ENERGY POLICIES OF IEA COUNTRIES

United States

2019 Review

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INTERNATIONAL ENERGY AGENCY

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Foreword

The International Energy Agency (IEA) has conducted in-depth peer reviews of its member countries' energy policies since 1976. This process not only supports energy policy development, but also encourages the exchange of and learning from international best practices and experiences. In short, by seeing what has worked – or not – in the "real world", these reviews help to identify policies that achieve objectives and bring concrete results. Recently, the IEA has moved to modernise the reviews by focusing on some of the key energy challenges in today's rapidly changing energy markets.

The shale revolution continues to be a driving force for United States (US) energy policy, shifting gears from a mindset of energy scarcity to one of energy abundance. Innovations in oil and gas extraction through horizontal drilling and hydraulic fracturing have made oil and gas production a mainstay of the US energy landscape and, indeed, the world. The timely siting of supporting infrastructure will be essential to ensuring continued gains from the shale boom. Notably, the shale revolution is expected to turn the United States from a net energy importer to a net exporter by 2020.

As with most IEA countries, energy security remains a priority issue for the United States, as the government steps up efforts to respond to new threats such as cyberattacks. Internationally, US energy exports are already playing an important role in diversifying global energy supplies.

US government policy is centred on the concept of "energy dominance", which reflects a strategy to maximise energy production, expand exports and be a leader in energy technologies. Environmental deregulation is a central focus, though it may have implications for the emissions trajectory.

I am pleased to observe that the United States has already achieved impressive emissions reductions over the past decade. A sizeable driver of this has been the switch away from coal-fired generation in the electricity sector towards low-cost shale gas and renewables, aided by falling costs and policy support. While these trends are expected to continue, the closure of additional coal and nuclear generation capacity also warrants monitoring. Policy and regulatory responses will likely be needed to ensure a smooth transition in the electricity sector that accommodates the growth in variable renewables while also ensuring reliability and resilience of the overall power system.

It is my hope that this report will help support the United States as it manages the transition of its energy sector to ensure a clean, safe and affordable energy system.

Dr Fatih Birol

Executive Director

International Energy Agency

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1. Executive summary

Overview

Since the 2014 International Energy Agency (IEA) review of United States (US) energy policies, the shale revolution has continued to be a driving force for US energy policy, shifting gears from a mindset of energy scarcity to one of energy abundance. Further innovation in oil and gas extraction through additional refinements in horizontal drilling coupled with hydraulic fracturing has made oil and gas production a mainstay of the US energy landscape and, indeed, the world. Domestic oil production[1] in the United States was 15.5 million barrels per day in 2018, a remarkable 124% increase from 2008, led by light tight oil production from shale formations. Meanwhile, indigenous natural gas production experienced a remarkable 40% growth to 760.4 billion cubic metres over the same time frame.

Notably, the shale revolution is expected to turn the United States from a net energy importer to a net exporter by 2020 as production growth of crude oil, natural gas and natural gas liquids exceeds consumption. As the United States is poised for further production growth over the coming decade, facilitating the buildout of supporting infrastructure will be a key factor to maximise the benefits of shale, both at home and abroad.

Moreover, the abundance of low-cost natural gas has resulted in gas-fired generation overtaking coal-fired generation in the power sector. Added to this, falling costs and policy support for renewable power have motivated a surge in wind and solar generation capacity. Combined with the growth in natural gas generation, both coal and nuclear – previous cornerstones of US electricity markets – are facing closures. Policy and regulatory responses will be needed to ensure a smooth transition in the electricity sector that accommodates the growth in variable renewables while also ensuring reliability and resilience of the overall power system.

Energy security remains a priority issue for the United States. The country continues to demonstrate a strong focus on reliability and resilience, recognising that its national and economic security depend on the reliable functioning of its energy infrastructure. The government has taken steps to update its security frameworks, including by introducing processes to address new trends such as cyberthreats. US energy exports are already playing an important role in diversifying global energy supplies and mitigating the potential impact of disruption events. In this regard, continued careful consideration is required when examining proposals to modernise and sell down its Strategic Petroleum Reserve, given its critical role in a future IEA collective response.

[1] Includes conventional oil, light tight oil, condensates, natural gas liquids and non-conventional oil.

"Energy dominance" strategy

Given that the shale revolution has made the United States not only the world's top producer of oil and gas but also a major exporter, the US approach to energy policy making has shifted from a scarcity mindset that emphasised energy security to one that is attempting to maximise the benefits of energy abundance. To this end, current US government policy centres on the concept of "energy dominance", which reflects a strategy to maximise energy production, benefit from larger energy exports, be a global leader in energy technologies and keep consumer energy bills in check.

Deregulation

A central implementing plank of the energy dominance strategy is to eliminate regulatory hurdles to expanding US energy production and boosting the competitiveness of the US energy industry. To this end, the administration has undertaken a strategy to revisit or rescind a number of environmental regulations applicable to broad segments of the energy sector, including the power, transport and upstream sectors.

As part of the energy dominance strategy, the US administration has made several key regulatory moves. It has repealed and replaced the Clean Power Plan to cut carbon dioxide (CO_2) emissions from the power sector; is revising Corporate Average Fuel Economy standards for automobiles; ended a moratorium on new coal leases on federal lands; rescinded regulations on hydraulic fracturing on federal lands; and plans to lower regulatory requirements to cut methane emissions from oil and gas production.

In 2017, the United States also announced its intention to withdraw from the Paris Agreement on climate change, effective in 2020. Still, US CO_2 emissions have fallen across all sectors – notably the power sector – in the past decade. While emissions are expected to continue to decline over the coming decade, there remains a risk that, over time, the trend will reverse as nuclear retirements, continued use of coal-fired generation and increased consumption of oil for transportation – coupled with less stringent emissions regulations – offset gains from the move towards natural gas and renewables for electricity generation.

Energy infrastructure

The energy dominance agenda also includes a focus on expanding US energy exports. Since the last IEA in-depth review, Congress lifted a ban on crude oil exports at the end of 2015. Moreover, the Department of Energy (DOE) streamlined the government's approach to liquefied natural gas (LNG) export approvals in 2014, helping to support the United States' becoming a major global supplier of LNG and a net exporter of natural gas. The administration is also supportive of coal exports, though coal export infrastructure is limited, especially from the West Coast.

However, future production growth and exports depend on a complementary buildout of oil and gas pipelines. While private companies decide on whether to develop new energy infrastructure, the government plays an instrumental role in permitting. Energy infrastructure projects often require approvals from various federal, state and local authorities. Though the government has made efforts to streamline federal licensing for energy infrastructure (including rapid approval of projects such as the Keystone XL oil pipeline), there remain cases of midstream infrastructure struggling to keep pace with shale production growth due to permitting setbacks, local opposition and court challenges. Timely siting of gas pipelines will also benefit efforts to reduce associated gas flaring rates from oil production.

Innovation

The United States is a global leader in energy-related research, development and demonstration (RD&D), and places a high value on innovation in the energy space. Federal government efforts to finance and support energy innovation are largely led by the DOE, including through its 17 national labs, which are considered world-class energy research and development centres. Current focus areas for DOE research include battery storage, small modular nuclear reactors, and carbon capture, utilisation and storage. With the growth in variable renewable electricity generation, greater deployment of electric vehicles, and increased extreme weather events and cyberthreats, research into modernising and strengthening the power grid is also becoming a more important focus area. The United States is also engaged in energy RD&D internationally, including by participating in most of the IEA Technology Collaboration Programmes and as a founding member of the Clean Energy Ministerial. In line with US global leadership in clean energy technology innovation, these and other international collaborations are expected to receive continued support.

Power sector transition

The fuel mix of US power generation is undergoing a considerable transition. Coal power, which produced nearly half of total electricity generation in 2008, has declined in the last decade to less than a third of the power mix in 2018. One of the main drivers for this development has been the shale gas boom, which has made natural gas-fired generators more cost-competitive than coal power plants. Natural gas-fired electricity production increased by over 60% in ten years, and now exceeds coal's share in the power mix. Meanwhile, renewable electricity has seen rapid growth as well, driven by reduced costs and policy support. Nuclear, which has been the most stable power source over the last decade, is challenged by cheap gas power and new renewable sources in some markets, and it struggles to remain cost-competitive.

As the US power mix shifts, and as more variable renewables are introduced into the system, bolstered by state policy goals, the question of smoothly and cost-effectively connecting new generation sources to the grid has already become more salient, and will grow increasingly pressing in the coming years.

Considering that the United States has a complex electricity system with a mix of competitive markets, vertically integrated markets, and private and publicly owned assets, regulatory responses to ensure a smooth transition of the power sector will vary across US regions. In particular, grid operators are increasingly integrating flexibility resources such as storage, demand response, transmission planning and capacity markets into market designs to safely accommodate larger shares of variable renewable sources such as wind and solar into the electricity system.

At the same time that renewable power is expanding, the other major source of low-carbon electricity – nuclear power – is facing growing economic pressure, prompting several plants to prematurely shut down. Looking ahead, the value of nuclear power as a stable, low-carbon generation source for overall power system resilience should be considered more closely.

Policy co-ordination

Under the US federal system of government, individual states also have considerable scope to establish energy and climate change policy, though they are required to be in compliance with federal policies.

Twenty-two US states plus the District of Columbia have adopted greenhouse gas reduction targets (though not all have been legislated), with policy tools ranging from carbon pricing to efficiency mandates and support for clean energy. Nine Northeastern states participate in the Regional Greenhouse Gas Initiative cap-and-trade programme, while California runs a separate cap-and-trade programme for CO_2 emissions. The disparities among state targets can lead to diverging regional outcomes for emissions reduction, and they can have implications for electricity markets that span several states.

A number of US states have in place renewable portfolio standards (RPS), which require retail electricity providers to source a certain share of supply from qualified renewable sources. While emissions reduction goals are a driver of state RPS policies, they are also enacted to harness local energy resources, diversify the fuel mix and support local economic activity. Twenty-nine states plus the District of Columbia currently have mandatory RPS policies in place, and they have been an important driver of renewables expansion in the United States. In addition to renewables targets, states are considering support to nuclear power in the form of zero emissions credits, which have passed in states such as New York and Illinois.

Energy security

Globally, the United States has been a cornerstone of energy security through its participation in the IEA as a founding member. The United States has participated in global oil stock releases through reserves held in the Strategic Petroleum Reserve (SPR), which is the world's largest stock of emergency crude oil. US oil stockholdings are well in excess of its obligation to hold 90 days of net oil imports, though the government in recent years has authorised sales from the SPR over the coming decade. After the authorised sales, the SPR will still be well above the IEA's 90-day obligation. As the United States quickly becomes a net exporter of petroleum liquids by the early 2020s, however, its IEA stockholding obligation will rapidly decline towards zero. Should the United States further draw down its SPR levels, there could be a challenge to the future effectiveness of the IEA stock system, particularly in the case of a large collective action, if the US no longer holds a substantial level of SPR.

For natural gas, the US president is authorised to declare and respond to a natural gas supply emergency. Provisions include authorities for emergency purchases and emergency allocations to protect high-priority users of natural gas. The shale revolution has significantly changed the role of natural gas in the country's energy mix, especially increasing its share in electricity generation. In this context, co-ordination between the electricity and the natural gas systems takes on special importance when dealing with gas supply disruptions, but also electricity blackouts.

The United States has for many years maintained a robust system that assesses and manages grid reliability to avoid power shortages. Yet in the face of rising extreme weather events, new cybersecurity threats, a growing share of variable generation, and retirement of older coal and nuclear plants (due in part to lower wholesale natural gas power prices), the United States has recently entered into a renewed debate on power sector reliability and resilience.

Energy systems resilience

The United States continues to strengthen its preparedness and response mechanisms to threats, such as natural disasters, extreme weather, climate change, cyberattacks and accidents, in a move to reduce risks and bolster resilience as a matter of national security.

While emergency response mechanisms are strong in the United States, preparedness is becoming even more important. Energy resilience does not just address the ability to withstand and recover from disruptions, but also emphasises prevention of and preparation for a potential crisis, flexible adaptation, and efficient recovery. The regular assessment of vulnerabilities is vital in this context and needs to encompass the entire energy sector, notably oil, gas and electricity.

Since the last IEA review, the US government has adopted a suite of policies and mechanisms that have reinforced preparedness. The energy sector is one of the 16 sectors classified for critical infrastructure security and resilience. Interagency co-ordination was strengthened under the 2015 Fixing America's Surface Transportation Act and by the National Response Framework under the Federal Emergency Management Agency and the Department of Homeland Security. Moreover, the creation of the Office of Cybersecurity, Energy Security, and Emergency Response (CESER) in the DOE in 2018 marked strong progress towards building resilience capabilities. CESER, which acts as the sector-specific agency for energy in emergency situations, is responsible for leading sector co-ordination and enabling sector-specific technical assessments and assistance. Notably, with the creation of CESER, there is an excellent opportunity to strengthen effective collaboration to foster preparedness and response to cybersecurity threats. Furthermore, the Office of Electricity leads the department's efforts – in partnership with industry, academia, national laboratories, and other government agencies – in developing next-generation technologies and tools that will improve the security and resilience of the nation's critical energy infrastructure.

Key recommendations

- Set effective and streamlined regulations to enable the United States to remain a global leader in emissions reduction and clean technologies.

- Foster the system integration of variable renewable energy by pursuing market regulations that leverage geographic diversity of resources, availability of transmission capacity, and flexible resources such as energy storage (including batteries, hydropower, pumped hydro and hydrogen) and demand response.
- Evaluate the allocation of decision-making authority for the permitting and siting of natural gas pipeline projects in order to identify possible ways to shorten lead times and reduce uncertainty for investors.
- Provide adequate support to international collaboration efforts of US national laboratories and DOE RD&D programmes to maintain global leadership on energy technology innovation.
- Conduct regular and comprehensive assessments of risks and vulnerabilities to foster preparedness, and maintain reliability and resilience in the face of new challenges.

2. General energy policy

Key data

(2018 provisional)

TPES: 2 228.3 Mtoe (oil 36.2%, natural gas 31.7%, coal 14.2%, nuclear 9.8%, bioenergy and waste 4.8%, hydro 1.1%, wind 1.1%, solar 0.5%, geothermal 0.5%, electricity 0.2%), -2.1% since 2008

TPES per capita: 6.8 toe per capita (IEA average: 4.2 toe)

TPES per unit of GDP: 125 toe per USD million PPP (IEA average: 105 toe)

Energy production: 2 176.6 Mtoe (natural gas 32.9%, oil 31.8%, coal 16.9%. nuclear 10.1%, bioenergy and waste 5.1%, hydro 1.2%, wind 1.1%, geothermal 0.5%, solar 0.5%), +27.9% since 2008

Note: All figures in Chapter 2, "General Energy Policy" are IEA annual data in a unified energy unit (Mtoe) based on country data submissions. Oil and gas chapters include volumetric units (barrels and cubic metres) based on country submissions of monthly data, and may differ from annual figures due to timing, availability and coverage.

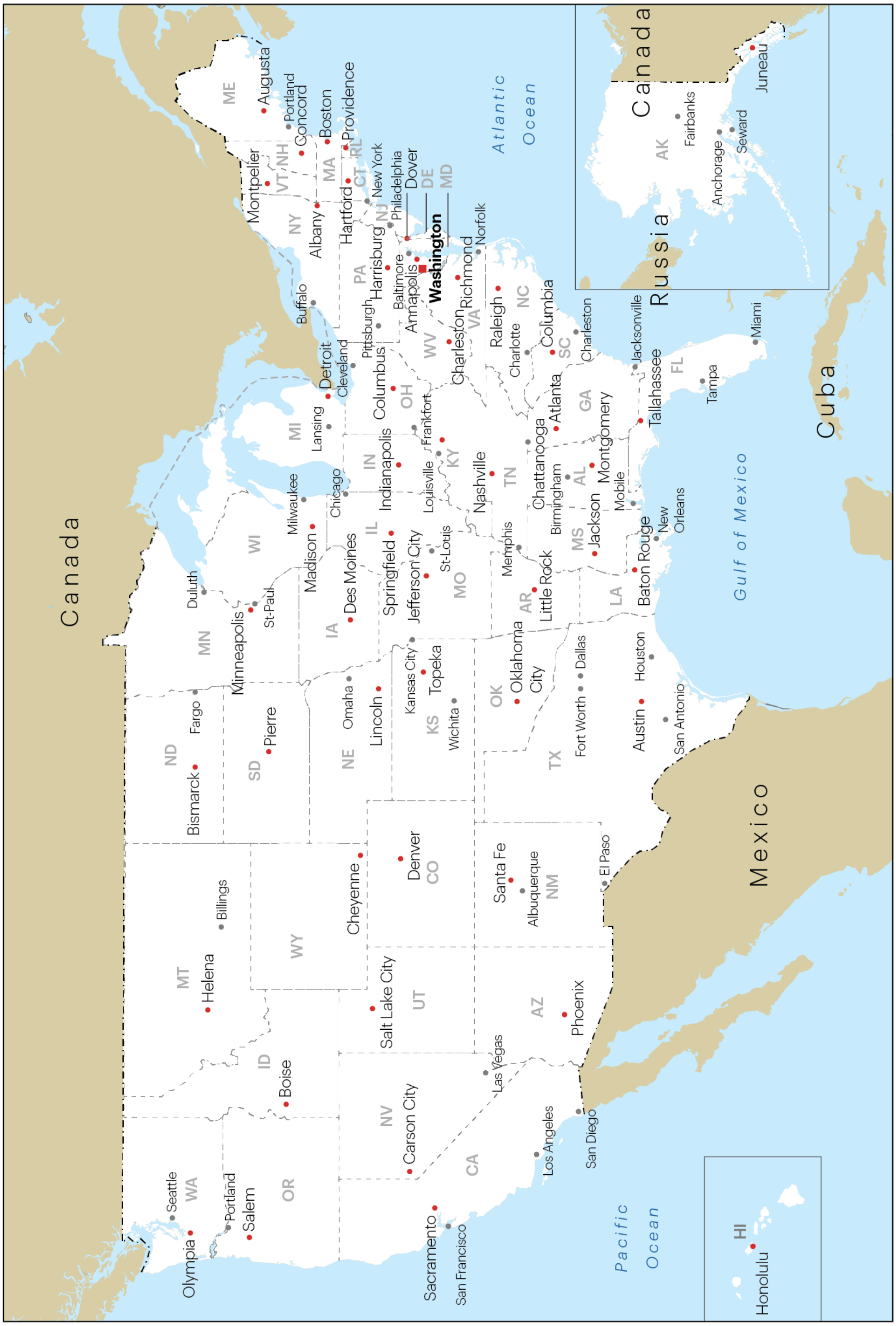
Country overview

The United States (US) is the world's largest economy based on nominal GDP value. It is also the third-largest country by geographic footprint, and the third largest in terms of population. The United States covers a total area of 9 833 517 square kilometres (including land and water) and has a diverse landscape that ranges from beaches to mountains, plains, forests and deserts (CIA, 2019). As such, the United States has highly varied climates across the nation. The country is situated in the middle of the North American continent, sharing a border with Canada to the north and Mexico to the south. Its west coast faces the Pacific Ocean, while the east coast borders the Atlantic Ocean.

The United States comprises 50 states plus the District of Columbia, a federal district that serves as the nation's capital. While 48 of these states are contiguous and situated between Canada and Mexico, Alaska is located to the northwest of Canada, and Hawaii is a group of islands in the Pacific Ocean. The United States also has five major territories, which are self-governing entities that fall under federal government control.

The United States is among the most populous countries in the world. As of February 2019, the US Census estimated the country's total population to be 328 498 078 (United States Cesus Bureau, 2019). The most populous states are (in order) California, Texas, Florida and New York, while the most populous cities are New York, Los Angeles and Chicago. Notably, despite an ageing population, the United States continues to post steady population growth, with immigration being a key driver of growth. In 2014, the Organisation for Economic Co-operation and Development (OECD) estimated a population growth rate of 0.75%.

Figure 2.1 Map of the United States



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

According to the OECD, US nominal gross domestic product (GDP) in 2016 stood at USD 18.7 trillion, the highest among OECD countries (OECD, 2019). The OECD expects real GDP growth of 2.7% in 2019 and 2.1% in 2020, relative to 2.9% in 2018. The economy, in particular business investment, will continue to benefit from tax cuts passed at the end of 2017. Consumption growth remains healthy, and unemployment is relatively low, compared with other OECD countries at 4% in January 2019 (Bureau of Labor Statistics, 2019). Still, the global economic outlook and recent trade measures can present near-term headwinds to growth. The Federal Reserve is continuing down a path of gradual monetary tightening as inflation approaches its 2% target (Board of Governors of the Federal Reserve System, 2018).

The system of government and laws of the United States are defined by the US Constitution. The Constitution establishes a federal system of government, which divides power between the federal government and the states. As such, states have a considerable degree of authority to set policy and regulation, including in the energy sector. The United States also has a republic system of government, under which representatives and a president are elected by the people.

As laid out in the Constitution, the federal government consists of three branches: executive, legislative and judicial. The Constitution calls for a separation of powers between each branch of government, in order to provide checks and balances on governance.

The president, who serves as the head of the executive branch, is elected to a four-year term. An individual is limited to serving two elected terms or ten years as president (because presidents are allowed to serve two years at most of another president's term). The executive branch also consists of a vice president, a Cabinet, and numerous executive departments, councils and agencies that help the executive branch carry out its mission to implement the laws of the country.

The legislative branch consists of two houses of Congress: the House of Representatives and the Senate. Members are elected to the House of Representatives on two-year terms without term limits. Each state is assigned representatives based on its population, divided among electoral districts. In contrast, senators are elected to six-year terms without limits; each state has two senators. There are currently 435 members of the House and 100 senators. Under the US Constitution, Congress has sole authority to pass laws. Legislation can be introduced in either the House or the Senate, but must pass both chambers (in the same form) and be signed by the president in order to become a law. The president has the power to veto legislation, though a presidential veto can be overturned by a two-thirds majority vote in both chambers of Congress.

Lastly, the judicial branch is tasked with upholding the tenets of the US Constitution. The branch is composed of the Supreme Court as well as numerous lower courts. The nine justices who serve on the Supreme Court (for lifetime terms) are appointed by the president and approved by the Senate. Laws and regulations passed or implemented by other branches of government can be appealed in the courts, which have ultimate authority to rule on their constitutionality.

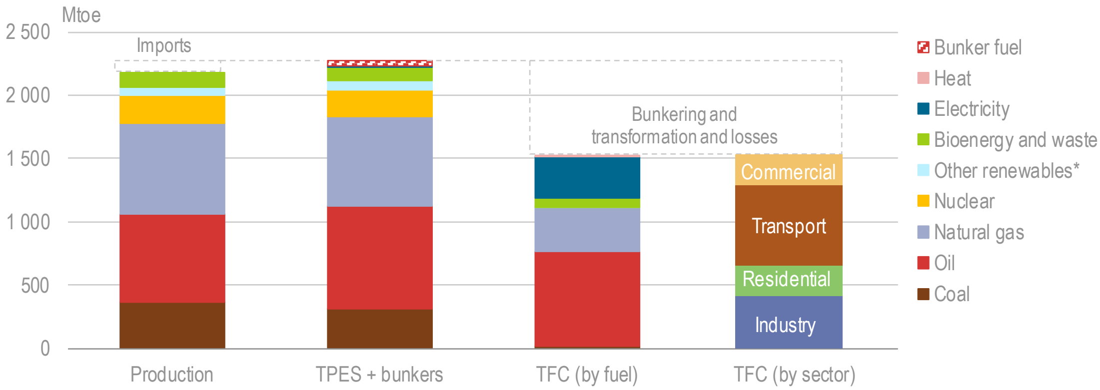
Supply and demand of energy

The United States is one of the largest energy producers in the world. The shale revolution, led by technological breakthroughs in hydraulic fracturing and horizontal drilling, has resulted in an unprecedented increase in production, and made the country the world's largest producer of oil and gas. In 2017, the United States accounted for 13% of total world production of crude oil and 20% of natural gas.

Thanks to this growth in oil and gas production, the United States is becoming more self-sufficient in energy. In 2017, domestic energy production accounted for 98% of total primary energy supply (TPES[1]) (Figure 2.2). As oil and gas production is projected to increase further, the United States is likely to become a net exporter of energy by 2020 (IEA, 2018).

The US energy sector is heavily dominated by fossil fuels. Oil is the largest energy source, accounting for over a third of TPES and nearly half of total final consumption (TFC[2]). Around 70% of total oil supply is used in transport, which is also the largest energy-consuming sector. Natural gas is the second-largest energy source with 32% of TPES in 2018 and 23% of TFC in 2017.

Figure 2.2 Overview of the US energy system by fuel and sector, 2018



The United States has large domestic energy production and is largely self-sufficient in terms of total oil, gas and coal consumption.

**Other renewables* includes wind, geothermal, hydro and solar energy.

Notes: Mtoe = million tonnes of oil equivalent. Production and TPES data are provisional. TFC data are for 2017.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Coal is still the third-largest fuel in TPES, but demand is rapidly declining. The growth in natural gas production from shale has resulted in falling gas prices, which has made natural gas a more competitive fuel in industry and power generation. Combined with strong growth in wind and solar power, this has led to a significant drop in coal power. Coal power has gone from supplying half of total electricity generation to supplying less than a third in just a decade. Meanwhile, nuclear energy has remained relatively stable at 10% of TPES, the fourth-largest energy source in the country.

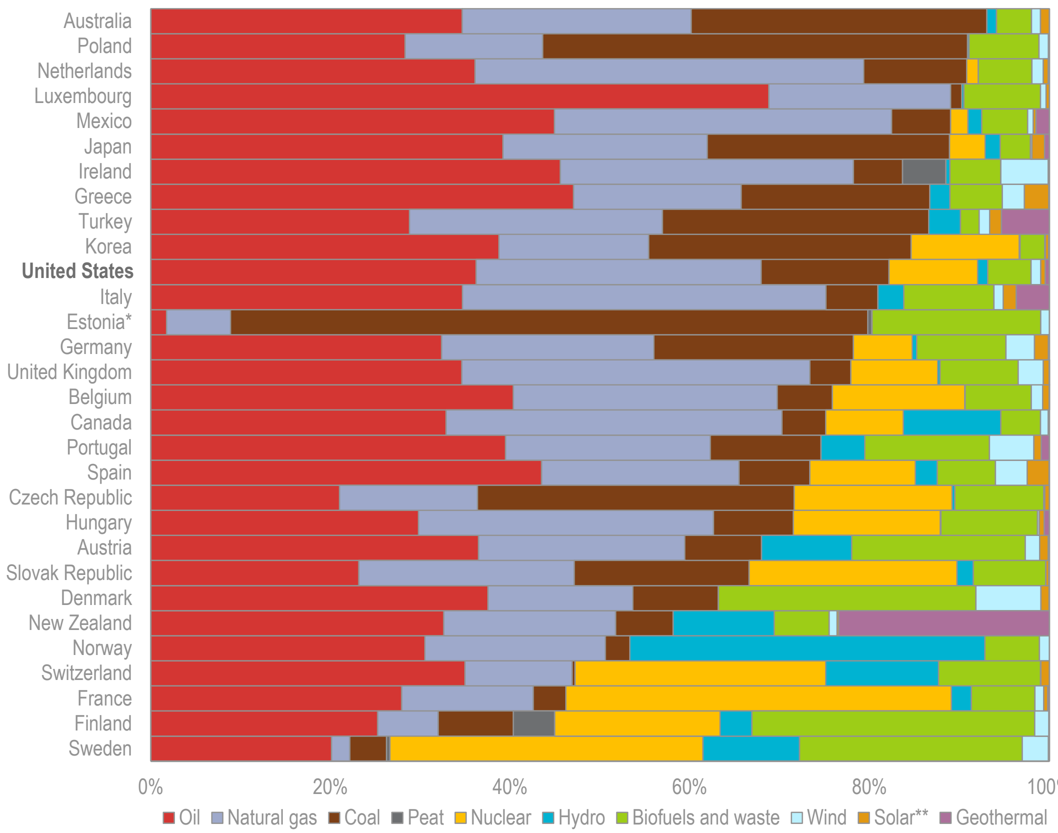
[1] TPES is made up of: production + imports – exports – international marine and aviation bunkers ± stock changes. This equals the total supply of energy that is consumed domestically, either in transformation (e.g. power generation and refining) or in final use. Nuclear energy supply in TPES includes losses. The primary energy equivalent of nuclear electricity is calculated from the gross electricity generation by assuming 33% conversion efficiency.

[2] TFC is the final consumption of energy (electricity, heat and fuels, such as natural gas and oil products) by end users, not including the transformation sector (e.g. power generation and refining).

Primary energy supply

Despite a strong increase in new renewable power generation in the last decade, the United States is still highly dependent on fossil fuels to cover its primary energy demand. In 2018, fossil fuels accounted for 82% of TPES in the country, the eleventh-highest share among International Energy Agency (IEA) member countries (Figure 2.3).

Figure 2.3 Breakdown of TPES in IEA member countries, 2018



Fossil fuels account for 82% of TPES in the United States, the eleventh-highest share among IEA member countries.

*Estonia's coal is represented by oil shale.

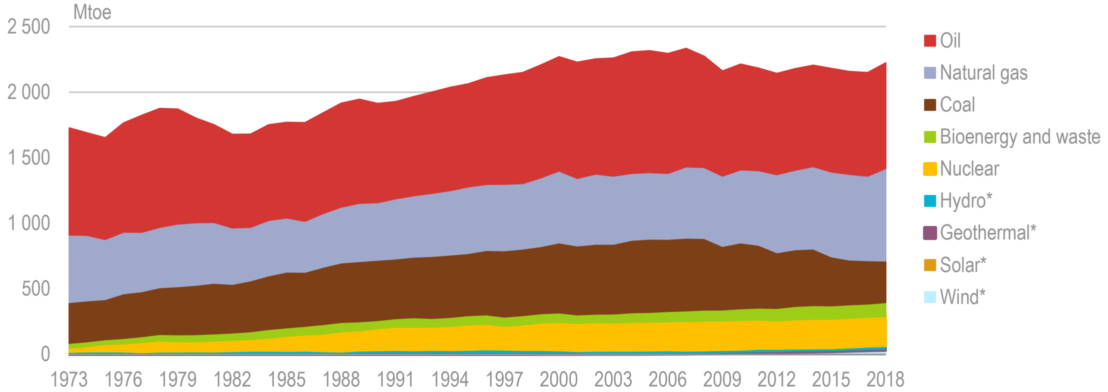
**Includes photovoltaics and solar thermal, plus small shares of wave and ocean power and other power generation.

Note: Data are provisional.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Nevertheless, US energy supply is under transformation. TPES increased steadily until it peaked in 2007 at 2 337 Mtoe. In the decade that followed, TPES declined by 8% to 2 155 Mtoe in 2017 (Figure 2.4). In 2018, it increased again to 2 228 Mtoe. The switch from coal to gas in power generation prompted coal production to decline by 36% in a decade (from 2008 to 2018) while natural gas production increased by 52%. Renewable energy sources have also increased significantly in recent years, although starting from low levels. In 2018, renewable energy accounted for 8% of TPES. Bioenergy and waste, including transport biofuels, is the largest renewable energy source in TPES, followed by hydro, wind, solar and geothermal.

Figure 2.4 TPES by source, 1973-2018



Since a peak in 2007, TPES has declined by 5%. In the same period, coal has been replaced in power generation by the more efficient power sources of natural gas and renewables.

*Not visible on this scale.

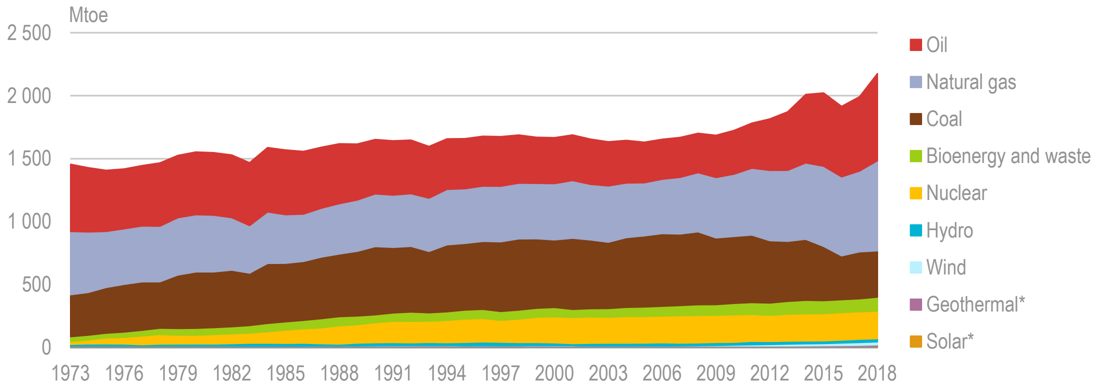
Note: Data for 2018 are provisional.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Energy production and self-sufficiency

The shale revolution has enabled previously stagnating oil and gas production to boom in the last decade. Between 2007 and 2017, US production of crude oil increased by 121% and natural gas production grew by 52%. As a result, total energy production grew by 28% (Figure 2.5).

Figure 2.5 Energy production by source, 1973-2018



Owing to the shale revolution, oil and gas production is increasing rapidly and replacing domestic coal in power generation.

*Not visible on this scale.

Note: Data for 2018 are provisional.

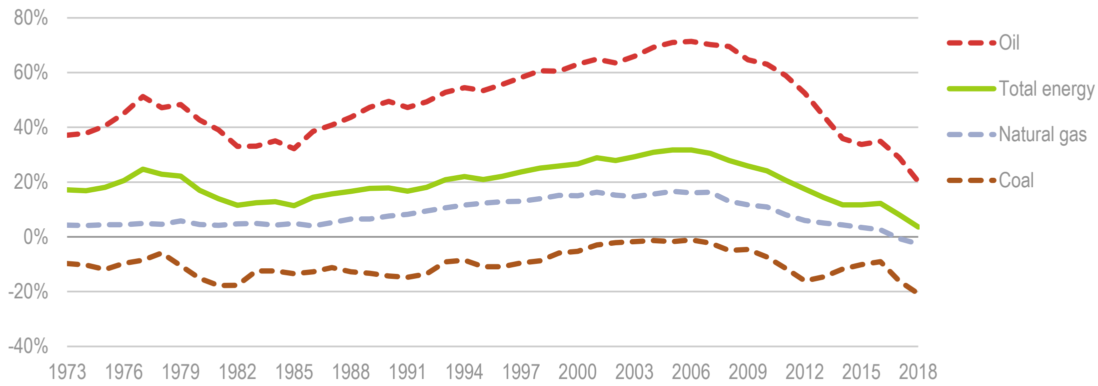
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

As gas and renewable energy sources replace coal in power generation, domestic coal production has started to decline in recent years. Coal production peaked in 2008 at 579 Mtoe, and has since fallen by over a third to 368 Mtoe in 2018, despite a small increase from 2016. These are the lowest levels of US coal production since the 1970s.

Besides fossil fuels, the United States also has stable production of nuclear power, which accounted for 10% of total domestic energy production in 2018, and an increasing share of renewables. Total renewable energy production reached a record high in 2018 and covered 8% of total domestic energy production, thanks to high availability for hydro (1.2%) and the recent growth in wind (1.1%) and solar (0.5%).

The United States is also the world's largest consumer of oil and gas, but demand has not increased with production. Instead, growth in domestic production has made the United States much less dependent on energy imports. In particular, oil import dependency (measured as the share of net imports in TPES) dropped from over 60% to below 20% in the last decade (Figure 2.6). The country is on a trajectory to become a total net exporter of oil by 2020.

Figure 2.6 Import dependencies for different energy sources in TPES, 1973-2018



The rapid increase in domestic oil and gas production has made the United States significantly less dependent on energy imports.

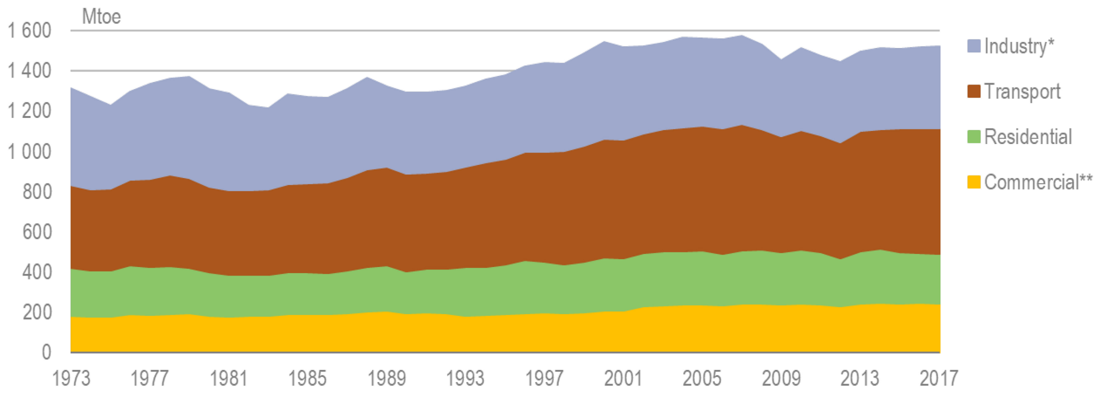
Notes: Energy net imports as share of TPES. Data for 2018 are provisional.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Energy consumption

Energy consumption has been more stable than TPES and energy production, but with some fluctuations in recent years. TFC peaked in 2007 at 1 576 Mtoe, after which it fell during the years following the financial crisis, but picked up again in 2013. Since 2014, TFC has been rather stable at around 1 500 Mtoe (Figure 2.7).

The transport sector is the largest consumer of energy, representing 41% of TFC in 2017 (Figure 2.8). Most of this is oil products (mainly gasoline and diesel), although the country has a relatively high share of biofuels in transport (mainly ethanol, driven by the Renewable Fuel Standard (RFS) policy, as discussed in Chapter 5, "Renewable Energy"). The residential and commercial sectors together accounted for 32% of TFC, mostly consuming electricity for appliances and natural gas for heating. The industry sector consumed the remaining 27%, including fuels used for non-energy purposes.

Figure 2.7 TFC by sector, 1973-2017



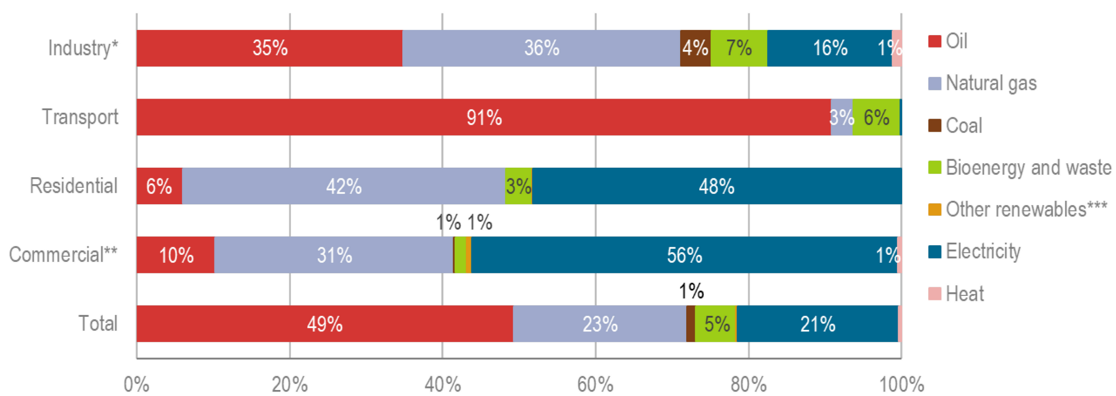
Final energy consumption is relatively stable around 1 500 Mtoe, with the transport sector accounting for over 40% of total consumption.

**Industry* includes non-energy consumption.

***Commercial* includes commercial and public services, agriculture, and forestry.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Figure 2.8 TFC by source and sector, 2017



Oil accounts for nearly half of TFC in the United States, dominating the large transport sector, while electricity and natural gas account for the largest supply to buildings.

**Industry* includes non-energy consumption.

***Commercial* includes commercial and public services, agriculture, and forestry.

****Other renewables* includes mainly geothermal and solar energy.

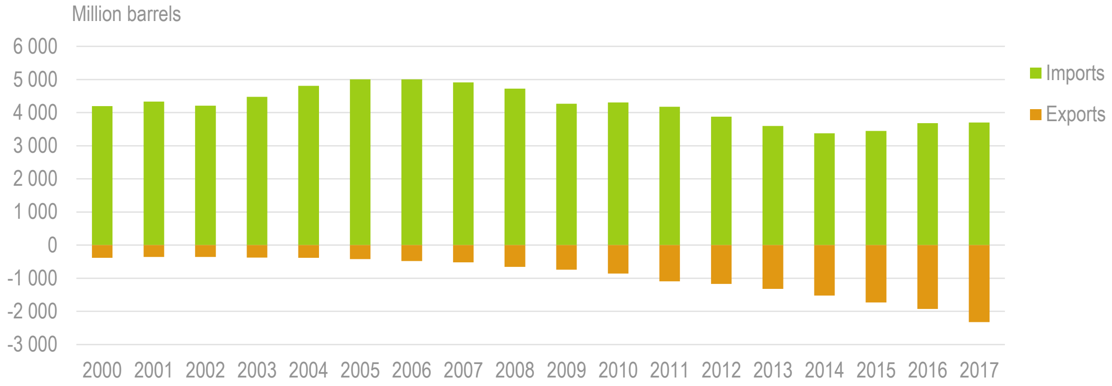
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Energy trade

In line with rising oil and gas production domestically, the US energy trade balance has shifted dramatically over the past decade. Compared to the period 2003-07, when the value of energy imports was ten times that of exports, by 2017, the value of imports was just 1.5 times greater than exports, according to the US Census Bureau.

The top energy import for the United States is crude oil, which makes up around two-thirds of the value of energy imports, followed by petroleum products, which account for roughly 20% of total energy imports by value.

Figure 2.9 US trade in crude oil and petroleum products, 2000-17



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Growth in domestic production has reduced the US call on oil and petroleum product imports and increased export volumes.

Source: EIA (2018a), *The Changing U.S. Energy Trade Balance is Still Dominated by Crude Oil Imports*.

Notably, the United States is expected to turn from a net energy importer to a net exporter by 2020 as production growth of crude oil, natural gas and natural gas liquids exceeds consumption (EIA, 2019a). The last time the United States was a net energy exporter was 1953. The shift is due to the projected change in US status as a net petroleum products exporter starting in 2020. The United States has been a net exporter of natural gas since 2017.

The US energy structure should be considered in the context of the North American energy system, given a high degree of connectivity and cross-border trade and investment flows with Canada and Mexico. In 2017, Canada was the largest foreign supplier of crude oil to the United States, while Mexico was the fourth largest. Meanwhile, both countries are heavily reliant on petroleum product imports from the United States. Overall, US energy trade within North America in 2017 amounted to USD 126 billion, of which USD 83 billion was spent on US energy imports and USD 43 billion on US energy exports. A considerable amount of cross-border infrastructure, including pipelines and transmission lines, support this trade, while a sizeable share is also transported by barge.

Table 2.1 Value of US trade in crude oil, petroleum products, natural gas and electricity with Canada and Mexico (USD in millions), 2017

	Import		Export	
	Canada	Mexico	Canada	Mexico
Crude oil	50 122	9 780	6 137	-
Petroleum products	9 952	1 244	8 476	20 666
Electricity	2 375	-	184	-
Natural gas	9 336	34	2 789	4 533

Note: Electricity trade between Mexico and the United States is relatively small, and US Census data do not include the values of these imports and exports, according to a US Census official.
Source: US Government Accountability Office (2018), *North American Energy Integration: Information about Cooperation with Canada and Mexico and among U.S. Agencies*, www.gao.gov/assets/700/693644.pdf

Institutions

At the national level, all three branches of government play a role in developing and implementing energy policy (USAGov, 2019).

Congress has sole authority to pass federal legislation, including on energy, which usually directs federal agencies to implement it. Any senator or representative can sponsor a bill, after which it is considered in relevant committees. A number of Congressional committees have authority over developing energy policy, though energy policy usually originates from the Senate Committee on Energy and Natural Resources in the upper chamber and the House Committee on Energy and Commerce in the lower chamber. Following a successful committee vote, the entire chamber still needs to vote on a bill before it can advance.

Within the executive branch, a number of federal agencies, commissions and advisory offices to the president are involved in developing, co-ordinating and implementing energy policy. Among White House Executive Offices, nearly all have input into charting an administration's course on energy and climate change, including:

The **Council of Economic Advisers** provides the president with objective advice on domestic and international economic policies, including on matters related to energy (White House, 2019a).

The **Council on Environmental Quality (CEQ)** was created under the National Environmental Policy Act in 1970 to incorporate environmental considerations into the operations and mandates of federal agencies (White House, 2019b).

The **National Security Council** consists of a group of advisers whom the president consults on national security issues, which can include energy and climate change matters (White House, 2019c).

The **Office of Management and Budget (OMB)** directs the budgetary activities for federal agencies and advises the president on financial aspects of policy and administrative functions, including for energy policy and regulation (White House, 2019d).

The **Office of Science and Technology Policy (OSTP)** was established by Congress in 1976 to advise the president on scientific and technological issues as they relate to the economy, national security, health, foreign relations and the environment. The OSTP supports the OMB's annual review of federal research and development (R&D) budgets and provides scientific and technological analysis to the president on major policies and plans (White House, 2019e).

Among federal departments, the **Department of Energy (DOE)** has the broadest influence on energy policy, though other agencies and departments play equally significant roles in various areas of the energy landscape (DOE, 2019a).

The DOE oversees the country's nuclear energy capabilities, nuclear non-proliferation activities, strategic reserves of oil, and clean energy R&D initiatives. The DOE also has oversight over the country's national labs. Within the DOE, a number of offices have responsibility over various energy programmes under the department's purview, including:

- Advanced Research Projects Agency – Energy promotes early-stage energy technologies that are too nascent to attract private investment, but are considered to have strong potential to shake up the way energy is produced, stored and consumed.
- The Loan Programs Office oversees over USD 40 billion in loans and loan guarantees to support large-scale energy infrastructure projects within the United States.
- The Office of Cybersecurity, Energy Security, and Emergency Response (CESER) was established in 2018. As the Sector-Specific Agency for the energy sector, DOE is charged with securing the nation's energy infrastructure against all threats and hazards, both man-made and natural, including cyber. CESER works closely with other federal agencies and private-sector partners to prepare for, respond to and recover from all hazards and threats, including events of a cyber nature, to the US energy system.
- The Office of Energy Efficiency and Renewable Energy (EERE) is tasked with supporting US leadership in the area of renewable energy through an R&D portfolio. The DOE estimates that taxpayer-funded investments of USD 12 billion have already resulted in over USD 230 billion in net benefits to the US economy. Technological areas of focus include sustainable transportation technologies, renewable power, energy efficiency, renewable energy manufacturing, grid integration of renewable energy sources and federal agency sustainability initiatives. The current work of EERE is directed by its 2016-2020 Strategic Plan and Implementing Framework.
- The Office of Environmental Management specifically focuses on environmental cleanup from nuclear weapons production and the government's nuclear energy research, including management of radioactive waste and spent nuclear fuel.
- The DOE's Office of Fossil Energy (FE) oversees all federal research, development and demonstration related to fossil fuel production and consumption. Areas of focus include advanced power generation; power plant efficiency; water management; carbon capture, utilisation and storage (CCUS); and unconventional oil and gas production. FE has a regulatory role over the imports and exports of natural gas, including liquefied natural gas (LNG), from the United States, via delegated authority under the Natural Gas Act. The office also oversees the country's emergency response tools in the event of a disruption to energy supplies, specifically the Strategic Petroleum Reserve (SPR) and the Northeast Home Heating Oil Reserve.
- The Office of Indian Energy Policy and Programs funds and implements programmes that help American Indian tribes and Alaska Native villages with energy development and access.

- The Office of Legacy Management was established in 2003 to manage the environmental legacy of World War II and the Cold War, including by cleaning up radioactive, chemical and hazardous materials from over 100 sites across the United States.
- The Office of Nuclear Energy (NE) advances nuclear power to boost the country's energy, environmental and national security goals. NE is guided by three research objectives:
  - enhancing the long-term viability and competitiveness of the existing US nuclear fleet
  - developing an advanced reactor pipeline
  - implementing and maintaining national nuclear strategic fuel cycle and supply chain infrastructure.
- The DOE's Office of Science is tasked with leading federal government efforts to support scientific research on energy. In this capacity, the Office of Science has authority over the operations of all the country's national labs. But the office's reach expands well beyond national labs to support research at the state level as well as in private universities and research institutions. The research capabilities include direct support to scientific research as well as direct support of the development, construction and operation of scientific facilities.
- The Federal Energy Regulatory Commission (FERC) is an independent commission under the DOE that is responsible for ensuring safe, reliable and secure energy supply to consumers (FERC, 2019a). In this regard, FERC regulates the interstate transmission of electricity, natural gas and oil. FERC is also tasked with regulating the operation of wholesale electricity markets. The commission is responsible for approving interstate natural gas pipelines as well as hydro projects and LNG export terminals (FERC, 2019b).
- The United States, under the authority of the DOE, also administers four federal Power Marketing Administrations (PMAs), which operate and sell power from federally owned hydropower facilities in 34 states. The four PMAs are Bonneville Power Administration, Western Area Power Administration, Southeastern Power Administration and Southwestern Power Administration.

Other executive departments and agencies that are crucial to implementing energy policy are:

The **Environmental Protection Agency (EPA)** was established in 1970 and is tasked with protecting human health and the environment, as directed by Congressional legislation (EPA, 2019a). The agency plays a central role in developing environmental regulations across all sectors. The EPA establishes regulations through "notice and comment" rule making under which it first issues draft proposals, receives public comment and then issues final rules. Repealing or revising existing regulations must also undergo a similar procedure.

The **Department of Transportation** has broad oversight over the transportation sector, including implementing fuel efficiency standards for automobiles through the National Highway and Transportation Safety Administration (U.S. Department of Transportation, 2019). The Pipeline and Hazardous Materials Safety Administration creates and implements safety and environmental standards for energy pipelines.

The **Department of the Interior** regulates all energy development on federal lands, including oil and gas, coal, and renewables (U.S. Department of the Interior, 2019). In this capacity, the Interior Department holds federal auctions for offshore energy leases in the Outer Continental Shelf (except for areas defined as falling under state jurisdiction) as well as on onshore federal lands. Environmental oversight over energy development on federal lands also falls under the Interior Department's jurisdiction. The Interior Department's Bureau of Land Management (BLM) overseas all leasing and regulation for onshore federal lands (BLM, 2019). Following the 2010 Deepwater Horizon oil spill, offshore regulation was split between two agencies: the Bureau of Ocean Energy Management and the Bureau of Safety and Environmental Enforcement. The Bureau of Ocean Energy Management overseas offshore oil, gas and wind leases in the Outer Continental Shelf, while the Bureau of Safety and Environmental Enforcement develops and enforces environmental and safety regulations for offshore drilling (Bureau of Ocean Energy Management, 2018; Bureau of Safety and Environmental Enforcement, 2019).

The **Nuclear Regulatory Commission** is an independent government agency that regulates civil nuclear power plants and nuclear materials, including licensing, inspection and enforcement of safety regulations.

The **US Army Corps of Engineers** is a federal agency under the Department of Defense that has regulatory oversight over energy infrastructure that is sited in the country's navigable waters.

The **Department of State** conducts international relations for the federal government, including representing the United States in international energy forums such as the IEA and United Nations Framework Convention on Climate Change (UNFCCC) (U.S. Department of State, 2019). The State Department's Bureau of Energy Resources is tasked with overseeing international energy policy initiatives with objectives to:

- Ensure economic and energy security for the United States and its allies and partners.
- Remove barriers to energy development and trade.
- Promote best practices regarding transparency and good governance.

The **Department of Homeland Security** is charged with protecting the nation's critical infrastructure, including hydroelectric dams and the civil nuclear energy fleet.

The judicial branch also plays an important role in energy policy. Given that the judicial branch is tasked with interpreting the US Constitution, the courts review energy policies and regulations within the context of specific legal cases or suits to ensure they are compliant with the country's laws. In recent years, a number of environmental regulations, in particular, have been challenged in the courts.

The federal structure of government in the United States affords states and local governments considerable scope in enacting energy policy as well. In particular, states have a large degree of oversight over energy development and transit within their territories (except for federal lands), though still need to comply with federal environmental standards. The federal government also has sole regulatory oversight over hydro and nuclear power projects. Power plants require regulatory approvals from the respective state in which they are situated, while oil pipelines require regulatory approval from each state they traverse. In contrast, interstate gas pipelines are regulated by FERC, though in many cases still require state environmental and water permits. States also have broad leeway to set mandates in areas such as greenhouse gas (GHG) reduction, efficiency and renewables.

“Energy dominance” strategy

The shale oil and gas boom has transformed the US approach to energy policy making. The shale revolution has made the United States not only a major producer of oil and gas, but also a major exporter. As a result, the US approach to energy policy making has shifted from a scarcity mindset that emphasised energy security to one that is attempting to maximise the benefits of energy abundance.

Under the current administration, US government policy is centred on the concept of “energy dominance”, which reflects a strategy to maximise energy production, play a larger role in energy exports and be a global leader in energy technologies (White House, 2017a).

The government’s National Security Strategy (NSS), released in December 2017, outlines the role that energy dominance will play in US national security plans, as part of the Promote American Prosperity pillar (White House, 2017b). Specifically, the NSS describes five goals related to energy dominance, which are:

- Reduce barriers to promote clean and safe energy development.
- Promote exports to help allies and partners diversify their energy sources.
- Ensure energy security, including by protecting global energy infrastructure from physical and cyberattacks.
- Attain universal energy access, including from highly efficient fossil fuels, nuclear and renewables to reduce poverty and promote economic growth and prosperity.
- Further America’s technological edge, including in areas of nuclear, batteries and carbon capture.

A central implementing plank of the “energy dominance” strategy is to eliminate regulatory hurdles to expanding US energy production and boosting the competitiveness of the US energy industry. To this end, the administration has undertaken a strategy to revisit or rescind a number of environmental regulations applicable to broad segments of the energy sector, including the power, transport and upstream sectors. Specifically, under Executive Order 13783 from March 2017, the White House directed the EPA to review all existing rules, a process the agency is still undertaking.

Beyond environmental deregulation, the energy dominance strategy also involves opening up more public acreage to energy production and lowering royalty rates.

Among the early steps that the administration highlights as part of its efforts to promote energy dominance are:

- Withdrawing the United States from the Paris Agreement.
- Directing the EPA to rescind the Clean Power Plan to cut carbon dioxide (CO_2) emissions from the power sector.
- Accelerating federal approval of the Keystone XL oil pipeline.
- Ending a moratorium on new coal leases on federal lands.
- Rescinding the Stream Protection Rule that restricted coal companies from placing debris from mountaintop coal mining into streams.
- Directing the Department of the Interior to reconsider regulations for hydraulic fracturing on federal lands.

The energy dominance agenda also includes a focus on expanding US energy exports. Since the last IEA in-depth review, Congress lifted a ban on crude oil exports at the end of 2015. Moreover, the DOE streamlined the government's approach to LNG export approvals in 2014, helping to support the United States' becoming a major global supplier of LNG and a net exporter of natural gas. The administration is also supportive of coal exports, though coal export infrastructure is limited, especially from the West Coast.

In a similar vein, the United States remains committed to an integrated approach to the North American energy system, ensuring the smooth flow of energy trade and investment across borders (DOE, 2019b). The NSS reaffirms this tenet of North American energy integration. The DOE's Office of International Affairs oversees energy co-operation among the United States, Mexico and Canada, on both a bilateral and trilateral basis. The DOE collaborates with Mexico's Secretariat of Energy and Natural Resources Canada in this regard. Areas of co-operation include energy data sharing, unconventional oil and gas development, CCUS, electricity grid reliability and resilience, and a North American Renewable Integration Study.

Globally, the United States has been a cornerstone of energy security through its participation in the IEA as a founding member. The Energy Policy and Conservation Act of 1975 allowed US participation in the International Energy Program. The United States participates in global oil stock releases through reserves held in the SPR, managed by the DOE. US oil stockholdings are well in excess of its obligation to hold 90 days of net oil imports, though the government in recent years has authorised sales from the SPR over the coming decade. After the authorised sales, the SPR will still be well above the IEA's 90-day obligation. As the United States quickly becomes a net exporter of petroleum liquids by the early 2020s, however, its IEA stockholding obligation will rapidly decline towards zero. Should the United States further draw down its SPR levels, there could be a challenge to the future effectiveness of the IEA stock system, particularly in the case of a large collective action, if the United States no longer holds a substantial level in its SPR.

The US administration also embraces an "all of the above" energy strategy – which promotes all forms of energy, including coal, gas, nuclear and renewables – in an effort to ensure reliable and affordable supply to consumers. As outlined in the NSS, the US government is advancing "an approach that balances energy security, economic development, and environmental protection" (White House, 2017b).

In this regard, as the administration looks to longer-term growth of low-emissions energy sources such as nuclear, CCUS and variable renewables, the issue of grid reliability and resilience is becoming more salient, which will require policy consideration.

The United States also places a high value on innovation in the energy space. Federal government efforts to finance and support energy innovation are largely led by the DOE, including through its 17 national labs, which are considered world-class energy research, development and deployment (RD&D) centres (see Chapter 6, "Energy Technology Research, Development and Demonstration"). In fact, DOE-led research helped unlock key advances in the US energy space, including technologies that enabled the shale revolution. Current focus areas for DOE research include small modular reactors and CCUS.

Energy policies

The US energy space is governed by a diverse set of laws that direct regulatory action for various aspects of the energy system. A few of the essential ones are listed below.

Federal Power Act

The Federal Water Power Act of 1920 was initially designed to co-ordinate hydroelectric projects in the United States. The act established the Federal Power Commission (later FERC) to license, co-ordinate and regulate hydro projects. In 1935, the law was renamed the Federal Power Act, and extended jurisdiction to the commission over all interstate activities of the wholesale electricity and natural gas industries. The Federal Power Act has seen many amendments since it was first passed; the most recent major changes to the act were passed by Congress as part of the Energy Policy Act of 2005.

Clean Air Act

The Clean Air Act is the fundamental environmental law governing the United States. Congress passed the law in 1963 and has amended it many times since, in subsequent pieces of legislation. It sets out regulatory requirements to control air emissions from stationary and mobile sources of emissions. One of its core focus areas is authorising the EPA to establish National Ambient Air Quality Standards and regulate hazardous air pollutants (EPA, 2017).

National Environmental Policy Act

Congress passed the National Environmental Policy Act (NEPA) into law in 1970. The law requires federal agencies to assess the environmental impacts of their planned actions before pursuing them, including as they relate to permit applications, federal land management actions, and construction of highways or other publicly owned facilities. More specifically, NEPA requires federal agencies to prepare comprehensive environmental impact statements or environmental assessments. The law directs the CEQ to oversee implementation of NEPA (EPA, 2019b). Globally, NEPA is among the more comprehensive approaches to federal environmental reviews and provides an example to other countries looking to introduce similar assessments into their government decision-making processes.

Natural Gas Act

The Natural Gas Act of 1938 establishes the regulatory framework for the natural gas industry. The main focus of the act was to grant the then-Federal Power Commission (now FERC) authority to permit and regulate interstate gas transmission (Interstate Natural Gas Association of America, 2019). A subsequent amendment defined the regulatory process for gas exports, requiring exporters to obtain a permit from the DOE. As part of its review, the DOE must establish that gas exports are not counter to the national interest, though Congress subsequently determined that gas exports to countries with which the United States has a free trade agreement would automatically be in the national interest (DOE, 2019c).

Energy Policy and Conservation Act

In response to the Arab Oil Embargo in 1973, Congress passed the Energy Policy and Conservation Act as a comprehensive piece of energy legislation. Among other things, the law established the US SPR, directed the DOE to enact energy efficiency and alternative energy programmes, and improved the quality of energy data.

Energy Policy Act of 2005

Under the Energy Policy Act of 2005, Congress repealed the Public Utility Holding Company Act of 1935, thereby overhauling the federal regulatory regime for the electricity sector. In doing so, Congress granted unprecedented regulatory authority to FERC, including a requirement for FERC to set and enforce reliability standards for the entire transmission network. The law also introduced the RFS, which required gasoline sold in the United States to be blended with biofuels, as well as a 30% investment tax credit (ITC) for solar power installations.

Energy Independence and Security Act

The Energy Independence and Security Act was signed into law in December 2007. Among other measures, the law increased Corporate Average Fuel Economy standards, updated the RFS, established new energy efficiency standards for equipment, and repealed some oil and gas tax incentives.

American Recovery and Reinvestment Act

The American Recovery and Reinvestment Act of 2009 substantially increased appropriations for energy programmes, in particular energy efficiency and renewable energy investments. The law included USD 21 billion of energy tax incentives as well as over USD 11 billion in DOE grants to state and local governments.

Energy permitting and regulatory regimes

From an energy production regulatory perspective, companies need to apply to respective states in which they plan to drill for oil and gas or mine for coal, with the exception of federal lands, for which the US Department of the Interior holds lease auctions. The Interior Department also oversees all offshore energy resource development that falls beyond states' purview. The Interior Department additionally imposes safety and environmental regulations on drilling and mining activity on federal lands. Outside of federal lands, this regulatory authority falls mostly to states, though the EPA can also impose environmental standards on production activities. In cases where both federal and state regulations exist, an operator must comply with both (in this regard, the federal requirement serves as a minimum baseline).

Midstream infrastructure requires a different set of regulatory approvals. While private companies decide on whether to develop a new pipeline project or export terminal, the government plays an instrumental role in infrastructure permitting. Not only does the FERC make a determination on market need for interstate gas pipelines, it also leads on environmental reviews for pipeline projects under NEPA. Where FERC does not have jurisdiction, state regulators lead on these functions. Additional state permits, such as

Water Quality Certifications under Section 401 of the Clean Water Act, are often required for energy infrastructure projects.

In an effort to streamline federal licensing for energy infrastructure, Congress in 2015 passed the Fixing America's Surface Transportation (FAST) Act. Title 41 of the FAST Act defined new co-ordination and oversight procedures, including early consultation among government agencies and increased transparency in permitting reviews and timelines.

In recent years, as shale oil and gas production have surged, midstream infrastructure has occasionally failed to keep up with the pace of output growth, resulting in transportation bottlenecks that widen regional price differentials, and can even restrain production. While in many cases, the pipeline bottlenecks stem from lags in private investment relative to unexpectedly high production growth levels, in some instances, regulatory impediments play a role. In particular, local opposition to pipelines on environmental grounds has grown, resulting in a lack of social acceptance in certain states that leads to rejections of state or local permits. The issue has been most pronounced in the Northeast, where takeaway capacity plans out of the Marcellus and Utica shale basins have, on occasion, been turned down; a recent example is when New York in 2016 rejected a permit application for the Constitution pipeline that was to run from Pennsylvania to New York.

Court challenges have also led to delays on pipeline construction. For example, a 2017 court ruling directed FERC to consider the downstream environmental impacts of its decision to approve the south-eastern Sabal Trail gas pipeline based on a lawsuit brought forward by environmental groups. Similarly, a federal court blocked the Keystone XL oil pipeline on the grounds that its federal permit from the State Department did not consider an alternative route that was approved by Nebraska regulators; the decision required a new State Department permit, which was issued in March 2019.

Energy pricing and taxation

The US energy system is largely governed by market-based principles. The prices of fuels are determined by supply and demand, but also incorporate variables such as transportation and taxation. By global standards, US energy taxation levels are relatively low (OECD, 2018).

The most common oil price benchmark in the United States is West Texas Intermediate (WTI), based on a type of light crude produced in the United States. The contracts for WTI are physically settled at the oil trading hub in Cushing, Oklahoma (EIA, 2018b). Henry Hub, which is cleared at a physical distribution hub in Erath, Louisiana, is the most heavily traded gas contract. While US oil prices are strongly influenced by global supply and demand dynamics given import dependency, so far US natural gas prices have tended to be independent of global gas market developments. Most coal used for power generation is sold under long-term contracts, though spot sales of coal also take place (EIA, 2018c). Coal prices vary based on their grade and geographic origin.

As a secondary source of energy, electricity prices comprise several inputs, including fuel costs, power plant operating costs, transmission and distribution, weather, and regulation (EIA, 2018d). Electricity pricing varies by state. While some states fully regulate prices, others have deregulated wholesale prices and regulated retail prices, and still others have fully deregulated pricing.

The main consumption tax levied on energy is the federal gasoline excise tax, first imposed at the rate of USD 0.01 per gallon in 1932. Currently the federal government imposes a tax of USD 0.1840 per gallon on gasoline and USD 0.2440 per gallon on diesel (EIA, 2018e). The tax levels are not adjusted to inflation and have not been changed since 1993, eroding the value of revenues on an inflation-adjusted basis. Proceeds from the tax are directed towards road infrastructure upgrades through the Highway Trust Fund, which was created by Congress in 1956. States are also at liberty to levy gasoline taxes on top of the federal tax. In 2018, the average state tax on gasoline was USD 0.2862 per gallon and the average state tax on diesel was USD 0.3021.

The federal government also raises money from energy produced on federal lands through royalties, lease sales and rental payments. Energy production subject to federal payments includes oil, gas, coal, hydrocarbon gas liquids and renewables. The Interior Department's Office of Natural Resources Revenue manages the revenues collected from energy development on federal lands, collecting an average of over USD 10 billion in revenue annually (Office of Natural Resources Revenue, 2019). The Mineral Leasing Act of 1920 fixed a royalty rate for competitive leases at no less than 12.5% of the amount or value of production. The BLM has set the royalty rate at 12.5% for onshore production. For offshore oil and gas leases, the royalty rate is set at 18.75%, though the administration lowered it to 12.5% for shallow water lease sales in 2018 to help attract investment amid low oil prices. For non-competitive leases, the act established a fixed royalty rate of 12.5%. Coal royalty rates vary depending on the type of mining activity: underground mines face a royalty rate of 8% while surface mines pay a rate of 12.5%. States usually impose royalties and production taxes on top of the federal rates (United States Government Accountability Office, 2017).

In 2017, the Interior Department announced the formation of the Royalty Policy Committee to review royalty rates for energy production on federal lands to ensure taxpayers received the maximum benefit from production (Bureau of Ocean Energy Management, 2017). In February 2018, the committee recommended lowering the royalty rate for offshore oil and gas drilling, and in September 2018 recommended granting companies the option to choose between two methods for calculating royalties – either based on how much they are paid (the traditional approach) or based on the quality and quantity of what they produce.

The US government also offers tax credits and other tax incentives to certain energy sectors to incentivise development or consumption of alternative technologies. For example, consumers can claim tax credits for buying alternative energy vehicles or installing energy-saving equipment in households (DOE, 2019d). Congress has granted the renewables sector support with tax credits in the form of production tax credits and ITCs for solar, wind energy and advanced nuclear technologies. The oil and gas sector does not receive any production tax credits but can claim several deductions, such as a domestic manufacturer's deduction and intangible drilling costs deductions (American Petroleum Institute, 2017). Oil and gas pipelines can also benefit from master limited partnership structures, under which they organise as partnerships and trade publicly on an exchange, receiving tax benefits. The Oil Spill Liability Trust Fund also serves as a backstop to cover costs associated with oil spills that the operator of a facility is not able to cover. More recently, in February 2018, Congress increased tax credits for CCUS under Section 45Q of the tax code.

Energy data

The Energy Information Administration (EIA) is the independent energy statistics and analysis arm of the US government. The EIA was established under the Department of Energy Organization Act of 1977 to serve as the federal government's authority on energy statistics and analysis, following up on data collection that was put in place in 1974, after the 1973 oil market crisis. The EIA is funded each year through the annual Congressional appropriations process (EIA, 2019b).

The EIA is housed within the DOE, though it operates independently from it and from any other departments or agencies within the federal government. In this regard, its data and analysis are not subject to prior review or approval by other government entities. The EIA collects, analyses and publishes objective data and information, which helps to inform energy policy decisions. The EIA's high quality and dependable data are also widely used around the world by financial markets, investors and the general public. Its data cover all aspects of the energy system, including production, stocks, demand, imports, exports and prices. The administration collects historical data as well as makes projections.

The EIA offers a number of products, services and tools to disseminate its work, including daily, weekly, monthly, quarterly, annual and special topic reports. Among the EIA's flagship publications are the *Annual Energy Outlook* (*AEO*) and the *Short-Term Energy Outlook* (*STEO*). The *AEO* provides long-term projections for US energy supply, demand and trade over a 25- to 30-year time horizon based on several scenarios, including a reference case, high and low resource and technology cases, high and low oil price cases, and high and low economic growth cases. The *STEO* is a monthly publication that provides forecasts of US energy supply, demand, trade and prices over a 12- to 24-month time horizon. The EIA's *Weekly Natural Gas Storage Report* and *Weekly Petroleum Status Report* are industry benchmarks for providing natural gas and oil stocks information, and help inform oil and gas markets and prices. All of the EIA's data are available from databases on its website: www.eia.gov.

Assessment

Since the last IEA review of US energy policies in 2014, energy markets and policies have undergone dramatic change in the United States.

The shale revolution continues to be a driving force in US energy policy, shifting gears from a mindset of energy scarcity to one of energy abundance. Further innovation in oil and gas extraction through additional refinements in horizontal drilling coupled with hydraulic fracturing has made oil and gas production a mainstay of the US energy landscape and, indeed, the world. The same types of technological breakthroughs that led to the shale revolution hold promise to unlock opportunities in other areas of the energy field. Notably, the United States remains at the forefront of clean energy technology innovation, more recently with regard to research efforts on small modular reactors and CCUS.

Commitment to innovation and sensible risk taking, combined with conducive legal, regulatory and tax frameworks as well as the general entrepreneurial culture of the United States, have contributed to economic growth. Key policies underpinning this success include the full liberalisation of oil exports by Congress in 2015, the federal approval process for LNG exports, improved co-ordination of infrastructure projects under the FAST Act, continuous public support to research, development and innovation as well as the favourable tax environment (decrease in corporate tax from 35% to 21%). The United States has extensive natural resource endowments, and bringing them to market will require that these conditions remain strong.

The results, so far, are impressive. Crude oil production is up 25% from October 2014 to October 2018, and natural gas production has increased by 19% over the same period. These changes, which make the United States the largest oil and gas producer in the world, put it on track to be a net energy exporter by 2020 on an annual average basis. While US energy costs are low compared with many of the other OECD countries, decreasing fossil fuel costs and wholesale electricity prices have not translated into decreasing retail electricity prices. While the fuel component of retail rates has declined, other rate components have increased, yielding slight overall increases in rates. Nevertheless, customer bills have remained relatively steady. This is a major driver for the competitiveness and productivity of US businesses, assisting continued economic growth and prosperity.

Improvements in energy efficiency and renewables are equally impressive, contributing to US prosperity, jobs and economic growth. Total energy consumption has fallen by 3.3% since 2007, while the economy grew by 15.5%. This gain in energy productivity has been an important boost to US productivity throughout the economy. From 2007 to 2017, energy-related CO_2 emissions fell by 16% due to lower energy demand, energy efficiency, the shift from coal to natural gas use in power generation, and growth in renewable electricity. In fact, the largest emissions reduction happened in power generation, with a decrease of 27% below 2007 levels, with coal-to-gas fuel switching being a dominant driver.

But this energy success has brought challenges. The United States now needs to address midstream bottlenecks, especially with regard to gas and oil. Infrastructure investment has been lagging behind production. Interstate pipeline transportation is occasionally challenged by the lack of public acceptance and concerns around environmental integrity along the pipeline track. Therefore, some states refuse pipeline projects. FERC has federal authority over siting, construction and operation of interstate gas pipelines and LNG export terminals and is the lead agency on environmental reviews (under the process defined in NEPA).

Other challenges include the fact that gas has overtaken coal as the main fuel source for electricity generation – it accounted for 31.4% in 2017 (compared with 31.0% for coal) and in some states 60% of total generation. The low cost of gas has assisted in significant GHG emissions reductions across the economy and in low wholesale power prices. In combination with the rapid growth of renewable energy, gas has been displacing higher-cost coal generation as well as nuclear, leading to the retirement of some of these plants. On the other hand, "lower for longer" energy prices, while desirable for end users, can also deter investment into existing and new energy infrastructure, especially in competitive markets, and may raise reliability concerns as more baseload generation is retired.

The US federal structure adds challenges to the policy-making process. Moreover, a complex array of regional wholesale markets and regional operators, North American regulatory authorities, state utility commissions, federal authorities, and split responsibilities with regard to infrastructure planning, regulation and permitting leaves business with a complex system, notably with regard to environmental and historical preservation rules.

US environmental and climate policies continue to face a lack of bipartisan support, and frequent regulatory course changes increase the risk of legal challenges against regulatory action and can create uncertainty for states and industry alike. The United States does not have national market-based carbon policy instruments such as a carbon tax or cap-and-trade programme. Past attempts at passing carbon pricing legislation have not garnered sufficient support in Congress. As a result, US federal emissions policy is directed mainly through regulation under existing environmental laws (primarily the Clean Air Act) rather than climate-specific legislation.

Planned US withdrawal from the Paris Agreement has resulted in some regulatory uncertainty. As a number of states, particularly some more populous ones, move to set clear, long-term targets, this uncertainty might be alleviated. There is a role for the federal government to continue to improve collaboration between states and between state and federal departments and regulators. The very different policy stances of various governments make this even more important. However, even without an encompassing federal emissions policy in place, according to the latest long-term projections from the EIA *AEO 2019*, CO_2 emissions from US energy consumption will remain near current levels through 2050, as emissions associated with coal and petroleum consumption fall and emissions from natural gas consumption rise (assuming current laws and policies).

Energy security remains a priority issue for the United States. The country continues to demonstrate a strong focus on reliability and resilience, recognising that its national and economic security depends on the reliable functioning of its energy infrastructure. In this respect, the DOE's creation of CESER is a welcome initiative.

The United States continues to work with its partners to ensure its own and global energy security. US energy exports are already playing an important role in diversifying global energy supplies and mitigating the impact of disruption events. In this regard, continued careful consideration is required when examining proposals to modernise and sell down its SPR, given its critical role in any future IEA collective response.

Innovation remains a hallmark of US energy policy. Significant resources continue to be directed to fundamental RD&D, including in the extensive network of DOE national laboratories as well as the research centres and universities with which the government collaborates. This is highly valued by industry. Noting that resources are always constrained, it is nonetheless worth continuing to explore whether additional market-oriented demonstration and commercialisation support might have net benefits. The international focus should also extend to continued US leadership in technological collaboration. The high-quality data and analysis by the EIA are acknowledged as best practice and relied upon by many in the industry.

The changing nature of the energy landscape means there will be continuing adjustment in the mining and supply chain sectors, particularly for coal and nuclear. As with any adjustment in the economy, careful attention is necessary to ensure that impacts on the market, human capital and affected communities are mitigated. There is a role for government to support the structural adjustments.

Very few people, if any, accurately predicted the extent of the shale boom and its broader implications for the energy market. This is a reminder that the future is inherently uncertain, and highlights the benefits of a focus on all-of-the-above technologies, as well as well-considered and largely "no regrets" policies.

Recommendations

The US government should:

- Utilise the federal government's role in the regulatory approval process for energy infrastructure to reduce logistical bottlenecks.
- Ensure that US energy security remains strong in addressing new threats and resilience as the country's energy position changes with the shale revolution.
- Conduct regular and comprehensive assessments of risks and vulnerabilities to foster preparedness, and maintain reliability and resilience in the face of new challenges.
- Engage with states and local authorities to ensure that their energy policy goals do not hamper the reliable functioning of the overall energy system.
- Lead on international energy collaboration and innovation in clean energy, using results of worldclass US R&D.

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3. Energy and climate change

Key data

(2017)

GHG emissions without LULUCF*: 6 456.7 $MtCO_2$-eq, -12.0% since 2005

GHG emissions with LULUCF*: 5 742.6 $MtCO_2$-eq, -13.0%% since 2005

Energy-related CO_2 emissions:

CO_2 emissions from fuel combustion: 4 759.2 $MtCO_2$, -16.6% since 2005

CO_2 emissions by fuel: oil 41.6%, natural gas 30.2%, coal 27.8%, other 0.4%

CO_2 emissions by sector: power and heat generation 38.3%, transport 36.2%, industry 9.0%, residential 6.0%, commercial 5.4%, other energy 5.1%

CO_2 intensity per USD GDP (PPP)**: 0.27 $kgCO_2$ (IEA average 0.23)

*Land use, land-use change and forestry.

Source: UNFCCC.

Overview

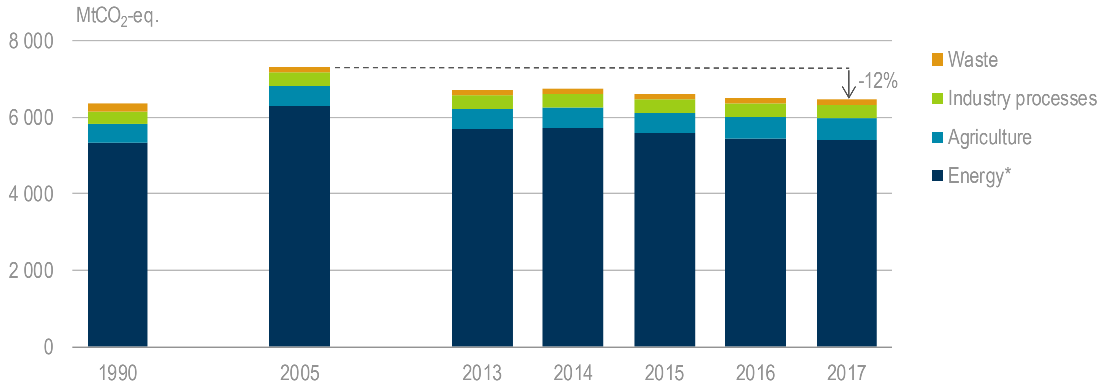
The United States (US) is pursuing a balanced approach that aims at mitigating climate change while expanding the economy.

In 2017, total greenhouse gas (GHG) emissions (excluding emissions from land use, land-use change and forestry) in the United States amounted to 6 457 million tonnes of carbon dioxide equivalent ($MtCO_2$-eq). This was around 12% of global emissions, the second-highest share in the world after the People's Republic of China (IPCC, 2018). Since 1990, total GHG emissions have increased by 1.3%, but since 2005, emissions have decreased by 11.5%, driven mostly by a fuel switch from coal to gas and renewables in power generation.

Energy-related emissions from combustion processes in the power and heat generation, transport, industry, households, and commercial sectors are the largest contributor to total GHG emissions. In 2017, energy-related emissions accounted for 84% of total emissions followed by the agriculture sector (8%), industrial process emissions (6%) and the waste sector (2%) (Figure 3.1). Energy-related emissions include carbon dioxide (CO_2) emissions from fossil fuel combustion, but also other emissions from the energy sector such as methane leakage from natural gas systems. CO_2 emissions from combustion are the focus of this chapter. Those accounted for around three-quarters of total GHG emissions in 2017.

CO_2 is the main GHG, accounting for 82% of total GHG emissions, largely corresponding to emissions from combustion processes. Remaining GHG emissions are mainly methane and nitrous oxide (N_2O), mostly from agriculture, waste management, and oil and gas production.

Figure 3.1 GHG emissions by sector, 1990-2017



US GHG emissions have fallen by 12% since 2005, mainly due to a decline in energy-related emissions driven by a fuel switch from coal to gas and renewables in power generation.

**Energy* includes power and heat generation, commercial, households, industrial energy consumption and transport. Energy-related emissions include both CO_2 emissions from combustion and other GHG emissions related to the energy sector.

