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Energy Policy Review

International Energy Agency

INTERNATIONAL ENERGY AGENCY

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Executive summary

The United States (US) has put in place significant energy and climate policy reforms designed to put the country on a path towards a clean, secure and affordable energy system for a net zero economy while promoting equity and high-quality jobs.

The United States is the world's second-largest consumer of energy and emitter of carbon dioxide (CO_2), but it is also a major technology and innovation leader, and rapid growth in clean energy investment has resulted in it becoming a world-leading market for renewables, battery, electrolyser and heat pump manufacturing, and electric vehicle (EV) sales. It is also the largest biofuels producer in the world. The United States is experiencing robust economic growth accompanied by declining emissions and efficiency improvements. In 2023, the rate of energy efficiency improvements is expected to reach 4%. This is the level also seen each year this decade at the global level in the IEA Net Zero Scenario and COP28 pledge to double global energy intensity progress from 2% to 4%. The United States has promoted significant investment in renewable energy capacity, nuclear lifetime extensions and new builds and low-carbon fuels. Domestic coal use has declined to a historic low. In 2023, total CO_2 emissions from energy combustion in the United States declined by 4%, while the economy grew by 2.5%. Two-thirds of the reduction in emissions came from the electricity sector.

Strengthening energy security and clean manufacturing while reducing emissions

Federal government action is focused on expanding the clean energy economy and creating diverse and resilient energy supply chains to strengthen energy security and clean manufacturing.

The government is delivering a historic financial stimulus under the Bipartisan Infrastructure Law (BIL), the Inflation Reduction Act (IRA), and the CHIPS and Science Act in support of its goals. The US government expects that the IRA and BIL will lead to substantial greenhouse gas (GHG) reductions by 2030 in line with the United States' climate goals, while significantly reducing net oil imports and delivering large savings on electricity bills. Under BIL, a total of USD 550 billion was allocated for clean energy and infrastructure, while the IRA provides an estimated USD 370 billion in funding to promote energy security and combat climate change. By March 2024, the BIL and IRA had leveraged announcements of private sector clean energy investment totalling USD 670 billion, according to the government tracker 'Investing in America'. From 2020 to 2023, 312 000 clean energy jobs were added in the US, the latest IEA World Energy Employment Report 2023 shows. By the end of 2023, BIL has already allocated USD 75 billion of funding to clean energy. Since 2020, clean energy investment has increased by almost 60%, according to the IEA World Energy Investment Report 2024.

This financial stimulus includes support for the world-leading clean energy technology research, development, demonstration and deployment (RDD&D) built up by the Department of Energy (DOE) since its creation almost 50 years ago. Under the BIL/IRA, the DOE is accelerating action in support of the clean energy economy, building on its world-class programmes, such as the ones implemented by the Advanced Research Projects Agency – Energy, Energy Earthshots™, the Loans Program Office, and the Office of Technology Transitions and its Technology Commercialization Fund. These aim to drive innovation, commercialise technologies and achieve cost reductions to accelerate the global energy transition. The federal government has also adopted ambitious clean energy procurement targets to promote domestic supply chains and jobs and to lead by example, including targets for the deployment of renewables on federal lands and for the use of zero-emission buildings and zero-emission vehicle fleets.

These actions are part of a whole-of-government approach to tackle climate change, a US foreign and domestic security policy priority. The US Nationally Determined Contribution seeks to reduce GHG emissions by 50-52% compared to 2005 levels by 2030, and to put the United States on a pathway towards net zero emissions by 2050 under the National Long-Term Climate Strategy.

Accelerating sector transitions towards clean energy

The US energy transition depends on the development of new infrastructure in all sectors, and the federal government is pursuing a “private sector-led government-enabled approach” to bring this about.

Under the Fiscal Responsibility Act of 2023, the federal government is modernising the National Environmental Policy Act (NEPA) and the Council on Environmental Quality regulations for environmental permits by federal agencies. Among other things, this involves adopting global best practices such as fixed timelines for decisions and streamlining approvals for faster permitting. It is also promoting investment and standards in every sector of the economy. The US government expects that with the BIL/IRA in place (all stated policies), the United States can achieve emissions reductions of 40% by 2030, and that additional emissions reductions will come from state-level and other subnational actions, future federal policy initiatives, and private sector and civil society initiatives, notably in transport, buildings and industry sectors.

In the power sector, the United States aims to have 100% carbon-free electricity generation by 2035, using wind, solar, geothermal, hydropower, nuclear and biomass alongside fossil fuels with carbon capture and storage (CCS). Thanks to IRA credits, IEA projections in the IEA World Energy Outlook 2023 indicate that the US power sector is on course for a 50% reduction in emissions and an 80% reduction in unabated coal-fired power by 2030. The US government is working to accelerate interregional transmission investment, including under Article 216 of the Federal Power Act, and FERC Order 2023 is fast-tracking renewable energy connections. Accelerated action brought about by Clean Electricity Tax Credits, faster permitting of transmission, investment in flexibility from battery storage, which has risen sixfold since 2020, and active demand response could see the share of renewable energy in the United States rise from 22% in 2023 to 34% by 2028, based on the IEA's Renewable Energy Progress Tracker. To reach 100% carbon-free electricity by 2035, the United States estimates it needs 2 000 GW of new clean electricity clean electricity capacity and energy storage by 2035.

In the industry sector, the United States aims to reduce emissions from industry, accounting for 30% of total energy-related CO_2 emissions, under the Industrial Decarbonisation Roadmap for 2030, compared to 2015 levels. IEA *World Energy Outlook 2023* analysis suggests that emissions are likely to decline by 15% between 2022 and 2030 thanks to incentives for industrial efficiency and abatement technologies under the IRA. To reach its goal, the US government needs to lower risks for infrastructure investment in grids, CO_2 and hydrogen pipelines while boosting efficiency standards and rules for low-carbon fuels both domestically and internationally. The United States could leverage first-of-a-kind (FOAK) demonstration and commercialisation through industrial lift-offs such as the Clean Fuels & Products Shot™ to capitalise on business and export opportunities. Initiatives to promote common international standards, data benchmarks and policy learnings could help to stimulate infrastructure investment.

In the transport sector, the United States adopted strong fuel economy standards and is promoting investment in a range of clean vehicles. The federal government has set a target for 50% of new passenger cars and light truck sales to be zero emissions by 2030. IEA *World Energy Outlook 2023* projections suggest that the United States is on course to achieve this target thanks in large part to IRA incentives for electric cars and stronger fuel economy standards, and to moves in several states to adopt new zero-emission vehicle standards. Looking further ahead, the National Blueprint for Transportation Decarbonisation has created an interagency framework for reaching net zero emissions in transport by 2050. Electric car sales have grown fast to reach around 9.5% of total light-duty vehicle sales in 2023. The build-out of a national charging network along highways is a key priority, and the US government needs to work with the private sector to speed up the roll-out of EV charging infrastructure and support electrification of freight.

In the buildings sector, the Blueprint for Decarbonising Buildings aims to achieve a 65% reduction in buildings' emissions by 2035 and a 90% reduction by 2050, compared to 2005 levels. Thanks to the implementation of model codes, including through the National Buildings Performance Standards Coalition of over 30 states, cities and local governments, progress in commercial buildings is good, but lags in the residential sector. Federal programmes and collaborative efforts should prioritise energy efficiency improvements in residential buildings and the renovation of the existing building stock, 70% of which will still be in place in 2050.

Implementing a people-centred energy transition

Affordability, equity and quality jobs are at the heart of federal government policy making. This is backed by good jobs principles and labour standards, which have been introduced, to also ensure investment supports high-quality jobs. The Justice40 Initiative directs 40% of the benefits of certain federal investments, notably investments in climate and clean energy, to disadvantaged communities. Both labour standards and the Justice40 Initiative is supported by federal action to ensure that many programmes and investments, including legacy programmes and new programmes under the BIL/IRA, benefit energy workers, including those facing displacement by the energy transition and marginalised disadvantaged communities that are underserved and overburdened by the energy system.

Under the leadership of the DOE's Office of Energy Jobs and the Office of Energy Justice and Equity, a strategy is being deployed for community and labour union engagement, including through the Community Benefits Plan, with a view to operationalise and mobilise labour standards and Justice40. The IRA also includes place-based bonus tax credits that will help drive additional investment in energy and underserved communities. A key priority is the creation of quality jobs to attract and retain skilled workers, and this is a fundamental pillar of the US manufacturing and supply chains strategy. Several federal programmes further support equity and affordability through a focus on low-income households. These include the Weatherization Assistance Program, the Energy Efficiency and Conservation Block Grant Program, and the Home Energy Rebates Program.

This enhanced focus on the people-centred aspects of energy transitions is well-aligned with the direction of energy and social policy in a number of other countries around the world. The Community Benefits Plan framework that operationalises both labour standards and the Justice 40 Initiative has the potential to be transformative and could help other governments around the world as they consider how to promote equity and justice in the energy transition. Engaging and partnering with workers, communities and citizens is a long-term investment and requires expanded programmes to build capacity and deliver equitable access, good jobs and other benefits. The US is tracking clean energy jobs as part of its excellent job data collection in the United States Energy and Employment Report (USEER). The Office of Jobs also intends to project workforce needs with a future looking companion study to USEER. The DOE's Community Benefits Program also sets shared goals and performance metrics to enable tracking progress over time.

Managing energy security during the transition

Managing energy security during the transition requires governments to accelerate the pace of clean energy investment on the supply and demand side, treating energy efficiency as the first fuel. Governments need to deal with emerging security risks, such as critical minerals supply chains, nuclear fuel security and climate change impacts, along with oil, gas and electricity security risks.

Mitigating rapidly growing global demand for critical minerals and the high market concentration of supply and processing is a key policy priority for the United States. Legislation under the IRA and BIL is having a meaningful impact on domestic mining, supported by the work of the Interagency Working Group on Mining Laws, Regulations and Permitting. The international Minerals Security Partnership, which includes a shared commitment to high environmental, social and governance standards, could be integrated with the DOE's efforts to diversify the supply of critical minerals under BIL and IRA investments. Close co-operation with international allies and partners is an essential pillar of the US critical minerals strategy, with a range of multilateral and bilateral co-ordination and collaboration platforms underway or under development. In the context of the Russian Federation's invasion of Ukraine, nuclear fuel diversification and increasing the supply of domestic uranium supply are also priorities. In 2023, the Nuclear Fuel Security Act established a Nuclear Fuel Security Program to boost domestic production and ensure a consistent supply of domestically produced, converted and enriched uranium.

The increasing frequency and impact of extreme weather events poses a challenge for electricity reliability. NERC (North American Electric Reliability Corporation) and the Federal Energy Regulatory Commission (FERC) are now working to develop new reliability standards which should help strengthen resilience once they are implemented. Alongside this, the federal government needs to compel owners and operators of critical energy infrastructure to take action to make infrastructure more resilient in the face of extreme weather and wildfires, following Winter Storm Elliot in December 2022. While adaptation is already recognised as a priority, more could be done to make progress based on the climate adaptation and resilience plans adopted by the DOE and 23 federal agencies. The National Climate Resilience Framework is a helpful step towards a collaborative framework across sectors and states and should help to catalyse actions in the coming years.

Economic incentives favour the retirement of older, less efficient fossil fuel power plants, and there is a risk that this might lead to insufficient power supply under adverse conditions if adequate alternative sources of energy are not put in place. Unjustified barriers to intra-regional power grids and other constraints on the ramping up of clean energy generation capacity need to be removed to avoid the deterioration of power system stability.

The orderly and secure transition of the energy system away from unabated fossil fuels is necessary to deliver on the United States' and global emissions reduction goals. A significant boost is needed for the full implementation of the programmes under the BIL/IRA designed to support new infrastructure and the retirement, reuse and repurposing of existing infrastructure. This offers an opportunity for the US government to work with industry on net zero compatible pathways and the implementation of new rules for sharply reducing methane and other GHG emissions from oil and gas operations, including through electrification and investment in clean energy.

Despite production growth, there are concerns around the security of natural gas supply in the domestic market, largely driven by usage in power generation to cover demand peaks. Regulators will need to ensure that natural gas infrastructure (transport and storage capacity) remains adequate to meet peak demand even as natural gas demand declines. Meanwhile, natural gas exports play an important role in enhancing global gas security following the fundamental changes in the global gas market brought about by Russia's invasion of Ukraine. US liquefied natural gas (LNG) exports are expected to continue to grow in the medium term. US LNG export capacity has more than tripled since 2018 and is set to nearly double by 2030, based on approved projects.

