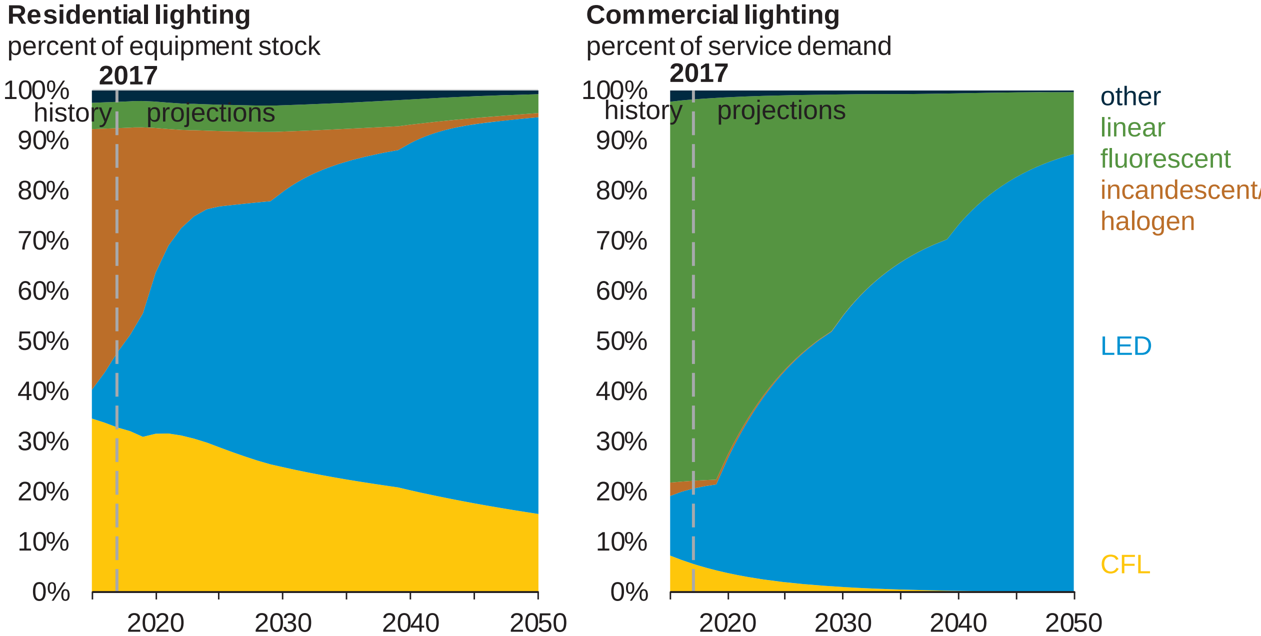
Use of purchased electricity per square foot of commercial floorspace
thousand kilowatthours per billion square feet



—as a result of adopting efficient LED lighting and the changing needs for space heating

- Electricity used for commercial HVAC equipment (heating, ventilation, and cooling) drops by more than one-third from 2017 to 2050 in the Reference case because of increases in energy efficiency and a continued population shift toward warmer parts of the country in the South and West. Commercial floorspace in the United States grows by 1% annually between 2017 and 2050.
- Although the United States has no federally-mandated commercial building energy code, state- and local-level building codes reduce energy used for heating and cooling.
- Lighting standards and the increased efficiency of light-emitting diode (LED) bulbs result in a 56% decrease in lighting intensity between 2017 and 2050 in the Reference case, as LEDs displace linear fluorescent lighting as the dominant commercial lighting technology.
- Office equipment and other uses, such as information technology network and telecommunications equipment, are major contributors to growth in commercial sector electricity consumption in all cases.
- Commercial on-site electricity generation, mostly from solar photovoltaic panels and combined heat and power systems, lowers total delivered electricity purchased from the electric grid.