Source: EPA (2018a), *Inventory of Greenhouse Gas Emissions and Sinks 1990-2016*, https://unfccc.int/documents/65674.

Energy-related CO_2 emissions

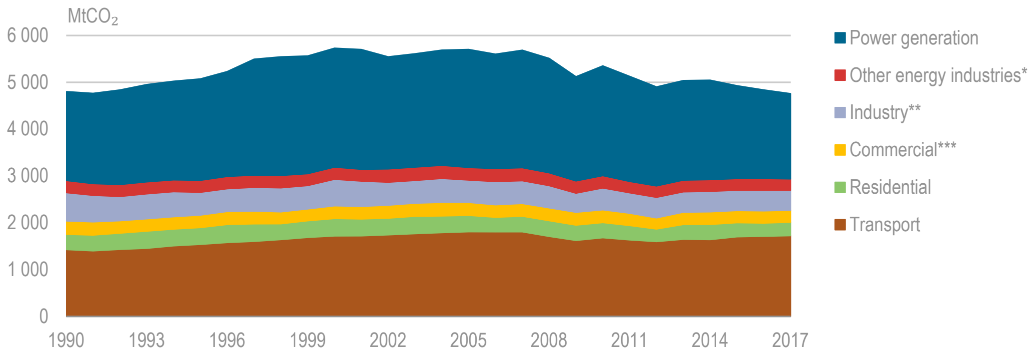
The trend for energy-related CO_2 emissions has changed multiple times in recent decades. Emissions increased until the 1990s, after which they plateaued in the early 2000s, followed by a decline in the last decade (Figure 3.2). In 2017, energy-related emissions amounted to 4 759 million tonnes of CO_2 ($MtCO_2$), a 17% reduction since the peak in 2005. Power generation accounted for 38% of energy-related emissions and transport for 36%. The rest was from industry (9%), residential (6%), commercial (5%) and other energy sectors (5%).

In the past decade, CO_2 emissions have fallen across all sectors, but the biggest decrease was in power generation. From 2007 to 2017, emissions from power generation dropped by 16%, despite electricity generation remaining stable during that period. This large reduction in emissions happened through rapid growth in renewable energy sources and natural gas from the shale revolution, replacing old coal-fired power generation systems. Emissions reductions in the power sector contributed to over 70% of total reductions in energy-related emissions in the United States in the last decade. Growth in renewables and in natural gas-fired generation each accounted for roughly half of power sector emissions reductions.

Emissions have also fallen in other sectors, notably in industry, where an overall decline in energy consumption as well as fuel switching from coal to natural gas led to emissions reduction of 12% between 2007 and 2017. Transport emissions have also declined in the last decade, but by a more modest 5%, and since 2012, the trend has been increasing. If continuing on the current trajectory, the transport sector will soon surpass the power sector as the largest source of CO_2 emissions in the United States.

In line with the growing share of transport emissions, the largest source of energy-related CO_2 emissions is oil combustion (Figure 3.3). In 2017, oil accounted for 42% of total emissions. Coal emissions have significantly fallen in recent years, and their share in total emissions fell from 38% in 2007 to 28% in 2017. This drop correlates with growth in natural gas emissions, which accounted for 30% of total emissions in 2017, up from 22% in 2007.

Figure 3.2 Energy-related CO_2 emissions by sector, 1990-2017



Emissions have fallen across all sectors in the past decade, most significantly in the power sector and less so in the transport sector.

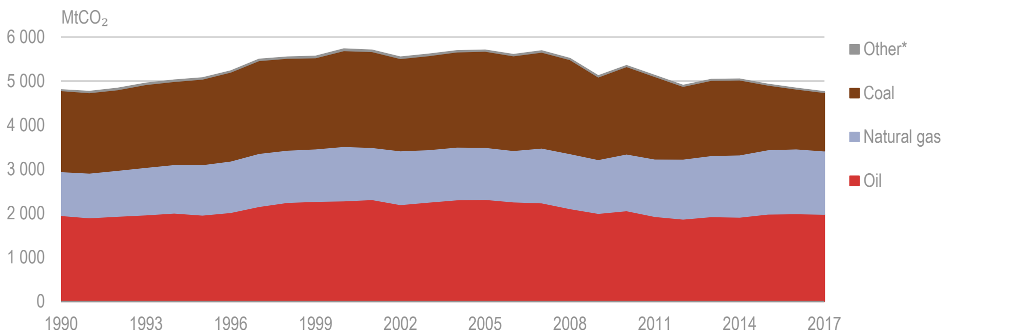
**Other energy industries* includes emissions from coal mines, oil and gas extraction, oil refineries, blast furnaces, and coke ovens.

***Industry* includes CO_2 emissions from combustion at construction and manufacturing industries.

****Commercial* includes commercial and public services, agriculture/forestry and fishing.

Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

Figure 3.3 Energy-related CO_2 emissions by energy source, 1990-2017



Oil is the largest source of CO_2 emissions in the United States, and its share is increasing, as transport emissions account for a growing share of the total and as coal use declines.

**Other* includes emissions from non-renewable waste.

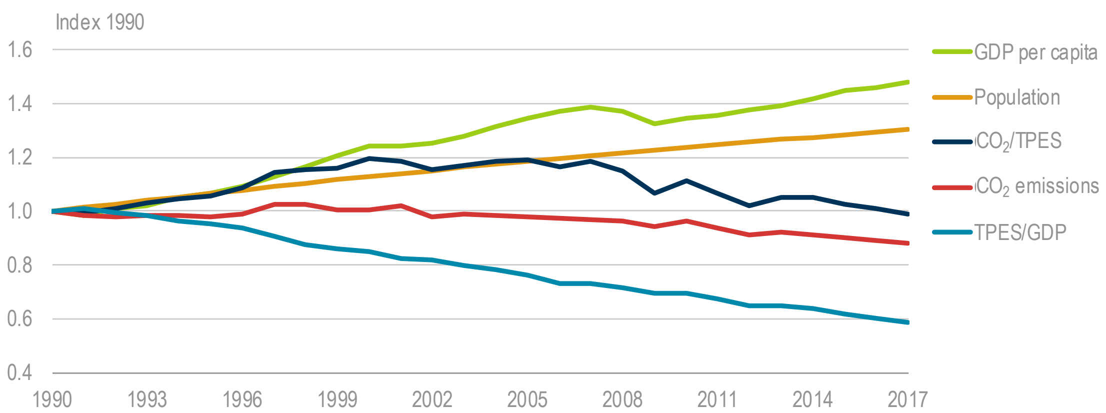
Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

CO_2 drivers and carbon intensity

Total energy-related CO_2 emissions in a country are driven by the growth in population, economic development and changes in the energy intensity of the economy (total primary energy supply [TPES] per gross domestic product [GDP]) and carbon intensity of energy supply (CO_2/TPES).

From 1990 to 2017, US GDP per capita grew by 48% and population increased by 30%, while energy-related CO_2 emissions remained relatively stable (Figure 3.4). This was achieved through a reduction in energy intensity of the economy by over 40% and a decline in carbon intensity of energy supply by 12%. During the last decade in particular, the United States has seen a decoupling between energy-related emissions and growth in the economy and population.

Figure 3.4 Energy-related CO_2 emissions and main drivers in US, 1990-2017



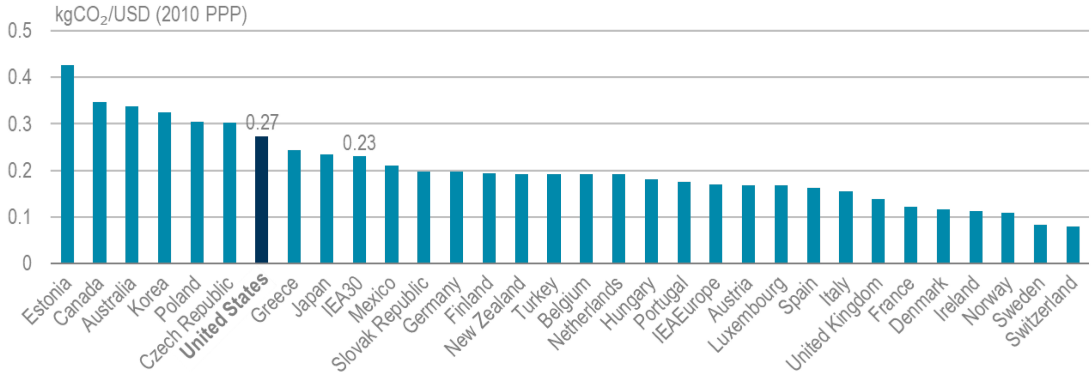
Despite large economic growth per capita, energy-related CO_2 emissions are on a similar level to 1990, thanks to reduced carbon intensity of the economy.

Note: Real GDP in USD 2010 prices and at purchasing power parity (PPP).
Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

Carbon intensity of the economy, measured as the ratio of CO_2 emissions per unit of GDP, is used as a common indicator of whether CO_2 emissions are decoupling from economic growth. In 2017, US carbon intensity was 0.27 kilogrammes of energy-related CO_2 ($kgCO_2$) per USD,[1] the seventh-highest among the 30 International Energy Agency (IEA) member countries and 16% above the IEA average (Figure 3.5). However, this reflects already significant improvement over the previous decade: US carbon intensity fell by 28% from 2007, more than the average reduction across IEA countries (Figure 3.6).

[1] United States dollars in 2010 real values and at PPP.

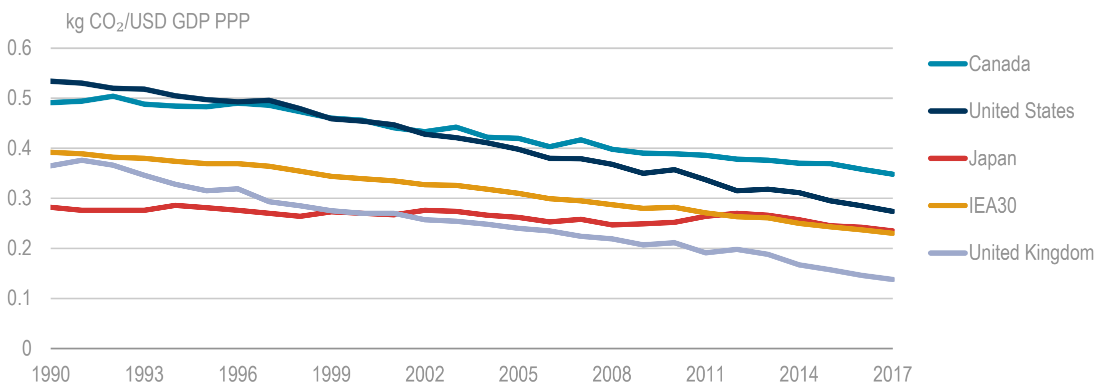
Figure 3.5 CO_2 intensity (energy-related emissions) in IEA member countries, 2017



The US economy has the seventh-highest CO_2 intensity among IEA member countries.

Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

Figure 3.6 CO_2 intensity of the United States and select IEA member countries, 1990-2017

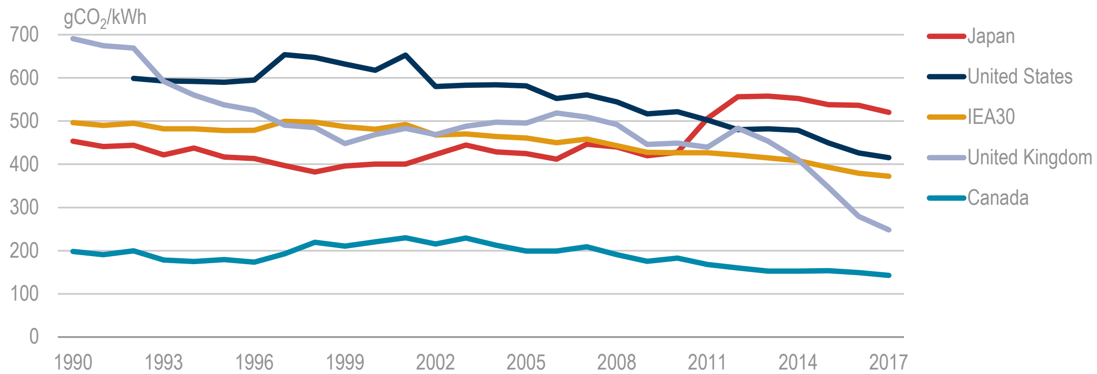


US CO_2 intensity has declined faster than the IEA average, but remains at a higher level.

Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

Lower carbon intensity in electricity generation has been a main driver of the recent decline in overall carbon intensity in the US economy. Substitution of coal-fired generation with less carbon-intensive natural gas-fired generation – enabled by rising domestic shale gas production – and growth in renewables have been the main contributing factors (Figure 3.7). Although nuclear power remains the dominant source of low-carbon electricity generation, growth in solar and wind power has significantly contributed to a decline in carbon intensity of electricity generation. Between 2007 and 2017, the share of fossil fuels in electricity generation declined from 72% to 63%, while the share of renewables in the sector increased from 8% to 17%.

Figure 3.7 CO_2 intensity of power and heat generation in the United States and in other selected IEA member countries, 1990-2017



CO_2 intensity in heat and power generation has fallen significantly in the United States, thanks to the decline of fossil fuel-fired generation, especially from coal.

Note: gCO_2/kWh = grammes of CO_2 per kilowatt-hour.

Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

Institutions

At the national level, both the executive and legislative branches of government play critical roles in developing climate change policy. Additionally, CO_2 emissions from energy are greatly affected by many policies not specifically related to climate change, such as tax credits for renewables and energy efficiency standards.

As with other forms of legislation, Congress has the sole authority to pass climate change legislation. The White House has broad authority to set the overarching strategy for the country on climate change and can make recommendations to Congress on legislative efforts. A number of Congressional committees have authority over developing climate change policy, though the committees most central to climate change policy are: the Senate Committee on Energy and Natural Resources, the Senate Committee on Environment and Public Works, and the House Committee on Energy and Commerce. Still, a number of other committees – including those focused on foreign relations, finance and science – also play an important role in Congressional climate policy action.

At the executive level, a number of federal agencies, commissions and advisory offices to the president are involved in developing, co-ordinating, and implementing climate change policies. Among White House Executive Offices, nearly all have input into charting an administration's course on climate change, including: the Council of Economic Advisers, Council on Environmental Quality, National Security Council, Office of Management and Budget, and Office of Science and Technology Policy.

Beyond Executive Offices, a number of federal agencies develop and implement climate change policies, as well as provide assessments and recommendations on climate change mitigation and adaptation. The Environmental Protection Agency (EPA) plays the most important role in climate change and other environmental regulation, as directed by Congress. The EPA sets out regulations through "notice and comment" rule making, including a rationale and assessment, under which it first issues draft proposals and regulatory impact analyses, receives public comment, and then issues final rules. Repealing or revising existing regulations must also undergo a similar procedure. The agency is led by its administrator, who is appointed by the president and approved by the Senate; the EPA is under the authority of the president.

The federal government, through the EPA, has an obligation to regulate GHG emissions under the Clean Air Act. Under the landmark *Massachusetts v. EPA* case, 12 states and several US cities brought a lawsuit against the EPA to force the agency to regulate CO_2 and other GHGs (US Department of Justice, 2015). The US Supreme Court in 2007 ruled that GHGs are qualified pollutants under the Clean Air Act. Subsequently, the EPA in 2009 issued a so-called "endangerment finding" based on a scientific review, which determined that GHGs endanger public health and welfare, which would require the EPA to pursue mitigation strategies under the Clean Air Act. Together, the two rulings underpin a legal basis for the EPA to regulate GHG emissions.

Other federal departments and agencies that play important roles in climate change and CO_2 policy are:

- Department of Energy (DOE), with oversight over research and development initiatives and clean energy development
- Energy Information Administration (EIA) (under DOE), which provides energy data and analysis to the administration and Congress
- Department of Transportation, with authority to set vehicle fuel efficiency standards
- Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), which assesses the impacts of climate change
- Department of Homeland Security's Federal Emergency Management Agency, which co-ordinates the federal response to natural disasters
- Department of State, which represents the United States in international climate negotiations
- Department of Defense, which assesses the national security implications of climate change
- Department of Agriculture, which helps the agricultural sector deal with the effects of climate change.

The judicial branch also plays an important role in climate change policy. Given that this branch of government is tasked with interpreting the US Constitution, the courts are arbiters of suits that are brought to challenge the executive branch's climate and environmental policies and regulations to ensure they are compliant with the country's laws.

The federal structure of government in the United States affords states and local governments considerable scope in enacting climate change and environmental regulation, separate from federal policy (see below section on "Regional, state and local policies"). As a result, there is a wide array of climate policy across the United States, including at the municipal level. The federal government supports state and local government actions that reduce GHG emissions by sponsoring policy dialogues, issuing technical documents, facilitating consistent measurement approaches and model policies, and providing direct technical assistance.

Climate change mitigation

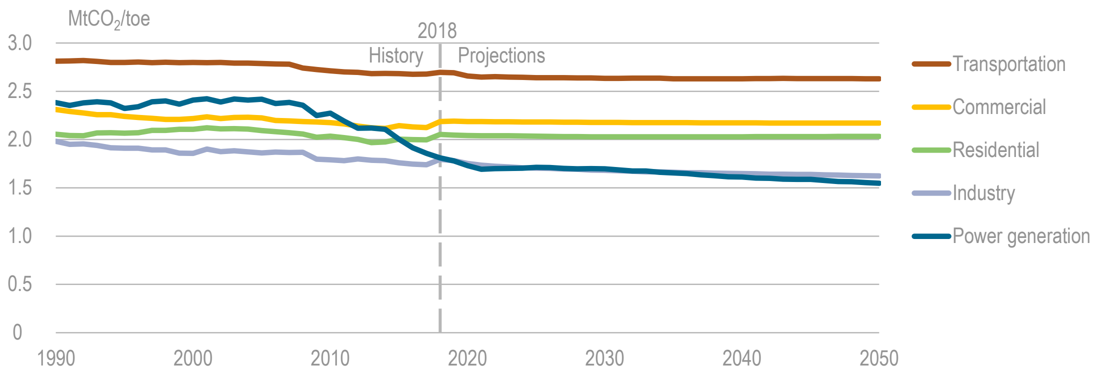
Emissions targets

On 1 June 2017, the United States announced its intention to withdraw from the Paris Agreement based on perceived costs to the US economy (White House, 2017a). The withdrawal will not take effect until next year as the United Nations Framework Convention on Climate Change (UNFCCC) rules dictate that the earliest a signatory can withdraw is four years following the Agreement's entry into force, or on 4 November 2020 (UNFCCC, 2017). Still, the US government continues to participate in UNFCCC meetings and in the UNFCCC process, including reporting emissions. The US administration is open to re-engaging in the Paris Agreement process under less onerous terms for the United States; under the Paris Agreement, the United States in 2015 established a target to reduce GHG emissions by 26-28% below 2005 levels by 2025 (UNFCCC, 2015). Regardless of the withdrawal from the Paris Agreement, the United States will remain a party to the UNFCCC, and therefore will continue to engage in multilateral climate negotiations.

A number of US states, cities businesses and academic institutions have supported the Paris Agreement and its targets as part of the US Climate Alliance.

The United States has focused its national policy for GHG emissions reduction through sectoral targets included within federal policies, reforming regulatory impediments, and allowing for financial incentives that foster clean energy production and use, as described below.

Figure 3.8 Emissions projections and outlook (based on EIA estimates)



Note: toe = tonnes of oil equivalent.

Source: EIA (2019), *Annual Energy Outlook 2019*, www.eia.gov/outlooks/aeo/.

Looking ahead, until around 2025, CO_2 emissions in the power sector are likely to decline further with strong growth of natural gas and renewables, supported by favourable market conditions (and policy conditions, in the case of renewables) (EIA, 2019). However, there remains a risk that emissions could pick up again in the subsequent decade if faster-than-expected nuclear plant retirements and continued use of coal offsets reductions from the shift towards natural gas and renewables.

Federal policies and regulations

At the federal level, the National Security Strategy underlines that the United States is pursuing a balanced approach that aims at reducing local air pollution as well as GHGs while expanding the economy (White House, 2017b). Environmental and climate policies of the United States continue to face a lack of bipartisan support and frequent regulatory course changes, which increases the risk of legal challenges against regulatory action and can create uncertainty for states and industry alike.

The United States does not have national market-based carbon policy instruments such as a carbon tax or cap-and-trade programme. Past attempts at passing carbon pricing legislation have not garnered sufficient support in Congress. As a result, US federal policy on GHG emissions is directed mainly through regulation under existing environmental laws (primarily the Clean Air Act) rather than climate-specific legislation.

The administration's energy policy emphasises the concept of "American energy dominance". The policy is based on a strategy to maximise energy production, increase energy exports and be a global leader in energy technologies. As part of the effort to boost the competitiveness of US industry, the administration has undertaken a review of most of the emissions regulations applicable to broad segments of the energy sector, including the power, transport and upstream sectors.

Under Executive Order 13783 from March 2017, the White House directed the EPA to review all existing environmental rules, a process the agency is still undertaking. Federal agencies have revoked, or are in the process of revoking, 60 environmental regulations. The administration places a high priority on market-driven technological solutions to emissions reduction (White House, 2017c).

Power sector

In 2014, the EPA introduced the Clean Power Plan (CPP) aimed at combating anthropogenic climate change more broadly. The CPP proposed state-specific targets for power plant emissions that amount to a total of 32% reductions from 2005 levels by 2030 for the United States as a whole (EPA Archives, 2016). Meeting the targets allowed for so-called "beyond the fence line" measures such as switching to cleaner power sources and demand-side management. The CPP was suspended by a Supreme Court ruling, based on a legal challenge brought forward by several states and industry groups, and never took effect. However, several states have voluntarily implemented the CPP.

In August 2018, the administration introduced its proposal to replace the CPP with the Affordable Clean Energy (ACE) rule (EPA, 2017).[2] Under Section 111 (d) of the Clean Air Act, the EPA is required to regulate emissions at existing power plants through the "best system of emissions reduction" (EPA, 2019a). The ACE rule focuses on emissions reduction actions at individual power plants rather than statewide, as under the CPP. The EPA's latest rule offers states several options to cut emissions from power plants, though recommends heat-rate efficiency improvements at existing power plants as the best choice (EPA, 2018b). The EPA estimates that when states have fully implemented the

[2] In October 2018, the US Supreme Court refused to consider any additional court challenges to the administration's decision to repeal the CPP.

measures in the ACE rule, US power sector CO_2 emissions could be 33% to 34% below 2005 levels (EPA, 2019b). The administration finalised the ACE rule in June 2019, though it could be subject to legal challenges by states and environmental groups, which might significantly delay its final adoption and future implementation.

In December 2018, the administration also announced a proposal to revise New Source Performance Standards (NSPS) for CO_2, applied under Section 111 (b) of the Clean Air Act. Unlike the CPP, the NSPS rule was not suspended by the courts and has been in effect since it was finalised in 2015. The existing rule established Carbon Pollution Standards for new, modified and reconstructed power plants with a limit of 635 gCO_2/kWh, which equals a highly efficient new supercritical pulverised coal utility boiler with partial carbon capture and storage (CCS) (EPA Archives, 2015). The new proposal calls for a standard of 860 gCO_2/kWh for large generators, which can be met without CCS (EPA, 2018c). Nevertheless, market conditions already disadvantage new coal plant construction (given the relative low cost of shale gas) and no new coal plants are under consideration currently.

Beyond GHGs, the EPA is also in the process of reviewing existing regulations on the power sector for other pollutants, including nitrogen oxides (NO_x), sulphur oxides (SO_x) and mercury. Though these regulations are primarily designed to combat fine particulate matter that contribute to smog, mitigation technologies can have benefits for GHG reduction as well, and raise the costs for coal-fired generation relative to other sources. While the EPA decided not to revisit NO_x and SO_x regulations, it has launched a review of the Mercury and Air Toxics Standard.

In addition, the United States also has policies that support renewable power through tax credits at the federal level and renewable portfolio standards (RPS) at the state level (see Chapter 5, "Renewable Energy"). The government also has policies and standards to promote energy efficiency in buildings and industry that continue to contribute to emissions reductions (see Chapter 4, "Energy Efficiency").

Transportation sector

The transportation sector is the second-largest energy consuming and CO_2 emitting sector in the United States, according to IEA data.

In response to the 1973 Arab oil embargo, the United States has had Corporate Average Fuel Economy (CAFE) standards in place since 1975 to mitigate oil consumption growth. Since 2009, the administration has harmonised CAFE standards – administered by the National Highway Traffic Safety Administration (NHTSA) – with vehicle emissions standards established by the EPA, in an effort to address mobile sources of GHG emissions as required by the 2007 *Massachusetts v. EPA* case and the 2009 GHG endangerment finding. At the time, the agencies laid out standards for two periods, 2012-16 and 2017-25. The standards are supposed to reach 163 grammes of CO_2 equivalent per mile (gCO_2-eq/m) (around 101 grammes of CO_2 per kilometre [gCO_2/km]) for model year 2025 vehicles, which translates into fuel economy levels of around 49.6 miles per gallon (mpg) (US Department of Transportation, 2014; National Archives and Records Administration, 2015).

As part of the rule making, the EPA and NHTSA agreed to perform a midterm evaluation of the standards for 2022-25. The EPA issued a finding in December 2016 that held that the standards were appropriate. In 2017, the administration reopened the review in conjunction with NHTSA, and in August 2018 announced a new proposal, the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks. The SAFE rule proposes to revise the standards on both economic and safety grounds, with the preferred option to freeze 2021 standards through 2026 at around 204 gCO_2-eq/m (37 mpg and around 127 gCO_2/km) for passenger cars and 284 gCO_2-eq/m (31.3 mpg and 176.5 gCO_2/km) for light-duty trucks (EPA, 2018d). The rule is expected to be finalised in 2019. By way of comparison, the EU requires new cars to achieve 95 gCO_2/km by 2021 and Japan requires cars to achieve 122 gCO_2/km by 2020 (though Japan already reached this target in 2013) (GIZ, 2017).

A complicating factor for the federal government in implementing the proposed changes will be a Clean Air Act waiver that California was granted in 2013 for vehicle standards, allowing the state to set emissions standards more stringent than those established by the federal government.[3] California's current standard is aligned with the administration's federal standards, but freezing the federal standards at 2021 levels under the SAFE rule would create a discrepancy. Moreover, 13 other states also follow California's standards, together accounting for over 40% of the automobile market. As such, automakers could encounter uneven standards across states.

Following its finalisation, the rule may face lawsuits from environmental groups and states. Moreover, California plans to launch a legal defence of its waiver, which the SAFE plan proposes to revoke. Ultimately, it is likely the final outcome will be decided by the courts.

Relatedly, in 2011, the United States also put in place the first-ever fuel efficiency and GHG emissions standards for heavy-duty vehicles. The standards applied to model years 2014-18 (Phase 1) and vary by type of vehicle, and require between 6% and 23% emissions reductions relative to a 2010 baseline. Phase 2 standards were finalised in 2016 and apply to model years 2021-27, and include targets of 16-25% CO_2 reductions compared with Phase 1.

Beyond vehicle standards, federal financial incentives also attempt to boost the uptake of electric vehicles (EVs), which can also help lower transportation sector CO_2 emissions – depending on how power generation emissions evolve – as well as help with local air pollution. The main policy tool offered by the federal government is a tax credit for purchases of EVs. As part of the Emergency Economic Stabilization Act of 2008, Congress authorised tax credits of USD 2 500 to USD 7 500 for each new EV purchased (depending on vehicle size and battery capacity), though it also imposed a manufacturer-based limit on the credit, as it applies to the first 200 000 vehicles sold by a given company (DOE, 2019a). GM and Tesla already reached this limit at the end of 2018, so purchases of their cars can no longer claim the full USD 7 500 credit. The United States also offers tax credits for EV charging stations. Moreover, the DOE offers loans under its Advanced Technology Vehicles Manufacturing programme to automakers including Ford, Nissan and Tesla for projects such as constructing advanced battery manufacturing plants in the United States or retooling existing plants to produce EVs. The DOE also offers up to USD 4.5 billion in loan guarantees for innovative renewable energy and energy efficiency projects, including EV charging infrastructure (DOE, 2019b). Lastly, German automaker Volkswagen (under a recently created unit, Electrify America), is also

[3] The Clean Air Act gave California special authority to enact more stringent air pollution standards for automobiles, though the EPA is still required to approve such waivers. In July 2009, the EPA granted California a Clean Air Act pre-emption waiver for vehicle GHG standards.

pursuing a sizeable buildout of EV charging stations throughout the United States as part of its USD 2 billion settlement with the EPA and California Air Resources Board over the company's diesel emissions scandal.

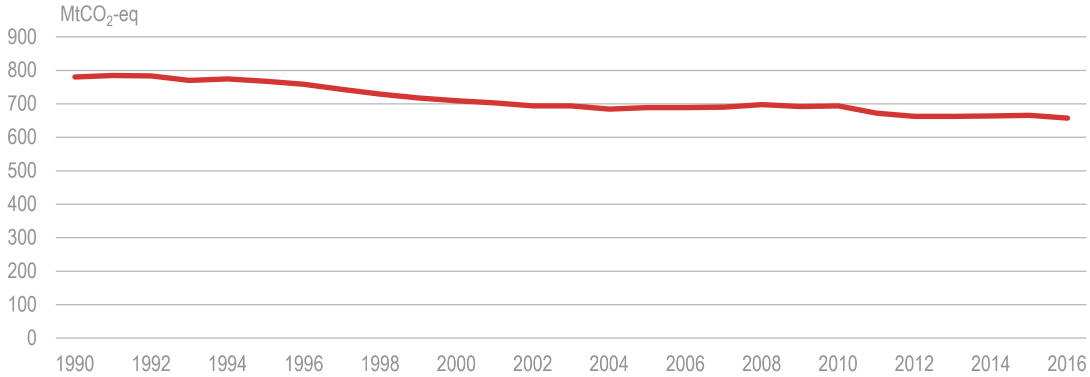
Oil and gas sector methane emissions and natural gas flaring

Since the start of the light tight oil (LTO) revolution in the United States, in some new oil-producing regions without sufficient natural gas infrastructure, large volumes of associated gas as a by-product of oil production have been flared (Environmental Defense Fund, 2019). With the expansion of liquefied natural gas (LNG) exports from the United States and gas pipeline shipments to Mexico, flaring comes with increased economic loss, and additional pipeline infrastructure is becoming a greater necessity. State regulatory action to limit flaring will also require additional gas capture and transport capacity.

For example, flaring has been a particular challenge in the Bakken shale region, the nation's second-largest LTO-producing area. In response, the state government of North Dakota imposed flaring restrictions on well operators, which has shown results in terms of reducing flaring. Regulations require oil producers to capture 91% of associated gas by November 2020 (from 88% in November 2018) (North Dakota Industrial Commission, 2015). More recently, flaring has experienced an uptick in the Permian Basin in Texas and New Mexico as gas takeaway capacity has not kept pace with a surge in oil and associated gas production (Oil & Gas Journal, 2018).

Nonetheless, over the past ten years, overall methane emissions have been in decline (Figure 3.9), led by reductions from coal mining activities and improved gathering in oil and gas operations (EPA, 2019c). The federal government has played an assisting role. The DOE has invested in methane emissions mitigation research to help quantify, record and mitigate methane emissions across the gas value chain, during production and gathering (which accounts for 66% of total emissions), processing and transmission, storage, and distribution.

Figure 3.9 US methane emissions



Note: All emissions estimates from EPA (2018). These estimates use a global warming potential for methane of 25, based on reporting requirements under the UNFCCC.

Source: EPA (2018a), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016* [Table 2-1], www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016.

The DOE, through the national laboratories and academic research and development (R&D) activities conducted in collaboration with the EPA, the National Aeronautics and Space Administration (NASA) and the NOAA, supports technology development of pipeline corrosion protection, leak detection systems, pipeline monitoring and sensor systems to detect methane leakage. While technologies and quantification have improved, flaring remains an issue in the Permian and Bakken basins because of insufficient gas takeaway infrastructure.

As part of a deregulatory push, the EPA announced in September 2018 changes to the 2016 NSPS for oil and gas wells under the Clean Air Act, which established regulatory requirements to reduce GHG emissions and volatile organic compound emissions from the sector. The EPA plans to lower requirements to monitor and repair leaks at well sites and compressor stations in an effort to reduce industry compliance costs (EPA, 2018e).

In the same month, the Interior Department's Bureau of Land Management (BLM) announced a final rule to revise and make less onerous the 2016 Waste Prevention Rule, a regulation to lower methane emissions on federal and tribal lands. According to the Interior Department, the previous regulation was too costly and would have led to an overlap of federal and state regulations overseeing drilling on public lands, which accounts for around 5% of oil and 9% of natural gas production in the United States. The new rule mostly reverts to the regulatory framework for venting and flaring that preceded the 2016 regulation, and defers authority to states or tribal groups to determine if flaring of associated gas at oil wells should require royalties (BLM, 2018).

In most of the efforts to roll back methane regulations, as with other regulatory changes, finalised rules are likely to face lawsuits that could delay implementation and extend policy uncertainty for the oil and natural gas industry. Ultimately, less stringent federal rules on methane emissions could delay emissions reductions in the oil and gas sector, though voluntary industry programmes – including those spearheaded by the EPA, such as Natural Gas STAR – can still lead to notable emissions reduction (EPA, 2019d).

Regional, state and local policies

Beyond federal policy, action on CO_2 emissions is also driven by state policies. A large number of states have implemented legally binding carbon pricing mechanisms, either individually or through regional programmes. Additionally, many states pursue ambitious decarbonisation goals for 2030 and beyond by supporting zero-carbon technologies through a wide range of regulatory and market-based mechanisms. Many US cities also have CO_2 reduction targets and have put in place local policies and regulations to help achieve them. Subnational actions are supported by the US Climate Alliance including 16 states, Puerto Rico, 240 US cities, around 1 900 businesses and 345 academic institutions.

Twenty-two US states plus the District of Columbia have adopted GHG reduction targets (though not all have been legislated), with policy tools ranging from carbon pricing to efficiency mandates and support for clean energy. The disparities among state targets can lead to diverging outcomes for emissions reductions regionally.

Regional Greenhouse Gas Initiative

The Regional Greenhouse Gas Initiative (RGGI) is a cap-and-trade programme among nine Northeastern states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island and Vermont (RGGI, 2019). New Jersey was an original member of RGGI, but withdrew in 2012, though the state has recently taken steps to rejoin. Virginia has also expressed interest in joining (ICAP, 2018a). The programme, which applies to fossil fuel electric generating units with capacity of 25 megawatts or greater, was first launched in 2009, and updated in 2014, following a comprehensive review in 2012. As of November 2017, 165 entities are part of the programme. The revised programme established a regional cap of 91 million short tonnes of CO_2 in 2014, which declines by 2.5% each year from 2015 to 2020. RGGI states expect that the programme will achieve 50% emissions reductions from 2005 levels by 2020. Nearly 90% of emissions allowances are sold by states via auction, with proceeds directed towards clean energy programmes such as energy efficiency and renewables. RGGI states completed another review of the programme in 2017 to plan for the post-2020 period. The review proposed to further cut the emissions cap by 2.275 million short tonnes per year between 2021 and 2030, with a target to achieve 30% emissions reductions from 2021 levels by 2030 (ICAP, 2018b).

California's climate action plan

At the state level, California has been at the forefront on GHG reduction policies. California's overarching climate change targets are codified under laws AB32, which passed in 2006 and set out a target to bring GHG emissions levels down to 1990 levels by 2020, and SB32, which passed in 2016 and established a target to cut GHG emissions by 40% from 1990 levels by 2030 (CARB, 2014; California Legislative Information, 2016). More recently, in 2018 the state legislature passed a law to achieve 100% of power from renewable sources by 2045. The state governor also signed an executive order for the state to achieve 80% GHG reductions from 1990 levels by 2050 and to achieve carbon neutrality by 2045.

California's original cap-and-trade programme was established by AB32, adopted in 2011, and launched in 2013. It applies a cap to power plants, industrial facilities and fuel distributors (petroleum and natural gas). The California Air Resources Board is tasked with implementing and enforcing the programme. The scheme first applied to the power and industrial sectors and was extended to the transportation sector in 2015. Approximately 450 entities are part of the programme. Since 1 January 2014, California's cap-and-trade programme has been linked with Quebec's emissions trading system. The two programmes also linked with Ontario's market on 1 January 2018, but the link was terminated in July 2018 after Ontario revoked its cap-and-trade regulation.

The California legislature in July 2018 voted to extend the state's cap-and-trade programme for GHG emissions (AB398), which had previously been due to expire in 2020, through 2030 (California Legislative Information, 2017). Though the state's 2030 emissions target was voted into law the previous year (under SB32), it did not specify the mechanism to achieve the emissions reductions. The cap-and-trade extension will provide longer-term clarity on how the state will achieve its climate targets.

Besides cap-and-trade, the state's policies also include a Low Carbon Fuel Standard (LCFS) and the ambitious 100% RPS. Importantly, the legislation passed with a supermajority (two-thirds voting margin), which will insulate the programme from legal challenges under California law, as the previous iteration of the programme faced.

In addition to pushing to maintain existing federal standards on light-duty vehicles and the LCFS, which mandates a falling carbon intensity of transport fuels annually (primarily through biofuels blending – see Chapter 5, "Renewable Energy"), California also has in place an Advanced Clean Cars Program to lower both GHG and particulate emissions from cars and light trucks. Part of the programme includes a Zero-Emission Vehicle (ZEV) programme, which mandates automakers to sell a growing share of ZEVs (which include full battery-electric, hydrogen fuel cell and plug-in hybrid electric vehicles) each year, starting with a 4.5% threshold in 2018 and reaching a 22% share in 2025 (CARB, 2019a). Nine other states (Connecticut, Maine, Massachusetts, Rhode Island, Vermont, New Jersey, New York, Maryland and Oregon) have since adopted ZEV programmes (EIA, 2016). California also offers EV owners a USD 2 500 rebate (designed to favour lower-income buyers) as well as benefits such as access to high-occupancy vehicle lanes. The rebate, which is funded by auction revenues from the state's cap-and-trade programme, expires when it runs out of funding for a given year (CARB, 2019b).

Other regional programmes

The Western Climate Initiative (WCI) was founded in 2007 as a collaboration among US Western states and several Canadian provinces. In November 2011, WCI established the Western Climate Initiative Inc. to provide technical support to states and provinces trying to implement carbon pricing initiatives. Current members include California and Canadian provinces British Columbia, Quebec, Manitoba and Nova Scotia (WCI, 2019).

The Midwestern Greenhouse Gas Reduction Accord (MGGRA) was established in 2007 by six Midwestern governors, though it never materialised into a regional programme (MGGRA, 2017). Democratic victories in the recent 2018 governors' races, however, have raised prospects of resurrecting the accord.

Adapting to climate change

Under the Global Change Research Act of 1990, the US Global Change Research Program (made up of various federal agencies) is required to put out a National Climate Assessment at least once every four years. To that end, the administration released the Fourth National Climate Assessment in two volumes in 2017-18, led by NOAA. Volume I provides an overview of the scientific evidence of how climate change is affecting the physical earth system across the United States, while Volume II addresses the impacts of climate change to help decision makers and various stakeholders develop response strategies. The report highlights a number of adverse economic and social impacts from climate change, including inland and coastal flooding, heat waves, wildfires, coastal infrastructure damage, drought and crop failures, and adverse energy and health effects (US GCRP, 2018).

Given the broad geographic footprint of the United States, the impacts of a changing climate will be felt differently across the country. The National Climate Assessment finds that average temperatures have increased by 1.2° Fahrenheit since 1900, with the Western parts of the country experiencing the most rapid warming. Looking ahead, annual average temperatures are expected to increase by a minimum of 2.3° Fahrenheit by mid-century relative to a 1986-2015 baseline, and by a maximum of 11° under a higher scenario. The report also predicts greater intensity of hurricanes, reduced snowpack and water supply in Western states, and rising sea levels in the Northeast and the Gulf of Mexico. Overall, under a scenario in which emissions continue to grow on their current trajectory, the assessment predicts employment costs to the US economy of

USD 155 billion annually by 2090, mortality costs of USD 141 billion, and coastal property damage of USD 118 billion per year.

The Notre Dame Global Adaptation Initiative Country Index ranked the United States as the 22nd least vulnerable country in the world and 12th most prepared to face climate change impacts. The index indicates that agricultural capacity, the projected change of cereal yields, and the projected change of annual river flows are among the most vulnerable areas to the impacts of climate change in the United States (University of Notre Dame, 2019).

The energy sector of the United States is already affected by climate change and extreme weather across all regions and all energy technologies. Increases in air and water temperatures, increasing probability of heat events, decreasing water availability, sea level rise, and increased storm events are likely to continue affecting the energy sector in the future. Extreme heat events can increase electricity demand while reducing electricity generation capacity and decrease the efficiency of the transmission grid. In particular, the US oil and gas sector has projects and operations in regions of greatest projected temperature rise and impact (e.g. in the Arctic) and potential sea level rise, and operations that demand large volumes of water (e.g. shale gas). Climate impacts can affect exploration, production, transport, infrastructure (terminals, pipelines, refining and processing plants) and neighbouring communities. Upstream, midstream and downstream oil and gas operations and facilities are generally designed to be resilient to historic weather-related events within fence-line operations. Generally, projects are designed with safety factors for one-time extreme weather events (e.g. major flood event). However, climate change has the greatest impact on the industry through the damage caused to communities and disruptions outside of facility fence lines.

A US Government Accountability Office study from September 2017 concluded that the federal government had already incurred costs of over USD 350 billion due to extreme weather and fire events. It noted a 2016 study by the Office of Management and Budget and the Council of Economic Advisers that estimated recurring costs to the federal government of USD 12 billion to USD 35 billion annually by mid-century, and USD 34 billion to USD 112 billion by late century (US Government Accountability Office, 2017).

Led by NOAA, the federal government put in place the Climate Resilience Toolkit website in November 2014 that offers scientific information and recommendations to help states and local communities mitigate the impacts of and respond to extreme weather events (U.S. Climate Resilience Toolkit, 2019). The toolkit includes recommended steps that local governments can take to assess risks as well as to develop a resilience action plan. The toolkit also includes a collection of nearly 200 digital tools, including maps, green infrastructure cost-benefit analyses and agricultural risk mitigation tools, among many others. It also includes a sizeable library of case studies that businesses and communities can use as examples to develop their own plans.

Beyond the federal government, many states and local communities have developed climate adaptation plans, especially coastal areas and those that have already seen an uptick in extreme weather events (see also section on climate change in Chapter 12, "The Resilience of US Energy Infrastructure").

However, there are still many opportunities to improve the climate resilience of the energy sector in the United States. First, standardised and accepted scenarios for climate change's future impacts and the vulnerabilities of power systems could be developed and used as the basis for infrastructure planning and investment decisions. Moreover, the understanding of climate change impacts on power systems themselves could be improved, as well as their interdependences, for example, as such climate change impacts relate to supply chains and transportation systems. Developing better equipment and facility design standards could also be beneficial, as well as tools to more precisely assess prospective costs and benefits of resilience investments, including assessment of the cost-effectiveness of past resilience investments.

Assessment

From 2005 to 2017, energy-related CO_2 emissions fell by 17% due to lower energy demand (in the aftermath of the financial crisis and subsequent economic slowdown), energy efficiency, the shift from coal to natural gas use in power generation, and the steady increase of renewable electricity. The largest emissions reduction happened in power generation, with a decline of 28% below 2005 levels. In 2017, power generation accounted for 38%, and the transport sector for 36%, of total CO_2 emissions, according to IEA data. Following the closure of the oldest coal-fired power plants in the past few years, as well as many years of policies controlling local air pollutants, NO_x and SO_x emissions have also declined.

At the federal level, the National Security Strategy underlines that the United States is pursuing a balanced approach to climate change, which aims at reducing traditional pollution as well as GHGs while expanding the economy. US environmental and climate policies continue to face a lack of bipartisan support and frequent course changes, which exposes regulatory action to legal challenges, and creates significant uncertainty for states and industry alike.

In 2017, the US government decided to withdraw from the Paris Agreement, but remains open to re-engage with the Paris Agreement process on improved terms for the United States. The United States had set a Nationally Determined Contribution to reduce GHG emissions by 26-28% below 2005 levels by 2025.

A core focus for the administration is a policy agenda to reduce the regulatory burden on industry (through Executive Orders 13771, 13777 and 13783 of 2017). Under Executive Order 13783, the EPA was directed to review all existing rules, a process the agency is currently undertaking. Federal agencies have revoked or are in the process of revoking 60 environmental regulations.

The federal government has an obligation to regulate GHG emissions under the Clean Air Act through the EPA, following a Supreme Court ruling in 2007. The administration in June 2019 finalised the ACE rule to replace the previous CPP to address GHG emissions from the power sector. The new rule sets out common emissions guidelines for states to encourage efficiency improvements at existing coal-fired plants. Compared with the CPP, the ACE rule is likely to delay the closure of newer coal-fired power plants and result in far fewer GHG emissions reductions over the next decade (estimates are up to ten times less). Existing EPA rules on mercury, NO_x and SO_x pollutants have also been under review. EPA decided not to change the SO_x/NO_x pollution limits.

The administration in August 2018 announced a new proposal to freeze CAFE standards for light-duty vehicles at the 2021 level through 2026. The proposal, however, has raised controversy over the right of the state of California to maintain more ambitious emissions standards than the ones mandated by the EPA. California has a waiver under the Clean Air Act to set more stringent air pollution standards due to its local air pollution, and 13 states have followed its lead.

Over the last decade, minimum fuel economy standards have stabilised the transport sector‘s energy consumption, after two decades of strong demand growth, and yielded incentives for the automotive industry to develop more efficient internal combustion engines or EVs using batteries and fuel cells. Ambitious fuel economy standards with a long timeline are paramount for a continuation of this trend and for maintaining the competitiveness of the US auto industry in the global marketplace. However, in light of the recently proposed relaxation of CAFE rules, if the United States were to experience continued growth in automobile ownership – especially stronger consumer preferences for larger sport-utility vehicles – along with an uptick in vehicle miles travelled, the United States may see a reversal of energy efficiency gains in transportation, even in a context of growing EV demand.

Since the start of the LTO revolution in the United States, large volumes of associated gas as a by-product of oil production have been either vented or flared as there was little incentive to market the associated gas or build and upgrade the necessary infrastructure needed to transport it. Flaring is particularly prominent in the Permian and Bakken shale oil producing regions. The start of LNG exports has raised the opportunity cost of flaring, and a regulatory push by states has borne results in reducing methane and CO_2 emissions. However, the administration’s plans to undo previous federal regulatory action to limit methane from oil and gas production could result in a reversal or slowdown of the recent trend in which methane emissions have been in decline.

Beyond the federal level, a large share of the US climate change policy is driven by state and local action, as well as efforts by the private sector. In response to federal withdrawal from the Paris Agreement, several US states, cities and businesses established the US Climate Alliance in order to continue to engage with the international community on the Paris Agreement. Moreover, a number of states, most notably California, have carbon reduction policies in place, including cap-and-trade programmes. Nonetheless, regional policy action cannot fully replace the importance of national carbon reduction policy.

Looking ahead, current trends suggest that energy-related CO_2 emissions in the United States are likely to continue to slowly decline. In the power sector especially, CO_2 emissions are likely to decline further with the strong growth of natural gas and renewables, but this trend may slow in the subsequent decade. Faster-than-expected nuclear plant retirements and the continued use of coal could lead to a rebound of emissions in the power sector. The oldest coal plants have retired and the new ones are likely to stay online for longer under new, less onerous environmental rules. Transport emissions are also expected to continue to rise, and the same holds for emissions from increasing industrial activity as well as fugitive emissions from oil and natural gas production.

Recommendations

The US government should:

- ☐ Set effective and streamlined regulations to enable the United States to remain a global leader in emissions reduction and clean technologies.
- ☐ Set future CAFE standards to create investment certainty and maintain US automobile competitiveness, operate a fuel-efficient vehicle fleet to set a precedent for the market, and support state-level efforts to decrease energy demand in the transportation sector.
- ☐ Address methane emissions and flaring by disseminating R&D results developed by the DOE, national laboratories and industry, while ensuring sufficient and timely investment in oil and gas supply infrastructure, through permitting and licensing.
- ☐ Refine and update tools to inform planning and investment decisions to improve the climate resilience of the US energy sector.

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4. Energy efficiency

Key data

(2017)

TFC: 1 523.7 Mtoe (oil 49.3%, natural gas 22.7%, electricity 21.1%, bioenergy and waste 5.3%, coal 1.1%, heat 0.4%, solar 0.1%) -3.3% since 2007

Consumption by sector: transport 41.0%, industry 26.9%, residential 16.1%, commercial 16.0%

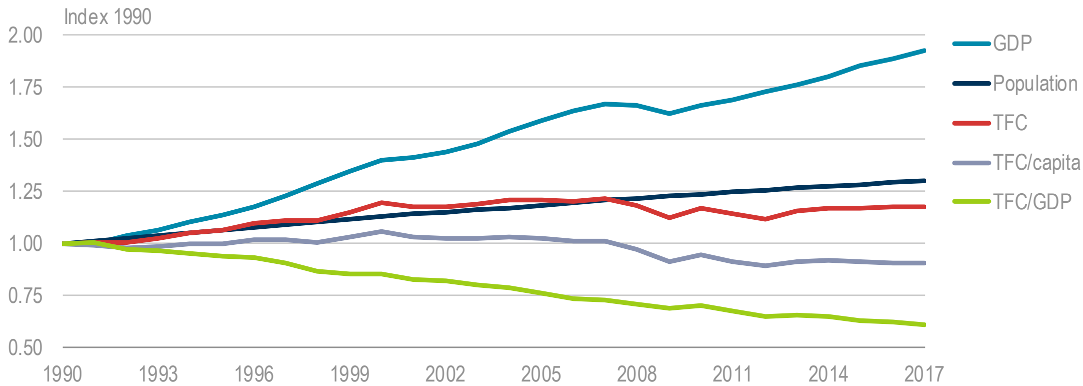
Energy consumption (TFC) per capita: 4.7 toe (IEA average 2.9 toe)

Energy intensity (TFC/GDP): 88 toe/USD million PPP (IEA average: 74), -21% since 2007

Overview

The United States (US) has seen a reduction in energy intensity in recent decades. From 1990 to 2017, the US population grew by around 30% and gross domestic product (GDP) nearly doubled, while total final energy consumption (TFC) increased more slowly by 18%. Especially since the decline in the economy and energy consumption after the financial crisis in 2008-09, TFC has decoupled from economic growth, and slightly also from population growth (Figure 4.1).

Figure 4.1 Energy supply and drivers, 1990-2017

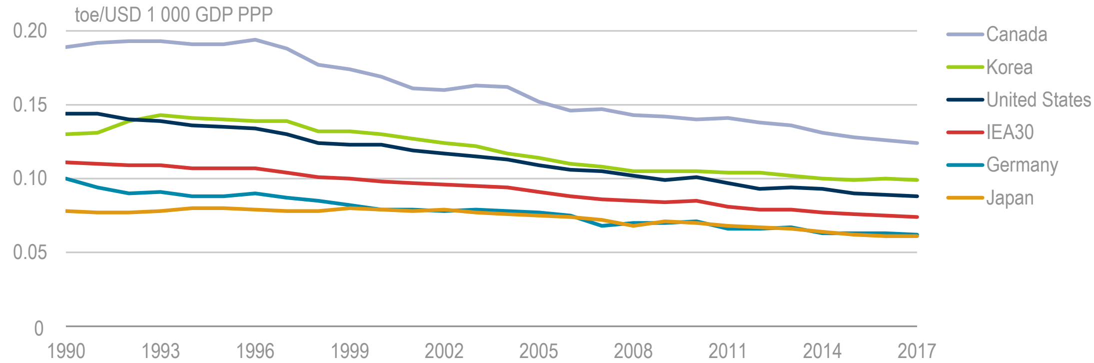


US energy intensity is declining and TFC stalling despite continued economic growth.

Notes: GDP data are in billion USD 2010 prices and purchasing power parity (PPP).
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

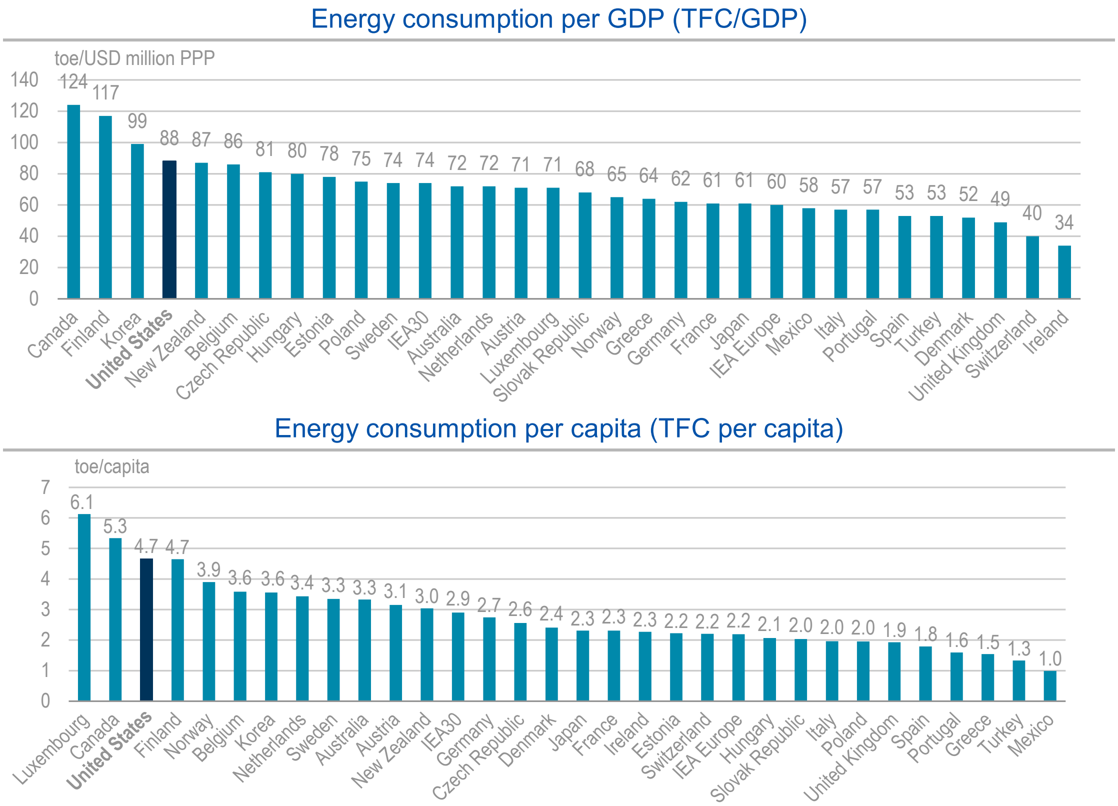
Notably, among International Energy Agency (IEA) member countries, the United States has seen more rapid improvement in energy efficiency compared with many other large economies (Figure 4.2). Despite this improvement, US energy intensity is one of the highest among IEA member countries (Figure 4.3).

Figure 4.2 TFC per GDP in the United States and selected IEA countries, 1990-2017



Notes: toe = tonnes of oil equivalent. Energy intensity in TFC per GDP (2010 prices with PPP).
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Figure 4.3 Energy intensity in IEA member countries, 2017



Despite energy efficiency improvements in recent years, the United States has among the highest energy-intensive economies in the IEA, measured both per GDP and per capita.

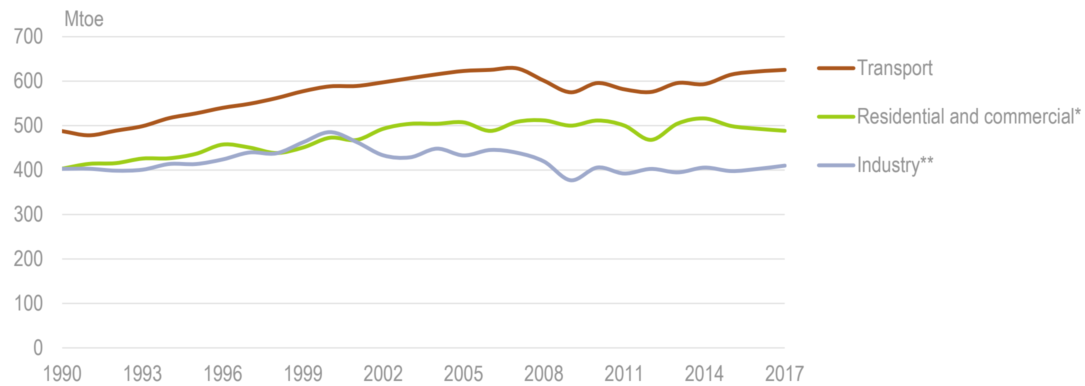
Notes: Energy intensity in TFC, not including the energy transformation sector. GDP data are in billion USD 2010 prices at PPP.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

In 2017, the United States had the fourth-highest TFC per GDP, 19% above the IEA average. Measured as per capita energy consumption, the United States placed third-highest in the comparison, 61% above the IEA average and around double the IEA median level.

There is potential for improving energy efficiency across all sectors, from improving efficiency of appliances and vehicles to setting stricter energy performance standards for buildings, including those owned by the public sector. Saving energy is often more cost-efficient than producing energy, and it can be combined with additional economic growth, job creation and environmental protection.

In 2017, US TFC was 1 524 million tonnes of oil equivalent (Mtoe), 3% below consumption in 2007. The transport sector accounts for the largest share, followed by residential and commercial buildings and the industry sector (Figure 4.4).

Figure 4.4 Final energy consumption by sector, 1990-2017



Transport accounts for over 40% of TFC, and is the only sector that has increased in recent years, while energy use in buildings and industry has been relatively stable.

*Includes the sectors residential, commercial and services, agriculture, forestry, and fishing.

**Includes non-energy use.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Institutional governance of energy efficiency policies

Energy efficiency policy is directed by the federal, state and local governments in the United States, and in some instances overlap with one another. Importantly, energy efficiency enjoys a considerable degree of bipartisan support based on benefits to reducing emissions, lowering energy bills and boosting energy security. At the federal level, energy efficiency policies are mostly administered by the Department of Energy (DOE) and the Environmental Protection Agency (EPA).

Policies and regulations for energy efficiency are carried out through a combination of mandatory and voluntary standards, as well as tax incentives, technical assistance, and research and development (R&D) support. Though the administration had proposed cuts to several energy efficiency programmes, the 2018 omnibus spending bill – passed by Congress in March 2018 – increased funding for the DOE's Office of Energy Efficiency and Renewable Energy by 11%, while the DOE's Advanced Manufacturing Office saw increased funding of 18%, and the Building Technologies and Vehicle Technologies Offices each saw 10% increases.

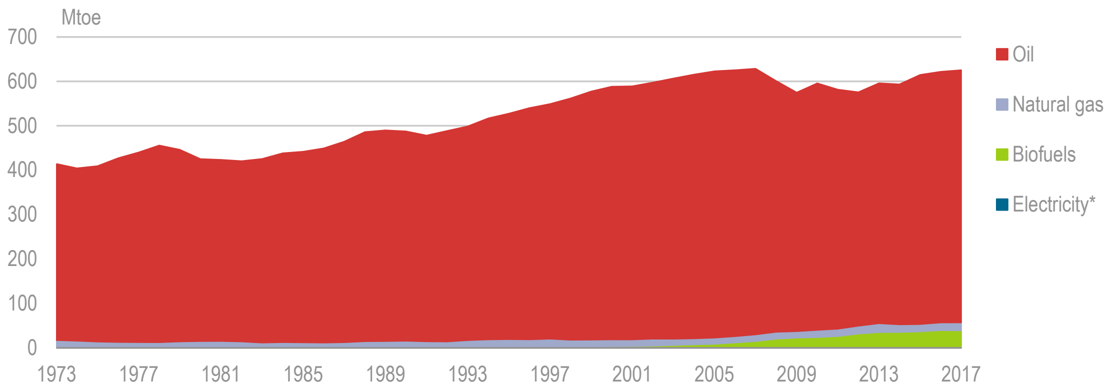
In 2013, the president set a target for energy productivity (the inverse of energy intensity) to double between 2010 and 2030. This target was later supported by a strategic roadmap released by the DOE in 2015. The current administration has not agreed to any targets as it has a policy agenda to reduce regulatory burden (which includes energy efficiency standards/regulations).

Transport sector

Energy consumption in the transport sector

In 2017, the transport sector consumed 625 Mtoe, 41% of TFC in the country. Total transport energy demand increased steadily until 2007, when it peaked at 629 Mtoe. After the financial crisis in 2008, demand fell, but has picked up again in recent years (Figure 4.5). Between 2012 and 2017, transport energy demand increased by 9%, and is on a trajectory towards record high levels.

Figure 4.5 TFC in transport by source, 1973-2017



Transport energy demand is increasing again, after a post-financial crisis decline. The sector is dominated by oil fuel, although biofuels have increased rapidly in the last decade.

*Not visible on this scale. EV charging done at home is registered as residential consumption.

Note: The transport sector demand excludes international aviation and navigation.

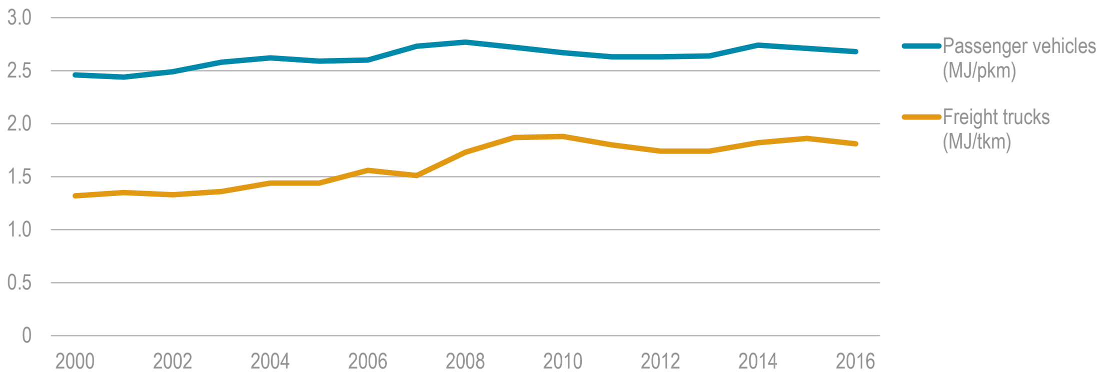
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Oil products dominate with 91% of total transport energy consumption in 2017. However, biofuels have nearly tripled in a decade, and accounted for 6% of consumed energy in 2017, mostly from ethanol used in road transport (see further in Chapter 5, "Renewable Energy"). The rest is mainly natural gas used in pipeline transport and a minor share of electricity in rail transport and electric road transport (electric vehicle [EV] charging done at home is registered as residential consumption).

Road transportation consumes most of total transport energy demand. In 2017, road transportation accounted for 85% of total domestic transport demand. Domestic aviation is also an important transport mode in a large country such as the United States, and accounts for 9% of total domestic transport demand. The rest is energy consumed in pipelines, domestic navigation and railways.

The fuel intensity of passenger cars has been relatively stable in the United States, with a slight reduction in the last few decades. However, as the passenger load factor (number of passengers per vehicle) has dropped, the overall energy intensity for passenger cars has increased (Figure 4.6). Between 2000 and 2016, the energy use per passenger kilometre (pkm) increased by 9%. For freight trucks, the trend is even stronger. Energy use for transporting one tonne of goods one kilometre – a tonne kilometre (tkm) – grew by 37%. However, the energy intensities have been more stable in recent years.

Figure 4.6 Energy intensity in road transport by mode, 2000-16



Road transport accounts for 85% of total domestic transport demand; energy intensity for both passenger cars and freight trucks has increased since 2000, though flattened recently.

Note: MJ = megajoule.

Source: IEA (2018), *Energy Efficiency Indicators 2018*, www.iea.org/statistics/.

Energy efficiency policies in the transport sector

The United States has had Corporate Average Fuel Economy (CAFE) standards in place since the Energy Policy and Conservation Act (EPCA) of 1975 to mitigate oil consumption growth.

Since 2009, the administration harmonised CAFE standards – administered by the National Highway Traffic Safety Administration (NHTSA) – with vehicle emissions standards, established by the EPA. At the time, the agencies laid out standards for two periods, 2012-16 and 2017-25 (NHTSA, 2018). The standards are supposed to achieve fuel economy levels of 48.7 miles per gallon (mpg) to 49.7 mpg for model year 2025 vehicles (EPA, 2012). Given the integration of the North American automobile market, these standards were also harmonised with those in Canada.

As part of the rule making, the EPA and NHTSA agreed to perform a midterm evaluation of the standards for 2022-25. In 2016 the EPA expedited its review and issued a finding that held that the standards were appropriate (EPA, 2016). However, in 2017 the administration reopened the review, in conjunction with the NHTSA, and in August 2018 announced a new proposal, the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks. The SAFE rule proposes to revise the standards on both economic and safety grounds, with the preferred option to freeze 2021 standards at around 37 mpg for passenger cars and 31.3 mpg for light-duty trucks, through 2026 (Federal Register, 2018). The rule is expected to be finalised in 2019.

A complicating factor for the federal government in implementing the SAFE rule will be a Clean Air Act waiver that California was granted in 2013, allowing the state to set emissions standards more stringent than those established by the federal government. California's current standard is aligned with the existing federal standards, but freezing the federal standards at 2021 levels under the SAFE rule would create a discrepancy between the federal and California standards (US Department of Transportation and EPA, 2018). Moreover, 13 other states also follow California's standards, together accounting for over 40% of the automobile market. As such, automakers could encounter uneven standards across states.

Following its finalisation, the new rule is expected to face lawsuits from environmental groups and states. Moreover, California plans to launch a legal defence of its waiver, which the SAFE plan proposes to revoke. Ultimately, the final outcome will likely be decided by the courts.

The administration in 2011 also put in place the first-ever fuel efficiency and greenhouse gas (GHG) emissions standards for heavy-duty vehicles. The standards applied to model years 2014-18 (Phase 1) and vary by type of vehicle and, based on a vehicle's specifications, require between 6% and 23% emissions reduction relative to a 2010 baseline. Phase 2 standards were finalised in 2016 and apply to model years 2021-27, and include targets of 16-25% carbon dioxide reductions compared with Phase 1 (ICCT, 2016).

Electric vehicles

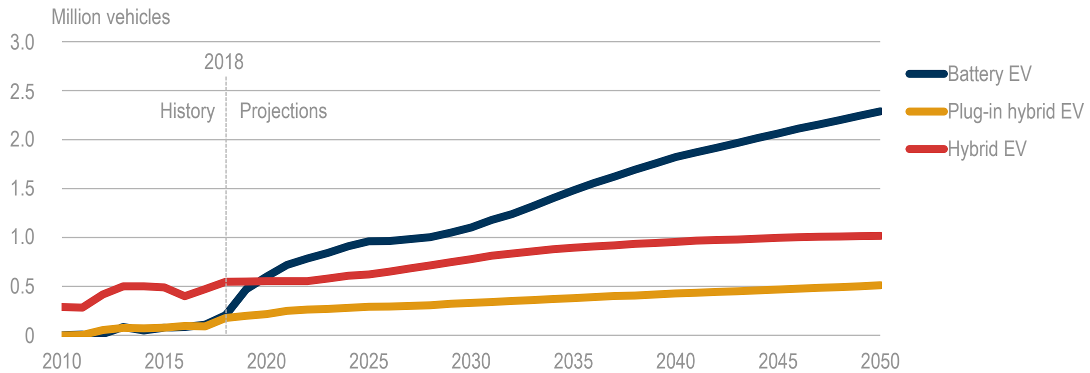
Policy support is a key driver of EV uptake in the United States, which also improve fuel efficiency of the vehicle fleet. In 2017, EVs, including pure battery EVs and plug-in hybrid EVs, accounted for 1.2% of new car sales in the United States. In 2017, the total number of EVs in the US vehicle fleet was 762 060.

Beyond vehicle standards, federal financial incentives also attempt to boost the uptake of EVs, which will have the added effect of boosting energy efficiency. The main policy tool offered by the federal government is a tax credit for purchases of EVs that meet specified emissions standards. As part of the Emergency Economic Stabilization Act of 2008, Congress authorised tax credits of USD 2 500 to USD 7 500 for each new EV purchased (depending on vehicle size and battery capacity), though imposed a manufacturer-based limit on the credit, so it applies to the first 200 000 vehicles sold by a given company (DOE, 2018a). GM and Tesla reached this limit at the end of 2018, so purchases of their cars can no longer claim the full USD 7 500 credit.

The United States also offers tax credits for EV charging stations, and the DOE supports R&D with USD 690 million in 2018 across the Vehicle Technologies, Bioenergy Technologies and Hydrogen and Fuel Cell Technologies Offices. It also provides loans under its Advanced Technology Vehicles Manufacturing programme (with USD 16 billion of remaining authority) to automakers and component makers for constructing or retooling manufacturing plants to produce advanced batteries or other components, or EVs. The DOE also offers up to USD 4.5 billion in loan guarantees for innovative renewable energy and efficient energy projects, including EV charging infrastructure. Lastly, the German automaker Volkswagen (under a recently created unit, Electrify America), is also pursuing a sizeable buildout of EV charging stations throughout the United States as part of its USD 2 billion settlement with the EPA and California Air Resources Board over the company's diesel emissions scandal (beyond investments planned by private companies in anticipation of growing demand).

California is leading market deployment. In 2016 and 2017, the governor of California issued executive orders to target 1.5 million zero-emission vehicles (ZEVs) on the road by 2025 and 5 million ZEVs by 2030 (CARB, 2018a). The targets are complemented by the state's clean vehicle rebates system and ZEV programme, which requires car manufacturers to sell a certain share of EVs or to buy credits from other companies with higher EV sales (CARB, 2018b). Following California's lead, nine other states (Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont) have also adopted ZEV programmes (EIA, 2016). In addition to ZEV targets, California's governor in 2018 also announced a USD 2.5 billion initiative to build 200 hydrogen fuelling stations and 250 000 EV charging stations in the state by 2025 (Green Car Congress, 2018).

Figure 4.7 Growth and projections for EV sales, 2010-50



The Energy Information Administration (EIA) projects increasing EV sales, but EVs are expected to account for just 23% of the vehicle fleet by 2050.

Source: EIA (2019), *Annual Energy Outlook 2019*, www.eia.gov/outlooks/aeo/.

Over the last decade, minimum fuel economy standards have stabilised the transportation sector's energy consumption, after two decades of strong demand growth, and yielded incentives for the automotive industry to develop more efficient internal combustion engines or EVs using batteries and fuel cells. However, in light of the recently proposed relaxation of CAFE rules, if the United States were to experience continued growth in automobile ownership – especially stronger consumer preferences for larger sport-utility vehicles – along with an uptick in vehicle miles travelled, the United States may see a reversal of energy efficiency gains in transportation, even in a context of growing EV demand.

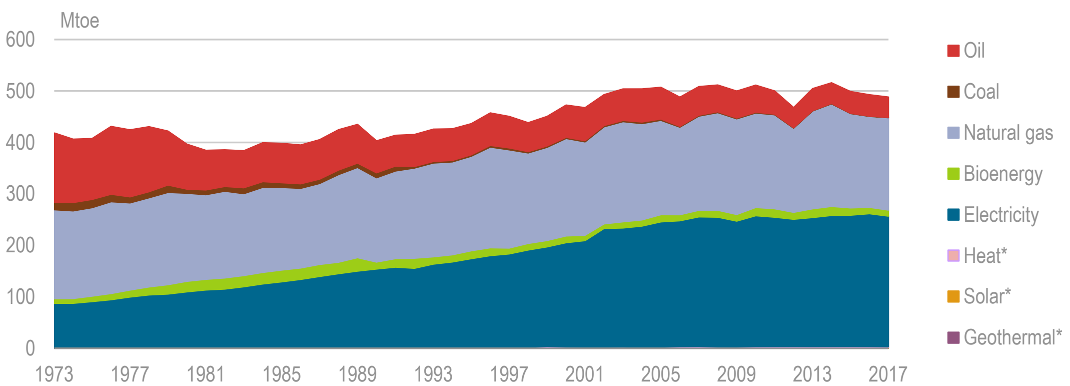
The DOE oversees the Energy Efficient Mobility Systems Program, which will conduct early-stage R&D to investigate how disruptive forces such as automated, connected, electric and/or shared vehicles will affect energy consumption in transportation (DOE, 2019a). It also helps communities determine how they can plan for and encourage energy efficiency increases in mobility.

Residential and commercial

Energy consumption in the buildings sector

In 2017, the residential and commercial sectors together consumed 488 Mtoe, or 32% of TFC in the country, with roughly equal shares. Since 2007, residential energy consumption decreased by 8.3%, whereas commercial consumption increased slightly by 0.8%, resulting in around 4% of total decline (Figure 4.8). Electricity accounts for 52% of total energy consumption in the sectors and natural gas for 37%. The rest is mainly oil (8%) and bioenergy (2%).

Figure 4.8 TFC in residential and commercial sectors by source, 1973-2017



Residential and commercial energy demand has flattened around 500 Mtoe, with electricity and natural gas together accounting for nearly 90% of total energy use in the sectors.

*Not visible on this scale.

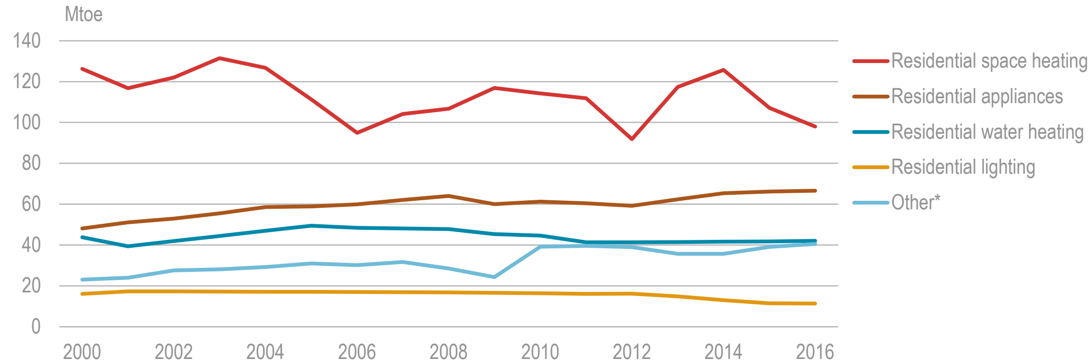
Note: The commercial sector includes commercial and public services, agriculture, forestry, and fishing.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

As in most countries, space heating accounts for the largest energy demand in the residential sector (Figure 4.9). Natural gas is the main source for heating, supplying around two-thirds of energy demand for space and water heating. The remaining third of residential heating is supplied by oil and electricity, plus a small share of biofuels. Oil consumption has declined as a result of energy efficiency improvements and a switch to mainly natural gas boilers. Since 2006, oil consumption in the residential and commercial sectors decreased by 27%.

Energy efficiency of building shells is improving, which reduces the overall energy intensity for heating in the residential sector. From 2000 to 2016, energy use for residential heating per square metre of floor area declined by 19%, and similarly, energy use for water heating per dwelling fell by 17% (Figure 4.10).

Figure 4.9 Residential energy consumption by category, 2000-16



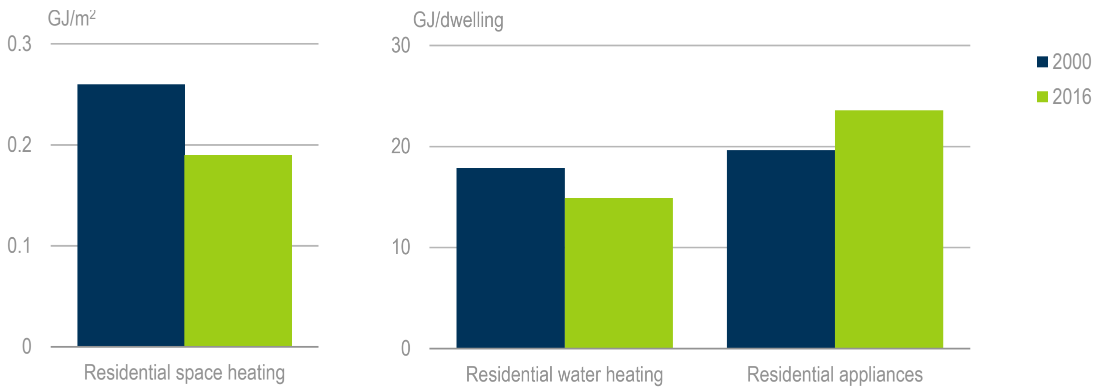
Space and water heating account for over half of residential energy consumption, but energy demand for appliances is increasing.

**Other* includes residential space cooling and residential cooking.

Source: IEA (2018), *Energy Efficiency Indicators 2018*, www.iea.org/statistics/.

Residential appliances consume the second-highest share of total residential energy demand after heating, which also explains the high and growing share of electricity consumption in the sector. With rapid growth in the use of home electronics, such as televisions, computers and smart devices, total energy consumption by appliances increased by 38% between 2000 and 2016 (Figure 4.9). Correspondingly, energy intensity for appliances (in energy consumption per dwelling) increased by 18% (Figure 4.10).

Figure 4.10 Residential energy intensity, 2000 and 2016



Energy efficiency improvements have resulted in lower energy intensities for space and water heating in residential buildings, while the energy intensity of appliances is increasing.

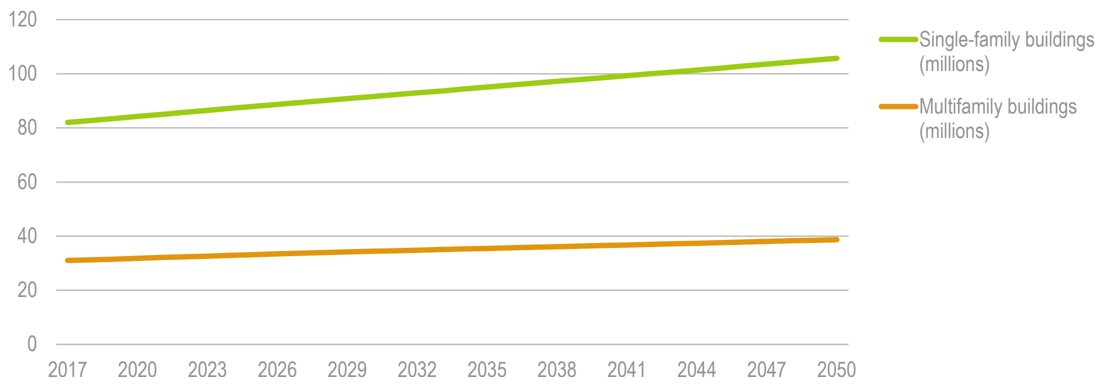
Note: GJ = gigajoule; m^2 = square metre.

Source: IEA (2018), *Energy Efficiency Indicators 2018*, www.iea.org/statistics/.

Improved energy efficiency has stabilised energy consumption in the sectors, despite a growing building stock. The US population is projected to continue to grow steadily in the coming decades, which is reflected in the outlook for the residential building stock. In the EIA projections, the number of single-family homes is projected to increase from

82 million in 2017 to 106 million in 2050, a total growth of 29%. Multifamily households are expected to increase by 25%, from 31 million in 2017 to 39 million in 2050 (Figure 4.11). Further energy efficiency improvements in buildings are therefore required to tackle energy consumption in the residential sector.

Figure 4.11 Outlook for household building stock per type, 2017-50



From 2017 to 2050, single-family homes will grow by 30% and multifamily buildings by nearly 40%, according to EIA projections.