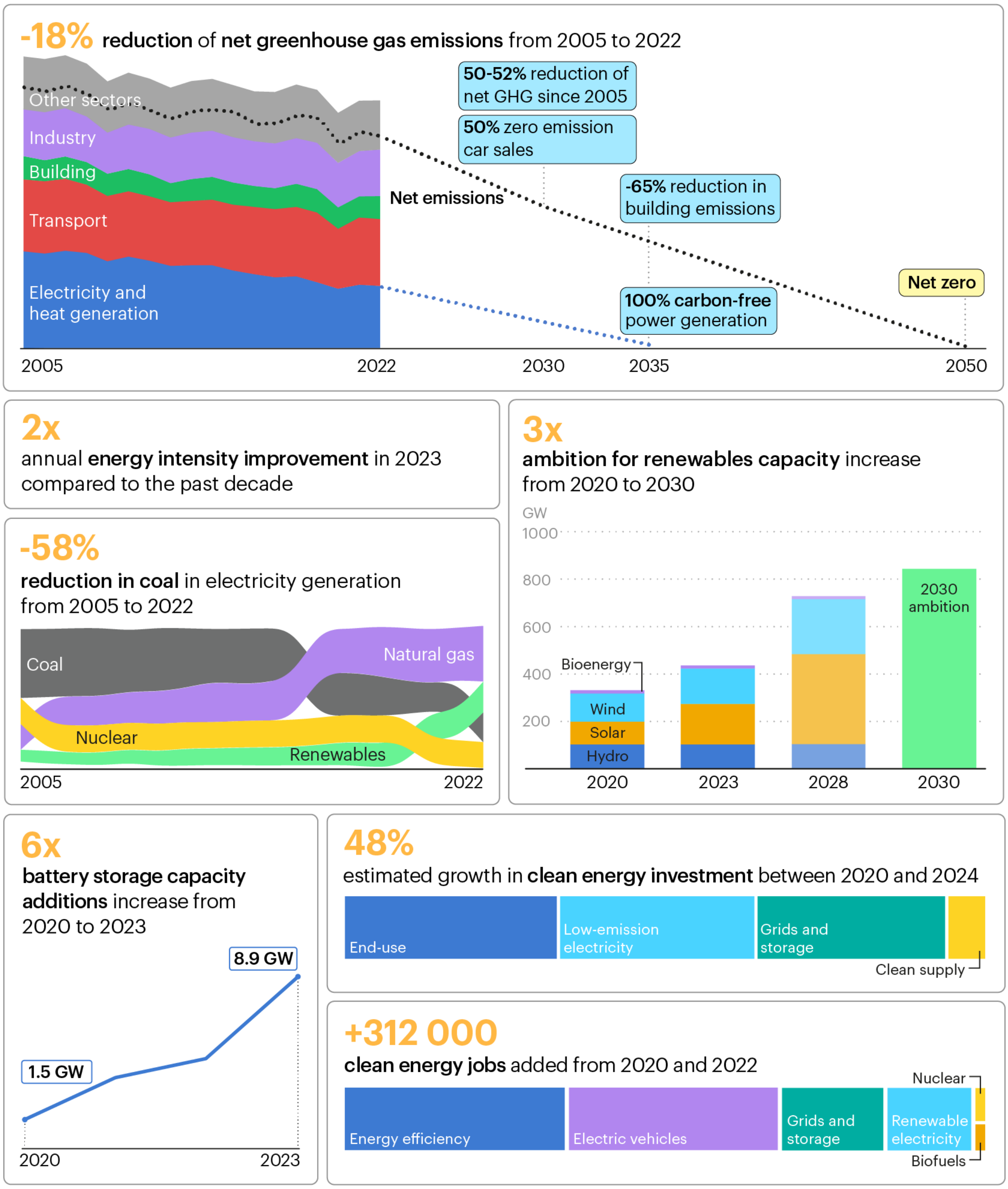
The United States remains vulnerable to global and domestic oil market tightness as a major oil consumer and net importer of crude oil. The Strategic Petroleum Reserve (SPR) remains of fundamental importance to domestic and global oil security and is a key pillar of the IEA's oil stockholding system. Stock releases from the SPR in 2022, including as part of the March and April 2022 IEA Collective Actions, played a significant role in alleviating supply tightness at a time of market uncertainty following Russia's invasion of Ukraine. As a result of emergency sales and unrelated sales mandated by Congress, the SPR fell to an historic 34-year low in 2023, which, if left at low levels, could undermine market confidence in the United States' ability to respond to worst-case scenario oil supply disruptions. To head off such concerns, the federal government has initiated a three-part SPR replenishment strategy, and progress is already being made. The successful implementation of this strategy should strengthen US and global resilience to oil market shocks.

Key recommendations

The government of the United States should:

- Seek to maximise investor confidence by maintaining a high degree of policy stability and continuity and accelerating cross-government collaboration.
- Increase the Department of Energy's and national laboratories' capacity to deliver federal programmes, notably those aimed at strengthening domestic supply chains and manufacturing and sectoral transitions to meet commercialisation goals across the research, development, demonstration and deployment continuum.
- Make further progress towards US 2030 and 2050 emissions reduction targets by continuing to develop sectoral pathways and reinforcing the planning, co-ordination and development of policies and technology programmes for scaling up energy efficiency, renewables and low-carbon technologies in each sector.
- Embed justice and equity over the long term by expanding programmes with state, local, tribal and territorial communities to build capacity and deliver equitable access and benefits, good jobs and other benefits in collaboration with those communities.
- Continue to develop a robust international energy strategy, working with partners to bolster global energy security, including through measures that promote critical minerals security, diverse nuclear fuels and sufficiently large Strategic Petroleum Reserve, while supporting clean energy transitions around the world, particularly in developing countries.
- Support the federal climate resilience framework by ensuring that rigorous reliability standards are in place for all critical energy infrastructure. Strengthen institutional arrangements for planning, monitoring and reporting, and prioritising investment in interregional networks to boost weatherisation, winterisation and cooling, notably for disadvantaged communities.

The United States is accelerating clean, secure and affordable transitions



1. Energy policy framework

1.1 Key energy and climate trends

The United States is the world's second-largest energy producer and consumer, and its energy system is currently undergoing rapid change. This highly advanced economy is the largest in the world in terms of nominal gross domestic product (GDP), accounting for 25% of the global economy, and it is home to a large number of global energy companies. It spends more on public energy R&D than any other country and has an enviable record of energy innovation. Having been a major energy importer for decades, it became a net energy exporter in 2019. Its economic strength and importance as both an energy producer and consumer make it hugely important in international terms. For all these reasons and more, US energy and climate change policies and outcomes are of enormous global significance.

IEA data shows US domestic energy production increased significantly from 72 exajoules (EJ) in 2010 to 96 EJ in 2022, driven by increasing oil and gas production. Energy production in 2022 consisted of natural gas (37%), oil (34%), coal (13%), nuclear (9%) and renewables (8%). Meanwhile, total energy supply (TES)[1] has decreased and in 2019 was lower than production for the first time, marking an historical switch for the United States from being a net importer to a net exporter of energy. In 2022, TES was 90 EJ, and consisted mainly of natural gas (35%), oil (35%), coal (11%) and nuclear (10%). In 2023, IEA Energy Efficiency 2023 analysis expects TES to fall by 1.7% while the economy grows by 2.4%. This is expected to yield an energy intensity improvement of 4% for 2023. This is the level also seen each year this decade at the global level in the IEA Net Zero Scenario and COP28 pledge to double global energy intensity progress from 2% to 4%. The United States aims to almost triple its renewable energy capacity from around 300 GW in 2020 to 845 GW in 2030 in order to make progress towards global goals agreed under the COP28 climate change conference.

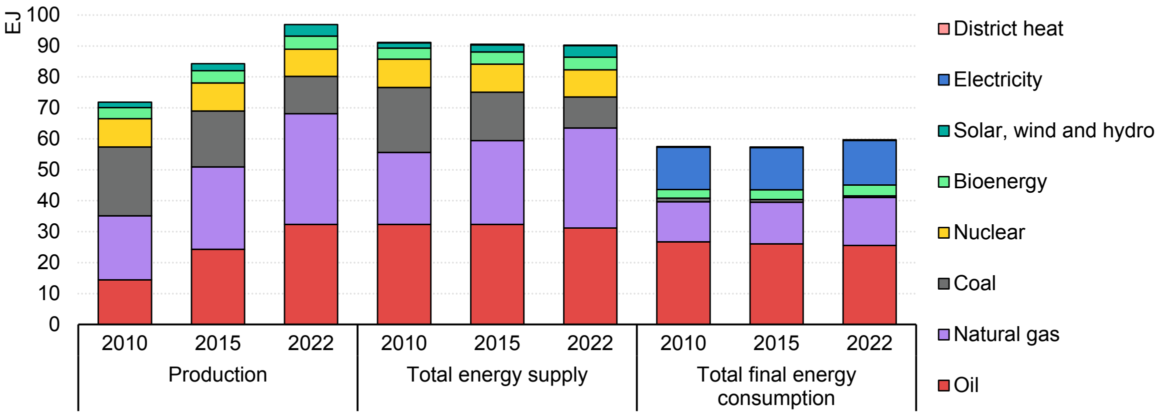
Total final consumption (TFC) has been roughly constant since 2010 and was 66 EJ in 2022, almost half of which covered by oil (47%), followed by natural gas (24%) and electricity (22%). As the US economy has grown by 28% since 2010, it improved its energy efficiency by an average of 2.3% each year. Transport

[1] Production comprises the production of primary energy, i.e. hard coal, lignite, peat, crude oil, natural gas liquids, natural gas, biofuels and waste, nuclear, hydro, geothermal, solar, and the heat from heat pumps that is extracted from the ambient environment. TES is made up of production + imports – exports – international marine bunkers – international aviation bunkers ± stock changes.

remains the sector with the highest energy consumption, followed by buildings and industry. The share of fossil fuels in TFC accounted for 86% in 1973 and 72% in 2022.

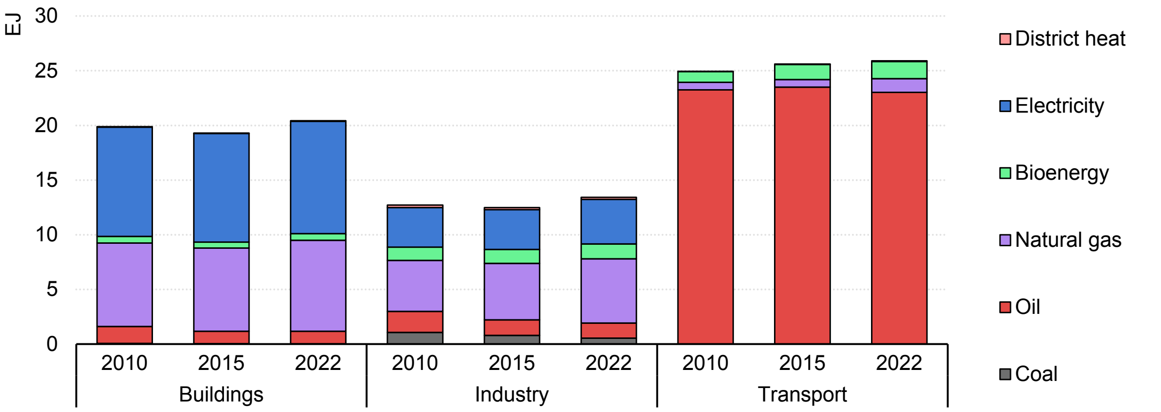
GHG emissions have decoupled from GDP growth over the decades thanks to the continued shift away from coal use towards more competitive and less carbon-intensive energy sources (i.e. natural gas and renewables) in the power sector, as well as improved energy efficiency. However, emissions remain relatively high on a per capita basis in global terms.

Figure 1.1 Energy system transformation across production, supply and demand in the United States, 2010-2022



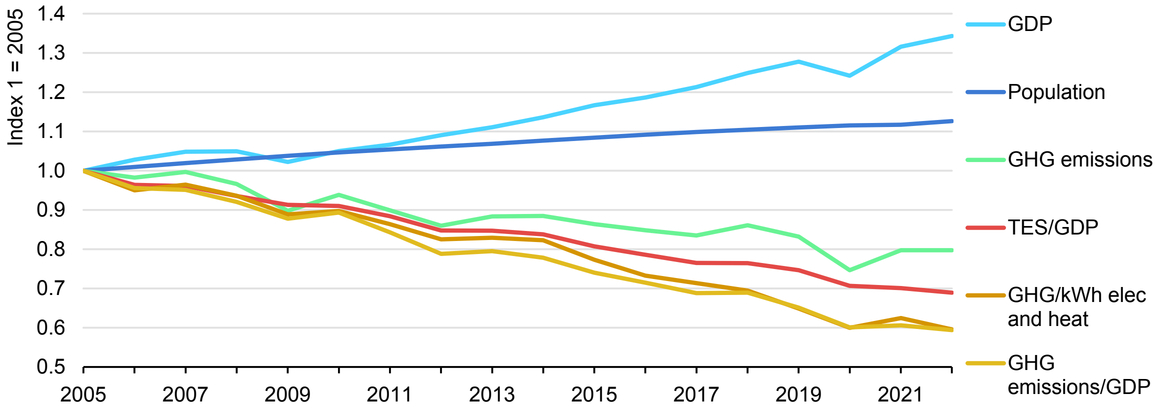
Source: IEA (2024), World Energy Balances (database).

Figure 1.2 Total final consumption by sector and fuel, United States, 2005-2022



Source: IEA (2024) World Energy Balances (database).

Figure 1.3 Trends in energy and emissions intensities, United States, 2005-2022



Note: kWh = kilowatt hour.
Source: IEA (2024) World Energy Balances (database).

1.2 The United States' energy and climate strategy

The federal government's energy transition strategy follows an approach that is private sector-led, government-enabled and embedded in the strategy for tackling climate change and reducing GHG emissions towards achieving net zero by 2050. The federal government promotes incentives for investment and standards in every sector of the economy. Its key focus is on the deployment of clean energy technologies to lower their cost, while creating new manufacturing and diversified supply chains for the US economy.