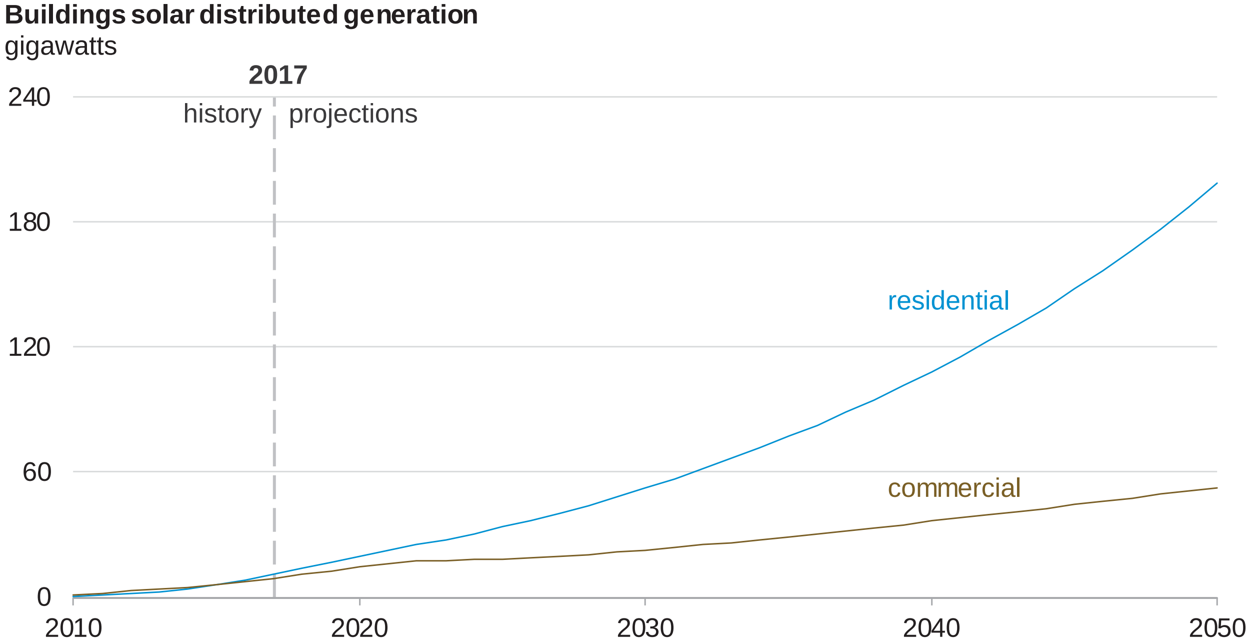
Energy efficiency incentives and standards contribute to rapid adoption of LED and CFL lighting in the near term—



—while lower costs associated with LEDs increase consumer use in later years

- Light-emitting diode (LED) adoption increases rapidly over the projection period. By 2050, LEDs meet most lighting demand in buildings across all cases.
- The use of compact fluorescent lamp (CFL) bulbs in residential buildings declines as the adoption of LED bulbs increases, a shift driven by lower LED prices and the gradual elimination of CFL subsidies through 2019.
- Utility and state energy-efficiency program incentives account for up to 30% of the cost for CFLs in 2014 and up to 55% of the cost for LEDs until 2019.
- Efficiency requirements under the Energy Independence and Security Act (EISA), which eliminate inefficient incandescent bulbs from general use after 2020, also bolster the adoption of LED lighting.
- LED prices decrease over the projection period, leading to further adoption. The purchase price of a typical LED light bulb decreases by about 70% between 2015 and 2050.