Source: EIA (2019), *Annual Energy Outlook 2019*, www.eia.gov/outlooks/aeo/.

Energy efficiency policies in the buildings sector

Tax credits

The federal government offers households tax credits for energy efficiency upgrades made to their homes. Specifically, the government currently offers the Residential Energy Efficient Property Credit of 30% for installation of qualified energy equipment, including solar equipment, wind turbines and fuel cells (Smarter House, 2018). In addition, under the Bipartisan Budget Act of 2018, Congress extended the Non-Business Energy Property Credit of 10% (up to USD 500) for qualified energy-saving improvements, such as insulation and high-efficiency heating and air-conditioning systems (ACEEE, 2018a). The credit will phase down after 2019 until the end of 2021, when it fully expires.

Several energy efficiency tax credits, however, expired at the end of 2017. Prior to that, builders of new efficient homes could claim a business tax credit of USD 2 000, while commercial buildings previously received a business tax deduction of up to USD 1.80 per square foot for new or retrofitted buildings with efficient lighting, insulation, and heating and cooling systems (ACEEE, 2018b; DOE, 2019b). Tax credits previously issued to manufacturers of efficient appliances are also no longer in effect.

In addition to the federal government, a number of states offer energy efficiency tax benefits, especially as sales or property tax exemptions for installing qualified equipment. Utilities also often provide rebates to customers for purchasing energy-efficient appliances or equipment.

Building codes

Building codes continue to be an important driver of efficiency improvements in the residential and commercial sectors. Building codes establish mandatory efficiency requirements for new and renovated buildings, covering areas such as wall insulation, windows and air leakage. The DOE estimates that 75% of buildings in the United States will be either new or renovated by 2035, offering considerable scope for improving the efficiency profile of the building stock (DOE, 2016a).

In the United States, there are no nationally mandated building energy codes, but voluntary model codes. States can choose to set building codes informed by model energy codes. Two private organisations develop model energy codes through a stakeholder process: the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 and the International Energy Conservation Code (IECC, developed by the International Codes Council). The IECC applies to both residential and commercial buildings while the ASHRAE standard applies only to commercial buildings. States may adopt these codes, or they can choose to develop their own separate codes. The latest IECC was issued in 2018, while the latest ASHRAE 90.1 was issued in 2016. The codes are updated every three years (ACEEE, 2018c).

The DOE, under the Building Energy Codes Program, is legally required to participate as a stakeholder in the model code setting process. The department also evaluates the energy savings of the model codes, tracks the adoption of energy codes across states, and provides technical assistance and training to states in adopting the codes. Enforcement of the codes takes place by inspectors at the local level (DOE, 2018b).

Beyond the prescriptive model codes, there are a number of voluntary codes, standards and certifications that have also achieved results in terms of improving energy efficiency, including ASHRAE 189.1, Leadership in Energy and Environmental Design (LEED) certification, and the DOE's Zero Energy Ready Home. Several states also have higher efficiency codes, including Massachusetts and New York. California's 2019 Building Energy Efficiency Standards require all new homes starting in 2020 to have advanced efficiency measures as well as rooftop solar installations.

In addition, other tracking and benchmarking tools also exist to provide information on energy use and efficiency of buildings. The most common for commercial buildings are LEED and ENERGY STAR Portfolio Manager, while the Residential Energy Services Network, Home Energy Rating System and ENERGY STAR certification are prevalent in the residential sector.

California, New York and Vermont are working with utilities and other partners on so-called pay-for-performance pilot programmes, which allow savings from energy efficiency improvements to be monetised in real time, based on meter readings.

Appliance and equipment standards

Under the EPCA of 1975, Congress directed the DOE to develop and implement minimum efficiency standards to lower energy consumption on appliances and equipment. Subsequent legislation has called on the department to upgrade and strengthen those standards (DOE, 2018c). The DOE's Building Technologies Office administers the Appliance and Equipment Standards Program, which imposes minimum energy conservation standards on over 60 types of appliances and equipment.

The products covered by these standards account for around 90% of household energy consumption and 60% of commercial building energy demand. Unlike with building codes, appliance and equipment standards are set at the national level to avoid patchwork standards for manufacturers across states. Though states are allowed to adopt their own appliance standards, federal standards for a given product category supersede state standards, even if the state standard is stronger. The DOE is required by law to review standards at least once every six years, including to reflect technological gains, and set standards to levels that are "technically feasible and economically justified" (DOE, 2018d).

The Federal Trade Commission (FTC) has overseen the EnergyGuide labelling programme for appliances and equipment since 1980. The labels provide consumers information on the energy consumption and costs associated with a given appliance in order for them to make more informed choices. Under the Energy Policy Act of 2005, Congress directed the FTC to update its guiding labels, which took effect in 2007. Most recently, the FTC imposed labelling requirements on select consumer electronics such as televisions in 2010 (ACEEE, 2018d).

Lastly, ENERGY STAR is a voluntary programme that is jointly administered by the EPA and the DOE, which certifies products that meet predetermined energy efficiency criteria. The EPA defines ENERGY STAR specifications for individual product classes, ranging from appliances to computers, home electronics and lighting (DOE, 2018f). The labelling system has proven successful in driving consumers to product choices that achieve both energy and cost savings. The EPA has also developed ENERGY STAR ratings for commercial and residential buildings. Since 2011, all ENERGY STAR classifications undergo third-party certification.

Co-generation

The EPA estimates that around two-thirds of energy consumption from electricity generation is released as wasted heat. As such, co-generation[1] installations that can capture the heat and use it for space heating, cooling, water heating or industrial processes hold significant potential to increase energy productivity. The EPA estimates that co-generation can reach efficiencies of over 80% compared with 50% for conventional technologies such as grid-supplied electricity or on-site boilers (EPA, 2019b). The Public Utilities Regulatory Policies Act, which permits private entities to sell power at a utilities avoided cost, was a large driver of co-generation installations in the United States, as were broader measures to deregulate the electricity sector. Co-generation is used in factories, residential and commercial buildings, and municipal facilities, though it has not experienced much growth in new installations in the past few years.

Under the Bipartisan Budget Act of 2018, Congress reinstated a 10% investment tax credit for co-generation projects up to 50 megawatts (MW) in capacity (limited to the project's first 15 MW) that exceed 60% energy efficiency and that commence construction by the end of 2021 (ICF, 2018). Facilities that use a minimum of 90% biomass are exempt from the efficiency requirement. In addition, the act also included other benefits for co-generation projects, including depreciation allowances. Notably, a major factor supporting co-generation projects is low and stable natural gas prices. In this regard, the shale gas production boom has brought an extended period of affordable gas resources, which could improve the investment case for co-generation projects (GE Power, 2017).

[1] *Co-generation* refers to the combined production of heat and power.

Federal buildings

The federal government is the largest energy consumer in the United States. The DOE estimates that the federal government operates over 350 000 energy-consuming buildings and 600 000 vehicles. As such, efforts by the federal government to trim energy consumption have important bearings on the overall energy consumption of the US economy.

Efforts to improve energy efficiency of federal agencies are overseen by the DOE's Federal Energy Management Program (FEMP) as directed by statute. Among the mandates of the programme are to issue legislative and executive guidance, facilitate technology integration, leverage funding resources, provide technical assistance, track agency accountability, and develop accredited training programmes (DOE, 2018e). FEMP works with multiple stakeholders, including federal agencies, national labs, Congress, and industry in order to achieve the energy efficiency goals of federal agencies. FEMP also oversees public-private partnerships on energy savings projects at federal agencies. The DOE estimates FEMP's efforts have achieved a 49% reduction in energy intensity since 1975 and cost savings of around USD 50 billion.

The Office of Federal Sustainability, administered by the White House Council on Environmental Quality, co-ordinates policy on energy and environmental sustainability across federal agencies, working closely with the FEMP (Council on Environmental Quality, 2018).

The administration issued Executive Order 13834 in May 2018, which reduces the directives that guide energy efficiency measures for buildings, vehicles and overall operations of federal agencies. Specifically, the order removes non-statutory requirements for energy efficiency and grants more discretion to agencies in improving their operational efficiency. Moreover, it encourages agencies to use performance contracting to improve energy efficiency, to avoid upfront costs to the government.

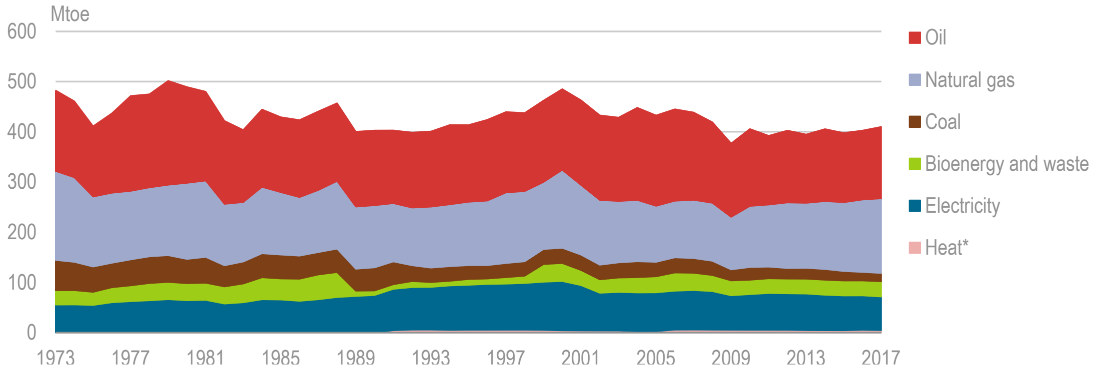
Industry

Energy consumption in the industry sector

In 2017, the industry sector consumed 410 Mtoe, 27% of US TFC. Industry energy consumption declined by 7% from 2007, the second-largest drop among end-user sectors following the residential sector. Consumption fell significantly during the financial crisis and has since stabilised on a level below pre-crisis consumption (Figure 4.12).

Natural gas and oil are the largest energy sources in industry, each accounting for over one-third of total energy consumption in the sector. In the last decade, there has been a fuel switch from oil, which decreased by 18%, to natural gas, which increased by 28%. The remaining energy consumption is mainly electricity, bioenergy and waste, and coal.

Figure 4.12 TFC in industry by source, 1974-2017



Since the economic crisis years, industrial energy consumption has stabilised around 400 Mtoe, of which oil and natural gas together account for 70%.

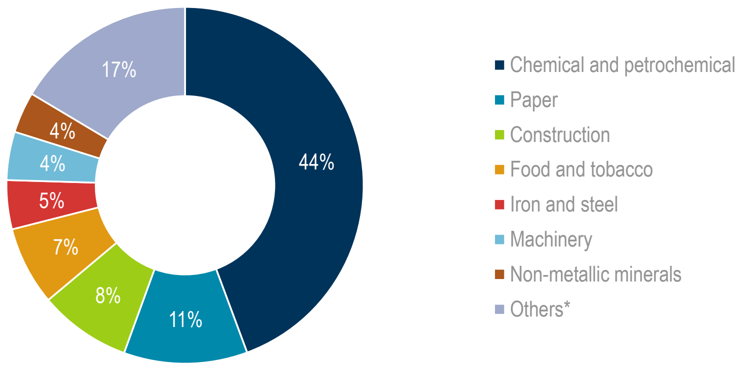
*Not visible on this scale.

Notes: Includes non-energy consumption.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Nearly one-third of total fuel consumption in industry is non-energy consumption, mainly oil products and some natural gas used as feedstock in the chemical and petrochemical sector and construction. The chemical and petrochemical sector is the largest user of energy and fuels, with 31% of total consumption, a majority of which is for non-energy purposes. Other large energy consumers are the paper and pulp, construction, and food and tobacco sectors (Figure 4.13).

Figure 4.13 Energy consumption in manufacturing industry sectors, 2017



The chemicals and petrochemicals industries account for 44% of industrial fuel consumption, a majority of which is oil products used as feedstock.

**Others* includes non-ferrous metals, mining and quarrying, transport equipment, wood and wood products, and textile and leather.

Note: Includes fuel consumption for non-energy use.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Energy efficiency policies in the industry sector

Policies aimed at improving energy efficiency in the industrial sector are directed from multiple jurisdictions, including the federal, state, municipal and utility levels.

At the federal level, the government establishes minimum performance standards for equipment used by the industrial sector, some of which are mandatory and others of which are voluntary. The EPA's ENERGY STAR programme also has applications for the industrial sector, whereby manufacturing facilities can earn designation as ENERGY STAR Certified Plants. The EPA also runs the ENERGY STAR for Industry programme that assists companies in developing energy management schemes. The Energy Policy Act of 1992 authorised the DOE to create minimum energy efficiency performance standards for certain common industrial systems, including motors, pumps, fans and compressors. Since then, voluntary labelling programmes such as the National Electrical Manufacturers Association's (NEMA's) NEMA Premium have gained traction. Under the Energy Independence and Security Act of 2007, Congress directed the DOE to upgrade the mandatory standards towards NEMA Premium levels.

Beyond standards, the federal government also provides financial and technical assistance for energy efficiency improvements in the industrial sector as well as R&D into technological efficiency solutions. For example, the DOE runs Industrial Assessment Centers (IACs) that provide no-cost assessments by teams located in universities to small and medium-sized manufacturers on measures they can pursue to achieve energy and cost savings. The DOE estimates that IACs usually identify at least USD 130 000 per year in savings for companies that it assesses. The DOE has conducted more than 18 000 IACs.

The DOE is the primary agency for federal industrial energy efficiency programmes, notably through its Advanced Manufacturing Office (AMO), which provides R&D support to early-stage manufacturing technologies that support energy savings. The AMO is also involved in the development and application of energy management-related ISO 50001 standards, which are standards issued for companies by the non-profit intergovernmental organisation International Organization for Standardization.

The DOE also administers the Superior Energy Performance (SEP) programme, which certifies companies based on energy management and performance improvements at industrial facilities. SEP certification requires companies to meet ISO 50001 standards and the American National Standard, ANSI/MSE 50021, which defines additional energy performance benchmarks. A DOE study of nine SEP-certified facilities found they achieved savings of USD 87 000 to USD 984 000 annually by pursuing low-cost or no-cost measures. On average, SEP implementation has demonstrated payback periods of less than two years for facilities that have total energy costs of more than USD 1.5 million.

Demand response

Demand response (DR) entails the shifting of energy consumption from periods of peak demand to periods of low demand, compared with energy efficiency measures that result in total energy consumption reductions. DR is thus not an energy efficiency measure per se, but can help balance the energy load more efficiently (see more on DR in Chapter 9, "Electricity").

In the past decade, DR has proliferated in the United States, playing an increasingly important role in electricity markets, where it is now valued as an integral resource in managing power markets (FERC, 2018). DR measures are rooted in providing incentives for consumers to postpone their energy consumption, either in the form of retail price reductions or direct payments, during periods of high demand.

According to the EIA, in 2017, 9.4 million customers across the United States participated in DR programmes, the vast majority of which (88%) came from the residential sector, resulting in around 1.3 million megawatt-hours of total energy savings. The commercial sector accounted for 11% of DR participation and the industrial sector just 1%. In terms of energy demand shifting, residential efforts accounted for 72%, commercial 19%, and industrial 9% of savings (EIA, 2018).

As part of this effort, utilities continue to deploy advanced meters to their customers. In 2017, the EIA estimated a total number of 79 million advanced meters operating nationwide out of a total of 152 million meters, accounting for 52% of all meters (a number that has been steadily rising in the past decade) (EIA, 2018). A number of state regulators have also approved, or are considering, time-based electricity rate setting, in an effort to galvanise DR.

Utility efficiency obligations

Though the federal government does not administer a national energy efficiency obligation on utilities, 26 states have energy efficiency resource standards (EERS) in place for the electricity sector while 16 states have EERS in place for natural gas (ACEEE, 2018d). These standards require utilities to achieve a set amount of energy savings over at least a three-year time horizon. Of these, seven states mandate that utilities achieve all cost-effective energy efficiency, or the maximum amount possible. The standards have resulted in improved energy efficiency and a reduction in consumer electricity bills since they were established.

The Federal Energy Regulatory Commission (FERC) is currently studying the role of distributed energy resources more broadly, including energy efficiency, in wholesale capacity and energy markets. In December 2017, FERC forbade states from preventing energy efficiency from competing in regional power markets without its approval.

Assessment

The United States continues to exhibit commendable improvements in energy efficiency since the last in-depth review in 2014. The energy intensity of the economy has been steadily falling, decoupling energy consumption (down by 1.7%) from economic growth (up by 15.3%) in the last decade.

Current projections in the EIA 2019 *Annual Energy Outlook* see a general improvement in energy efficiency, albeit at a slower pace than in the past. The EIA's estimated 1.6%

average annual decrease in energy intensity from 2018 to 2050 under the current policy regime will keep energy consumption essentially flat, but fall short of reaching the previously set national goal of reducing energy intensity by half by 2030 compared with 2005. US energy efficiency potential indicates that a further cost-effective reduction of total energy consumption should be possible.

Saving energy is often more cost-efficient than producing energy; improving energy efficiency directly translates into economic growth, job creation and environmental protection for the society, but these wider benefits do not always align with the financial interest of energy suppliers or landlords. EERS, which mandate a quantified energy efficiency goal for an energy provider or jurisdiction within a predetermined time frame, have proven one of the most cost-effective state-level policies, yet the extension of these policies to all states has been stalling in the last decade. The federal government should expedite ongoing efforts to ease the bidding of energy efficiency resources into wholesale capacity markets (where they exist) regulated by FERC. The development of a standardised product recognised and understood throughout the industry would also help provide clarity on the role of energy efficiency in the power system.

The federal level of support to applied R&D of energy-efficient technologies has substantially increased. The R&D budget for energy efficiency and renewables has grown by 25% since the last in-depth review (USD 2 379 billion appropriated for the 2019 fiscal year), and continues to offer the basis for efficiency gains. The research in national laboratories and institutions supported by federal funds has helped develop many technologies driving past energy productivity gains, such as light-emitting diodes (LEDs). The use of outside research contracts and technology transfer are important steps to accelerate and focus beneficial R&D output. The continued high levels of funding in efficient technologies and advanced manufacturing bodes well for future energy demand reductions while improving the competitiveness of the US economy. Additional support of newly developed technologies towards market readiness could complement policies and foster cost-effective energy productivity.

Since the last in-depth review, the DOE's technical assistance to building energy codes allowed state authorities to update requirements in line with technological developments to ensure their effectiveness. The floor space covered under energy use benchmarking or disclosure policies continued to grow from 7.8% to over 13%, further supporting the energy efficiency renovations in the building sector but leaving a lot of potential for improving transparency and certification. Still, given that 75% of the building stock is expected to be either new or renovated by 2035, there is more scope to ensure that new builds or updates achieve significant energy savings. The inclusion of demand optimising and managing technologies in building codes and the development of building code strategies towards energy-neutral buildings offer the potential to achieve more cost-effective savings in more buildings.

The federal government is the largest owner and user of building space in the United States, with an annual federal energy bill of USD 16.1 billion. The Federal Energy Management Program Office assists federal agencies in identifying economically sensible energy efficiency improvements co-ordinated by the Office of Federal Sustainability, and fosters access to private-sector financing and third-party contracting. The DOE has identified self-financing efficiency measures of up to USD 15 billion. While total federal energy savings performance contracts (ESPCs) investment was down in 2017, the federal government has invested more than USD 1.8 billion in ESPCs since the last in-depth review. This trend is a signal that federal agencies might not have the resources to tackle this task outside of their core objective. A centralised management and contracting of all federal building efficiency improvements, supported by federal loan guarantees for service providers, could allow for economies of scale and a more optimal allocation of resources, thus reducing costs to the federal budget. A fixed federal building improvement rate as a continuation of the reduction goals in the Energy Independence and Security Act and contrary to Executive Order 13834 that abolished previous cost-effective annual reduction rates would further help create a market for efficient technologies and service companies while benefiting the federal budget and the whole economy.

The ongoing shale gas revolution offers some benefits to energy efficiency. The abundance of gas allows for more flexible gas-fired co-generation, which has multiple benefits, including improving energy productivity and electricity systems reliability and supporting a better integration of variable renewable energy sources, and decreasing energy system costs overall. Conversely, the operational capacity of co-generation has not increased by much since the last in-depth review, providing only 8.5% of total generation in 2017.

Steady industrial efficiency improvements have played a large role in past energy productivity gains. Federal programmes such as SEP and the IACs are important drivers. Nevertheless, industry still offers the largest potential for future gains. Demand for energy audits is greater than current capacities, signalling potential benefits in extending these programmes. Implementing smart manufacturing, utilising efficient technologies such as inline-four (IE4) motors and promoting a strategic approach to energy management can enable significant future energy productivity gains. During 2012-17, the United States saw a growth in certification of ISO 50001 from 6 in 2012 to 77 in 2017. While the energy performance improvements that US companies participating in the SEP programme have obtained are impressive, the programme hasn't driven ISO 50001 certifications to the same extent as other measures in Europe, specifically tax incentives in Germany. The government's financial support of the ISO 50001 energy management standard in other IEA member countries is an example of how the federal government could nudge companies in implementing this standard, delivering benefits to the whole economy. Incentivising a system of energy audits in large industries could help identify potential cost-effective efficiency improvements and spread best practice solutions for energy efficiency.

The transportation sector is the second-largest energy consumer in the United States. Over the last decade, minimum fuel economy standards have stabilised the sector's energy consumption, after two decades of strong demand increase, and yielded incentives for the automotive industry to develop more efficient internal combustion engines or EVs using batteries and fuel cells. Ambitious fuel economy standards with a long timeline are paramount for a continuation of this trend and requested by the US car industry for investment certainty: light- and heavy-duty vehicles are globally traded products with US manufacturers developing and producing to satisfy global demand. The federal government should take these additional benefits into account when projecting developments in the transportation sector: *i*) set ambitious future CAFE standards to create investment certainty in line with global trends; *ii*) continue to incentivise efficient vehicles and support the development of efficient mobility solutions; *iii*) operate only the most fuel-efficient vehicle fleet itself to pull the market; *iv*) and fully support state-level efforts to decrease the energy demand of transportation. Moreover, a global trend towards growth in EVs and an increasing push by US automakers to manufacture EVs will require an ongoing government effort to ensure a conducive environment for EV growth.

Federal minimum energy efficiency standards are a story of success and currently apply to more than 60 different product groups. They will push the worst-performing appliances from the US market, saving end users USD 2.4 trillion by 2035. In addition, EnergyGuide labels significantly improve transparency on energy consumption and running costs, giving end users a better-informed decision on the total costs of a product and pulling the market towards more efficient appliances. The voluntary ENERGY STAR programme allows end users to pick energy efficient products going beyond federal standards or not covered by them. Building off the efficacy of standards to date, the federal government could seek to include more product groups where cost-effective, and use the review process of existing standards, labels and programmes to reflect more rapid technological developments to adapt them to cost-optimal levels.

Recommendations

The US government should:

- Set an appropriate annual energy efficiency renovation rate for buildings owned or used by the federal government, and centralise the organisation and management for contracting of all federal building efficiency improvements, for example in the Federal Energy Management Program Office or Office of Federal Sustainability.
- Update efficiency standards for appliances and vehicles to give industry investment certainty and reduce costs for end users, and improve the effectiveness of ENERGY STAR and EnergyGuide labelling through updated requirements and presentation formats.
- Support states in the updating of building codes, including of energy-neutral buildings, and develop a US-wide building energy performance rating and labelling system beyond ENERGY STAR.
- Financially incentivise companies‘ uptake of the Superior Energy Performance platinum and ISO 50001 standards, for example through tax credits, and expand energy audit support programmes for small and medium-sized enterprises.

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5. Renewable energy

Key data

(2018 provisional)

Total supply: 173.2 Mtoe (7.8% of TPES) and 750.2 TWh (17.0% of electricity generation)

IEA median: 12.3% of TPES and 32.2% of electricity generation

Bioenergy and renewable waste: 103.0 Mtoe (4.6% of TPES) and 67.4 TWh (1.5% of electricity generation)

Solar: 10.9 Mtoe (0.5% of TPES) and 91.8 TWh (2.0% of electricity generation)

Wind: 23.9 Mtoe (1.1% of TPES) and 277.9 TWh (6.3% of electricity generation)

Hydro: 25.3 Mtoe (1.1% of TPES) and 294.1 TWh (6.7% of electricity generation)

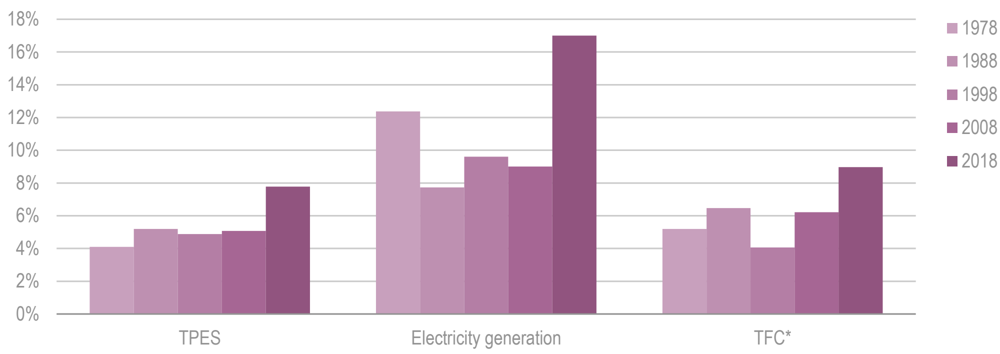
Geothermal: 10.1 Mtoe (0.5% of TPES) and 19.0 TWh (0.4% of electricity generation)

Overview

Renewable energy is playing an increasingly important role in the United States (US) energy system, especially in power generation (Figure 5.1). In 2018, renewables accounted for 17% of electricity generation, after an unprecedented growth of wind and solar across the United States, driven by lower costs and state policies such as renewable portfolio standards. Renewable energy also accounted for around 8% of total primary energy supply (TPES) and 9% of total final consumption (TFC) of energy (including the use of renewable electricity), with a notable contribution from ethanol in transport.

Continued growth in renewable energy offers both challenges and opportunities for the country. As wind and solar power continue to grow, efficient and secure integration of variable renewables into the power system will become more important. Renewable energy can also continue to play a larger role in decarbonising the transport sector, if supported by the right mix of policy and technological development.

Figure 5.1 Share of renewable energy in TPES, electricity and TFC, 1978-2018



Renewable energy is increasing in the US, especially in electricity generation, where the share of renewables doubled in the last decade.

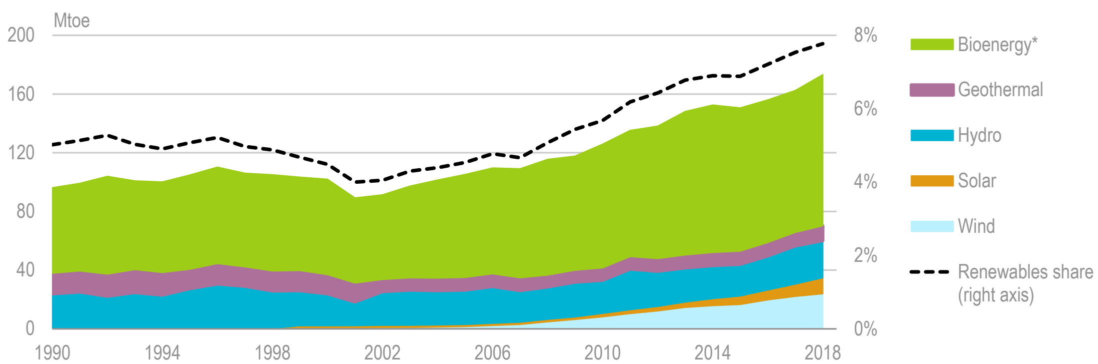
*Includes direct use of renewable energy plus renewable shares of electricity and district heat in TFC. Latest TFC data are for 2017.
Notes: Excludes non-renewable waste. Data for 2018 are provisional.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Supply and demand

Renewable energy in TPES

Renewable energy accounts for an increasing share of TPES in the United States (Figure 5.2). In the past decade, renewable energy supply grew by 50%, and its share in TPES increased from 5% in 2008 to 8% in 2018. Although wind and solar are growing rapidly, the major source of renewable energy in primary energy supply is still bioenergy and waste, followed by hydro.

Figure 5.2 Renewable energy in TPES, 2000-18

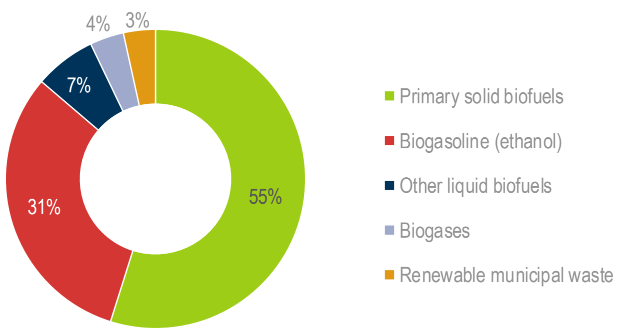


Bioenergy dominates renewable energy in TPES, and has increased in the last decade, but the total share for renewables is still modest at close to 8%.

*Includes solid biofuels, renewable waste, liquid biofuels and biogases. Excludes non-renewable waste.
Notes: Mtoe = million tonnes of oil equivalent. TPES includes conversion losses when using biomass and waste fuels in heat and power generation, which is not the case for hydro, wind or solar. Data for 2018 are provisional.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

In 2018, bioenergy and renewable waste accounted for 5% of TPES in the country. The largest share of bioenergy results from the usage of solid biofuels in electricity generation and in the industrial sector, mainly in the pulp and paper subsector (Figure 5.3). The other main use of bioenergy is biofuels in the transport sector. Biogasoline, or fuel ethanol, is the most commonly consumed biofuel, and the United States is a world-leading ethanol producer (Box 5.1). In 2017, ethanol accounted for 5.2% of total energy use in transport, which was by far the highest share among International Energy Agency (IEA) member countries. Biodiesel[1] consumption has also increased rapidly in recent years.

Figure 5.3 Bioenergy and waste supply by source and sector, 2018



Bioenergy accounts for over half of the total supply of renewable energy, and the United States is a world-leading producer and consumer of fuel ethanol for transport.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Box 5.1 Ethanol as transport biofuel in the United States

The United States is the world's largest producer of biogasoline (ethanol), with around 60% of total global production in 2017. Some of this biofuel is exported but over 90% is used domestically. Corn is the primary feedstock for ethanol production in the United States, and six of the top corn-producing states account for over 70% of fuel ethanol production in the country (Iowa, Nebraska, Illinois, Minnesota, Indiana and South Dakota).

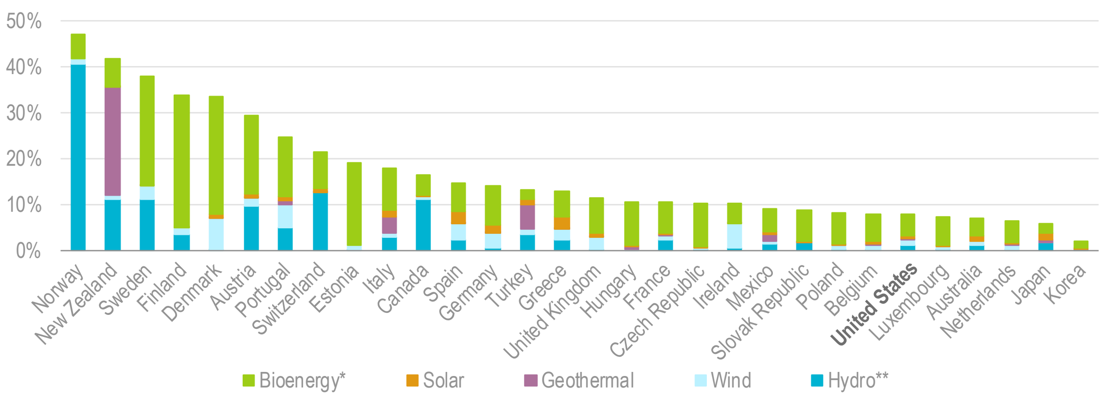
The supply of transport biofuels has increased rapidly since 2005, driven first by the Energy Policy Act of 2005. The act created the Renewable Fuel Standard (RFS) programme with blending requirements that have resulted in 10% ethanol blending (by volume) in most motor gasoline sold in the country. From 2007 to 2017, ethanol supply more than doubled, driven by expansion of the RFS under the Energy Independence and Security Act of 2007. However, growth has slowed down in recent years, as the sector runs up against the current 10% limit at which ethanol can be blended into conventional gasoline for use in non-flex-fuel vehicles.

Sources: EIA (2018a), Six States Account for more than 70% of U.S. Fuel Ethanol Production; EPA (2017), Overview for Renewable Fuel Standard.

[1] Includes biodiesel of diesel quality produced from vegetable or animal oil, biodimethylether, Fischer-Tropsch produced from biomass, cold-pressed bio-oil, and all other liquid biofuels that are added to, blended with or used straight as transport diesel.

Hydro is the second-largest renewable energy source, contributing 1.1% of TPES, followed by small but growing shares of wind and solar. Despite the recent strong growth of renewable energy sources, renewables still account for only a small share of energy supply in the country. Compared with other IEA member countries, the United States has the sixth-lowest share of renewable energy in TPES (Figure 5.4).

Figure 5.4 Share of renewable energy in TPES in IEA member countries, 2018



Despite recent growth in biofuels, wind and solar, the United States has the fifth lowest share of renewable energy sources in TPES among IEA member countries.

*Includes solid biofuels, renewable waste, liquid biofuels and biogases.

**Includes hydropower (excluding pumped storage), tidal, wave and ocean energy.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Electricity from renewable energy

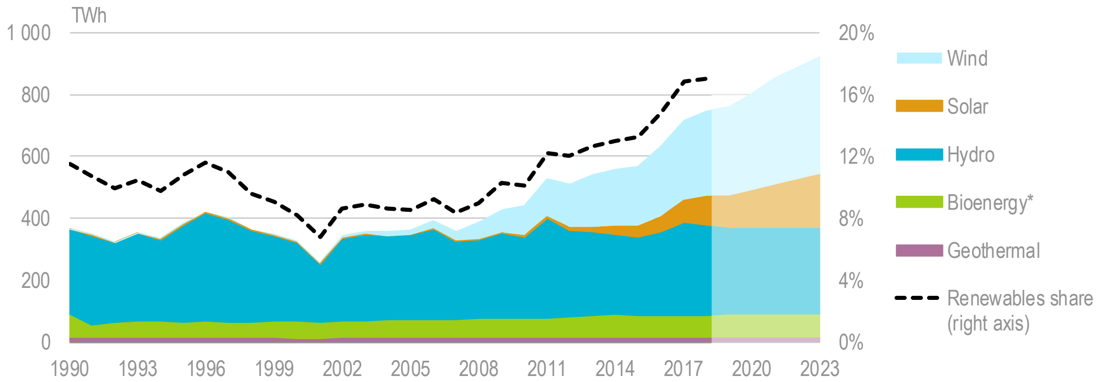
Total electricity generation from renewable energy sources has nearly doubled over the past decade, backed up by state and federal support (EIA, 2019a). The share of renewables in power generation increased from 9% in 2008 to 17% in 2018, mainly as a result of strong growth of solar photovoltaic (PV) and wind (Figure 5.5).

Wind power accounts for the largest increase in renewable electricity generation in the last decade, from 55 terawatt-hours (TWh) in 2008 to 278 TWh in 2018. Meanwhile, US electricity demand has remained relatively constant at around 4 300 TWh, and the share of wind in total electricity generation increased from just over 1% in 2008 to over 6% in 2018. Texas and Iowa were the states with the most wind power capacity at the end of 2018 (AWEA, 2019a).

Solar PV installations have seen an even faster growth rate than wind power in the last decade, although from a lower baseline. In 2018, solar power generated 92 TWh, over 80% more than the production only two years before. California remains the leading state for solar PV installations in the country (SEIA, 2019a).

The growth in wind and solar is expected to continue in the medium term. According to a recent IEA five-year forecast for 2018-23, wind power is set to increase by 122 TWh, an increase of nearly 50% compared with 2017. Similarly, solar power is projected to grow by 102 TWh, an increase by 143% from 2017 (IEA, 2018b). Federal tax incentives and state-level renewable portfolio standards (RPS) and technology-specific incentives, especially for distributed solar PV, along with continued technology advances and cost reductions will remain strong drivers of this growth. However, the forecast has been revised down slightly from last year due to recent tax reforms and trade policy changes.

Figure 5.5 Renewable electricity generation and projections, 1990-2023



Renewable electricity has doubled in ten years, driven by large increases in wind and solar, and the forecast shows continued growth.

*Includes solid biofuels, renewable waste, liquid biofuels and biogases.

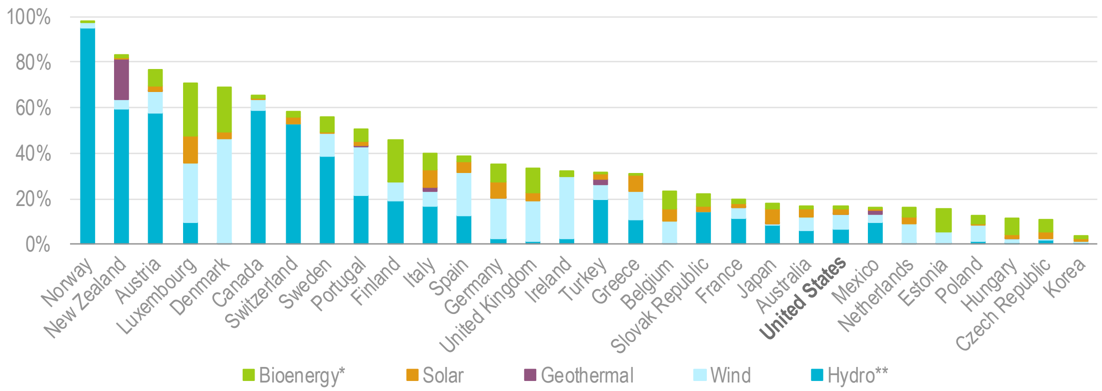
Notes: Data for 2018 are provisional. 2019-23 are projections.

Sources: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/; IEA (2018), *Renewables 2018*.

Hydropower is the largest source of renewable electricity in the United States and the fourth-largest power source after gas, coal and nuclear, accounting for 6.7% of electricity generation in 2018. Due to hydrological conditions, hydropower production can show large annual variations, but the overall trend is relatively stable. Hydropower generation was relatively high in 2017-18, which can be attributed to the reduction of drought conditions in the West and Southwest of the country, where a large proportion of hydropower capacity is located. Power generation from bioenergy and geothermal are more stable and have both increased by around 12-13% in the last decade.

In an IEA comparison, the share of renewable energy in electricity generation is quite low. In 2018, the US share of renewable energy in power generation was the eighth-lowest among IEA member countries (Figure 5.6).

Figure 5.6 Share of renewables in electricity generation in IEA countries, 2018



The US share of renewable energy in electricity generation has increased from 8% to 17% in ten years, but it is still the eighth-lowest among IEA member countries.

*Includes solid biofuels, renewable waste, liquid biofuels and biogases.
**Includes hydropower (excluding pumped storage), tidal, wave and ocean energy.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Policies and measures

Federal tax credits

Aside from innovative clean energy technology research and development (R&D) efforts, the main policy tool at the federal level to support the growth of renewables are tax credits, which can be used to offset income tax obligations for households and companies. The tax credits are administered by the Internal Revenue Service (IRS), which issues implementing guidance to recipients.

For solar, the primary policy support is a 30% investment tax credit (ITC) for residential, commercial and utility-scale solar installations. Congress established the 30% ITC under the Energy Policy Act of 2005. The original 30% credit was valid for two years, but Congress subsequently extended it, most recently as a multi-year extension under the Omnibus Appropriations Act of 2015 (SEIA, 2019b). The latest extension was achieved through a bipartisan compromise that included lifting the US ban on crude oil exports. Despite some discussion of revising the tax credits to fund a corporate income tax reduction as part of the Tax Cuts and Jobs Act of 2017, Congress decided to leave the credits intact, which will continue to provide support for renewables energy expansion throughout the United States.

The most recent changes extend the solar ITC through 2023, though phase down its rate over that time frame. The ITC will fall to 26% in 2020 and 22% in 2021. After 2021, residential tax credits fall to zero, while commercial and utility-scale projects will fall to 10%. The legislation also changed the qualification of projects from those in service to those that begin construction, allowing more projects to qualify for the credits.

Policy support for wind energy has been in place since 1992 (and extended multiple times) in the form of the renewable electricity production tax credit (PTC), valid for ten years after a project goes into service (DOE, 2019a). Though wind producers can opt instead for an ITC, the PTC has proven more attractive for wind investments. The ITC is generally expected to be more valuable to US offshore developers, however. As part of the 2015 legislation that extended the solar ITC, Congress also agreed to phase out the PTC by the end of 2019 (AWEA, 2019b). Projects that started construction before 2017 qualified for a PTC of USD 0.023 per kilowatt, adjusted for inflation; the PTC ratchets down by 20% in 2017, 40% in 2018 and 60% in 2019, until it expires entirely for projects beginning construction after 2019.

Public Utility Regulatory Policies Act

Amid an energy crisis, the United States passed the Public Utility Regulatory Policies Act (PURPA) in 1978 in order to promote the use of alternative energy sources and to establish a marketplace for non-utility power producers. Under the law, regulated utilities are obliged to purchase power from "qualified facilities" at a rate equal to the utility's cost to produce the power, or at the utilities' so-called "avoided cost" (FERC, 2019).

With the emergence of competitive wholesale markets, the Federal Energy Regulatory Commission (FERC) has applied a waiver to the purchase obligations under PURPA in most states (under the Energy Policy Act of 2005). It found several regional electricity markets (PJM, the New York Independent System Operator [NYISO], ISO New England [ISO-NE], the California Independent System Operator [CAISO], the Midcontinent Independent System Operator [MISO], the Electric Reliability Council of Texas [ERCOT], and the Southwest Power Pool [SPP]) to be sufficiently competitive for non-utility power producers to enter these markets on their own. FERC waived the mandatory purchase obligation in those regions with respect to projects between 20 megawatts (MW) and 80 MW. However, in states not governed by regional transmission organisations, which include Idaho, Utah, Wyoming, North Carolina and Montana, PURPA has become a significant driver for renewables buildouts as cost reductions for wind and solar (especially utility-scale solar) have allowed them to clear the PURPA threshold for avoided cost (EIA, 2018). Yet there remains a considerable degree of disagreement between utilities on the one hand, which contend that they cannot manage the influx of renewables they are forced to take, and renewable power developers on the other hand, who worry that changes to PURPA terms will chill investment. In response, a number of these states have introduced changes to contract length, eligibility and remuneration, which will slow the buildout of renewables (Utility Dive, 2018a).

In 2016, FERC began a review of PURPA, along five main areas: *i*) whether the mandatory purchase obligation PURPA places on utilities with respect to qualified facilities under 20 MW in organised, competitive markets should be retained; *ii*) whether FERC's "one-mile rule", which provides that projects that are at least one mile from each other are separate for purposes of determining whether they meet the 20 MW threshold, should be reconsidered; *iii*) when power generated by qualified facilities may be curtailed; *iv*) potential improvements to the avoided cost analysis; and *v*) whether there are minimum contract terms and conditions necessary for developers to secure financing (Utility Dive, 2018b). FERC committed to revisiting the review in 2018, but the commission has not announced any additional steps yet.

Renewable portfolio standards

The federal government does not have an RPS policy in place, though several proposals have been introduced in Congress at various times. However, a number of US states have adopted RPS policies, which require retail electricity providers to source a certain share of supply from qualified renewable sources (National Conference of State Legislators, 2019). Twenty-nine states plus the District of Columbia currently have RPS policies in place (eight states have voluntary targets), and they have been an important driver of renewable technology deployment in the United States, estimated to account for around half of renewables generation and capacity growth in the electricity sector since 2000 (Lawrence Berkeley National Laboratory, 2019). RPS plans have been particularly important in driving renewable energy growth in the Northeast, Mid-Atlantic and West. While emissions reduction goals are a driver of state RPS policies, they are also enacted to harness local energy resources, diversify the fuel mix and support local economic activity.

Most states administer their RPS targets on the basis of a percentage of retail electricity sales, though Iowa and Texas measure them based on explicit quantities of renewable capacity and Kansas as a share of peak demand. The specific rules of each RPS plan can vary widely from state to state, including the targets themselves, carve-outs for specific technologies, cost caps and rules governing the trading of renewable energy credits (NREL, 2016).

Since their adoption, many states have raised their RPS targets to encourage more uptake of renewables. More recently, in 2019, several states made significant changes to strengthen their RPS programmes, including Colorado, District of Columbia, Maryland, Maine, New Mexico, Nevada, New York and Washington. California, Hawaii and Washington are among the states that have the most ambitious targets; they have legislated that 100% of electricity will come from renewable sources by 2045 (with interim targets to inform the pathway) (Greentech Media, 2018a). Nevada in April 2019 passed legislation that targets 100% of carbon-free electricity by 2050, while New York passed legislation in June to achieve 100% carbon-free electricity by 2040 (EIA, 2019b).

Corporate tax policy

Renewables projects have enjoyed tax advantages in the form of accelerated depreciation allowances. However, recent changes in federal tax policy might have implications for financing of some renewables projects. In December 2017, the US Congress passed the Tax Cuts and Jobs Act of 2017, which reduced the maximum corporate tax rate from 35% to 21%. While the overall reduction in the corporate income tax will benefit developers' profitability for renewable projects, the changes could have negative impacts on tax equity financing for renewables, under which returns are partially based on the value of tax credits a project can claim (Norton Rose Fullbright, 2017). A sizeable share of renewables projects is financed through tax equity (a Greentech Media study estimated 40-60%), so the reduction in the tax rate could lower the value of tax deductions and thus increase the cost of tax equity (Greentech Media, 2018b). However, developers and the financial community are working on innovative business models to minimise this impact.

In addition, the tax bill included a base erosion and anti-abuse tax (BEAT), which is a new minimum tax designed to prevent multinational companies from claiming large tax deductions through cross-border payments. Renewables developers often sell their tax credits to multinational investors to reduce their tax obligations (Bloomberg, 2018a). The final version of the legislation included a provision that still allows multinational companies to use up to 80% of the federal ITC and PTC values to offset BEAT obligations (Greentech Media, 2017).

Trade policy

Several trade policy actions by the administration will also have implications for the renewables sector. The most direct trade action impacting renewable electricity is the January 2018 imposition of import tariffs on imported crystalline-silicon solar PV cells and panels under Section 201 of the Trade Act of 1974 (Bloomberg, 2018b). The decision followed an investigation by the US International Trade Commission based on complaints of financial distress filed by US solar producers Suniva and SolarWorld. The tariffs will be in effect for four years. They were set at 30% in the first year, falling by 5% each subsequent year, though include a 2.5 gigawatt (GW) exemption for solar cells each year. Given the US industry's heavy dependence on imported solar cells and panels, the policy is expected to raise costs in the short-term and could have an impact on the pace of new solar capacity installations for the next few years (Reuters, 2018).

In March 2018, the administration imposed a 25% tariff on imported steel and a 10% tariff on imported aluminium on national security grounds under Section 232 of the Trade Expansion Act of 1962 (US Customs and Border Protection, 2019; White House, 2018). Though the administration offers some country-level exemptions and company-specific exemptions, the measures could raise costs for renewables installations, such as wind turbines, which use these commodities during construction (Greentech Media, 2018c).

For biofuels, imports of biomass-based diesel were down following the imposition of anti-dumping and countervailing tariffs on Argentinian and Indonesian imports in March 2017. Moreover, countries importing US fuel ethanol have also raised tariffs, setting back US exports. The People's Republic of China (hereafter "China") raised its import tariff on fuel ethanol from 5% to 30% in 2017, while Brazil imposed a 20% tariff on US ethanol volumes of over 150 million litres per quarter.

Net metering

A number of US states have net metering laws in place, which permit residential and commercial customers who generate their own renewable power to sell surplus electricity (usually at retail rates) back to the grid (DOE, 2019a). The plans primarily apply to rooftop solar installations, and have been an important driver for the expansion of residential and commercial applications. As of July 2017, 38 states plus the District of Columbia had mandatory net metering rules in effect (SEIA, 2019c).

The success of rooftop solar policies in several states has occasionally resulted in an abundance of solar power fed into the grid, creating challenges for utilities in balancing demand with more unpredictable supply (NREL, 2019a). The issue is particularly acute during the afternoon, when the maximum amount of sunlight can generate more electricity than the load requires in some locations. Subsequently, demand tends to pick up again during the evening hours after people return home from work, when the sun is no longer shining. In states like California, the situation has created the so-called "duck curve" that highlights supply-demand imbalances that can emerge from rooftop solar generation at certain times of the year. In some cases, the amount of rooftop solar generation can result in surplus power on the grid that creates negative electricity pricing and forces curtailment. For California, in particular, which has required nearly all new homes to be fitted with rooftop solar panels starting in 2020, addressing the issue of integrating large volumes of distributed solar will become more salient in the coming years.

As such, utilities in many states have pushed back against net metering with retail pricing policies, which they contend erode revenues that are essential to maintaining the distribution grid infrastructure. Net metering programmes have also been the subject of opposition on the grounds that they unfairly subsidise households with rooftop solar installations and redirect the cost burden of that subsidy to customers without solar panels.

In response, some states are adjusting their net metering rules to better align rooftop solar payments with grid requirements, including by introducing time-of-use rates and location-specific rates (Utility Dive, 2018c). Other states, such as Indiana, however, are phasing out net metering payments entirely, which would set back new investments into rooftop solar in those locations.

Grid upgrades

Transmission upgrades and grid expansions have been important components in supporting state RPS policies, avoiding curtailment and ensuring reliability, especially as renewable resources are often situated in less populated parts of the country. Therefore, carrying power from remote generation sites to load centres near cities is essential to maximising the benefits of renewable power.

To this end, following the passage of legislation in 2005, the Public Utilities Commission of Texas completed the buildout of Competitive Renewable Energy Zones (CREZ) in 2014, which entailed a 3 588-mile, 18 500 MW buildout of transmission infrastructure to connect the state's wind resources in the northern and western regions to large cities (ERCOT, 2017). The project was a major driver for the significant wind generation expansion that Texas has experienced in the past decade (Greentech Media, 2010). In a similar vein, MISO in 2011 approved a portfolio of 17 projects that provided cost allocation to support a buildout of transmission infrastructure to carry power generated from more remote wind resources to load centres (RTO Insider, 2018). Elsewhere, CAISO has run the Energy Imbalance Market (EIM) since 2014 as a real-time balancing market between California and surrounding states, which manages congestion on transmission lines and provides more optionality in accommodating growing levels of renewable power sources, thereby reducing curtailment (Power Mag, 2018). More recently, the SPP in June 2019 announced that it would develop a Western Energy Imbalance Service market to balance real-time regional generation and demand.

Department of Energy initiatives

The Department of Energy's (DOE's) R&D efforts in the space of renewable energy (which comprises solar, wind, water and geothermal energy) are focused on technologies that will make renewable electricity cost-competitive with other sources of power generation. Examples of this include (but are not limited to):

Solar PV

The DOE in March 2019 announced USD 130 million for early-stage solar research as well as USD 36 million in research, development and demonstration funding projects that will boost the role of solar in strengthening the US electricity grid. The DOE's Office of Energy Efficiency and Renewable Energy also runs the American-Made Solar Prize, a USD 3 million competition aimed at reviving US solar manufacturing capabilities. The DOE previously in 2011 launched the SunShot programme to fund research that helps bring down the costs of solar power (DOE, 2019b). In 2017, the DOE announced that utility-scale solar had achieved its cost target of USD 0.06 per kilowatt-hour (kWh), three years sooner than expected. The department set new 2030 targets of USD 0.03/kWh for utility-scale solar (DOE, 2019c). It also halved the 2020 commercial target for 2030 to USD 0.04/kWh and the residential target to USD 0.05/kWh.

Grid Modernization Initiative

The DOE also oversees the Grid Modernization Initiative, which works across the department with public and private partners to develop strategies and technology to improve the reliability and resiliency of the grid, which will further support the grid's ability to accommodate a higher share of intermittent renewable sources (DOE, 2019d).

The National Renewable Energy Laboratory (NREL) also runs an Energy Systems Integration Facility, which conducts cutting-edge research and simulations to assist the industry in clean energy integration into the grid (NREL, 2019b).

Hydropower Vision

The DOE oversees the Hydropower Vision Initiative, which aims to advance the role of low-cost hydropower in the nation's energy system, including maximising value from existing facilities. The programme released a *Hydropower Vision Report* in 2016 that lays out a roadmap that is focused on three pillars of analysis: optimisation, growth and sustainability. The report found that technological advancements could result in hydropower growth from 101 GW in 2015 to nearly 150 GW of capacity (both generating and storage) by 2050.

Offshore wind

Offshore wind is a more recent development in the United States, with the first US offshore wind project, the 30 MW Block Island Wind Farm off Rhode Island, going into service in 2016 (AWEA, 2019c). More recently, policy and regulatory changes indicate that offshore wind is likely to see additional growth in the United States, especially on the East Coast, where sea depths and wind conditions are considered comparable to the North Sea (which is seeing substantial progress in offshore wind) (DOE, 2017).

Currently, there are 15 active offshore wind lease areas in federal waters, one research lease and three leases in state waters. As part of its plans to expand federal offshore leasing for energy development, the Department of the Interior's Bureau of Ocean Energy Management (BOEM) in April 2018 launched a high-level assessment of all US Atlantic waters for potential offshore wind lease locations (US Department of the Interior, 2018). Since then, BOEM has held a successful auction for three lease areas in Massachusetts, solicited input on potential leases off New York and New Jersey, initiated an environmental review for a project off Rhode Island, and laid the groundwork for the first wind auction off California's coast (Clean Technica, 2018). The administration has also proposed streamlining the permitting process for offshore wind projects. In fact, Bay State Wind, a project off Massachusetts' shore, was the first to receive FAST 41 status under Title 41 of the Fixing America's Surface Transportation Act, meant to expedite federal permitting processes (Wind Power Engineering, 2018).

Though the US offshore wind sector is heavily dependent on imported components – mainly from Europe – as the number of installations grows, a domestic supply chain and manufacturing capacity are also expected to follow.

The US offshore wind market continues to be driven by state-level offshore wind procurement policies and state-led offshore wind solicitations. Currently, Massachusetts is targeting 3 200 MW of offshore wind capacity by 2035, New York's goal is 9 000 MW by 2035, New Jersey's goal is 3 500 MW by 2030, Maryland's goal is 1 200 MW by 2030, and Virginia's goal is 2 000 MW by 2028. To date, solicitations have been held in Massachusetts, Rhode Island, Connecticut, New York, New Jersey and Maryland. The first commercial project selected in Massachusetts's offshore wind solicitation, Vineyard Wind (800 MW), recently had its 20-year power purchase agreement approved by state regulators at a levellised price of USD 65 per megawatt-hour (MWh) (including the federal ITC). The low-cost power prices exhibited by the first few commercial projects continue to provide momentum to a rapidly expanding US offshore wind industry.

Battery storage

In addition to advancing renewables policies, a number of US states are increasingly adopting storage targets as well. As an early mover on storage, to accompany its 2030 target of 50% for renewables, California adopted an ambitious storage mandate in 2013, which required utilities to procure 1 325 MW of energy storage by 2020 (to be online by 2024) (California Energy Commission, 2014). In response to the Aliso Canyon natural gas storage facility leak in 2015, the state in 2016 followed up by legislating that utilities procure an additional 500 MW of storage capacity (Renewable Energy World, 2018). Importantly, California regulators have also modified market rules to ensure that battery storage options are valued more accurately in the wholesale power market. California's policies have paid off in the form of new investments, including a 30 MW battery storage facility installed in 2018 in San Diego by AES as well as the massive battery storage facility (100 MW/400 MWh) that will be built by AES and Siemens in Long Beach (Utility Dive, 2018d).

California's efforts have been followed by Massachusetts, which established a more modest target of 200 MWh of storage by January 2020 (Mass.gov, 2019). More recently, New York state regulators in December 2018 approved storage targets of 1.5 GW by 2025 and 3 GW by 2030, as directed by 2017 legislation (Utility Dive, 2018e). Oregon also has a smaller storage target of 5 MWh by January 2020, though it has not mobilised investments in the state.

Other states are also seeing solar-plus-storage installations bid at increasingly competitive rates into power auctions, even without storage mandates. For example, in January 2019 in Minnesota, Xcel Energy launched a tender for a solar-plus-storage facility, which received bids (that reflect subsidies) as low as USD 36/MWh, while a tender for wind plus storage received a median bid of USD 21/MWh (Star Tribune, 2018). Meanwhile in Arizona, NextEra signed a deal with Tucson Electric Power in May 2017 for a solar-plus-storage power purchase agreement at USD 45/MWh, while First Solar's February 2018 bid for a solar-plus-storage system topped those from gas peakers (PV Magazine, 2018). Markets with traditionally high power prices, such as Hawaii, will also be suitable markets for more battery storage options.

At the federal level, FERC, which overseas power markets, finalised a rule in February 2018 that directs regional grid operators to establish non-discriminatory rules that will allow energy storage to compete with other power sources in wholesale power markets on a level playing field (FERC, 2018). Additional regulatory moves will be needed to boost the role of storage in wholesale power markets, but state policies will push regulators further in this direction. Moreover, the federal ITC for solar projects can also be applied to solar-plus-storage installations.

Renewable Fuel Standard

On the transportation sector side, the RFS is the primary federal policy tool to promote additional use of renewables in road transportation. The RFS was originally established under the Energy Policy Act of 2005, and was updated under the Energy Independence and Security Act of 2007 as the RFS2, which is the programme that is currently in effect. The targets established under the programme were defined under statute to gradually increase to 36 billion gallons by 2022, divided between 15 billion gallons of conventional (corn-based) ethanol and 21 billion gallons of advanced biofuels (of which 16 billion is supposed to be cellulosic biofuel) (Congressional Research Service, 2019).

The Environmental Protection Agency (EPA) was designated as the implementing authority over the programme, and was tasked with defining specific blending targets for refiners based on the volumetric targets through annual notice-and-comment rule making. The oil sector has pushed back against the rule as being too costly while biofuel producers and the agricultural sector have insisted on implementation in line with statutory levels. Given pushback from both the oil sector and the biofuels sector, RFS rule making is frequently challenged in the courts, though has not yet resulted in a fundamental overhaul of implementation.

One intent of the policy was to incentivise higher production of advanced – and particularly cellulosic – biofuels over time. However, cellulosic biofuels have not achieved the level of commercial success that the RFS2 law envisioned. As such, in recent years, the EPA has had to cut the overall volumetric requirements under the RFS to adjust for significantly lower volumes of cellulosic ethanol production. Moreover, in 2015, the EPA also revised RFS rule making to account for the so-called "blend wall" (Biofuels Digest, 2015). This refers to the challenge of increasing ethanol consumption beyond 10% (by volume) of gasoline demand. Passing this level requires consumption of higher ethanol blends such as E15 (15% ethanol by volume) and E85 (85% ethanol by volume), which in turn requires certifications for both automobiles and retail fuelling pumps, or flex-fuel vehicles in the case of E85. The administration in June 2019 decided to allow year-round sales of E15, which were previously banned in the summer months (Bloomberg, 2018c).

Most recently, the EPA in November 2018 released its final 2019 rule making for the RFS. The agency raised the overall renewable volume obligation from 19.29 billion gallons in 2018 to 19.92 billion gallons in 2019 by increasing allocations for advanced biofuels from 4.29 billion gallons to 4.92 billion gallons, of which cellulosic biofuels would increase from 288 million gallons to 418 million gallons (EPA, 2018). That effectively preserves the implied volumes for conventional biofuels – or corn ethanol – at 15 billion gallons, the volume laid out by statute. The EPA also raised the volume of biomass-based diesel from 2.1 billion gallons in 2018 and 2019 to 2.43 billion gallons in 2020. The total volumes are still well below overall statutory volumes under the RFS, requiring the EPA to draw upon its waiver authority to reduce volumes in annual rule making. Cellulosic ethanol volumes have failed to keep up with mandated levels mainly due to technological challenges in achieving commercial production.

Given some of the outlined challenges with RFS implementation, there have been ongoing efforts in Congress to reform the programme, though none have earned sufficient support to pass into law. In particular, lawmakers from Midwestern states where agriculture is an important economic sector are generally opposed to changes that might disadvantage biofuels production in their respective states. There is also lingering uncertainty about the programme after 2022, as the statute defines volumes only until that date. After 2022, the law grants the EPA the authority to set volumes, unless Congress makes legislative changes to the programme for application in the post-2022 period.

Biofuels tax credits

The biodiesel blending credit of USD 1 per gallon was first established in 2005 (DOE, 2019e). After expiring for the fifth time at the end of December 2016, Congress most recently extended it in February 2018 under a last-minute deal, but only applied it retroactively for one year through 2017 (S&P Platts, 2019). The biodiesel industry continues to work with its backers in Congress to secure another extension for 2018 and beyond.

Low Carbon Fuel Standard

California's Low Carbon Fuel Standard (LCFS) was originally established as part of its AB32 law (passed in 2006) to address transportation sector emissions, which account for around 39% of the state's total emissions. The programme has been in place since 2011, with a target to achieve a 10% reduction in the carbon intensity of transportation fuels by 2020. The primary pathway to achieve these reductions is to introduce more low-carbon (non-petroleum) fuels into the transportation mix, including hydrogen, electricity and biofuels.

The California Air Resources Board (CARB) oversees implementation of the LCFS, under which the carbon intensity target declines annually. The state assesses that the programme is achieving results, despite a modest increase to prices at the pump attributed to the programme. In 2017, over 2 billion gallons in petroleum and natural gas volumes were estimated to have been displaced by the LCFS, and it has been a notable driver of biofuels demand in the state (as well as for biofuels production and imports into the state) (CARB, 2019).

More recently, in September 2018, CARB voted to extend the LCFS, to achieve a carbon intensity reduction of 20% by 2030 (Green Car Congress, 2018). Alternative or renewable aviation fuels will also be able to qualify for LCFS credits for the first time.

Oregon also has had a Clean Fuels Program in place since 2016, which requires a 10% reduction in the average carbon intensity of transportation fuels from 2015-25 (Oregon.gov, 2019).

Assessment

Renewables are playing an increasingly important role in the US power mix. State-driven RPS and state climate policies and targets have brought about an unprecedented growth of wind and solar PV across the United States. This growth was spurred by federal tax incentives and the rapid decline in technology costs. Aided by policy support, prices for power purchase agreements have come down to as low as USD 20/MWh for solar and USD 17/MWh for wind in some parts of the country, including tax credits. In 2018, the share of renewables (including hydro) in total US electricity generation reached 17.0%, close to the share of nuclear energy (19%). Wind penetration levels have broken records to exceed 60% on occasion in 2018 in the SPP, while Texas/ERCOT reached a record-breaking 50% in March 2017. In May 2016, wind, solar and hydro reached 42% in California (CAISO).

Total wind capacity in the United States reached 90 GW in 2018 – the world's second-largest capacity after China, almost entirely from onshore wind, with strong deployment in Texas (23 GW), Oklahoma (8 GW) and Iowa (7 GW). Onshore wind is projected to grow by 43 GW over 2018-23, according to the IEA *Renewables 2018* report, accounting for nearly 40% of the total US renewable power expansion. Due to PTC expiration, however, capacity additions are expected to peak in 2020 and slow thereafter, despite falling costs.

Solar PV is expected to see even stronger growth in the short term. By the end of the first half of 2018, the Solar Energy Industry Association estimated that there was 58.3 GW of solar capacity installed nationwide, of which 22.8 GW was in California alone. The IEA expects solar PV to account for over 61% of US renewable capacity growth over 2018-23, growing by 70 GW.

However, in the medium term, according to the EIA *Annual Energy Outlook*, current growth rates will not be sustained. The anticipated 4-10% cost increase for solar (because of tariffs imposed on imported crystalline silicon solar modules) has been offset by declining prices as Chinese PV demand has slowed. However, the eventual winding down of federal tax incentives (ITC reduction and PTC phase-out) will likely still have a negative impact on growth. After 2021, generation capacity growth for wind is expected to slow considerably, while solar could slow down in the medium term if tax credits expire, creating possible implications for jobs in the renewables sector.

DOE energy R&D capabilities and associated networks of academia and industry support the work on systems integration and flexibility. The DOE's SunShot Initiative, the new Battery Initiative and the large-scale collaboration Grid Modernization Initiative are best-practice examples in this context. The NREL has supported these efforts and has a world-class energy systems integration facility, which also provides policy advice to states, cities and industry to support their ambitions to have higher shares of renewables.

Excellence in energy systems R&D can form the basis for a technology revolution. The renewable energy sector offers growth potential in many areas; however, this will require the prioritisation of technology R&D action and funding in support of better system and market integration of renewables. Related work on the integration of variable renewables with nuclear generation, notably through the concept of hybrid energy systems, is also under way, which can provide additional insight into the future role that nuclear energy, and small modular reactors in particular, can play in reliable, affordable and clean energy systems.

US offshore wind has not developed as strongly as in other parts of the world yet. The first offshore wind project developed by Deepwater Wind (30 MW, Block Island Wind Farm) came into service in 2016, and several other projects are in the pipeline. Policy support from coastal states and the federal government has the potential to lead to more pronounced growth in offshore wind over the coming years.

Automakers, oil companies and technology companies are investing in hydrogen and fuel cells. The DOE released a hydropower roadmap (*Hydropower Vision*), which outlines a potential of 50 GW of pumped hydro storage by 2050 (with continued technology advancements), innovative market mechanisms and a focus on environmental sustainability.

Other policies support distributed generation. In 2017, net metering was available to most customers in 38 states and the District of Columbia. Seven states – Arizona, Georgia, Hawaii, Indiana, Nevada, Maine and Mississippi – have statewide distributed generation compensation rules. However, with slow or even negative power demand growth, a goal of net metering reform should be to introduce policies that accurately reflect the true costs and benefits of adding distributed generation to the overall system. Moreover, the policy framework should avoid retroactive changes to the remuneration of existing installed capacity to provide certainty to the investment environment.

Regional transmission organisations/independent system operators have responded to the fast growth of renewable energy. Systems integration of wind has been supported by significant transmission grid investments in ERCOT through CREZ and is under way in MISO, with the Multi-Value Projects initiative. CAISO's Western EIM has expanded across the Western Interconnection and new system services are flourishing. California is developing smarter grids with battery storage, time-of-use pricing and demand response (from aggregators, electric vehicles and elsewhere).

Challenges remain for system operations, including in California, ERCOT and MISO, where a proliferation of renewable power at certain times of the day can create surpluses that collapse wholesale prices and lead to curtailment. In California, 1% of solar and wind generation was curtailed (95 gigawatt-hours of electricity) in April 2018, a new record, according to CAISO. California exports to Arizona and regularly sees negative prices during the daytime.

Thanks to the federal RFS and state standards and subsidies such as California's LCFS, the United States saw strong investment in biofuels from 2005 to 2012, though growth has slowed since. The RFS originated with the Energy Policy Act of 2005 and was expanded by the Energy Independence and Security Act of 2007. The second period of the RFS (2014-22) has ambitious volumetric targets, requiring renewables to be blended into transport fuel in increasing amounts each year. However, the total renewable fuel statutory target has not been met since 2014; the EPA has used its waiver authority to lower required blending volumes relative to statutory levels. The production of cellulosic ethanol has not developed as anticipated, and volumes have been significantly below the target since 2015, while biomass-based diesel was higher than expected. Fixed volume targets have not been able to keep pace with market and technology realities. The RFS2 would benefit from a review with a view to transitioning to a longer-term framework, based on obligations defined as a percentage of fuel sales. More widespread adoption of technology-neutral LCFS policies, as employed by California, are also an option for states wishing to decarbonise transport.

In addition, the US government has previously provided a "blenders tax credit". However, this has often been applied retroactively after the blending was carried out. Therefore, there is no certainty for the availability of the tax credit at the time of blending. A more stable forward-looking application of the biodiesel tax credit would provide greater certainty to producers and blenders. The US ethanol market has hit the "blend wall" (10% of blending) and further growth in consumption requires a transition to consumption of higher ethanol blends such as E15 (the administration decided to lift a ban on summer sales of E15, starting in June 2019). The biodiesel market is growing as a result of the RFS2 policy. There is uncertainty for the industry on future RFS2 volumetric requirements beyond 2022.

Recommendations

The US government should:

- Foster the system integration of renewable energy by pursuing market regulations that leverage geographic diversity of resources, availability of transmission capacity, and flexible resources such as energy storage (including batteries, hydropower, pumped hydro and hydrogen) and demand response.
- Review the RFS2 and consider a long-term federal framework for transport sector decarbonisation post-2022, focusing on shares of biofuels instead of volumes, and innovative technologies such as advanced biofuels. In order to move beyond the blend wall, consider measures to increase the availability of 15% ethanol blends at service stations, and "drop-in"[2] biofuels such as renewable diesel.

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6. Energy technology research, development and demonstration

Key data

(2017)

Government energy RD&D spending: USD 7 289 million

Share of GDP: 0.38 per 1 000 GDP units (IEA* median: 0.30, IEA average: 0.43)

RD&D per capita: USD 22.4 (IEA* median: USD 13.8)

* Median of 19 IEA member countries for which 2017 data are available.

Overview

The United States (US) is a global leader in energy-related research, development and demonstration (RD&D). Federal energy RD&D efforts are almost entirely directed out of the Department of Energy (DOE), where RD&D activities are a core tenet to the department's mandate. Central to this are the DOE's national laboratories, federally funded research centres with worldclass facilities for advanced energy research.

A large share of public RD&D funding is allocated to clean energy research, including energy efficiency. With the growth in variable renewable electricity generation, greater deployment of electric vehicles (EVs), and increased extreme weather events and cyberthreats, research into modernising and strengthening the power grid is becoming a more important focus area. Other low-carbon technologies that benefit from more RD&D funding are nuclear – especially to develop small modular reactors (SMRs) – and carbon capture, utilisation and storage (CCUS).

The United States is also engaged in energy RD&D internationally, for instance by participating in most of the Technology Collaboration Programmes (TCPs) co-ordinated by the International Energy Agency (IEA). The United States is also a founding member of the Clean Energy Ministerial (CEM). For the United States to maintain its global leadership in clean energy technology innovation, these and other international collaborations should receive continued support.

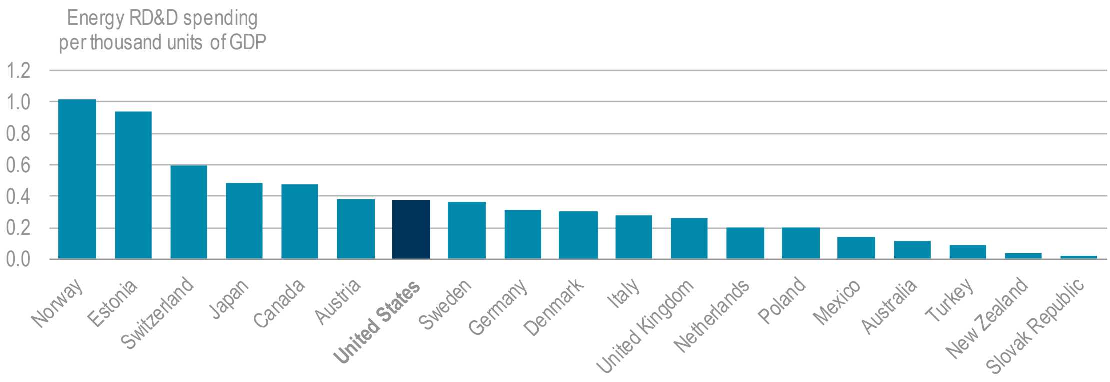
Public spending on energy RD&D

The United States spent 0.038% of its gross domestic product (GDP) in 2017 on energy-related RD&D.[1] This was among the higher shares in an IEA comparison although significantly below the top-ranked countries (Figure 6.1). In absolute numbers, however, the US energy RD&D budget is by far the largest, and accounts for around 40% of total public spending among all IEA member countries (Figure 6.2).

In 2017, the United States spent USD 7.3 billion on energy-related RD&D, a 9% increase from the year before (Figure 6.3). Basic energy research received the largest share of public funds, with 31% of the total. Energy efficiency received the second-largest share (24% of the total), mainly for research in efficient transport. Renewable energy received the third-largest share (16%), mostly directed at biofuels and smaller shares allocated for solar and wind research.

Nuclear received 11% of total public RD&D funding in 2017. Approximately half of that was spent on fission research, including the uranium fuel cycle and nuclear waste management, and the other half on fusion power, which is a technology that is not commercially available. Fossil fuels RD&D received 6% of total public funding, of which more than half went to research on CCUS. Electric power systems, including generation, transmission and distribution, and storage technologies received another 5%.

Figure 6.1 Government energy RD&D spending per GDP in IEA countries, 2017



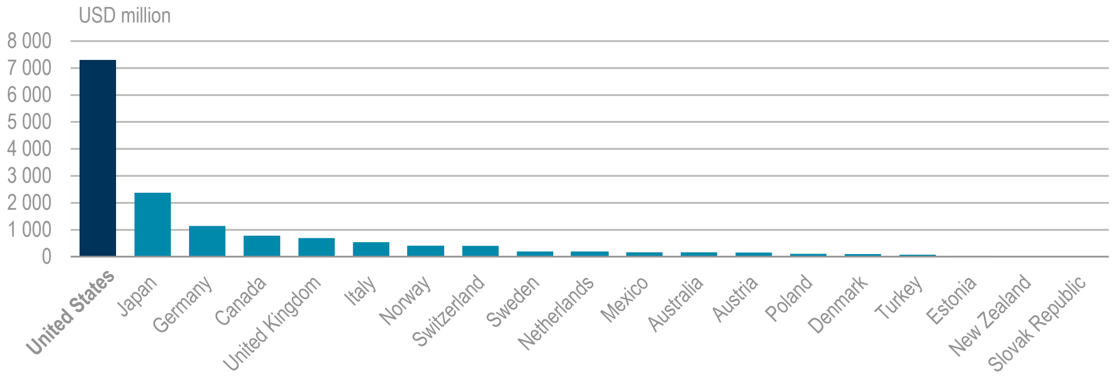
The United States ranks high in RD&D spending per unit of GDP, but below the top IEA countries.

Note: Data are not available for Belgium, the Czech Republic, Finland, France, Greece, Hungary, Ireland, Korea, Luxembourg, Portugal and Spain.

Source: IEA (2018), *Energy Technology RD&D Budgets 2018*, www.iea.org/statistics/.

[1] IEA calculations based on budgetary approvals for five agencies: DOE, Department of Defense, National Aeronautics and Space Administration, US Agricultural Department, and Department of Transportation.

Figure 6.2 Government energy RD&D spending in IEA countries, 2017

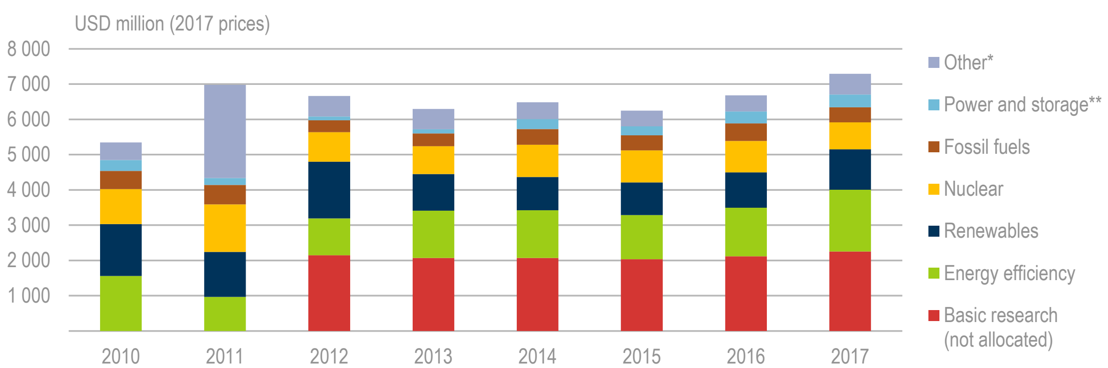


US spending accounts for nearly half of the total public energy RD&D budget in the IEA.

Note: Data are not available for Belgium, the Czech Republic, Finland, France, Greece, Hungary, Ireland, Korea, Luxembourg, Portugal and Spain.

Source: IEA (2018), *Energy Technology RD&D Budgets 2018*, www.iea.org/statistics/.

Figure 6.3 Government energy RD&D spending by category, 2010-17



The government spent USD 7.3 billion on energy related RD&D in 2017, of which basic research, energy efficiency, renewable energy and nuclear received the largest shares.

**Other* includes hydrogen and fuel cells and other non-allocated funding.

***Power and storage* includes electric power generation, electricity transmission and distribution, and other power and storage technologies.

Source: IEA (2018), *Energy Technology RD&D Budgets 2018*, www.iea.org/statistics/.

Institutional framework

The DOE is at the centre of US energy RD&D efforts, with a range of programmes, sizeable funding and a variety of technological focus areas under its jurisdiction. In fact, the DOE's mission itself is defined as supporting "transformative science and technology solutions", making RD&D a cornerstone of the department's mandate.

An important component of DOE's RD&D efforts are programmes run out of its Office of Science, including administration of ten of the country's energy national laboratories. The Office of Science oversees a broad portfolio of basic research that is focused on transformational technologies. It hosts six programme areas: 1) Advanced Scientific Computing Research; 2) Basic Energy Sciences; 3) Biological and Environmental Research; 4) Fusion Energy Sciences; 5) High Energy Physics; and 6) Nuclear Physics. The Office of Science also oversees knowledge and training programmes, including Workforce Development for Teachers and Students, the DOE's Small Business Innovation Research and Small Business Technology Transfer programmes, and the Office of Project Assessment.

With a renewed emphasis on the pathway to market, in 2015, the Office of Technology Transitions (OTT) was established in the DOE to advance the commercialisation of the DOE's RD&D efforts (DOE, 2019a). The Technology Commercialization Fund and the Energy Investor Center (see below for more details) are both run out of the OTT. The office is required to submit two reports on its programmes to Congress each year: the Technology Transitions Execution Plan and the Report on Technology Transfer and Related Technology Partnering Activities at the National Laboratories and Other Facilities. The OTT director also serves as the technology transfer co-ordinator to co-ordinate the OTT's efforts with that of the broader DOE and the Secretary of Energy.

In addition, individual applied programme offices within the DOE oversee RD&D efforts that fall under their subject areas, such as nuclear power and renewable fuels.

A core aspect of DOE's RD&D efforts is the funding it offers to universities, research institutions and industry for projects that support energy technology development and commercialisation. The department conducts two types of funding announcements: Funding Opportunity Announcements (FOAs) that can be open to several institutional types as defined by individual announcements, and DOE National Laboratory Announcements that are open only to DOE labs (DOE, 2019b).

The DOE's budget, including for RD&D efforts, is decided by Congress. In its DOE budget request to Congress for fiscal year (FY) 2020, the administration noted a focus on early-stage RD&D and a reliance on the private sector to finance later-stage efforts (DOE, 2019c).

Energy RD&D programmes

The United States has directed large amounts of resources towards energy RD&D for many decades in order to promote innovation in the energy space, boost the competitiveness of US industries and address the challenges associated with a changing energy landscape.

The US National Security Strategy, issued in 2017, highlights "energy dominance" as its core strategy for the energy sector, and notes the role of innovation, technology breakthroughs and energy efficiency gains as the leading driver for emissions reduction in the United States (White House, 2017). In particular, the strategy identifies as a priority action area boosting the US technological edge in nuclear, battery, carbon capture and advanced computing applications, as well as those that address the interconnection between energy and water resources.