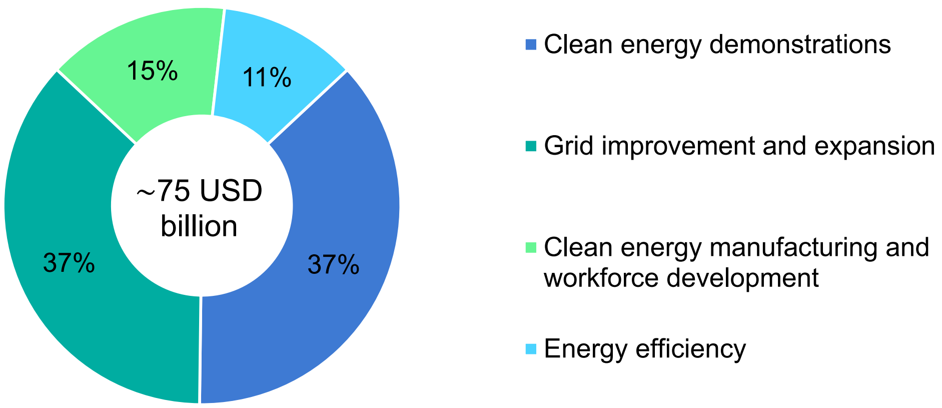
The clean energy economy is the federal government's key priority as part of its industrial strategy. In this context, Executive Order 14017 on America's Supply Chains is a key strategy, which aims to build resilient, diverse and more secure supply chains in the United States. In response to this Order, in February 2022, the DOE presented a comprehensive plan to increase US energy security and independence. The plan sets out a number of strategies aimed at building a secure, resilient and diverse domestic energy sector industrial base to help establish the United States as a global leader in clean energy manufacturing and innovation, supported by 13 deep-dive assessments.

The plan identified seven key areas for action, with follow-up action largely linked to funding under the BIL. These key areas focus on increasing the availability of critical materials; expanding domestic manufacturing capabilities; supporting the formation of diverse, reliable and socially responsible foreign supply chains; increasing the adoption and deployment of clean energy; improving end-of-life energy-related waste management; attracting and supporting a skilled workforce for the clean energy transition; and enhancing supply chain knowledge and decision making.

The federal government's energy and climate change strategies are underpinned by three key pieces of legislation: 1) the BIL; 2) the CHIPS and Science Act; and 3) the IRA.

The Infrastructure Investment and Jobs Act or Bipartisan Infrastructure Law (BIL) was signed into law in November 2021. Its aims to upgrade the power infrastructure to deliver clean, reliable energy across the country and deploy cutting-edge energy technology to achieve a zero-emission future; build a national network of EV chargers; and reduce GHG emissions through the largest investment in public transportation in US history. By end of 2023, BIL allocated around USD 75 billion earmarked for clean energy, including projects related to grid improvement and expansion (USD 21.3 billion), clean energy demonstrations (USD 21.5 billion), energy efficiency (USD 6.5 billion) and clean energy manufacturing and workforce development (USD 8.6 billion).

Figure 1.4 Clean energy funding programmes under the Bipartisan Infrastructure Investment and Jobs Act



Source: IEA analysis based on US Senate HR 3684 Infrastructure and Jobs Act, White House Guidebook.

The CHIPS and Science Act was signed into law in July 2022. It aims to boost US innovation and competitiveness, and in so doing to enhance national security. Its primary focus is semiconductor manufacturing, but it also provides funding to support R&D in a number of leading-edge technologies, including clean energy, and the subsequent domestic manufacturing and commercial deployment of those technologies. Among other things, it established a new federal office to organise clean energy innovation.

The Inflation Reduction Act (IRA) was signed into law in August 2022. It aims to promote the development and deployment of leading-edge clean energy technologies with the aim of significantly reducing carbon emissions by 2030. It provides a mix of grants, loan guarantees and tax incentives. The IRA expands and/or creates tax credits for emissions reductions across all sectors of the US economy (see Table 1.1 overview):

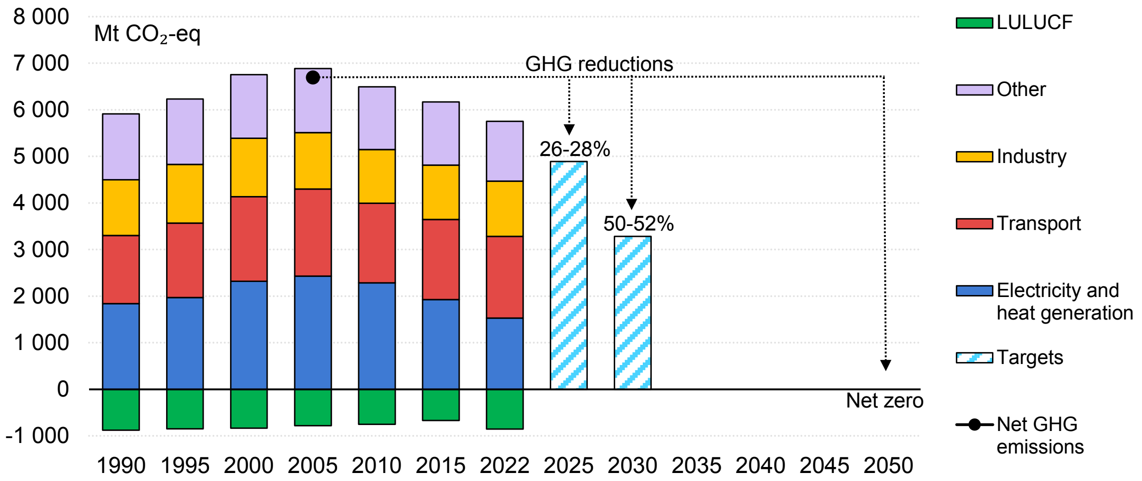
- **transport:** there are incentives for bioenergy and alternative fuels and a tax credit for sustainable aviation fuel (SAF), a tax credit for clean fuels, credits for clean energy vehicles and for refuelling clean energy vehicles
- **electricity:** there are tax credits for clean electricity production and investment together with grant programmes for transmission grids
- **buildings:** there are tax credits for energy efficient homes and appliances and expanded deduction for energy efficiency in commercial buildings
- **industry:** there are tax credits for carbon capture, utilisation and storage (CCUS), clean hydrogen and clean energy manufacturing investment.

Infrastructure is the pacing element of the energy transition. In 2023, the federal government reformed the NEPA under the Fiscal Responsibility Act. The Council on Environmental Quality is amending the regulations for conducting NEPA reviews – a major reform since the 1970s.

A key component of BIL and IRA is the permitting reform, aimed to make the federal environmental review processes required for infrastructure projects more efficient and effective. The BIL, for example, made the Federal Permitting Improvement Steering Council permanent and expanded its authorities. The Biden-Harris Permitting Action Plan promoted early cross-agency co-ordination; clear timelines and tracking of key project information; early and meaningful outreach and communication; improved responsiveness, technical assistance and support; and adequately resourcing of agencies and their accountability. This is supported by the IRA funding for the Steering Council and the related USD 625 million for timely, robust and transparent efficient environmental reviews.

Executive Order 14008 of 27 January 2021 on Tackling the Climate Crisis at Home and Abroad made climate change a priority for US foreign and national security policy and institutionalised a whole-of-government approach through the creation of the National Climate Taskforce, which is chaired by the National Climate Advisor with Cabinet-level leaders from 25 federal agencies. This led to the United States rejoining the Paris Agreement in 2021 and the publication of the US National Climate Strategy and a Long-Term Strategy (LTS), released in November 2021. These two documents set a goal for net zero emissions by 2050 and plans for achieving it. The LTS identified five key transformations to achieve net zero emissions by 2050: 1) decarbonise electricity; 2) electrify end uses and switch to other clean fuels; 3) cut energy waste; 4) reduce methane and other non-CO_2 emissions; and 5) scale up CO_2 removal. Actions will be needed to enable the transformations through federal leadership, innovation, non-federal leadership and all-of-society action. In line with its LTS, the federal government submitted a Nationally Determined Contribution to the United Nations Framework Convention on Climate Change in 2021, with an economy-wide target of reducing net GHG emissions by 50-52% below 2005 levels in 2030.

Figure 1.5 Trends in greenhouse gas emissions by sector in the United States, 1990-2022, and net zero targets



Notes: Mt CO_2-eq = million tonnes carbon dioxide equivalent; LULUCF = land use, land-use change and forestry. Other includes agriculture, forestry, fishing, fugitive emissions, waste, CO_2 transport and storage, and not specified elsewhere.

Sources: IEA analysis based on UNFCCC (2023), Greenhouse gas inventory data; UNFCCC (2023), 2023 Voluntary Supplement to the U.S. Fifth Biennial Report, EPA (2024), Inventory of U.S. Greenhouse Gas Emissions and Skins 1990-2022.

The goal of net zero emissions by 2050 is supported by a number of other targets. These include raising zero-emission car sales to 50% of total sales by 2030 and reaching 100% low-carbon electricity by 2035. By 2025, the United States aims to achieve an overall 26-28% emissions reductions below 2005 levels by 2025.

According to recent US government projections in 2023, the impacts of the IRA/BIL could result in GHG reductions of about 33-41% by 2030 below 2005 levels. Emissions reductions will be enabled in each sector. According to the latest US data, energy-related carbon dioxide reductions in 2030 could reach 49-80% in the electricity sector, 12-25% in the transportation sector, 49-63% in the buildings sectors and 17-43% in the industrial sector, compared to 2005 levels.

However, expected emissions reductions are all contingent on the capacity of the public and private sectors to scale up investments at a very rapid pace. Additional actions at the federal and/or state level are required to reach the 50% by 2030 target and keep the net zero by 2050 target within reach. Additional action is needed in the transport and industry sectors but also in the US buildings sector.

The federal government aims to leverage investment through tax credits, grants and loans; build the necessary infrastructure; improve energy efficiency across all sectors of the economy; electrify end use sectors (transport, buildings and industry); shift to zero-emission or carbon-neutral fuels for industries and transport modes that need energy-dense fuels; apply CCS for industries with large process-related emissions; advance work on CO_2 removal; and reduce methane and other non-CO_2 emissions under the Methane Emissions Reduction Plan (2022 update) and new Environmental Protection Agency standards for all these sectors.

Table 1.1 Overview of tax incentives under the Inflation Reduction Act*

Category	Num	Name of credit
Clean energy generation and carbon capture incentives		
Extended/modified credit	45	Renewable Energy Production Credit
Extended/modified credit	48	Energy Investment Credit
New credit	45U	Zero-Emission Nuclear Power Production Credit
Ext/modified credit	45Y	Clean Electricity Production Credit
Extended/modified credit	48E	Clean Electricity Investment Credit
Extended/modified credit	45Q	Carbon Capture Credit
Homes and buildings incentives		
Extended/modified credit	25C	Extended and Modified Non-business Energy Property Credit
Extended/modified credit	25D	Residential Clean Energy Credit
Extended/modified deduction	179D	Energy Efficient Commercial Buildings Deduction
Extended/modified credit	45L	Extended, Increased and Modified New Energy Efficient Home Credit
Clean Vehicles Credits		
Extended/modified credit	30D	Clean Vehicle Credit
New credit	25E	Previously Owned Clean Vehicle Credit
New credit	45W	Qualified Commercial Clean Vehicles
Extended/modified credit	30C	Alternative Fuel Refuelling Property Credit
Clean fuels production credits		
New credit	45Z	Clean Fuel Production Credit
Extended/modified credit	45V	Clean Hydrogen Production Tax Credit
Extended/modified credit	40A	Biodiesel and Renewable Diesel Used as Fuel Credit
Extended/modified credit	40B	Sustainable Aviation Fuel
Credit enhancements		
New provision	45(b)	Prevailing Wage and Registered Apprenticeship requirement
		Domestic Content Bonus
		Energy Communities Bonus
New provision	48(e)	Low-Income Communities Bonus
Credit monetisation		
New provision	6417	Elective Pay of Applicable Credits
New provision	6418	Transfer of Certain Credits
Manufacturing credits		
Extended/modified credit	48C	Extension/Modification of the Qualifying Advanced Energy Project Credit
Extended/modified credit	45X	Advanced Manufacturing Production Credit™

* Credits are listed by category and can figure more than once. For many credits, guidance has been issued; see: https://home.treasury.gov/policy-issues/inflation-reduction-act/ira-related-tax-guidance.

The IRA contains over USD 100 billion in grants and loans to accelerate investments in clean energy, manufacturing and supply chains, climate resilience, and environmental justice.

By the end of 2023, US agencies had announced 18%, or USD 23 billion, in IRA grant awards, allocations and other non-loan funding. They have launched more than two-thirds of the IRA programmes that have competitive grants as a component and announced USD 61 billion in Notice of Funding Opportunity, which agencies plan to obligate in 2024.

Between them, the BIL and IRA will provide a total of USD 430 billion for clean energy programmes between 2022 and 2031. The federal government is committed to deliver 40% of the benefits from certain federal investments in climate and clean energy to disadvantaged communities (Justice40). The CHIPS legislation provides a further USD 280 billion, largely for clean energy research and development (R&D).