Solar photovoltaic adoption grows between 2017 and 2050—



—with residential growth outpacing commercial growth

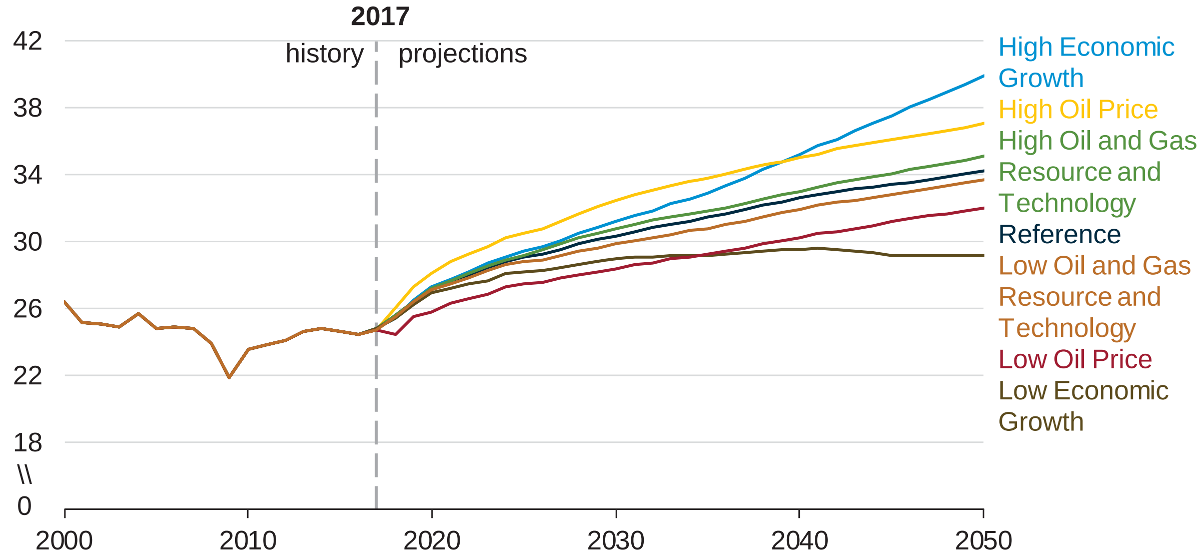
- In the Reference case, most distributed solar capacity growth occurs in the residential sector, which increases by 9%/year from 2017 through 2050, compared with 6%/year growth in the commercial sector.
- Rising incomes, declining technology costs, and social influences contribute to continued adoption of residential photovoltaic (PV), despite the phase-out and expiration of federal solar investment tax credits between 2019 and 2022.
- Stable retail electricity rates and economic considerations lead to slower but steady PV adoption by commercial consumers, as declining system costs offset the phasedown in the federal business investment tax credit from 30% in 2019 to 10% in 2022.
- Adoption of other distributed generation technologies, such as small wind and combined heat and power (mostly in the commercial sector), grows more slowly and reaches about 16 gigawatts (GW) of capacity by 2050 in the Reference case.
- The more robust economic assumptions in the High Economic Growth case lead to an additional 20 GW of solar PV capacity and an additional 1 GW of non-solar capacity by 2050 in the buildings sectors.

Industrial

With economic growth and relatively low energy prices, energy consumption in the industrial sector increases between 2017 and 2050 across all cases. Consumption of all energy sources except coal increases significantly. Energy intensity declines across all cases as a result of technological improvements.