Science and innovation programmes

National laboratories

Based on the substantial investment the US government directed at scientific research during World War II, the United States currently has 17 national laboratories – under the authority of the DOE – that conduct leading research on scientific innovation in the energy space (DOE, 2019d). The national labs focus on large-scale RD&D efforts using a multidisciplinary approach with a goal to transform basic science into innovative applications and solutions. As part of these efforts, the national labs have state-of-the-art facilities and equipment, some of which cannot be found anywhere else in the world. In this regard, the labs also attract the nation's top scientific talent. The 17 energy labs are:

- Ames Laboratory
- Argonne National Laboratory
- Brookhaven National Laboratory
- Fermi National Accelerator Laboratory
- Idaho National Laboratory
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- National Energy Technology Laboratory
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- Princeton Plasma Physics Laboratory
- Sandia National Laboratories
- Savannah River National Laboratory
- SLAC National Accelerator Laboratory
- Thomas Jefferson National Accelerator Facility.

Among their notable achievements, with funding from DOE, the national labs developed the advanced cathode technology that powers the Chevy Volt's battery; reduced the losses that typically occur during transmission by removing the resistance to the flow of electricity using high-temperature superconducting technology; and created high-efficiency airfoils that lowered the cost of wind power by more than 80% over the last three decades. The revolution in light-emitting diodes (LEDs), which provide significantly more efficiency compared with traditional light bulbs, was also developed in collaboration between industry and the national labs (DOE, 2019e).

The national labs also have a long history of collaboration with universities, including through joint research programmes, personnel exchanges and the use of scientific facilities.

Loan Programs Office

The DOE's Loan Programs Office (LPO) is authorised to oversee over USD 70 billion of loans and loan guarantees to support the deployment of large-scale energy infrastructure projects. In this regard, LPO offers opportunities for project developers to access debt that financial markets might not have otherwise granted them. LPO manages its portfolio of loans and loan guarantees through a team of in-house financial, legal and technical experts (DOE, 2019f).

The loan programmes finance a range of technologies, in line with the government's "all-of the above" approach to energy development. The office has a staff of in-house financial, legal, technical and environmental experts. So far, LPO has granted over USD 30 billion in loans and loan guarantees to more than 30 projects. LPO finances projects within three programmes: the Advanced Technology Vehicles Manufacturing Loan Program, the Tribal Energy Loan Guarantee Program and the Title 17 Innovative Energy Loan Guarantee Program. The Title 17 programme was established under the Energy Policy Act of 2005 and aims to support innovative clean energy projects through loan guarantees. Projects must meet certain criteria to qualify for Title 17 loan guarantees, including greenhouse gas abatement, new or significantly improved technologies, and a reasonable likelihood of repayment (DOE, 2019g).

Advanced Research Projects Agency for Energy

Based on a 2005 recommendation by the National Academies, Congress in 2007 established the Advanced Research Projects Agency for Energy (ARPA-E), designed after the Defense Advanced Research Projects Agency. Under the purview of the DOE, ARPA-E advances early-stage, high-potential, high-impact energy technologies that would otherwise not attract private financing (DOE, 2019h). In this regard, it does not fund basic or incremental research. ARPA-E is structured to be institutionally independent and structurally flexible, which means it is able to disburse and withdraw funds from projects relatively quickly, in line with the short-term (three-year programmes) nature of funding that the agency was meant to support. In this regard, ARPA-E has a robust process for setting and tracking project milestones (ARPA-E, 2019a).

Since 2009, when ARPA-E first received funding, it has provided around USD 1.8 billion in RD&D funding to over 660 energy technology projects with transformational potential. Focus areas for projects include new wind turbine designs, transportation fuels made from bacteria and innovative energy storage solutions. A number of the projects supported by the agency have demonstrated success, with 71 having formed new companies, 109 partnering with other government agencies, and 136 projects raising over USD 2.6 billion in private-sector financing. The projects have also led to the issuance of 245 patents (ARPA-E, 2019b).

As part of its founding, Congress required an independent assessment of ARPA-E six years after it was operational, which the National Academy of Sciences (NAS) conducted in 2017. Although the NAS could not yet definitively conclude that any ARPA-E project was transformational to the energy space (which would require a decade or longer), it did find that the early-stage support helped companies overcome their most financially challenging early years, in line with the agency's statutory objectives (National Academies Press, 2017).

For FY2019, Congress authorised USD 366 million for the programme, up slightly from the USD 353 million authorised in the previous fiscal year (Congressional Research Service, 2018).

Nuclear energy

Given the administration's focus on promoting the use of nuclear energy and reviving the US nuclear industry, funding and research efforts have been especially strong to reduce the risks and costs associated with developing advanced nuclear technologies and support an expanded role for nuclear energy. To this end, the DOE's Office of Nuclear Energy conducts RD&D in a wide array of nuclear areas, including fuel cycle technologies, SMRs, light water reactors and advanced reactors. These efforts include advanced modelling and simulation through the Energy Innovation Hub for Modeling and Simulation and the Nuclear Energy Advanced Modeling and Simulation programme.

The DOE's Office of Nuclear Energy maintains a multifaceted approach to supporting nuclear RD&D activities. Among its initiatives is the Gateway for Accelerated Innovation in Nuclear (GAIN), which establishes public-private partnerships to help bridge the gap between private-sector innovators and the DOE's research capabilities through its national labs.

The Nuclear Energy Enabling Technologies (NEET) programme pursues RD&D activities to advance innovating and cross-cutting nuclear energy technologies, including through the Crosscutting Technology Development subprogramme. NEET also invests in modelling and simulation tools for existing and advanced reactors and fuel systems. In addition, the programme provides access to nuclear research resources for universities, industry and national labs under the Nuclear Science User Facilities initiative.

The DOE has issued several FOAs in the area of nuclear technology, based on the department's goals to boost the long-term viability and competitiveness of the existing nuclear fleet, to develop an advanced reactor pipeline, and to ensure a national strategic fuel cycle and supply chain. Under the FOA US Industry Opportunities for Advanced Nuclear Technology Development, the DOE's Office of Nuclear Energy has advanced four rounds of financing for public-private partnership projects to date since April 2018, totalling USD 117 million (DOE, 2019i). The solicitation has three funding tracks: 1) First-of-a-Kind Nuclear Demonstration Readiness Projects for existing projects with sizeable technical or licensing risks that can go on line by the mid-to-late 2020s; 2) Advanced Reactor Development Projects for improving the commercialisation potential of advanced reactor technologies; and 3) Regulatory Assistance Grants for direct support in navigating regulatory and licensing processes.

In order to provide additional support to revitalising the nuclear energy sector, Congress in September 2018 signed into law the Nuclear Energy Innovation Capabilities Act of 2017, which is aimed at improving the efficiency of nuclear sector licensing. As part of the act, Congress directed the DOE to establish a fast neutron testing facility (Congress.gov, 2018). In February 2019, the DOE announced the launch of the Versatile Fast Neutron Source (or Versatile Test Reactor), which will update the DOE's nuclear energy infrastructure and allow for the testing of advanced nuclear technologies and fuels (DOE, 2019j). The facility will be run by the DOE's Idaho National Laboratory.

In order to support the only advanced nuclear reactor currently under construction in the United States, the DOE in March 2019 announced additional loan guarantees of up to USD 3.7 billion (for a total of USD 12 billion) for the Vogtle nuclear facility in Georgia (DOE, 2019k).

To address the full nuclear cycle, the DOE also conducts RD&D activities in the area of spent nuclear fuel, under the Used Nuclear Fuel Disposition Research and Development programme. The focus of the programme is on disposal as well as storage and transportation of spent nuclear fuel and waste.

The DOE also grants scholarships to undergraduate and graduate students in nuclear engineering to foster the next generation of expertise and innovation in nuclear sciences. Since 2009, it has administered the Nuclear Energy University Program, which oversees all university support programmes. In addition, the DOE runs the Millennial Nuclear Caucus, to convene young leaders in nuclear innovation to hold discussions on the future role of nuclear technology.

Energy efficiency and renewable energy

The mission of the DOE's Office of Energy Efficiency and Renewable Energy (EERE) is to support an expanded role for clean energy in the US economy, including ensuring a leadership role for the United States in clean energy technologies. In this respect, EERE devotes a considerable share of its initiatives and financing to RD&D efforts, including overseeing activities of the National Renewable Energy Laboratory and several other DOE national labs. EERE comprises 11 technology offices, falling under three broad technology categories: efficiency, renewables and transportation. EERE has run its agenda through multi-year roadmaps, the most recent of which is the 2016-2020 Strategic Plan. According to the DOE, based on third-party evaluations of one-third of EERE's RD&D portfolio, USD 12 billion of investments had resulted in a net economic benefit of over USD 230 billion (yielding an annual return of around 20%) (DOE, 2019l).

EERE runs or participates in several initiatives to support efficiency and renewable RD&D efforts, including collaborating with universities, industry and foreign countries. Among the initiatives is the Grid Modernization Initiative – an effort co-led with the Office of Electricity – which co-ordinates across the DOE and collaborates with public and private partners to develop grid technologies that are better suited to address changes in the power mix, especially the introduction of larger shares of variable renewable generation.

Efficiency

In an effort to promote energy savings in buildings and manufacturing processes, EERE undertakes RD&D efforts to develop new and innovative ways to achieve more cost-effective energy efficiency outcomes.

To this end, EERE's Buildings Technologies Office (BTO) funds RD&D projects, both competitively awarded and through national labs. BTO's Emerging Technologies Program, in particular, finances projects that usually last for three years and undergo both merit and peer reviews at least once during those three years. The Emerging Technologies subprogramme areas comprise: heating, ventilation and air conditioning; water heating and appliances; windows and building envelope; solid-state lighting; building energy modelling; sensors and controls; and building-to-grid integration.

In a similar vein, the Advanced Manufacturing Office (AMO) provides competitive funding to support RD&D projects and early-stage technical partnerships with national laboratories, industry, state and local governments, and universities to promote new advanced manufacturing technologies that result in energy savings. AMO maintains a diverse RD&D portfolio of projects including in the following areas: electric machines, co-generation,[2] high-performance computing, lab-embedded entrepreneurship, next-generation manufacturing processes, emerging research exploration, innovative process and materials technologies, small business innovation, and next-generation materials. AMO also hosts RD&D consortia and promotes technical partnerships among academia, industry and national labs.

EERE also supports research efforts to identify ways to cut energy consumption and energy costs in federal facilities, in co-ordination with the Federal Energy Management Program.

Renewables

EERE's RD&D efforts in the space of renewable energy (which comprises solar, wind, water and geothermal energy) are focused on technologies that will make renewable electricity cost-competitive with other sources of power generation.

To this end, the DOE in March 2019 announced USD 130 million for early-stage solar research as well as USD 36 million in RD&D funding projects that will boost the role of solar in strengthening the US electricity grid. EERE also runs the American-Made Solar Prize, a USD 3 million competition aimed at reviving US solar manufacturing capabilities. Solar subprogrammes include photovoltaics, concentrating solar power, systems integration, soft costs, technology-to-market and national labs research.

Similarly, the Wind Energy Technologies Office supports over 250 advanced wind energy RD&D projects throughout the country, including through partnerships with universities, industry and national labs. Research areas include: offshore wind, distributed wind, atmosphere to electrons, resource assessment and characterisation, next-generation wind technology, testing and certification, manufacturing and supply chains, grid integration, environmental impact and siting, and workforce development and education.

EERE's Geothermal Technologies Office provides RD&D support to enhanced geothermal systems with an eye to commercialisation by 2030, with focus areas of technology validation, cost reduction and performance enhancement.

EERE also houses the DOE's Water Technologies Office, which supports RD&D to advance marine energy and next-generation hydropower and pumped storage technologies.

Transportation

EERE also leads a robust RD&D programme focused on developing the next generation of sustainable transportation technologies, including programmes on vehicles, bioenergy, and hydrogen and fuel cells. The Vehicle Technologies Office supports development of a broad range of advanced vehicle technologies, including EVs, internal combustion engine efficiency and vehicle lightweighting.

[2] *Co-generation* refers to the combined production of heat and power.

Meanwhile the Bioenergy Technologies Office targets RD&D through funding and partnerships to facilitate the advancement of innovative bioenergy technology, including biofuels, bioproducts and biopower from domestic biomass resources.

Lastly, the Fuel Cell Technologies Office undertakes early-stage RD&D efforts on hydrogen and fuel cell technologies for use in the transportation sector. Programmatic areas include hydrogen production, delivery and storage; fuel cells; and manufacturing research and development (R&D). Among its accomplishments, the DOE notes that its research efforts have brought down the costs of high-volume automotive fuel cells by 60% since 2006 and lowered the cost of producing hydrogen from renewable sources by 80% since 2002 (DOE, 2019m).

Fossil energy

The DOE's Office of Fossil Energy is involved in a number of initiatives to promote techno-logical advances for the safe and affordable production and consumption of fossil fuels.

Office of Clean Coal and Carbon Management

The Office of Fossil Energy directs the Office of Clean Coal and Carbon Management, which promotes RD&D efforts that support the use of fossil fuels in more environmentally and economically advantageous ways. These RD&D efforts are designed to develop and demonstrate advanced power generation and CCUS technologies for both new and existing facilities. The near-term focus is to advance technologies that allow for greater efficiency and carbon capture at new facilities, while the longer-term focus is to enable these technologies for use in both new and existing coal plants, which will help preserve coal's role in the country's fuel mix in an environmentally sound way. Programme areas of focus under the Office of Clean Coal and Carbon Management include:

- Advanced Energy Systems: promotes efficiency improvements at coal plants.
- Crosscutting Research: serve as an intermediary between basic and applied research.
- Carbon Capture, Utilization and Storage Research: promotes safe, cost-effective carbon capture technologies, geological storage and carbon dioxide (CO_2) usage.
- Carbon Capture, Utilization and Storage Major Demonstrations: partners with industry to develop and demonstrate advanced, commercial-scale CCUS technologies.
- Systems Analysis: conduct systems analysis covering environmental issues, policy and regulatory frameworks, financing and economic analysis, and data and support tools.
- International Engagements: works with international partners to undertake R&D on advanced CCUS technologies.

Advanced fossil energy systems

A large focus area for the Office of Fossil Energy's RD&D efforts is developing and demonstrating advanced power generation technologies, including CCUS. Changes to the US electricity industry are forcing a paradigm shift in how the nation's generating assets are operated. Coal-fired power plants optimised as baseload resources are being increasingly relied on as load-following resources to support electricity generated from variable renewables, as well as to provide critical ancillary services to the grid.

In this regard, the United States launched the Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) initiative, which is aimed at developing smaller-scale coal-fired power plants that are capable of flexible operations, while improving efficiency and reducing emissions. The DOE expects that the fossil energy power fleet of the future will include the following attributes:

- high overall plant efficiency (40%+ higher heating value at full load)
- small (50 megawatts [MW] to 350 MW)
- near-zero emissions including CO_2 capture
- capable of high ramp rates and minimum loads
- integration with thermal or other energy storage
- minimised water consumption
- reduced design, construction and commissioning schedules
- enhanced maintenance features including technology advances with monitoring and diagnostics to reduce maintenance and minimise forced outages
- integration with coal upgrading or other plant value streams
- capable of natural gas co-firing.

The initiative integrates advancements from all of the DOE's R&D areas, including crosscutting (sensors, controls, water R&D and computational R&D); advanced energy systems (advanced combustion, gasification, turbines and advanced materials R&D); and CCUS technologies as appropriate. It performs new research that creates a fossil power generation system that meets most, if not all, of the above requirements that future power generation demands in the United States.

Carbon capture, utilisation and storage

The United States has been a leader on advancing CCUS technology for some time. The country has the largest number of large-scale CCUS facilities worldwide, which capture around 25 million tonnes of CO_2 ($MtCO_2$) annually (the bulk of which comes not from coal generation plants, but rather natural gas processing plants and industrial facilities, including bioethanol plants). In particular, CCUS projects that direct CO_2 into enhanced oil recovery (EOR) and have proven successful are expected to remain a driver for new investments in the field. The DOE funds a number of projects to support CCUS technologies, which have seen renewed focus over the past two years.

The DOE's Office of Clean Coal and Carbon Management, in collaboration with the National Energy Technology Laboratory, administers the Carbon Storage Program, which has been in place since 1997. The programme focuses on supporting applied research projects to advance and disseminate CCUS knowledge. As part of the Carbon Storage Program, the DOE runs the Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative, which helps achieve commercial-scale geological storage (over 50 $MtCO_2$) to support CO_2 emissions reductions. The DOE's Office of Fossil Energy selects geological storage sites under this programme, with six projects currently undergoing feasibility studies. Beyond this, a number of small-scale projects are also under way throughout the country.

CCUS RD&D efforts are further bolstered by tax credits authorised by Congress. As part of the Bipartisan Budget Act that passed in February 2018, Congress extended and significantly increased tax credits for CO_2 use and storage under Section 45Q of the Internal Revenue Code. Specifically, the changes raised the amount of tax credits that carbon capture for EOR receives from USD 10 per tonne to USD 35 from 2026, while lifting the credit for carbon capture in geological storage sites from USD 20 per tonne to USD 50 (Greentech Media, 2018). The legislation also did away with a previous annual cap on the tax credits of 75 $MtCO_2$ (Global CCS Institute, 2018). The moves are expected to boost the business case for CCUS projects and stimulate investment in new projects. Utilising 45Q credits, Occidental Petroleum in 2018 announced a partnership with White Energy to study the economic feasibility of a project to capture CO_2 from White Energy's ethanol plant and transport it for EOR to Occidental's Permian Basin oil reservoirs.

Oil and gas

A major success story for US energy RD&D efforts has been the boom in production of unconventional oil and gas, through the advancement of hydraulic fracturing and horizontal drilling technologies. Over the period 1978-92, the DOE invested around USD 137 million in the Eastern Gas Shales Program that helped to advance demonstration and commercialisation of shale production technologies. In 1975, a joint venture between the DOE and the industry drilled the first directional well in the Appalachian Basin to produce shale gas. Since then, DOE projects, primarily through the National Energy Technology Laboratory, helped to advance a number of shale production technologies, including directional drilling and microseismic monitoring of multistage drilling. In this regard, DOE-funded research played an important role in unlocking the unconventional oil and gas boom that has transformed US and global energy markets (DOE, 2019m).

The Office of Fossil Energy, along with the National Energy Technology Laboratory, is currently undertaking RD&D to further support the production of natural gas in a safe and environmentally sustainable manner. Focus areas include: water management, induced seismicity, methane emissions, subsurface science, footprint reduction, and transportation and storage.

In addition to unconventional oil and gas, the DOE also supports RD&D on methane hydrates, offshore oil and gas (deepwater and ultra-deepwater), and CO_2 injection and EOR.

Electricity

The DOE's Office of Electricity undertakes RD&D efforts to advance technologies that enhance the six key characteristics of a more modernised electric grid: reliability, resilience, efficiency, flexibility, affordability and security. In this capacity, for grid modernisation, the Office of Electricity works with other relevant parts of the federal government, state governments and a range of industry participants, from equipment manufacturers to electric utilities.

In particular, the Office of Electricity identifies four challenges that the future electric grid will need to address: 1) changing demand based on population growth, economic shifts, energy efficiency and electrification in other sectors; 2) a changing power mix and growing distributed energy resources; 3) more variability in supply and demand with the growth in renewables supply and more active participation of consumers in electricity consumption and distributed generation; and 4) reliability, resilience and security threats to the electric infrastructure, including cyber- and physical threats and extreme weather.

To help modernise the electric grid while overcoming challenges, the Office of Electricity invests in advanced grid RD&D activities focusing on four priorities:

- North American Energy Resiliency Model (NAERM): develop an integrated NAERM to conduct planning and contingency analysis to address vulnerabilities in the North American energy system.
- Megawatt-scale grid storage: pursue grid-scale storage capable of supporting frequency regulation, ramping and energy management for bulk and distribution power systems.
- Revolutionising sensing technology utilisation: pursue integration of high-fidelity, low-cost sensing technology for predictive and correlation modelling for electricity and oil and natural gas systems.
- Transmission: pursue electricity-related policy issues by carrying out statutory and executive requirements, while also providing policy design and analysis expertise to states, regions and tribes.

As the US electric grid sees increasing variability in supply and demand under growing threat environments (cyber, physical, extreme weather), the DOE's RD&D efforts into improving the six key grid characteristics are critical and timely, and will be increasingly relevant in future years.

The DOE's Office of Cybersecurity, Energy Security and Emergency Response (CESER) also runs the Cybersecurity for Energy Delivery Systems RD&D programme to assist private owners of energy infrastructure in developing cybersecurity protections to improve the reliability and resilience of US energy delivery systems. Since 2010, CESER has devoted over USD 240 million in funds to cybersecurity RD&D projects conducted by industry, national labs and universities.

Pathways to commercialisation

Technology-to-Market

In an effort to promote the deployment of energy technologies beyond national labs, the DOE runs the Technology-to-Market Program (Tech-to-Market), which helps remove barriers that promising technologies might face on their way to market.

The first focus area under Tech-to-Market is market readiness, which fosters collaboration with industry to bring the perspective of market participants into the labs. Among its work streams are: Build4Scale, which teaches energy innovators about manufacturing and design principles; the Cleantech University Prize, which provides competitive funding opportunities to clean-energy student entrepreneurs; Energy I-Corps, which fosters partnerships between researchers and industry mentors; and Lab-Embedded Entrepreneurship Programs, which embed top entrepreneurial scientists and engineers in national labs.

The second focus area for the Tech-to-Market programme is resource access, which enables access to physical and capital resources for innovators and entrepreneurs. The work streams under this focus area include: the Lab-Embedded Entrepreneurship

Programs (as described in the previous paragraph); the National Incubator Initiative for Clean Energy, which facilitates co-ordination and collaboration among incubators around the country to develop best practices and improve performance standards; the Small Business Innovation Research and Small Business Technology Transfer Programs, which offer grants to small businesses that are working on the development and commercialisation of new and innovative research; and Small Business Vouchers, which facilitate access to national labs for qualified clean energy small businesses.

Energy Investor Center

Given the size and scale of DOE funding for new, early-stage, high-potential energy technologies, the Department in 2016 created the Energy Investor Center (EIC) to establish a single access point for investors to connect with and identify investment opportunities from the DOE's energy technology programmes and national labs. The EIC facilitates access for investors through stakeholder round tables (under the Laboratory-Investor Knowledge Series) and through an online platform (known as the Laboratory Partnering Service). The centre also runs Innovation Interface, which conducts seminars fostering information exchange between DOE energy technology experts and investors, as well as technical assistance, in which the centre shares research and analysis from the DOE's scientific programme managers with the investor community. The EIC falls under the authority of DOE's OTT (DOE, 2019o).

Technology Commercialization Fund

Under Section 1001 of the Energy Policy Act of 2005, Congress established the Technology Commercialization Fund (TCF). The fund is required to use 0.9% of the applied research funding granted to the DOE to finance applied research, development, demonstration and commercial applications of technologies that demonstrate promising potential for commercial use. Based on this level, the TCF provided around USD 20 million in funding in 2018 for 64 projects, with additional (required) 50% matching funds from the private sector (DOE, 2018). The projects are divided into two topic areas: projects that identify additional maturation of technology to attract private investment and projects that identify co-operation potential between lab-developed technology and private partners to improve commercial application. In 2018, funding was awarded to projects ranging from smart EV charging adapters to integrated thermal energy storage with co-generation systems and advanced biofuels solutions (NREL, 2019). Overall, the TCF helps move energy technology projects towards commercialisation.

STEM

In order to support its mission, the DOE also runs a programme called STEM Rising, which supports education and training in science, technology, engineering and mathematics (STEM) for students, teachers and the energy workforce.

International collaborations

Through its prominent role in international forums such as the IEA, the United States undertakes a number of international collaborations on energy RD&D, under the responsibility of the DOE's Office of International Affairs. In particular, the United States is an active contributor to IEA TCPs, participating in 37 out of 38 TCPs, the highest of any IEA member country (IEA, 2019a). The United States is also co-leading the

Committee on Energy Research and Technology (CERT) task force on TCP enhancement established in February 2018 (IEA, 2019b).

The United States was a founding member of the CEM, established in 2009. It hosted the first CEM conference, which convened energy ministers from major economies to promote the expansion of clean energy technologies globally. Following that, the country also hosted the seventh CEM in 2016 (Clean Energy Ministerial, 2019). The DOE acted as secretariat of the CEM from its start in 2009 until the function was handed over to the IEA in 2016. Currently, the United States is one of 26 CEM members (including the European Commission). Within the CEM, the United States is a leading country on ten programmes: 21st Century Power Partnership; International Smart Grid Action Network; Global Lighting and Energy Access Partnership; Electric Vehicles Initiative; Energy Management Working Group; Super-Efficient Equipment and Appliance Deployment Initiative; Clean Energy Education and Empowerment Initiative; Clean Energy Solutions Center; Nuclear Innovation: Clean Energy Future Initiative; and Carbon Capture, Utilization and Storage Initiative. It is also a participating country in an additional set of CEM programmes: Multilateral Solar and Wind Working Group, Advanced Cooling Challenge, Corporate Sourcing of Renewable Energy Campaign, Energy Management Campaign, and Global Lighting Challenge.

Through the DOE and its focus on early-stage RD&D, the United States is also a member of Mission Innovation (MI), as one of 23 founding countries (along with the European Commission). The United States hosted the first MI ministerial in 2016 and is a member of the MI steering committee. As part of MI, the United States participates in several initiatives, including: Smart Grids Innovation Challenge, Off-Grid Access to Electricity Innovation Challenge, Carbon Capture Innovation Challenge, Sustainable Biofuels Innovation Challenge, Converting Sunlight Innovation Challenge, Clean Energy Materials Innovation Challenge, Affordable Heating and Cooling of Buildings Innovation Challenge, and Renewable and Clean Hydrogen Innovation Challenge (Mission Innovation, 2019). In November 2018, the DOE announced up to USD 30 million in funding for novel and enabling carbon capture transformational technologies through MI. At present, the administration is reviewing its MI activities (Mission Innovation, 2018).

In addition to multilateral activities, the United States – through the DOE – is also involved in a number of bilateral RD&D initiatives. These include: the US-China Collaboration in Fossil Energy R&D; the US-UK Collaboration in Fossil Energy R&D; the US-China Bilateral Civil Nuclear Energy Cooperative Action; the US-India Civil Nuclear Energy Working Group; and the US-Japan Bilateral Commission on Civil Nuclear Cooperation (DOE, 2019q). The United States is also a participant in the International Cooperation in Methane Hydrate Research, the International Nuclear Energy Research Initiative and the Carbon Sequestration Leadership Forum.

Assessment

The United States is a global leader in public and private RD&D spending. The shale revolution was driven by innovation and public investment in RD&D and has benefited from the capabilities of the DOE, national laboratories, academic institutions and industry, which have brought about significant economic growth. Thanks to the uninterrupted strength of public funding for early-stage RD&D, the United States continues, through the DOE and the national laboratories, to maintain worldclass facilities and collaborative consortia with industry and academia.

The 2017 National Security Strategy underlines the critical importance of understanding worldwide science and technology trends, attracting and retaining inventors and innovators, and leveraging private capital to maintain competitive advantages. The United States has a significant opportunity to replicate the shale revolution in other sectors, notably in emerging clean energy technologies and industrial process innovation.

In 2017, the United States spent 0.038% of its GDP on energy-related RD&D, according to IEA data. This was around the median among IEA member countries. However, based on absolute numbers, the United States is by far the largest energy RD&D spender. In 2017, the United States spent USD 7 289 million on energy-related RD&D, or 40% of the IEA total.

A Congressional Research Service study from 2018 found that over the period FY 2009-FY 2018, nuclear energy received the largest share of energy technology funding (28.6%), followed by fossil energy (20.8%), renewable energy (19.5%), energy efficiency (17.1%) and electric systems (14%, though a sizeable share of this came from the American Recovery and Reinvestment Act of 2009) (Congressional Research Service, 2018b). Public RD&D funding has been on the rise, which illustrates bipartisan support for US national laboratories as well as academic collaborations supported by public funding. However, demonstration funding has been in decline, as industry is expected to invest in these areas.

Since the last IEA review in 2014, the DOE has continued to expand the commercialisation of RD&D results, technology transfer, industry engagement through partnerships, benchmarking, output measuring and de-risking first-of-a-kind technology innovation. The USD 40 billion Energy Loan Guarantee Program and the establishment of the OTT in 2015 with its Energy I-Corps programme, the USD 26 million/year TCF and the EIC illustrate this renewed focus. The Loan Guarantee Program has resulted in USD 30 billion of investment in over 30 projects thus far, including in renewable energy, tribal energy, nuclear energy (Vogtle plant), advanced technology vehicles manufacturing and carbon capture and storage (Lake Charles Methanol facility in Texas).

Public funding for nuclear RD&D is becoming a priority, as reflected in the DOE budget, which saw an increase for nuclear spending. USD 1.3 billion is allocated for 2019 with a larger focus on the demonstration stage. The government prioritises support for technology innovation, in first-of-a kind plants, as a quarter of the current nuclear fleet is expected to retire before the end of their licences and investment in new reactors is not advancing.

The DOE has been active in promoting RD&D in advanced nuclear reactors and SMRs, and at engaging the private sector in cost-sharing partnerships. Funding for RD&D and licence application was made available to the NuScale SMR, which is currently undergoing design certification. The Nuclear Regulatory Commission is also received funding from Congress to develop regulatory frameworks for advanced reactors. Under the Nuclear Innovation Capability Act, the DOE has been authorised to develop a new test reactor (Versatile Test Reactor) to be operational by 2026, and improve modelling and simulation capabilities. Together with public-private partnerships under the GAIN initiative, which would open access to research facilities for the private sector, strong university programmes and targeted international collaborations, the United States aims at maintaining its leadership in nuclear technology.

The United States is the country with the largest overall participation in IEA TCPs, participating in 37 out of 38 TCPs as either a contracting party or a sponsor. The United States has a total of 47 participants from 28 distinct US entities (several TCPs see participation of more than one entity from the United States) with the DOE as the single largest participant (in 32 out of a total 47 US participants). US representatives hold a leadership position (chair/vice-chair) in 13 TCPs – about one-third of all TCPs – which illustrates the continuous relevance of the TCP mechanism for the current administration. The United States is also committed to foster the work of the TCPs going forward by co-leading the CERT task force on TCP enhancement established in February 2018.

As a founder of the CEM and a member of MI, the United States has plans to double by 2020 public RD&D spending in clean energy technologies. Besides its focus on advanced nuclear reactors and CCUS, however, since early 2017, all US participation in MI challenges as well as in CEM initiatives and campaigns have been under review, and funding for international collaboration has been reduced. The IEA encourages the government to dedicate funding and efforts to maintain a high level of international collaboration to ensure it can understand worldwide trends and retain a competitive advantage, in line with the National Security Strategy.

Recommendations

The US government should:

- Promote innovation and cost reductions in CCUS and nuclear technology by modernising and building research facilities as well as initiating demonstration projects (for instance advanced reactor technology demonstrators), in collaboration with industry and targeted international partners.
- Strengthen energy RD&D towards demonstration of critical technologies required to support the cost-effective growth of renewable energy. Based on the Grid Modernization Initiative, develop a roadmap for system flexibility.
- Provide adequate support to international collaboration efforts of US national laboratories and DOE RD&D programmes to maintain global leadership on energy technology innovation.

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7. Oil

Key data

(2018 provisional)

Domestic oil* production: 15.5 mb/d

Net imports of crude oil:** 5.9 mb/d, -49% since 2008

Domestic oil products production: 19.0 mb/d

Net exports of oil products: 3.3 mb/d

Share of oil: 31.8% of TPES and 0.9% electricity generation

Consumption by sector (2017)**:** 790.3 Mtoe*** (transport 70.7%, industry 17.8%, commercial 3.1%, other energy 5.7%, residential 1.8%, heat and power generation 0.9%)

*Includes conventional oil, LTO, condensates, NGLs and non-conventional oil.

**Supply data presented in million barrels per day; data in million tonnes unit excludes aviation bunkers.

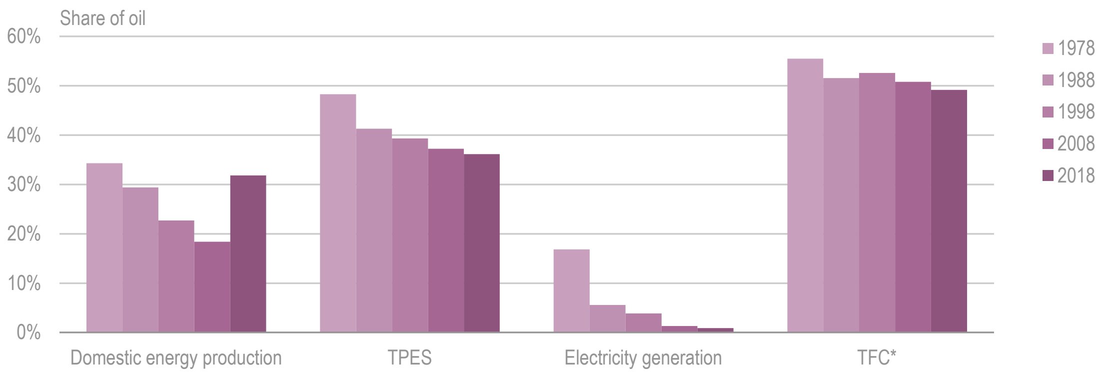
***Demand data are presented in energy units (Mtoe) for comparisons over different fuels and sectors.

Overview

Oil remains the largest source of energy supply in the United States (US), accounting for 36.5% of total primary energy supply (TPES) in 2017. Between 2007 and 2014, both the absolute volume of total oil supply and its share in the energy mix declined; since 2014, thanks to the remarkable growth in domestic light tight oil (LTO) production, driven by technological advancements in horizontal drilling and hydraulic fracturing, oil supply has been picking up again. The unprecedented growth allowed the country's oil import dependency to more than halve to 25% over the last decade and supported the case for lifting the 40-year-old ban on crude oil exports in late 2015 in response to an abundance of domestic supply. The Unites States has become the largest oil producer globally and is expected to become a net oil exporter in 2021.

A key challenge for the country is to resolve infrastructure bottlenecks caused by the rapid increase in oil supply and changes in the geography of production regions. On the decarbonisation front, there has been notable fuel-switching from oil to biofuels in the transport sector, with the share of oil in total transportation fuel consumption dropping by 5% to almost 90% over the last decade. Oil has also essentially phased out to below 1% in power generation. The US Strategic Petroleum Reserve (SPR) is the world's largest stock of emergency crude oil with a volume of 650 million barrels (mb). The federally owned oil stocks are stored in huge underground salt caverns along the Gulf of Mexico coastline. In 2028, the expected SPR volume will be around 400 mb after all existing mandated sales are completed. If the United States no longer holds a substantial level of SPR, there could be a challenge to the future effectiveness of the International Energy Agency (IEA) emergency response system, particularly in the case of a large collective action. At the same time, this rapid decrease in SPR volumes will free up storage space for possible joint stockpiling or commercial leasing, creating an opportunity for the United States to help other IEA member countries reach and/or maintain their obligation to hold oil stocks equivalent to 90 days of their net oil imports.

Figure 7.1 Share of oil in different energy metrics, 1978-2018



The United States experienced a strong increase in domestic energy production between 2008 and 2018. Oil phased down to below 1% in electricity generation.

*Latest TFC data are for 2017.

Note: TFC = total final consumption.

Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

Supply and demand

Crude oil production

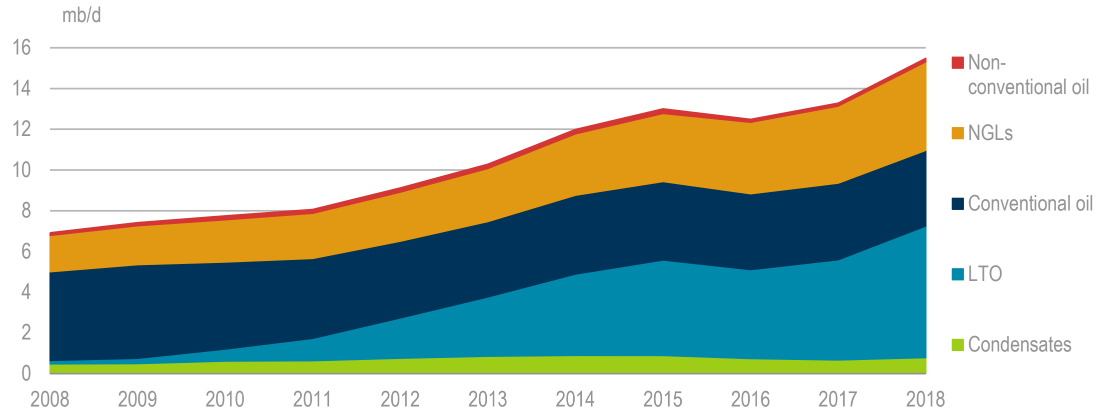
Domestic oil production in the United States was 15.5 mb per day (mb/d) in 2018, a remarkable 124% increase from 2008, with LTO taking the largest share of total production (42%), followed by natural gas liquids (NGLs) (28%), conventional oil (24%), condensates (5%) and non-conventional oils[1] (1%) (Figure 7.2).

The exponential growth of LTO is the main driver of the overall increase in oil production, jumping from an almost non-existent volume in 2008 to 6.5 mb/d in 2018. The production of NGLs has more than doubled from less than 2 mb/d in 2008 to 4.4 mb/d in 2018, while the production of condensates has increased by 65% from 475 thousand barrels per day (kb/d) in 2008 to 784 kb/d in 2018. The production of conventional oil has declined by 15% for the last ten years with 3.7 mb/d in 2018, and non-conventional oils have increased by around 29% over the same period.

[1] Non-conventional oil includes synthetic crude oil from tar sands, oil shale, liquids from coal liquefaction, liquids from gas-to-liquids processes, hydrogenated and emulsified oils, refinery additives and methyl tertiary butyl ether (MTBE).

The first wave of the domestic oil production boom that started in 2009 slowed down with a temporary fall in 2015-16, when global oil prices declined rapidly. During the downturn, oil and gas companies optimised their portfolios and cut exploration and production costs. Oil production picked up again in 2017, indicating a second wave of production growth that has continued up to the time of writing, reaching a historical high of 15.5 mb/d for total oil production in 2018. US crude oil production exceeded that of Saudi Arabia in February 2018 and that of the Russian Federation (hereafter "Russia") in June 2018 (EIA, 2018a).

Figure 7.2 US domestic oil production, 2008-18



Supported by more advanced and cost-effective drilling technology, US oil production continues to break historical highs.

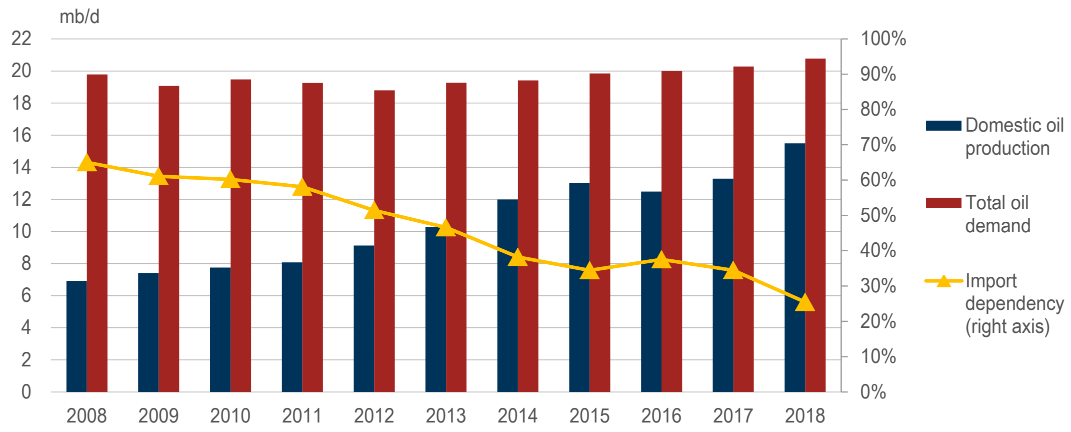
Notes: LTO and condensates are presented separately in Figure 7.2. Crude oil stated in the main text includes conventional oil, LTO, condensates, NGLs and non-conventional oils.

Source: IEA (2019b), *Oil Information 2019*, www.iea.org/statistics/.

Crude oil is produced in 32 states and coastal waters (predominantly the Gulf of Mexico). In 2017, the top producing states were Texas, accounting for around 38% of total domestic crude oil production, North Dakota (11%), Alaska, California and New Mexico (each 5%). Crude oil produced from offshore wells in the federally administered waters in the Gulf of Mexico would rank second (18%) if the area were a state (EIA, 2018b).

While the level of domestic production is still below oil demand, the gap between oil supply and demand has halved over the last decade, and oil import dependency dropped from 65% to 25% (Figure 7.3) between 2008 and 2018. The country lifted its 40-year-old ban on crude oil exports in late 2015 (Box 7.1). The United States exported 2.5 mb/d of crude oil in 2018 to 42 destinations (see section on Outlook of Oil Supply and Demand).

Figure 7.3 US oil import dependency



Since 2008, oil import dependency has more than halved to 25%.

Source: IEA (2019b), *Oil Information 2019*, www.iea.org/statistics/.

Box 7.1 Suspension of 40-year-old ban on crude oil exports

Prior to 2015, US law and regulations required that a company must obtain a licence from the Bureau of Industry and Security (BIS) of the US Department of Commerce to export crude oil. While crude oil export licences were reviewed on a case-by-case basis, select categories of transactions were generally approved as in the national interest, including from Alaska's Cook Inlet, California heavy crude (up to 25 000 barrels per day), exports to Canada, exports related to refining or exchange of SPR oil, exports consistent with international energy supply agreements, and re-exports of foreign crude. Additionally, the BIS approved that condensate processed through a distillation tower be classified as a "petroleum product" instead of crude oil, which was exportable without a licence.

In December 2015, Congress voted to lift the 40-year-old ban on crude oil exports. This policy change has brought significant changes to the global oil market landscape. It boosted the market for light, sweet crude pumped out of US shale deposits, increased the productivity of global refiners as a wider variety of oil became available and consolidated the position of West Texas Intermediate (WTI) as a global benchmark.

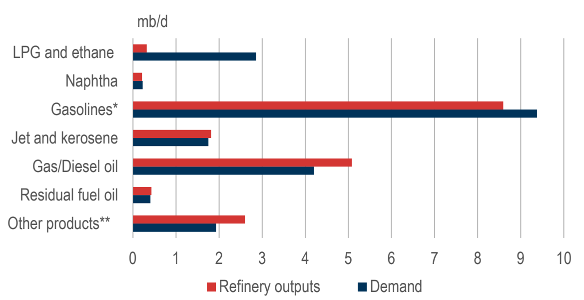
Sources: EIA (2015), *Effects of Removing Restrictions on U.S. Crude Oil Exports* www.eia.gov/analysis/requests/crude-exports/; EPA (2014), *U.S. crude exports in April rise to highest level in 15 years*, www.eia.gov/todayinenergy/detail.php?id=16711 .

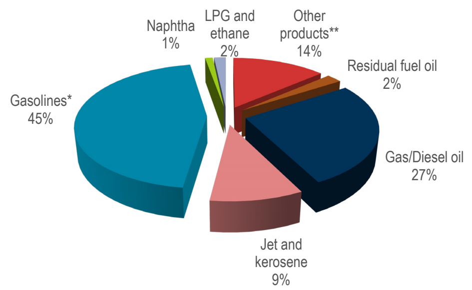
Refined oil products

In 2018, the United States processed 17.0 mb/d of crude oil and produced 19.0 mb/d of oil products. Over the last decade, the gross volume of refining outputs increased by 5%, with gasoline accounting for the largest share, but the total supply of oil products still could not cover total demand of 21 mb/d (Figure 7.4).

In 2018, liquefied petroleum gas (LPG) – mainly propane and butane – ethane and gasoline showed considerably higher demand over domestic supplies, which were met by imports. For the category LPG and ethane, refinery outputs were short by 2.5 mb/d compared with demand,[2] and gasoline output was short by 0.8 mb/d.[3] Supply and demand for naphtha, jet and kerosene, and residual fuel oil were well balanced with demand, while there were excess supplies of gas/diesel oil and other products. The United States is one of the largest exporters of diesel and other products, which include lubricants, bitumen and waxes.

Figure 7.4 Refinery gross outputs and demand by products, 2018





Total domestic supply of oil products still falls short of total demand.

**Gasolines* include blended biofuels.

***Other products* includes refinery gas, aviation gas, other kerosene, petroleum cokes, white and industrial spirit, lubricants, bitumen, paraffin waxes, and other non-specified products such as tar and sulphur.

Source: IEA (2019b), *Oil Information 2019*, www.iea.org/statistics/.

Trade: Imports and exports

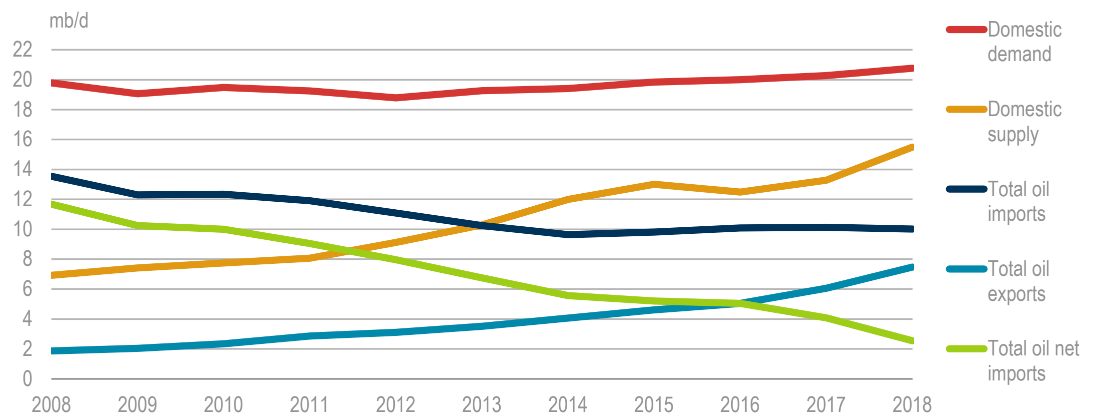
The United States' commendable growth in domestic oil production has changed the country's oil trade dynamics over the last decade. Although the gap between domestic oil supply and demand has been falling quickly over the last decade, the country was still a net importer of oil in 2018 (Figure 7.5).

In 2018, the United States imported around 10.0 mb/d of oil (crude and oil products); total net imports were 2.6 mb/d, down 78% from a decade ago, due to various factors including an overall decline in oil consumption and increased fuel switching to domestic biofuels, but mostly the strong growth in domestic oil production.

[2] For LPG alone, the US net exports of LPG were 840 kb/d in 2017.

[3] Biofuels largely make up for this shortage of demand. In 2017, the US net exports of (non-bio) gasoline was 145 kb/d.

Figure 7.5 Overview of US oil supply, demand and trades, 2008-18



While still a net importer, total oil net imports dropped by 78% over the last decade.

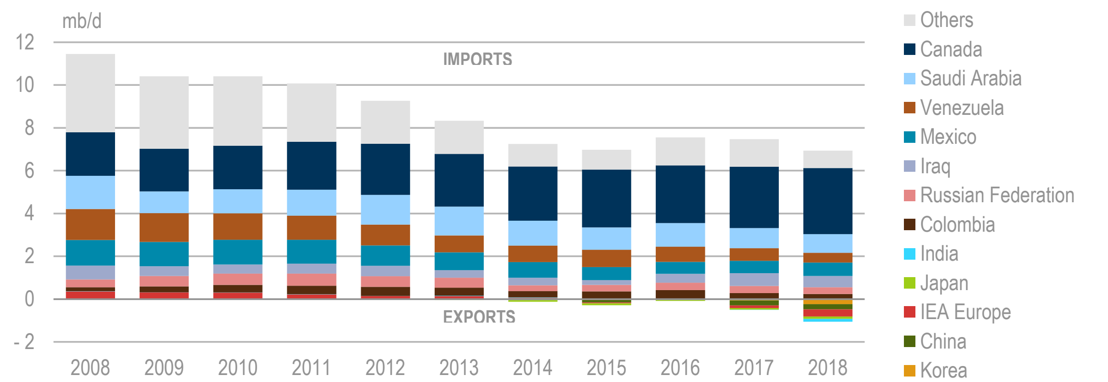
Note: *Total oil* includes conventional crude oil, LTO, condensates, non-conventional oils and NGLs.
Source: IEA (2019b), *Oil Information 2019*, www.iea.org/statistics/.

Trade of crude oil

The lion's share of total oil imports in 2018 was for crude oil, equivalent to 8.4 mb/d; the major sources of imports were Canada (44%), Saudi Arabia (10%), Mexico (8%), and Venezuela and Iraq (each 6%) (Figure 7.6). Although supply sources were diverse in terms of geographical coverage, two countries (Canada and Saudi Arabia) represented more than half of total oil imports.

Crude oil exports rose to average 2.5 mb/d in 2018, up from 1.2 mb/d in 2014, and for certain weeks in 2018 reached as high as 2.8 mb/d. While the majority of US crude oil exports were destined for Canada before 2015, their destinations have greatly diversified since then, with increasing amounts (largely from the Gulf Coast) heading as far as the People's Republic of China (hereafter "China") and India in 2018. Total crude oil exports in 2018 mostly headed to Canada (25%), followed by Korea (10%), China (9%), the United Kingdom (7%), the Netherlands (6%), India (5%), Japan (4%) and Colombia (3%). The Gulf Coast, as the largest refining and storage cluster in the world, was the exit point for 79% of US crude exports.

Figure 7.6 US crude oil net imports per country, 2008-18



US crude oil trade has become dynamic in terms of volume and trading partners.

Note: Crude oil includes conventional oil, LTO, condensates, NGLs and non-conventional oil.

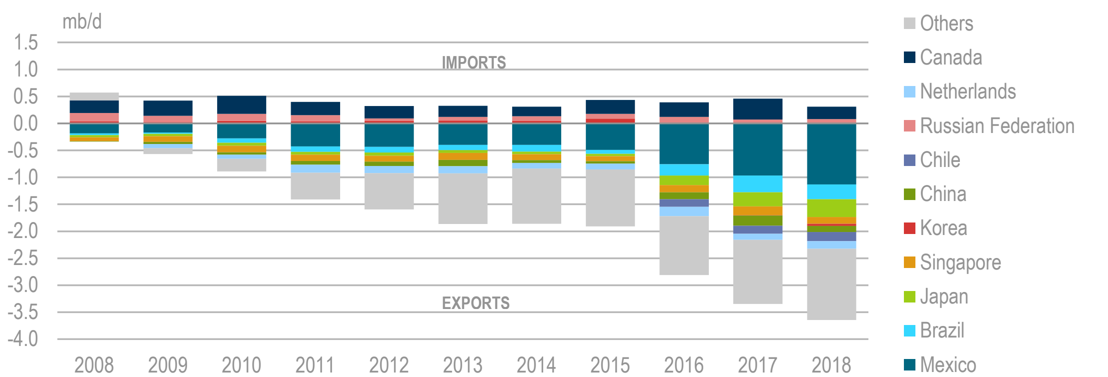
Source: IEA (2019b), *Oil Information 2019*, www.iea.org/statistics/.

Trade of refined oil products

With no export bans in place, the oil products trade has been more dynamic and geographically spread out compared with crude oil (Figure 7.7). Canada has been the largest source of oil product imports and accounted for 34% of the total in 2018, followed by Korea (6%), India, Russia, Venezuela and the United Kingdom (5% each). A notable change in product imports is the declining share of European countries and the emergence of new trading partners such as India.

The United States is the world's largest exporter of refined oil products. In 2018, the United States exported 5.0 mb/d of oil products, of which 24% were delivered to Mexico, 7% to Japan, 6% each to Brazil and Canada, and 3% each to China, India and Singapore. With remarkable growth in domestic oil production, an even larger volume of oil products will be available for export in the future.

Figure 7.7 US oil products net imports per country, 2008-18



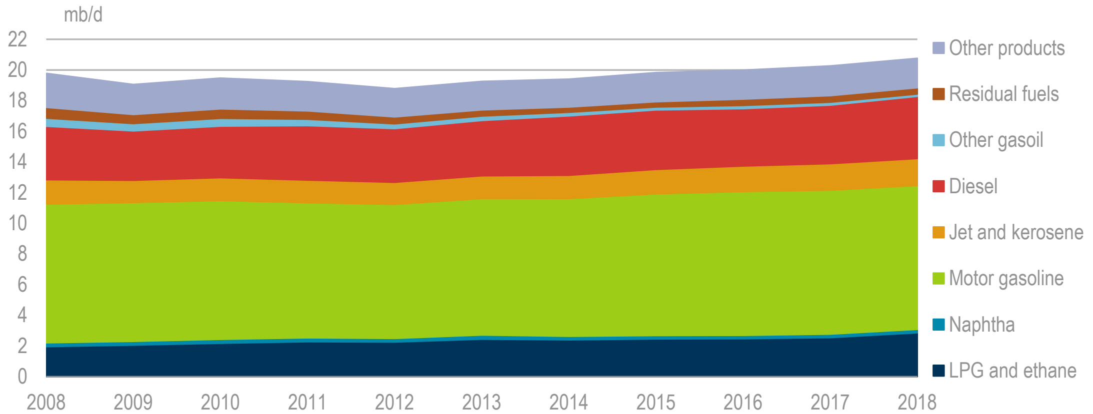
US oil product exports have not only increased in absolute volume but also diversified in terms of destinations over the last decade.

Source: IEA (2019b), *Oil Information 2019*, www.iea.org/statistics/.

Oil demand

Oil is by far the largest energy source consumed in the United States. In 2018, total oil consumption[4] was 20.8 mb/d, the highest record since the 2008 financial crisis (Figure 7.8). Over 2007-12, there was an overall decline in US oil consumption due to various factors such as high oil prices, the global economic downturn and energy efficiency improvements, particularly vehicle fuel economy. Since then, oil consumption has started to pick up again, registering a cumulative 11% increase over the last five years, mainly due to an economic recovery as well as abundant domestic oil supplies that pushed global oil prices down.

Figure 7.8 US oil consumption by product, 2008-18



Oil consumption has been on the rise in the last five years, as the economy recovered and abundant supplies pushed oil prices down.

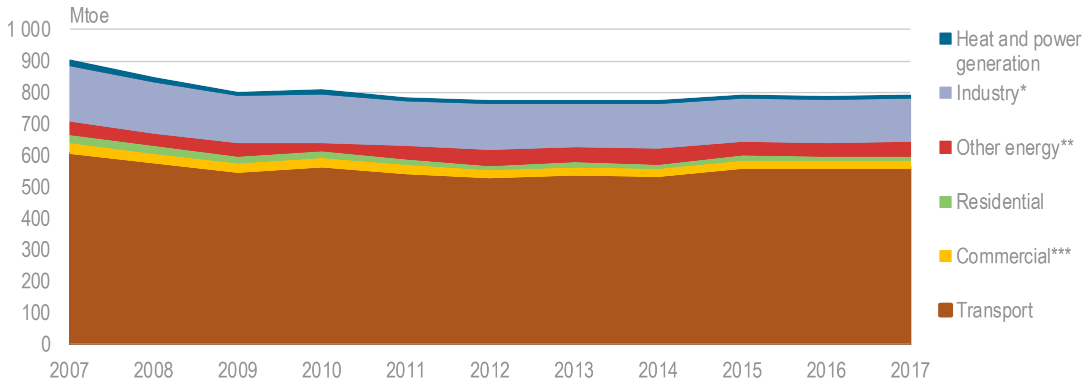
Note: Total demand includes refinery fuels and bunkers and exclude backflows from the petrochemical sector.
Source: IEA (2019b), *Oil Information 2019*, www.iea.org/statistics/.

Motor gasoline is the most consumed oil product in the United States. Motor gasoline demand has remained stable at around 9.1 mb/d, and accounted for 45% of total demand in 2018. In second place, diesel has grown both in absolute volume (16%) and share (2%), but not as fast as LPG and ethane, with the latter being a competitive feedstock for the growing US petrochemical sector. In 2018, LPG and ethane recorded a historical high level of demand at 2.9 mb/d, a 46% increase from a decade ago, and the most significant growth among all oil products. Other gasoil (in addition to gasoil that counts as diesel), residual fuels and minor products have all decreased in terms of absolute volumes and shares over the same period.

By sector, transport is by far the largest oil-consuming sector, accounting for 70.7% of total oil consumption in 2017, followed by industry (17.8%), which includes the booming petrochemical industry (9.4%), other energy (5.7%), and minor sectors with less than 5% each (Figure 7.9). The increase in total oil consumption in 2012-17 mainly came from the transport sector, which saw a 6% increase while other sectors declined slightly. The largest declines came from heat and power generation (8%) and other energy (14%).

[4] The US Energy Information Administration uses product supplied as a proxy for US petroleum consumption.

Figure 7.9 US oil consumption sectors, 2007-17



Transport remains the largest oil-consuming sector, with a booming petrochemical industry increasing demand for feedstocks.

**Industry* includes non-energy consumption.

***Other energy* includes consumption in refineries.

****Commercial* includes commercial and public services, agriculture, forestry, and fishing.

Note: Consumption by sector data are presented in energy units (million tonnes of oil equivalent [Mtoe]) for comparisons over different fuels.

Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

Increasing biofuels demand in the United States

In 2018, bioenergy and waste[5] accounted for 4.8% of TPES in the country. The largest share of bioenergy results from the usage of primary solid biofuels to generate electricity and heat in power plants and in the industrial sector, mainly in the pulp and paper sector. The other main use of bioenergy is biofuels in the transport sector. Biogasoline, the most common of which is ethanol, is the largest biofuel, and the United States is a world-leading ethanol producer. In 2017, biogasoline accounted for 5.2% of total energy use in transport, which was by far the highest share among IEA member countries. Biodiesel[6] consumption has also increased rapidly in recent years (see Chapter 5, "Renewable Energy").

Outlook of oil supply and demand

By 2024, total oil supply in the United States will reach close to 20 mb/d. Already a top global producer of oil products, the United States will be self-sufficient consumer of oil with the anticipated level of production. Crude oil production is expected to rise as the growth from LTO will more than offset declines in conventional oil supply. NGLs will also continue to grow above 5 mb/d in 2024.

Outside of the tight oil patch, crude oil production will decline in the near future. Up to 2020, output from the Gulf of Mexico is expected to remain steady at around 1.7 mb/d, thanks to the start-up of five projects and the expansion of two existing assets. Other conventional supply, from California and Alaska, will fall further. The administration

[5] Including industrial waste (non-renewable), and renewable and non-renewable municipal waste.

[6] Includes biodiesel of diesel quality produced from vegetable or animal oil, biodimethylether, Fischer-Tropsch produced from biomass, cold pressed bio-oil and all other liquid biofuels that are added to, blended with or used straight as transport diesel.

issued a proposal in 2018 to allow offshore oil and gas drilling in nearly all US coastal waters. This is unlikely to make a material, immediate impact on production.

Increased products exports are expected due to the sizeable increase in domestic oil and gas production as well as highly efficient and cost-competitive refining economics. Thanks to growing crude oil production and increasing inflows of discounted Canadian crude oil, the Gulf Coast region will continue to drive US refining activity to new export records, particularly to meet growing demand in Asia. Extra refining capacity is expected to come online in the United States, including light crude processing units in Gulf Coast refineries, such as ExxonMobil's 350 kb/d addition to its Beaumont refinery in 2023. In this time frame, the United States will remain an importer of heavy crudes that suit the configuration of its refineries.

US oil demand has been growing very fast since 2015 to reach 20.8 mb/d in 2018, supported by gasoline demand and the commissioning of new petrochemical projects. Efficiency improvements and slower economic growth will cap the gains from 2020 onwards. Total oil demand is expected to increase from 20.8 mb/d in 2018 to 21.1 mb/d in 2024.

Improving fuel economy will contribute to a contraction in gasoline demand. The Corporate Average Fuel Economy (CAFE) standards, introduced in 2012, mandate a 3.8% annual improvement in passenger cars' fuel economy to 2025. In 2018, CAFE standards were reviewed and the administration proposed updating them under the Safer Affordable Fuel-Efficient (SAFE) Vehicles proposal, which fixes post-2022 targets at the 2021 level, rather than requiring further improvements (see Chapter 4, "Energy Efficiency").

The petrochemical industry has been and will continue to be the major source of oil demand growth. LPG and ethane will be the fastest-growing components, supported by strong US demand for ethane. Jet fuel demand is also expected to post robust growth. On average, total demand is expected to grow by 0.3% per year over the forecast period.

Prices and taxes

There are no price controls on oil products in the United States. Fuel taxes are applied at the federal, state and sometimes even local levels, and several other programmes provide subsidies such as the Low Income Home Energy Assistance Program.

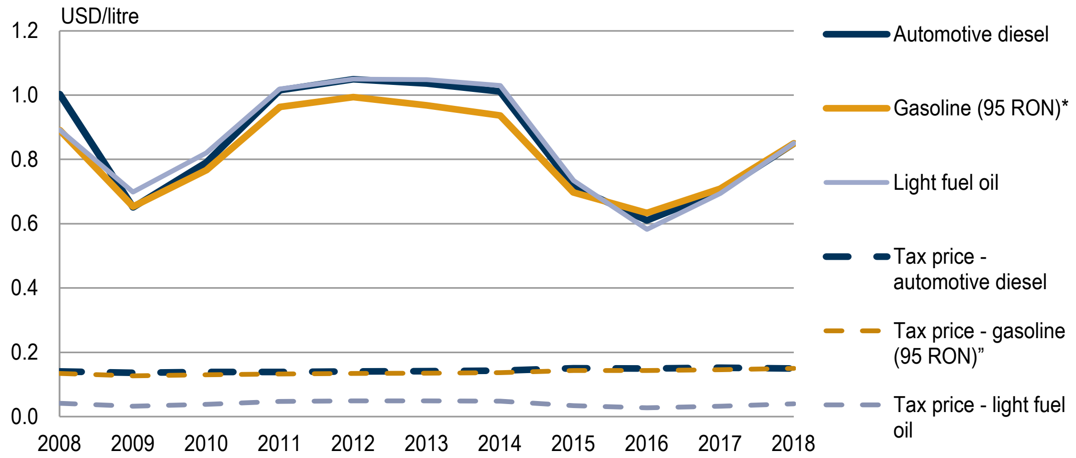
Among IEA countries, the United States has the lowest prices for diesel fuel and gasoline, and ranks sixth-lowest for light fuel oil[7] prices. Low taxation levels and the fact that oil commodities are traded globally in US dollars make US oil prices very responsive to fluctuations in domestic supply and demand and to international market developments. Aside from favourable taxation structures, the country has the most competitive and fully developed market for refined products in the world, which allows it to operate at very low operational costs, mainly along the US Gulf Coast.

Similar trends have been observed for diesel, gasoline and light fuel oil prices in the last ten years (Figure 7.10). Following the 2008 financial crisis and the sharp fall in crude oil prices, the price for diesel dropped sharply by 35%, for gasoline by 22% and for light fuel

[7] Light fuel oil for end-use prices generally comprises light distillate fuel oils. Light fuel oil can be used for heating purposes.

oil by 28%. From 2009 onwards, prices started to pick up again to reach pre-crisis levels in 2011 and stabilised at these levels for about three years.

Figure 7.10 US oil fuel prices, 2008-18



Oil fuel prices have increased since 2016 following the growth in global crude oil prices.

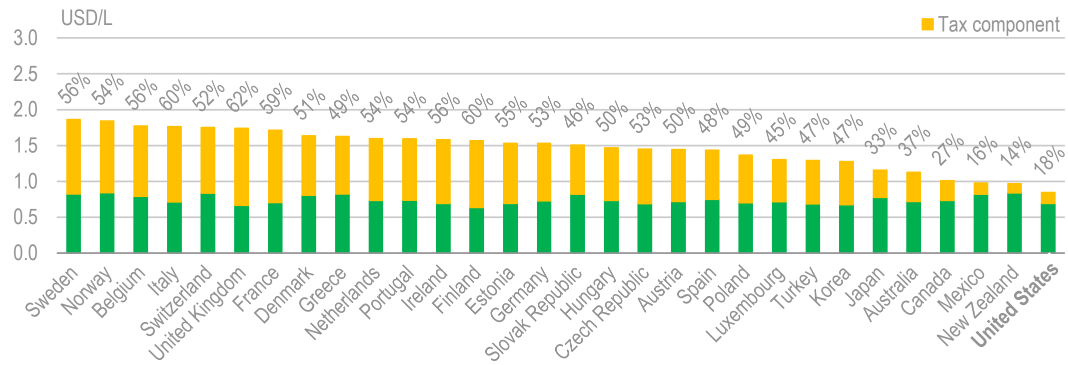
* 95 RON refers to premium unleaded.
Note: The oil fuel prices presented are average retail prices.
Source: IEA (2018a), *Energy Prices and Taxes 2018*, www.iea.org/statistics/.

From the second half of 2014, and following the drop in crude oil price, oil fuel prices started to decline again. The diesel price almost halved down to the lowest point at USD 0.55/litre[8] in the first quarter of 2016. The gasoline price hit its lowest point at USD 0.57/litre in the first quarter of 2016, compared with almost USD 0.95/litre in early 2014. The light fuel oil price halved down to USD 0.54/litre in early 2016. Over the last two years, average prices have increased to close to pre-crisis levels. In the third quarter of 2018, the diesel price was USD 0.86/litre, the gasoline price bounced back up to USD 0.84/litre and the light fuel oil price increased again to USD 0.90/litre. The United States has among the lowest tax rates for all oil products (Figure 7.11).

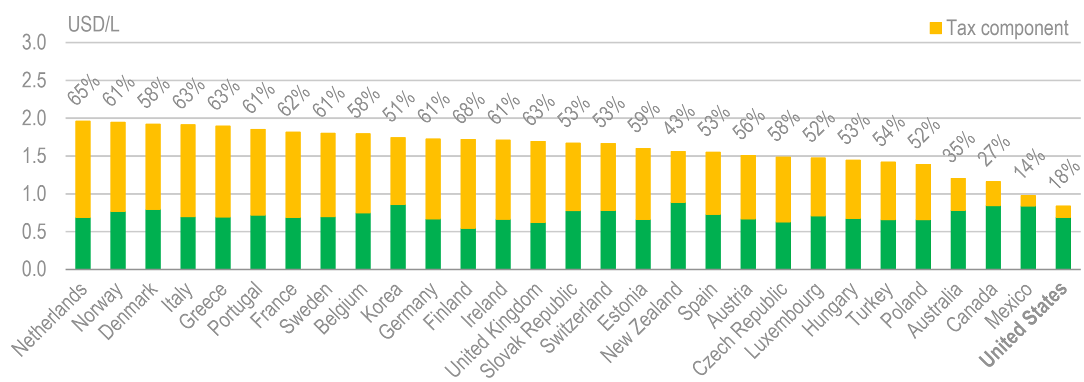
[8] The US gallon is defined as 3.785 litres.

Figure 7.11 Oil fuel prices in IEA member countries, second quarter of 2018

Automotive diesel fuel

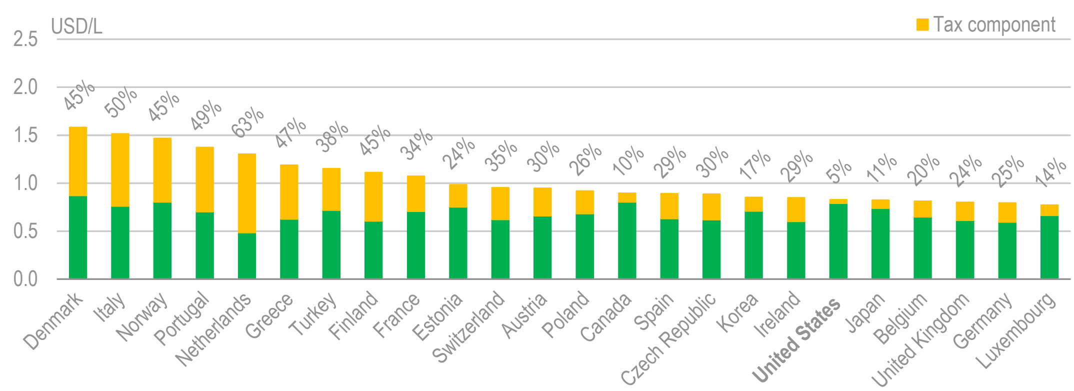


Premium unleaded gasoline (95 RON)



Note: Premium unleaded gasoline data are not available for Japan.

Light fuel oil



The United States has the lowest diesel and gasoline prices with the second-lowest taxes among IEA countries, and the sixth-lowest fuel oil price with by far the lowest tax component.

Note: No light fuel oil data for Australia, Hungary, Mexico, New Zealand, the Slovak Republic and Sweden.
Source: IEA (2018a), *Energy Prices and Taxes 2018*, www.iea.org/statistics/.

In the third quarter of 2018, US diesel and gasoline prices both ranked the lowest among IEA countries. The US federal tax rate for diesel was 18%, which was higher than New Zealand (14%) and Mexico[9] (16%); the US federal tax rate for gasoline was also 18%, higher than Mexico (14%). However, states and sometimes even local governments levy taxes on motor fuel. These vary on a state-by-state basis, but can often represent a significant portion of the taxes that consumers pay at the retail level. Although the US light fuel oil price ranked sixth-lowest in the IEA comparison, its tax rate (5%) was by far the lowest among all IEA countries.

Institutions

The Department of Energy (DOE) acts as the National Emergency Strategy Organization (NESO), with responsibility for initiating and co-ordinating the US response in the event of an oil supply disruption. The DOE's Office of Petroleum Reserves has management responsibility for the US SPR, provides information on the status of SPR stocks, interfaces with SPR-connected refineries and develops potential SPR response options to address crises. The responsibility for an SPR release during oil supply emergencies is held by the SPR office under the authority of the Assistant Secretary for Fossil Energy. The DOE's Office of Fossil Energy also leads federal government efforts on research and development (R&D) related to oil production.

The Federal Energy Regulatory Commission (FERC) is an independent commission with regulatory powers in electricity, hydropower, natural gas and oil markets. It regulates interstate gas and electricity markets such as pipelines and transmission services, and is nominally part of the DOE but operates independently, with appointed commissioners and professional staff.

The Bureau of Ocean Energy Management (BOEM) is part of the Department of the Interior and is responsible for developing programmes related to offshore oil, gas and other marine minerals, including the Outer Continental Shelf (OCS). It oversees OCS leasing policy as well as the planning of its lease sales. BOEM also carries out technical work such as economic analysis and studies based on geographic information system data and mapping (BOEM, 2018a).

The Bureau of Safety and Environmental Enforcement is also under the Department of the Interior and responsible for enforcing safety and environmental regulations for offshore oil and gas production. Its functions consist of all field operations, including permitting, inspections, offshore regulatory programmes and oil spill response (BSEE, 2018).

Oil exploration policies

Given an abundance of domestic shale oil production, US policy is no longer guided by a strong focus on reducing oil dependency, though it still recognises an "all of the above" energy policy doctrine. In 2017, the administration put forward the pursuit of "American energy dominance" as its guiding strategy, based on three elements:

[9] Taxes on gasoline and diesel in Mexico are higher in proportion to their end-consumers prices. Since January 2019, the main taxes for gasoline and diesel prices are: 1) special tax on production and services (approximately 25%) and 2) value-added tax (16%). Each tax is independent from the other.

- producing more energy to lower input costs to the economy
- removing regulations on the energy sector to increase production opportunities
- pursuing energy trading opportunities with other countries.

The shared objective of “all of the above” and “American energy dominance” strategies is to maximise energy production opportunities and expand the role of the United States in the global energy system. Despite declining import dependency, however, the United States will continue to be a major oil consumer, as the US economy remains the second-largest energy consumer in the world, behind China. Also, in the event of a global supply disruption, the global nature of the oil market means that US consumers could still see their retail fuel prices impacted by global price movements.

Oil exploration

The level of import dependency can be affected by the opening of new domestic drilling areas. The administration’s support for US energy dominance is well reflected in recent energy policy changes. In April 2017, the president issued an executive order, implementing an America-First Offshore Energy Strategy, which flagged energy innovation as well as more exploration and production in the United States, including the Arctic OCS.

In January 2018, the US Interior Department submitted a draft plan, the 2019-24 Outer Continental Shelf Oil and Gas Leasing Program, to open 25 out of 26 regions of the OCS for drilling, leaving out only the North Aleutian Basin in Alaska (BOEM, 2018b). The proposed plan includes 47 potential lease sales in four regions: 19 sales off the coast of Alaska, 7 in the Pacific Region, 12 in the Gulf of Mexico and 9 in the Atlantic Region. The draft schedule starts with 1 lease sale in the Beaufort Sea in Alaska in 2019, and then between 6 and 8 lease sales per year for the following five years in the four regions, except for 2023 when a peak of 20 lease sales is planned.

The BOEM that manages offshore leasing estimated in 2016 that total undiscovered, technically recoverable resources in the US OCS consist of 89.97 billion barrels of oil (BOEM, 2017). Almost two-thirds of the country’s oil reserves that companies can drill for lie in seas already open to drilling. The proposed plan aims to open 90% of the total federal OCS acreage for drilling, a significantly higher level compared with before.

To evaluate the possible regional impacts of this new lease plan, the BOEM is now preparing an environmental analysis following the process prescribed by the National Environmental Policy Act. The administration granted Florida an exclusion from the draft plan, and 12 other states have asked for the removal of leases in their regions due to fears that oil and gas drilling may affect their tourism industries.

R&D has been the driver for continuous innovation for both unconventional and conventional exploration and production. Research-based innovation is considered vital for the longevity of the oil and gas industry and a prerequisite for maintaining and growing output. One key technology area is carbon capture, utilisation and storage (CCUS) for enhanced oil recovery (EOR) and to reduce CO_2 emissions. In February 2018, Congress passed a bill that extends and expands an existing tax credit regime (45Q), which encourages carbon dioxide (CO_2) injection for improving oil recovery rates. The tax credit increase, from USD 10 to USD 35 per tonne of stored CO_2, has been well received by the oil industry (see Chapter 6, "Energy Technology Research, Development and Demonstration").

Tax reform

In December 2017, Congress passed and the president signed the Tax Cuts and Jobs Act, which, among its various provisions, reduced the corporate tax rate from 35% to 21%. The act took effect on 1 January 2018.

Its impact on the economics of multiple energy projects is complex as it depends on the interplay with other factors such as new depreciation and capital structures. However, the lowering of the corporate tax rate has been positive for oil and gas producers.

Permitting and mineral rights

A unique aspect of US oil and gas development is the structure of mineral rights. In the United States, ownership of subsurface mineral resources is granted to the individuals or organisations that are surface landowners. These property owners have both surface rights and mineral rights. This complete private ownership is known as "fee simple" ownership, under which an owner controls the surface, the subsurface and the air above a property. The owner also has the freedom to sell or lease these rights individually or entirely to other entities. Most states have laws that govern the transfer of mineral rights from one owner to another. They also have laws that govern mining and drilling activity. The ownership structure for mineral rights in the United States has helped enable the growth of onshore production as property owners are more economically vested in resource development compared with many other countries, where the government owns all subsurface mineral rights.

Permits for oil wells mostly fall under the jurisdiction of state governments where the drilling will take place, rather than the federal government. The exception is OCS drilling, which falls under the authority of BOEM, as well as drilling on onshore federal lands, which falls under the authority of the Department of the Interior's Bureau of Land Management. The Environmental Protection Agency (EPA) has jurisdiction over oil spills.

Similarly, state governments also take the lead on environmental regulations for oil and gas wells within their territories, though the EPA also sets federal environmental regulations. Following rules to tighten regulations around emissions from new oil and gas wells in 2016 (specifically to target methane emissions), the administration in 2018 proposed rolling back those requirements, in line with "American energy dominance" efforts to lower the costs of environmental regulations in order to promote increased production.

Infrastructure

Pipelines

Pipelines are the most commonly used mode of transport for moving oil across the United States. In 2018, the country had 215 625 miles (346 940 kilometres) of crude gathering and distribution pipelines operated by more than 2 300 companies, and the top 10 operators were responsible for 30% of the network.

For crude oil, the major pipelines are the Capline, Centurion, Border, Midvalley, Seaway and Basin pipelines, with a combined capacity of around 2.5 mb/d. They were built in the 1970s to transport oil from the Gulf Coast to the Midwest area. This historical flow has been radically changed with the shale revolution. For instance, the Seaway pipeline was reversed in 2012 to flow from the Midwest to the Gulf Coast, and there is now a project to reverse the Capline pipeline by 2021. In addition, in the last five years, new takeaway capacity was built to transport oil. For the Gulf Coast, the pipeline takeaway capacity is expected to almost double from 2018 to 2023, from 2.5 mb/d to 4.9 mb/d. In west Texas, if all planned investments are realised, Permian and Eagle Ford takeaway capacities would more than double from 2.7 mb/d to 5.8 mb/d by the end of 2020.

Four major pipeline systems provide oil products from the Gulf Coast to the East Coast and Midwest regions: Colonial, Plantation, Explorer and TEPPCO.

- The Colonial pipeline system originates in Houston and terminates in New York City. The pipeline has four lines from Houston to North Carolina, with a combined capacity of 2.4 mb/d. Two lines, with a capacity of 1.1 mb/d, extend beyond North Carolina and continue delivery into the Northeast region, up to New York City.
- The Plantation pipeline system transports products from the Gulf Coast to the East Coast. The pipeline originates near Baton Rouge, Louisiana, and terminates in the Washington, DC, area. The Plantation pipeline comprises two lines with a combined capacity of 700 kb/d and runs largely parallel to the Colonial pipeline.
- The Explorer pipeline system originates in the Gulf Coast near Port Arthur, Texas, and terminates in Ardmore, Oklahoma, and Hammond, Indiana. The Explorer pipeline consists of two lines and has a combined capacity of 720 kb/d.
- The TEPPCO pipeline system originates near Beaumont, Texas, and extends into Chicago; two lines continue to the Northeast region. It has an operating capacity of 230 kb/d.

The Northeast imports 80% of its fuel supplies from outside the first Petroleum Administration for Defense District (PADD 1). The pipeline infrastructure in the Northeast plays a key role in balancing supply and demand within the region.

The Calnev pipeline system transports refined products from Los Angeles and extends to terminals in Barstow, California and Las Vegas, Nevada. The Calnev pipeline has a capacity of approximately 120 kb/d.

Unlike gas pipelines, interstate oil pipelines are not usually subject to federal permitting, with the exception of cross-border pipelines (which require a permit from the State Department) and for certain water crossings (which require a permit from the US Army Corps of Engineers) or federal crossings (which warrant a permit from divisions of the Interior Department). Instead, each state that a pipeline traverses must issue a permit for construction (FERC, 2018). Pipeline safety is monitored and regulated by the Department of Transportation's Pipeline and Hazardous Materials Safety Administration, while FERC regulates rate-setting and other operational aspects for oil pipelines (PHMSA, 2018; FERC, 2019).

Box 7.2 Oil flows from Canada

In 2017, Canada exported around 3.3 mb/d of crude oil, which represents more than 85% of its production. The majority went via pipelines to the United States, with a small portion going by rail and ship. In 2018, Canadian crude oil exports by rail were around 250 kb/d. Exports from Canada to the United States of Canadian oil sands and crude have almost doubled in the last decade.