Table 1.2 Overview of major Inflation Reduction Act grants and loans

Programme	Budget	Details
Greenhouse Gas Reduction Fund	USD 27 billion	The Environmental Protection Agency's Greenhouse Gas Reduction Fund will mobilise financing and leverage private capital for clean energy and climate projects, with an emphasis on projects for low-income and disadvantaged communities
Climate-Smart Agriculture and Forestry	USD 24 billion	Funding at the Department of Agriculture, including through the Forest Service, to promote climate-smart agriculture, address wildfire risks, and advance nature-based climate solutions in the agriculture and forest sectors
Rural Co-operatives Financing	USD 9.7 billion	Through a combination of updated or existing loan and grant programmes, these funds turbocharge clean energy for rural electric co-operatives, which serve 42 million Americans
Home Efficiency Rebates	USD 9 billion	Two new Department of Energy programmes will offer low- and middle-income Americans rebates on efficient consumer appliances, like heat pumps and home energy efficiency retrofits
"Buy Clean" Procurement	USD 5.7 billion	Under the President's December 2021 federal sustainability Executive Order, the United States was working on "buy clean" government procurement – the Inflation Reduction Act brings more resources to that work
Department of Energy Loan Program	USD 12 billion	New and expanded Department of Energy Loan Program subsidies for repurposing/retooling legacy energy infrastructure (up to USD 250 billion in authority), advanced vehicle manufacturing, innovative clean energy projects (additional USD 40 billion in authority) and tribal projects (USD 20 billion in authority)
Clean Energy Manufacturing	USD 500 million	This provides funding for use of the Defense Production Act for heat pumps and critical materials

Source: United States, Department of the Treasury.

In the past, the uncertainty of the continuity and applicability of tax credits over time has impacted renewable energy development in the United States, notably wind energy development. Building on this experience, the federal government is implementing policies that can guarantee investment certainty in the coming years. To address some of the lessons learnt, the IRA has amended and expanded current tax credits; this is expected to have a positive impact on renewable energy development.

In support of the IRA/BIL programmes, the federal government takes the lead, using its purchasing power and ownership position of federal buildings and vehicle fleet to boost a range of clean, inclusive and just transition actions. The Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability (December 2021) requires federal agencies to:

- Achieve 100% carbon pollution-free electricity by 2030, with at least 50% on a 24-hour a day, 7 days a week basis, meaning the electricity is produced in the same hour that it is consumed by the federal agency.
- Reach 100% zero-emission vehicle purchases by 2035, including 100% light-duty acquisitions by 2027.
- Achieve net zero building emissions by 2045, including a 50% reduction by 2032.
- Reduce Scope 1 and 2 GHG emissions by 65% from 2008 levels by 2030.
- Establish targets to reduce energy and potable water use intensity by 2030.
- Reduce procurement emissions to net zero by 2050.
- Have climate-resilient infrastructure and operations.
- Develop a climate- and sustainability-focused workforce.
- Advance environmental justice and equity-focused operations.
- Accelerate progress through domestic and international partnerships.

1.3 Co-operation with state, local, tribal and territorial governments

The United States is a federal republic of 50 states, plus the District of Columbia and US territories. The Constitution assigns certain powers to the federal government, with other responsibilities entrusted to the states. Local governments are charged with governance responsibilities. In addition, there are 574 federally recognised tribes that operate as sovereign nations within the borders of the United States. This shared responsibility for policy in areas such as economic growth, energy development, transport, land-use planning and natural resource use requires co-ordination at multiple levels. States have their own net zero goals, renewable electricity standards and energy efficiency resources standards that require certain amounts of renewable or efficiency procurement. States have policies on green procurement, methane emissions, hydrogen production and many other key energy policy issues. Importantly, state, local, tribal and territorial governments have set several ambitious climate and energy goals, including:

- **economy-wide GHG reduction goals** (23 states/territories: California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nevada, New Jersey, New Mexico, New York, North Carolina, Oregon, Pennsylvania, Puerto Rico, Rhode Island, Vermont and Washington, in addition to multiple tribes)
- **100% clean electricity goals** (18 states/territories: California, Colorado, Connecticut, Hawaii, Illinois, Maine, Maryland, Minnesota, Nevada, New Mexico, New Jersey, New York, North Carolina, Oregon, Puerto Rico, Rhode Island, Washington and Wisconsin, in addition to multiple tribes)
- **zero-emission vehicle standards** (16 states: California, Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, New Mexico, Nevada, New Jersey, New York, Oregon, Rhode Island, Vermont and Washington).

The federal government's work on energy and climate change is ambitious and wide-ranging, with new interagency and cross-government working groups to facilitate consistent and strong policy progress.

A great number of different federal agencies are involved in policy making and preparing and delivering programmes under recent legislation, and the same is true at the state level. There could also be value encouraging a built-in mechanism for the federal government and state governments to support the implementation of policies, exchange best practices and, where possible, try to find ways to co-ordinate actions at the federal and state levels by expanding and broadening the DOE's work in engaging with states, local governments and tribes as well as philanthropic organisations, notably through the State, Local, Tribal and Territorial Program.

1.4 Tracking progress in the implementation

There could be value in creating a single delivery body to oversee the work of all the different federal agencies, monitor overall progress and address any common problems that emerge, such as permitting delays, workforce shortages and social acceptance of the siting of renewable energy and other infrastructure projects.

The federal government tracks progress in public and private investments through several metrics, including the Loan Program Office Monthly Application Activity Report data, the White House Invest.gov tracker and the manufacturing investment logged in public trackers (IEA Clean Energy Demonstration Database or Bloomberg NEF investment data).

According to the White House tracker, by March 2024, private companies had announced USD 670 billion in commitments to invest in semiconductors, clean manufacturing, clean power, biomanufacturing, EVs and batteries, and heavy industry, creating more than 210 000 jobs through these investments in the United States. By March 2024, a total of USD 455 billion of public funding had been announced under the BIL/IRA.

1.5 Clean energy economy

The post-pandemic fiscal stimulus under the IRA, the BIL, and the CHIPS and Science Act strongly supported the growth of the US economy in 2022 and 2023 thanks to investment in infrastructure, supply chains and manufacturing geared towards the clean energy transition and economy. Clean energy growth accounted for around 6% of GDP growth in 2023, comparable in scale to the contribution to GDP growth in 2023 from the United States' booming, artificial-intelligence-driven digital economy.[2]

The United States has made significant strides in scaling up investments in clean energy, reflecting a shift in capital flows towards alignment with the long-term net zero target. In 2020, investments in clean energy surpassed those in fossil fuels for the first time, as oil and gas spending plummeted. This trend has continued, with clean energy investments increasing from USD 200 billion in 2020 to USD 280 billion in 2023. For every USD 1 spent on fossil fuels in 2023, USD 1.4 was directed towards clean energy. IEA projections for 2024 estimate that investment in clean energy will exceed USD 300 billion, marking a 1.6-fold increase from 2020 levels. According to the Announced Pledges Scenario (APS), reduced demand for fossil fuels is expected to significantly cut upstream and midstream spending, while investments in low-emissions power are projected to double, and spending on energy efficiency is anticipated to nearly triple by 2030.

Furthermore, investment in manufacturing and construction has performed strongly in recent years, contributing the most to GDP growth since the 1950s. In May 2024, US inflation stood at 3.3%, with government gross debt of 121% and an unemployment rate of 4%, much below the long-term unemployment rate of 15%. Recent US jobs data show a net increase in energy employment including a larger rate increase in the renewable energy sectors and decline in the coal sector. In recent years, the job vacancy rate, an indicator for labour shortages, has been growing in energy-related industries, such as manufacturing, utilities and construction. In total, the latest DOE data show that 11% of energy workers were represented by a union, over 50% higher than the private sector average, where only 7% of workers are unionised. Unionised firms report substantially less difficulty hiring skilled workers than non-unionised firms, indicating that perceived labour shortages may be due to the quality of jobs.

[2] IEA (2024), Clean energy is boosting economic growth.

1.6 International energy strategy

The United States' energy strategy has a strong international dimension, including regular, co-ordinated interagency processes to develop and implement policies on international development, energy engagement and other related areas. The main goals of the United States' international strategy are to accelerate global clean energy transitions that address the climate crisis, enhance and ensure energy security, and create good-paying jobs and prosperity for the American people and communities everywhere. The strategy intends to help countries achieve their energy security, energy access and climate goals. Through high-level diplomacy and the mobilisation of technical expertise – including through 17 national labs – the DOE is helping to solve some of the world's most complex energy challenges, especially in emerging economies, at a time when geopolitical conflicts are stressing energy markets.

Engagement has been stepped up and significantly increased in recent years towards advancing collective action and global leadership on climate, achieving critical energy technology breakthroughs and strengthening global energy security.

The United States pursues intergovernmental agreements and bilateral partnerships with emerging markets and developing economies, like Argentina, Brazil, India, Saudi Arabia, and the United Arab Emirates. The United States engages bilaterally through strategic energy dialogues and agreements with Australia, Canada, Poland, Ukraine and the United Kingdom, among others. The United States takes a central role in regional and multilateral discussions on energy with partners in the G7, G20, Association of Southeast Asian Nations, Asia-Pacific Economic Cooperation, the Partnership for Transatlantic Energy and Climate Cooperation, the Clean Energy Ministerial, Mission Innovation, the North Atlantic Treaty Organization, and others.

The partnerships aim at building global markets for US clean energy goods and services; building diverse, resilient clean energy supply chains (critical minerals and materials, clean energy technologies, clean fuels, etc.); protecting against aggressive, predatory investments from maligned actors in critical technologies (including through the BIL and IRA); and providing world-class analysis to inform federal and global energy policies.

Launched in 2021, the Net Zero World Initiative leverages expertise across US government agencies and DOE national laboratories, including the National Renewable Energy Laboratory (NREL), for a whole-of-government approach for advancing the decarbonisation of global energy systems for its partners. The programme supports countries committed to raising their climate ambitions through the development of strategies addressing technical clean energy pathways and deployment and investment opportunities that keep net zero within reach. Country partners include Argentina, Chile, Egypt, Indonesia, Nigeria, Singapore, Thailand and Ukraine. Led by the DOE, the initiative partners with nine other US federal agencies, including the Department of State, the United States Agency for International Development, and the US Trade and Development Agency. NREL serves as the principal implementer along with nine other national labs.

There are many areas of US energy policy making that have strong international engagement functions, including in the area of clean energy technology collaboration, including through global fora, such as the IEA Technology Collaboration Programmes, the Clean Energy Ministerial and Mission Innovation. As the multilateral agenda on climate and energy is expanding, there is a strong momentum for the United States to set out a comprehensive energy and climate engagement agenda across the US government, building on its technical expertise to advance global energy transitions. For instance, good jobs principles and statutory labour standards, the Justice40 Initiative and the Community Benefits Plan are informative and instructive for partner countries. On the other hand, the federal government and state governments could share learnings and expand expertise on sectoral decarbonisations.

Key recommendations

The US government should:

- Seek to ensure investor confidence and willingness to invest by maximising policy stability and cross-government collaboration on IRA/BIL implementation.
- Maintain and strengthen interagency and cross-governmental approaches to the energy transition and sustain the Department of Energy's (DOE) strengthened institutional capacity and breadth of focus across the research, development, demonstration and deployment value chain and in support of the DOE's commercialisation mission, including through national laboratories.
- Continue to expand and fully resource a robust international energy and climate strategy, working with partners to bolster energy security and support sectoral clean and just energy transitions around the world, particularly in developing countries.

2. Sector transitions towards clean energy

2.1 Electricity

The US federal government committed to 100% clean electricity by 2035[3] which will translate into a huge shift for the power systems and markets across the United States. In December 2022, the federal government joined the Powering Past Coal Alliance and committed to phase out coal-fired power plants with unabated emissions (that are not equipped with CCS).

The DOE put forward a 10-point action plan for reaching 100% clean electricity by 2035:

1. Maintain the existing clean energy generation and storage fleet and increase flexibility where appropriate.
2. Rapidly increase generation of established clean energy generation and storage technologies.
3. Increase options for clean generation, storage and carbon management technologies.
4. Plan and deploy enabling infrastructure, including transmission and distribution grids.
5. Proactively invest in and engage with disadvantaged and energy communities to ensure the impacts and benefits of 100% clean power are distributed equitably.
6. Augment planning, operations and markets to enable 100% clean grids.
7. Ensure system security and resiliency as new technologies and threats emerge.
8. Dramatically accelerate electric energy efficiency and demand flexibility.
9. Strengthen domestic manufacturing capabilities and develop resilient and sustainable supply chains.
10. Equitably expand the United States' clean energy workforce.

Projections by the DOE and NREL estimate that IRA incentives would boost the share of clean electricity generation from 41% in 2022 to 71-90% in 2030.