Industrial delivered energy consumption grows in all cases—

U.S. industrial delivered energy consumption
quadrillion British thermal units

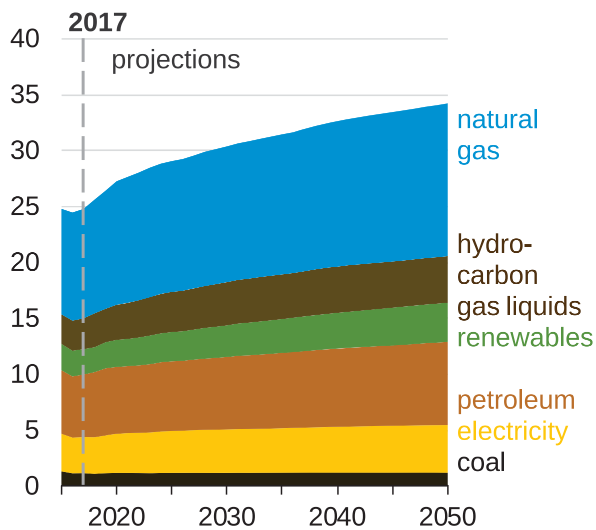


— driven by economic growth and relatively low energy prices

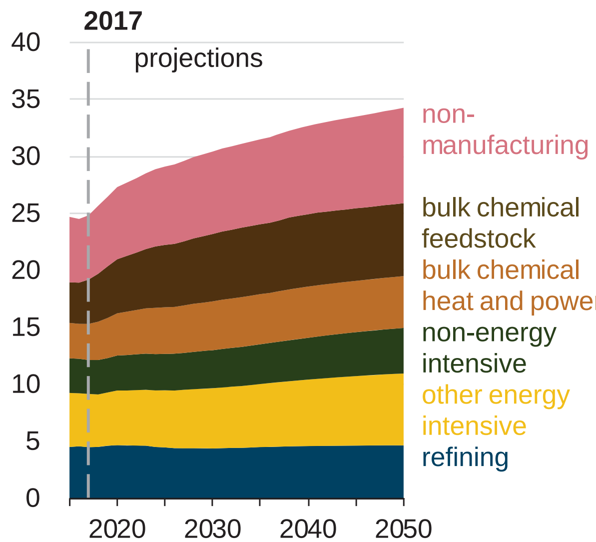
- Reference case industrial delivered energy consumption is projected to grow 38%, from 25 quadrillion British thermal units (Btu) to 34 quadrillion Btu, between 2017 and 2050.
- Industrial energy consumption is highest in the High Economic Growth case in 2050, reaching 40 quadrillion Btu, an increase of 61% from the 2017 levels, as more energy is used to produce products such as steel, fabricated metal products, and paper.
- Energy consumption in the High Oil Price case exceeds energy consumption in other cases before 2040 as a result of higher demand for U.S. products and greater amounts of energy used for natural gas liquefaction.

Industrial sector energy consumption increases at a similar rate for most fuels in the Reference case—

Industrial energy consumption by energy source
quadrillion British thermal units



Industrial energy consumption by subsector
quadrillion British thermal units



—and bulk chemicals and nonmanufacturing are the fastest-growing industries

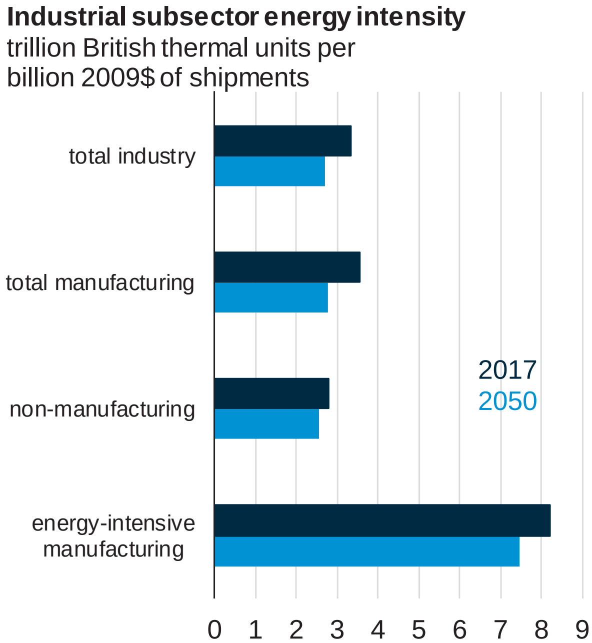
- Total industrial delivered energy consumption grows 1% per year from 2017 to 2050 in the Reference case. All fuels have a similar annual growth rate (1%, ±0.5%), with the exception of coal, which remains relatively flat through the projection period. Overall energy consumption in the industrial sector grows more slowly than economic growth because of efficiency gains.