At the end of 2017, the amount of oil available in Canada for export to the United States was 310 kb/d higher than pipeline takeaway capacity. When the Keystone pipeline closed for an unplanned outage in November 2017, operational capacity fell even more. The shutdown left Canadian producers with few choices other than to store crude or cut output. Canadian oil delivered at the Hardisty, Alberta, terminal came under significant price pressure as a result and traded USD 32 per barrel (bbl) below WTI Cushing on average during 2018. Keystone restarted in late November 2017 and operated at reduced rates until late January 2018. Rail shipments have picked up in recent months to partially address the bottleneck on pipeline takeaway capacity. Despite this increase, new rail car standards (which resulted in the decommissioning of a lot of older units), competition from grain exports and a lack of trained staff have made it difficult to ramp up rail exports quickly.

In 2019, most of the gains in Canadian takeaway capacity are likely to come from the optimisation or replacement of existing pipelines. Enbridge plans to replace its Line 3 pipeline (maintaining its 760 kb/d capacity) between Hardisty and Superior, Wisconsin. The project received a green light from the Canadian government in 2016 but is still awaiting approval from Minnesota. This project is planned for completion by the end of 2020.

Kinder Morgan is also planning to expand the capacity of the Trans Mountain pipeline to 890 kb/d (from 590 kb/d) by the addition of a parallel line. The Trans Mountain pipeline starts in Edmonton, Alberta, and ends in Vancouver, British Columbia, from where crude oil is shipped to US refineries on the West Coast. This project was approved by the Canadian government in 2016 but lawsuits have caused major delays. The pipeline was acquired by the Canadian government in 2018.

Finally, the largest project is TransCanada's new-build 830 kb/d Keystone XL crude oil pipeline, which would take a more direct route from Canada to Cushing, Oklahoma, than the existing Keystone line. The US administration put this project on hold in 2015 but revived it in 2017 based on a presidential permit issued that year and again in 2019. TransCanada has secured 500 kb/d of firm supply commitments and has started to plan construction work, though it has faced a few legal setbacks related to its permits. The pipeline could be operational by mid-2021, at the earliest, due to the requisite permitting and construction timelines.

Sources: IEA (2018), *Oil 2018: Analysis and Forecasts to 2023*; IEA (2019), *Oil 2019: Analysis and Forecasts to 2024.*

Price differentials

The historical hub for crude oil prices in the United States is in Cushing, Oklahoma, where contracts for WTI are settled. Additional hubs exist for WTI Midland, located near the Permian and Eagle Ford basins, and more recently at the refining and export hub of Houston.

Based on price data from 2012 to 2014, WTI Midland saw discounts to Cushing of up to USD 20/bbl, reflecting a lack of pipeline takeaway capacity. Since 2014, the WTI price in Midland has largely been in line with the Cushing price based on new pipeline capacity. Early in 2018, WTI Midland was trading above WTI Cushing, reflecting the commissioning of the 300 kb/d Sealy pipeline and the expansion of the Cactus pipeline. However, WTI Midland traded at an average discount of USD 7.30/bbl compared with WTI Cushing later in 2018, due to planned maintenance shutdowns of refineries.

Since 2010, WTI Houston has consistently been at a premium to WTI Midland, due to increased crude shipments from Canada to Cushing, increased US production in the Cushing area, and a lack of pipeline infrastructure from Cushing to the US Gulf Coast. The Midland discount versus Houston increased sharply during 2018, up to USD 25/bbl, as pipelines from the Permian to Houston filled up.

Expected new pipeline projects will further alleviate the current bottlenecks in takeaway capacity, but with additional strong production growth in the Permian and Eagle Ford basins over the next few years, the question of whether new pipeline takeaway capacity will keep pace with crude oil output to avoid regional price differentials might arise again.

Refining

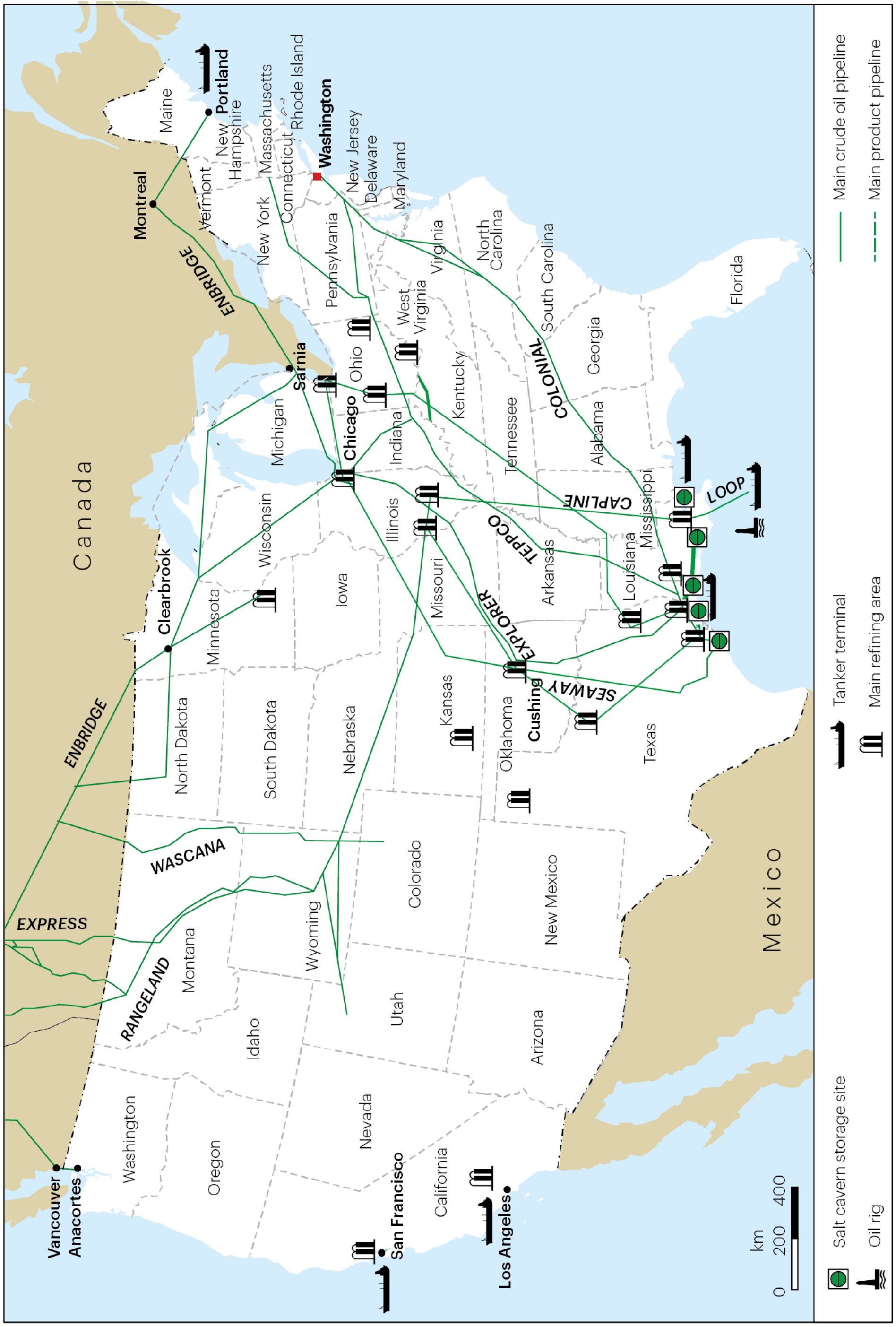
As of January 2019, there were 132 refineries operating in the United States, with the top 10 refineries representing 25% of total capacity (18.8 mb/d). The refineries operated with an average capacity utilisation rate of 91%, which is considered high. More than 45% of the refining capacity is located along the US Gulf Coast (8.4 mb/d), which corresponds to PADD 3. In 2017, the Gulf Coast region was the exit point for 79% of crude oil deliveries to both domestic (Northeast and Midwest) and overseas markets (Latin America, Europe and Asia).

Table 7.1 Top ten refineries in the United States

Rank	State	Company	Refinery	Capacity (bbl per day)	Share of total US refinery capacity (%)
1	Texas	Motiva Enterprises LLC	Port Arthur	607 000	3.2
2	Texas	Marathon Petroleum Co. LP	Galveston Bay	585 000	3.1
3	Louisiana	Marathon Petroleum Co. LP	Garyville	564 000	3.0
4	Texas	ExxonMobil Refining and Supply Co.	Baytown	560 500	3.0
5	Louisiana	ExxonMobil Refining and Supply Co.	Baton Rouge	502 500	2.7
6	Indiana	BP Products North America Inc.	Whiting	430 000	2.3
7	Louisiana	Citgo Petroleum Corp	Lake Charles	418 000	2.2
8	Texas	ExxonMobil Refining and Supply Co.	Beaumont	369 024	2.0
9	California	Tesoro Refining and Marketing Co.	Carson	363 000	1.9
10	Mississippi	Chevron USA Inc.	Pascagoula	356 440	1.9

Note: The table includes only refineries with atmospheric crude oil distillation capacity.
Source: EIA (2019), *Top 10 US refineries operable capacity*, www.eia.gov/energyexplained/index.php?page=oil_refining#tab4.

Figure 7.12 Oil infrastructure in the United States, 2018



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Ports

The oil port infrastructure is well developed in the United States; most of the ports have import terminals for crude oil and petroleum products. There are currently four major ports handling crude oil and condensate exports in Texas: Houston, Beaumont, Port Arthur and Corpus Christi. Houston, Beaumont and Port Arthur have pipeline connectivity with west Texas and the Midwest. Corpus Christi is the largest crude export hub in North

America thanks to high connectivity with the Permian and Eagle Ford basins and a deepwater harbour. In the Northeast and Southeast regions, four ports take only product imports and no crude oil imports: Boston; Baltimore; Jacksonville, Florida; and Charleston, South Carolina. Other ports are able to import both crude oil and oil products. In 2017, US crude oil exports averaged 1.6 mb/d and, in 2018, 2.5 mb/d.

All onshore ports in the Gulf Coast are located in inland harbours and are connected to the open ocean through shipping channels or rivers. These marine transport routes are not deep enough for vessels such as very large crude carriers (VLCC), the largest and most economic vessels used for crude oil transportation. Instead, export growth was mostly achieved using smaller and less cost-effective ships: Suezmax and Aframax. To circumvent depth restrictions, VLCCs transporting crude oil to or from the Gulf Coast have typically used partial loadings and ship-to-ship transfers, an approach known as reverse lightering.

Infrastructure bottlenecks have pricing implications for crude oil exports. Costs associated with using smaller vessels are less of a factor for short-distance exports, but since the share of exports to Asia is growing, these costs will become more important. In 2018, new expansion projects were built to add storage capacity, new terminals and new docks in the ports of Beaumont, Corpus Christi and Houston. In addition, a new export line was built at the Louisiana Offshore Oil Port (LOOP). The LOOP is located offshore southern Louisiana in the Gulf of Mexico and it is currently the only facility that can accommodate a fully loaded VLCC. In early 2019, the US Maritime Administration (MARAD) – in charge of permitting for deepwater offshore ports – had no pending applications for new deepwater ports similar to LOOP. Crude oil export projects with the intention to accommodate fully loaded VLCCs will be located near the port of Corpus Christi in southern Texas; a project led by the company Magellan is scheduled for completion in 2022.

Emergency response policy

Legislation and emergency response policy

The US emergency response policy is based on the 1975 Energy Policy and Conservation Act (EPCA) (Public Law 94-163 as amended). This act provides the statutory authority for the establishment of the US SPR (DOE, 2018a).

Section 161 of the EPCA provides specific authorities and conditions governing the release or drawdown of oil from the SPR. This section states that “drawdown and sale of petroleum products from the SPR may not be made unless the President has found drawdown and sale are required by a severe energy supply interruption or by obligations of the United States under the International Energy Program.” The EPCA does not distinguish between a domestic supply disruption and an IEA collective action, but the United States has utilised different authorities to respond to domestic or regional interruptions versus a global disruption (DOE, 2018b).

In 2000, the president directed the establishment of the Northeast Home Heating Oil Reserve (NEHHOR) in response to high volatility of heating oil prices during the cold winter of 1999-2000. In 2012, the events caused by Hurricane Sandy highlighted the need for a reserve of refined petroleum products to ease shortages caused by supply disruptions following an extreme weather event. The Northeast Gasoline Supply Reserve (NGSR) was authorised by the Secretary of Energy and established in 2014 (DOE, 2014).

National Emergency Strategy Organization

The US DOE acts as the NESO, with responsibility for initiating and co-ordinating the US response in the event of an oil supply disruption. The NESO structure includes a DOE executive team, a crisis assessment team and DOE support offices.

The DOE executive team deliberates on the technical team's findings and submits a proposal for action to the president based on recommendations from the crisis assessment team. The executive team analyses and discusses the findings of the crisis assessment team and co-ordinates a response with other departments and White House staff offices. The Secretary of Energy is responsible for forwarding the executive team's recommendations to the president.

The DOE, through the Office of Cybersecurity, Energy Security, and Emergency Response (CESER) Infrastructure Security and Energy Restoration Division, sponsors preparedness exercises at the local, state and national levels. In May 2018, DOE sponsored Clear Path VI, which addressed the co-ordination among industry, state and federal partners in managing interdependencies within and between infrastructure sectors. The Clear Path exercise is the DOE's flagship annual energy sector simulation crisis exercise; in 2018, Clear Path VI was linked to the Federal Emergency Management Agency's (FEMA's) 2018 National Level Exercise.

Oil emergency reserves

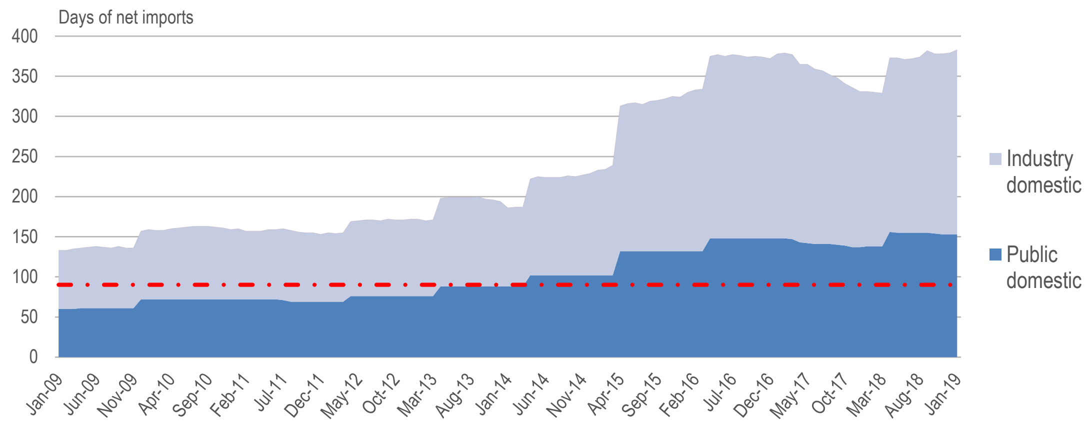
The SPR was established in 1975 under the EPCA to reduce the impacts of supply disruptions and to carry out obligations of the United States under the IEA International Energy Program Agreement. The United States has always complied with the IEA requirement of holding 90 days of net imports (DOE, 2018c).

The NGSR contains 1 mb of seasonal gasoline blend stock stored in terminals in New York Harbour and New England ports. The products are commingled with industry stocks. The NEHHOR contains 1 mb of ultra-low-sulphur distillates, which are stored in above-ground tanks in New York Harbour and New England ports and cover about five days of consumption.

At the end of January 2019, the United States held 382 days of net imports; public stocks accounted for 153 days and industry stocks accounted for 229 days of net imports (Figure 7.13).

There is no statutory obligation on industry to hold stocks for emergency purposes, thus all amounts of industry stocks are held for commercial and operational purposes. The ample industry stocks have ensured that the United States remains fully compliant with its 90-day stockholding obligation. The United States does not hold any stocks abroad, but foreign entities are allowed to hold emergency reserves in the United States, either as tickets or as owned stocks. The United States signed a first-of-its kind arrangement in 2018 with the government of Australia to facilitate such stockholding.

Figure 7.13 Oil stocks in days of net imports and 90-day IEA obligation, end-January 2019



As of the end of January 2019, the US SPR accounted for 382 days of net imports.

Source: IEA (2019d), *Monthly Oil Data Service*, www.iea.org/statistics/mods/.

Storage locations

At the end of September 2018, the total working storage capacity of the United States was 2.14 billion barrels (EIA, 2018d). This volume was split between storage at refineries with 602 mb, product terminals (1 046 mb) and crude oil tank farms (489 mb). The total crude oil volume stored was 297 mb, with 100 mb stored at refineries and 197 mb stored in tank farms. The amount of product stored at refineries was 252 mb and the amount stored at product terminals was 463 mb.

The SPR has a design storage capacity of 713.5 mb; the reserves are located in four underground storage sites in Texas and Louisiana with a total of 60 operational caverns. The SPR storage locations are connected to 28 refineries on the Gulf Coast and to 15 refineries in the Midwest via the Midvalley (9 refineries) and Capline (6 refineries) pipelines. The SPR storage locations are also connected to four marine terminals with a total distribution capacity of 2.4 mb/d.

SPR modernisation programme, planned sales and commercial lease

In the last few years, the level of stocks of the SPR has been reduced from more than 700 mb to around 650 mb as of the end of December 2018. This rapid reduction is the result of the completion of mandated sales by Congress. There were several bills enacted in 2015 and 2016 that collectively called for the sale of 149 mb in FY2017-FY 2025. A section of one of those bills includes authorisation for funding an SPR modernisation programme by selling up to USD 2 billion worth of SPR crude oil in FY 2017- FY 2020. Two other Congressional bills collectively call for the sale of another 112 mb of crude oil in FY 2022 through FY 2028. After all existing mandated sales are complete, the expected SPR volume will be around 400 mb in 2028.

The DOE is currently working to determine which SPR facilities could be leased and what changes would be needed to preserve the long-term integrity of the caverns. Private companies may want to lease excess SPR capacity, which are more cost-competitive than above-ground storage. However, for regular drawdowns, a drawdown process based on brine (salt water) will have to be used to avoid altering the cavern structures. This process will likely involve investments to build up the required facilities, such as brine ponds.

Emergency response to supply disruptions

The United States is subject to various natural hazards: volcanoes and earthquakes around the Pacific Basin, hurricanes along the Atlantic and Gulf of Mexico coasts, and tornadoes in the Midwest and Southeast. The West Coast is not as vulnerable to hurricanes as the Gulf Coast, but a severe earthquake in the Los Angeles Basin or San Francisco region would cause significant disruptions to fuel supplies (DOE, 2018d) .

Impacts of hurricanes

Hurricanes in the Gulf of Mexico are of particular concern, since almost half of the nation's refining capacity is located in the region, as are large import and export hubs, and pipelines to the hinterland; moreover, the SPR storage sites are located in Texas and Louisiana, two states often affected by hurricanes.

In October 2012, Hurricane Sandy affected coastal states from North Carolina to Maine with significant damage to energy infrastructure. Refinery capacity of up to 308 kb/d was shut down for several days, and the Buckeye, Colonial and Plantation product pipelines were also affected, as was the New Jersey Natural Gas pipeline. Crude pipelines were not affected, but several ports were affected with shutdowns at 57 petroleum terminals. Electricity infrastructure was also affected, with 20 states and the District of Columbia experiencing power outages affecting 8.5 million customers.

A more recent example was Hurricane Harvey, which made landfall in late August 2017 as a Category 4 hurricane, making it the strongest storm to strike Texas since 1961. The hurricane had severe impacts on onshore and offshore production and caused dramatic flooding in Houston. During the last week of August, US crude production was cut by more than 700 kb/d and in September crude oil production was nearly 300 kb/d lower than the previous month estimate.

Responses to hurricanes

To address supply disruptions caused by hurricanes, the primary response is an emergency exchange programme to restore supply to refineries, which cannot get access to crude feedstock using regular supply sources. If a refiner submits a request for an emergency loan, SPR staff will perform due diligence to ensure that there is no other source of oil available to the requesting refiner.

Since 2005, there have been four occasions when the emergency exchange process was activated to respond to hurricanes; the volume of stocks released range from 1.0 mb to 9.8 mb. In 2012, to respond to disruptions caused by Hurricane Sandy, refined products from the NEHHOR were released for use by emergency responders, generators and emergency equipment, and buildings, as well as to alleviate fuel shortages in Connecticut.

Participation in IEA collective actions

As an IEA member country, the United States participated in the three IEA collective actions. The administration responded by making the required amount of stock (100% of which was crude oil) available from the SPR by market tender. At the federal government level, oil demand restraint is not among the policy options available for use during an oil supply disruption. The United States used demand restraint measures in the 1970s by imposing a national speed limit of 55 miles per hour and restricting gasoline purchases to odd and even days corresponding to vehicle licence plates. However, none of these programmes are now active, and some of the underpinning legislation has since been repealed. US oil demand restraint policies and regulations exist at the state level and vary from state to state. During Hurricane Sandy, the New York City mayor issued an executive order (number 163) on 8 November 2012 restricting gasoline purchases to odd and even days corresponding to vehicle licence plates. The federal government allows each state to determine the scope and use of demand restraint measures, and aside from information sharing, there is little demand restraint policy co-ordination between states.

Assessment

Oil upstream

Oil is the dominant energy source in the energy mix of the United States, accounting for 36.5% of TPES. Domestic oil production boomed in the last decade, mostly by developing unconventional LTO through hydraulic fracturing and horizontal drilling techniques that allowed the country's oil import dependency to drop from 65% in 2008 to 25% in 2018.

The regulatory environment has been revised to facilitate crude oil exports, such as the suspension of the crude oil export ban in 2015 and the lowering of the domestic corporate tax level. Moreover, domestic refining infrastructure is still geared to heavier and sourer crudes, supporting the case for LTO exports.

The United States became the largest crude oil producer in 2018, mainly due to increased LTO production. Thanks to short drilling completion times and lean cost structures, the industry was able to quickly adapt to changing market conditions, as demonstrated in the last five years with volatile oil prices. However, for conventional offshore oil in the Gulf of Mexico, the last three to four years have proved challenging as low crude oil prices have slowed down investments. Furthermore, no major discoveries have been made in recent years, and the industry is facing output losses from post-peak conventional crude oil fields. The US Gulf of Mexico accounts for 18% of US crude oil production; and the Gulf of Mexico OCS covering about 160 million acres, is estimated to contain about 48 billion barrels of undiscovered, technically recoverable oil and 141 trillion cubic feet (4.0 trillion cubic metres) of undiscovered, technically recoverable gas.

To unlock these resources, the BOEM has embarked upon five-year lease programmes for the OCS. The most recent development was a BOEM proposal to offer 78 million acres for a region-wide lease sale that took place in March 2019. Going forward with offshore permitting, also in other parts of the OCS, regulatory certainty and stability for exploration and production investment decisions are paramount. This calls for streamlined regulatory processes that do not cause unnecessary delays. For instance, early engagement with local communities and joint spatial planning are important to ensure that the development of offshore resources does not result in negative impacts on local activities (e.g. fishing interests, maritime activities).

Technology R&D has been the driver for continuous innovation, for both the unconventional and conventional oil and gas sectors. Research-based innovation is considered vital for the longevity of the oil and gas industry and a prerequisite for maintaining and growing output. One key technology area is CCUS for EOR and to reduce CO_2 emissions. In February 2018, Congress passed a bill that extends and enhances an existing tax credit regime (45Q), which encourages CO_2 injection for improving oil recovery rates. The tax credit increase, from USD 10 to USD 35 per tonne of stored CO_2, has been well received by the oil industry.

Recognising the need for basin-specific technologies for unconventional oil and gas, the DOE is supporting development of different methods to deal with subsurface challenges, and thus ensures maximum value creation in the unconventional oil and gas sector. There is further room for improvement to share best practices and promote innovative technologies among industry players.

Oil markets

In 2018, refinery crude oil intake in the United States reached a record high of 17.0 mb/d, with a monthly record of 17.7 mb/d set in June. Capacity utilisation rates were at 90%. There were 132 refineries in operation as of January 2019, with the top 10 refineries representing one-fourth of total capacity (18.8 mb/d). More than 45% of the nation's refining capacity is located along the US Gulf Coast; this region is the world’s largest exporter of refined products and delivered more than 4 mb/d of gasoline and diesel in 2017 to both domestic (Northeast and Midwest) and overseas markets (Latin America, Europe and Asia). The share of exports has increased significantly over the last five years and reached almost half of total output by 2017. The United States has boosted its export capacity and strengthened its position as a net oil products exporter. During 2018, the net export of motor gasoline was 692 kb/d; diesel net exports reached 1 042 kb/d and jet fuel 53 kb/d.

While US refining throughput is expected to increase further, the intake of conventional crude oil is unlikely to change as the increment will be fulfilled by heavy oil suppliers in Canada and domestic LTO; increased LTO output will likely be exported to emerging Asian countries.

The further expected increases in the production of crude oil and finished products come with challenges for the underlying transportation, storage and distribution infrastructure. Gulf Coast crude oil terminals are geared towards imports rather than exports, and due to their limited depth they cannot accommodate the largest tankers, causing some bottlenecks. In addition, the main crude oil pipelines in the United States were built to transport oil from the Gulf Coast to the Midwest. To absorb booming LTO output, investment in new pipeline capacity and terminals continues. One of the most important projects under design is the Keystone XL crude oil pipeline, for which a presidential permit was issued in 2017 and again in 2019. This pipeline is planned to transport crude oil from the Western Canadian Sedimentary Basin to Steele City in Nebraska. From there the crude oil will be transported through existing pipeline systems to supply refineries in Texas.

The shortage of pipeline takeaway capacity limits further growth of LTO production; oil exceeding pipeline capacity has to be transported instead by rail, and this bottleneck results in regional price differentials of up to USD 25/bbl. The expansion of the crude oil pipeline network would improve the situation.

Oil security

As referenced previously, the DOE serves as the US NESO, with responsibility for initiating and co-ordinating a US response to an oil supply disruption. The Office of International Affairs co-ordinates these efforts. The NESO structure's primary components include the DOE executive team, the crisis assessment team, and DOE support offices. These groups work together to generate DOE recommendations to the president and execute any response to a crisis. The newly created CESER is responsible for co-ordinating response efforts with FEMA and the Department of Homeland Security.

The United States complies with the IEA requirement of holding 90 days of net imports. The volume of SPR was at 650 mb at the end of December 2018, and it will be around 400 mb in 2028 after all existing mandated sales are completed. The United States will remain fully compliant with the IEA obligation to hold 90 days of net imports after those sales, as net imports are declining and the United States might become a net exporter in 2021.

SPR sales free up space in the caverns that hold the SPR oil. As such, these caverns represent an affordable storage option that could be leased by the US government to foreign governments to store their obligated oil stocks. At the time of writing, Congress is also working on legislation to facilitate such use of SPR caverns by private companies. In order to make the commercial option happen, technical modifications seem necessary.

Recommendations

The US government should:

- ☐ Provide timely access to attractive acreage on the OCS and ensure a streamlined regulatory process for exploration and production in areas outside the Gulf of Mexico. Make use of joint spatial planning to take into account the different interests of the oil and gas industry and other users of the OCS (e.g. fishing interests, maritime activities and wind farm developments).
- ☐ Monitor and measure the results of the 45Q tax credit scheme for onshore EOR based on CCUS, and assess how such a scheme could be better used to stimulate offshore EOR.
- ☐ Facilitate a platform for enhanced transfer of technologies and best practices among the oil and gas industry, technology vendors, and the academic sector.

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8. Natural gas

Key data

(2018 provisional)

Domestic production: 861.9 bcm (715.9 Mtoe), +51% since 2008

Net exports: 20.3 bcm (exports 102.2 bcm, imports 81.8 bcm), became a net exporter in 2017 from 19.0 bcm net imports in 2016

Share of gas: 31.7% of TPES, 34.3% of electricity generation, 22.8% of TFC (2017)

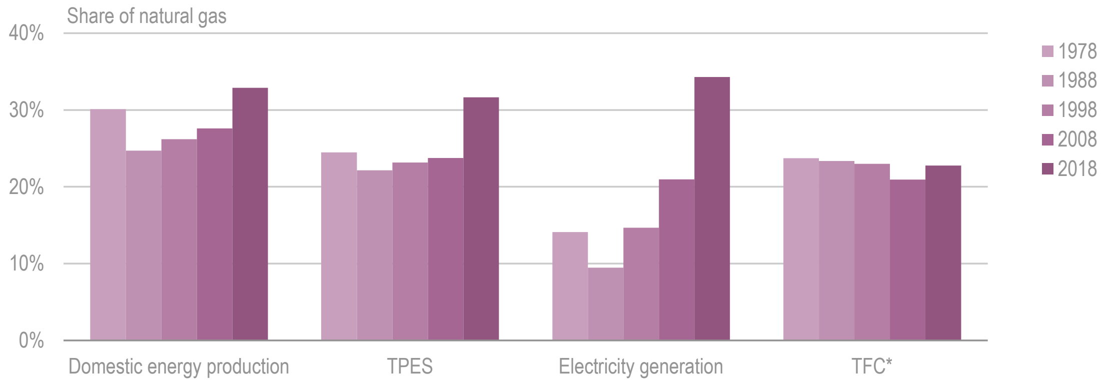
Gas consumption by sector (2017)**:** 769.8 bcm, transformation (power and heat generation) 36.9%, industry 23.2%, residential 16.2%, commercial 11.8%, transport 2.8%, energy 9.0%

Overview

The shale gas revolution has sharply increased the United States' (US') natural gas output and fundamentally recast the role of natural gas in the country's energy profile. Since 2009, the United States has been the top natural gas producer in the world, and natural gas has significantly increased its share as the second-largest energy source in the country, accounting for 32% of total primary energy supply (TPES) in 2018, up from 24% in 2008. The country became a net exporter of natural gas in 2017. Over the last decade, natural gas was the only fossil fuel that registered demand growth, and has been a major energy fuel for all sectors, except for transport. In particular, an increasingly competitive gas price has accelerated coal-to-gas switching in power generation, which accounts for the largest share of natural gas consumption. The share of natural gas in power generation increased from about 21% in 2008 to 34% in 2018 (Figure 8.1).

The natural gas market in the United States is mature and dynamic, but questions remain how to optimise the use of abundant gas supply and adapt supply and export infrastructure to reflect the rapid change of the United States to one of the world's largest gas exporters. In efforts to address bottlenecks for gas pipeline takeaway capacity and liquefied natural gas (LNG) terminals, the government has already worked to streamline administrative barriers, notably for small-scale LNG terminals. As more gas pipelines are commissioned, the potential of gas in accelerating the country's low-carbon transition will materialise, while at the same time enhancing energy security.

Figure 8.1 Share of natural gas in different energy systems, 1978-2018



The revolutionary growth in gas production bolstered its price competitiveness to drive up natural gas consumption, particularly in electricity generation.

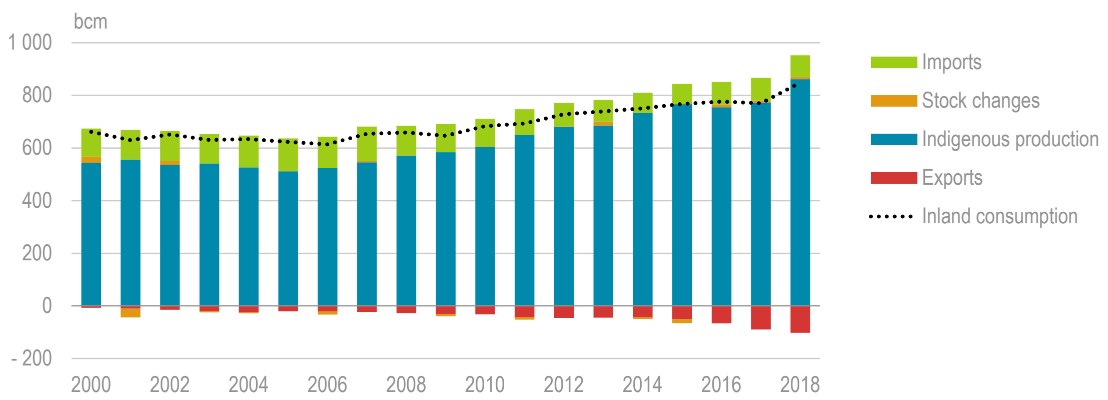
*Latest TFC data are for 2017.
Note: TFC = total final consumption.
Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

Supply and demand

Production

The United States has been the world's top producer of natural gas since 2009, when the country surpassed production levels of the Russian Federation (hereafter "Russia"). Over the last decade, total supply of natural gas increased by 29% to 852.7 billion cubic metres (bcm) in 2018, mainly thanks to a remarkable 40% growth in indigenous gas production from 571.1 bcm to 861.9 bcm. In 2017, the volume of gas exports (89.7 bcm) exceeded the volume of imports (86.1 bcm) for the first time in history when the United States became a net exporter of gas (Figure 8.2). In 2018, net exports increased significantly to 20 bcm.

Figure 8.2 Overview of US total supply of natural gas, 2000-18

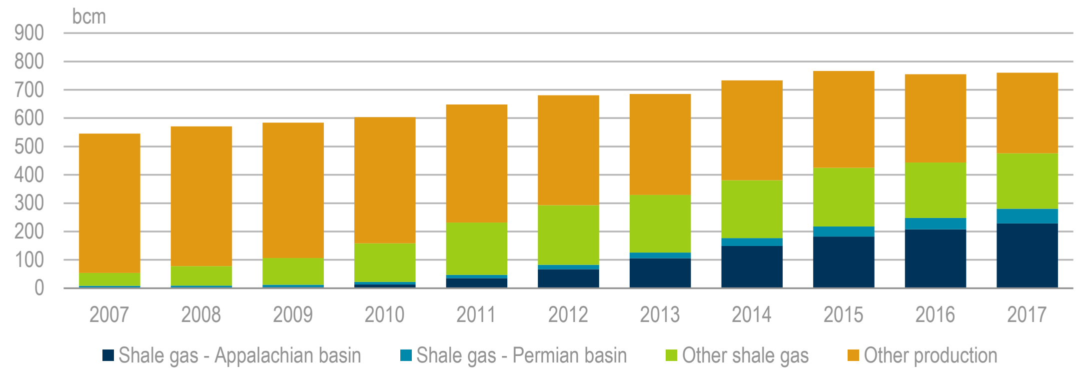


The US has been the top gas producer since 2009 and a net exporter since 2017.

Note: Stock changes are the change in stock level of recoverable gas held on national territory – the difference between opening stock levels at the first day of the year and closing stock levels at the last day of the year of stocks held on national territory. A stock build is shown as a negative number and a stock draw as a positive number.
Source: IEA (2019b), *Natural Gas Information 2019*, www.iea.org/statistics/.

US natural gas production has been growing strongly since 2005 thanks to the shale revolution. Growth has been uneven: it went through a brief stagnant period in 2012 and 2013, with just 1% growth since the shale gas production boom in 2005, followed by the first drop in production by 11.2 bcm to 755.3 bcm in 2016 (Figure 8.3). However, gas production picked up and returned to sharp growth again in 2017 and 2018, mostly driven by a recovery in the oil price that supported light tight oil (LTO) and its associated gas production, indicating a second wave of the shale gas revolution. The notable increase in domestic shale gas production remains an integral element of US natural gas development, and the share of shale gas in total gas production reached around 66% in 2017. In 2018, US natural gas production increased to 861.9 bcm.

Figure 8.3 US natural gas production, 2007-17



Shale gas from the Appalachian and Permian basins is the primary driver of natural gas growth in the United States.

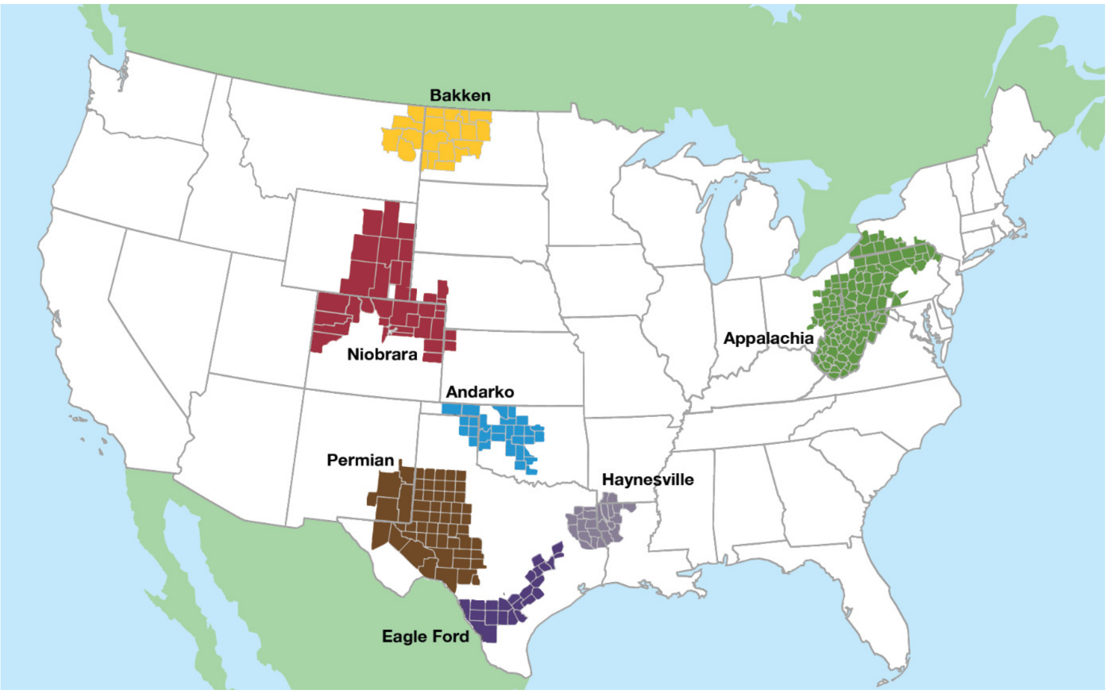
Note: *Other production* includes conventional gas and other unconventional gas such as tight gas and coalbed gas.
Source: IEA (2018), *Gas 2018: Analysis and Forecasts to 2023*, www.iea.org/gas2018/.

From a geographic perspective, in 2017, the top gas-producing states by shares of total production were: Texas (23.1%), Pennsylvania (19.7%), Oklahoma (8.5%), Louisiana (7.7%) and Ohio (6.3%). Gas produced in the federal offshore waters of the Gulf of Mexico accounted for 4% of the total (EIA, 2018a).

There are seven major regions for shale production (LTO and shale gas) in the United States that went through successive waves of developments: Haynesville and Eagle Ford in the early 2000s; Appalachia in the mid-2000s; and Permian (which produced the largest amount of associated gas) from the mid-2010s (Figure 8.4). Developments in the Bakken, Anadarko and Niobrara basins are mainly oil- rather than natural gas-driven. The Permian basin is a sedimentary basin located in western Texas and south-eastern New Mexico, and the Appalachian basin refers to Ohio, Pennsylvania and West Virginia's Marcellus and Utica shale plays.

Northeast dry shale gas, predominantly from the Appalachian basin, will maintain its integral role in the US gas portfolio, and is still registering strong growth. Though pipeline bottlenecks are limiting near-term gas deliveries, associated gas from the Permian basin will be the strongest production growth story.

Figure 8.4 Seven major shale plays across the United States, 2018



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: US Energy Information Administration (2018b), *Drilling Productivity Report,* www.eia.gov/petroleum/drilling/

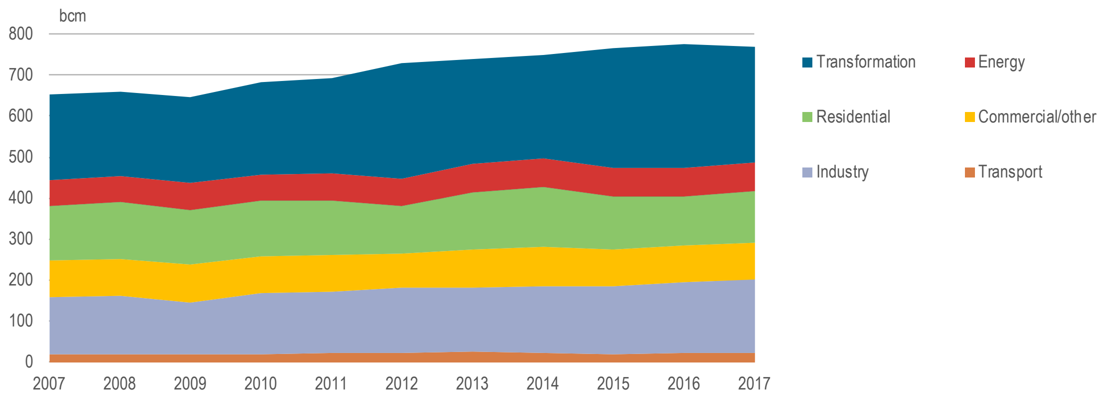
Consumption

Domestic consumption of natural gas in the United States is estimated to have reached a historic peak in 2018 at around 850 bcm, largely due to increasingly affordable domestic gas supplies. In line with strong domestic production, gas consumption recorded an 18% increase from 2007 to 2017, mainly driven by growth in the two largest gas-consuming sectors: transformation (heat and power generation), which accounted for 37% of the total US gas consumption of 773.7 bcm in 2017, and industry, which accounted for 23% of consumption (Figure 8.5). The remaining consumption shares were residential (16%), commercial and other (11%), energy (9%), and transport (3%). The transformation sector, mostly power generation, saw a notable 35% surge in natural gas consumption, with important increases in all the other sectors as well: industry (27%), transport (19%), energy (11%), and commercial and others (3%). Only the residential sector had a decline in gas consumption, falling by 7% due to mild weather conditions in 2017 and lower demand for heating and air conditioning.

Within the industry sector, gas consumption in the chemicals sector (including petrochemicals) increased by 129% from 2007 to 2017 and accounted for 52% of total industry gas consumption in 2017. Two key sectors of US natural gas consumption, power generation and petrochemicals (e.g. ethane feedstock), have benefited the most from low gas prices. The competitiveness of natural gas accelerated coal-to-gas switching in power generation and incentivised industry – particularly the chemicals sector – to use more abundant and affordable natural gas as a fuel and feedstock.

The five states that consumed the most natural gas in 2017 were: Texas (14%), California (8%), Louisiana (6%), Florida (5%) and Pennsylvania (5%) (EIA, 2018a).

Figure 8.5 US natural gas consumption by sector, 2007-17



Supported by increasingly competitive gas prices, US natural gas consumption has grown steadily in the last decade.

Notes: *Transformation* includes fuel inputs to public/private electricity, heat and co-generation units. *Industry* includes chemicals and petrochemicals as well as non-energy use. *Energy* includes refineries, oil and gas extraction, and the energy industry's own use. *Commercial/other* includes public and commercial services, agriculture, and fishing.

Source: IEA (2019b), *Natural Gas Information 2019*, www.iea.org/statistics/.

Box 8.1 Key drivers of US natural gas consumption: Power generation and chemicals

Natural gas accounted for 34% of total electricity generation in 2018. Power generation demand growth is changing the seasonality of gas demand with a summer peak for gas, which is a recent trend (see Chapter 9, "Electricity"). Natural gas is expected to remain the dominant source for power generation up to 2050, but increasing renewable power production and low electricity demand growth suggest limited growth of gas demand for power generation.

Gas consumption in industry continued its growth in 2017 (up 2% year-on-year), mainly driven by increasing demand in the chemical sector. In 2017, around 44% of total industry gas consumption came from chemicals production, particularly for methanol and ammonia. Whereas ammonia production has been the main driver of recent industrial demand growth – increasing capacity by around 5 metric tonnes (mt) to 15 mt over 2011-17 – most of the growth in gas feedstock consumption in the medium term is expected to come from methanol production in Louisiana and Texas. Abundant gas supply has bolstered the competitiveness of the US petrochemical and agrochemical sectors, which aligns with the International Energy Agency's (IEA) five-year outlook that oil and gas demand will shift from motor fuels to petrochemicals in developing Asian markets. Gas demand in the residential and commercial sectors has been and will likely remain relatively stable in the future, with extreme weather being the biggest factor for peak demand.

Source: IEA (2018), *Gas 2018: Analysis and Forecasts to 2023*, www.iea.org/gas2018/.

Biogas

Biogas is a proven source of energy used in the United States; since 2014, the country has built over 2 000 sites producing biogas including 239 anaerobic digesters on farms, 1 241 wastewater treatment plants using an anaerobic digester and 636 landfill gas projects. The potential for growth is significant, with approximately 11 000 sites ready for development today: 8 002 dairy and swine farms and 2 440 wastewater treatment plants that could support a digester and 450 untapped landfill gas projects. If fully realised, these biogas systems could produce enough energy to power and heat 3.5 million American homes (USDA et al., 2014).

Unlike variable renewables, such as wind and solar power, biogas delivers a continuous source of renewable energy with a very high capacity factor. The flexibility and reliability of biogas systems are important assets. In 2014, 37 states recognised biogas in their state renewable energy goals. For instance, the Los Angeles County Sanitation District in California has operated a 50 megawatt (MW) gas project at its Puente Hills Landfill since 1985, producing electricity for customers throughout Los Angeles.

Supply and demand outlook

Conventional offshore gas production in the Gulf of Mexico will continue to decline in the near future, but this drop will be largely offset by growth in shale gas production. LTO development will be accompanied by an increase in associated natural gas production, mainly from the Permian basin and Eagle Ford shale plays. Dry shale gas production increased by 14% in 2018 compared with 2017, thanks to continuous growth from the Appalachian and Haynesville plays. By 2024, gas production from the Appalachian basin is expected to grow further, while gas production from the Haynesville play will stabilise.

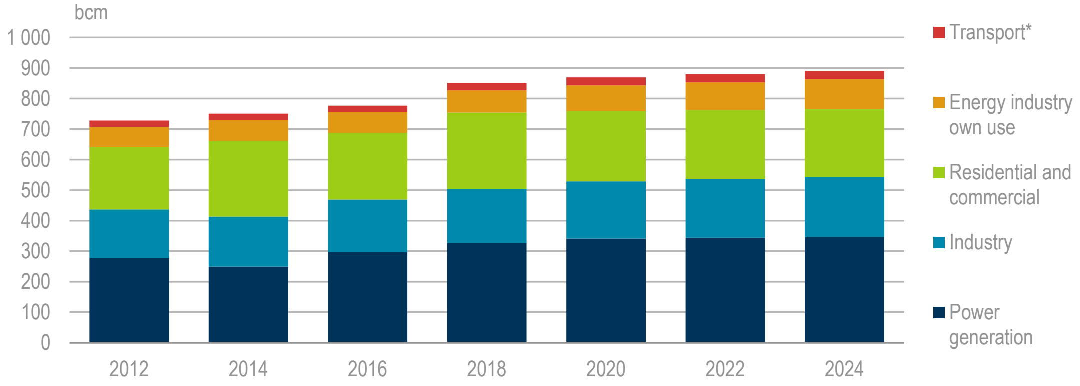
Today, shale gas accounts for more than 70% of total US gas production and within five years, this share is expected to surpass 80%. The United States will account for over 40% of global gas production growth until 2024, after which growth in US shale gas production will decline compared with the rapid increases seen since 2007.

Between 2018 and 2024, US gas production will increase from 860 bcm to 1 016 bcm, and will reach 1 074 bcm in 2040. Low-cost US production will keep Henry Hub prices relatively low until the mid-2020s at around USD 3.5 per million British thermal units (MBtu).

The United States is the second-largest individual contributor to growth in natural gas consumption after the People's Republic of China (hereafter "China"), with an average growth rate of 0.8% per annum from 2017 to 2024, accounting for 10% of global demand growth by 2024.

Abundant gas supply will continue to support growth in the industry sector (including petrochemicals and agrochemicals) for the foreseeable future. In the next five years, industry and power generation will have the strongest demand growth, with around 20 bcm from each of these two sectors (Figure 8.6). US natural gas consumption will reach almost 900 bcm in 2024. Gas demand for the energy industry's own use will grow by over 20 bcm partly driven by the build-up of LNG liquefaction plants as well as the fuel needed to support continuously increasing oil and natural gas production. Natural gas consumption in the residential and commercial sectors grew by 12% in 2018 compared with 2017, driven by lower temperatures during the heating season. For these sectors, extreme weather events, such as cold snaps or heat waves, will be the biggest drivers of seasonal peak demand. Gas consumption in the transport sector is expected to remain limited.

Figure 8.6 US natural gas consumption outlook, 2012-24



US natural gas consumption will increase and reach around 900 bcm in 2024.

* *Transport* includes pipelines.

Source: IEA (2019c), *Gas 2019: Analysis and Forecast to 2024*, www.iea.org/gas2019/.

Trade: Imports and exports

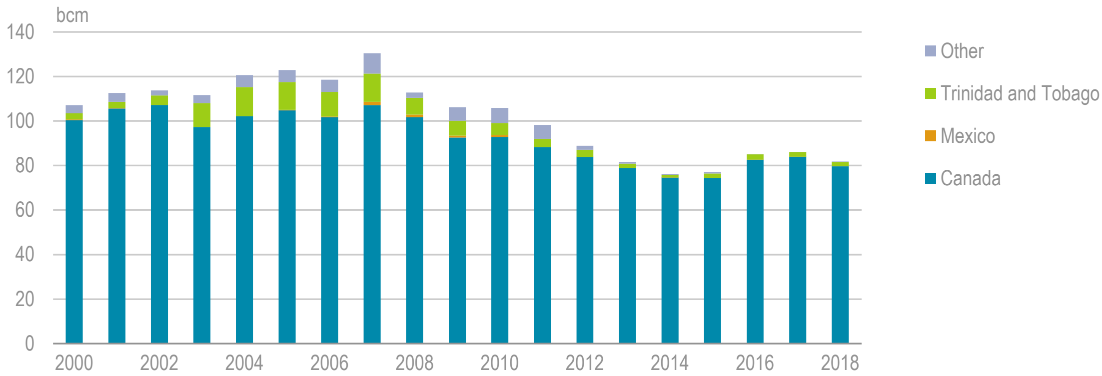
Total gas imports increased to reach a peak of 130 bcm in 2007, followed by a sharp decline down to 82 bcm in 2018. Gas exports started to pick up with the domestic shale gas production boom in the mid-2000s, both through pipelines and as LNG. The United States became a net exporter of natural gas in 2017 for the first time in nearly 60 years and significantly increased those net exports in 2018.

Canada remains the only notable source of natural gas imports, accounting for 97% of the total in 2018, followed by 2% from Trinidad and Tobago. Reliance on LNG imports has become a rather ad hoc measure in case of a temporary supply shortage against high demand, such as heating against cold snaps in the Northeastern region,[1] in particular New England.[2] Meanwhile, western pipeline gas imports from Canada have remained relatively steady, while the eastern gas trade has, at times, reversed, with US shale gas now flowing upwards to eastern Canada (though flows vary by state and seasonally).

[1] The Northeast region comprises three states: New York, New Jersey and Pennsylvania.

[2] New England comprises six states: Maine, Vermont, New Hampshire, Massachusetts, Rhode Island and Connecticut.

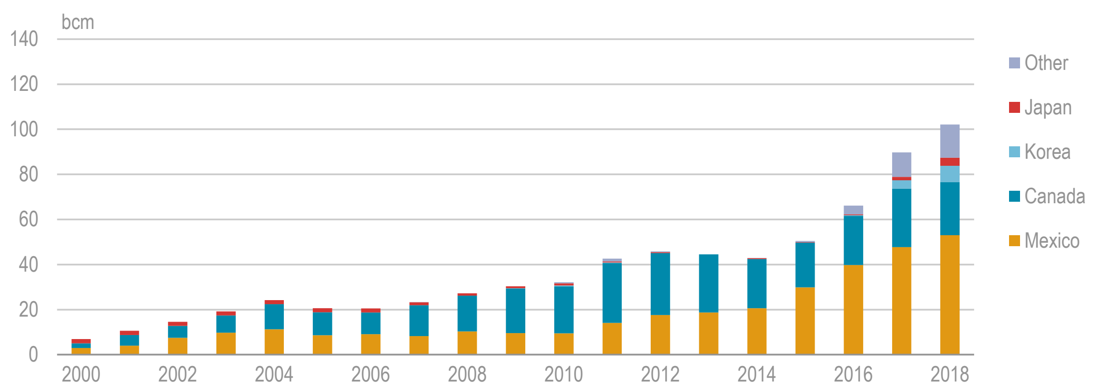
Figure 8.7 US natural gas imports, 2000-18



US dependence on natural gas imports has significantly decreased; Canada remains a key partner.

Source: IEA (2019b), *Natural Gas Information 2019*, www.iea.org/statistics/.

Figure 8.8 US natural gas exports, 2000-18



The US became a net exporter of natural gas in 2017, with LNG exports reaching destinations in Asia.

Source: IEA (2019b), *Natural Gas Information 2019*, www.iea.org/statistics/.

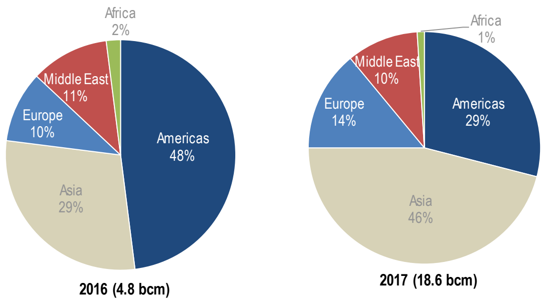
The shale revolution has significantly changed the gas market dynamics in the United States and beyond. US gas exports reached a historical high in 2018 at 102 bcm, nearly four times as high as in 2008.

By country shares, Mexico accounted for 52% of 2018 exports, followed by Canada (23%). The rest mostly went to Asia, including Korea (7%), China (3%) and Japan (3%).

In 2016-17 alone, US gas exports increased by 35%. Of this 24 bcm increase, 40% was delivered through pipelines and the remaining 60% in the form of LNG. Over this period, the volume of US LNG exports quadrupled, mainly due to capacity increases at the Sabine Pass terminal on the US Gulf Coast, the only commercially operating liquefaction terminal at the time (see Natural Gas Infrastructure section).

For pipeline exports, Mexico and Canada remained the major destinations, whereas the primary destinations for US LNG shifted from the Americas to Asia in 2017 (Figure 8.9).

Figure 8.9 US LNG exports by destination, 2016-17



US LNG's primary destination shifted from the Americas to Asia in 2017.

Source: IEA (2018), *Gas 2018: Analysis and Forecasts to 2023*, www.iea.org/gas2018/.

Market structure

In the United States, ownership of subsurface mineral resources is granted to the individuals or organisations that are surface landowners. This unique ownership structure for mineral rights in the country has helped enable the growth of onshore production as property owners are more economically vested in resource development compared with many other countries, where the government owns all subsurface mineral rights (see Chapter 7, "Oil").

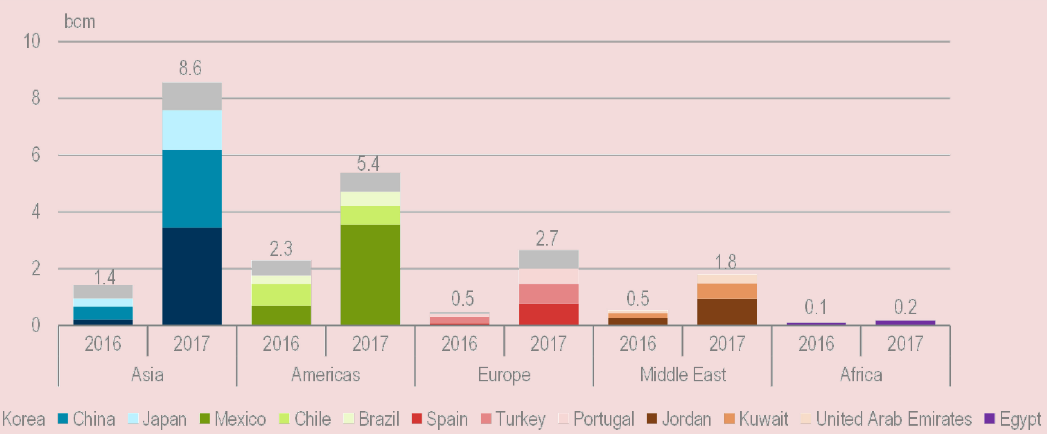
The gas industry has a high degree of private ownership with little vertical integration. The natural gas market is highly competitive and wellhead prices are not regulated. The federal government supervises production on federal land and states regulate production on non-federal lands – which accounts for the majority of domestic production. The main segments of the industry are largely unbundled by Federal Energy Regulatory Commission (FERC) regulations, with supply, transportation, distribution and other services provided by different companies. Interstate transportation, including trans-border facilities, is regulated by FERC, and local distribution is regulated at the state level.

While prices are generally set by competitive markets, state public utilities commissions can exercise regulatory authority over retail gas prices, and are responsible for consumer protection, natural gas facility construction and environmental issues that are not covered by FERC or the Department of Transportation (DOT). One of the primary features of the current market is the existence of natural gas marketers, who serve as middlemen to connect producers and end users by offering both bundled and unbundled services.

Box 8.2 Growth of the US LNG trade and its outlook

For the United States, the current growth in LNG trade indicates a further diversification of US gas exports. In 2016-17, the number of US LNG export destinations increased from 17 to 25 (Figure 8.10).

Figure 8.10 US LNG exports by destination (by region and country), 2016-17



Note: Light grey bars represent volumes of US LNG to destinations other than the top three importing countries in a region.

LNG exports to Mexico are being replaced by pipeline flows with additional capacity being commissioned. By 2023, Mexico is expected to import approximately 45 bcm from the United States by pipeline, meeting around 50% of the growing domestic demand in Mexico.

While gas trade through pipelines is still dominant, the expansion of the US LNG trade will continue to reshuffle trade relations, not only for the United States but for the global market. With a notable 2.2 bcm increase in exports in 2016-17, Europe will remain an attractive market for US LNG, though overall flows will shift eastwards to the Pacific basin, driven by higher demand growth and margins. The IEA projects that the Pacific basin will eventually account for around two-thirds of US LNG exports by 2023.

Looking at the global LNG market, most of the increase in LNG exports will come from new projects in Australia, Russia and the United States, further diversifying supply sources as well as shipping routes. Of these countries, US output will lead LNG market supply growth until 2023, with US projects accounting for over 75% of incremental exports in the 2017-23 period.

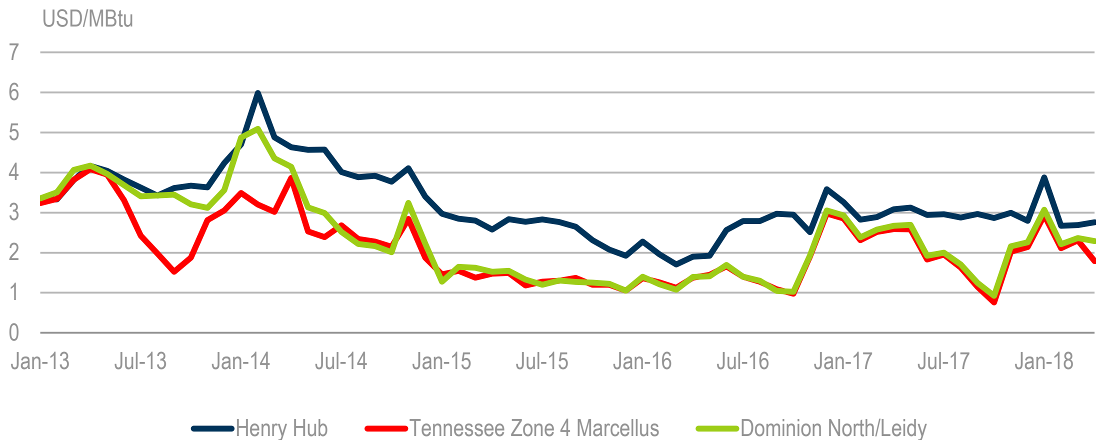
Source: IEA (2018), *Gas 2018: Analysis and Forecast to 2023*, www.iea.org/gas2018/.

Price and taxes

The most widely referenced wholesale gas prices are observed at the Henry Hub (HH). HH is a natural gas distribution hub located in Erath, Louisiana, that serves as the official and national pricing reference for futures contracts on the New York Mercantile Exchange (NYMEX).

Over the last five years, consumption in the Northeast did not keep up with incremental natural gas production from the Appalachian basin; the lack of additional pipeline capacity to move this extra gas production to other US regions and to Canada kept a large portion of the gas where it was produced and put a lid on the regional price. Wholesale gas prices at the Appalachian pricing hubs Tennessee Zone 4 Marcellus and Dominion North/Leidy were lower than the wholesale gas price at HH (Figure 8.11). Price spreads between HH and regional prices in the Appalachian basin narrowed in 2017, due to pipeline capacity increases, compared with the period between 2014 and 2016 (Figure 8.11). However, in the Permian region, the regional price differentials are persisting at the time of writing with a lack of sufficient pipeline capacity to accommodate growing production and placing downward pressure on natural gas prices.

Figure 8.11 Average wholesale gas prices at three US hubs, 2013-18



The price spreads between HH and regional prices in the Appalachian basin narrowed in 2017 due to pipeline capacity increases.

Note: HH is a pricing hub in Louisiana; Tennessee Zone 4 and Dominion North are pricing hubs in the Appalachian basin.

Source: IEA (2018), *Gas 2018: Analysis and Forecasts to 2023*, www.iea.org/gas2018/.

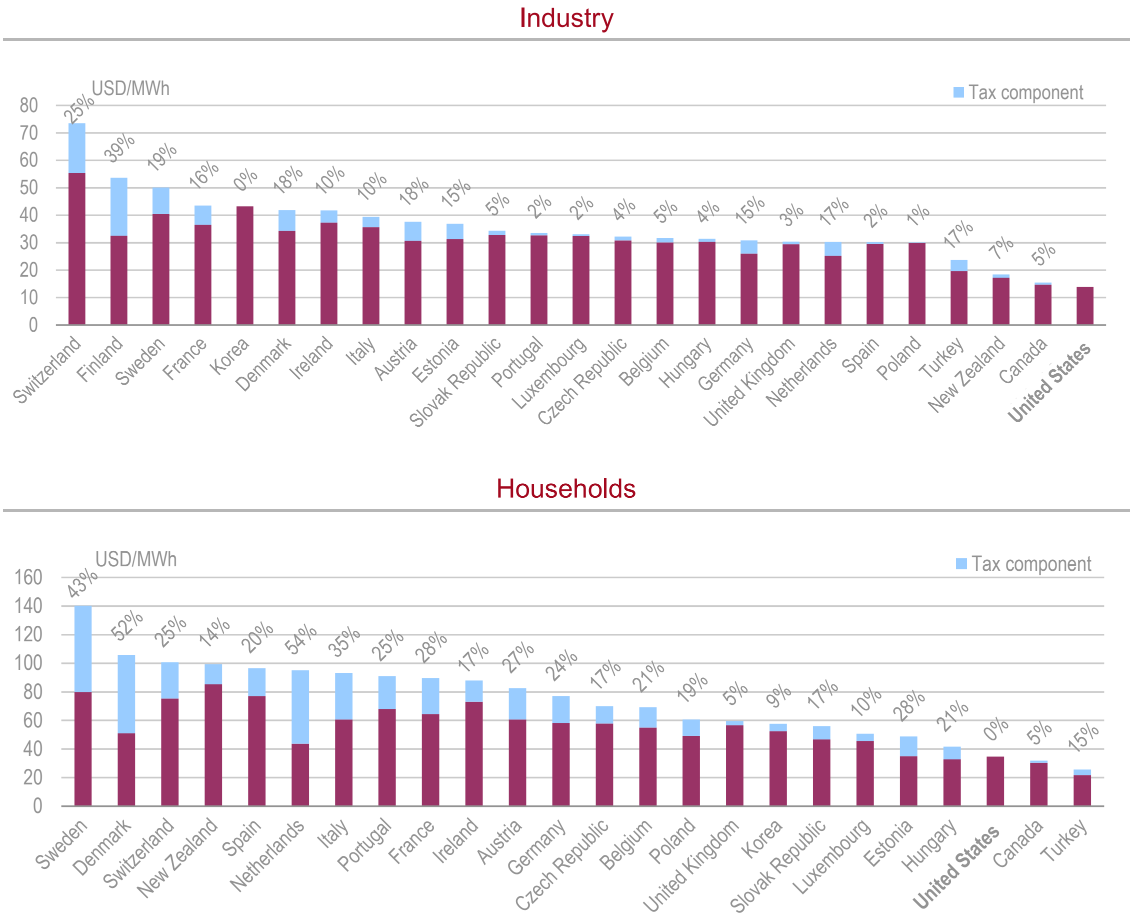
As for retail gas prices, the United States had the lowest industry gas price (USD 13.9 per megawatt-hour [MWh]) and third-lowest household price (USD 34.6/MWh) among IEA countries in 2018 (Figure 8.12) [3]. Over the last five years, industry gas prices in the United States have varied from USD 18.3/MWh in 2014 down to USD 11.6/MWh in 2016. Household prices have been more stable around USD 34/MWh. In 2017, gas-fired electricity prices stood at USD 11.6/MWh, 22% below the 2013 level.

[3] Tax component figures not available for the United States, and hence not included.

It should be noted that with an increasing share of associated gas in total US supply, domestic gas production is also influenced by fluctuations in oil prices. The recovery of the oil price (West Texas Intermediate) was one of the key drivers of natural gas production growth, specifically LTO associated gas, in 2017.

The United States provides subsidies for oil and gas production, mostly in the form of tax breaks to producing companies. Between fiscal years (FYs) 2013 and 2016, direct federal financial incentives and subsidies in energy markets decreased by nearly half, from USD 29.3 billion in FY 2013 to USD 15.0 billion in FY 2016. Federal subsidy support for fossil fuels, including natural gas, declined from almost USD 3.9 billion to USD 489 million in FY 2013-16 (EIA, 2018c).

Figure 8.12 Natural gas prices in IEA member countries, 2018



US gas prices are one of the lowest among the IEA member countries.

Notes: Tax information not available for the United States. According to the US country notes submitted to the IEA, taxes are included in the prices for households, industry and electricity generation, and mostly refer to general sales taxes levied by the states. The rates range between 2% and 6% and the national average is currently unknown. Industry price data are not available for Australia, Greece, Japan, Mexico and Norway; household price data are unavailable for Australia, Finland, Greece, Japan, Mexico and Norway.

Source: IEA (2019d), *Energy Prices and Taxes 2019*, www.iea.org/statistics/.

Infrastructure

Gas pipeline networks

The shale revolution has significantly changed the role of natural gas in the country's energy mix. Gas pipeline infrastructure plays a key role in the co-ordination between the electricity and natural gas systems. This is supported by FERC initiatives such as Order No 809, published in 2015, on the co-ordination of the scheduling processes between interstate natural gas pipelines and public utilities (FERC, 2015a). Order No 809 was revised to better co-ordinate the scheduling practices of the wholesale natural gas and electric industries, as well as to provide additional scheduling flexibility to all shippers on interstate natural gas pipelines (FERC, 2018). Another relevant example is Order No 787, finalised in 2013, which provides explicit authority to interstate natural gas pipelines operators and electricity transmission public utilities to share operational information with each other to foster reliable services by pipelines or public utility systems (FERC, 2015b).

The US natural gas pipeline network is highly integrated and moves gas throughout the continental United States (referred to as the Lower 48 states) via interstate and intrastate pipelines. There are approximately 210 natural gas pipeline systems in the United States and over 300 000 miles (483 000 kilometres) of transmission pipelines. The density of pipelines is highly diverse. The state with the most developed natural gas pipelines by far is Texas (58 588 miles); the other five states with the most developed gas pipelines are Louisiana (18 900 miles), Oklahoma (18 539), Kansas (15 386), Illinois (11 900) and California (11 770).[4]

In 2017, the gas transportation network delivered about 25 trillion cubic feet (708 bcm) of natural gas to 75 million customers. Since around half of the network was built in the 1950s- and 1960s, these pipelines have not always kept pace with recent changes in the volumes and geography of gas production. Although improvements and system expansions are under way, renovating ageing assets to keep pace with the necessary deliveries is essential to maintain a high level of safety and security of supply in the country.

In September 2014, the Department of Energy (DOE) launched the Natural Gas Infrastructure research and development (R&D) programme with the objectives to co-ordinate existing R&D programmes, within and outside the federal government, to enhance pipeline reliability and identify research needs to improve pipeline deliverability and operational efficiency. This programme is designed to promote research on advanced materials and sensor technologies to improve gas infrastructure efficiency and reliability.

Development of technologies for emissions mitigation provides enhanced ability to assess risk and prevent leaks from natural gas infrastructure that can improve safety, reliability and operational efficiency across the natural gas value chain. Sharing the results of this research and making it available to industry players is also an important aspect to accelerating technology field deployment.

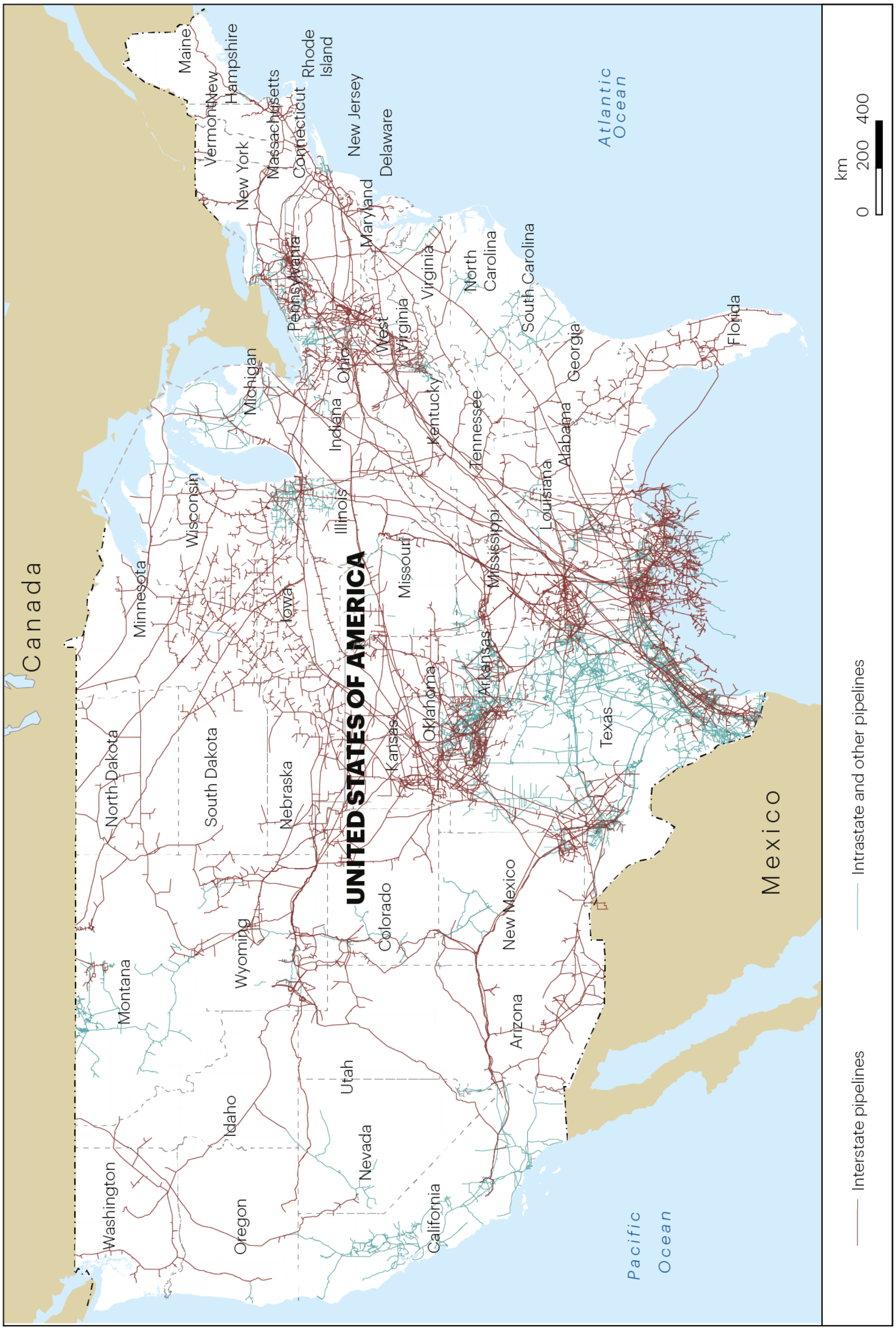
Ongoing projects in the Northeast and New England

For the United States, the share of natural gas in power generation in 2017 was 31%, up from 21% a decade ago, and is likely to further increase.

[4] These figures are indicative and based on 2007 data from the US Energy Information Administration (EIA).

Gas pipeline expansion projects in the Northeast and New England could deliver additional fuel to gas-fired power stations, which can help offset electricity production from the recent retirements of the Vermont Yankee nuclear power station (620 MW) and the Brayton Point coal-fired power plant (1 500 MW), as well as the expected retirement of the Pilgrim Nuclear Station (677 MW) in 2019.

Figure 8.13 Gas pipeline map, 2018



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Gas pipeline projects in the Northeast region are facing delays, which add uncertainty to projected commissioning dates, particularly for greenfield projects. There are different reasons for delays of the gas pipeline projects, including local opposition, permitting processes and uncertainty for long-term supply contracts. For instance, the Northeast Supply Enhancement pipeline project was set back by denial of a water quality certification in May 2019, requiring the project developer to revise its plan and resubmit its application (New York Times, 2019).

Ongoing projects between the United States and Mexico

Mexico and the United States are highly connected through 26 cross-border gas pipeline interconnections. With the development of new cross-border pipeline capacity, substantial US volumes of gas can be transported from the Permian and Eagle Ford shale formations to cover demand in the Mexican industry, power generation and residential sectors.

Recent regulatory developments related to the construction of energy projects

On 10 April 2019, the administration issued two executive orders to speed up construction of pipelines and other energy projects to enhance the production and transport of oil and natural gas between states and across international borders. One order directs the Environmental Protection Agency (EPA) to review implementation rules under Section 401 of the Clean Water Act (related to state water quality certifications to avoid water pollution) (EPA, 2019). The immediate impact of these orders might be limited since they are likely to attract legal challenges from states; a fundamental shift of regulatory authority from states to the federal government would require Congressional action.

LNG terminals

Regulation

There are three main federal agencies in charge of various aspects of LNG regulation: FERC, the Maritime Administration (MARAD) (part of the DOT) and the DOE.

FERC is responsible for authorising the siting and construction of onshore and near-shore LNG import or export facilities under Section 3 of the Natural Gas Act of 1938 (NGA) (FERC, 2019). Under Section 7 of the NGA, FERC also issues certificates of public convenience and necessity for LNG facilities engaged in interstate natural gas transportation by pipeline. As required by the National Environmental Policy Act, FERC prepares environmental assessments or impact statements for proposed LNG facilities under its jurisdiction. Once approved and built, projects are subject to FERC oversight for as long as the facility is in operation.

The front end engineering development phase of an LNG plant has to be finalised before all authorisations can be given. Total costs for an investor can be up to USD 100 million. In August 2018, federal regulators laid out a timeline for permitting decisions on 13 pending LNG export projects, issuing a memorandum of understanding to streamline and speed up environmental reviews for complex projects. The new process of FERC and the Pipeline and Hazardous Materials Safety Administration will allow the finalisation of authorisations for the proposed LNG export projects by early November 2019, leading to the completion of the federal permitting process by early February 2020 on all the projects (PHMSA, 2018). As of January 2019, FERC has approved one import terminal (which is now under construction) and nine export terminals (five of which are under construction).

MARAD has authority over the siting, construction and operation of deepwater offshore LNG terminals and is the co-lead agency on environmental reviews of offshore facilities with the US Coast Guard (MARAD, 2018).

The DOE has authority over the import and export of natural gas. Under Section 3 of the Natural Gas Act, LNG export facilities have to request authorisation from the DOE to export to free trade agreement (FTA) countries and non-free trade agreement (non-FTA) countries. Exports to FTA countries are granted without modification or delay. For exports to non-FTA countries, authorisation for export must be granted, unless after review, the proposed exports are found not to be consistent with the public interest or where trade is explicitly prohibited by US law or policy. In July 2018, the DOE announced a final rule to provide faster approval of applications for small-scale exports[5] of natural gas, including LNG, from US export facilities.

LNG developments

The existing gas infrastructure was originally geared towards LNG regasification terminals, and pipelines coming from Canada. With the shale gas revolution, flows have changed significantly from imports to exports.

In the Lower 48 states, there are 12 operational LNG import terminals of which 1, an offshore terminal in the Gulf of Mexico, has taken steps towards decommissioning. The Lower 48 states began exporting LNG in February 2016, when the Sabine Pass liquefaction terminal in Louisiana shipped its first cargo. Since then, Sabine Pass has expanded from one to four operating liquefaction trains. As of December 2018, three large-scale LNG export terminals, with liquefaction facilities, are operating: Corpus Christi, Sabine Pass and Cove Point.

In 2019, more LNG export facilities will be commissioned in the country (Figure 8.14).

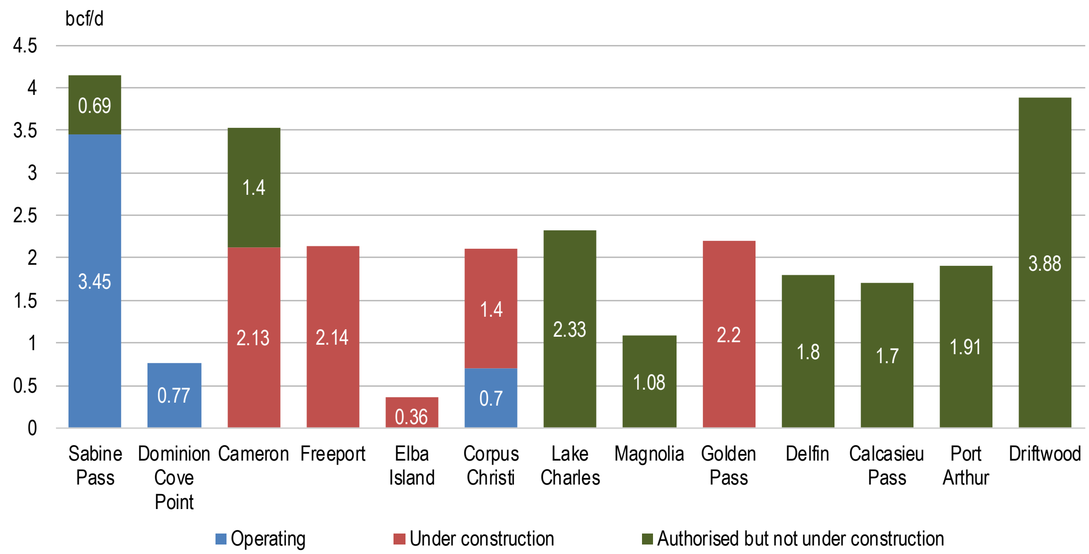
A final investment decision (FID) was taken in early 2019 for the Golden Pass terminal with a capacity of 2.2 bcf per day (bcf/d) (0.06 bcm per day [bcm/d]). Golden Pass is expected to begin operating in 2024 or 2025 and, once completed, will bring cumulative US export capacity to approximately 13 bcf/d (0.364 bcm/d).