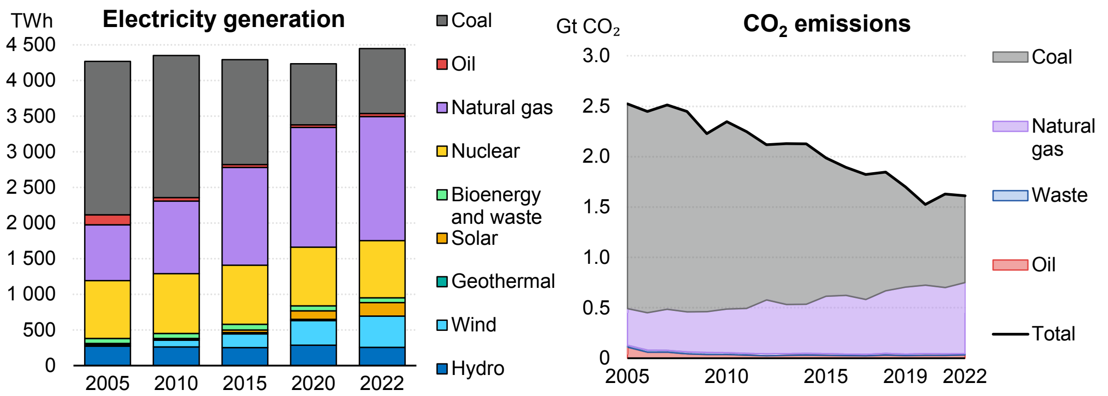
Key climate and energy trends in the US power sector

In the United States, the power sector remains one of the most CO_2 emissions-intensive sectors along with transport. GHG emissions have come down thanks to coal-to-gas switching, the growth of renewable energy, and continued demand-side energy efficiency efforts since 2005. In 2022, power generation was

[3] The United States defines the target as 100% carbon-free electricity generation by 2035 and includes wind, solar, geothermal, hydropower, nuclear, biomass with and without CCS, and fossil energy with CCS.

composed of natural gas (39%); coal (20%); and nuclear generation (18%); with 22% from wind, solar, hydropower, geothermal and bioenergy. Due to the factors listed above, along with regulations on pollution in the power sector, the US power sector is witnessing a fast decline of coal-fired generation, which has fallen by 58% since 2005, contributing to a 37% decline in emissions from the power sector.

Figure 2.1 Power generation and emissions by fuel use, United States, 2005-2022

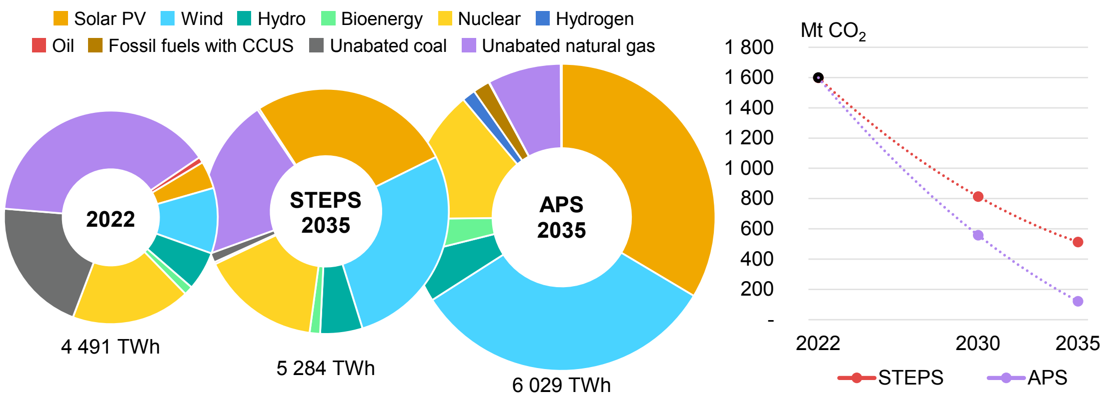


Note: TWh = terawatt hour.
Sources: IEA (2024) World Energy Balances (database).

IEA analysis of the IRA expects an 80% reduction in unabated coal power by 2030. This will be accomplished through rapid deployment of clean electricity, especially wind and solar. In the medium term, the United States will need to invest in flexibility, including grids, batteries, flexible thermal capacity with clean fuels, and a much more active demand and consumer response. This will enable further expansion in the deployment of renewable energy.

According to the IEA's *World Energy Outlook 2023*, CO_2 emissions in the power sector are expected to be 50% lower in 2030 than today with current policies in place (STEPS), as illustrated in Figure 2.2.

Figure 2.2 Electricity generation and emissions, United States, 2022 and 2035 outlook



Note: PV = photovoltaic; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario.
Source: IEA (2023), World Energy Outlook 2023.

The impact of the IRA will be enduring, as it provides long-term extensions of key tax credits beyond the annual fiscal cycle. The IRA extended and expanded existing key tax credits for clean electricity, including the Investment Tax Credit (ITC) and Production Tax Credit (PTC), providing significant economic incentives and investment certainty to support the deployment of clean electricity and storage. From 2025 onwards, the Investment Tax Credit/Production Tax Credit will become emissions-based, technology-neutral Clean Electricity Investment and Production Credits. A new supply-side tax credit (Advanced Manufacturing Production Credit) supports domestic manufacturing for solar, wind, inverters and battery components. Tax credits can be scaled up through bonuses for certain clean electricity activity in low-income communities or historic energy communities and for meeting domestic sourcing standards.

The IRA and BIL also support existing clean electricity generators, such as hydro and nuclear power plants. The Civil Nuclear Credit programme is a financial assistance that can be awarded to existing nuclear plants otherwise at risk of early retirement owing to economic factors, while the IRA contains a tax credit for existing nuclear plants. The BIL also incentivises production and efficiency improvements at existing hydropower facilities. The Energy Earthshots™ Initiative drives clean energy breakthroughs by reducing the cost of critical technologies. It also includes a vision to partner with the private sector to realise the first fusion pilot plants and FOAK commercial plants in the 2030s.

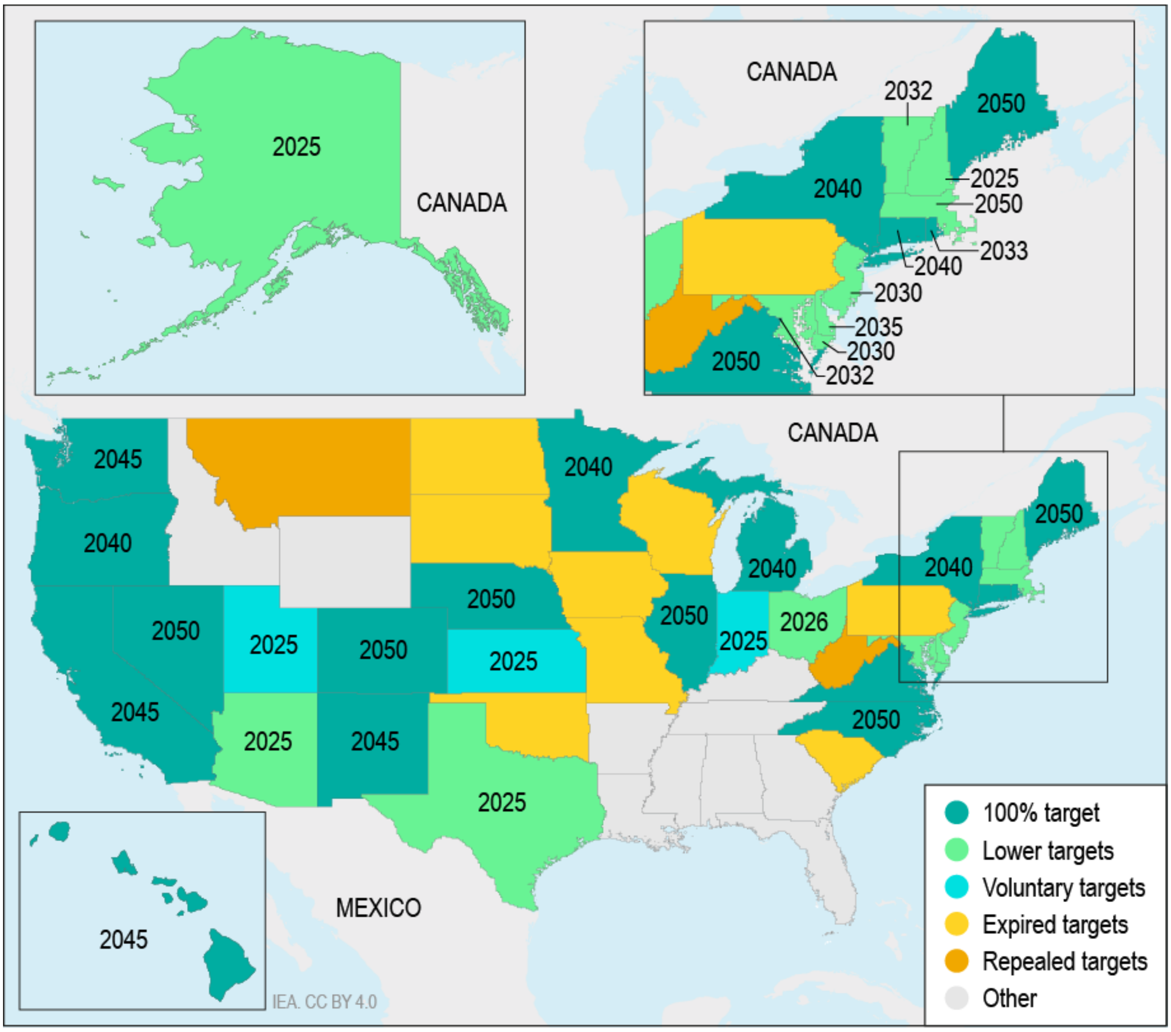
Federal regulatory mechanisms, such as standards, work alongside these major incentives. In May 2024, the Environmental Protection Agency (EPA) finalised emissions limits and guidelines for CO_2 from new and existing fossil fuel power plants based on cost-effective and available control technologies. The rules presented under the Clean Air Act for existing power plants are proposed to be phased in from 2032 onwards. The United States uses regulatory mechanisms for power plant facilities rather than federal emissions policies (carbon pricing or caps). In June 2022, the Supreme Court ruled in the case West Virginia vs. EPA that the Clean Air Act does not give the EPA the authority to require states to shift generation from high-intensity GHG-emitting resources to other cleaner resources. Therefore plant-specific technologies, such as CCS and natural-gas co-firing underpin the final EPA emissions limits for facilities.

Focus: Expanding system integration of higher shares of variable renewables

Renewable energy objectives and market dynamics

Besides the federal incentives to drive power sector decarbonisation by 2035, many state-level policies provide stability, such as minimum requirements for the share of electricity supply from renewable or clean energy sources. Renewable portfolio standards and clean energy standards vary widely in terms of the inclusion of non-renewable clean energy technologies, programme structure, enforcement mechanisms, size and application across the country.

Figure 2.3 Renewable portfolio standards and clean energy standards in the United States



Sources: IEA based on State Renewable Portfolio Standards and Goals; C2ES; Database of State Incentives for Renewables & Efficiency; Berkeley Lab.

As of November 2022, 36 states and the District of Columbia had renewable portfolio standards or a renewable energy goal or clean energy standards or net zero emissions commitments. In 21 of those states (and the District of Colombia and Puerto Rico), the requirement is for 100% clean electricity by 2050 or earlier. Indiana and Utah have voluntary clean energy goals. In Iowa, Kansas, North Dakota, Missouri, Oklahoma, Pennsylvania, South Carolina, South Dakota and Wisconsin, renewable portfolio standards/clean energy standards requirements or goals have expired. There are also several US states, especially in the south-east, without any renewable portfolio standard/clean energy standard targets.

The United States has been a pioneer in promoting corporate power purchase agreements (PPAs). To meet renewable energy growth, the IEA forecasts US corporate PPAs to account for the largest share (40%), mostly in the form of virtual PPAs in deregulated wholesale markets. The remainder (60%) will come from utility-owned plants, competitive auctions and PPAs with utilities. Over 80% of the virtual PPAs signed between 2021 and 2023 were in several regional power systems or interconnection areas (Texas ERCOT, MISO and Eastern interconnection PJM service areas).

However, PPA prices have been on the rise, reflecting climbing interest rates, equipment price increases and interconnection queues, which have all driven up costs for developers. In 2022, the forecasted expected US solar PV capacity shrank almost 15% owing to supply chain difficulties and rising costs. Equally, supply chain difficulties for onshore wind supply chain challenges also slowed the pace of construction in the United States.

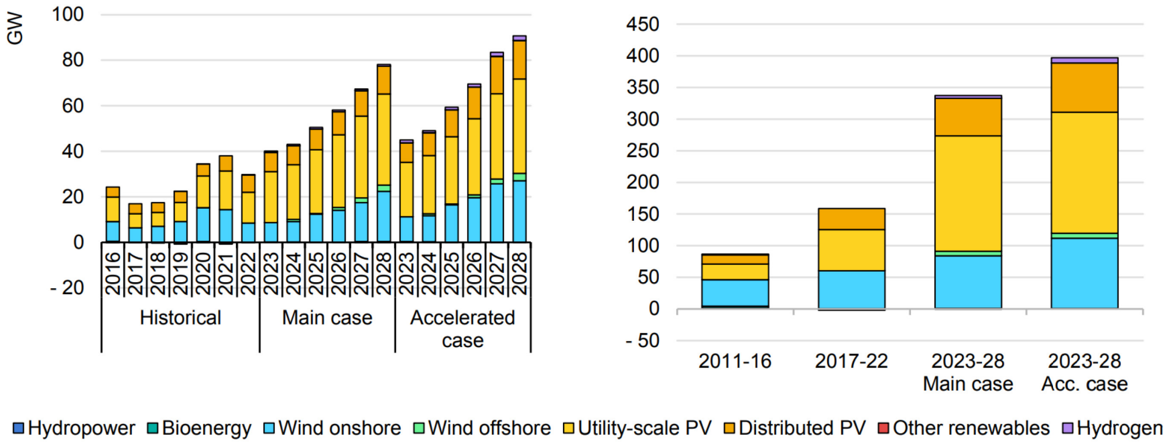
After the People's Republic of China (hereafter "China") and the European Union, the United States was the third-largest onshore wind and solar PV market in terms of total installed capacity, which reached 400 GW in 2023.