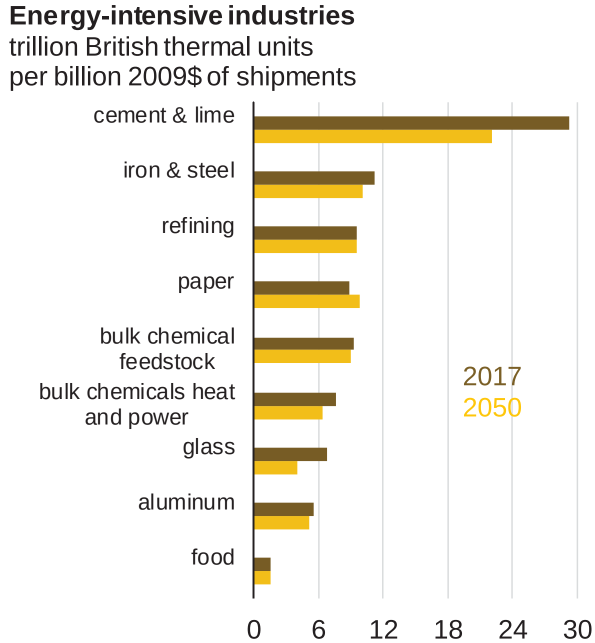
- Natural gas (used for heat and power in many industries) and petroleum (a feedstock for bulk chemicals) account for the majority of delivered industrial energy consumption. Hydrocarbon gas liquids such as ethane, propane, and butane are used as feedstock for bulk chemical production and are a major source of growth in industrial use of petroleum.

- The bulk chemicals industry constitutes about 30% of total industrial energy consumption through the projection period and is one the fastest growing energy-intensive industries, exceeding consumption of 10 quadrillion British thermal units in the Reference case by 2029.

- Nonmanufacturing industries' energy consumption grows at more than 1% per year from 2017 to 2050 as a result of relatively fast consumption growth in the mining and construction industries. Agriculture energy consumption growth is much slower.

In the Reference case, energy intensities decline in most energy-intensive industries—



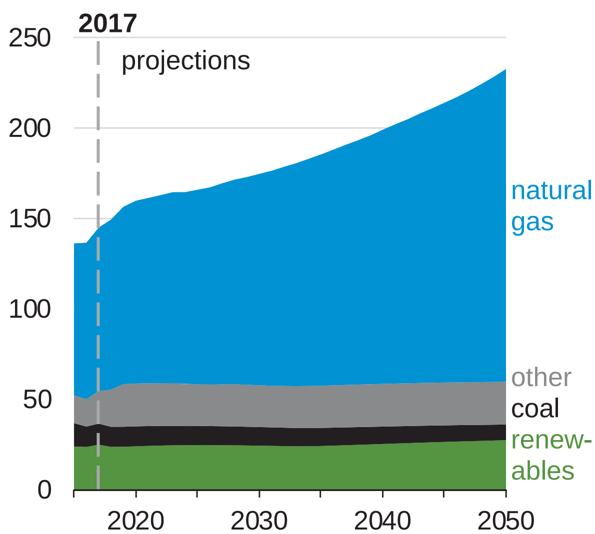


— reflecting efficiency gains in existing capacity and implementation of new, more energy-efficient technologies

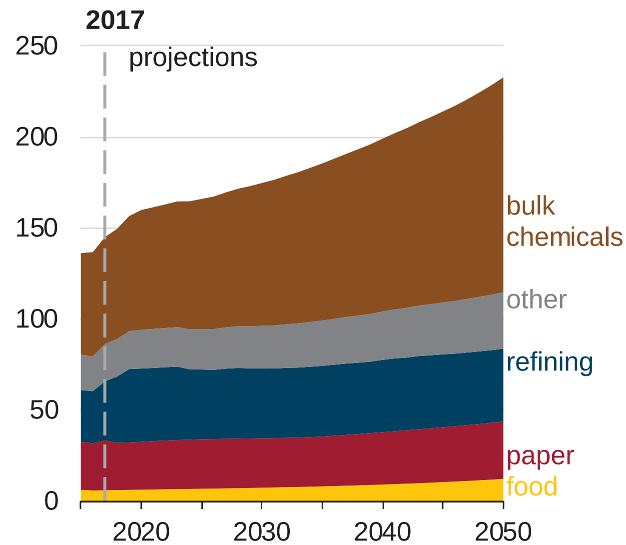
- Energy intensity (consumption per unit of output) in the industrial sector declines by about 0.6%/year from 2017 to 2050 in the Reference case.
- For manufacturing, energy intensity declines as a result of increases in energy efficiency in new capital equipment as well as a shift in the share of production away from energy-intensive industries toward non-energy intensive industries, such as metal-based durables, over time.
- Energy-intensive industries account for about 65% of total industrial energy consumption throughout the projection period in the Reference case, even though they almost always account for less than 25% of U.S. industrial output.
- Non-energy intensive manufacturing industries exhibit the greatest relative decline in energy use per unit of output—nearly 30% over the projection period—about three times greater than the declines in other industrial sectors.