As of 19 May 2019, there were six additional US export projects – Magnolia LNG, Delfin LNG, Lake Charles, Venture Global Calcasieu Pass, Driftwood and Port Arthur – that have received all major regulatory approvals from both FERC and the DOE and are awaiting a FID. There are also approved liquefaction trains at Sabine Pass and the Cameron LNG facility that have not made a FID. The approved export capacity across the six new projects, as well as the additional trains at Sabine Pass and Cameron LNG, would bring another 14.8 bcf/d (0.415 bcm/d) of approved export capacity potential.

The emergence of the United States as a global gas exporter challenges historical aspects of the LNG trade. This wave of liquefaction projects, expected in the coming two years, ensures ample supply and growth of LNG trade but also challenges the traditional features of supply contracts. US exports with flexible destinations and gas-indexed pricing present different models from standard fixed-delivery and oil-indexed supply agreements.

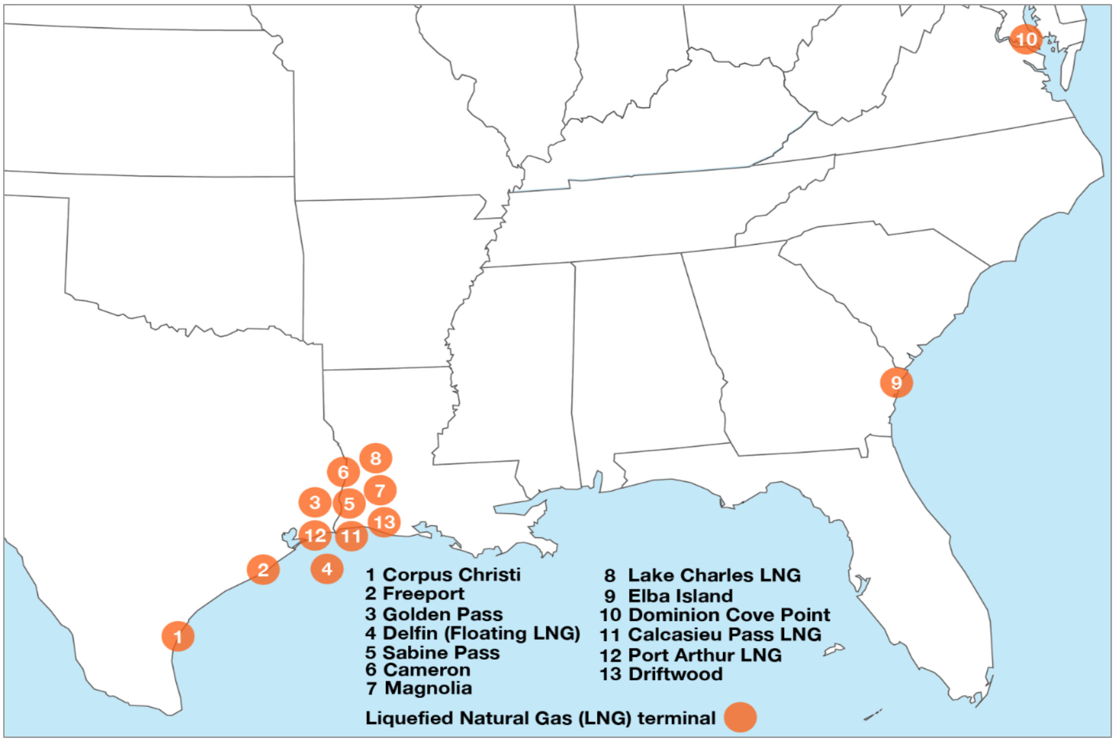
[5] A small-scale LNG facility has a capacity of up to 51.75 billion cubic feet (bcf) (1.47 bcm) per year.

Figure 8.14 Infrastructure development for LNG export terminals, May 2019



Source: EIA (2019), *U.S. Liquefaction Capacity* (Database of U.S. LNG export facilities), www.eia.gov/naturalgas/U.S.liquefactioncapacity.xlsx.

Figure 8.15 Infrastructure developments for LNG export terminals, 2019



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Storage

The Energy Policy Act of 2005 added a new section to the NGA, stating that FERC may authorise natural gas companies to provide storage and storage-related services at market-based rates. FERC ensures reasonable terms and conditions are in place to protect consumers, and the commission periodically reviews the market-based rates.

The geological formation is critical to build underground storages and not all regions are suited for that. For instance, there are no underground storage facilities in the states of New Jersey or Florida. Natural gas storage plays a critical role in meeting demand fluctuations, both seasonal and on peak-demand days. Underground natural gas storage provides all actors in the gas market with an inventory management tool and seasonal and daily supply backup to avoid imbalances between receipts and deliveries on a pipeline network. In the United States, generally more natural gas is used in the winter for home heating. Natural gas is injected into storage fields from April to October and withdrawn from November to March.

By the end of 2017, there were 388 active storage fields reported with a design storage capacity of 4 791 bcf (135.0 bcm). In 2017, the growth rate was about 0.7%, due to the expansion of existing facilities in the east. Only a few new underground natural gas storage facilities were built in the Lower 48 states in the past five years, and there were no new additions in 2017, except for an expansion of a facility in the east; in 2018, there was only one project under construction in Oregon, with a working capacity of 4 bcf (0.113 bcm).

Gas flaring

Flaring has become an issue in the United States with the rapid development of unconventional resources over the past 15 years. There has been a significant increase in flaring of gas associated with oil production (mainly LTO) in plays where there is not enough gas gathering and transportation infrastructure. Based on economics, the most attractive solution is, in some cases, to produce valuable oil and burn the associated gas (for regulatory responses to flaring, see also Chapter 3, "Energy and Climate Change").

In 2012, North Dakota had the highest volumes of flared natural gas, produced as associated gas with LTO. In response, the North Dakota Industrial Commission (NDIC) established Order No 24665 as a system of gas capture to reduce the volume of natural gas flared in the state. Adopted on 3 March 2014 and effective on 25 June 2014, the order established a drilling permit review policy that requires producers to submit a gas capture plan with every drilling permit application. The order established new targets to gradually limit flaring to a maximum of 10% of produced gas flared by 2020. Based on data from the NDIC, the volume of flared natural gas declined by 40% between 2014 and 2017.

Permian gas output (including associated gas) in Texas and New Mexico increased by over a third in 2018 and led to an increase in flaring. The oversupply situation has been resulting in negative pricing at the Waha hub in west Texas for the real-time or next-day market since the end of March 2019 (Reuters, 2019). Negative pricing means that drillers are paying pipeline operators with spare takeaway capacity to take the unwanted gas.

In the short term, flaring percentages are expected to again rise above current levels in shale-producing states such as Texas and North Dakota. Because of the economic benefits of increased crude oil production, state regulators are reluctant to curtail flaring by limiting oil production until takeaway capacity can catch up.

In states where a large number of associated gas flares have been permitted, a combination of regulatory action and planned increases in natural gas processing and pipeline takeaway capacity appear to be on track to reduce the immediate flaring problem gradually over the next two to five years.

Gas emergency response

Gas emergency policy

There are two primary statutory authorities for addressing a natural gas emergency. First, under the Natural Gas Policy Act of 1978 (NGPA), the US president is authorised to declare a natural gas supply emergency if:

- "[A] severe natural gas shortage, endangering the supply of natural gas for high-priority uses, exists or is imminent in the United States; and"
- "[T]he exercise of authorities…is reasonably necessary, having exhausted other alternatives to the maximum extent practicable, to assist in meeting natural gas requirements for such high-priority uses."

The emergency provisions under the NGPA include emergency purchase and emergency allocation authorities.

The other legislation relevant to natural gas emergencies is the NGA, as amended. The DOE is authorised by Section 3 of the NGA to issue supplemental orders that modify or withdraw prior authorisations to export natural gas if it is determined that they are not consistent with the public interest. The DOE is also authorised by Section 16 of the NGA to "perform any and all acts and to prescribe, issue, make, amend, and rescind such orders, rules, and regulations as it may find necessary or appropriate" to carry out its responsibilities. The DOE has never before rescinded a long-term export authorisation for any reason. Further, the department has no record of ever having vacated or rescinded an authorisation to import or export natural gas over the objections of the authorisation holder. The DOE has published a policy statement affirming its commitment to all export authorisations issued under the NGA.

Gas emergency organisation: Roles and responsibilities

The DOE has two important programmes that deal with emergency preparedness and resilience:

- Emergency Support Function 12 (ESF-12): ESFs are mechanisms for grouping functions most frequently used to organise the federal response to declared disasters and emergencies; ESF-12 is dedicated to energy. The DOE's Office of Cybersecurity, Energy Security, and Emergency Response is responsible for fulfilling the ESF-12 role.
- US State Energy Program (SEP): For 30 years, the US SEP, established by Congress in 1989, provides financial resources directly to the states. SEP provides complete discretion and deference to the nation's governors in the use of SEP funds within a broad statutory

framework established by Congress. The DOE's Office of Energy Efficiency and Renewable Energy administers the SEP. Congressional appropriation for SEP in FY 2019 is USD 55 million, which is then allocated to state energy offices. This level of funding is similar to the 2018 level.

In the event of an emergency, the DOE provides emergency situational awareness reports, co-ordinates the response among industry partners and federal, state and local agencies, and helps facilitate the restoration of energy systems. Providing timely and accurate reports and situational assessments plays a crucial role in helping other government agencies and industry to prepare for and recover from disruptions.

Gas emergency response measures

Strategic storage

The US government neither holds strategic reserves of natural gas nor places a minimum natural gas stockholding obligation on industry.

Interruptible contracts

The US government does not have any policies in place at the federal level to promote interruptible contracts as a natural gas emergency management tool.

Demand restraint

The US government does not have any demand restraint policies in place at the federal level for use during a natural gas supply disruption. However, the federal government has provided grants to state energy offices to develop energy emergency response plans, including natural gas allocation, demand restraint policies and associated regulations.

With regard to developing emergency response policies and associated measures in advance of an emergency, the federal and state levels share information about policies and best practices through the National Association of State Energy Officials (NASEO). In 1986, NASEO was created by the states to improve the effectiveness of state energy programmes and provide policy analysis. NASEO acts as a repository of information on challenges of particular concern to the states and shares successes among its members. NASEO derives basic funding from the states and the federal government via the SEP.

Fuel switching

There are several legal authorities that authorise the president to declare an emergency that will require fuel switching or prohibit the burning of natural gas for power generation. These authorities have not previously been used. The electricity generation sector has significant fuel-switching capacity in place. According to the EIA 2017 *Electric Power Annual* report, 28.8% of generators reporting gas as the primary fuel can switch to oil in case of a disruption; and 21.4% of the generators reporting petroleum liquids as the primary fuel can switch to gas. These numbers are average figures across all three sectors (electric power, industrial and commercial) using gas or oil generators.

Assessment

Natural gas markets

Demand for natural gas increased by around 30% between 2007 and 2017. The shale gas revolution has resulted in abundant supplies and extraordinarily competitive prices, which has accelerated coal-to-gas switching in electricity generation, the main source of demand growth. Residential and commercial gas demand have remained at the same levels for the last 20 years, despite a 20% growth in consumer numbers.

In 2017, natural gas was the second-largest energy source in the United States, accounting for 30% of TPES. The substitution of coal by natural gas in electricity generation was a major factor in the 14% reduction of greenhouse gas emissions since 2005.

The legal and institutional framework of natural gas business operations and economic activities is stable. The natural gas industry is open to competition and choice. The price of natural gas is dependent on supply and demand interactions. Domestic wholesale natural gas prices are determined at the HH through market pricing. Marketers facilitate the movement of natural gas from the producer to the end user.

The existing gas infrastructure is largely geared towards imports (with regasification terminals for LNG) and pipelines from Canada. In 2017, the United States had 12 LNG import terminals, compared with just 3 operating LNG export terminals (liquefaction terminals). In 2018, FERC approved 11 new export terminals (7 of which are under construction).

On the regulatory front, US LNG export projects are required to go through several authorisation processes before reaching FID, including the submission of a non-FTA application to DOE and construction authorisation to FERC. In August 2018, federal regulators laid out a timeline for permitting decisions on 13 pending LNG export projects, issuing a memorandum of understanding to streamline and speed up environmental reviews for complex projects.

The United States became a gas net exporter in 2017 and this status is likely to continue for a considerable time. For pipeline exports, Mexico and Canada remained the major destinations, whereas the primary destinations for US LNG shifted from the Americas to Asia in 2017. US LNG exports have changed the global LNG market with more flexible and short-term contracts, thus increasing competitiveness and transparency. It is also worth mentioning the recent trend of de-linking US LNG export prices from oil indexation, which influences LNG seller-buyer transactions in the global market. US natural gas can substitute for other fossil fuels with higher carbon emissions in many countries, which has a positive impact on global carbon emissions.

The growth of natural gas production in some shale basins is constrained by the lack of available pipeline takeaway capacity to move it to new markets. As new pipeline projects come online, they will create an outlet for increased production. In the Northeast and New England regions, there is often not enough pipeline takeaway capacity to cover peak demand in the winter months, increasing prices and decoupling the region from the rest of the US market. In January 2018, the monthly regional spread relative to HH exceeded USD 10/MBtu. By the end of 2018 more than 23 bcf/d of takeaway capacity was online out of the Northeast (three times more than the takeaway capacity at the end of 2014).

However, no major pipeline capacity expansions are planned to come online in New England and in the Northeast regions in the near future.

The diversification of supply regions brought about by abundant shale gas production, along with a vast buildout of new pipeline infrastructure, has also changed gas storage needs. Instead of a heavy reliance on annual injection/extraction cycles, some pipelines now provide a considerable degree of intraday flexibility to gas supply.

The shale revolution has made gas a competitive source of energy. Favourable economic returns for unconventional oil and gas are largely based on high production volumes, rapid development projects and strategies for fast depletion.

A timely development of high integrity and flexible pipelines for gas transportation could improve overall resource management.

Natural gas security

More than any factor, the increase in US natural gas production has increased supply security in the country. The expanded production and attendant construction of new gas transportation infrastructure affords the United States substantial gas supply resiliency.

The shale revolution has also significantly changed the role of natural gas in the country's energy mix. In 2017, electricity generation totalled 4 234 terawatt-hours, and gas accounted for 31% of the total generation. Co-ordination between the electricity and natural gas systems takes on special importance. FERC's initiatives such as Order No 809 (Coordination of the Scheduling Processes of Interstate Natural Gas Pipelines and Public Utilities) and Order No 787 (Communication of Operational Information between Natural Gas Pipelines and Electric Transmission Operators) are examples of good practices.

Under the NGPA, the US president is authorised to declare and respond to a natural gas supply emergency. The emergency provisions include emergency purchase and emergency allocation authorities to protect high-priority users of natural gas. The federal energy emergency response functions are designed to address both oil and natural gas emergencies; ESF-12 provides federal support to states to respond to declared disasters and emergencies.

The US government does not have any policies in place to promote interruptible contracts as a gas emergency management tool and to supply vulnerable customers. It also does not have any demand restraint policies in place at the federal level for use during a gas supply disruption. However, the federal government has provided grants to state energy offices to develop energy emergency response plans, including gas allocation, demand restraint policies and associated regulations. The DOE maintains a mechanism whereby it can work effectively with individual states during emergencies.

Recommendations

The US government should:

- ☐ Further reduce administrative barriers and streamline the authorisation process for liquefaction plants by reducing permitting timelines and costs.
- ☐ Evaluate the allocation of decision-making authority for the permitting and siting of natural gas pipeline projects in order to identify possible ways to shorten lead times and reduce uncertainty for investors.
- ☐ Strengthen R&D efforts to support maintenance of the existing pipeline network, especially with ageing systems, to improve leak detection, reduce waste and ensure infrastructure integrity.

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9. Electricity

Key data

(2018 provisional)

Electricity generation: 4 413.4 TWh (natural gas 34.3%, coal 28.4%, nuclear 19.1%, hydro 6.7%, wind 6.3%, solar 2.1%, bioenergy and waste 1.7%, oil 0.9%, geothermal and others 0.5%), +1.6% since 2008

Electricity net imports: 44.5 TWh (imports 58.3 TWh, exports 13.8 TWh)

Installed capacity (2017)**:** 1 100.3 GW

Electricity consumption (2017)**:** 3 869.0 TWh (commercial 40.7%, residential 35.5%, industry 20.1%, other energy 3.4%, transport 0.3%)

Overview

The United States (US) has a complex electricity system with a mix of competitive markets, vertically integrated markets, and private and publicly owned assets. A majority of the country's power system operates under regional competitive bulk markets. Regulatory authority over bulk power markets, including competitive and traditionally regulated, rests with the Federal Energy Regulatory Commission (FERC).

The US power system has a strong track record of ensuring reliability and resilience thanks to the strength of its federal crisis response policy and its reliability governance, such as the North American Electric Reliability Corporation (NERC).

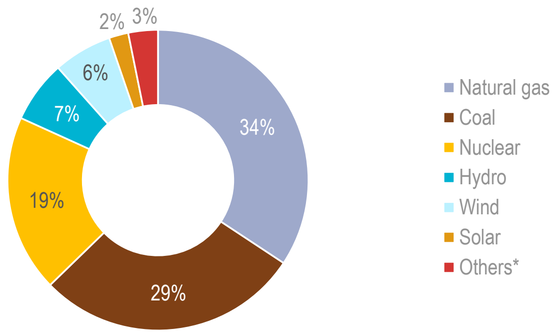
In the face of rising extreme weather events, new cybersecurity threats, a growing share of variable generation, and retirement of older coal and nuclear plants (due in part to lower wholesale natural gas power prices), the United States has recently entered into a renewed debate on reliability and resilience.

This debate is taking place alongside additional challenges. The US bulk power system is increasingly facing uncertainties stemming from the rise of distributed energy resources, electric vehicles, digitalisation and an ageing power infrastructure. Some grid operators have reacted to these challenges by revising rules that adapt to new demand and supply sources based on guidance from FERC and NERC. However, the complexity and governance of the US power system requires a range of market-specific reforms, several of which are already under consideration.

In this context, a challenge for regulators at both the federal and states levels will be to establish and apply rules across different markets in response to changes in the generation mix. This would be beneficial to avoid potential reliability risks in a context of growth in renewables and natural gas generation, which are replacing coal as the dominant energy source (and increasingly, ageing nuclear generation as well).

There is currently an active debate and testing of different solutions regarding electric reliability and resilience, including on changes to market designs for wholesale power markets to respond to future trends, at the federal, regional, state and local levels.

Figure 9.1 Electricity generation by source, 2018



Coal, natural gas and nuclear accounted for over 80% of total electricity generation in 2018, but the share of renewable energy is increasing.

**Others* includes oil products, geothermal and other non-specified generation.
Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

Electricity supply and demand

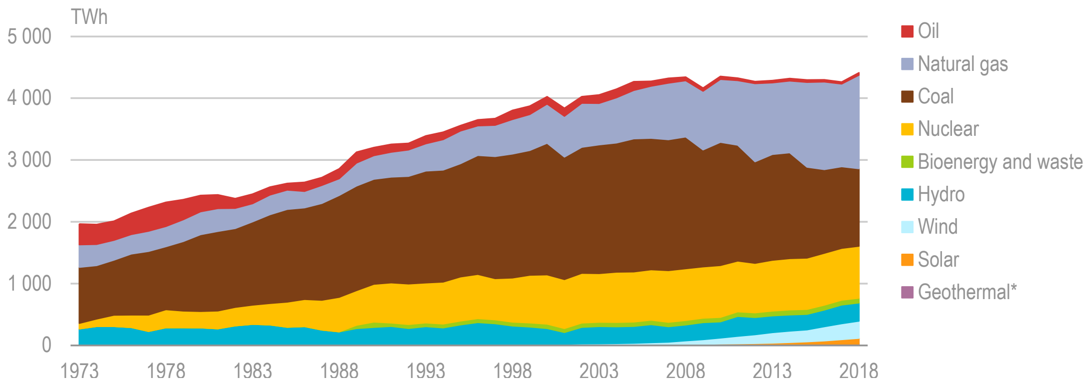
Electricity generation and trade

The total volume of US power generation has been stable at around 4 300 terawatt-hours (TWh) over the last decade. In 2018, the United States generated 4 413 TWh of electricity, which is 2% higher than in 2008. However, the fuel mix of US power generation has gone through a considerable transition. Coal power, which used to cover half of total electricity generation, has declined in the last decade to 28% of the power mix in 2018. One of the main drivers for this development has been the shale gas boom, which has made natural gas-fired generators more cost-competitive than coal power plants. Natural gas-fired electricity production increased by 66% in ten years, and now exceeds coal's share in the power mix (34% for natural gas in 2018 compared with 28% for coal).

Another development is the growth of renewable electricity, driven by reduced investment costs and policy support. Wind power production increased from 55 TWh in 2008 to 277 TWh in 2018, and is on track to overtake hydro as the largest renewable power source in 2019. Solar power is also growing rapidly, but from a much lower base. In 2018, solar power accounted for 2% of total generation, but production has increased fivefold in the last five years. While wind and solar power are expanding, hydropower remains relatively stable at around 250 TWh to 300 TWh per year.

The remaining share of power generation is mainly from nuclear power, which accounted for 19% of total generation in 2018. Nuclear has been the most stable power source over the last decade, with annual outputs varying from 801 TWh (in 2012) to 841 TWh (in 2018). However, in some power markets, nuclear is challenged by cheap gas power and new renewable sources, and struggles to remain cost-competitive (see further in Chapter 10, “Nuclear”).

Figure 9.2 Electricity supply by source, 1973-2018



Total power generation has been stable around 4 300 TWh over the last decade, but there has been a significant fuel shift from coal to natural gas and wind power.

*Not visible on this scale.
Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

The ongoing energy transition is clearly visible when looking at installed capacity (Table 9.1). Coal power plant retirements have experienced declining installed capacity, falling from around 320 gigawatts (GW) in 2011 to around 260 GW in 2017. Meanwhile, the natural gas power fleet has increased substantially and accounts for the largest installed capacity in the country, with over 40% of the total. Increased installed wind and solar capacity is also remarkable, from a few gigawatts in 2000 to over 130 GW in 2017. Nuclear and hydro capacities remain stable at around 100 GW each.

Table 9.1 Installed electricity generating capacity, 2000-17 (GW)

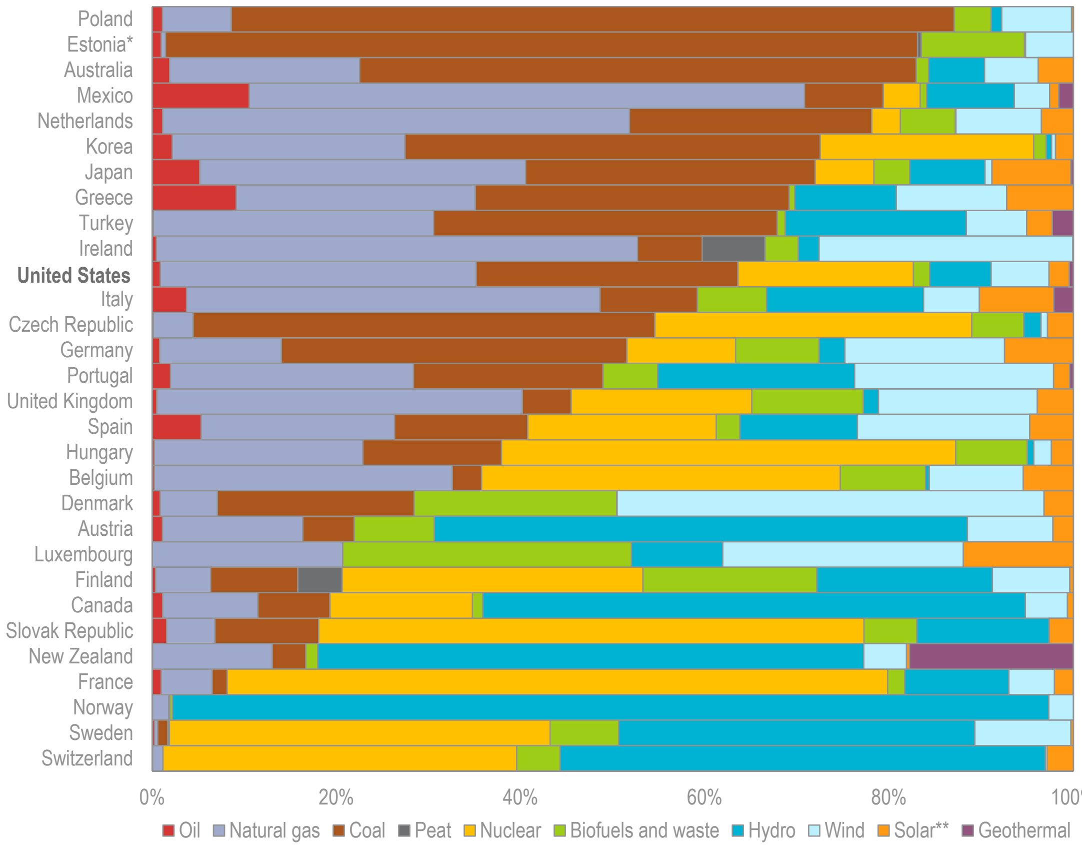
	2000	2005	2010	2015	2016	2017
Nuclear	97.9	100.0	101.2	98.7	99.6	99.6
Hydro	97.6	98.9	101.0	102.2	102.7	102.7
Wind	2.4	8.7	39.1	72.6	81.3	87.6
Solar	0.6	0.9	3.4	23.4	34.7	43.1
Geothermal	2.8	2.3	2.4	2.5	2.5	2.5
Other sources	0.0	0.5	0.3	1.3	1.3	2.0
Combustible fuels	610.1	767.3	793.6	771.7	764.8	762.8
Coal	321.1	315.4	319.0	281.5	269.1	258.9
Natural gas	95.8	383.1	407.0	439.4	446.8	456.0
Other combustion	45.8	68.8	67.6	50.8	48.9	47.8
Total capacity	**811.3**	**978.5**	**1 041.0**	**1 072.5**	**1 086.8**	**1 100.3**

Source: IEA (2019b), *Electricity Information 2019*, www.iea.org/statistics/.

In 2017, low-carbon electricity from renewables and nuclear accounted for 37% of total generation in the United States. In comparison with other International Energy Agency (IEA) member countries, this share was in the lower half, with a median of 50% low-carbon electricity (Figure 9.3).

US power systems are interconnected with Canada in the north and Mexico in the south. Most traded electricity consists of imports from Canada, mainly from the hydropower-rich Quebec region, which feeds into northeastern US power markets. Net imports peaked in 2015 at 67 TWh, and have since fallen slightly (Figure 9.4). In 2017, net imports were 56 TWh, equal to 1.3% of total domestic generation.

Figure 9.3 Electricity generation by source in IEA, 2018



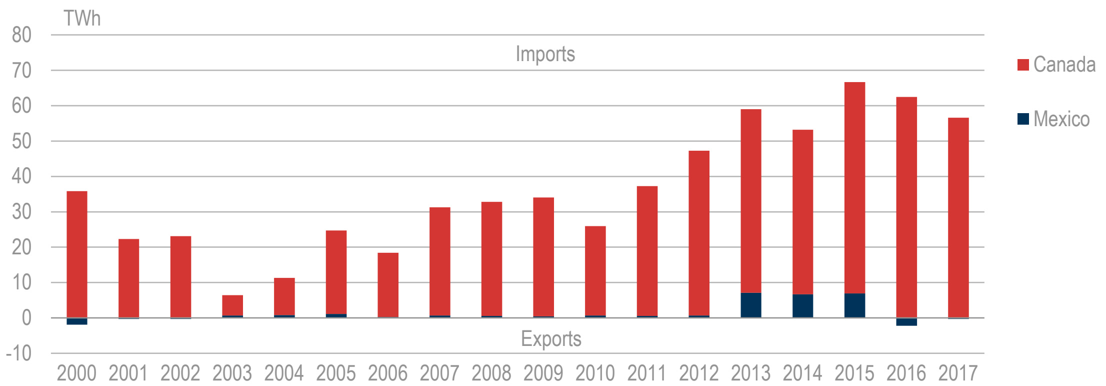
With 64% fossil fuels in electricity generation, the United States is close to average in the IEA.

*Estonia's coal represents oil shale.

**Includes solar photovoltaic (PV), solar thermal, wave and ocean power, and other power generation (e.g. from fuel cells).

Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

Figure 9.4 Electricity net imports and exports by country, 2000-17



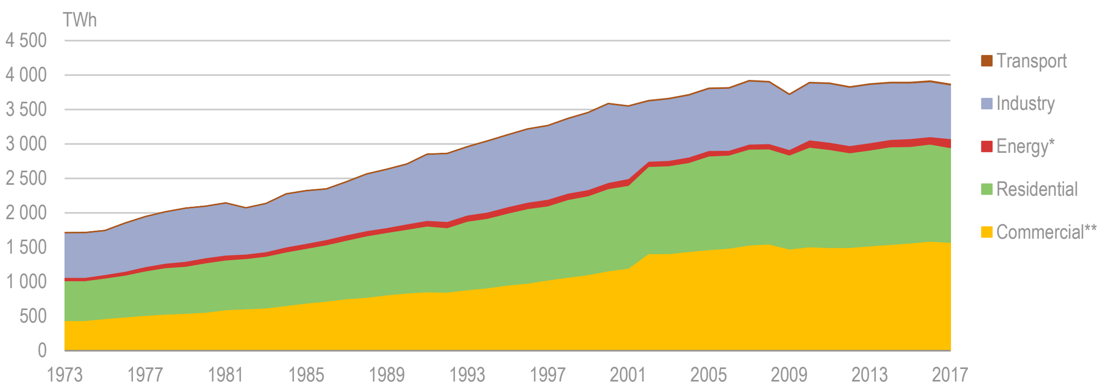
US electricity imports are mostly from hydropower in Canada.

Source: IEA (2019b), *Electricity Information 2019*, www.iea.org/statistics/.

Electricity consumption

Total electricity consumption has been relatively stable at just below 4 000 TWh per year over the last decade. The only exception was a decline in 2009, in the aftermath of the financial crisis, which led to reduced energy demand in industry. The residential and commercial sectors dominate electricity consumption, with 76% of total demand in 2017. Residential electricity consumption per capita was 4.2 megawatt-hours (MWh) in 2017, the fourth-highest in the IEA (after Norway, Canada and Sweden).

Figure 9.5 Electricity consumption (TFC) by consuming sector, 1973-2017

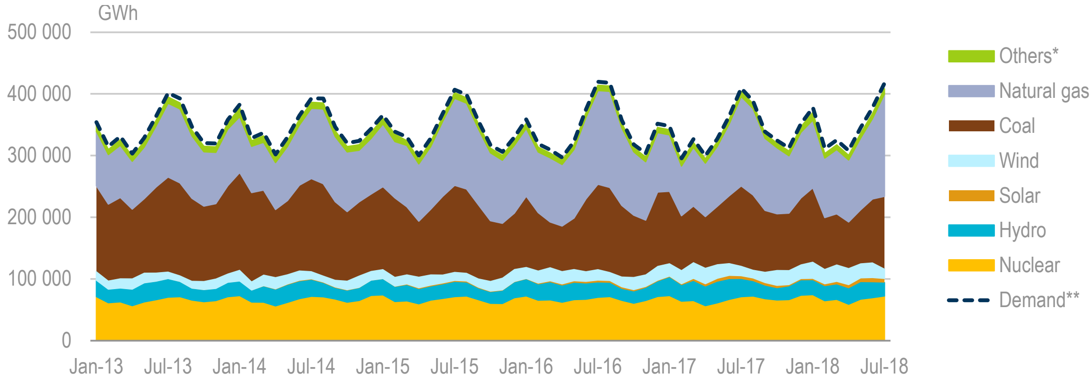


The residential and commercial sectors dominate electricity consumption.

**Energy* includes petroleum refineries, coal mines, oil and gas extraction, coke ovens, and blast furnaces.
***Commercial* includes commercial and public services, agriculture, and forestry.
Note: TFC = total final consumption.
Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

The United States is a large country with several different climate zones, which is reflected in seasonal variations in electricity consumption. Electricity is used for both heating, in electric boilers or heat pumps, and for cooling purposes in air conditioners. This leads to consumption peaks in both summer and winter periods (Figure 9.6).

Figure 9.6 Monthly electricity generation by source, January 2013-July 2018



US electricity demand peaks in both summer, when used in air conditioning, and in winter, when used for heating; coal and natural gas are used for covering demand peaks.

**Others* includes oil, combustible renewables and other combustible non-renewables.

***Demand* refers to final consumption including distribution losses.

Note: GWh = gigawatt-hours.

Source: IEA (2019c), *Monthly Electricity Statistics 2019*, www.iea.org/statistics/.

The summer peaks are higher, with monthly demand sometimes above 400 TWh. Coal and natural gas are used as flexible power sources for covering the demand peaks. The shift towards increased gas demand for power generation has also created a summer peak for gas, which did not exist previously.

Electricity system regulation

The US electricity system, which covers generation, transmission, distribution and sales of electricity, is governed by government institutions at the federal, state and local levels. At the federal level, FERC is the primary regulator with broad authority over system reliability and interstate transmission, while state regulatory commissions generally oversee intrastate distribution and sales of electricity. In some states, local governments also have authority over issues such as the siting of power infrastructure (NREL, 2016).

FERC

FERC is an independent federal agency tasked with regulating the bulk power system, including interstate transmission of electricity and the operation of wholesale electricity markets. (The commission also regulates interstate flows of natural gas and liquefied natural gas [LNG] export terminals.) FERC comprises five commissioners, all appointed by the president for five-year terms, one of whom serves as chairperson. As an independent body, FERC is not subject to review by either the executive or legislative branch of government, though its decisions can be challenged through the judicial branch. Among its primary responsibilities for the electricity sector are:

- Regulating rates and services for the interstate transmission and sales of wholesale electricity.
- Reviewing and approving interstate transmission reliability standards developed by NERC (described below).
- Monitoring wholesale electricity markets to ensure competitiveness, fairness and efficiency, as well as to detect market manipulation or violation of rules.
- Reviewing corporate transactions of public utilities (such as mergers and acquisitions and issuance of securities).
- Licensing of hydropower projects.

NERC

NERC is a non-profit organisation, originally formed by the electric utility industry, which ensures the reliability of the North American bulk power system. In 2006, FERC designated NERC as the government's electrical reliability organisation for the United States. As such, NERC has the authority to develop and enforce reliability standards and assess the reliability (both seasonal and long-term) of the physical grid, which it does on an annual basis. There are six regional reliability entities spanning the United States, Canada and Baja California in Mexico that fall under NERC's jurisdiction to ensure reliability. Failure to comply with NERC reliability standards can carry hefty penalties.

State regulators

There are a number of regulatory areas that lay outside the purview of FERC, which fall to state regulatory commissions, most commonly referred to as state public service commissions or state public utility commissions. State commissions regulate the electricity distribution system, including retail rates and reliability of supply to end users of electricity within their respective jurisdictions. Ultimately, they are responsible for ensuring reliable retail supply of electricity to consumers at fair prices. State public utility commissions also oversee the siting and construction of generation assets (with the exceptions of licensing for hydropower and nuclear power facilities) as well as transmission and distribution infrastructure. If a given project crosses more than one state, then its developers must seek regulatory approval from each relevant state's public utility commission or other state authority. Most commonly, state public utility commissions regulate investor-owned utilities rather than federal power agencies, rural electric co-operatives or municipal utilities (see below for more details on types of utilities).

The physical grid

The US electricity grid is divided into three main interconnection areas, which overlap with portions of Canada and Mexico: the Western Interconnection (comprising the western third of the United States, the provinces of Alberta and British Columbia in Canada, and parts of Baja California in Mexico); the Eastern Interconnection (comprising the eastern two-thirds of the United States and Central Canada eastward, except for Quebec); and the Electric Reliability Council of Texas (comprising most of the state of Texas). Hawaii and Alaska, as non-contiguous states, are not connected to the rest of the US grid. The power systems within each interconnection area connect to one another, allowing the free flow of electricity, but there is limited synchronisation between interconnection areas (DOE, 2015).

Within each interconnection area, balancing authorities ensure that supply is sufficient to meet demand. In many states, utilities serve the role of balancing authority, though independent system operators and regional transmission organisations play the role of balancing authorities in regions that they cover (see below).

The US transmission network includes the power lines that link electric power generators to each other and to local electric companies. The transmission network in the 48 lower states is composed of approximately 697 000 circuit-miles (1 121 000 kilometres) of power lines and 21 500 substations operating at voltages of 100 kilovolts (kV) and above. Of this, 240 000 circuit-miles are considered high-voltage, operating at or above 230 kV.

The vast majority of transmission lines operate with alternating current (AC). With commonly used technology, system operators cannot specifically control the flow of electricity over the AC grid; electricity flows from generation to demand through many paths simultaneously, following the path of least electrical resistance. A limited number of transmission lines are operated using direct current (DC). Unlike AC transmission lines, the power flows on DC lines are controllable. However, their physical characteristics make them cost-effective only for special purposes, such as moving large amounts of power over very long distances or interconnecting unsynchronised areas.

Distribution is the delivery of power from the transmission system to the end users of electricity. There are almost 6.3 million distribution line-miles in the United States. Thirty distribution substations connect to the transmission system and lower the transmission voltage to medium voltage. This medium-voltage power is carried on primary distribution lines, after which distribution transformers again lower the voltage, and secondary distribution lines carry the power to customers who are connected to the secondary lines.

Market structure

Wholesale electricity markets

The core of the wholesale electricity system is generation and transmission. FERC's authorities to establish rates and services for electric transmission in interstate commerce and electric wholesale power sales in interstate commerce form the basis for the economic regulation of the bulk electricity system. FERC directly regulates the economic performance of investor-owned utilities. Those companies are empowered to choose how they will operate their transmission systems and choose their generation sources, subject to state regulations, such as renewable portfolio standards. Regions differ in the structures they use to manage their wholesale electricity transactions (FERC, 2019).

Traditional vertically integrated utility bulk systems

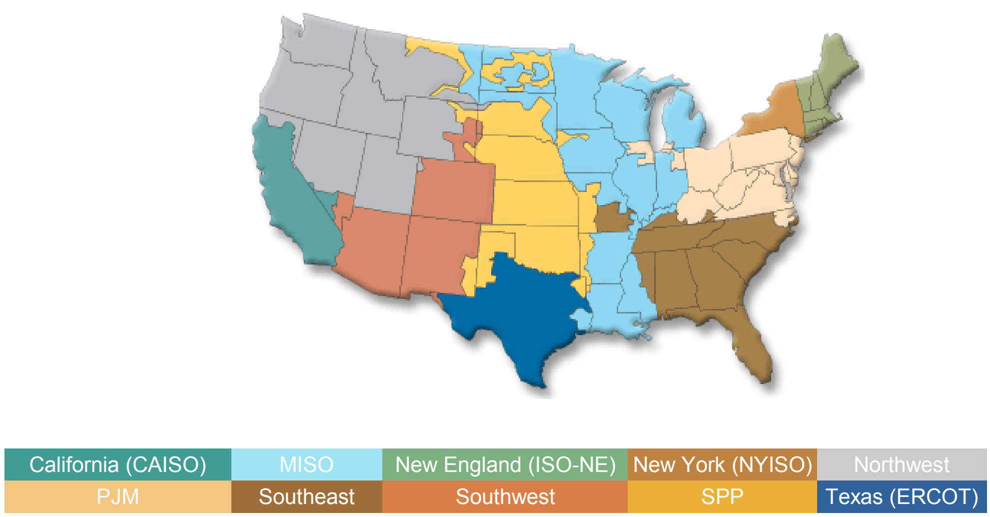
For most of the 20th century, the dominant entities for generating and transmitting bulk power were vertically integrated electric utilities (VIEUs). Today, only a subset of the US electricity system is based on the traditional VIEU organisation; these regions are the Northwest, Southeast and Southwest. In these regions, individual utilities control the generation and transmission needed to serve their service territories. These entities either own their own generation and transmission facilities or can purchase electricity through contracts with other suppliers. Sellers and buyers also enter into bilateral contracts, which tend to include agreed volumes and prices.

ISOs and RTOs

Since the late 1990s, utilities in most regions have opted to join Independent System Operators (ISOs) and Regional Transmission Operators (RTOs), organisations that centrally dispatch electricity for all participants. ISOs and RTOs were formed at the suggestion of FERC with the belief that increased competition among generators would help to reduce generation costs and help achieve “just and reasonable rates”.

Utilities in six regions have chosen RTO/ISO structures under FERC authority: California ISO (CAISO), New York ISO (NYISO), Midcontinent ISO (MISO), ISO New England (ISO-NE), PJM Interconnection and Southwest Power Pool (SPP). A seventh organisation, Electric Reliability Council of Texas (ERCOT), centrally dispatches the generation for most of Texas, but it is not subject to FERC wholesale market regulation because it is not interconnected to the rest of the US grid. Two-thirds of US electricity load is served by ISOs or RTOs.

Figure 9.7: US electricity ISO and RTO regions



Source: Courtesy of the U.S. Federal Energy Regulatory Commission (2019).

Among their core functions, ISOs and RTOs control (but do not own) their respective region’s electricity transmission system, administer wholesale electricity markets and ensure the reliability of the bulk electricity system. ISOs and RTOs help maintain system reliability by co-ordinating generation and transmission operations. ISOs and RTOs administer wholesale power auctions, where generators submit bids for a specified amount of electricity at a given price and time period based on their marginal cost of production. Combined, the bids create an energy market supply curve, or generation stack. The market clearing price is the level at which demand intersects with the supply curve, i.e. the marginal cost. Given near-zero generation costs for wind and solar power, they often clear first, while nuclear and fossil generators tend to place higher bids on the generation stack and occasionally do not clear an auction, especially during periods of low demand, such as nighttime hours.

In addition, RTOs and ISOs purchase ancillary services from generators. These include services such as frequency control, operating reserves and voltage support; they enable transmission operators to balance supply and demand.

Competitive markets can face challenges ensuring adequate revenues to generators to sustain the existing fleet and to secure timely and efficient investments in new generation capacity (Congressional Research Service, 2016). In the United States, the share of total generation costs covered by wholesale electricity revenues has been in decline mainly due to low natural gas prices. Stagnant demand and the rising share of variable renewables have intensified the downward pressure on wholesale electricity prices in several US electricity markets, and the main drivers of low wholesale electricity prices are likely to stay, with wind and solar set for further growth to meet state-level targets, and natural gas prices staying low. Therefore, US electricity sales may continue to recoup less than the total cost of generation in some states, despite the possibility of a return to growth for electricity demand from heating and cooling as well as transport.

Capacity markets

Federal and state reliability obligations require utilities to ensure that they have sufficient resources to meet projected demand as well as an additional reserve margin that covers unexpected demand spikes or supply disruptions. Capacity markets are used in some markets to ensure adequate reserve supply where the RTO/ISO is responsible for resource adequacy (i.e. ISO-NE, PJM and NYISO). In other regions (RTO/ISO and traditional), the principal responsibility for resource adequacy rests on the electric utility distributing the electricity and serving load (GAO, 2017).

Where capacity markets are used, ISOs and RTOs incentivise generators to provide reserve capacity and award incentives based on auctions that seek the lowest-cost capacity resources. Capacity markets seek to ensure adequate reserves over various time horizons, from one month (MISO) to three years (PJM and ISO-NE). Demand response, under which utilities signal consumers to cut demand during periods of tight supply (usually through time-based rates or other financial incentives), can also bid into capacity markets (see more on demand response under Policies and Regulations section).

Energy Imbalance Market

Launched in 2014, the Western Energy Imbalance Market (EIM) is a real-time bulk power trading market run by CAISO across eight Western states (Western Energy Imbalance Market, 2019). Regional utilities and balancing authorities outside of CAISO can opt into participating in the EIM. Like the RTOs/ISOs, the EIM is designed to identify the lowest-cost energy resource to reduce costs and optimise use of all generation resources (variable renewable generation and conventional fossil resources) across the geographical footprint, and increase system flexibility (NRDC, 2017). The EIM also monitors congestion on transmission lines across participating areas to boost reliability, but unlike RTO/ISO participants, EIM participants control their respective transmission systems (Power mag, 2018).

More recently, the SPP announced that it plans to launch the Western Energy Imbalance Service market in December 2020 to balance regional real-time load and generation (Power Mag, 2019).

Distribution system rates and competition

State regulators determine how rates and prices for retail electricity customers will be determined. Where states rely on regulated distribution utilities to provide retail service, retail rates are set based on traditional costs of service. Retail rates are approved by state public utility commissions, which have regulatory purview over the rates of return and expenditures of investor-owned utilities.

Selected states have chosen to implement retail electricity competition, where at least a portion of the electricity is sold on a competitive basis. Retail competition is most common in states where the state forced utilities to divest generation assets, as part of restructuring (21st Century Power Partnership, 2017). In the competitive model, multiple electricity suppliers sell electricity sourced from wholesale markets or the company's own generation. Customers choose their supplier based on offers made by multiple suppliers.

Currently, 18 states plus the District of Columbia have deregulated retail electricity markets, out of which 13 states and the District of Columbia have full retail choice (Littlechild, 2018). Moreover, the number of customers participating has increased substantially over time. Texas has the largest participation because it does not allow the local distribution utility to engage in retail sales, whereas most retail competition states require the local distribution utility to provide retail supply at regulated rates to customers that do not pick a competitive supplier.

Ownership

Consistent with the regulatory models that prevailed, US electricity system ownership was dominated by vertically integrated utilities that owned generation, transmission and distribution assets that served a group of customers defined by the state regulatory authorities until the late 1990s. In addition, firms owned by non-investor-owned entities have served selected segments of the market for many decades:

- Municipal utilities owned by local governments at the city or county level generally provide retail distribution services, but also own interests in transmission and generation.
- Rural co-operatives are owned by the customers they serve; co-operatives take the form of distribution utilities, or generation and transmission co-operatives.
- Federally owned entities are bulk power system only and include power marketing administrations that sell power generated by federally owned plants (mostly hydro) in 33 states. These include the Bonneville Power Administration in the Northwest, the Southeastern Power Administration, the Southwestern Power Administration and the Western Area Power Administration. The Tennessee Valley Authority is a federal corporate agency that both generates and transmits electricity to seven states in the Tennessee Valley. Other agencies, such as parts of the Department of the Interior, also own generation assets.

While these ownership types continue, electricity restructuring has fostered other business models in some states and regions:

- For the wholesale power market, merchant generators have emerged, primarily in RTO/ISO markets that are dominated by states that chose competition for both the wholesale and retail markets. Merchant generators are privately owned, non-utility generators that sell power as part of an RTO/ISO's economic dispatch or contract directly with utilities and other end users.
- Merchant transmission owners that own portions of the electricity system have emerged in several regions. Nevertheless, regulated distribution utilities continue to be the dominant transmission owners.
- In states with retail choice, vertically integrated investor-owned utilities have "unbundled" by selling their generation and becoming distribution- and transmission-only utilities.
- Many companies, including investor-owned utilities, engage in power trading to hedge costs.

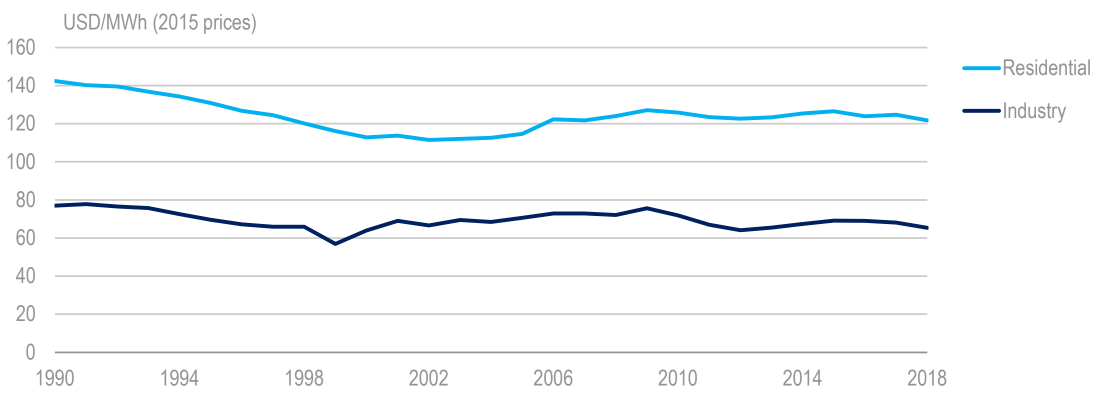
Retail prices and taxation

US retail electricity prices have been quite stable in terms of annual average rates, both for industries and for households (Figure 9.8). In 2018, US industries paid on average USD 69/MWh and households paid USD 129/MWh. In real prices, the household price decreased by 1.8% over the decade from 2008 while industry prices fell by 9.3%.

In an IEA comparison, US average retail prices for electricity are relatively low. In 2018, industries in the United States paid the second-lowest price, above only Norway. Household prices were a bit higher but still the fifth-lowest in the comparison (Figure 9.9).

The United States does not apply any federal electricity-specific taxes, aside from income taxes charged to companies operating at various stages of the power supply system. Many US states have sales taxes, which often include electricity, though several offer partial or full exemptions for electricity sales.

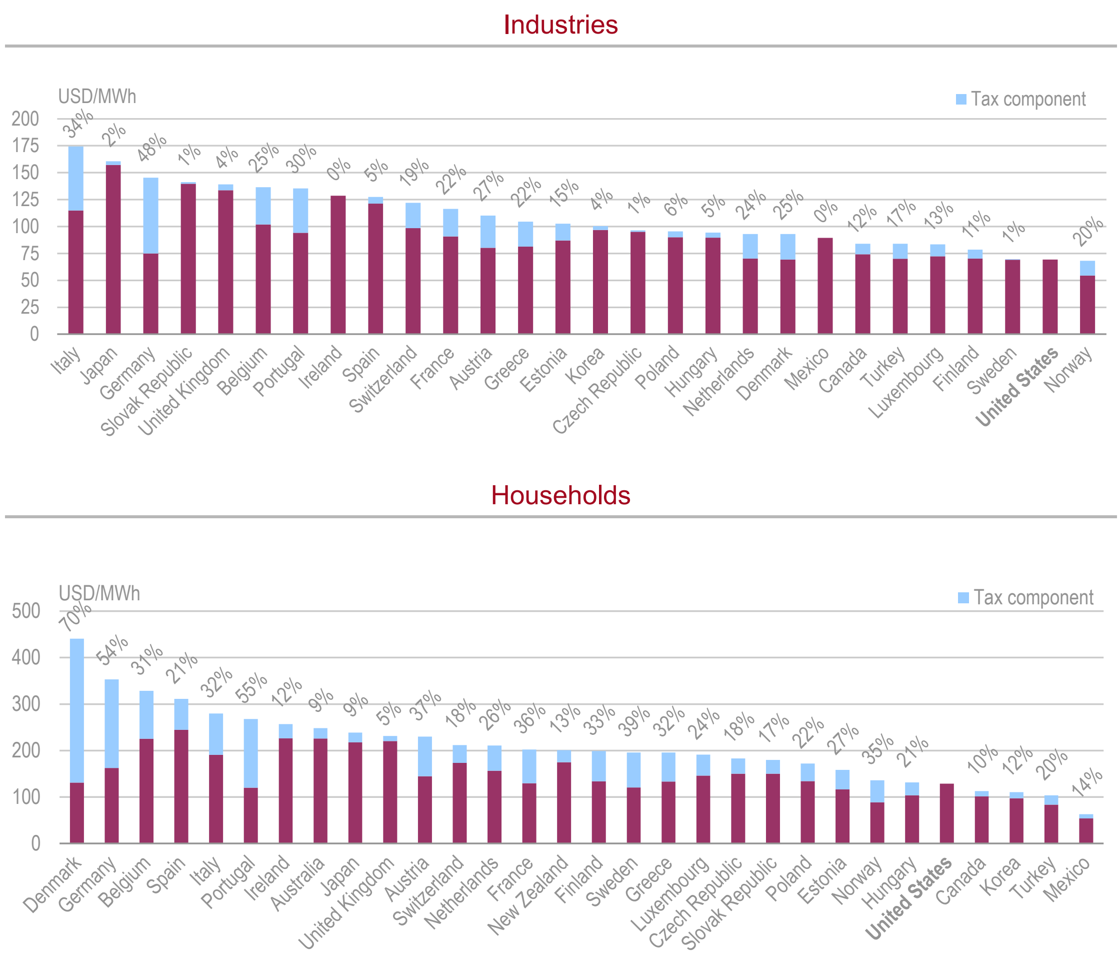
Figure 9.8 Electricity price trends in the US, 1990-2018



Electricity prices have been quite stable for both industries and households in recent years.

Source: IEA (2019d), *Energy Prices and Taxes 2019*, www.iea.org/statistics/.

Figure 9.9 Industry electricity prices in IEA member countries, 2018



US customers pay relatively low prices for electricity in an IEA comparison.

Notes: Nominal prices. Tax information not available for the US. Industry price data not available for Australia and New Zealand.

Source: IEA (2019d), *Prices and Taxes 2019*, www.iea.org/statistics/.

Policies and regulations

Over the past few decades, the US electricity sector has undergone a series of policy and regulatory changes that led to a shift away from a vertically integrated model towards one that is today marked by more competition and liberalisation. Still, as the sector undergoes considerable change – including in the form of sizeable new additions of intermittent renewables, new technologies for provision of services and a shift towards performance-based utility metrics – the regulatory structure will continue to evolve. The basic regulatory framework of the US electricity system is embodied in the following legislative and regulatory actions:

Federal Power Act

The Federal Water Power Act of 1920 was initially designed to co-ordinate hydroelectric projects in the United States. The act established the Federal Power Commission (later FERC) to license, co-ordinate and regulate hydro projects. In 1935, the law was renamed the Federal Power Act, and extended jurisdiction to the commission over all interstate activities of the wholesale electricity and natural gas industries. The Federal Power Act has seen many amendments since it was first passed, underpinning electricity market liberalisation over the past few decades; the most recent major changes to the act were passed by Congress as part of the Energy Policy Act of 2005. Among its many provisions, the act authorises FERC to ensure just, reasonable and non-discriminatory rates.

Public Utilities Regulatory Policies Act

One of the first major efforts to introduce more competition into the electricity sector came when Congress passed the Public Utilities Regulatory Policies Act (PURPA) in 1978, in response to the energy crisis of the 1970s. In an effort to reduce dependency on foreign oil and diversify energy sources, PURPA required utilities to purchase power from independent power companies, including renewable energy generators and co-generation[1] plants, if they could produce electricity for less than the cost of the utility's plants (or the utility's "avoided cost"). Prior to the passage of PURPA, utilities had monopolistic control over generating plants, so the law had a significant impact in opening up the generating sector to competition from independent power producers (IPPs). PURPA has also been a major driver of non-hydro renewable power installations, especially in recent years as the costs for renewables have fallen considerably, making it easier to clear the "avoided cost" threshold. Even more so, PURPA has led to notable growth in gas-fired co-generation facilities.

Energy Policy Act of 1992

Congress in 1992 passed comprehensive energy legislation under the Energy Policy Act of 1992. The legislation called on FERC to require utilities to open up transmission access to non-utility electricity providers on a non-discriminatory basis, thereby improving the outlook for IPPs and boosting competition in the wholesale power market.

FERC Orders 888 and 889

In 1996, FERC released the landmark Orders 888 and 889, in response to concerns that vertically integrated utilities were limiting competition and under-utilising surplus grid capacity. The orders required utilities to unbundle wholesale generation, transmission and ancillary services and required owners of transmission networks to offer non-discriminatory access to transmission lines. In that regard, Order 888 encouraged the creation of ISOs to serve as independent organisations with operational control over the grid to ensure open access to transmission systems. Though many regions moved forward with establishing ISOs, some states modified their laws to force utilities to unbundle electricity services to comply with the order. Order 889 specifically launched the Open Access Same-Time Information System (OASIS) and established standards for information sharing between utilities and consumers to improve transparency and limit anticompetitive behaviour on the part of utilities. As such, Orders 888 and 889 were critical to opening the US electricity sector to competition.

[1] *Co-generation* refers to the combined production of heat and power.

FERC Order 2000

In an effort to further address shortcomings on competitive access in the electricity sector, FERC in 1999 issued Order 2000. Building upon the ISO framework, the order introduced the concept of RTOs and encouraged transmission owners to participate in them (on a voluntary basis). The order presented 12 criteria that an organisation must meet in order to qualify as an RTO. Generally speaking, ISOs and RTOs serve similar functions, though RTOs co-ordinate electricity transmission on a broader regional basis.

Energy Policy Act of 2005

Under the comprehensive Energy Policy Act of 2005 (EPAct 2005), Congress repealed the Public Utility Holding Company Act of 1935, thereby overhauling the federal regulatory regime for the electricity sector. In doing so, Congress granted unprecedented regulatory authority to FERC, including a requirement for FERC to set and enforce reliability standards for the entire transmission network (which it delegated to NERC). The law also rolled back some of the requirements under PURPA, specifically by not forcing utilities to enter into new contracts from PURPA-qualifying entities if the facility has non-discriminatory access to competitive markets. EPAct 2005 also granted FERC the authority to issue permits for transmission projects in areas under a “national electric transmission corridor”, as designated by the Department of Energy (DOE).

Electricity in the low-carbon transition

Federal environmental policy

Since 2017, the administration’s overarching energy policy is focused on rolling back a number of environmental regulations on the energy sector, including the power sector. The administration believes a number of existing regulations impose excessive costs on the sector. For the power sector, the main regulatory rollback proposal has been to repeal and replace the Clean Power Plan for greenhouse gas emissions.

On 21 August 2018, the administration introduced its proposal to replace the Clean Power Plan with the Affordable Clean Energy rule. Under Section 111(d) of the Clean Air Act, the Environmental Protection Agency (EPA) is required to regulate emissions at existing power plants through the best system of emissions reduction (BSER). The Clean Power Plan, which was suspended by a Supreme Court ruling and therefore never took effect, proposed statewide targets for power plant emissions that collectively added up to a 32% reduction from 2005 levels by 2030. Meeting the targets allowed for so-called “beyond the fence line” measures such as switching to cleaner power sources and demand-side management. In contrast, the replacement plan focuses on site-specific emissions cuts at individual power plants. The EPA’s latest rule – finalised in June 2019 – offers states several options for candidate technologies, though recommends heat-rate efficiency improvements at existing power plants as the BSER (Utility Dive, 2019a).

The administration in December 2018 also announced a proposal to revise New Source Performance Standards (NSPS) for CO_2, applied under Section 111(b) of the Clean Air Act. The NSPS rule has been in effect since it was finalised in 2015. The previous rule established an emissions threshold of 1 400 pounds (635 kilogrammes) of carbon dioxide (CO_2) per MWh for new coal-fired generators, which would require partial carbon capture and sequestration (CCS). The new proposal calls for a standard of 1 900 pounds

(862 kilogrammes) of CO_2/MWh for large generators and 2 000 pounds (907 kilogrammes) for smaller generators, which would not require CCS.

Beyond CO_2, the EPA also reviewed existing regulations on the power sector for other pollutants, including nitrogen oxides (NO_x), sulphur dioxide (SO_2) and mercury. These regulations are primarily designed to combat fine particulate matter that contribute to smog, and raise the costs for coal-fired generation relative to other sources. While the EPA decided not to revisit NO_x and SO_2 regulations, in December 2018, it proposed a revised Supplemental Cost Finding for the Mercury and Air Toxics Standard, which would not change implementation of the existing rule, but would limit future regulatory action on hazardous air pollutants under Section 112 of the Clean Air Act. The EPA also finalised its revision of the 2015 coal ash rule for coal plants, which governs how power plants manage coal ash waste from burning coal. The new rule relaxes requirements for plant operators and gives states and the industry more flexibility in waste management.

State-level clean energy policies

Renewable portfolio standards

A number of US states have in place renewable portfolio standards (RPS), which require retail electricity providers to source a certain share of supply from qualified renewable sources. While emissions reduction goals are a driver of state RPS policies, they are also enacted to harness local energy resources, diversify the fuel mix and support local economic activity. Twenty-nine states plus the District of Columbia currently have mandatory RPS policies in place (eight states have voluntary targets), which have been an important driver of renewables expansions in the United States (Lawrence Berkeley National Laboratory, 2019). RPS plans have been particularly important in driving renewable energy growth in the Northeast, Mid-Atlantic and West.

Since their adoption, many states have raised their RPS targets to encourage more uptake of renewables. More recently, in 2019, several states made significant changes to strengthen their RPS programmes, including Colorado, District of Columbia, Maryland, Maine, New Mexico, Nevada, New York and Washington. California, Hawaii, New York and Washington have the most ambitious legislated targets; they require that 100% of electricity come from clean sources by 2045 (2040, in the case of New York), with Hawaii's policy specifically requiring 100% from renewables (Utility Dive, 2019b). New Jersey's governor signed an executive order in 2018 for a 100% clean energy (renewables and nuclear) target by 2050. In January 2019, the District of Columbia increased its RPS target to 100% by 2032, while Nevada in April 2019 passed legislation that targets 100% of carbon-free electricity by 2050.

Table 9.2 RPS across US states

State	Renewable portfolio target	Target year
Iowa	105 MW	1999
Montana	15%	2015
Texas	5 880 MW	2015
Wisconsin	10%	2015
Maine	84%	2030
Washington	15%	2020

State	Renewable portfolio target	Target year
Oregon	50%	2040
Colorado	30%	2020
New Mexico	80%	2040
Maryland	50%	2030
Michigan	15%	2021
Missouri	15%	2021
Pennsylvania	18%	2021
North Carolina	12.5%	2021
Nevada	50%	2030
Arizona	15%	2025
Minnesota	26.5%	2025
New Hampshire	25.2%	2025
Illinois	25%	2026
Ohio	8.5%	2026
Delaware	25%	2026
California	60%	2030
New York	70%	2030
Massachusetts	41.1%	2030
Connecticut	44%	2030
New Jersey	54.1%	2031
Vermont	75%	2032
Washington, DC	100%	2032
Rhode Island	38.5%	2035
Hawaii	100%	2045

Source: Lawrence Berkeley National Laboratory (2019), *U.S. Renewables Portfolio Standards: 2019 Annual Status Update*, http://eta-publications.lbl.gov/sites/default/files/rps_annual_status_update-2019_edition.pdf.

Zero-emissions credits

In addition to renewables targets, a few states have also provided support to nuclear power in the form of zero-emissions credits (ZECs). Though nuclear power has accounted for roughly a fifth of US electricity generation in recent history, competition from low-cost natural gas and renewables, combined with mounting costs for nuclear plant upgrades, is presenting challenges for both portions of the existing fleet of nuclear plants and new projects. Viewed by certain states as a critical source of baseload zero-emissions power, dwindling nuclear capacity – if not replaced by renewables – will result in growing emissions from the electricity sector. As a result, some states facing nuclear closures have intervened to keep plants in service (also see Chapter 10, "Nuclear"). Most notably, in 2016, New York and Illinois enacted policies that allow nuclear plants to qualify for ZECs that help the states meet their clean energy standards. In New York, the policy provided support to three nuclear plants – the James A. Fitzpatrick, Nine Mile Point and Ginna plants – while the Three Mile Island nuclear facility is still slated for closure due to safety concerns. In Illinois, the policy prevented the closures of the Clinton and Quad Cities nuclear plants. Both state programmes were upheld in court challenges. More recently, in 2019, New Jersey passed legislation to provide ZECs to its nuclear capacity at the Salem-Hope Creek nuclear plant (Exelon's Oyster Creek plant was shuttered last year). Elsewhere, however, state governments have resisted such support for nuclear, including in places facing imminent plant closures, such as Pennsylvania, Ohio and California.

Net metering

A number of US states also have net metering laws in place, which permit residential and commercial customers (mostly rooftop solar) who generate their own renewable power to sell surplus electricity (usually at retail rates) back to the grid. The success of rooftop solar policies in several states has occasionally resulted in an abundance of solar power fed into the grid, creating challenges for utilities in balancing demand with more unpredictable supply. The issue is particularly acute during the afternoon hours, when the maximum amount of sunlight can generate more electricity than the load requires. Subsequently, demand tends to pick up again during the evening hours after people return home from work, when the sun is no longer shining. In some cases, the amount of rooftop solar generation can result in surplus power on the grid that creates negative electricity pricing and forces curtailment. In response, some states are adjusting their net metering rules to better align rooftop solar payments with grid requirements, including by introducing time-of-use rates and location-specific rates. Other states, such as Indiana, however, are phasing out net metering payments entirely, which will significantly slow down rooftop solar buildouts in those parts of the country.

System integration of renewables

As the US power mix shifts, and as more variable renewables are introduced into the system, bolstered by state policy goals, the question of smoothly and cost-effectively connecting new generation sources to the grid has already become more salient, and will grow increasingly pressing in the coming years (also see section on Grid Reliability and Resilience below). In particular, grid operators are already grappling with some misalignments between state policies such as RPS and ZEC programmes and their price formation rules (Joskow, 2019).

A number of US states are adopting storage targets to accompany their renewables targets, led in large part by California. To complement its 2030 target of 50% renewables, the state adopted an ambitious storage mandate in 2013, which required utilities to procure 1 325 MW of energy storage by 2020 (to be online by 2024). In response to the Aliso Canyon natural gas storage facility leak in 2015, the state in 2016 followed up by legislating that utilities procure an additional 500 MW of storage capacity. Importantly, California regulators have also modified market rules to ensure that battery storage options are valued more accurately in the wholesale power market. California's efforts have been followed by Massachusetts, which established a target of 1 000 MWh by 2025 (up from the previous target of 200 MWh by 2020). More recently, New York state regulators in December 2018 approved storage targets of 1.5 GW by 2025 and 3 GW by 2030, as directed by 2017 legislation, while New Jersey in 2018 legislated a storage target of 2 GW by 2030. Oregon has a very small storage target of 5 MWh by January 2020, which has not mobilised investments in the state.

Other states are also seeing solar-plus-storage installations bid at increasingly competitive rates into power auctions, even without storage mandates. For example, in January in Minnesota, Xcel Energy launched a tender for a solar-plus-storage facility that received bids (which reflect subsidies) as low as USD 36/MWh, while a tender for wind plus storage received a median bid of USD 21/MWh. Meanwhile in Arizona, NextEra signed a deal with Tucson Electric Power in May 2017 for a solar-plus-storage power purchase agreement at USD 45/MWh, while First Solar's February 2018 bid for a solar-plus-storage system topped those from gas peakers. Markets with traditionally high power prices, such as Hawaii, will also be suitable markets for more battery storage options to complement ambitious 100% renewables targets.

At the federal level, in response to the growth in renewables deployment, FERC in February 2018 issued Order 841, which required RTOs and ISOs to adjust rate structures to facilitate the participation of energy storage resources in regional wholesale power markets. The move places energy storage on a level playing field with other generation sources, and is expected to open up more opportunities for energy storage investments.

To further support efforts to ensure smooth integration of renewables into the grid and manage risks stemming from the retirement of baseload generation, FERC also issued Order 842 in February 2018, which requires new generators to install equipment capable of providing primary frequency response as a precondition for grid interconnection. There are lingering concerns that higher levels of renewables penetration could impact frequency response capabilities in power grids, given that synchronous baseload generation such as coal plants – which have maintained system frequency – are increasingly facing retirement. Wind and solar facilities are now required to install technologies such as inverters and battery storage to ensure primary response capabilities. More broadly, storage solutions – including those promoted by Order 841 – can help provide frequency response services.

Transmission

An important aspect of grid planning to accommodate growing shares of renewable energy is the building of transmission lines to carry electricity from often-remote generation sites to urban load centres. Examples of challenges facing large renewables projects due to transmission setbacks include the rejection by New Hampshire regulators of the Northern Pass Transmission project, meant to carry hydropower from Quebec through New Hampshire to Massachusetts. Moreover, the buildout of renewables and distributed energy resources would require more sophisticated and flexible transmission infrastructure, which is misaligned with the ageing state of the existing infrastructure. In 2015, FERC estimated that around 70% of transmission infrastructure was over 25 years old (Lawrence Berkeley National Laboratory, 2017).

In response, FERC in 2011 finalised Order No 1000, which revised rules for transmission planning, cost allocation and competitive bidding for transmission. The intent of the order was to shift the market towards competitive, cost-effective regional transmission plans that allocate costs to beneficiaries and accommodate state policy goals, especially with respect to renewables. The order also promoted interregional transmission solutions based on increased co-ordination between regional planners. In the eight years since the order was issued, a number of projects have been selected for regional cost allocation. Of these, some but not all have been selected through competitive processes. Many projects have also been selected through regional planning processes managed by

RTO/ISOs. In view of this record, some observers have suggested that FERC should consider whether modifications to Order No 1000 are merited, but the commission has not indicated its intentions.

Demand response

Demand response (DR) entails the shifting of energy consumption from periods of peak demand to periods of low demand (compared with energy efficiency measures that result in total energy consumption reductions).

In the United States, electricity demand usually peaks in the summer and natural gas demand peaks during winter months. In the past decade, DR has proliferated in the United States, playing an increasingly important role in electricity markets, where it is now valued as an integral resource in managing power markets. DR measures are rooted in providing incentives for consumers to postpone their energy consumption, either in the form of retail price reductions or direct payments, during periods of high demand.

According to the Energy Information Administration (EIA), in 2017, 9.4 million customers across the United States participated in DR programmes, the vast majority of which (88%) came from the residential sector, resulting in around 1.3 million MWh of total energy savings (EIA, 2019). The commercial sector accounted for 11% of DR participation and the industrial sector just 1%. In terms of energy demand shifting, residential efforts accounted for 72%, commercial 19% and industrial 9% of efforts. DR can take the form of wholesale DR, which is overseen by grid balancing authorities in wholesale power markets, or retail DR, which is managed by utilities directly with their customers.

As part of this effort, utilities continue to deploy advanced meters to their customers. In 2017, the EIA estimated a total number of 79 million advanced meters operating nationwide out of a total of 152 million meters, accounting for 52% of all meters (a number that has been steadily rising in the past decade). The large-scale deployment of smart meters is part of ongoing efforts by utilities to undertake grid modernisation strategies, which have been supported by state regulators, albeit at varying paces. There continue to be some concerns regarding data privacy that have led to a more cautious approach in some states, along with concerns about deployment costs.

A number of state regulators have also approved, or are considering, time-based electricity rate setting, in an effort to galvanise DR. Time-based rates allow electricity prices to vary based on the time of day, which provide more accurate signals to consumers on when to adjust demand to lower their bills. One of the main drivers of time-based rates is the growth of distributed energy resources, notably rooftop solar, as time-based rates can help shift demand patterns towards peak solar supply hours. Time-based rates can also improve the effectiveness of advanced metering investments to further support DR. Almost all states now offer some type of time-based rates, though uptake has been relatively weak.

The Energy Independence and Security Act of 2007 directed FERC to conduct a national assessment of DR potential and create a national action plan for DR. As part of that effort, FERC – along with the DOE – released a national assessment in 2009, crafted a national action plan in 2010 and issued an implementation proposal in 2011, which included the creation of a National Forum on DR to be led by the DOE and FERC. In

2011, FERC also issued Order 745, which ruled that DR be compensated on an equivalent basis to other generation resources in wholesale electricity markets. While providing a significant boost to DR, the order was challenged in the courts on the premise that FERC, whose authority is limited to regulating interstate wholesale power markets, was intervening in states' rights to regulate retail markets within their borders. The order was vacated by a Court of Appeals in 2014 but ultimately upheld and reinstated by the US Supreme Court in 2016.

Energy security

Grid reliability and resilience

The United States has for many years maintained a robust system that assesses and manages grid reliability to avoid power shortages. Looking ahead, however, the changing US fuel mix – in particular, the growth of natural gas and renewables at the expense of coal and nuclear generation – is raising new concerns about potential impacts on grid reliability (limiting disruptions) and resilience (minimising the duration and impact of disruptions). While reliability has long been a focus of grid operators, the concept of resilience is gaining traction and prompting more regulatory attention (National Academies of Sciences, Engineering, and Medicine, 2017).

NERC assessments

NERC's Reliability Risk Management group performs assessments on the reliability and adequacy of the bulk power system and identifies potential risks. In this capacity, it provides bulk power system awareness, event analysis and performance analysis to ensure ongoing monitoring and preparedness (NERC, 2019a).

On an annual basis, NERC conducts assessments and reports on the overall reliability and adequacy of the power system, as well as identifies risks to reliability on both a seasonal (winter and summer) and long-term basis (NERC, 2019b). In cases where it identifies risks, NERC conducts special assessments to provide more detailed insight, technical analysis and recommendations to industry to improve reliability.

The electricity chapter in the EPAct 2005 called for the establishment of a self-regulatory electric reliability organisation (ERO) across North America, under the purview of FERC within the United States. As such, NERC issues the following ERO reports:

- Long-term reliability assessments: assesses the adequacy of the bulk electricity system in the United States and Canada over a ten-year time horizon on an annual basis, including by forecasting supply and demand, evaluating transmission adequacy, and identifying issues that pose risks to reliability.
- Summer and winter assessments: assesses the adequacy of power supply in the United States and Canada for the next summer and winter peak demand periods. Summer assessments are published in May and winter assessments in October.
- Special assessments: performed on an as-needed basis to assess regional, interregional or interconnection-wide reliability risks.
- Methods and assumptions documents: outline the methodology and assumptions that underpin reliability assessments.

In its seasonal assessments, NERC provides a target reserve margin level for each reliability region. Reserve margins are measured as the surplus generation capacity above expected peak demand (EIA, 2012). By way of example, in its latest "Winter reliability assessment" (2018/2019), NERC estimated that all areas either met or exceeded their reserve margin levels (NERC, 2018). However, in its most recent summer estimate (2018), NERC noted that all regions except for ERCOT had adequate reserve margins (EIA, 2018a).

NERC also conducts event analysis as part of its reliability efforts, which study disruption events to determine causes, track preventive actions, and disseminate lessons-learned and best practices to the industry (NERC, 2019c). Event analysis also serves as a basis for training and education and for the development of reliability standards.

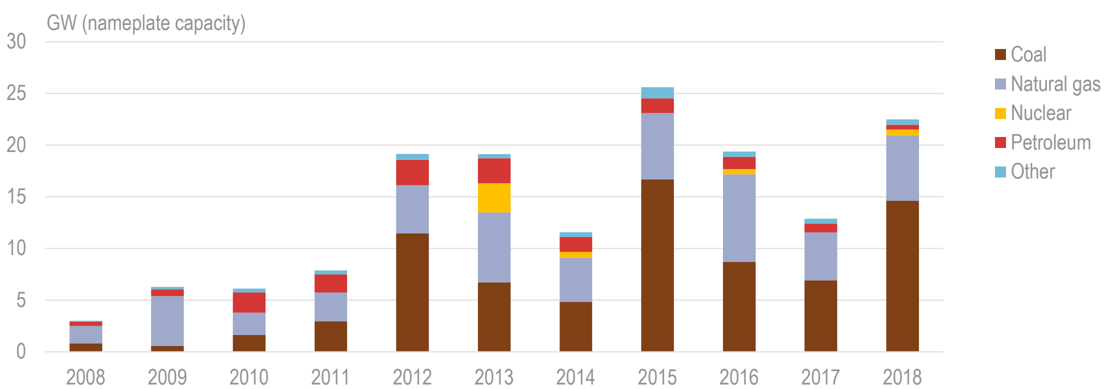
As part of its standards-setting exercise, NERC also created critical infrastructure protection (CIP) standards, which require companies to not only put in place antivirus software and firewalls to protect against cyberthreats, but also to ensure security of personnel and physical infrastructure as well as employee training (360 Training, 2015). CIP standards are enforced through periodic audits and investigations, and violations carry hefty penalties of up to USD 1 million daily.

In 2018, NERC started a two-year special reliability assessment of risks facing the electric power system due to a changing generation mix (EIA, 2018b).

DOE and FERC efforts

In response to growing concerns about the reliability impacts of the closure of coal and nuclear generation (Figure 9.10), the DOE in September 2017 issued a notice of proposed rule making (NOPR) that urged FERC to develop cost recovery mechanisms for baseload power generators that support grid reliability and resiliency. The proposal specifically called for ISOs and RTOs, under the direction of FERC, to develop compensation mechanisms for baseload plants that have 90 days of fuel supply on-site, which primarily include coal and nuclear plants (DOE, 2017).

Figure 9.10 Electricity generation capacity retirements, 2008-18



Source: EIA (2019), *Form EIA-860M, Preliminary Monthly Electric Generator Inventory.*

In response, the FERC in January 2018 issued an order that unanimously rejected the DOE's NOPR on the grounds that it did not provide sufficient evidence of supply risks to the grid, and therefore did not demonstrate that current RTO/ISO tariffs are "unjust or unreasonable", which is the threshold requirement to pursue changes to rate structures (FERC, 2018). Instead, FERC directed regional grid operators to undertake a comprehensive, longer-term evaluation of grid resiliency.

Following FERC's rejection of DOE's NOPR in support of fuel-secure baseload generation, the commission in January 2018 opened a study on grid resilience – defined as the grid's ability to recover from disruptions – that is still under way (Utility Dive, 2019c). The purpose of the investigation is to receive stakeholder input regarding whether further action is needed to protect the resilience of the bulk electricity system. Regional grid operators made their submissions to FERC in March 2018. Among the many comments received, PJM argued for FERC to develop a national approach to defining and compensating resiliency attributes, while other grid operators pushed to allow RSOs and ITOs to develop plans based on resilience risks identified within each region, highlighting ongoing divisions across the industry on the issue.

Capacity market reforms

As state-level clean energy policies push more renewables into the power mix and, in some instances, subsidise nuclear plants, other sources of electricity (especially coal) are finding themselves disadvantaged from depressed prices, in some cases forcing early retirement. As a result, grid operators are currently attempting to redefine rules for capacity markets, to adjust for the state-driven subsidisation of certain generation sources. FERC in June 2018 rejected two proposals from PJM on capacity market reforms to address state-subsidised generation resources. While FERC previously approved a similar proposal from ISO-NE, the rejection of PJM's proposal was because of its focus on subsidised existing generation (especially nuclear) rather than new subsidised resources (which the ISO-NE rule proposed including in a second round auction in which retiring generation could transfer capacity supply obligations to new, subsidised resources) (Utility Dive, 2018a). The ruling could lead to a fundamental shake-up in capacity markets. PJM has since proposed a resource carve-out plan that would disqualify subsidised resources from the capacity market through a minimum offer price rule, or a price floor. FERC is due to rule on PJM's revised proposal in the first half of 2019, which would take effect for its next scheduled capacity auction in August 2019.

Changes to capacity markets in reaction to state-level support are an integral component in the broader debate on grid resiliency (S&P Global Platts, 2019).

Other capacity mechanisms

Individual grid operators have also changed market rules to adjust to changing generation mixes. CAISO has a short-term resource adequacy mechanism. Resource adequacy has become a concern in CAISO, as generating capacity has exited the market, notably older oil/gas thermal capacity originally constructed for baseload and mid-merit operations. This capacity with high heat rates and start-up costs is not suitable to rapid variations in supply and demand, especially after the fast penetration of solar PV (CAISO had 10 GW of utility-scale solar PV and 6 GW of behind-the-meter solar PV in 2018). The California Public Utilities Commission is considering revising short-term contracting requirements in its existing out-of-market "forward" (one-year) resource adequacy protocols to require contracts for up to five years to ensure that retirements do not threaten reliability. FERC is examining a complaint by a CAISO generator to abandon its resource adequacy mechanism in favour of a full capacity market.

Elsewhere, ERCOT – which does not operate a capacity market – is facing low reserve margins (7.4% in summer 2019 compared with a target of 13.75%) as around 4.7 GW of coal-fired capacity has retired since May 2017 (RTO Insider, 2019). In response, ERCOT implemented changes in March 2019 to its operating reserve demand curve, which informs scarcity pricing during periods of tight supply. The changes effectively increase payments to generators during shortages by raising the probability of an outage (that is used for calculating payments) (Utility Dive, 2019d). ERCOT hopes that the higher payments will motivate new investments in generation capacity (or prevent the closure of existing capacity).