According to DOE and the IEA Renewable Energy Progress Tracker, US renewable energy capacity could almost triple from around 300 GW in 2020 to 845 GW in 2030.

The IEA renewable energy market update 2024 forecasts a significant growth in the US renewable energy sector, with a total of 340 GW of new renewable energy capacity expected to come online between 2023 and 2028, which is equal to a doubling of current capacity. Growth could be accelerated by 17% in the forecast period if the United States is able to lift grid constraints, adapt remuneration to the new economic conditions, and address wind and solar PV manufacturing and supply chains bottlenecks. With that progress, the share of renewable energy in power generation is expected to increase from 22% to 34% by 2028. This includes hydro, wind and solar power, geothermal, bioenergy, ocean energy and renewables for hydrogen production.

The IEA's market forecast, based on projects in the pipeline, shows that there is still a gap in deployment and many actions are needed in the near future to promote renewables at the scale needed to meet the United States' clean energy objectives and targets.

Figure 2.4 Renewable capacity net additions and total capacity by technology in the United States



Notes: Hydrogen refers to renewable capacity dedicated to hydrogen production. Other renewables includes geothermal and CSP. Negative net additions refer to retirements.
Source: IEA (2024) Renewable Energy Market Update.

The financial health of renewable energy value chains is critical for the sustainable growth of the industry. Stable and predictable policies help guarantee this health over time. As elsewhere, the onshore and offshore wind industry faces social acceptance challenges, volatile commodity prices and interest rates, as well as long permitting timelines and auction designs that fail to reflect changing financing environments. It is necessary to adapt policies, support mechanisms and market design to ensure a resilient regulatory environment for large-scale investment in renewables.

Box 2.1 The United States' strategy to boost offshore wind power development

Since 2017, the American offshore wind industry has emerged with the first large-scale projects under construction and new wind energy areas identified along the Atlantic, Pacific and Gulf of Mexico coasts. As part of the US offshore wind strategy, the US government targets an installed capacity of 30 GW of offshore wind by 2030, with around 23 GW under development in 2023, to boost supply chains and increase the skilled workforce for offshore wind, as set out in the US Offshore Wind Supply Chain Roadmap, presented by the Department of Energy and National Offshore Wind R&D Consortium. By the end of 2023, the United States had deployed 42 megawatts (MW) of offshore wind and the first large-scale offshore wind farms began delivering electricity to the grid in New England in early 2024 (South Fork Wind Farm and Vineyard Wind 1). According to the 2023 US Offshore Wind Report, ten US states have set offshore wind targets totalling more than 112 GW by 2050. A total of 15 GW of offshore wind projects were cancelled or postponed during 2022-23, lowering the market outlook. Major investors such as Orsted or BP have cancelled or postponed offshore wind developments on the east coast due to supply chain issues; a lack of equipment reliability and cost increases; lack of a skilled workforce; and rising interest rates, commodity prices and inflation. Other lead markets experienced similar challenges.

A combination of state tenders and auctions in federal waters supports the development of US offshore wind supply chains and jobs. The US government advances offshore wind leases and promotes federal-state implementation partnerships, involving many east coast states and federal agencies. As of early 2024, the Department of the Interior had leased more than 2.5 million acres of federal waters for offshore wind development. On the West Coast, the federal government is supporting progress on floating offshore wind, including through Floating Offshore Wind Earth Shot, which has the goal of reducing the costs by over 70% by 2035. The US government is focusing on efficient and effective permitting and leasing offshore wind and other clean energy development on the US Outer Continental Shelf, led by the Bureau of Ocean Management, in collaboration with states and offshore transmission grid planning and investment.

Adapting the US power markets and systems

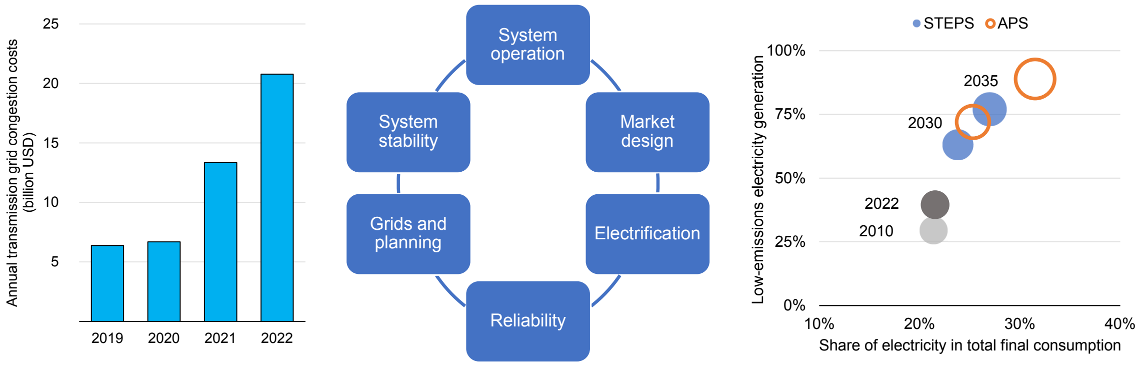
As the power sector is decarbonising and electrification of end uses increases, electricity is projected to reach a share of 30% in total final consumption by 2035, up from 25% in 2022. In the longer term, the share of electricity is set to grow to 50% by 2050 under the net zero emissions pathway. This translates into an expected 1.3-1.5% growth rate by 2025, with a stable growth rate through 2050. Electricity demand growth projections follow two decades of stagnation. Today, electricity demand has reached 2005 levels, thanks to growth in the residential sector. Demand for electricity in the commercial and industrial sectors has been flat over the past five years.

To meet its target of 100% carbon-free electricity generation by 2035, the United States would need 2 000 GW of new clean energy capacity and energy storage by 2035.

The transition of the power sector requires the adaptation of the power system and the market design for modernising the existing system (grids and generation) through replacements and retirements, adapting system and market operations to enable the new system with higher shares of variable renewables, more modern and resilient grids, and growing electricity consumption as electrification advances and domestic manufacturing grows. More system flexibility sources on the side of supply and demand are needed to support this transition. Optimised battery dispatch and demand-side flexibility allow following hourly variability of supply and support the reliability and stability of power quality, alongside dispatchable low-emissions capacity – fossil fuel capacity with CCUS, hydropower, biomass power, nuclear, and hydrogen and ammonia-based plants – to address seasonal and diurnal variability.

Electricity markets across the independent system operators and regional transmission organisations (ISOs/RTOs) are increasing the scope and amount of flexibility sources to adapt to system operations with higher shares of variable renewables. The FERC and its rules are actively supporting the adaptation of the existing market designs across regional electricity markets, which can ensure greater consistency and coherence in the future market design. US electricity markets are complex, with strong regional markets that remain weakly interconnected, which exacerbates the challenges.

Figure 2.5 Adapting electricity markets and systems in the United States



Sources: IEA analysis based on IEA (2023), Electricity Grids and Secure Energy Transitions; World Energy Outlook 2023.

The United States is the second-largest battery storage market globally, showcasing remarkable growth and potential in the sector. Battery storage additions in the United States has experienced a significant surge, doubling year-on-year to exceed 8 GW in 2023, a sixfold increase compared to 2020. Investments in battery storage rose to USD 11 billion in 2023 and are expected to continue growing in 2024. This expansion is largely driven by improving economics, market reforms, falling equipment costs, and substantial incentives. The IRA offers a federal tax credit of up to 50% for storage projects, alongside a residential clean energy credit that provides a 30% tax credit for installing clean energy equipment, including behind-the-meter battery storage systems with at least 3 kWh capacity. These financial incentives have enabled utility-scale batteries to penetrate ancillary service markets, where they provide balancing services and securing capacity, particularly in states with a high share of variable renewable energy generation.

Additionally, there has been a noticeable uptick in the announcement of new battery storage projects in the United States, spurred by the rising demand for storage in microgrid projects and further investment support under the IRA. To date, nine states have set ambitious storage targets, aiming for over 50 GW of cumulative additions over the next two decades. IEA analysis anticipates that annual battery storage additions in the United States will continue to climb, projecting a rise to 28 GW by 2030 under the Stated Policies Scenario (STEPS). Moreover, the United States spearheads efforts in support of a global energy storage target of 1 500 GW by 2030, which is a G7 commitment from the Turin G7 Climate, Energy and Environment Ministerial in April 2024.

The country is navigating significant changes in its traditional energy infrastructure and needs to ensure power sector reliability during the transition. In 2022, the United States had the world's third-largest fleet of coal-fired power capacity (after China and India). However, no new coal plant has been built in the past decade. Based on industry data, the Energy Information Administration (EIA) expected 59 GW, or 28% of the total US coal-fired capacity (200 GW), to retire during the period 2021-35, mostly in Michigan, Texas, Indiana and Tennessee.

The current fleet of nuclear reactors and hydropower facilities is a cornerstone for the provision of affordable, dispatchable and reliable clean electricity (see Chapter 5 for electricity security). Hydropower supports the balancing of the system and is also a source of flexibility. Ensuring lifetime extensions of nuclear power plants and licence renewals and efficient relicensing of existing hydropower plants will reduce new deployment needs. The BIL provides up to USD 6 billion of support for existing nuclear and over USD 800 million for existing hydropower facilities.

By 2035, a total of 17% of the US hydropower installed capacity, or 17 GW, will need to be relicensed (459 hydropower plants with a generating capacity of around 9 100 MW of hydropower and 8 400 MW of pumped storage).

The US nuclear fleet has an average age of 42 years. As of September 2023, 92% of the US nuclear fleet had received regulatory approval from the Nuclear Regulatory Commission (NRC) to operate up to 60 years. Six units have the NRC's approval to operate up to 80 years, with 10 subsequent licence renewals under NRC review, 1 under acceptance review and 8 more expected to be submitted.

Electricity grids

The United States (much like Japan and the European Union) has ageing grid infrastructure and its modernisation is overdue. Over the past ten years, the United States has added around 925 000 kilometres of new distribution lines (compared to 715 000 kilometres in the European Union). However, the United States only expanded its transmission grid by 3% (compared to 7% in the European Union). The DOE's latest infrastructure review found that 70% of US transmission lines are well into the second half of their typical 50-year lifespan, while the average age of large power transformers, which handle 90% of US electricity flow, are now more than 40 years old.

The US power grid will have to double in capacity between 2022 and 2050 to meet increasing demand from data centres and energy-intensive industry. The most newly built capacity will be from renewable energy technologies, according to the EIA's Annual Energy Outlook 2023.

The latest IEA analysis on the role of grids in clean energy transitions confirms that worldwide overhaul of energy planning is needed. This includes more proactive grid development, the remuneration of grid investment, and the digitalisation and considerations of security of grid supply chains.

The federal government has deployed major new initiatives to advance significantly the planning of electricity grids. The federal government is prioritising investment in expanding large interregional transmission projects to increase reliability and resilience, and is speeding up the grid connection of clean electricity generation by means of a combination of improved planning and cost-allocation across regions (FERC Order 1000 and Order 1920), loan programmes, grants to states as part of permitting and siting assistance, more co-ordinated and efficient processes with a two-year timeline under the Coordinated Interagency Transmission Authorizations and Permits, and the designation of national interest electric transmission corridors.

The federal government is taking significant steps to remove connection and permitting barriers, which include actions by the DOE, FERC and the NEPA reforms, as described in Chapter 1. Building on these reforms of federal environmental reviews and permitting processes and the memorandum of understanding signed between federal agencies, the DOE issued a final rule in April 2024 to establish the Coordinated Interagency Transmission Authorizations and Permits (CITAP) Program.

In July 2023, FERC Order 2023 adopted the first major change to FERC's interconnection requirements in two decades to expedite connections for power generation projects to the electric grid. The FERC rule uses bundling of connection requests, the "first-ready, first-served" cluster study process to quicken grid connection, as well as deadlines on interconnection studies and penalties if transmission providers fail to complete their interconnection studies on time. In support of FERC Order 2023, in April 2024, the DOE released a roadmap to accelerate connections of clean energy sources through improved data access, streamlined interconnection processes, and greater economic efficiency, with targets set for significant interconnection improvements by 2030.

In the United States, the authority to issue permits for the siting of transmission has traditionally resided with the states' public utility commissions. Transmission investment requires each state to approve the cost and siting of the transmission lines. For some interstate transmission facilities, some degree of co-operation among regulators for regional transmission lines across states was initiated under FERC Order 1000. In May 2024, FERC finalised Order 1920 which in part requires additional long-term planning by regional transmission providers and to determine how to allocate costs of regional transmission expansion.