Electricity generated by industrial combined heat and power technologies grows in the Reference case—

Combined heat and power generation by fuel
billion kilowatthours



Combined heat and power generation by industry
billion kilowatthours



—with most growth occurring in the bulk chemicals and food industries

- Electricity consumption associated with combined heat and power (CHP) production in the industrial sectors grows from 0.5 quadrillion British thermal units (Btu) in 2017 (more than 10% of total industrial electricity consumption) to 0.8 quadrillion Btu by 2050 (about 15% of total industrial electricity consumption) in the Reference case.

- Industrial CHP is most commonly used in large, steam-intensive industries—for example, the refining industry used CHP for about 40% of its electricity consumption in 2017, paper about 30%, and bulk chemicals about 20%. Continued penetration of CHP within these industries as well as growth in these industries lead to higher use of CHP over the projection period.

- CHP is most commonly generated with natural gas, but renewables such as black liquor (a byproduct of the pulping process) are used by the paper industry. Other byproduct fuels such as blast furnace gas and still gas are used in the iron and steel industry and the refining industry, respectively.

References

Commonly used acronyms and abbreviations used in this report

AEO = Annual Energy Outlook
b = barrel(s)
BEV = battery-electric vehicle
b/d = barrels per day
BkWh = billion kilowatthours
Btu = British thermal unit(s)
CFL = compact fluorescent lamp
CHP = combined heat and power
CO2 = carbon dioxide
CPP = Clean Power Plan
EIA = U.S. Energy Information Administration
gal = gallon(s)
GDP = gross domestic product
GW = gigawatt(s)
HGL = hydrocarbon gas liquid(s)
ITC = investment tax credit
kWh = kilowatthour(s)
LED = light-emitting diode
LNG = liquefied natural gas
MARPOL = marine pollution, the International Convention for the Prevention of Pollution from Ships
MMBtu = million British thermal units
MMst = million short tons
NEMS = National Energy Modeling System
NGPL = natural gas plant liquids
OPEC = Organization of the Petroleum Exporting Countries
PHEV = plug-in hybrid electric vehicle
PTC = production tax credit
PV = photovoltaic
Tcf = trillion cubic feet
ZEV = zero-emission vehicle

Graph sources

In general:

- Projected values are sourced from:
  - *Short-Term Energy Outlook*, October 2017
  - Projections: EIA, AEO2018 National Energy Modeling System (runs: ref2018.d121317a, highprice.d122017a, lowprice.d121317a, highmacro.d121317a, lowmacro.d121317a, highrt.d121317a, lowrt.d121317a, ref_cpp.d121317a)
- Historical data are sourced from:
  - *Monthly Energy Review* (and supporting databases), September 2017
  - IHS Markit, Macroeconomic, Industry, and Employment models, August 2017

Historical values in some graphs are derived from other sources. For source information for specific graphs published in this document, contact annualenergyoutlook@eia.gov.

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U.S. Energy Information Administration homepage | www.eia.gov

Short-Term Energy Outlook | www.eia.gov/steo

Annual Energy Outlook | www.eia.gov/aeo

International Energy Outlook | www.eia.gov/ieo

Monthly Energy Review | www.eia.gov/mer

Today in Energy | www.eia.gov/todayinenergy