Fuel security

Amid the growing focus on grid resilience, grid operators are beginning to evaluate the fuel security of their systems, especially as more coal and nuclear capacity is pushed out of the power mix in favour of natural gas, which is more susceptible to supply disruptions and price volatility. The situation is particularly salient in the Northeast, where extreme winter temperatures often result in fuel scarcity for natural gas, forcing generators to switch to coal and fuel oil, both of which are seeing capacity retirements. ISO-NE estimates that around 4 600 MW of power plants supplied by non-natural gas fuels will go offline by June 2021.

In response, ISO-NE released an assessment of its fuel security challenges in light of growing natural gas dependency in January 2018. The report concluded that in 19 out of 23 scenarios examined, the region – which is dependent on electricity and LNG imports – would face fuel shortages that would result in rolling blackouts. The study will serve as the basis for ongoing discussions about fuel security risks and mitigation options.

In May 2018, ISO-NE requested that FERC waive its market rules to prevent the 1 700 MW, natural gas-fired Mystic Generation Station from retirement on the grounds that the plant's shuttering would force the closure of the neighbouring Everett LNG import terminal, which is critical to gas supplies in the Northeast, especially during peak periods. As such, the request focused on security of fuel supply rather than the reliability attributes of the power plant itself. FERC in July rejected the request, but upheld the grid operator's fuel security concerns and requested alternative proposals that address cost support for the plant as well as fuel security. In December, FERC approved ISO-NE's revised interim proposal, under which ISO-NE can enter into cost-of-service agreements with retiring generators considered necessary for fuel security reasons, until the grid operator can arrive at a compensation system for fuel secure generators. The interim proposal requires that generators with fuel security agreements be price-takers in forward capacity auctions, which allows them to be counted in capacity auctions and prevents over-procurement. The ruling sets up for future changes that could value and compensate generation resources based on their fuel security attributes.

Towards the end of 2018, PJM released the results of a fuel security study it launched in May in response to FERC's grid resilience docket. The report found that over the next five years, there were no fuel security risks to the grid in the PJM region, even under extreme winter weather, based on the expected retirements of coal and nuclear facilities (PJM, 2018). However, the report also noted that in a scenario of accelerated closures of coal and nuclear facilities, fuel supply disruptions could force outages. Moreover, PJM highlighted that fuel security was a critical component of reliability and resilience; as such, the grid operator is also looking into measures that would value resources based on their fuel security attributes.

Extreme weather

Extreme weather can often damage power systems and warrant emergency response procedures to restore services, minimise risks and ensure preparedness. Moreover, climate change is increasing the frequency and severity of extreme weather events, which will make further emergency response efforts more important in the coming years. In particular, as identified by the *Fourth National Climate Assessment*, climate change is expected to result in rising sea levels and flooding along the US coastline, more wildfires in the Southwest, increased risk of more intense hurricanes around the Gulf Coast and eastern United States, and more intense precipitation and extreme temperature events (both heat and cold) across the United States (USGCRP, 2018).

In recent years, several extreme winter weather events have tested the reliability and resilience of the power grid. Cold temperatures can impact the power system in various ways, including by freezing pipelines, downing power lines, halting operations at thermal or nuclear power plants, and causing ice accumulation that shuts down operations of wind turbines. Cold weather can also result in disruptions to natural gas supplies for home heating, prompting a switch to space heaters that increase demand for electricity (Litterman, 2019).

The most significant event in recent years was the January 2014 polar vortex that brought extreme cold through a broad area of the middle and eastern parts of the United States. The incident broke peak winter demand records across several regional grids, including MISO, PJM, SPP, ERCOT and NYISO, as well as several utilities in the Southeast. Utilities were the first and primary line of defence, calling upon DR and conservation measures from its customer base, reducing voltage, and increasing power trade across regions. The freezing temperatures led several power plants to go offline, requiring some utilities to institute rotating outages to shed load (at very minor levels). An estimated 50 000 MW of generation capacity was taken offline, compared with average wintertime outages of 33 000 MW (NERC, 2014). A number of coal piles also froze, which limited supplies to coal-fired generators. More significantly, natural gas pipeline constraints led to prioritisation of supplies to home heating rather than for power generation, slashing fuel supply to gas-fired generators, particularly in the Northeast (which is highly dependent on both gas generation and natural gas for heating). Though power systems overall held up relatively well in the face of extreme winter weather, the incident led grid operators to develop new winter performance standards (building upon improvements made after a 2011 cold snap) to better ensure power adequacy in similar future situations (Washington Post, 2019). Such measures include winter preparation site reviews, securing on-site fuel supply, applying for exemptions from emissions limits and updating weatherisation programmes for generators. Since then, grid operators have boosted capacity payments to generation resources for winter preparedness and imposed hefty penalties on plants that cannot deliver on supplies cleared during auctions. Disruption to natural gas supplies during the 2014 polar vortex was a significant justification for the DOE's NOPR to FERC on compensating generators such as coal and nuclear plants that can store 90 days of on-site fuel.

The upgraded defences put in place after the 2014 polar vortex were put to the test in the Northeast during the 2018 Bomb Cyclone. During that event, extreme frigid temperatures combined with an outage at the Pilgrim nuclear plant in Massachusetts meant that the ISO-NE region was forced to rely heavily on dual-fuel generators that could switch to fuel oil as well as to import more electricity from neighbouring New York (Utilitiy Dive, 2018b).

As the Northeast region sees more nuclear retirements and already has limited coal-fired units, dependency on fuel oil for reliability will grow stronger there.

Most recently, a polar vortex front that descended upon the Midwest of the United States in January 2019 prompted extreme freezing temperatures across the region. In anticipation of the event, grid operators PJM and MISO put in place emergency procedures ahead of the event that included directing utilities to insulate pipes and top up backup fuel tanks (Utility Dive, 2019f). Utilities in Minnesota and Michigan issued notices to their customers to turn down thermostats in order to minimise the system load. The DOE's Office of Cybersecurity, Energy Security, and Emergency Response (CESER) as well as NERC also monitored the situation on an ongoing basis in the event it warranted a more extraordinary or national response. Overall, the bulk power system withstood the impacts of the January polar vortex well, with minimal disruptions to supply.

To assist in preparation for extreme weather, NERC publishes reliability guidelines for the bulk power system in anticipation of unusually cold weather. The guidelines outline several focus areas to ensure winter readiness, including safety, management roles and expectations, processes and procedures, evaluation of potential problem areas, testing, training, and communications (NERC, 2017b). In addition, NERC publishes review reports and analysis from major weather events, along with a vast library of reference materials on its website, including training materials and lessons learned (NERC, 2012). Moreover, RSOs and ITOs also publish preparedness guidance and hold workshops for operators in their coverage regions.

Beyond extreme cold, Puerto Rico experienced the longest blackout in US history as a result of Hurricane Maria, a Category 4 hurricane, which made landfall in September 2017. All of the Puerto Rico Electric Power Authority (PREPA) utility's 1 570 000 electricity customers were without power immediately after Hurricane Maria. Most of Puerto Rico's electricity infrastructure was damaged, causing total electricity sales to drop below 0.3 million MWh in October 2017 (compared with 17.3 million MWh in 2016) (EIA, 2018c).

An uptick in the incidence of wildfires is also having lasting impacts on the electricity sector, particularly in the state of California. Given a greater number of wildfires in recent years, California's utilities have put in place response procedures that include activating emergency operations centres and notifying customers in the impacted area of a risk to power supplies. Utilities can also enact a "public safety power shutoff", triggered by high-risk circumstances such as high winds and dry conditions.

California's investor-owned utility Pacific Gas & Electric (PG&E) filed for bankruptcy in January 2019, largely stemming from liabilities incurred due to wildfires in California that were attributed to its equipment. State investigations through 2018 revealed that the utility's electrical equipment triggered several wildfires in California in 2017, prompting PG&E to report an estimated USD 2.5 billion in charges related to the wildfires to federal regulators in June 2018 (Utility Dive, 2019e). California legislators, backed by its governor, passed legislation in July 2018 that limited some wildfire liabilities for utilities in an effort to stem financial losses and help ensure solvency of major utilities. Subsequently, however, the state's deadliest wildfire – Camp Fire in Paradise, California – in November 2018 prompted PG&E to file for Chapter 11 bankruptcy protection to mitigate up to USD 30 billion in liabilities associated with the 2017 and 2018 wildfires (Axios, 2019).

The *Fourth National Climate Assessment* report issued by the federal government estimates that the frequency and duration of wildfires will increase significantly in the coming decades, posing particular risks for Western utilities and power supplies, and requiring increased risk mitigation and response strategies (USGCRP, 2018).

Cyberthreats

There has been significant growth in instrumentation and automation at the level of the high-voltage, or bulk power, system. This allows the electricity system to operate more efficiently and provides system operators with much better situational awareness; this can improve grid reliability and resilience in the face of outages, but the added complexity can also introduce cybersecurity vulnerabilities.

As a result, the Energy Independence and Security Act of 2007 directed FERC and the National Institute of Standards and Technology to develop smart grid standards based on concerns about cyberattacks stemming from the growth of smart grids.

The vulnerability of the US power grid to cyberattacks has gained more salience following evidence of a targeted cyberattack by Russia that began in March 2016 using third-party vendors to infiltrate the US electricity system. Moreover, a core rationale for the DOE push to value coal and nuclear capacity based on their fuel security attributes was the risk of cyberattacks on natural gas pipelines that could result in supply disruptions to gas generators. As the electricity system moves towards more digitalisation, the threats of cyberattacks will become even more pronounced.

In response to the May 2017 White House Cybersecurity Executive Order, the Department of Homeland Security and the DOE released an assessment of cyber-risks to the US electricity system. The report, which is a first step led by the DHS and DOE to manage cyber-risks, identified six gaps in the nation's capabilities to prevent and respond to cyberattacks: 1) cyber-situational awareness and incident impact analysis; 2) roles and responsibilities under cyber-response frameworks; 3) cybersecurity integration into state energy assurance planning; 4) electricity cybersecurity workforce and expertise; 5) supply chain and trusted partners; and 6) public-private cybersecurity information sharing.

FERC is tasked with developing cybersecurity standards for the bulk electricity system, while the Department of Homeland Security's Transportation Safety Administration is tasked with overseeing threats, including from cyberattacks, to the nation's pipelines. Under FERC's direction, NERC developed CIP cybersecurity reliability standards that went into effect in 2008. In 2018, FERC further directed NERC though Order 848 to develop modifications to the CIP reliability standards to update reporting of cyber-incidents, moving beyond just a requirement to report incidents that have compromised reliability to those that could pose a future threat to the system.

Emergency response

In the United States, government agencies at all levels and across multiple disciplines are involved in emergency response efforts. Primarily, in most emergencies, the federal government's role is centred on co-ordination and communication among the various stakeholders.

Electric utilities, in this regard, play a crucial role, as they are responsible for repairing damage to infrastructure and restoring services to customers (EEI, 2016). Power providers conduct year-round planning and preparation, including exercises and drills, for various types of emergencies, including weather and cyber- and physical attacks on infrastructure.

However, in severe emergencies, the government also provides logistical support, including equipment, skilled repair staff, damage assessment expertise and security forces. The most extreme type of event is classified as a National Response Event, which can be either a natural (such as a hurricane or earthquake) or human-caused disaster (such as an act of war or terrorist attack), and requires a multiregional response that is led by the federal government (DOE, 2019).

The United States has a sophisticated threat assessment network that gathers and disseminates information to relevant stakeholders even before an event takes place. Government agencies that participate in this type of risk assessment include the National Weather Service, the US Army Corps of Engineers, the US Department of Homeland Security and the DOE. Industry organisations such as Edison Electric Institute, the American Public Power Association and the National Association of Regulatory Utility Commissioners also help share information.

Power providers are responsible for reporting significant events to the DOE, NERC and their respective regional organisations. The DOE requires utilities that serve as balancing authorities or ISOs/RTOs to report incidents. ISOs/RTOs, balancing authorities and generators also need to file incident reports to NERC (California ISO, 2018).

During and after an emergency incident, power companies take the lead in restoring services to customers, often prioritising service to critical emergency facilities such as hospitals before restoring wider service. It is standard practice in the United States for utilities to provide aid and assistance to one another during emergencies, in a process known as mutual assistance (NARUC, 2015). In this capacity, utilities can share emergency response personnel and services, thereby saving costs. Should a larger-impact incident require a broader co-ordination effort, the power system relies on regional mutual assistance groups (RMAGs). Though state public utility commissions are not responsible for emergency response, they do oversee utilities' cost recovery mechanisms and their approval is, therefore, required to activate mutual assistance.

In September 2014, FERC and NERC, along with the eight regional reliability entities, undertook a joint review to assess the restoration and recovery plans of the regional entities after a blackout or major outage (NERC, 2017a). Those policies include restoration plans approved by reliability co-ordinators, procedures for deploying black-start resources, steady state and dynamic simulations testing the effectiveness of the plans, and cybersecurity incident response and recovery plans for critical cyber-assets. The report's overall estimation was that the entities' plans are sufficiently detailed and thorough. Periodic assessments to reflect changing conditions in the energy and electricity space will ensure appropriate changes to response policies over time.

The DOE role

The US government conducts emergency responses based on the National Response Framework, which identifies various Emergency Support Functions (DOE, 2018). The DOE is designated as the lead department co-ordinating efforts for the energy sector under this construct, which is primarily tasked with maintaining and restoring energy supplies in the event of a national emergency. In this capacity, the DOE must facilitate the restoration of energy services in cases where a federal response is required, collect and disseminate information on damages and impacts, provide information on restoration efforts and progress, facilitate restoration of energy services through emergency responder services, and provide technical support to utilities and other companies to restore services.

In 2018, the Office of Electricity Delivery and Energy Reliability was split into two offices: the Office of Electricity and CESER. The DOE co-ordinates emergency response for the energy sector through the Infrastructure Security and Energy Restoration (ISER) division of CESER, which was established in 2018. Types of emergency events include hurricanes, wildfires, earthquakes and typhoons. The rationale for the creation of CESER was to improve energy infrastructure security, address national security threats, and enable stronger and more effective preparedness and responses to natural and human-caused threats. For fiscal year 2019, the federal budget allocated USD 156 million to the Office of Electricity and USD 120 million to CESER, of which USD 90 million is dedicated to cybersecurity.

ISER prepares staffing plans and emergency response ahead of an expected natural disaster by deploying responders to state emergency operations centres in at-risk regions as well as the Federal Emergency Management Agency (FEMA) Regional Response Coordination Center in the affected areas. ISER continues to monitor the situation from its headquarters and remains in close co-ordination and communication with various official and industry representatives at the state and local levels. Following an incident, ISER experts are on hand in the impacted area to provide subject matter expertise and advice to help restore system capabilities. In this capacity, ISER holds daily calls with companies in the electricity (and oil and gas) sector, as well as offers twice-daily situation reports and analysis to the energy sector. In cases where the recovery efforts take longer, ISER works with local utilities, FEMA and the US Army Corps of Engineers to identify temporary power supply options, especially for first responders. Pursuant to an emergency response, ISER also conducts a review of its procedures in order to improve upon its capabilities and expertise.

Assessment

Bulk power markets

The United States has experienced and managed significant changes to its electricity generation mix since the last IEA review in 2014. Since then, according to the EIA October 2018 “Monthly Electric Generator Inventory”, approximately 75 GW of electricity generation capacity retired, predominantly coal-fired, followed by gas- and oil-fired generation. In the same period, approximately 92 GW of new generation was added, largely natural gas and renewables. This occurred all under a period of relatively flat electricity demand and resulted in a decrease in carbon intensity. The EIA *Annual Energy Outlook 2019* projects this trend to continue with more gas-fired and renewables units coming online in the coming decade.

The United States has a complex electricity system with a mix of competitive markets, bilateral markets, and private and publicly owned assets. A majority of the country’s power system operates under federally regulated regional competitive bulk markets. Competition in these markets has fostered the introduction of innovative new technologies and business models. Regulatory authority over bulk power markets rests with the FERC. Within this market structure, electricity market innovation includes participation of demand response aggregators in capacity markets and the creation and expansion of energy imbalance markets. NERC plays an important role in developing standards to ensure reliable system operation.

To develop new market rules, FERC uses a spectrum of robust and transparent proceedings to capture the views of market participants. To establish market rules and regulations, FERC uses a prescribed process that respects commercially sensitive information. FERC also has the ability to provide guidance and regulatory certainty by issuing policy statements that allow for a holistic discussion on relevant market issues.

Individual states influence their respective energy generation mix through different policy mechanisms, such as rate base approval for adding new generation or distribution systems, RPS, or ZEC programmes. State RPS policies are not static and evolve over time. Within a given FERC-regulated ISO or RTO area, there can be states with different RPS levels. As individual states change their respective RPS targets or ZEC programmes, there is potential for misalignment between state energy goals and ISO/RTO market price formation rules.

FERC continues to respond to the needs of evolving competitive electricity markets to ensure efficient and reliable markets. Evidence of this includes, but is not limited to, Order 841 to facilitate the participation of electric storage resources in RTO/ISO markets; Order 842 to address the potential reliability impact of an evolving generation resource mix; and Order 848 to augment the mandatory reporting of cybersecurity incidents. On occasion, FERC and an RTO/ISO can disagree on measures to boost reliability in the face of changes to power systems. A recent example is a 2018 decision by FERC to reject two proposed options by PJM on capacity market reform, which will require PJM to offer alternative options. This is a good illustration of the potential challenge confronting regional system operators as they try to ensure the operation of competitive bulk electricity markets amid ambitious state-driven clean energy policy goals.

The ongoing and forthcoming changes to US power markets – especially the growth of renewables generation and the need to pay for cyber- and physical security mitigation measures – will also require upgrading and expanding the nation's ageing transmission networks. To this end, FERC issued Order No 1000 in 2011 to support cost-effective regional transmission planning. Some observers have suggested that FERC should consider whether modifications to Order No 1000 are merited, but the commission has not indicated its intentions.

Recent court rulings and federal regulatory decisions provide more jurisdictional clarity on issues relating to electricity markets. Recent rulings in the federal courts affirm state jurisdiction to support clean energy generation sources. The decision by the US Court of Appeals for the 7th Circuit supported the Illinois ZEC programme. The US Court of Appeals for the 2nd Circuit supported New York's ZEC programme. The court rulings provide more clarity to state and regional market participants to inform their respective investment decisions.

In September 2017, the Secretary of Energy proposed that FERC set a rule for "fuel secure" generation, including coal and nuclear (NOPR for the Grid Resiliency Pricing Rule). FERC rejected DOE's request but opened a docket to explore bulk power resilience and to understand how each RTO and ISO assesses resilience in its geographic area to evaluate the need for modification. The DOE is exploring options to address grid vulnerabilities, including those potentially posed by increased reliance on natural gas generation.

Electricity reliability

Amid low gas prices and renewables growth, combined with flat electricity demand, a period of "lower for longer" power prices might discourage new investments in a variety of generation capacity. In particular, coal and nuclear power – which have traditionally been reliable sources of baseload generation – are falling as a share of the fuel mix. Resource diversity is an important component of reliability. As continuous large retirements of coal and nuclear are expected over the coming decades, replacement with renewables will need to be further complemented with additional technologies, such as storage or gas peakers, in order to fully compensate for baseload retirements and address reliability concerns.

While recent (2016, 2017) reliability assessments of regional electric co-ordinators have identified sufficient capacity, a recent high-impact weather event (Bomb Cyclone of 2017) tested the limits of the resiliency of the integrated electric and gas energy system. The importance of the gas system to ensure reliable operation of the electricity grid highlighted a need for having a more holistic understanding of energy system vulnerability, including through modelling efforts such as the North American Energy Resilience Model (NAERM). The DOE Office of Electricity is currently undertaking a plan to develop the NAERM, which will provide planning and contingency analysis to identify threats and address vulnerabilities in the North American energy system.

Recommendations

The US government should:

- Based on the completion of the FERC review of bulk power resilience, ensure that standards and market rules are upgraded in a timely fashion to respond to changes in the power system.
- Initiate a FERC-governed generic policy statement proceeding to inform price formation rules that can ensure compatibility of state subsidies with competitive bulk electric market operations.
- Prioritise ongoing efforts at the DOE to identify and inform respective energy utilities and utility market operators of vulnerabilities that pose reliability and resilience threats to the North American bulk power system, including Canada and Mexico.
- Reassess the efficacy of existing regulatory structures for regional transmission planning in light of forthcoming requirements to upgrade the nation's ageing infrastructure.
- Promote regulatory innovation in the work of FERC to address emerging challenges with the introduction of new energy technologies and business models (energy efficiency, demand response, distributed generation, storage and others).

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10. Nuclear

Key data

(2018 provisional)

Number of reactors: 98 reactors

Installed capacity (2017): 99.6 GW

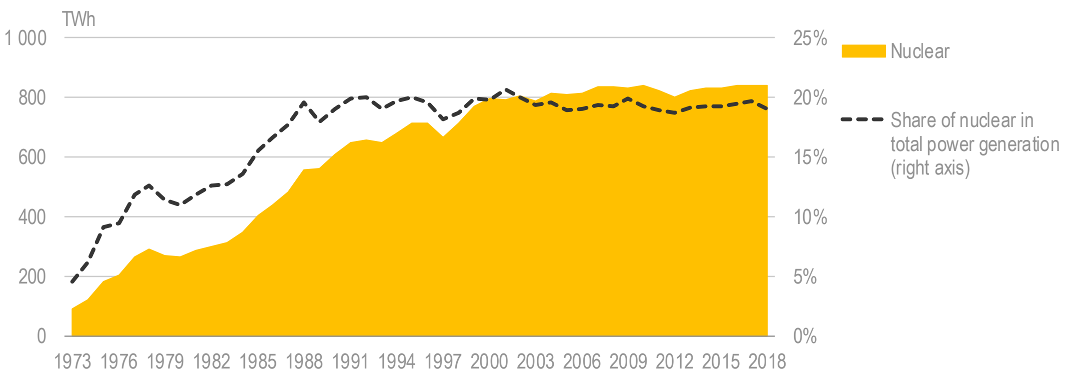
Electricity generation: 841.3 TWh

Share of nuclear: 20% share of electricity generation in the US (53% of low-carbon electricity generation)

Overview

The United States (US) is the world's largest producer of nuclear power, with nearly a third of global nuclear electricity generation. Nuclear accounts for a fifth of electricity generation in the US, which makes it the largest source of low-carbon electricity in the country. The US nuclear fleet consists of 59 commercially operating nuclear power plants (NPPs) in 30 states, with 98 light water reactor (LWR) units (65 pressurised water reactors [PWRs] and 33 boiling water reactors). These were mostly built between 1967 and 1990. US NPPs are characterised by very high capacity factors (92.2% in 2017 compared with 50% in the early 1970s and 70% in the 1990s). Electricity production from nuclear grew rapidly from the 1970s to the late 1990s, and has since been relatively stable at around 800 terawatt hours (TWh) per year (Figure 10.1).

Figure 10.1 Nuclear power generation, 1973-2018



Nuclear power increased rapidly in the 1970s-90s, but has in the past two decades remained relatively constant at around 800 TWh/year.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

In recent years, and even immediately following the Fukushima Daiichi accident in Japan in March 2011, a majority of American people have supported nuclear energy. A recent Gallup opinion poll from March 2019 suggests that the US public is now evenly divided, with the reduced support possibly linked to the perception that nuclear energy's cost-competitiveness is challenged by other technologies, including cheap natural gas as well as wind and solar power (Reinhart, 2019).

Over the past six years, several reactors have shut down for economic reasons, before reaching the end of their operation licences. As the share of other energy sources – notably natural gas and renewables – continues to increase, that of nuclear power is likely to decline, which might have an impact on the resilience and stability of the US electricity system. The electricity market regulator in the United States is currently assessing how to value resilience. In parallel, some states are introducing measures to help nuclear generators stay in the market by valuing their contribution to low-carbon electricity generation.

The nuclear sector provides about half a million jobs (according to the Nuclear Energy Institute), and the administration is reviewing the country's nuclear energy policy to revive and expand the sector, including by streamlining regulatory processes and promoting innovation, and by supporting the completion of the Vogtle new-build project. For nuclear power to remain an important source of electricity in the United States, both technological and market/policy developments are needed. Small modular reactors (SMRs) and other advanced nuclear systems that can integrate better with variable renewable energy sources can provide new opportunities. Finally, the United States needs to develop a system for safe disposal and long-term storage of nuclear waste.

Institutional oversight and regulation

The Nuclear Regulatory Commission

The Nuclear Regulatory Commission (NRC) is responsible for regulating the nuclear industry and is in charge of reactor safety oversight, reactor licence renewal for existing plants, materials safety oversight and materials licensing for a variety of purposes, as well as waste management of both high-level waste and low-level waste. It also evaluates applications for new plants, including the licensing of advanced reactors such as SMRs. The NRC was established as an independent regulator in 1974, and is headed by five commissioners appointed by the president and confirmed by the Senate for five-year mandates, one of whom is designated by the president to be the chairperson of the NRC.

The NRC receives its funding from Congress on a yearly basis. However, it is required by law to recover approximately 90% of its annual budget from the applicants for NRC licences, in particular the utilities that operate the country's 98 reactors. Collected money is then given back to the US Treasury. The two main laws that govern the NRC's fee recovery are the Independent Offices Appropriation Act of 1952 and the Omnibus Reconciliation Act of 1990, as amended.

The NRC licenses NPPs for an initial term of 40 years. Currently operating NPPs have been licensed under a two-step process described in Title 10 of the Code of Federal

Regulations (10 CFR) under Part 50. This process requires both a construction permit and an operating licence. Over a plant's lifetime, safety is ensured through maintenance of the plant and its unique licensing basis. A plant's licensing basis is a specific set of evolving requirements and commitments. Over time, as technology advances and operating experience provides new information, a plant's licensing basis may change – for example, when the NRC issues new requirements and the plant has to make modifications.

Since the start of the nuclear industry in the United States, a total of 102 reactors have received licences and been built. The vast majority of the nuclear fleet is located in eastern and Midwestern states.

Following the Fukushima Daiichi accident, the NRC issued new requirements including: adding capabilities to maintain key safety functions following a large-scale natural disaster; updating evaluations on the potential impact from seismic and flooding events; new equipment to better handle potential core damage events; and strengthening emergency preparedness capabilities.

Licences may be renewed for periods of up to 20 years, with no limit on the number of renewals. The first licence renewal application (for a total of 60 years) was approved in March 2000. Today, 90 out of the country's 98 units have received a licence renewal. An additional four units were also granted a licence renewal but have been prematurely shut down.

Some operators have already applied for a second licence renewal, which the NRC calls "subsequent license renewal" (SLR). The NRC is currently reviewing six applications to operate for a total of 80 years, and a further two are expected by 2020 (see Table 10.1).

Table 10.1 Status of SLR (80 years of operation)

Units (states)	Status of SLR
Turkey Point Units 3 and 4 (Florida)	Application received January 2018
Peach Bottom Units 2 and 3 (Pennsylvania)	Application received July 2018
Surry Units 1 and 2 (Virginia)	Application received October 2018
North Anna Units 1 and 2 (Virginia)	Application expected 2020

Source: US NRC (2019).

The NRC is also reviewing applications to build new reactors. In an effort to improve regulatory efficiency and add greater predictability to the process, the NRC in 1989 established alternative licensing processes in 10 CFR Part 52 that included a combined licence (COL). This process combines a construction permit and an operating licence with conditions for plant operation. Other licensing options under Part 52 include early site permits that allow an applicant to obtain approval for a reactor site without specifying the design of the reactor(s) that could be built there, and certified standard plant designs, which can be used as pre-approved designs.

In either process, NRC approval is necessary before an NPP can be built and operated.

In recent years, many utilities that had applied for COLs withdrew their applications: nine applications to build EPRs, AP1000 reactors or Economic Simplified Boiling Water Reactors (ESBWRs) were withdrawn. Fourteen COLs were issued, essentially to build AP1000 reactors, though today, only two new reactors are under construction in the

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United States (at the Vogtle plant in Georgia). Among the new reactor designs to be certified, most of which are large LWR designs, the NRC is currently reviewing the design of the SMR NuScale, which is a LWR. A NuScale power plant can contain up to 12 individual units of 60 megawatts (MW), representing a total capacity of 720 MW. Design certification for NuScale is expected in 2020.

The Department of Energy

The mission of the Department of Energy's (DOE's) Office of Nuclear Energy is to advance nuclear power to meet the nation's energy, environmental and national security needs, specifically by working on the following objectives: enhancing the long-term viability and competitiveness of the existing US reactor fleet; developing an advanced reactor pipeline; and implementing and maintaining national strategic fuel cycle and supply chain infrastructures (DOE, 2019).

The US administration is particularly concerned about the situation of the nuclear sector, based on the following issues:

- For the existing fleet, nuclear utilities – especially those operating in liberalised markets – see the competitiveness of nuclear generation challenged by low-cost natural gas prices as well as generation from renewables. This has led several operators to prematurely shut down some plants. Others are seeking support to more adequately value the contribution of nuclear power to low-carbon, resilient electricity supply.
- New-build projects V.C. Summer and Vogtle (two Westinghouse AP1000 reactors planned on each site) faced cost overruns and delays, due in part to supply chain and project management issues. Westinghouse's bankruptcy filing in 2017 caused additional complications. The company's troubles cost then-parent firm Toshiba close to USD 5 billion in losses, while the uncertainty forced South Carolina utilities Santee Cooper and South Carolina Electric & Gas to abandon construction of two reactors at the V.C. Summer plant in July 2017. The Vogtle project is currently the only new reactor construction project in the United States.
- The US nuclear industry is looking to rebuild its leadership in terms of new build projects and exports. While four AP1000s were successfully built in the People's Republic of China in Sanmen and Haiyang (benefiting from that country's experienced workforce), no other project involving US reactor design has been launched in recent years. In the meantime, Russian Federation, Chinese, and to a lesser extent, Korean companies have successfully built reactors both domestically and in foreign markets.

To address the threat of early retirements within the current fleet, the US administration has explored several avenues to recognise the contribution that nuclear energy makes to the country's security of supply and low-carbon power generation. In particular, the administration has been keen to value nuclear's contribution to resilience, and potential measures are being reviewed by various regulatory organisations.

To support the new-build project at Vogtle, the US administration has provided loan guarantees as well as production tax credits similar to those granted to renewable generation projects. The administration is also actively seeking export markets for US technology, in particular in India, Poland and Saudi Arabia.

To regain US leadership, the administration has taken a number of measures to support the nuclear industry, innovation and education. Accelerating the launch of the first SMR projects, and in particular the NuScale project, has been at the forefront of DOE's efforts. These include research, supporting the preparation of the licence application through the SMR Licensing Technical Support Program and the site selection process. As the regulator, the NRC is in charge of evaluating and certifying the designs.

More details on the measures taken by the DOE are described below.

Operational fleet

The US nuclear fleet has reached extremely high capacity factors (over 92% in recent years). Average nuclear generation costs have come down from USD 40 per megawatt-hour (MWh) in 2012 to USD 34/MWh in 2017 through gains in power plant utilisation, as well as refuelling and more efficient maintenance procedures (IAEA, 2019). Capital expenditures on the existing fleet peaked in 2012 when post-Fukushima safety measures were implemented, and have since fallen to about USD 6 billion per year.

Utilities have been taking action to reduce operational costs, in particular through the Electric Power Research Institute, to optimise maintenance, reduce the use of critical components, develop standardised performance indicators and implement various digital innovations. According to Electric Utility Cost Group data, the average generation costs of the US nuclear fleet, which were around USD 29 per kilowatt-hour (kWh) (2017 dollars) in 2002, rose to USD 41.35/kWh in 2012 and through cost-reduction measures, came down to USD 33.50/kWh in 2017.

Of the 99 gigawatts (GW) of net installed capacity, 54 GW are in vertically integrated markets and 45 GW in liberalised markets, where electricity is sold competitively on a short-term basis and priced according to short-run marginal costs.

In unregulated markets, the US nuclear fleet faces two main challenges: competition from cheap shale gas and subsidised wind power (which in 2016 received a federal production tax credit of USD 23/MWh). Coupled with priority dispatch of wind power on the grid, these conditions have made it particularly difficult for merchant fleet operators to be sufficiently profitable. With falling costs, renewables are also able to compete without subsidies in certain regions. The existence of capacity mechanisms and payments (in some markets) is, to a certain extent, able to offset some of these effects. The ability for nuclear operators to clear capacity auctions and guarantee capacity payments is, therefore, of high importance.

In recent years, several plants have shut down before the end of their operating licences (premature shutdown). Some plants shut down due to excessive costs for repair or refurbishment, or for meeting new environmental policy requirements (for example, related to cooling technologies). For most plants, however, the decisive factor was the economics of the plants in their respective electricity markets (Table 10.2).

In the absence of any carbon pricing policy at the federal level, some states have put in place specific measures to value and recognise the low-carbon electricity generation from NPPs.

Valuing low-carbon generation

States such as New York, Illinois and New Jersey have put in place zero-emissions credit (ZEC) programmes in an effort to secure the long-term operation of NPPs.

- The New York Department of Public Services developed a ZEC programme that is providing subsidies of USD 17.54/MWh, a little lower than the 2016 federal production tax credits for wind (USD 23/MWh). The ZEC programme benefits the Fitzpatrick, Ginna and Nine Mile Point NPPs (total 3.4 GW). It was claimed that this programme would lead to economic and environmental benefits of USD 5 billion, which far outweighs the total subsidies (USD 1 billion).
- Illinois' ZEC to support the Quad Cities and Clinton NPPs (2.8 GW) provides subsidies of USD 16.5/MWh to the two plants. A legal challenge to the Illinois and New York ZECs was not successful; in April 2019, the Supreme Court refused to hear an appeal by power companies.
- New Jersey in early 2019 passed legislation to create a ZEC programme, which could provide relief to the Hope Creek and Salem NPPs (with a subsidy of around USD 10/MWh).

Ohio is looking at introducing a bill establishing a similar ZEC programme to support the NPPs in its state (Davis-Besse and Perry). The proposal would create a "clean air fund" of USD 300 million annually, USD 180 million of which would subsidise the two NPPs. Pennsylvania is also looking to set up a ZEC-like subsidy system; failure to do so is expected to lead to the early closure of several NPPs in the state, in particular Three Mile Island unit 1, which is reported to have operated at a loss for several years. Connecticut passed legislation to support the state's Millstone NPP, which is the largest in New England and provides half of the state's electricity and nearly all of its low-carbon electricity. In Connecticut, the utility Dominion – operator of Millstone – won a bid for zero-carbon energy in December 2018 from the state's Department of Energy and Environmental Protection. The governor announced in April that this deal, which is still awaiting approval by the state's Public Utilities Regulatory Authority, should keep Millstone generating for at least another decade. Table 10.3 lists nuclear power plants that were saved by state policy measures.

Valuing resilience

To help maintain the existing nuclear fleet, the US administration has focused its attention on finding ways to value the contribution that nuclear energy makes to security of supply and resilience. Several extreme weather events (in particular polar vortex situations) have demonstrated the resilience of NPPs in maintaining power generation, compared with fossil fuel generation. Natural gas-fired power generation depends on continuous gas supply through pipelines, which is also needed to meet heating demand. Discussions are ongoing at several levels of government, within the DOE as well as with the Federal Energy Regulatory Commission (FERC), to improve electricity market designs and capacity markets to value this contribution. The DOE in 2017 proposed rule making on grid resilience and reliability, which would have recognised the attributes of generation technologies that can have on-site fuel storage (such as nuclear and coal). FERC instead directed the regional transmission organisations and the independent system operators to assess the resilience of the electricity grid and to make recommendations on how to improve it. Another proposal that was circulated in 2018 would see the DOE use authority under existing laws (the Federal Power Act and the Defense Production Act) to delay early retirements of power plants by directing system operators to purchase electricity or generation capacities from a list of strategic plants. In August 2018, FERC worked with the Department of Defense (DOD), the DOE and the National Security Council to identify a list of power plants that are critical to the nation's power system, in particular to ensure security of supply to military bases, hospitals and other critical infrastructure.

PJM, the country's largest grid operator, indicated that potential market intervention that would require customers to buy electricity from designated plants would be damaging to competitive power markets and costly. It further stated that early closures of NPPs in Ohio and Pennsylvania would not threaten the reliability of the grid.

Table 10.2 Premature shutdowns and planned shutdowns

Units (MW net)	State	Date of shutdown	Reason
Crystal River 3 (860 MW)	Florida	February 2013	Cost of repair to containment following damage during retrofitting
Kewaunee (566 MW)	Wisconsin	May 2013	Economic reasons
San Onofre Units 1 and 2 (1 070 MW and 1 080 MW)	California	June 2013	Regulatory uncertainty following retrofitting of ill-functioning steam generators
Vermont Yankee (612 MW)	Vermont	December 2014	Economic reasons
Fort Calhoun (478 MW)	Nebraska	October 2016	Economic reasons
Oyster Creek (608 MW)	New Jersey	Sept 2018	Economic reasons/policy
Total net capacity retired (end 2018): 5 274 MW			
Pilgrim (677 MW)	Massachusetts	*Planned 2019*	Economic reasons
Three Mile Island 1 (819 MW)	Pennsylvania	*Planned 2019*	Economic reasons
Davis-Besse (894 MW)	Ohio	*Planned 2020*	Economic reasons
Duane Arnold (601 MW)	Indiana	*Planned 2020*	Economic reasons
Indian Point 2 and 3 (2 028 MW)	New York	*Planned 2020, 2021*	Economic/policy reasons
Perry (1 240 MW)	Ohio	*Planned 2021*	Economic reasons
Beaver Valley 1 and 2 (1 813 MW)	Pennsylvania	*Planned 2021*	Economic reasons
Palisades (805 MW)	Michigan	*Planned 2022*	Economic reasons
Diablo Canyon (2 256 MW)	California	*Planned 2024, 2025*	Policy reasons
Additional net capacity that could be retired: 11 133 MW			

Source: NEI (2019a), *Nuclear by the Numbers*.

Table 10.3 Plants that have benefited from state policies

Units (MW net)	State	Projected closure date	Reason for potential closure
Clinton (1 065 MW)	Illinois	2017	Market
Fitzpatrick (852 MW)	New York	2017	Market
Ginna (582 MW)	New York	2017	Market
Hope Creek (1 172 MW)	New Jersey	2020	Market
Millstone 2 and 3 (2 096 MW)	Connecticut	2020	Market
Nine Mile Point 2 and 3 (1 770 MW)	New York	2017-18	Market
Quad Cities 1 and 2 (1 819 MW)	Illinois	2018	Market
Salem 1 and 2 (2 328 MW)	New Jersey	2020-21	Market
Total capacity saved from premature closure: 11 683 MW			

Source: NEI (2019a), *Nuclear by the Numbers*, www.nei.org/CorporateSite/media/filefolder/resources/fact-sheets/nuclear-by-the-numbers.pdf.

New builds

With the liberalisation of wholesale electricity markets in the 1990s, financing of capital-intensive power projects such as NPP has become difficult. New-build projects in the United States have advanced only in regulated electricity markets, where it is possible to pass on construction costs to consumers through taxes.

In spite of several applications to construct new reactors in the United States, only two projects – V.C. Summer and Vogtle – moved forward in the last decade, the first new construction for over 30 years.[1]

V.C. Summer

In March 2008, South Carolina Electric & Gas, a subsidiary of the South Carolina regulated utility SCANA, applied for a COL for the construction of two Westinghouse AP1000 units at its V.C. Summer site. The same year, an engineering, procurement and construction (EPC) contract was signed with Westinghouse. Costs at the time were estimated at approximately USD 10 billion for the two units. The COL was granted in 2012, and construction started in March 2013, the first new construction in 30 years in the United States. Grid connection was expected in 2017 (first unit) and 2018 (second unit). The project encountered many fabrication, construction and regulatory delays, pushing up costs to an estimated USD 16 billion. In March 2017, Westinghouse filed for Chapter 11 bankruptcy. Soon after, SCANA reconsidered its options and decided to abandon the project and stop construction, after spending USD 9 billion.

Vogtle

The Vogtle 3 and 4 project is the only NPP currently under construction in the United States. The project to build two AP1000 reactors at the Vogtle site started in April 2008 with Georgia Power's signing of an EPC contract with Westinghouse. Long lead components (heavy forgings such as pressure vessels and steam generators) were

[1] Watts Bar 2, a Generation II PWR whose construction commenced in 1973, did come online in 2016. Construction was suspended for many years, and resumed in 2007, when the operator, Tennessee Valley Authority, decided to complete construction.

ordered from Doosan in Korea. The COL was issued by the NRC in February 2012, and construction started in March 2013. Like V.C. Summer, the project experienced delays and cost escalations, and a change of project management after the demise of Westinghouse. Unit 3 is expected to enter operation in 2021, and unit 4 a year later.

In total, the DOE will have provided USD 12 billion in loan guarantees for the project. The Secretary of Energy confirmed in March 2019 that supporting the Vogtle project was critically important to ensure the revitalisation of the US nuclear industry, especially helping to rebuild a nuclear workforce and supply chain.

In addition to loan guarantees, the Vogtle project is benefiting from production tax credits (PTCs). Under the Energy Policy Act of 2005, up to 6 000 MW of new nuclear power was eligible for PTCs, provided commercial operation started by 2021. Congress voted to extend the measure in 2018, which was critical for the Vogtle project given the construction delays. The PTC is set at USD 0.018/kWh, for a duration of eight years, with a maximum annual payment of USD 125 million for each 1 000 MW of new nuclear capacity.

SMRs and other advanced reactors

SMRs have received significant attention in recent years, and the United States has been at the forefront of the SMR technology push. There are basically two types of SMRs, LWR and non-LWR based. Those based on LWR technology, a well-known technology, make up most of the world's nuclear fleet. It is also the same technology that powers nuclear propulsion vessels (submarines and aircraft carriers). LWR-based SMRs are often derived from the design of those propulsion reactors, with compact integrated designs. Another class of SMRs are those based on non-LWR technology, i.e. where the coolant is either liquid metal (sodium, lead), molten salts or gas (helium in most cases). Many of the latter technologies are similar to those of the Generation IV reactors, a class of nuclear reactor technology that has been under development for the past two decades. Commercial deployment of Generation IV reactors and non-LWR-based SMRs is not expected before the 2030-40 period at the earliest. LWR-based SMRs, on the other hand, are expected to be deployed in the next decade.

Promoters of SMRs advocate that modular designs, with factory assembly and production of a large number of identical designs, could prove more cost-effective than large-scale LWRs, which benefit from economies of scale. In addition, design features of SMRs such as passive safety, reduced number of operators, and a smaller emergency planning zone around the NPP could further increase the competitiveness of such reactors, and the possibility of siting SMRs (for example, on sites that currently have coal-fired power plants). There is also the belief that SMRs can provide enhanced flexibility and resilience to the grid compared with larger reactors. This needs to be clearly evaluated: while LWRs in the United States have traditionally operated only as baseload generation, utilities have started implementing "flexible operation" for large LWRs to address the challenge of integrating large shares of variable renewables (wind, solar). In other countries (France, Germany), large NPPs have been load-following for decades. Modular reactors such as SMRs could provide increased flexibility with the ability to switch modules on and off. In terms of resilience, large NPPs have demonstrated their resilience in extreme weather conditions such as polar vortexes. But at the same time, intense heat and drought can challenge the operation of large NPPs, which require large quantities of water for cooling. SMRs by their reduced size would have fewer cooling requirements.

A few LWR-based SMR designs are currently under construction in the world – the Russian KLT-40s design for a floating NPP, and the Argentinian CAREM design). But the design that has received the most attention is the US NuScale reactor design, a genuinely modular concept currently under design certification review by the NRC. There are two projects in the United States that could see the construction of NuScale SMRs in the next decade.

Utah Associated Municipal Power Systems (UAMPS), which provides wholesale electricity, transmission and other energy services, on a non-profit basis, to its members (which include 52 public power utilities throughout Utah, Arizona, California, Idaho, Nevada, New Mexico and Oregon), launched the Carbon Free Power Project in 2015. As part of the project, UAMPS plans the development of a 12-module NuScale power plant at a site at the Idaho National Laboratory (INL). In December 2018, the DOE signed a memorandum of understanding with UAMPS and INL's operator, Battelle Energy Alliance, for the use of 2 of the 12 modules. One of them will be dedicated to research on hybrid energy systems and the integration of nuclear energy with renewables; the other will be used for electricity generation, which INL will buy through a power purchase agreement.

In a separate project, Tennessee Valley Authority, a federally owned corporation that provides electricity generation to the Tennessee Valley region, is continuing its plans to site an SMR on its Clinch River Valley site, and is currently looking at the NuScale design. In April 2019, the NRC issued an early site permit for the site, where two or more SMRs could be built.

In addition to the NuScale SMR, other vendors are working on other LWR-based designs, including GE-Hitachi's 300 MW SMR, based on its large-scale ESBWR reactor design, and a 160 MW SMR developed by Holtec.

In terms of non-LWR SMRs and other advanced reactors, there are also active developments by several companies to develop sodium-cooled, gas-cooled or molten salt-cooled advanced reactors. Terrapower (sodium-cooled and molten-salt cooled designs), X-Energy (gas-cooled modular reactor) and others, which are also actively involved in design evaluation processes in Canada, are active in this space.

Besides producing electricity, SMRs and advanced reactors can also provide non-electric products such as district heating or desalination, and for non-LWR SMRs that have higher operating temperatures, process steam, hydrogen production and energy (heat) storage. This can potentially facilitate the integration of advanced reactors in future low-carbon systems with large shares of renewables, with nuclear reactors producing electricity and heat depending on market conditions.

Finally, another class of SMRs that is receiving attention in the Unites States is the micro-reactor (1 MW to 10 MW). Micro-reactors are being considered as possible sources of electricity for military bases or critical infrastructure and remote/island communities, to address security of supply and cybersecurity concerns. Their development is supported by both the DOE and the DOD.

Nuclear fuel cycle

Interim storage and the Yucca Mountain repository

The United States has over 90 000 metric tonnes of nuclear waste that requires disposal. Most of this waste – 80 000 metric tonnes – consists of used fuel from the commercial nuclear fleet (US GAO, 2019). This spent nuclear fuel is enough to fill a football field about 20 metres deep. The rest, about 14 000 metric tonnes, comes from the US government's nuclear weapons programme and includes high-level waste from chemical reprocessing of spent fuel. For the most part, all of this waste is stored where it was generated, at 80 sites in 35 states.

Providing nuclear utilities with a final repository for high-level waste (spent fuel from NPPs) is a federal responsibility under the Nuclear Waste Policy Act of 1982. This Act created a tax on electricity generated by NPPs, which has accumulated into a Nuclear Waste Fund (which has a balance of more than USD 40 billion) to build a deep geological repository (DGR) (DOE, 2018). There is a wide consensus among world experts that DGRs are the most appropriate solution to dispose of nuclear waste safely and with no impacts on the environment. DGRs are being constructed or at advanced planning stages in countries such as Finland, Sweden and France. However, there is still no disposal site in the United States. The NRC received an application from the DOE on 3 June 2008, for a licence to construct the nation's first geologic repository for high-level nuclear waste at Yucca Mountain, Nevada. In 2010, the DOE filed a request to withdraw the application, which was denied. The NRC continued to review the application but with little funding available. The DC Circuit Court of Appeals in August 2013 ordered the NRC to resume its review using existing funds from previous appropriations. The NRC completed the five-volume *Safety Evaluation Report* in January 2015, and also developed and published a supplement to the DOE *Environmental Impact Statement*, and conducted additional knowledge management activities to preserve information developed during its initial review.

Failure to provide utilities a DGR to dispose of spent nuclear fuel by the 1998 deadline set in the Nuclear Waste Policy Act is costing the administration (and US taxpayers) nearly USD 800 million per year to compensate utilities that have to store spent fuel on-site, and construct additional interim storage until a final repository is in place.

In the meantime, interim storage at NPP sites face several challenges: availability of space to store the spent fuel, the need in some cases to demonstrate that extended storage in canisters that were not designed for such long interim storage remain safe. The option of developing centralised interim storage solutions, or consolidated interim storage facilities (CISF), is therefore being seriously considered. The NRC is currently considering two proposals, one submitted in 2016 by Interim Storage Partners, LLC, for a site in Texas, and one submitted by Holtec International in 2017, to build a CISF in south-eastern New Mexico. It could eventually hold up to 120 000 metric tonnes of spent uranium fuel, storing it until a permanent repository is developed (NEI, 2019b).

In 2019, the president's fiscal year (FY) 2020 budget request included USD 116 million for the resumption of the licence review for the repository at Yucca Mountain and for interim storage of nuclear waste. As of April 2019, Congress was still in the midst of the FY 2020 appropriations process, and had not yet directed funding for the licence application to resume.

Production of enriched uranium

The DOE is providing support to produce high-assay low enriched uranium (HALEU) to accompany the development of advanced reactors. HALEU fuel (enrichment from 5% up to 20% uranium-235 [U^{235}]) differs from that used in the existing LWR fleet (enrichment typically between 3.5% and 5% U^{235}), and has many advantages that improve reactor performance. Because U^{235} is more concentrated, the fuel assemblies and reactors can be smaller, which is one reason many SMR designs will run on HALEU. The reactors do not need to be refuelled as often, and they can achieve higher "burnup" rates, which means less fuel will be required and less waste will be produced.

Accident tolerant fuels

As part of the policy to encourage innovations in the nuclear industry, on a cost-shared basis, the DOE awarded in January 2019 over USD 111 million to three industry partners to develop accident tolerant fuel (ATF). Additional funding is planned in future fiscal years. ATFs are meant to provide additional safety margins, and improved reliability and economics for NPPs, for example by enabling more significant ramping of nuclear power (flexible operation), a mode of operation that could be required more often in future electricity systems with large shares of variable renewable generation. While the US nuclear fleet has operated principally as baseload generation, flexible operation of NPPs is not new, with significant operational experience in France and Germany. An added feature of ATF would be to offer an additional "grace period" to operators of NPPs in the event of a nuclear accident with loss of cooling and/or loss of external power, providing time to bring on emergency cooling and power systems. DOE funding is aimed at ensuring demonstration of test assemblies in a commercial NPP, as well as preparing for the licensing of such fuels, in co-operation with the NRC.

Innovation, nuclear research, human resources, education

Developing human resources, competences and research facilities is key to supporting US ambitions to regain leadership in civil nuclear technologies. The administration recognises this, and has put in place a suite of initiatives, including the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative. The GAIN initiative was launched in November 2015 to provide a way to fast-track nuclear innovation, providing stakeholders with a means of accessing DOE research and development (R&D) infrastructure to help them meet the challenges of bringing new technologies towards engineering-scale demonstration and market deployment (also see Chapter 6, "Energy Technology Research, Development and Demonstration").

Versatile Test Reactor

The DOE is supporting the design and promoting the construction of a new research facility, a flexible material- and fuel-testing reactor based on sodium-cooled fast reactor technology (one of the six Generation IV technologies). This facility, called the Versatile Test Reactor, will be located at the INL. The project, which was included in the Nuclear Energy Innovation Capabilities Act of 2017 (formally enacted into law in September 2018), was officially launched in February 2019. It will provide the United States with the domestic capability to test and qualify advanced fuels and materials that are essential features of advanced reactors. After the shutdown of the Experimental Breeder Reactor II (EBR-II) in 1994, the United States has not operated a fast neutron reactor for over 20 years.

Funding for nuclear innovation

The DOE is committing funding to accelerate nuclear innovation and the development of advanced reactors. Between April 2018 and March 2019, approximately USD 117 million was granted to support cost-shared projects covering technology development, concept design and preparation of regulatory reviews.

Training nuclear scientists and engineers

Together with the supporting industry, the nuclear supply chain and the associated workforce, the administration is making special efforts to foster scientific skills in the nuclear research and energy sectors. In March 2019, the DOE announced more than USD 5 million in undergraduate scholarships and graduate fellowships at US colleges and universities.

While the United States has clearly taken an active role in promoting advanced reactor technology development and capacity building, other countries (Canada, the United Kingdom) are also promoting the development and deployment of SMRs. International initiatives, such as the Generation IV International Forum (of which the Unites States is a member), are promoting joint R&D activities, the sharing of research infrastructure and, perhaps more importantly, collaborative work with regulators to develop safety standards for advanced reactors. Having a consensus-based safety approach that meets regulatory requirements from various countries is a key success factor for the deployment of advanced reactors in global markets.

Assessment

Nuclear energy represents 20% of US electricity production, the largest source of low-carbon electricity, with hydro and other renewables combined representing nearly 18%. The share of nuclear power has remained stable over the last ten years, but is likely to decrease with early retirements of NPPs, in a context of flat electricity demand and increasingly competitive market conditions, brought on by low natural gas prices and subsidised renewables.

The US nuclear fleet, the largest in the world, consists of 98 LWR units. The NRC, the regulator, has granted licence renewals to 90 units allowing them to operate for a total of 60 years. It has not identified any technical showstoppers. The NRC also established in early 2018 an SLR guidance for operation beyond 60 years (up to 80 years), and received the first three applications in 2018 for six units.

Notwithstanding the clear regulatory framework for long-term operation, some NPPs are being retired before the end of their licences, often for economic reasons. In spite of being fully depreciated a while ago and low uranium prices, the operating costs of some of the plants – especially merchant ones – cannot be covered by the revenues generated from the sale of electricity in wholesale markets, where natural gas-fired generation usually sets the marginal price for electricity. Between 2013 and 2018, a total of seven units were retired, representing 5.3 GW. A further 11 units are expected to be retired by

2025, representing an additional 11 GW. Increasing shares of zero-marginal-cost renewable power can also displace conventional generation, decreasing the amount of baseload generation and affecting its economics.

The administration is concerned that the premature closure of NPPs (as well as of coal-fired power plants) can pose significant resilience issues for the electric grid, as the power mix becomes dominated by natural gas and renewables. Extreme cold spells have stretched gas supply that is required for heating and industry, as well as for electricity generation. Large nuclear plants, which have on-site fuel reserves, can provide ancillary services, such as frequency control, spinning and operating reserves, and their gradual removal from the electricity system can pose reliability risks. While the North American Reliability Corporation (NERC) does not see any immediate risks, it notes that measures will need to be taken to address reliability. FERC is currently assessing how to value resilience in the marketplace. Compensating the contribution of nuclear power to grid resilience can help the economics of the fleet but also requires the development of robust and transparent criteria that can stand legal challenges. It should also be recognised that the power system is evolving, and technology developments correlated with renewable electricity penetration may provide future solutions to today's resilience issues. Advanced reactors with various modes of flexible operation (load-follow or switching between electricity and heat production) may offer ways to better integrate renewables and nuclear systems into future low-carbon grids.

While the federal government is contemplating action with respect to security and resilience issues, some states are putting in place measures that are helping nuclear generators stay in the market, essentially by recognising their contribution to reducing greenhouse gas emissions. Clean energy standards, zero carbon procurement and ZEC programmes are some of the measures taken by states such as New York, Connecticut and New Jersey. Twelve units representing over 11 GW of generating capacity, which would likely have been retired for economic reasons, could thus be saved from premature closures stemming from current unfavourable market conditions.

Construction of new nuclear capacity in the United States has been limited over the last three decades. The few initiatives for new plants have experienced delays and cost overruns, due in large part to problems with the industrial supply chain and loss of experience in managing nuclear construction projects. In March 2017, Westinghouse Electric, the designer of the Generation III+ AP1000 reactor, filed for bankruptcy. The construction of two AP1000 units at the V.C. Summer plant in South Carolina was abandoned in July 2017, and only the Vogtle project (two AP1000s) remains today. The Vogtle project benefited from DOE loan guarantees and will also benefit from federal production tax credits of USD 18/MWh. Such tax credits are available for future projects, in an effort to encourage new builds, in particular the construction of SMRs. Maintaining a viable industrial nuclear supply chain until significant domestic construction projects happen will be challenging, unless the United States manages to develop projects abroad in a very competitive international market.

The DOE is also actively pursuing the development of advanced reactor technologies, including SMRs, micro-reactors and Generation IV reactors, promoting innovation, supporting licensing efforts together with the NRC, funding university programmes and building new R&D infrastructure. Continued collaboration with international partners can further contribute to the ambition of developing the next generation of nuclear technologies with higher levels of standardisation, and with common safety approaches that can facilitate licensing at the global level.

Even if nuclear energy benefits from strong bipartisan support, there remains an area where little progress has been made: the management of the country's high-level waste. The inability of successive administrations to collect the country's used fuel in a repository has created a liability for the American taxpayer, which has to pay about USD 800 million per year to compensate utilities for the costs of on-site extended storage. Resuming licensing work for the Yucca Mountain repository site, as well as developing a centralised interim storage solution, are necessary conditions for the long-term sustainability of the nuclear industry.

Recommendations

The US government should:

- Assess in a robust and transparent way the contribution of NPPs to the resilience of the current electricity system, and value their contribution to low-carbon electricity generation.
- For the longer term, investigate the integration of advanced nuclear systems and variable renewable generation in future low-carbon energy systems, and continue to work internationally to promote standardisation and harmonised safety requirements.
- Work with Congress to move ahead with the development of a long-term repository at Yucca Mountain for the country's used fuel, as well as centralised interim storage facilities to reduce the burden on utilities.

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11. Coal

Key data

(2018 provisional)

Production: 685 Mt/368 Mtoe, -35.5% since 2008

Net exports: 99.5 Mt/65.8 Mtoe

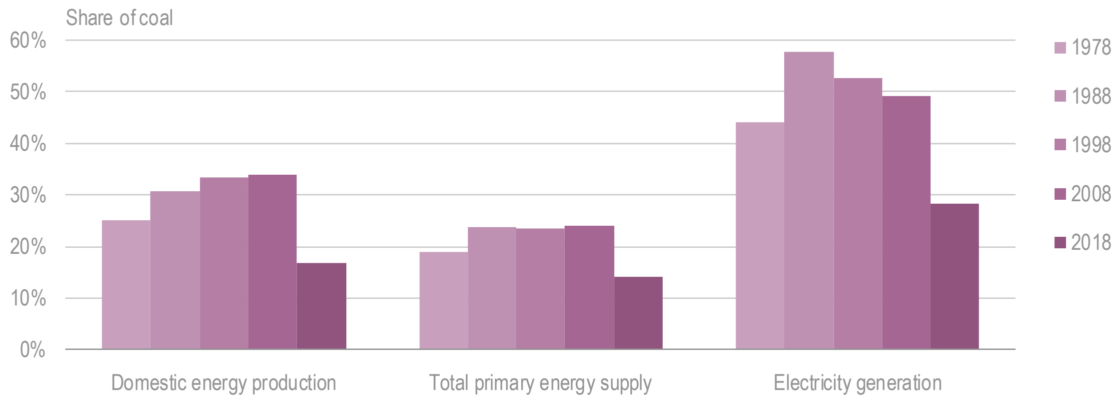
Share of coal: 14.2% of TPES and 28.4% of electricity generation

Consumption by sector (2017): 330.7 Mtoe (heat and power generation 92.0%, industry 4.9%, other energy 2.9%, commercial 0.1%)

Overview

The United States (US) is a major coal producer and consumer; in energy terms, it is the second-largest producer after the People's Republic of China (hereafter "China") and the third-largest consumer after China and India (IEA, 2018). Most coal produced in the United States is used in domestic power generation. In the last decade, a combination of factors – including the shale gas revolution, flat power demand growth, environmental regulations and an expansion in renewables – has led to a decline in coal demand. Coal went from supplying nearly 50% of US electricity generation in 2008 to just below 30% in 2018 (Figure 11.1). As a result, coal production has dropped in all coal-producing regions. Over half of total coal production in the United States comes from just two states: Wyoming and West Virginia.

Figure 11.1 Share of coal in different energy supplies, 1978-2018



After long-term growth in coal production and supply, the use of coal has dropped dramatically in the last decade, in particular in electricity generation.

Note: Data are provisional for 2018.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

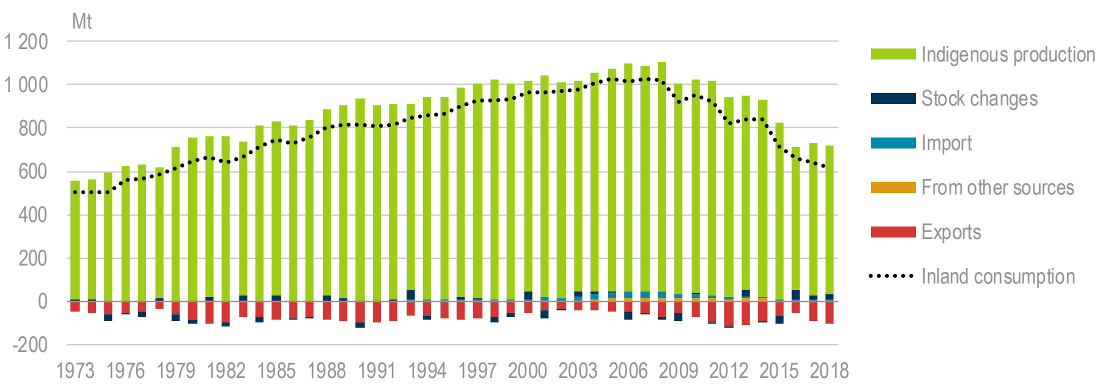
Coal power is associated with higher emissions of greenhouse gases (GHGs) as well as other pollutants such as mercury, sulphur dioxide (SO_2) and nitrogen oxides (NO_x) compared with other power generation sources. The United States has a strong platform for research, development and demonstration (RD&D), which can be used to support further improvements to reduce emissions from coal power. The country is also one of the leaders in carbon capture, utilisation and storage (CCUS) technology, which could enable coal power generation with much lower emissions and provide additional revenue streams for generators.

As domestic demand declines, the United States could start exporting more to maintain its coal sector. However, the US coal industry would need to be cost-competitive on the global market. Increased exports would also require investments in new infrastructure.

Supply and demand

Coal production in the United States covers both domestic demand and exports (Figure 11.2). In 2018, the United States produced 685 million tonnes (Mt) of coal, mostly sub-bituminous and non-coking bituminous coal. Around two-thirds of the coal is produced in surface mines, and one-third comes from deep underground mines (IEA, 2019b). The largest coal-producing area in the United States is the Powder River Basin (PRB) in the western states of Wyoming and Montana (Figure 11.3). In line with falling consumption, US coal production has also declined in recent years.

Figure 11.2 Coal supply by source, 1973-2018



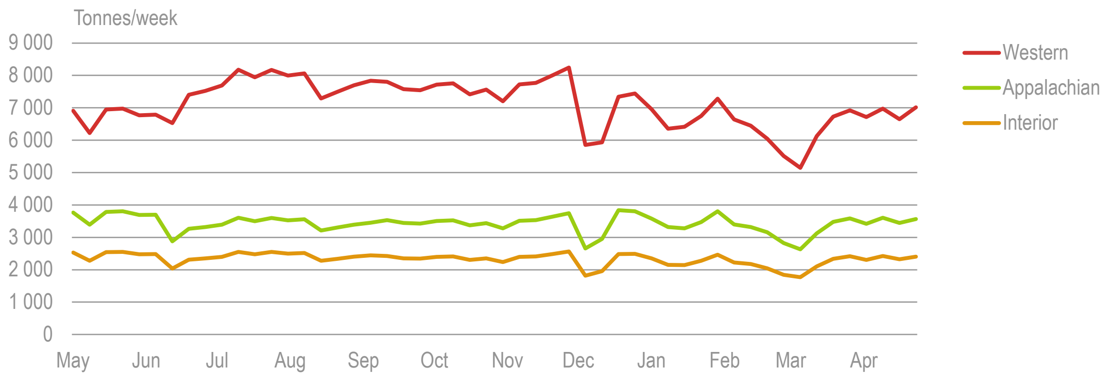
The vast majority of the coal produced in the United States is used domestically, and in the last decade, production dropped by a third as a result of falling demand in the power sector.

Note: Data are provisional for 2018.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

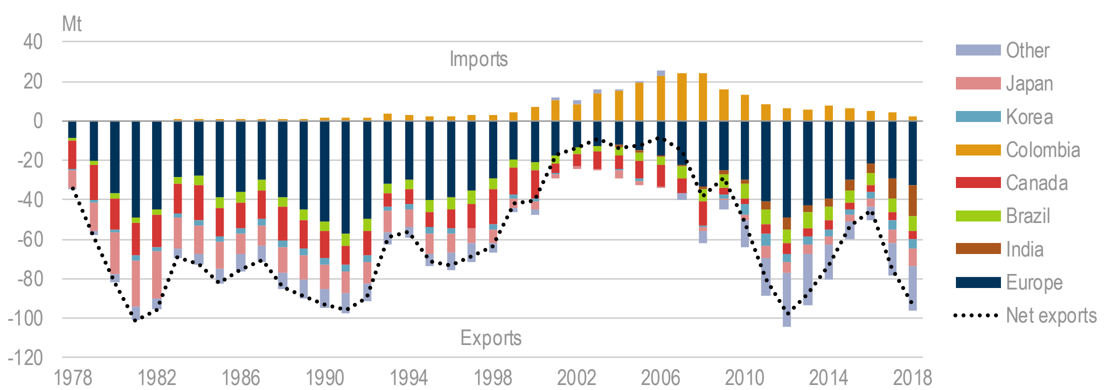
The United States also trades coal on the global market, with net exports averaging 8% of domestic production in the last decade. Coal is imported from Colombia and exported to a large number of countries, mainly in Europe and increasingly in Asia (Figure 11.4). Regionally, Europe is the largest importer of US coal, though on a country basis, the biggest importers in 2018 were India, the Netherlands (mostly for re-export) and Brazil. In 2017, the United States was the world's fourth-largest coal exporter overall, and the world's second-largest metallurgical coal exporter. Metallurgical coal represented 57% of total 2017 US coal exports, while steam coal accounted for 43% (EIA, 2019a).

Figure 11.3 Weekly coal production by region, May 2018-April 2019



Source: EIA (2019b), *Weekly Coal Production,* www.eia.gov/coal/production/weekly/.

Figure 11.4 Hard coal trade by country, 1978-2018



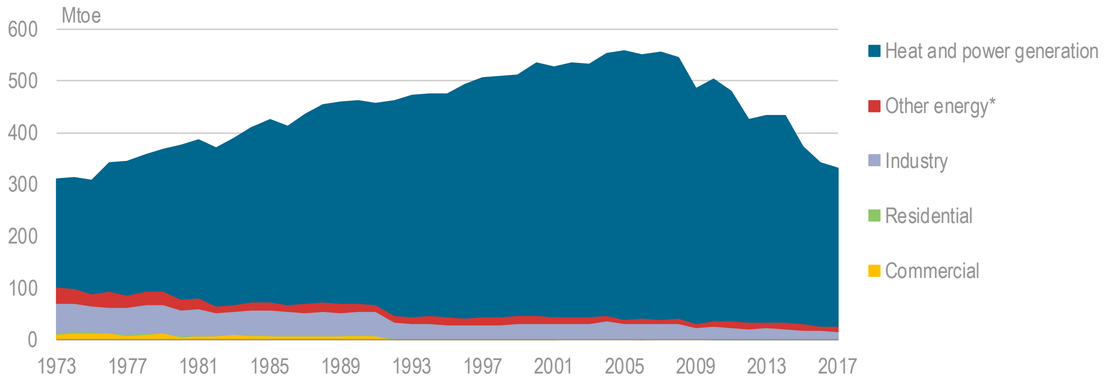
US coal exports have increased as domestic demand has declined, but the export capacity is limited and cannot easily be increased to compensate for the drop in demand.

Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

The power sector is the main coal consumer in the United States. In 2017, 92% of total US coal supply was used for heat and power generation, and the rest (both thermal and metallurgical) was mostly used in the industrial sector, e.g. non-metallic minerals (Figure 11.5). Due to competition from other sources, coal demand has fallen dramatically in the last decade. Total coal consumption peaked in 2005 at 558 million tonnes of oil equivalent (Mtoe), and has since fallen by over 40% to 331 Mtoe in 2017 (EIA, 2018c).

Over the past decade, a combination of factors has contributed to increased retirements of coal-fired power generation capacity in the United States (Figure 11.6). According to US Energy Information Administration (EIA) data, most of the coal retirements were of older, smaller and less efficient units; retired units between 2008 and 2017 had an average age of 52 years and a capacity of 105 megawatts (MW) (EIA, 2018a). In addition to environmental regulations – notably mercury limits that took effect in 2015-16 – the abundance of low-cost natural gas as well as falling costs and policy support for renewables have made coal generation less economical. Looking ahead, the same conditions are likely to put continued pressure on coal units, which will likely result in additional retirements in the coming years (EIA, 2018c).

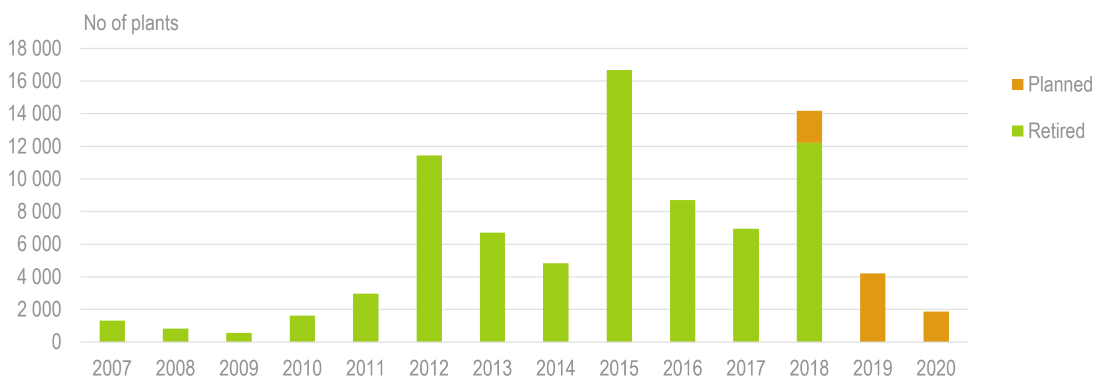
Figure 11.5 Coal consumption by sector, 1973-2017



The shale gas revolution has transformed the electricity sector and led to a sharp drop in demand for coal power, which accounts for over 90% of total coal consumption.

**Other energy* includes gas works, coke ovens and blast furnaces, and coal used in coal mining.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Figure 11.6 US coal plant retirements and planned retirements, 2007-20



Source: EIA (2018a), *Preliminary Monthly Electric Generator Inventory*, www.eia.gov/electricity/data/eia860m/.

In recent years, as demand for coal in the domestic power generation sector has fallen, high international trading prices have offered US coal producers export opportunities (E&E News, 2019). The EIA estimates that US coal exports accounted for 15% of total US production in 2018, driven by Asian and European demand (EIA, 2019b). While Appalachian coal can more easily access existing export infrastructure on the East Coast and Gulf of Mexico, higher costs and longer distances make it more challenging for eastern US coal to compete in Asian markets. Western coal exports are challenged by the lack of coal export infrastructure on the Pacific Coast; moreover, PRB coal has lower heat content, albeit lower sulphur. Proposed terminals in Washington State have been cancelled or stalled due to local opposition, regulatory setbacks and market conditions (National Coal Council, 2018). Following an increase of 20% in 2018, the EIA expects US coal exports to fall over the following two years due to a decline in international benchmark prices.

Institutions

Regulation of the US coal sector is governed by a broad array of institutions at both the state and federal levels. Regulatory oversight varies for coal mining versus coal consumption. Federal regulation of the coal sector is predominantly directed by:

- The Department of Labor, which oversees miner safety.
- The Bureau of Land Management (BLM), which regulates mining on federal lands.
- The Environmental Protection Agency (EPA), which regulates emissions from power plants.
- The Department of Energy (DOE), which oversees research and development (R&D) efforts related to coal technologies.

Coal mining regulations are dominated by worker safety rules, most notably embodied in the Mine Safety and Health Act of 1977. That act created the Mine Safety and Health Administration (MSHA), housed in the Department of Labor, which is tasked with developing health and safety regulations for coal mining. Since the act was passed, mining fatalities have fallen considerably (MSHA, 2019a). In addition to developing and enforcing labour regulations, MSHA also provides technical assistance to mine operators. Congress in 2006 passed the Mine Improvement and New Emergency Response (MINER) Act, which requires mine-specific emergency response plans for underground coal mines, new regulations on mine rescue teams and sealing of abandoned mines, timely notice of accidents, and increased civil penalties for violations (MSHA, 2019b).

In order to address the safety and health implications for coal mine workers from coal dust, the Coal Mine Health and Safety Act of 1969 created the Black Lung Disability Trust Fund (set up in 1977). The programme is funded by a coal excise tax to cover health, disability and death benefits to miners suffering from black lung disease due to coal dust exposure (Congressional Research Service, 2019). The trust fund's fiscal year 2017 revenues stood at around USD 450 million, though it borrowed USD 1.3 billion from the US Treasury's general budget that same year to cover debt repayments. In 2014, MHSA updated coal dust rules, adding additional protections for miners (MSHA, 2016).

The Surface Mining Control and Reclamation Act of 1977 established requirements for coal mine rehabilitation after mining activities have ceased. The legislation created the Interior Department's Office of Surface Mining Reclamation and Enforcement to regulate surface coal mining and oversee restoration of abandoned coal mines.

The BLM, under the Department of the Interior, has regulatory oversight over coal mining on federal lands, which accounts for around 41% of total coal produced in the United States, predominantly in Western states (BLM, 2019). As part of its responsibilities, BLM oversees the leasing of federal lands for coal mining, covering around 2.3 million square kilometres of land. The federal leasing programme also includes establishing royalty rates for coal mining and environmental protections associated with mining. In an effort to remobilise investment in coal mining, the administration in March 2017 lifted a moratorium that had been in place since January 2016 on new coal leases on federal lands to evaluate their environmental impacts and reassess royalty rates.

Environmental regulations on coal-fired power generation are predominantly directed by the EPA, based on authority granted to it under the Clean Air Act and its amendments. National Ambient Air Quality Standards (NAAQS) are established for six so-called criteria pollutants, including NO_x, SO_2, ozone, lead, carbon monoxide and particulate matter (EPA, 2019a). The Clean Air Act defines two types of NAAQS: primary standards for public health protection and secondary standards for public welfare protection. The EPA defines air quality control regions and designates them as either “attainment” or “non-attainment”, depending on whether they are, respectively, in compliance with required levels or not (EPA, 2019b). States then implement the standards through state implementation plans under the EPA’s oversight and with guidance from a menu of control measures provided by the agency. The EPA is required to review (and update, if needed) NAAQS every five years. For other pollutants not covered by NAAQS, the EPA sets National Emissions Standards for Hazardous Air Pollutants based on maximum achievable control technology.

Under 1977 amendments to the Clean Air Act, Congress established the New Source Review (NSR), which requires facilities, including power generators, to obtain specific permits. NSRs include Prevention of Significant Deterioration (PSD) permits for new or upgraded facilities to meet NAAQS, non-attainment permits for modifications that do not meet NAAQS, and minor source permits for facilities that do not require PSD or non-attainment permits (EPA, 2019c). Following the 2007 *Massachusetts v. EPA* Supreme Court case, the EPA is also required to regulate GHG emissions.

The DOE Office of Fossil Energy leads federal government R&D efforts related to fossil fuel-based power generation. Areas of focus include power plant efficiency, CCUS and water management. The office’s research is conducted in close collaboration with national labs, also under the purview of the DOE.

US states also have regulatory authority over coal mining and power sector operations within their borders. As such, states with coal mining operations can have more stringent health and safety regulations governing coal mining, which can impact the outlook for coal supply.

US coal exports are not subject to any federal regulatory approvals, though coal export terminals must undergo environmental reviews for permitting. Depending on their location, the relevant state’s regulators lead the permitting reviews; the US Army Corps of Engineers also plays an important role at the federal level.

Policy and regulation

The coal sector is subject to a wide array of policy and regulation at both the point of production and at final csumption. The administration considers the economic costs of existing regulations on the energy sector as exceeding their benefits, and is rolling back a number of environmental regulations, including those that have raised costs for coal production and coal-fired generation.

Coal mining

Coal mining is subject to an excise tax that funds the Black Lung Disability Trust Fund. In 2018, underground coal mining was subject to a USD 1.10 per tonne excise tax while surface mining was subject to a USD 0.55 per tonne tax, limited to 4.4% of the sales price. Based on the original rules of the Trust Fund from 1977, in 2019, the taxes fell to USD 0.50 for underground mining and USD 0.25 for surface mining, limited to 2% of the sales price (Congressional Research Service, 2019).

In September 2017, the Interior Department repealed the so-called Valuation Rule, which changed the way that royalty payments for coal (and oil and gas) production on federal and tribal lands were calculated. Specifically, the 2017 Valuation Rule required companies to value coal production for royalty payments based on gross proceeds from the first unaffiliated customer (known as the first arm's-length sale) in order to minimise perceived underpayment of royalties on the part of coal mining companies that use affiliated brokers to settle royalty payments on exports (Reuters, 2017). The intent of repealing the 2017 rule was to minimise confusion and uncertainty to the coal industry. The changes will affect PRB producers the most given longer distances that the coal is shipped (warranting the use of more brokers), causing the delivery price to be several times what the miner receives. To help develop a replacement rule, the Interior Department directed the Royalty Policy Committee to propose alternative options, a process that is still ongoing. In the meanwhile, the pre-2017 system of calculating royalties will remain intact. The committee in September 2018 recommended granting companies the option to choose between two methods for calculating royalties – either based on how much they are paid (the traditional approach) or based on the quality and quantity of what they produce (Seattle Times, 2018).

In order to lower regulatory costs for the coal mining industry, Congress in February 2017 passed a "resolution of disapproval" under the Congressional Review Act to repeal the Stream Protection Rule that took effect in January 2017 (The New York Times, 2017). Though rarely used, the Congressional Review Act allows Congress to revoke an executive rule within 60 days of it taking effect (Congressional Research Service, 2001). The rule restricted coal companies from placing debris from mountaintop coal mining into streams, which companies contended would make mountain removal mining (mostly used in Appalachian operations) uneconomical (Congressional Research Service, 2017). A proposal to replace the rule has not yet been issued.

From a health perspective, to reduce the incidence of black lung disease among coal miners, which had started to trend up after 2000, the administration in 2014 finalised a new coal dust rule that imposed lower dust exposure limits and increased sampling frequencies on coal mining operations (The New York Times, 2018). The rule was upheld by the courts in 2016 following an industry challenge over its cost burdens. As part of the administration's broader review of regulations, the Department of Labor's MSHA began a review of the coal dust rule in 2017, but has not proposed any changes.

Environmental regulations for coal-fired power plants

Among the environmental rules that have had or are expected to have the greatest impact on coal-fired generation are ozone standards, the Mercury and Air Toxics Standard (MATS), the Cross-State Air Pollution Rule (CSAPR) and the Affordable Clean Energy (ACE) rule.

The most recent update to ozone NAAQS occurred in October 2015, which updated the 2008 standard of 0.075 parts per million (ppm) to 0.070 ppm (EPA, 2018a). The administration issued a proposed rule making for implementation in 2016, and finalised implementation requirements in 2018, which also cover requirements for coal-fired generators (Power Magazine, 2018). The standard and implementation rules are the subjects of legal challenges. The EPA plans to complete its next review of the ozone NAAQS by 2020.