The BIL brought about significant amendments of the Federal Power Act (FPA) regarding the siting of interstate transmission lines (Section 216), clarifying the DOE's authority to designate national corridors and related FERC jurisdiction in the siting of transmission facilities in specific situations where they address transmission capacity constraints or congestion. FERC can issue a permit for a transmission project in a national corridor where a state does not have the authority or does not act within a certain time frame or denies a permit for such a project. In 2022, based on the new FPA 216, FERC proposed a rule change to revise its existing 2006 regulations governing applications for permits to site electric transmission facilities under Section 216 of the FPA and invited comments on the Notice of Proposed Rulemaking in 2023. In May 2024, FERC finalised Order 1977 outlining improvements to implementation of this backstop siting authority. DOE proposed 10 potential national interest transmission corridors to accelerate transmission development in those areas with identified need.

Over a decade, the United States has focused on modernising the existing grid and investing in greater interregional capacity. The federal government is pursuing efforts to reach greater efficiency (noteworthy is FERC's new inquiry into dynamic line rating) and to carry out advanced power grid upgrades while expanding long-distance transmission, building on the Grid Modernisation Initiative. Major upgrades are carried out on the Chateauguay high-voltage direct current line (connecting Quebec and the state of New York grids) and the replacement of converter stations on the Intermountain Power Project, linking Delta, Utah to Adelanto, California. Today's replacement and upgrades should also be done with a view to prepare for the future system, using innovative technologies.

The “Building a Better Grid” initiative provides more than USD 15 billion in funding from the BIL. The DOE’s Grid Deployment Office administers the USD 10.5 billion Grid Resilience and Innovation Partnerships Program to enhance grid flexibility and climate resilience through three schemes: 1) grid resilience utility and industry grants; 2) smart grid grants; and 3) grid innovation programme in support of capacity building and technical assistance for states and local governments. In October 2023, the DOE announced up to USD 3.46 billion investments for 58 projects across 44 states, with 16 projects selected under grid resilience utility and industry grants. Besides transmission funding programmes, the DOE supports innovation through the Transformer Resilience and Advanced Components Program, which aims to reduce transmission costs and improve grid reliability and resilience by means of advanced transformers and other innovative technologies, and the HVDC moonshot, which targets a 35% cost reduction by 2035.

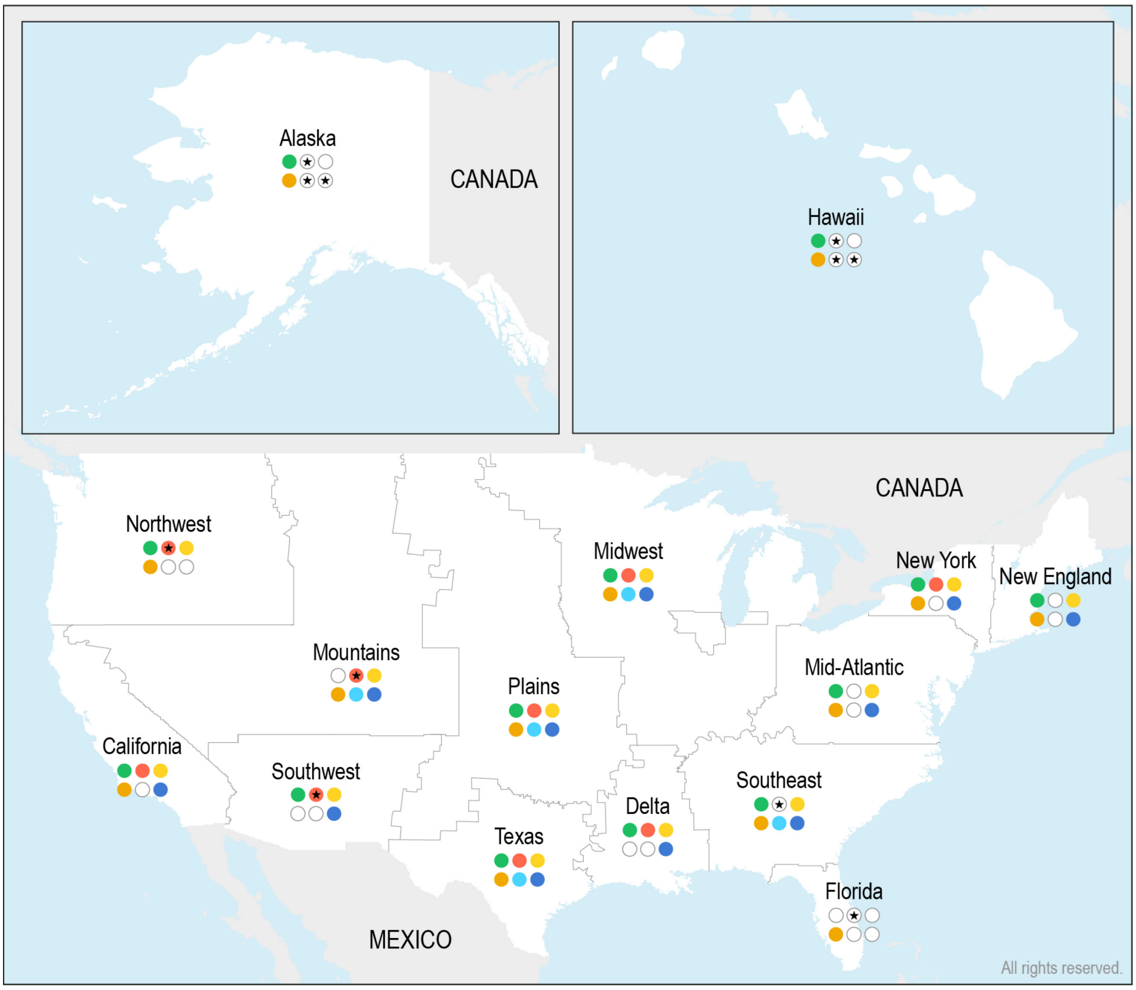
In support of the BIL, the Transmission Facilitation Program provides the DOE with authorisation to employ up to USD 2.5 billion through three financing tools: 1) capacity contracts with eligible projects where the DOE would serve as an “anchor customer” to buy up to 50% of planned line rating for up to 40 years and to sell the contract to recover costs; 2) loans from the DOE; and 3) DOE participation in public-private partnerships within a national interest transmission corridor necessary to accommodate an increase in electricity demand across more than one state or transmission planning region. The Transmission Facilitation Program is best fit for projects that are nearly “shovel-ready”, are located in regions that rely on firm point-to-point transmission and that would not be constructed without support. Since October 2023, the DOE has entered into capacity contract negotiations with a commitment of up to USD 1.3 billion in three transmission projects across five states aimed to add 3.5 GW of additional grid capacity. Construction for these projects is expected to start in Q1 2025/late 2026:

- **Cross-Tie 500 kilovolt Transmission Line Project (Nevada, Utah),** developed by TransCanyon, is a 214-mile, 1 500 MW transmission line connecting existing transmission systems in Utah and Nevada to increase transmission capacity, improve grid reliability and resilience, relieve congestion on other key transmission lines, and expand access to low-cost renewable energy across the region.
- **Southline Transmission Project (Arizona, New Mexico**), developed by Southline Transmission LLC (Grid United LLC, Black Forest Partners LP and Hunt Transmission Services LLC), is a 175-mile, 748 MW transmission line from Hidalgo County, New Mexico to Pima County, Arizona to support renewable energy development in southern New Mexico and deliver low-carbon energy to growing markets in Arizona that rely on fossil fuel generation. The project, which is the first phase of a longer line, will make use of existing transmission rights of way along parts of its route while also upgrading ageing transmission facilities.

- **Southwest Intertie Project - North (Idaho, Nevada)** is 285-mile, 2 000 MW transmission line from Twin Falls, Idaho to Ely, Nevada, to bolster resource adequacy in the West by bringing wind energy from Idaho to Southern Nevada and to California and enable solar resources to meet evolving reliability needs in the Pacific Northwest. The construction is anticipated to start in 2025, which would create over 300 new construction jobs. The line will also help increase grid resilience during wildfires or other system disruptions by providing an alternate route to deliver power supplies during such events. This project will also upgrade a key substation in Nevada, unlocking an additional 1 000 MW of capacity along the existing One Nevada Line, a major transmission corridor in Southern Nevada.

In line with the BIL and amended FPA, the DOE has presented a National Transmission Needs Study (formerly the Congestion Study), which examines historic and anticipated future capacity constraints and transmission congestion and consumer impacts. The study finds that transmission investment would help alleviate congestion that keeps several regions under high prices (Plains, Midwest, Mid-Atlantic, New York and California), reduce intra-regional congestion (Northwest, Mountain, Texas and New York regions) and lower unscheduled flows (California, Northwest, Mountain and Southwest regions). Between regions, the DOE confirms the need for three key interconnections: Mountain and Plains; Texas and Delta, Southwest and Texas; and the Plains and Texas regions. In a dynamic analysis, interregional transmission capacity will be needed across the country after 2040.

Figure 2.6 Anticipated congestion and electricity transmission needs in the United States



		Region													
		California	Northwest	Mountain	Southwest	Texas	Plains	Midwest	Delta	Southeast	Florida	Mid-Atlantic	New York	New England	Alaska	Hawaii
Current or anticipated need	Improve reliability and resilience															
	Alleviate congestion and unscheduled flows		*	*	*					*	*				*	*
	Alleviate transfer capacity limits between neighbours															
	Deliver cost-effective generation to meet demand															
Anticipate d need	Meet future generation and demand with within-region transmission														*	*
	Meet future generation and demand with interregional transfer capacity														*	*

Notes: Wholesale market price data are limited for non-RTO/ISO (regional transmission organisations/independent system operators) regions and capacity expansion modelling data are limited for Alaska and Hawaii. The absence of data does not necessarily indicate that there is no need for new transmission.

Source: DOE (2023), National Transmission Needs Study as modified by the IEA.

Demand-side flexibility, smart grids and storage

According to FERC's 2023 report and EIA data, the United States had around 111 million advanced smart meters in operation, representing over 68% of around 163 million total meters in operation across all customer classes. The American Recovery and Reinvestment Act of 2009 supported the first roll-out of smart meters in the United States. The next stage of smart meter deployment will require a focus on developing data privacy and transparency rules.

Across RTOs/ISOs, demand response contributions from wholesale markets are slowly increasing to a total of 32.9 GW, or around 6.5% of peak demand (in the California Independent System Operator, PJM Interconnection and Midcontinent Independent System Operator even 7-10%), according to a FERC 2023 report. Load management plays an increasingly important role for RTOs/ISOs to manage extreme weather events.

FERC Order 2222 enables distributed energy resources to participate alongside traditional resources in the regional organised wholesale markets through aggregations, as new sources of energy and grid services. Participation helps provide a variety of benefits, including lower costs for consumers through enhanced competition, more grid flexibility and resilience, and more innovation within the electric power industry. Under Order 2222, regional grid operators must revise their tariffs to establish distributed energy resources as a market participant according to their physical and operational characteristics.

Policy makers are increasingly making demand response and dynamic pricing a part of system integration policies. For example, in 2023, the California Energy Commission adopted a target of up to 7 000 MW of electricity available through load flexibility by 2030. Also in 2023, the Washington Utilities and Transportation Commission approved Puget Sound Energy's first Clean Energy Implementation Plan, which required the company to update its specific target for demand response technology and establish and increase procurement targets.

The DOE's Loan Programs Office (LPO) also targets the development of virtual power plants (VPPs) of 80-160 GW, or triple the current amount, by 2030. VPPs are networks of aggregated distributed energy resources, such as rooftop solar PV, home battery storage, heat pumps, EV chargers, and commercial and industrial electricity load. The DOE expects VPPs to increase grid capacity to reliably support rapid electrification while redirecting grid spending from peaking plants to participants and reducing overall grid costs by USD 10 billion per year, according to the DOE's commercial liftoff report on VPPs.

The DOE LPO, which finances large-scale energy infrastructure projects, leverages investment in renewable energy projects, VPPs and advanced nuclear.

In 2023, the LPO had 177 active applicants for a total envelope of USD 157.1 billion, with more than 2 new applications per week.

Moreover, the DOE's Office of Electricity is focusing on reducing the cost of long-range storage (more than ten hours' duration) by 90% this decade under the long-duration energy storage shot and technology-specific strategy efforts, such as the long duration storage shot technology strategy assessments. Other important initiatives include the Energy Storage Grand Challenge to accelerate the development, commercialisation and utilisation of next-generation energy storage technologies, and the Pathways to Commercial Liftoff report on Long Duration Energy Storage, supported by the Office of Technology Transitions in co-ordination with other DOE offices, and examined commercialisation pathways for long-duration energy storage technologies.