The EPA in 2011 finalised the MATS, which imposed limits on mercury emissions from coal-fired power plants. Control technologies include selective catalytic reduction with flue-gas desulphurisation and activated carbon injection. The rule gave power plants four years to comply with MATS, with an optional additional year to install mitigation technologies (EPA, 2018b). The MATS rule was a major driver of coal plant closures in 2015-16. In December 2018, the EPA proposed a revised Supplemental Cost Finding for the MATS rule, which would not change implementation of the existing rule, but would limit future regulatory action on hazardous air pollutants under Section 112 of the Clean Air Act (Utility Dive, 2018).

In 2011, the EPA also finalised the CSAPR, designed to control interstate air pollution of NO_x and SO_2. Often, pollution from coal-fired power plants can travel to other states, pushing them out of attainment with NAAQS (so-called "downwind" states). Under the Clean Air Act, the "good neighbour" provision requires the EPA to address this type of interstate pollution. CSAPR, which took effect in 2015, requires states with "upwind" emissions, mostly in the eastern part of the country, to limit NO_x and SO_2 pollution from their power plants to avoid emissions crossing over into other states (EPA, 2018c). Under the cap-and-trade rule, each obligated state is assigned a pollution cap and issued emissions allowances accordingly, which entities under the rule can trade among themselves to achieve compliance (EPA, 2018c).

Though not specific to pollutants, in 2014, the EPA finalised cooling water intake requirements under Section 316(b) of the Clean Air Act, which applies to power plants that draw at least 2 million gallons of cooling water daily from neighbouring lakes, rivers, estuaries or oceans to cool their facilities (Power Magazine, 2014; EPA, 2019e). The rules, which are enforced as part of National Pollutant Discharge Elimination System permits, provide several technology options to coal plants to limit impacts on fish populations.

In order to address GHG emissions from power plants, as required by the *Massachusetts v. EPA* Supreme Court ruling, in August 2018, the administration introduced its proposal to replace the 2015 Clean Power Plan with the ACE rule. Under Section 111(d) of the Clean Air Act, the EPA is required to regulate emissions at existing power plants through the "best system of emissions reduction" (BSER). The Clean Power Plan, which was suspended by a Supreme Court ruling and therefore never took effect, proposed statewide targets for power plant emissions that collectively added up to a 32% reduction from 2005 levels by 2030. Meeting the targets allowed for so-called "beyond the fence line" measures such as switching to cleaner power sources and demand-side management. In contrast, the replacement plan focuses on site-specific emissions cuts at individual power plants. The EPA's ACE rule offers states several options for candidate technologies, though recommends heat-rate efficiency improvements at existing power plants as the BSER. The ACE rule also raises the threshold of plant upgrades that would trigger an NSR by using a benchmark of hourly emissions rates rather than an annual rate, thereby lowering the regulatory requirements for upgrading existing coal facilities. After finalisation in June 2019, the ACE rule may be subject to legal challenges by states and environmental groups, which could take over a year to reach conclusion. If upheld, the ACE rule will help prevent early closure of coal plants.

The administration in December 2018 also announced a proposal to revise New Source Performance Standards (NSPS) for carbon dioxide (CO_2), applied under Section 111(b) of the Clean Air Act. The NSPS rule has been in effect since it was finalised in 2015. The rule established an emissions threshold of 1 400 pounds (635 000 grammes) of CO_2 per megawatt-hour (MWh) for new coal-fired generators, which would have required at least partial carbon capture and sequestration (CCS). The new proposal calls for a standard of 1 900 pounds (862 000 grammes) of CO_2/MWh for large generators and 2 000 pounds (907 000 grammes) for smaller generators, which would not require CCS. Whether the rule has any material impact remains to be seen, as market conditions already disadvantage new coal plant construction, and none are under consideration currently.

Lastly, the EPA in 2018 also finalised its revision of the 2015 Disposal of Coal Combustion Residuals from Electric Utilities rule (also known as the coal ash rule) for coal plants, which govern how power plants manage coal ash waste from burning coal. The new rule relaxes requirements for plant operators and gives states and the industry more flexibility in waste management.

Fuel security

The DOE in September 2017 issued a notice of proposed rule making (NOPR) that urged the Federal Energy Regulatory Commission (FERC) to develop cost recovery mechanisms for baseload power generators that support grid reliability and resiliency. The proposal specifically called for grid operators, under the direction of FERC, to develop compensation mechanisms for baseload plants that have 90 days of fuel supply on-site, which primarily include coal and nuclear plants.

In response, FERC in January 2018 issued an order that unanimously rejected the DOE's NOPR on the grounds that it did not provide sufficient evidence of supply risks to the grid. Instead, FERC opened a new proceeding on grid resilience, which is still under way, and directed regional grid operators to undertake a comprehensive, longer-term evaluation of grid resiliency as part of the proceeding (see Chapter 9, "Electricity").

Emissions reduction efforts for coal-fired generation

The United States places an emphasis on technologies that improve efficiency and reduce emissions from coal-fired generation.

As part of these efforts, the DOE in January 2019 announced that it would fund USD 38 million for cost-shared R&D projects that improve the performance, reliability and flexibility of the existing coal fleet (but this funding will focus on efficiency improvements rather than CCUS) (DOE, 2019a).

Refined coal

Among the moves to make coal generation cleaner, Congress, under the American Jobs Creation Act of 2004, put in place a tax credit for refined coal production. Refined coal is coal that has been treated to lower emissions when burned, mainly by increasing mercury oxide production, which can then be captured by existing technologies in coal plants. In order to qualify for the tax credits, producers must certify that burning the refined coal results in 20% fewer NO_x emissions and 40% fewer SO_2 or mercury emissions compared with untreated coal. The tax credit is adjusted for inflation, and amounted to USD 6.91 per short tonne of refined coal produced in 2017 and USD 7.10 per short tonne in 2018 (EIA, 2019d). The EIA estimates that the production of refined coal grew in 2017 and likely grew again in 2018, accounting for a larger share of overall coal production at 21% over the first three quarters of 2018.

Small-scale coal plants

In August 2017, the DOE announced USD 50 million in funding for two pilot projects to develop transformational coal technologies, for which nine projects were shortlisted under Phase I in February 2018, focused on small-scale applications. Project finalists will move on to Phase II, focused on front-end engineering and regulatory clearances, while Phase III will focus on construction and operation (DOE, 2018).

In November 2018, the DOE's Office of Fossil Energy unveiled the Coal FIRST (Flexible, Innovative, Resilient, Small and Transformative) initiative, with a focus on developing smaller, more efficient, modular coal plants (50 MW to 350 MW) that have near-zero emissions and are more flexible and better suited to the changing needs of the US grid (DOE, 2019b). These types of plants could also prove beneficial for export to less economically developed countries.

CCUS

The United States has been a leader in advancing CCUS technology for some time. The country has the largest number of large-scale CCUS facilities worldwide, though the bulk of current projects are focused on natural gas processing and industrial facilities rather than coal-fired power plants (for more details on CCUS, see Chapter 6, "Energy Technology Research, Development and Demonstration").

As part of the Bipartisan Budget Act that passed in February 2018, Congress extended and significantly increased tax credits for CCUS under Section 45Q of the Internal Revenue Code (see Chapter 6 more information).

The DOE's Office of Fossil Energy directs the Office of Clean Coal and Carbon Management, which promotes R&D efforts that support the use of fossil fuels in more environmentally and economically advantageous ways. In the longer term, the administration expects that progress on CCUS technologies can be applied to both new and existing coal-fired power plants.

Assessment

The United States is the world's second-largest coal producing country, after China, and has the largest coal resources globally. Coal is produced in 25 states in three main regions: the Appalachian coal region, the Interior coal region and the Western coal region. Wyoming accounted for 41% and West Virginia 12% of total production in 2017.

Coal production fell from just over 1 000 Mt in 2008 to around 700 Mt in 2018. From a consumption perspective, the share of coal in total primary energy support decreased from 24% to 14% over the same period. Most of this decline happened in the power generation sector, which accounted for 92% of total coal consumption in 2017.

Over the last decade, energy developments in the United States have been dominated by the light tight oil and shale gas revolutions; they have brought great benefits to the country, in terms of both economic development and energy security. Though natural gas exports are rising, abundant shale gas production drove down prices and boosted demand for gas in power generation.

Electricity demand in the United States has been almost flat in the last decade due to efficiency improvements and an economic slowdown in 2008-09. Low-cost natural gas and renewables (mostly wind) increased their share in the generation mix, to the detriment of coal. In 2008, coal had a share of 49% in the mix, while natural gas had only 21%. In 2018, natural gas accounted for 34%, while coal accounted for 28%. Demand for coal from the power sector fell from around 829 Mt in 2007 to only 607 Mt in 2017.

Equally, US coal production has seen a decline, mainly driven by falling consumption in the power sector. The coal sector has traditionally been geared towards domestic power production; only small shares are used in industry or exported. As a consequence, for PRB coal (which is relatively low-cost to produce), there is very little logistical infrastructure to move coal out of the country, unlike for instance in Indonesia and Australia, where coal production traditionally was driven by exports. Mining costs for Eastern coal are also relatively high (due to geological reasons) by international standards; Illinois coal is lower in quality, making it less attractive in foreign markets, especially considering shipping distances.

The reduced coal production and closure of mines, together with the retirement of the older portion of the coal power fleet and automation in the mining sector, is hitting some coal regions hard. The shale gas revolution together with a growing renewable energy sector bring new economic development and employment opportunities, but not necessarily in the same regions. Therefore, the administration is looking for ways to stop the decreasing use of coal in power generation, to increase coal exports and to find other uses for coal. One of the administration's main initiatives to help coal communities is the Department of Commerce's Assistance to Coal Communities programme, which in 2017 awarded USD 30 million to support 35 economic diversification projects in 16 states. All these avenues to revitalise the coal sector come with challenges.

The US administration is repealing or revising several environmental regulations, such as the Clean Power Plan and coal ash rule, which have raised costs for coal-fired generators. Similarly, the administration has taken steps to simplify royalty calculations and has lifted a moratorium on mining on federal lands. Moreover, in order to reduce early retirements of coal-fired power generation, the government is looking at ways to value (and compensate for) the unique characteristics of these plants, such as energy security that comes with the ability to store fuel on-site. Overall, however, coal-fired generation will continue to face competitive challenges from low-cost shale gas and renewables.

Another way to retain a role for coal in power generation in the longer run might be developing smaller, modular, less costly and more flexible coal generation plants. There is also R&D ongoing into increasing the efficiency of existing plants. Under the current EPA rules, a renovated plant has to comply with environmental permitting requirements for new-build plants, which increases costs considerably, thereby reducing the appetite to invest in such renovations. The EPA's ACE rule aims to address this issue and allow easier efficiency upgrades to the current coal power fleet.

Increasing coal exports could be another way to provide some relief to the coal industry in affected regions. Until now, the United States has been a swing exporter, filling the gap if supplies from other more competitive exporters are disrupted. Without any changes, this role seems likely to continue in the future. There is strong uncertainty in international markets, as imports by countries such as China, India, Japan and South Korea are difficult to predict and skewed towards coking coal. Moreover, recent tariffs imposed by countries such as Turkey and China in response to US tariff actions could further set back opportunities to US coal exports, though a resolution to trade disputes would alleviate this risk.

Increasing exports will also require investment in export facilities; currently there is no coal export infrastructure on the West Coast, and shipping from the East Coast to Asia is less competitive compared with other supply options. Apart from port facilities, coal shipments compete with other goods and commodities for rail capacity. Though mining costs vary considerably across US regions, technology development should seek to further increase productivity for the United States to be more competitive.

Finally, the United States can research uses for coal aside from power generation. A large R&D programme is set up to investigate this area. One promising route could be the Rare Earth Elements Program, which seeks to extract valuable rare earth elements from coal and by-products such as coal ash and slack coal. The DOE, through the National Energy Technology Laboratory, is also funding efforts into coal beneficiation, including converting coal into high-value carbon products such as carbon fibre and cement additives.

The United States is a global leader in CCUS development and deployment. It is host to one of only two operating commercial-scale coal-fired power plants with CCUS globally, with a further eight large-scale projects applying CCUS to industrial processes. The DOE has an R&D programme of about USD 200 million per year to support the development of CCUS for power and industrial applications. The extension and expansion of the 45Q tax credits for CCUS projects to provide up to USD 50 per tonne of CO_2 captured and stored could make CCUS an attractive option for coal-fired power plants and other industrial sources of CO_2 under certain conditions.

Recommendations

The US government should:

- Further promote CO_2 emissions reduction technologies through R&D in increasing efficiency of existing coal plants, study the economic feasibility of small modular plants, and examine options to support the development and deployment of CCUS in the power sector.
- Improve the competitiveness of domestically sourced coal by increasing productivity of coal mining through stimulating technology development and R&D.
- Stimulate new economic activities in those coal regions that are confronted with declining coal production and retirement of coal-fired power plants.

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12. The resilience of US energy infrastructure

Key data
(2018)

2018 energy infrastructure federal response efforts: 14 instances

SAIDI (Average duration of electric power service interruptions) (2016): 250 minutes

SAIFI (Average frequency of electric power service interruptions) (2016): 1.3 instances

Total electricity losses (2017): 202 544 GWh

Estimated total cost of 2017 hurricane season: USD 265 billion

Mean shut-in oil production as a percentage of normal monthly production (1995-2012): Intense hurricanes (Cat. 3, 4 and 5): 28.5%

Mean shut-in gas production as a percentage of normal monthly production (1995-2012): Intense hurricanes (Cat. 3, 4 and 5): 25.0%

Number of cyber-vulnerabilities co-ordinated for the energy sector (2016): 186

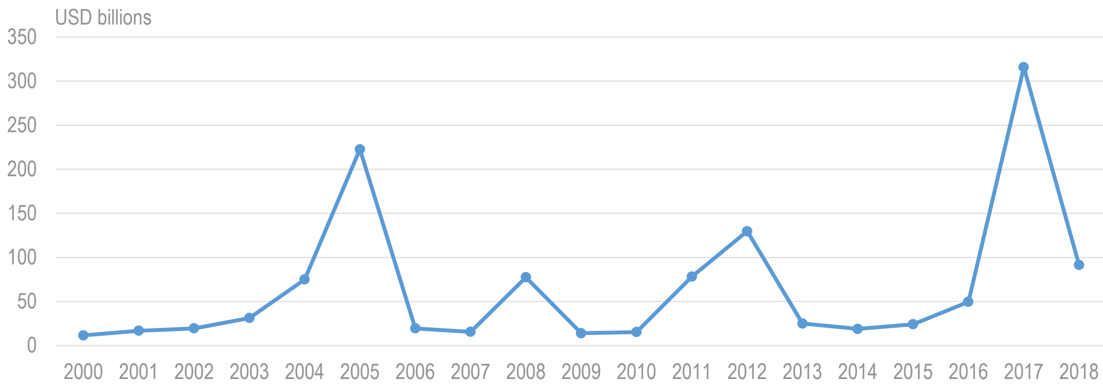
Sources: DOE (2018a) *Office of Cybersecurity, Energy Security and Emergency Response: 2018 Emergency Response Summary*; EIA (2018) *Annual Electric Power Industry Report*; FEMA (2018) *2017 Hurricane Season FEMA After-Action Report*; EIA (2013) *Short-Term Energy Outlook Supplement: 2013 Outlook for Gulf of Mexico Hurricane-Related Production Outages*; NCCIC (2016)), *ICS-CERT Annual Vulnerability Coordination Report.*

Overview

Being prepared and able to respond efficiently and effectively to extreme weather events, cyberattacks, climate change or other hazards has become important for maintaining energy security in the United States (US) (Figure 12.1). The United States has strong emergency response mechanisms for its national security, including energy security. In light of increasing and new threats, both natural and human-caused, the United States has been strengthening its work on preparedness – by improving comprehensive risk assessment, planning and information sharing – as part of its National Security Strategy 2017. The 2015 Fixing America's Surface Transportation (FAST) Act and 2017 National Security Strategy also reinforced the importance of intra-agency communication and co-ordination as part of emergency preparedness and response for energy supply disruptions as well as resiliency of electricity, oil and natural gas infrastructure.

US energy infrastructure, much of which crosses state borders, is mostly owned and operated by private entities or local governments, and incidents regularly affect several jurisdictions simultaneously. Therefore, a federal and well-coordinated approach that engages the private sector, regulators, and state and local governments is essential.

Figure 12.1 Losses from billion-dollar weather events (inflation-adjusted)



Note: 2018 data are preliminary.

Source: NCEI (2019), *U.S. Billion-Dollar Weather and Climate Disasters*, www.ncdc.noaa.gov/billions/.

Definition of resilience

In a narrow sense, resilience can be defined as the ability to withstand and recover rapidly from disruptions, including from accidents, natural disasters, and stresses, shocks and threats to economic and political systems (ACE, 2018).

Energy resilience in a broader sense extends to ensuring a comprehensive risk management framework, going beyond addressing immediate supply disruptions. Rather, it emphasises prevention of and preparation for a potential crisis, flexible adaptation, and efficient recovery. Resilience also provides for the assessment of medium- to long-term risks, including more extreme weather events, as well as new technology threats such as cyberattacks on power grids and oil and gas facilities, thereby covering all interconnected components of the energy sector.

A 2016 document titled *State Energy Resilience Framework* from the Department of Energy's (DOE's) Argonne National Laboratory outlined a set of resilience-enhancing measures for state and local governments based on key components of resilience over time, which are to anticipate, resist, absorb, respond, adapt and recover (Table 12.1).

Table 12.1 Components of resilience and resilience-enhancing measures

Resilience-enhancing measures	Components of resilience	Definition
Preparedness	Anticipate	Activities taken by an entity to define the hazard environment to which it is subject.
Mitigation	Resist and absorb	Activities taken prior to an event to reduce the risk by reducing consequences, vulnerabilities and threats/hazard.
Response	Respond and adapt	Immediate and ongoing activities, tasks, programmes and systems that have been undertaken or developed to manage the adverse effects of an event.
Recovery	Recover	Activities and programmes designed to effectively and efficiently return conditions to a level that is acceptable to the entity.

Source: DOE (2016), *State Energy Resilience Framework*,
www.energy.gov/sites/prod/files/2017/01/f34/State%20Energy%20Resilience%20Framework.pdf.

Institutional governance

The US Department of Homeland Security (DHS) is responsible for emergency response across the country and sectors. *The 2014 Quadrennial Homeland Security Review* (*QHSR*) established a series of goals and objectives in the areas of critical infrastructure, global movement and supply chain systems, and cyberspace (DHS, 2014). Under QHSR Mission 5, the DHS has worked to strengthen national preparedness and resilience. The Federal Emergency Management Agency (FEMA) developed the National Incident Management System (NIMS), which was refreshed in 2017 (FEMA, 2017). FEMA was established in 1979 as the statutory authority for federal disaster relief response with the objective to facilitate the restoration of damaged energy systems and components during a declared emergency. The Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1988 established the procedure, still in place today, under which a presidential declaration of an emergency triggers FEMA response and financial assistance.

The US DOE oversees national energy security issues in collaboration with other relevant government authorities, states and industry partners. The creation of the DOE Office of Cybersecurity, Energy Security, and Emergency Response (CESER) in February 2018 brought together a range of US national energy security mechanisms (DOE, 2018c). The DOE Infrastructure Security and Energy Restoration (ISER) division is housed within CESER and is the lead for DOE's efforts as the Sector-Specific Agency (SSA) for energy as specified under Presidential Policy Directive 21 (PPD21) on Critical Infrastructure Security and Resilience, and as the co-ordinating agency for Emergency Support Function 12 (ESF-12) under the National Response Framework. For fiscal year 2019, the federal budget allocated USD 120 million to CESER, of which USD 90 million was dedicated to cybersecurity. CESER's capabilities involve emergency response, real-time monitoring and training nationally, with neighbouring countries (Canada and Mexico) as well as overseas (Ukraine).

CESER's emergency response programme is co-ordinated with FEMA on all hazards incidents that affect the energy sector (oil, gas and electricity). During an incident it keeps policy makers informed; provides real-time monitoring and energy outage and supply information; co-ordinates and communicates with state, local, tribal, territorial, industry and interagency stakeholders; and deploys staff under the National Response Framework (NRF).

ISER serves as the day-to-day interface between the federal government and the private-sector entities that own approximately 87% of US energy infrastructure. CESER co-chairs the Energy Sector Government Coordinating Council (EGCC) to represent the needs and interests of the sector across the government, and it co-chairs joint meetings of EGCC and the Electricity Subsector Coordinating Council, and EGCC and the Oil and Natural Gas Subsector Coordinating Council.

CESER, together with energy stakeholders, prepares for various types of emergencies through exercises such as Clear Path (DOE's annual energy sector incident response exercise with local, state and industry partners) and GridEx (Grid Security Exercise Series), which help DOE, industry and government partners test and improve plans, as well as share insights for future research and development (R&D) needs. In case of an emergency, CESER facilitates co-ordination across the government and with the energy sector to enhance response and recovery efforts while co-ordinating federal capabilities to mitigate the impact of energy disruptions.

The DOE has provided grants to state energy offices to develop energy security plans, including gas allocation, demand restraint policies and associated regulations. The DOE maintains a mechanism whereby it can work effectively with individual states during emergencies.

The DOE also works regularly with private-sector utilities to address critical energy infrastructure challenges, including resiliency.

Under the direction of the Federal Energy Regulatory Commission (FERC), the North American Electricity Reliability Corporation (NERC) is the national entity most responsible for the oversight of standards relating to short-term (operational) reliability in US electricity systems (see also Chapter 9, “Electricity”). Many areas are outside of FERC’s jurisdictional responsibility and are overseen by state public utility commissions. FERC is an independent federal agency tasked with regulating the interstate transmission of electricity and the operation of wholesale electricity markets. (The commission also regulates interstate flows of natural gas and liquefied natural gas [LNG] export terminals.)

NERC and FERC created an information-sharing hub for cybersecurity, and NERC has upgraded reliability standards over time to address new cybersecurity risks. FERC, NERC, the Electricity Information Sharing and Analysis Center, the Computer Emergency Response Teams of the Industrial Control Systems and the Cyber Threat Intelligence Integration Center all are active in this space.

On climate change resilience specifically, the Environmental Protection Agency (EPA) oversees planning and adaptation strategies at the federal level. The National Oceanic and Atmospheric Administration (NOAA) under the Department of Commerce serves as the main scientific body to assess climate change risks and resilience (see Chapter 3, “Energy and Climate Change”).

Energy resilience policies

This section explains federal emergency response policies and federal resilience policies, including the ability of federal assistance to rebuild more resilient infrastructure, including energy infrastructure, after a disaster.

In 2013, the PPD21 played an important role in promoting the concept and importance of resilience. The energy sector is one of the 16 sectors classified as having critical infrastructure for security and resilience in the United States. The federal government is responsible for strengthening the security and resilience of critical infrastructure, including the energy sector. According to the PPD21, resilience is defined as “the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions”. It includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. Focus on preparedness, in particular, increased under the PPD21.

The FAST Act of 2015, which amended the Federal Power Act of 1935, includes several components to improve the security of US energy infrastructure. The FAST Act provides the Secretary of Energy with broad new authority to address grid security emergencies (US Congress, 2014). "Grid security emergency" is defined to include a physical attack, "a malicious act using electronic communication or an electromagnetic pulse, or a geomagnetic storm event". Also as part of the FAST Act, FERC and the DOE are required to develop and implement processes and tools to protect critical electric infrastructure information and to facilitate needed sharing of this information among stakeholders to ensure security and resilience of energy infrastructure during emergencies. In addition, the FAST Act provides authority for the DOE to mandate specific actions to protect energy infrastructure in response to a grid security emergency, as identified by the president. These actions include: 1) assessing and monitoring risk; 2) developing and implementing new protective measures to reduce risk; 3) managing incidents; and 4) sustaining security improvements.

In addition, recent amendments to Section 406 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act) authorise FEMA to provide contributions to state, local and certain private non-profit organisations to repair public facilities damaged by a major disaster. The reconstruction should be done according to the latest standards that incorporate a hazard-resistant design. This provision requires FEMA to fund improvements in infrastructure resilience, including energy infrastructure resilience, rather than limit the repair or replacement of damaged assets to pre-disaster design. The DOE provides technical support to FEMA in the identification of relevant energy infrastructure hazard-based codes and standards, and the development of implementing policy to the Disaster Recovery Reform Act of 2018.

Incident emergency response

The DHS develops supporting guides and tools to assist jurisdictions in their implementation of the NIMS, which guides all levels of government, non-governmental organisations and the private sector to work together to respond to and recover from incidents. The NIMS applies to all incidents, from traffic accidents to major disasters, and provides all stakeholders with the shared vocabulary, systems and processes to successfully deliver the capabilities described in the National Preparedness System. Finally, the NIMS defines operational systems, including the Incident Command System, Emergency Operations Center structures and Multiagency Coordination Groups that guide how personnel work together during incidents.

The NRF is a guide to how the nation responds to all types of disasters and emergencies. It is built on scalable, flexible and adaptable concepts identified in the NIMS to align key roles and responsibilities across the nation. This framework describes specific authorities and best practices for managing incidents that range from serious but purely local, to large-scale terrorist attacks or catastrophic natural disasters.

When there is a potential major incident, such as a hurricane, ISER begins preparing staffing plans to co-ordinate its emergency response duties. Working with FEMA, ISER dispatches responders to both State Emergency Operations Centers in threatened states and the FEMA Regional Response Coordination Center in the threatened region(s) in advance of the incident (DOE, 2018c).

Once a disaster happens, on-the-ground ISER responders provide subject matter expertise to state and industry partners about assessing the disaster's impacts on the energy sector, restoring the system to full capacity, and identifying any unmet needs that may require federal support or co-ordination. Throughout the restoration period, ISER holds daily calls with both the electricity and the oil and natural gas subsectors to ensure there is a unified response effort, as well as co-ordination calls with the impacted states and various federal partners. ISER also provides twice-daily situation reports and analysis of impacts to the energy sector, including potential regional and national impacts for large events.

For areas where restoration may be prolonged, ISER responders work closely with local utilities, the affected state(s), FEMA and the US Army Corps of Engineers on temporary emergency power requirements.

Table 12.2 ISER response efforts, 2018

Emergency response period	Event	Region/State
August 2017 - August 2018	Hurricane Maria	Puerto Rico
February 2018	Cyclone Gita	American Samoa
May-June 2018	Kilauea volcano	Hawaii
July-August 2018	Carr wildfire	California
August 2018	Hurricane Hector	Hawaii
August 2018	Hurricane Lane	Hawaii
September 2018	Hurricane Isaac	US Virgin Islands, Hawaii
September 2018	Hurricane Olivia	Hawaii
September 2018	Hurricane Florence	Alabama, Florida, Georgia, North Carolina, South Carolina
September 2018	Typhoon Manghkut	Guam, Northern Mariana Islands
October 2018	Hurricane Michael	Florida, Georgia, North Carolina, Virginia, Maryland
November 2018	Camp and Woolsey wildfires	California
November 2018-January 2019	Typhoon Yutu	Guam, Northern Mariana Islands
November-December 2018	Alaska earthquake	Alaska

Source: DOE (2018a), *2018 Emergency Response Summary*, www.energy.gov/ceser/articles/2018-emergency-response-summary.

ISER reviews response and recovery processes to improve its emergency response organisation capabilities and optimise future recovery support. For remote locations, the recovery efforts are reviewed extensively, with issues of grid resilience and energy reliability taking priority in future response planning efforts.

Exercises

Emergency response exercises are a crucial part of ensuring that industry and government are well prepared to work together during emergencies, both naturally occurring and human-caused. The DOE (through ISER) sponsors preparedness exercises at the local, state and national levels. In May 2018, for example, the DOE sponsored Clear Path VI, which addressed co-ordination between industry, state and federal partners in managing interdependencies within and between infrastructure sectors. Clear Path VI was linked to the FEMA National Level Exercise 2018, which focused on the response and recovery from a major hurricane impacting the Mid-Atlantic region. ISER also sponsors the Liberty Eclipse series, which is an exercise to assess the grid's ability to recover from a significant cyberattack. Another relevant example is GridEx, which is a NERC-sponsored (with ISER support) biennial exercise designed to simulate cyber- and physical attacks on electric and other critical infrastructures across North America.

After each exercise or emergency incident, lessons learned are developed, which result in corrective actions and improvements to the DOE's plans, policies and procedures. Once these corrections are made, the responders train towards the corrections and validate the training and corrections through exercises. This is referred to as the preparedness cycle, as referenced in Presidential Policy Directive 8.

Climate resilience

Several studies have assessed in depth how the US energy sector can improve its resilience to climate change. These include, among others, the *Regional Energy Sector Vulnerabilities and Resilience Solutions* report published by DOE:

- "U.S. energy sector vulnerabilities to climate change and extreme weather" (DOE, 2013)
- *Climate Change and the U.S. Energy Sector: Regional Vulnerabilities and Resilience Solutions* (DOE, 2015)
- *Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning* (DOE, 2016a) and "A review of climate change vulnerability assessments: Current practices and lessons learned from DOE's Partnership for Energy Sector Climate Resilience" (DOE, 2016b).

The *Fourth National Climate Assessment, Vol II: Impacts, Risks, and Adaptation in the United States*, led by the NOAA and published in 2018, is the fourth report in the *National Climate Assessment* series and focuses on the human welfare, societal and environmental elements of climate change and variability for 10 regions and 18 national topics (GlobalChange.gov, 2018). The DOE led the development of the energy chapter that characterises the effects of climate change on the energy supply, delivery and demand sectors in the United States. In addition to analysing the climate adaptation challenges (Table 12.3), the report also assesses how the US energy sector can enhance its resilience to climate change.

The report lays out current efforts to increase the resilience of the energy system in the United States (Table 12.3). Energy companies, utilities and system operators are increasingly adopting data collection methods, modelling and data analysis to support planning activities that enhance the climate resilience of energy systems. For instance, coastal infrastructure planning is beginning to consider rising sea levels and the risk of flooding, while thermal power plants started taking into account the potential changes to fuel and water supplies. Private and public-private partnerships are increasingly used to support co-ordinated action on climate resilience in the sector. The deployment of new, innovative energy technologies (e.g. alternative cooling systems that reduce water withdrawals, or use non-traditional water sources) for adapting energy assets to extreme weather hazards has also started improving the resilience of the energy system. However, some key barriers to scaling up resilience efforts in the US energy sector still exist, including the lack of reliable projections of climate change at the local level and the associated risks to energy assets, and the lack of national or regional cost-effective risk reduction design standards and strategy.

Table 12.3 Potential energy sector impacts from extreme weather and climate change

Energy demand	- Higher summer temperatures drive increasing demand for cooling energy (primarily electricity). - Higher winter temperatures drive reduced demand for heating energy (including natural gas, oil and electricity).
Electric grid	- Winds, ice storms and wildfires damage transmission and distribution towers/lines. - Extreme heat reduces power line/transformer capacity. - Flooding can damage substations/transformers/underground lines.
Wind, solar and biofuels	- Changes in wind patterns and solar resources impact generation. - Extreme winds damage wind and solar infrastructure. - Increasing temperatures reduce generating capacity. - Extreme heat/drought reduces biofuels production.
Hydropower	- Drought and reduced run-off reduce power production. - Earlier snowmelt shifts peak production earlier in the year. - Flooding increases risk of damage and disruption.
Thermoelectric power	-Higher air and water temperatures can reduce power plant efficiency and capacity. - Reduced water availability can reduce capacity and lead to shutdowns. - Inland and coastal flooding can disrupt operation and damage equipment. - Increasing scarcity of fresh water can limit siting of new generation.
Fuel transport	- Inland and coastal flooding inundates low-lying roads and rails and can damage bridges, river and coastal ports, and storage facilities. - Reduced river run-off can impede barge traffic. - Extreme weather, flooding and blackouts can disrupt distribution outlets and gas stations.
Refineries	- Extreme weather/flooding damages refineries. - Reduced water availability can constrain fuel refining and processing. - Loss of electricity impacts refining operations.
Pipelines	- Flooding damages pumping stations, undermines/scours river crossings. - Loss of electricity impacts pumping operations.
Oil, gas and coal	- Extreme weather, sea level rise and flooding disrupt/damage offshore and onshore energy operations and facilities. - Reduced water availability constrains drilling, fracking and mining operations. - Thawing permafrost and subsidence reduce access and impact production.

Source: NOAA (2018), *Fourth National Climate Assessment, Vol II: Impacts, Risks, and Adaptation in the United States*.

Table 12.4 Examples of energy sector resilience solutions

Flood protection	- Building/strengthening berms, levees and flood walls - Elevating substations, control rooms and pump stations - Expanding wetlands restoration - Installing flood monitors

Wind protection	- Inspecting and upgrading poles and structures - Burying power lines underground - Improving vegetation management efforts
Drought protection	- Adopting water-efficient thermoelectric cooling - Utilising non-freshwater sources - Expanding low-water-use generation
Modernisation	- Deploying sensors and control technology - Installing asset databases/tools, including supervisory control and data acquisition system redundancies - Deploying energy storage and microgrid infrastructure (distributed energy resources, demand response programmes, islanding capabilities)
Advanced planning and preparedness	- Conducting extreme weather risk assessment planning, preparedness and training - Participating in mutual assistance groups and public-private partnerships - Purchasing or leasing mobile transformers and substations - Utilising geographic information system (GIS) analysis to help identify vulnerabilities and plan for new builds and relocations
Storm-specific readiness	- Co-ordinating priority restoration and waivers - Securing emergency fuel contracts - Improving communication during outages to assist customers

Source: NOAA (2018), *Fourth National Climate Assessment, Vol II: Impacts, Risks, and Adaptation in the United States*.

As previously mentioned, the DOE works regularly with private-sector utilities to address critical energy infrastructure challenges, including resiliency.

The US Climate Resilience Toolkit (CRT) was launched in November 2014 and is managed by the NOAA Climate Program Office and hosted by the NOAA National Centers for Environmental Information (U.S. Climate Resilience Toolkit, 2019). The tool is a result of interagency co-ordination and initiative among the NOAA, US Geological Survey, Bureau of Reclamation, EPA and National Aeronautics and Space Administration (NASA), with guidance from the US Global Change Research Program. As part of the US federal climate data-sharing initiative, the toolkit is a website designed to help people and institutions find and use tools, information and expertise to promote climate resilience.

Mapping and monitoring climate risks requires a solid database. Given the importance of the energy-climate nexus, energy is examined as one of ten topics under the CRT with a particular focus on the impact of climate change on energy security. The DOE in collaboration with the NOAA and NASA has included climate data relevant for energy sector resilience planning.

Climate-related factors are critical to energy production and demand, notably when it comes to water and cooling needs, or the geographic location of infrastructure (see also Chapter 3, “Energy and Climate Change”).

Energy production

Energy production in the United States is exposed to climate-related environmental changes, which can reduce the efficiency of energy production, especially for production processes that require water for cooling, thereby straining the resilience of energy systems.

Water withdrawals for hydraulic fracturing represent a large demand for fresh water in the United States, and when water supplies are constrained, it affects the supply of oil and natural gas. In 2012, during one of the worst droughts in US history, certain companies that extract oil and gas using hydraulic fracturing faced higher water costs or were denied access to water for six weeks or more in several states, including Kansas, Texas, Pennsylvania and North Dakota. Some companies started to reuse hydraulic fracturing fluids to reduce freshwater requirements (EPA, 2019a).

Decreased precipitation, increased evaporation and increased temperatures associated with climate change may also reduce longer-term energy production in some regions such as the Southeast, Southwest and Northeast. For instance, water needs for cooling in power plants (the United States has a large nuclear and coal-fired power plant fleet) represents the largest demand for fresh water in the country, accounting for up to 41% of total water withdrawals in some regions. If water supplies are constrained, the supply of energy could be as well.

The Fourth National Climate Assessment also notes that in warmer climate, the efficiency of thermal power plants as well as the efficiency of transmission and distribution lines decline.

Reliable hydropower generation is also at risk as precipitation levels decline and seasonal streamflow becomes more irregular; California periodically faces serious water shortages and has cut the water use of its energy infrastructure.

Energy consumption

As the average temperature goes up, a combination of milder winters and hotter summers is expected to result in a net increase in energy consumption at a national level, but regional impacts may vary. Hotter and longer summers will increase power demand for air conditioning or cooling, particularly in the Southeast and Southwest parts of the country, while warmer winters will reduce the natural gas demand for heating, notably in the Northeast, Midwest and Northwest (EPA, 2019b).

The mix of energy sources in different regions may also change. Since heating depends on a mixture of electricity, fuel oil and natural gas, whereas cooling primarily uses electricity, the rise in temperature over time will increase demand for electricity and reduce demand for fuel oil and natural gas. These changes will alter the resilience attributes of the energy system, and increase the need to bolster electricity infrastructure resilience, in particular (EPA, 2019c).

Energy infrastructure siting

Making the most informed choices for siting, operating and managing energy facilities can promote resilience in the energy sector. Energy infrastructure assets are increasingly exposed to the threats of rising sea levels and extreme weather events. Sea level rises and resulting higher storm surges have the potential to impact multiple major energy facilities along the coast of the United States, such as power plants in California or oil and gas facilities near the Gulf of Mexico.

Planning flexible operation schedules to better manage energy peak hours; deploying more climate-resilient technologies, such as decentralised renewable energy; smart grids; ensuring regional multi-fuel product reserves for supply disruptions; and diversifying supply chains to reduce the risks against various disruptions can all help enhance the overall level of resilience in the energy sector.

Resilience in electricity

Outages caused by extreme weather events in the United States provide an indication of the vulnerability of the energy infrastructure, notably of electricity grids. Lessons learned from hurricanes are plentiful and have helped to render infrastructure more secure and safe.

Established after the North American blackout in 2003, NERC regularly assesses risks to the bulk power system by conducting regular short-term and long-term reliability assessments under the supervision of FERC, and in close collaboration with industry, market participants and the DOE (see also Emergency Response section in Chapter 9, "Electricity") (NERC, 2017). NERC co-ordinates action across regions, the so-called reliability councils, which cover several interconnected systems, including areas in Canada. NERC ensures the reliability of the bulk power system by setting harmonised reliability standards across the United States and Canada, including the following:

- transmission planning: specifies transmission planning requirements for ensuring the bulk system will operate reliably for future forecast scenarios across normal and credible contingency conditions
- protection and control: specifies protection and control performance requirements to ensure operational reliability of the bulk system
- critical infrastructure protection: specifies requirements for identifying and protecting critical electric power sector infrastructure across a broad range of potential threats
- generation and load balancing: specifies performance requirements for ensuring system frequency remains within acceptable ranges as supply resources balance supply in real time
- transmission operation: specifies requirements to ensure that the transmission system is scheduled, operated and monitored to ensure operational reliability
- interconnection reliability operations and co-ordination: specifies co-ordination requirements to ensure operational reliability across regions of the interconnected power system
- emergency preparedness and operations: specifies requirements to ensure a return to reliable operation as efficiently as possible after wide-area system disturbances.

Over the past years, the DOE and NERC have evaluated the impacts of possible gas supply disruptions on electricity security, amid the fast growth of natural gas-fired power generation, although without a focus on improving the resilience of the gas infrastructure itself. Most recently, NERC issued "Special reliability assessment: Potential bulk power system impacts due to severe disruptions on the natural gas system" in November 2017. In 2018, FERC opened a generic proceeding on bulk power resilience.

The DOE's Grid Modernization Initiative also assesses resilience across the strongly integrated North American energy system more broadly. Specifically, the initiative co-ordinates across the DOE and collaborates with public and private partners to develop grid technologies that are better suited to changes in the power mix, especially the integration of larger shares of variable renewable generation.

One of the lessons learned from past electricity blackouts relates to the role that decentralised renewable energy can play to improve resilience by expanding flexibility in the power system through diversification of resources and technologies.

Resilience in oil and gas infrastructure

Resilience options for the oil and gas sectors depend heavily on the threats facing critical energy infrastructure (see also Emergency Response section in Chapter 7, "Oil" and Chapter 8, "Natural Gas").

Upstream

In 2005, Hurricanes Katrina and Rita inflicted significant damage on Gulf Coast wells and refineries, destroying 115 offshore platforms and damaging 52 others, damaging 535 pipeline segments, and causing a near total shutdown of the Gulf's offshore oil and gas production for several weeks. A more recent example was Hurricane Harvey, which made landfall in late August 2017 as a Category 4 hurricane, making it the strongest storm to strike Texas since 1961. The hurricane had severe impacts on onshore and offshore production and caused dramatic flooding in Houston. Logistical issues ranging from diesel shortages to difficulties getting sand to well sites for hydraulic fracturing operations delayed return to normal operations for several weeks (see also chapters 7 and 8).

Downstream

Hurricane rains and flooding can also cause extensive damage to refineries, and normally result in extended recovery times. The hurricanes of 2005 and 2008 caused extensive water damage to refinery control systems, electrical equipment and pump motors, and caused storage tanks to move off their foundations. In response, government and industry have built common flood protection structures such as flood walls. In response to extensive water damage, many refineries have also elevated substations, control rooms and pump stations above the likely flood level. In many cases, facilities have been elevated 15 feet to 25 feet above ground level.

A number of refineries have invested in portable generators, but the majority of facilities have instead established plans that enable them to quickly lease generators in advance of an approaching hurricane. Even the largest mobile generators, however, cannot provide sufficient electricity supply to operate a refinery. Refiners rely on portable generators only to provide critical service (the data control centre, critical information and technology facilities, and the water pumps) or safely shut down operations until grid power can be restored. Winds of hurricane strength can cause severe damage to refineries, and their cooling towers are especially susceptible to wind damage. High winds can cause the fan blades inside a cooling tower to become dislodged and launched from the tower if they are not properly secured. Several refiners have installed special braces to stop the fan blades from dislodging.

As a more recent example, in August 2017, Hurricane Harvey also affected US LNG exports; the Sabine Pass terminal stopped loading LNG vessels for 12 days. In the meantime, 10 LNG vessels were waiting in the Gulf of Mexico to be loaded. As this experience has shown, extreme weather events can cause significant damage to energy infrastructure and disruption to supplies, highlighting the critical importance of resilient and flexible supply chains that are able to adapt and respond to domestic disruptions.

Midstream

The DOE collaborates regularly with the other government entities and the private sector regarding natural gas infrastructure, safety and reliability. Additionally, it works with the National Association of Regulatory Utility Commissioners to provide technical assistance to states interested in natural gas infrastructure modernisation.

After the Aliso Canyon leak in Los Angeles from October 2015 to February 2016, the Pipeline and Hazardous Materials Safety Administration (PHMSA) released an interim final rule on underground gas storage in December 2016. This interim final rule revised the federal pipeline safety regulations to address critical safety issues related to wells, wellbore tubing and casing at underground gas storage facilities.

In April 2019, PHMSA issued an advisory bulletin to remind all operators of gas and hazardous liquid pipelines of the potential for damage to pipeline facilities caused by severe flooding and pointed to actions that operators should consider taking to ensure the resilience and integrity of pipelines (PHMSA, 2019).

Although significant progress has been made, there are limited mechanisms at the federal level to assess reliability and adequacy of privately owned infrastructure for oil and gas. Permitting and siting as well as export authorisation do not consider the privately owned supply chain across the country or the integrated markets in North America. A supply chain assessment could help inform assessments of security and adequacy of gas supply infrastructure, the role of the Strategic Petroleum Reserve to maintain oil supply in the event of a disruption, and the impact of natural disasters on the oil products supply chain. As the US export infrastructure is becoming a vital backbone of the US and global economy and more exposed to global market trends, maintaining a high level of regional and international security collaboration to foster preparedness and response on the part of the US government will be essential.

Cybersecurity resilience

Increased frequency and sophistication of cyberthreats require a strategic approach based on constructive R&D and advanced technologies. CESER's Cybersecurity Risk Information Sharing Program provides continuous monitoring tools and capabilities for information systems and control networks to identify best practices for cybersecurity (DHS, 2018). CESER's cybersecurity programme supports activities in three key areas:

- strengthening energy sector cybersecurity preparedness
- co-ordinating cyber-incident response and recovery
- accelerating research, development and demonstration (RD&D) of game-changing and resilient energy delivery systems.

The first two strategic efforts are building the energy sector's day-to-day operational capabilities to share cyber-incident information, improve the organisational and process-level cybersecurity posture, and perform cyber-incident response and recovery. The remaining effort is innovating cyber-resilient energy infrastructure through the RD&D of new tools and technologies to reduce the risk that energy delivery is disrupted by a cyber-incident (DOE, 2018d).

With more than 80% of the nation's power infrastructure privately held, co-ordinating and aligning efforts between the government and the private sector is vital. To achieve its vision, CESER works closely with representatives of the energy sector, companies that manufacture energy technologies, the national laboratories, universities, other government agencies and other stakeholders.

Recent examples of research being conducted with a combination of these partners are:

- Efforts in utilising cloud computing, which could be used to optimise operations of the power grid.
- Utilising lessons learned from cyberattack research that will be applied to the development of attack-resilient and self-healing attributes of the respective applications.
- The Artificial Diversity and Defense Security project, which will develop solutions to introduce unpredictability and enhance situational awareness to energy delivery control systems.

The National Institute of Standards and Technology Cybersecurity Framework provides standards, guidelines and best practices for private-sector organisations to help manage their cybersecurity-related risks. The framework is available on a voluntary basis to owners and operators of critical infrastructure.

The Cybersecurity Capability Maturity Model (C2M2) programme is a public-private partnership effort that was established as a result of US efforts to improve electricity subsector cybersecurity capabilities, and to understand the cybersecurity posture of the grid. The C2M2 helps organisations of all types evaluate, prioritise and improve their own cybersecurity capabilities. The model focuses on the implementation and management of cybersecurity practices in information technology and related systems. In addition to the C2M2, there are two sector-specific models: the Electricity Subsector Cybersecurity Capability Maturity Model and the Oil and Natural Gas Subsector Cybersecurity Capability Maturity Model.

Assessment

The United States continues to strengthen its preparedness and response mechanisms to new threats, such as natural disasters, extreme weather and climate change, cyberattacks, and accidents, in a move to reduce risks and bolster resilience as a matter of national security. Emergency response exercises are a crucial part of ensuring that industry and government are well prepared to work as a team during emergencies, whether naturally occurring or human-caused.

While response mechanisms are strong in the United States, preparedness is becoming even more important. The 2017 US National Security Strategy stresses the need to improve risk assessment, build a culture of preparedness, and improve planning and information sharing. The regular assessment of vulnerabilities is vital in this context and would need to encompass the entire energy sector, notably oil, gas and electricity. Using the outcomes of these assessments and learning from incidents such as natural disasters are vital to improve the resilience of the US energy infrastructure.

Since the last International Energy Agency (IEA) review, the government has adopted a suite of policies and mechanisms that have reinforced preparedness. The energy sector is one of 16 sectors classified for critical infrastructure security and resilience. Interagency co-ordination was strengthened under the 2015 FAST Act and by the NIMS under FEMA and the DHS.

The creation of CESER in the DOE in February 2018 marked strong progress. CESER acts as the energy SSA and is responsible for leading sector co-ordination and enabling sector-specific technical assessments and assistance. ISER within CESER is the lead on ESF-12 under the NRF, and is the designated energy SSA under PPD21 for national efforts. ISER works in co-operation with public and private-sector stakeholders to enhance the preparedness, resilience and recovery of the US energy sector (oil, natural gas and electricity) from all threats and hazards, including cyber-risks.

The DOE is well placed to lead efforts to regularly assess risks, in collaboration with other government authorities, states and industry, and to give guidance to improve the quality and ability of infrastructure to withstand natural disasters. Still, there are a number of agencies involved in the collection and dissemination of threat incidence information and response actions, which might potentially lead to overlap and inefficiencies within those agencies involved. With the creation of CESER, there is an excellent opportunity to strengthen effective collaboration to foster preparedness and response to cybersecurity threats.

NERC, under the supervision of FERC and in close collaboration with industry and market participants and the DOE, monitors emerging risks to the bulk power market by conducting regular short-term and long-term reliability assessments. Over the past years, the DOE and NERC have evaluated the impacts of possible gas supply disruptions on electricity security, amid the fast growth of natural gas-fired power generation, although without a focus on improving the resilience of the gas infrastructure itself. In 2018, FERC opened a generic proceeding on bulk power resilience. The DOE’s Grid Modernization Initiative also assesses resilience across the strongly integrated North American energy system more broadly.

For gas and oil, there are limited mechanisms at the federal level to assess reliability and adequacy of privately owned infrastructure, as permitting and siting as well as export authorisation do not consider the privately owned supply chain across the United States or the integrated markets in North America. As US export infrastructure is becoming a vital backbone of the country and global economy and is more exposed to global market trends, the US government should maintain a high level of regional and international security collaboration to foster its preparedness and response.

The number of outages caused by extreme weather events provides an indication of the vulnerability of the energy infrastructure, notably for electricity grids. Widespread industry adoption of resiliency measures for energy infrastructure have been limited to date by lack of full definition of design standards and understanding of their associated cost and benefit. Hence, partial renovation and modernisation of the existing facilities and better advance planning are essential to improve the resilience of the energy infrastructure. The US government should continue to work with government and industry stakeholders to strengthen the resilience of the energy infrastructure against weather damage, especially as the impacts of climate change become more pronounced in future years. Lessons learned from hurricanes, intense storms and wildfires are ample and have helped to render infrastructure more secure and safe.

Recent amendments to Section 406 of the Stafford Act authorise FEMA to provide contributions to state, local and certain private non-profit organisations for the repair or replacement of a public facility damaged by a major disaster.

The DOE provides technical support to FEMA in the identification of relevant energy infrastructure hazard-based codes and standards. Cybersecurity is a top priority for the government; CESER also acts to address the threats from cyberattacks and protect the reliability and security of the energy sector. Cyberthreats against utilities and the electric grid are growing in frequency. In order to protect the electric grid from significant disruption, it is critical to share threat information with stakeholders in a timely fashion.

CESER's emergency response programme co-ordinates with FEMA on all hazards incidents that affect the energy sector (oil, gas and electricity). During an incident it keeps leadership informed; provides real-time monitoring and energy outage and supply information; co-ordinates and communicates with state, local, tribal, territorial, industry and interagency stakeholders; and deploys staff under the NRF. A key goal is to facilitate the re-establishment of damaged energy systems and components during a declared Stafford Act emergency.

Recommendations

The US government should:

- Run regular risk assessments based on a holistic approach, looking at a variety of risks (cyber, reliability, extreme weather impacts), across fuels (oil, natural gas, electricity) and energy infrastructure (grids, power plants, gas/oil pipelines) to improve preparedness and devise actions to mitigate the risks identified, in collaboration with other relevant government authorities and industry.
- Allocate sufficient resources to ensure effectiveness of CESER and its collaborative structures.
- Strengthen mechanisms to ensure timely sharing of relevant information on all hazards including cyberthreats to participants in the bulk power system.
- Maintain high levels of regional and international security collaboration with partners on oil, gas and electricity resilience.
- Support the development of innovative resilient energy technologies and frameworks for energy infrastructure to effectively mitigate current and future risks.

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ANNEX A: Organisations visited

Review criteria

The Shared Goals, which were adopted by the IEA Ministers at their 4 June 1993 meeting in Paris, provide the evaluation criteria for the in-depth reviews (IDRs) conducted by the International Energy Agency (IEA). The Shared Goals are presented in Annex C.

Review team and preparation of the report

The IEA's joint in-depth review and emergency response review team visited the United States from 24 September-1 October 2018. The team met with government officials, energy companies, interest groups, research institutions, and other organisations and stakeholders. This report was drafted on the basis of the review team's preliminary assessment of the country's energy policy and information on subsequent policy developments from the government and private-sector sources. The members of the team were:

IEA member countries:

Mr. Rob Heferen, Australia (team leader)

Mr. Gumersindo Cue Aguilar, Mexico

Mr. Brad Little, Canada

Mr. Torgeir Knutsen, Norway

Mr. Sergio López Pérez, Spain

European Union:

Mr. Ruben Kubiak

OECD Nuclear Energy Agency:

Mr. Henri Paillere

IEA Secretariat:

Mr. Aad van Bohemen

Ms. Sylvia Beyer

Ms. Lucie Girard

The team is grateful for the co-operation and assistance of the many people it met throughout the visit in Washington. Thanks to their kind hospitality, openness and willingness to share information, the visit was highly informative, productive and enjoyable. The team expresses particular gratitude to the Department of Energy for organising the visit, especially Glen Sweetnam and Gina Erickson. The team is also sincerely grateful to Dan Brouillette, Deputy Secretary of Energy, Theodore Garrish, Assistant Secretary for the Office of International Affairs, and Andrea Lockwood, Deputy Assistant Secretary for Africa, Middle East, Europe & Eurasia, for all their support throughout the review process.

Sylvia Beyer managed the review visit, while Divya Reddy drafted the report, with the exception of the oil, gas and resilience chapters, which were drafted by Lucie Girard and Jihyun Selena Lee. Henri Paillere from the Nuclear Energy Agency drafted the nuclear chapter.

The report was prepared under the guidance of Aad van Bohemen, Head of Energy Policy and Security Division. Helpful comments and updates were provided by the review team members and IEA staff, including Carlos Fernandez Alvarez, Heymi Bahar, Toril Bosoni, Jean-Baptiste Dubreuil, Peter Fraser, Simone Landolina, Pharoah Le Feuvre, Olivier Lejeune, Luca Lo Re, Diana Louis, Samantha McCulloch, Gergely Molnar, Kristine Petrosyan, Andrew Prag, Joe Ritchie, Sacha Scheffer and Matthew Wittenstein.

Oskar Kvarnström and Lilly Lee prepared the figures. Roberta Quadrelli and Faidon Papadimoulis provided support on statistics. Therese Walsh managed the editing process, Astrid Dumond, Isabelle Nonain-Semelin and Clara Vallois managed the production process. Jad Mouawad supported the press launch.

Organisation visited

During its visit in Washington, the review team met with the following organisations:

American Coal Council
American Coalition for Clean Coal Electricity
American Council for an Energy-Efficient Economy
American Petroleum Institute
BP America Inc.
Business Council for Sustainable Energy
Chevron Corporation
ClearPath
District of Columbia Public Service Commission
Duke University, Nicholas Institute for Environmental Policy Solutions
Edison Electric Institute
Electric Power Research Institute
Energy Information Administration
Energy Policy Research Foundation, Inc.
Environmental Protection Agency
Federal Energy Regulatory Commission
Fuel Cell & Hydrogen Energy Association
Geothermal Resources Council
Grid Strategies, LLC
Institute for Energy Research

Lawrence Berkeley National Laboratory

National Association of Regulatory Utility Commissioners

National Association of State Energy Officials

National Association of State Utility Consumer Advocates

National Hydropower Association

National Energy Technology Laboratory

North American Electric Reliability Corporation

Nuclear Energy Institute

Nuclear Regulatory Commission

Pacific Northwest National Laboratory

Partnership for Affordable Clean Energy

PJM

United States Council for Automotive Research, LLC

U.S. Chamber of Commerce

U.S. Department of Energy

U.S. Department of the Interior

U.S. Department of State

Wilkinson Barker Knauer, LLP

ANNEX B: Energy balances and key statistical data

Energy balances and key statistical data

Unit: Mtoe

SUPPLY		1973	1990	2000	2010	2016	2017	2018P
TOTAL PRODUCTION		**1456**	**1653**	**1667**	**1724**	**1916**	**1993**	**2177**
Coal		333	542	537	532	348	373	368
Peat		-	-	-	-	-	-	-
Oil		535	433	366	348	560	591	693
Natural gas		503	418	447	495	627	642	716
Biofuels and w aste[1]		38	62	73	90	102	103	111
Nuclear		23	159	208	219	219	219	219
Hydro		23	23	22	23	23	26	25
Wind		-	0	0	8	20	22	24
Geothermal		2	14	13	8	9	9	10
Solar/other		-	0	2	2	7	8	11
TOTAL NET IMPORTS[2]		**282**	**300**	**559**	**486**	**221**	**126**	**31**
Coal	Exports	31	68	38	48	36	58	69
	Imports	1	2	10	11	5	4	3
	Net imports	-30	-66	-28	-37	-31	-53	-66
Oil	Exports	11	39	51	115	238	288	343
	Imports	315	413	600	623	512	516	506
	Int'l marine and aviation bunkers	-15	-42	-47	-48	-44	-48	-49
	Net imports	289	333	502	460	229	180	114
Natural gas	Exports	2	2	6	26	53	74	85
	Imports	24	35	88	87	70	70	67
	Net imports	22	33	82	61	17	-4	-18
Electricity	Exports	0	2	1	2	1	1	1
	Imports	1	2	4	4	6	6	5
	Net imports	1	0	3	2	5	5	4
TOTAL STOCK CHANGES		**-8**	**-38**	**47**	**7**	**27**	**37**	**21**
TOTAL SUPPLY (TPES)[3]		**1730**	**1915**	**2274**	**2217**	**2163**	**2155**	**2228**
Coal		311	460	534	503	342	331	317
Peat		-	-	-	-	-	-	-
Oil		817	757	871	807	784	790	806
Natural gas		515	438	548	556	653	644	705
Biofuels and w aste[1]		38	62	73	89	102	101	107
Nuclear		23	159	208	219	219	219	219
Hydro		23	23	22	23	23	26	25
Wind		-	0	0	8	20	22	24
Geothermal		2	14	13	8	9	9	10
Solar/other		-	0	2	2	7	8	11
Electricity trade[4]		1	0	3	2	5	5	4
Shares in TPES (%)								
Coal		*18.0*	*24.0*	*23.5*	*22.7*	*15.8*	*15.3*	*14.2*
Peat		-	-	-	-	-	-	-
Oil		*47.3*	*39.5*	*38.3*	*36.4*	*36.3*	*36.7*	*36.2*
Natural gas		*29.7*	*22.9*	*24.1*	*25.1*	*30.2*	*29.9*	*31.7*
Biofuels and waste[1]		*2.2*	*3.3*	*3.2*	*4.0*	*4.7*	*4.7*	*4.8*
Nuclear		*1.3*	*8.3*	*9.1*	*9.9*	*10.1*	*10.1*	*9.8*
Hydro		*1.3*	*1.2*	*1.0*	*1.0*	*1.1*	*1.2*	*1.1*
Wind		-	-	-	*0.4*	*0.9*	*1.0*	*1.1*
Geothermal		*0.1*	*0.7*	*0.6*	*0.4*	*0.4*	*0.4*	*0.5*
Solar/other		-	*0.0*	*0.1*	*0.1*	*0.3*	*0.4*	*0.5*
Electricity trade[4]		*0.1*	-	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*

0 is negligible, - is nil, .. is not available, x is not applicable. Please note: rounding may cause totals to differ from the sum of the elements.

Unit: Mtoe

DEMAND							
FINAL CONSUMPTION	**1973**	**1990**	**2000**	**2010**	**2016**	**2017**	**2018P**
TFC	**1315**	**1294**	**1546**	**1513**	**1517**	**1520**	**..**
Coal	74	56	33	27	18	17	..
Peat	-	-	-	-	-	-	..
Oil	693	683	793	762	744	748	..
Natural gas	367	303	360	322	338	346	..
Biofuels and waste[1]	37	23	52	68	81	80	..
Geothermal	-	0	1	0	0	0	..
Solar/other	-	-	1	2	2	2	..
Electricity	143	226	301	326	327	321	..
Heat	-	2	5	7	7	6	..
Shares in TFC (%)							
Coal	*5.6*	*4.3*	*2.1*	*1.8*	*1.2*	*1.1*	..
Peat	-	-	-	-	-	-	..
Oil	*52.7*	*52.8*	*51.3*	*50.4*	*49.1*	*49.2*	..
Natural gas	*27.9*	*23.4*	*23.3*	*21.3*	*22.3*	*22.8*	..
Biofuels and waste[1]	*2.8*	*1.7*	*3.4*	*4.5*	*5.3*	*5.3*	..
Geothermal	-	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	..
Solar/other	-	-	*0.1*	*0.1*	*0.1*	*0.1*	..
Electricity	*10.9*	*17.5*	*19.5*	*21.5*	*21.6*	*21.1*	..
Heat	-	*0.2*	*0.3*	*0.4*	*0.4*	*0.4*	..
TOTAL INDUSTRY[5]	**483**	**403**	**485**	**406**	**403**	**407**	**..**
Coal	60	46	30	25	17	17	..
Peat	-	-	-	-	-	-	..
Oil	161	149	161	154	138	140	..
Natural gas	177	124	155	122	144	149	..
Biofuels and waste[1]	29	9	36	29	30	30	..
Geothermal	-	-	0	-	-	-	..
Solar/other	-	-	-	-	-	-	..
Electricity	56	75	98	71	69	67	..
Heat	-	-	4	5	5	5	..
Shares in total industry (%)							
Coal	*12.5*	*11.4*	*6.3*	*6.2*	*4.2*	*4.1*	..
Peat	-	-	-	-	-	-	..
Oil	*33.4*	*37.1*	*33.2*	*37.9*	*34.3*	*34.3*	..
Natural gas	*36.7*	*30.7*	*32.0*	*30.0*	*35.8*	*36.6*	..
Biofuels and waste[1]	*5.9*	*2.2*	*7.4*	*7.1*	*7.4*	*7.4*	..
Geothermal	-	-	-	-	-	-	..
Solar/other	-	-	-	-	-	-	..
Electricity	*11.5*	*18.5*	*20.2*	*17.5*	*17.0*	*16.5*	..
Heat	-	-	*0.9*	*1.3*	*1.3*	*1.1*	..
TRANSPORT[3]	**414**	**488**	**588**	**596**	**622**	**625**	**..**
OTHER[6]	**419**	**403**	**473**	**511**	**493**	**488**	**..**
Coal	14	10	2	2	1	0	..
Peat	-	-	-	-	-	-	..
Oil	135	62	63	53	42	40	..
Natural gas	173	164	189	184	177	180	..
Biofuels and waste[1]	9	14	13	16	12	12	..
Geothermal	-	0	0	0	0	0	..
Solar/other	-	-	1	2	2	2	..
Electricity	87	152	202	254	258	254	..
Heat	-	2	1	1	1	1	..
Shares in other (%)							
Coal	*3.3*	*2.4*	*0.5*	*0.3*	*0.1*	*0.1*	..
Peat	-	-	-	-	-	-	..
Oil	*32.4*	*15.4*	*13.3*	*10.3*	*8.4*	*8.1*	..
Natural gas	*41.3*	*40.6*	*40.1*	*35.9*	*35.9*	*36.8*	..
Biofuels and waste[1]	*2.1*	*3.4*	*2.8*	*3.1*	*2.5*	*2.4*	..
Geothermal	-	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	..
Solar/other	-	-	*0.3*	*0.4*	*0.4*	*0.4*	..
Electricity	*20.9*	*37.6*	*42.8*	*49.7*	*52.3*	*51.9*	..
Heat	-	*0.5*	*0.2*	*0.3*	*0.3*	*0.3*	..

Unit: Mtoe

DEMAND							
ENERGY TRANSFORMATION AND LOSSES	**1973**	**1990**	**2000**	**2010**	**2016**	**2017**	**2018P**
ELECTRICITY GENERATION[7]							
Input (Mtoe)	430	750	960	936	868	850	..
Output (Mtoe)	169	275	346	374	370	367	380
Output (TWh)	1966	3203	4026	4354	4300	4264	4413
Output shares (%)							
Coal	*46.2*	*53.1*	*52.9*	*45.8*	*31.5*	*31.0*	*28.4*
Peat	-	-	-	-	-	-	-
Oil	*17.1*	*4.1*	*2.9*	*1.1*	*0.8*	*0.8*	*0.9*
Natural gas	*18.6*	*11.9*	*15.8*	*23.4*	*33.0*	*31.4*	*34.3*
Biofuels and waste[1]	-	*2.7*	*1.8*	*1.7*	*1.8*	*1.8*	*1.7*
Nuclear	*4.5*	*19.1*	*19.8*	*19.3*	*19.5*	*19.7*	*19.1*
Hydro	*13.5*	*8.5*	*6.3*	*6.0*	*6.3*	*7.1*	*6.7*
Wind	-	*0.1*	*0.1*	*2.2*	*5.3*	*6.0*	*6.3*
Geothermal	*0.1*	*0.5*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Solar/other	-	-	-	*0.2*	*1.3*	*1.8*	*2.2*
TOTAL LOSSES	**430**	**636**	**758**	**691**	**654**	**645**	**..**
of which:							
Electricity and heat generation[8]	261	472	606	550	486	473	..
Other transformation	8	14	1	-16	21	26	..
Own use and transmission/distribution losses	161	149	151	157	147	146	..
Statistical differences	**-15**	**-14**	**-31**	**13**	**-8**	**-10**	**..**

INDICATORS	**1973**	**1990**	**2000**	**2010**	**2016**	**2017**	**2018P**
GDP (billion 2010 USD)	5466.01	9001.23	12620.27	14992.05	16972.35	17348.63	17844.28
Population (millions)	211.94	250.18	282.40	309.79	323.67	325.98	328.01
TPES/GDP (toe/1000 USD)[9]	0.32	0.21	0.18	0.15	0.13	0.12	0.12
Energy production/TPES	0.84	0.86	0.73	0.78	0.89	0.92	0.98
Per capita TPES (toe/capita)	8.16	7.65	8.05	7.16	6.68	6.61	6.79
Oil supply/GDP (toe/1000 USD)[9]	0.15	0.08	0.07	0.05	0.05	0.05	0.05
TFC/GDP (toe/1000 USD)[9]	0.24	0.14	0.12	0.10	0.09	0.09	..
Per capita TFC (toe/capita)	6.21	5.17	5.48	4.88	4.69	4.66	..
CO_2 emissions from fuel combustion ($MtCO_2$)[10]	4691.1	4803.1	5729.9	5352.1	4838.5	4761.3	..
CO_2 emissions from bunkers ($MtCO_2$)[10]	45.6	130.8	147.5	148.8	136.9	148.2	..

GROWTH RATES (% per year)	**73-90**	**90-00**	**00-10**	**10-15**	**15-16**	**16-17**	**17-18**
TPES	0.6	1.7	-0.3	-0.3	-1.1	-0.4	3.4
Coal	2.3	1.5	-0.6	-5.7	-8.7	-3.2	-4.2
Peat	-	-	-	-	-	-	-
Oil	-0.5	1.4	-0.8	-0.4	-0.7	0.8	1.9
Natural gas	-0.9	2.3	0.2	3.1	1.0	-1.4	9.5
Biofuels and waste[1]	3.0	1.6	2.0	2.7	-0.4	-0.7	6.0
Nuclear	12.0	2.7	0.5	-0.2	1.2	-0.1	0.3
Hydro	0.2	-0.8	0.4	-0.9	7.4	12.1	-2.7
Wind	-	6.3	32.6	15.2	18.9	12.1	8.0
Geothermal	11.8	-0.7	-4.3	1.3	1.9	0.6	9.7
Solar/other	-	39.5	4.0	19.7	16.6	24.3	30.4
TFC	-0.1	1.8	-0.2	-0.0	0.4	0.2	..
Electricity consumption	2.7	2.9	0.8	-0.0	0.7	-1.8	..
Energy production	0.7	0.1	0.3	3.2	-5.3	4.0	9.2
Net oil imports	0.8	4.2	-0.9	-13.3	1.6	-21.5	-36.7
GDP	3.0	3.4	1.7	2.2	1.6	2.2	2.9
TPES/GDP	-2.3	-1.6	-2.0	-2.4	-2.6	-2.6	0.6
TFC/GDP	-3.0	-1.6	-1.9	-2.2	-1.2	-2.0	..

0 is negligible, - is nil, .. is not available, x is not applicable. Please note: rounding may cause totals to differ from the sum of the elements.

Footnotes to energy balances and key statistical data

1 Biofuels and waste comprises, for the United States, solid biofuels, liquid biofuels, biogases, industrial waste and municipal waste. Data are often based on partial surveys and may not be comparable between countries.

2 In addition to coal, oil, natural gas and electricity, total net imports also includes biofuels.

3 Excludes international marine bunkers and international aviation bunkers.

4 Total supply of electricity represents net trade.

5 Industry includes non-energy use.

6 Other includes residential, commercial and public services, agriculture/forestry, fishing, and other non-specified.

7 Inputs to electricity generation include inputs to electricity and CHP plants. Output refers only to electricity generation.

8 Losses arising in the production of electricity and heat at main activity producer utilities and autoproducers. For non-fossil fuel electricity generation, theoretical losses are shown based on plant efficiencies of approximately 33% for nuclear and solar thermal, between 10% and 20% for geothermal, and 100% for hydro, wind and solar photovoltaic.

9 Toe per thousand US dollars at 2010 prices.

10 "CO_2 emissions from fuel combustion" have been estimated using the Intergovernmental Panel on Climate Change Tier I Sectoral Approach methodology from the *2006 IPCC Guidelines*. Emissions from international marine and aviation bunkers are not included in national totals.

ANNEX C: International Energy Agency "Shared Goals"

The member countries* of the International Energy Agency (IEA) seek to create conditions in which the energy sectors of their economies can make the fullest possible contribution to sustainable economic development and to the well-being of their people and of the environment. In formulating energy policies, the establishment of free and open markets is a fundamental point of departure, though energy security and environmental protection need to be given particular emphasis by governments. IEA countries recognise the significance of increasing global interdependence in energy. They therefore seek to promote the effective operation of international energy markets and encourage dialogue with all participants. In order to secure their objectives, member countries therefore aim to create a policy framework consistent with the following goals:

1. Diversity, efficiency, and flexibility within the energy sector are basic conditions for longer-term energy security: the fuels used within and across sectors and the sources of those fuels should be as diverse as practicable. Non-fossil fuels, particularly nuclear and hydro power, make a substantial contribution to the energy supply diversity of IEA countries as a group.

2. Energy systems should have **the ability to respond promptly and flexibly to energy emergencies.** In some cases this requires collective mechanisms and action: IEA countries co-operate through the Agency in responding jointly to oil supply emergencies.

3. The environmentally sustainable provision and use of energy are central to the achievement of these shared goals. Decision makers should seek to minimise the adverse environmental impacts of energy activities, just as environmental decisions should take account of the energy consequences. Government interventions should respect the Polluter Pays Principle where practicable.

4. More environmentally acceptable energy sources need to be encouraged and developed. Clean and efficient use of fossil fuels is essential. The development of economic non-fossil sources is also a priority. A number of IEA member countries wish to retain and improve the nuclear option for the future, at the highest available safety standards, because nuclear energy does not emit carbon dioxide. Renewable sources will also have an increasingly important contribution to make.

5. Improved energy efficiency can promote both environmental protection and energy security in a cost-effective manner. There are significant opportunities for greater energy efficiency at all stages of the energy cycle from production to consumption. Strong efforts by governments and all energy users are needed to realise these opportunities.

6. Continued **research, development, and market deployment of new and improved energy technologies** make a critical contribution to achieving the objectives outlined above. Energy technology policies should complement broader energy policies. International co-operation in the development and dissemination of energy technologies, including industry participation and co-operation with non-member countries, should be encouraged.

7. Undistorted energy prices enable markets to work efficiently. Energy prices should not be held artificially below the costs of supply to promote social or industrial goals. To the extent necessary and practicable, the environmental costs of energy production and use should be reflected in prices.

8. Free and open trade and a secure framework for investment contribute to efficient energy markets and energy security. Distortions to energy trade and investment should be avoided.

9. Co-operation among all energy market participants helps to improve information and understanding, and encourages the development of efficient, environmentally acceptable, and flexible energy systems and markets worldwide. These are needed to help promote the investment, trade. and confidence necessary to achieve global energy security and environmental objectives.

(The Shared Goals were adopted by IEA Ministers at the meeting of 4 June 1993 Paris, France.)

* Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States.

ANNEX D: Glossary and list of abbreviations

In this report, abbreviations and acronyms are substituted for a number of terms used within the International Energy Agency. While these terms generally have been written out on first mention, this glossary provides a quick and central reference for the abbreviations used.

Acronyms and abbreviations

AC	Alternating current
ACE	Affordable Clean Energy
AEO	Annual Energy Outlook
AMO	Advanced Manufacturing Office
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATF	Accident tolerant fuel
BEAT	Base erosion and anti-abuse tax
BIS	Bureau of Industry and Security
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Energy Management
BSER	Best system of emissions reduction
BTO	Buildings Technologies Office
CAFE	Corporate Average Fuel Economy
CAISO	California Independent System Operator
CARB	California Air Resources Board
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CEM	Clean Energy Ministerial
CEQ	Council on Environmental Quality
CERT	Committee on Energy Research and Technology
CESER	Cybersecurity, Energy Security, and Emergency Response
CHP	Combined heat and power
CIP	Critical infrastructure protection
CISF	Consolidated interim storage facilities
COL	Combined licence
CPP	Clean Power Plan
CREZ	Competitive Renewable Energy Zones
CRT	Climate Resilience Toolkit
CSAPR	Cross-State Air Pollution Rule
DGR	Deep geological repository
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DR	Demand response
EERE	Energy Efficiency and Renewable Energy

EERS	Energy efficiency resource standards
EGCC	Energy Sector Government Coordinating Council
EIA	Energy Information Administration
EIC	Energy Investor Center
EIM	Energy Imbalance Market
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency
EPC	Engineering, procurement and construction
EPCA	Energy Policy and Conservation Act
ERCOT	Electric Reliability Council of Texas
ERO	Electric reliability organisation
ESBWR	Economic Simplified Boiling Water Reactors
EV	Electric vehicle
FAST	Fixing America's Surface Transportation
FE	Fossil energy
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
FID	Final investment decision
FIRST	Flexible, Innovative, Resilient, Small, Transformative
FOA	Funding Opportunity Announcements
FRCC	Florida Reliability Coordinating Council
FTA	Free trade agreement
FTC	Federal Trade Commission
GAIN	Gateway for Accelerated Innovation in Nuclear
GDP	Gross domestic product
GHG	Greenhouse gas
GIS	Geographic information system
HALEU	High-assay low enriched uranium
HH	Henry Hub
IAC	Industrial Assessment Center
IEA	International Energy Agency
IECC	International Energy Conservation Code
INL	Idaho National Laboratory
IRS	Internal Revenue Service
ISER	Infrastructure Security and Energy Restoration
ISO	International Organization for Standardization
ITC	Investment tax credit
LCFS	Low Carbon Fuel Standard
LEED	Leadership in Energy and Environmental Design
LNG	Liquefied natural gas
LOOP	Louisiana Offshore Oil Port
LPG	Liquefied petroleum gas
LPO	Loan Programs Office

LTO	Light tight oil
LWR	Light water reactor
MARAD	Maritime Administration
MATS	Mercury and Air Toxics Standard
MGGRA	Midwestern Greenhouse Gas Reduction Accord
MI	Mission Innovation
MINER	Mine Improvement and New Emergency Response
MISO	Midcontinent Independent System Operator
MRO	Midwest Reliability Organization
MSHA	Mine Safety and Health Administration
NAAQS	National Ambient Air Quality Standards
NAERM	North American Energy Resiliency Model
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASEO	National Association of State Energy Officials
NDIC	North Dakota Industrial Commission
NE	Nuclear Energy
NEET	Nuclear Energy Enabling Technologies
NEHHOR	Northeast Home Heating Oil Reserve
NEPA	National Environmental Policy Act
NERC	North American Electric Reliability Corporation
NESO	National Emergency Strategy Organization
NGA	Natural Gas Act
NGPA	Natural Gas Policy Act
NGSR	Northeast Gasoline Supply Reserve
NHTSA	National Highway Traffic Safety Administration
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
NOPR	Notice of proposed rulemaking
NPCC	Northeast Power Coordinating Council
NPP	Nuclear power plants
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NRF	National Response Framework
NSPS	New Source Performance Standards
NSR	New Source Review
NSS	National Security Strategy
NYISO	New York Independent System Operator
NYMEX	New York Mercantile Exchange
OASIS	Open Access Same-Time Information System
OCS	Outer Continental Shelf
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
OTT	Office of Technology Transitions

PG&E	Pacific Gas & Electric
PHMSA	Pipeline and Hazardous Materials Safety Administration
PPP	Purchasing power parity
PRB	Powder River Basin
PREPA	Puerto Rico Electric Power Authority
PRIS	Power Reactor Information System
PSD	Prevention of Significant Deterioration
PTC	Production tax credit
PV	Photovoltaic
PURPA	Public Utility Regulatory Policies Act
QHSR	Quadrennial Homeland Security Review
R&D	Research and development
RD&D	Research, development and demonstration
RF	Reliability First
RFS	Renewable Fuel Standard
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable portfolio standard
SAFE	Safer Affordable Fuel-Efficient
SEP	Superior Energy Performance
SIP	State Implementation Plan
SLR	Subsequent license renewal
SMR	Small modular reactors
SPP	Southwest Power Pool
SPR	Strategic Petroleum Reserve
SSA	Sector-Specific Agency
STEM	Science, technology, engineering and mathematics
STEO	Short-Term Energy Outlook
TCF	Technology Commercialization Fund
TCP	Technology Collaboration Programmes
TFC	Total final consumption
TPES	Total primary energy supply
UAMPS	Utah Associated Municipal Power Systems
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USDA	United States Department of Agriculture
VIEU	Vertically integrated electric utilities
VLCC	Very large crude carriers
WCI	Western Climate Initiative
WECC	Western Electricity Coordinating Council
WTI	West Texas Intermediate
ZEC	Zero-emissions credit
ZEV	Zero-emission vehicle

Units of measure

bcm	billion cubic metre
CO_2-eq	carbon dioxide equivalent
g	gramme
gCO_2	grammes of carbon dioxide
gCO_2/km	grammes of carbon dioxide per kilometre
GW	gigawatt
GWh	gigawatt hour
kb/d	thousand barrels per day
$kgCO_2$	kilogrammes of carbon dioxide
km	kilometre
ktoe	kilotonnes of oil equivalent
kV	kilovolts
kWh	kilowatt hour
kWh/m^2	kilowatt hours per square metre
m	metre
m^3	cubic metre
mb	million barrels
mcm	million cubic metres
mcm/d	million cubic metres per day
Mt	million tonnes
$MtCO_2$	million tonnes of carbon dioxide
$MtCO_2$-eq	million tonnes of carbon dioxide equivalent
Mtoe	million tonnes of oil equivalent
MW	megawatt
MW_e	megawatts of electricity
MWh	megawatt hours
MWh_{th}	thermal megawatt hour
tCO_2-eq	tonne of CO_2 equivalent
toe	tonnes of oil equivalent
TWh	terawatt hours
USD/L	US dollars/litre

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ENERGY POLICIES OF IEA COUNTRIES

United States

2019 Review

The International Energy Agency (IEA) regularly conducts in-depth peer reviews of the energy policies of its member countries. This process supports energy policy development and encourages the exchange of international best practices and experiences.

In the United States, the shale revolution continues to be a driving force for energy policy, shifting it from a mindset of energy scarcity to one of energy abundance. Innovations in oil and gas extraction through horizontal drilling and hydraulic fracturing have vastly increased the importance of US production in the energy landscape, both at home and internationally. The timely siting of supporting infrastructure will be essential to ensure continued gains from the shale boom.

US government policy is centred on the concept of “energy dominance,” which reflects a strategy of maximising energy production, expanding exports and being a leader in energy technologies. Environmental deregulation is a central focus, though it may have implications for the trajectory of greenhouse gas emissions.

The United States has achieved notable reductions in CO_2 emissions over the past decade, led by its power sector. Low-cost shale gas combined with falling costs and policy support for renewables have shifted dependence away from coal-fired generation. Still, closures of coal and nuclear plants are expected to continue, requiring policy and regulatory responses to ensure a steady transition.

Energy security remains a priority for the United States, which continues to demonstrate a strong focus on reliability and resilience.

In this report, the IEA provides energy policy recommendations to help the United States smoothly manage the transformation of its energy sector.