Focus: Nuclear energy

Long-term operation of the US nuclear fleet

Nuclear power remains the largest source (46%) of low-carbon electricity in the United States in 2023. The country operates 94 nuclear reactors across 54 sites, accounting for an installed capacity of 97 GW, producing 772 TWh, or 18% of total electricity generation. The share is down from the historical 20%, partially due to the closure of the 800 MW unit at Palisades Nuclear Power Plant in May 2022.[4]

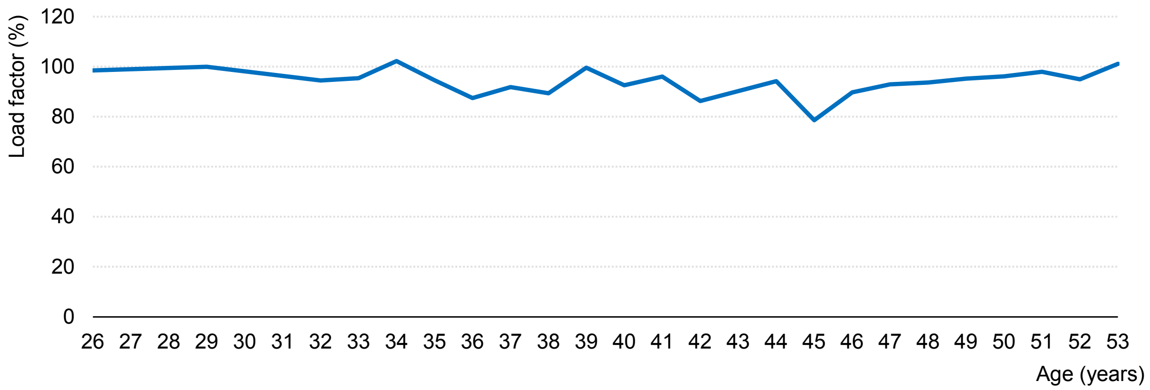
The share of nuclear power in electricity generation increased in 2023 with the connection of Vogtle Unit 3 in the state of Georgia. Unit 4 has entered into service in April 2024.

The US nuclear fleet is one of the oldest in the world, with an average age of 42 years. The oldest unit, Nine Mile Point Unit 1, remains operational after almost 54 years in service. Of the 93 reactors currently in operation, 54 (more than 50%) are over 40 years old and are operating within 20-year licence extensions granted by the NRC. Despite its advanced age, the fleet is also one of the top-performing globally. Its average capacity factor has exceeded 90% over the past decade, reaching a peak of 93% in 2019. In 2022, the average capacity factor was 92.7%, with the 12 units older than 50 years maintaining 97.5% availability. Since 2012, the average refuelling outage time has also steadily decreased to under 35 days on average, according to the International Atomic Energy Agency.

[4] Following the acquisition of the plant in June 2022, Holtec has taken steps to seek federal reauthorisation for restarting the plant. The LPO has announced an offer of conditional commitment of up to USD 1.52 billion for a loan guarantee to Holtec Palisades to finance the restoration and resumption of service, and Holtec has signed a PPA with Wolverine Power Cooperative.

As of September 2023, 92% of the US nuclear fleet had received regulatory approval from the NRC to operate up to 60 years. A total of six units have NRC approval to operate up to 80 years, with 10 subsequent licence renewals currently under NRC review, 1 under acceptance review and 8 more expected to be submitted in the near future. These trends suggest there is a robust knowledge base in the United States to safely operate nuclear power plants, specifically light-water reactor types, over the long term, at minimum up to 60 years, with technical uncertainties being addressed for long-term operation up to 80 years.

Figure 2.7 Capacity factor of US nuclear reactors by age, 2022



Source: IEA analysis based on IAEA (2024). Power Reactor Information System.

The long-term operation of existing nuclear reactors is also one of the most cost-effective options for low-carbon electricity generation in the United States, as shown in IEA dedicated analysis based on the value-adjusted levelized cost of electricity. The typical generation costs for these reactors range between USD 32-35 per MWh, while new builds are mostly above USD 80 per MWh. Despite being relatively competitive, some units have been closed prematurely in the United States for market reasons, especially single units operating in states with competitive electricity markets. Since 2012, 13 reactors totalling 10.2 GW of capacity have been shut down in the United States, representing around 20% of all retired reactors globally, based on IAEA data.

Several policies have been introduced at the state and federal levels to support the continued operation of existing nuclear reactors, recognising their value for providing low-carbon generation and energy security to meet net zero emissions targets by 2050. These state-level efforts catalysed action at the federal level with the Civil Nuclear Credit Program, established through the BIL. The Program provides USD 6 billion in funding for nuclear power plants that may otherwise be forced to close without financial assistance.

For instance, in January 2024, the federal government announced an envelope of up to USD 1.1 billion of federal funding to keep California's last operating nuclear power plant (Diablo Canyon Power Plant) online for at least five more years in the period up to 2030.

Table 2.2 Status of licence renewals and subsequent renewals of US nuclear reactors, 2023

	Under review	Under acceptance review	Completed	Future submission
Licence renewal – 60 years	2	1	86	1
% of total operating reactors	2%	1%	92%	1%
Subsequent licence renewal – 80 years	10	1	6	8
% of total operating reactors	11%	1%	6%	9%

Sources: IEA analysis based on data from August 2023 from the Nuclear Regulatory Commission, Status of Initial License Renewal Applications and Industry Initiatives and Status of Subsequent License Renewal Applications.

In addition to the Civil Nuclear Credit Program, the IRA enables nuclear plants under financial stress to receive a Production Tax Credit, which provides up to 15 USD/MWh for electricity generated, provided certain labour requirements are met. This credit is available to facilities operational in 2024 through 2032, helping existing reactors remain competitive with other power generators. While these measures offer short-term relief, they do not fully address underlying electricity market design issues that prevent nuclear generation from being properly valued in competitive electricity markets. Some ISO/RTOs have capacity markets (i.e. PJM) and/or are exploring the introduction of performance credit mechanisms (i.e. ERCOT), which creates additional reliability revenue streams beyond energy only that may benefit existing nuclear generation. The ability of this new market mechanism to compensate the revenue gap in nuclear units under financial stress is uncertain. Further efforts may be needed to incentivise continued operation of the existing US nuclear fleet through 2050.

Long-term operation of existing nuclear power plants also brings additional benefits beyond carbon emissions avoidance and affordable electricity generation. Nuclear power is recognised as a source of fuel diversity in the electricity mix and supplies services such as inertia and system strength, contributing to overall grid stability and smooth system operation in a system with high shares of variable renewables. The reliability of existing nuclear plants becomes even more critical in a context of accelerated retirements of coal plants, higher electrification and electricity generation decarbonisation and the slow pace of grid expansion projects.

Nuclear power plants also confer social benefits locally by providing high-skilled, well-paying jobs and tax revenue. With ambitions to build new nuclear power plants, the existing US nuclear fleet also helps sustain the necessary supply chain and talent pipeline required to support future construction.

New nuclear build

The federal government is supporting the development of new nuclear power plants to help meet net zero emissions targets. The EIA's scenarios show a stable or declining share of nuclear in the US electricity mix, while the IEA's *World Energy Outlook 2023* has a 33% increase in capacity by 2050 (based on the US climate pledges).

An ambitious scenario of electrification and technology innovation was presented by the federal government in the Pathways for Commercial Liftoff: Advanced Nuclear" report. To meet the estimated 550-770 GW of additional clean, firm power capacity in the United States by 2050, nuclear power would potentially provide around 200 GW of this capacity addition, which would translate into 13 GW of new nuclear capacity to be added annually. Delivering new nuclear projects at this pace and scale would, however, not be possible under today's conditions and pose very significant challenges. At the COP28 in 2023, the federal government spearheaded jointly with France and 18 other countries the global call for tripling nuclear power generation by 2050.

New nuclear construction in the United States faces challenges, mainly attributable to the FOAK nature of recent projects combined with a loss of industrial capabilities after a long hiatus in new builds. Since its inception, the construction of Westinghouse's AP1000 units in the United States has experienced time and cost overruns. The V.C. Summer project was abandoned in 2017, while Vogtle – consisting of Units 3 and 4 accounting for 2.2 GW – has continued, reaching over USD 10 000 per kilowatt electrical (kW_e). Unit 3 entered commercial operation in July 2023 while Unit 4 entered into service as of April 2024. The high costs and construction risks of recent FOAK, large nuclear projects have dissuaded the US industry from building additional large plants domestically. This contrasts with Europe, where FOAK builds of a given reference design have been followed by subsequent post-FOAK projects aimed at leveraging renewed industrial capabilities, lessons learnt and best practices to reduce costs and risks (see OECD Nuclear Energy Agency analysis). Examples are the United Kingdom's European pressurized reactor (EPR) projects at Hinkley Point C and Sizewell C, and France's programme for six EPR units. The DOE targets cost reductions by leveraging best FOAK practices between 30% and 40%, which supports the economic rationale of continuing to build large AP1000 units, identical to those at Vogtle.

In parallel, small modular reactors (SMRs) have gained momentum in North America. SMRs are expected to benefit from serial factory production in a standardised fashion, potentially reducing costs and risks compared to large projects. They also come in various sizes, configurations and output temperatures, expanding the value proposition of nuclear power. Some designs are evolutionary versions of existing light-water technology while others explore more innovative concepts with lower technology and regulatory readiness and, therefore, a more uncertain deployment timeline.

In contrast to the trends observed with large nuclear power reactor units, the US industry has shown interest in building SMRs. While new SMR units may initially cost more per kilowatt due to the lack of economies of scale and the novelty of the technology, they have attributes that make them perceived to be less risky investments. First, the upfront capital outlay for SMRs is lower than for large reactors. For example, a 150 MW SMR unit costing 8 000 USD/kW$_e$ with a 7% discount rate represents around USD 1.2 billion in investment cost. This is less than one year's worth of capital expenditures for some utilities or less than 30% of their annual revenue. Even with significant cost and schedule overruns, the financial risks of SMRs are more manageable for the private sector than a large nuclear unit with an initial capital expenditure approaching USD 10 billion. Second, the modular design and constructability of SMRs could enable higher learning and efficiency gains per unit at the same site and provide more certainty in meeting initial cost and schedule targets, resulting in a potentially lower risk of overruns. However, while supported by extensive experience in other sectors (e.g. aviation, shipbuilding), these potential SMR benefits remain unproven.

As of 2023, the United States had around 14 SMR designs under development and in different status of progress (Table 2.3). The NRC approved the VOYGR design in 2020, making it the first SMR design to be certified by the NRC. Several sites have been selected to host FOAK SMR units, including the Natrium demonstration project to be constructed in Kemmerer, Wyoming, and X-energy's Xe-100 reactor for Dow Chemical's Seadrift site in Texas. Some utilities are also including SMRs in their long-term integrated resource plans.

Table 2.3 US-based small modular reactor designs

Design organisation	Name	Technology	High-assay low-enriched uranium requirement (HALEU)
BWX Technologies Inc.	BANR SMR	Gas-cooled micro reactor	Yes
BWX Technologies Inc.	Project Pele	Gas-cooled micro reactor	Yes
GE Hitachi	BWRX-300	Water-cooled	No
Holtec International	SMR-160	Water-cooled	No
Kairos Power	Hermes	Molten salt	Yes

Design organisation	Name	Technology	High-assay low-enriched uranium requirement (HALEU)
Last Energy	PWR-20	Water-cooled micro reactor	No
NuScale Power	VOYGR	Water-cooled	No
Oklo	Aurora	Fast-spectrum/micro reactor	Yes
Radiant	Kaleidos	Gas-cooled micro reactor	Yes
TerraPower	Natrium	Fast-spectrum	Yes
Ultra Safe Nuclear	MMR	Gas-cooled micro reactor	Yes
Westinghouse Electric Company	eVinci	Micro reactor	Yes
X-energy	Xe-100	Gas-cooled	Yes

Sources: IEA analysis based on data from the Nuclear Energy Agency (2023), The NEA Small Modular Reactor Dashboard and The NEA Small Modular Reactor Dashboard: Volume II.

The federal government has several provisions in place to derisk advanced reactor designs and incentivise the construction of new nuclear projects (Table 2.4). They cover the different stages of the life cycle of a nuclear power plant, from design and demonstration to operations, and to some extent the construction phase. The Advanced Reactor Demonstration Program provides USD 3.2 billion for the demonstration of advanced nuclear designs. The role of the DOE LPO has also been reinforced and is able to provide more than USD 300 billion in loans and loan guarantees. Eligible projects cover all the fuel cycle, including the front-end (i.e. conversion, enrichment and fabrication), new units as well as power uprates and upgrades in existing units. LPO has granted up to USD 12 billion in loan guarantees to the Vogtle project and conditionally committed an up to USD 1.52 billion loan guarantee to restore and resume service at the Holtec Palisades Nuclear Plant. LPO's role could be instrumental in enabling new nuclear projects in the United States.

Table 2.4 Federal provisions to incentivise the construction of new nuclear projects

Demonstration	Construction		Operation
Reducing technology and performance risks	Debt financing	Construction cost and risk-sharing	Reducing electricity market risks
Up to USD 3.25 under the Bipartisan Infrastructure Law and the Advanced Reactor Demonstration Program	> USD 300 billion in loans and loan guarantees by the Loan Programs Office	N/A	USD 25 per MWh of PTC or 30% of ITC if prevailing wage and apprenticeship requirements are met. Both incentives have +10% bonus for siting in energy communities and +10% for use of domestic content

Source: IEA analysis based on DOE (2022), Inflation Reduction Act Keeps Momentum Building for Nuclear Power.

Despite existing federal provisions to incentivise new nuclear builds, the United States is facing challenges securing an initial order book for new nuclear projects.

The high perceived risk of uncontrolled cost overruns discourages investment in and ownership of new nuclear plants, as first movers could face severe economic penalties. The DOE describes the situation as an industry stalemate between potential customers and the supply chain needed for project deployment. This impasse poses risks – without demand materialising for a critical mass of reactors, supply chain development will be inefficient. Moving down the learning curve requires opportunities for repeated deployments, which may not occur given the current situation. The United States also has a great variety of SMR designs under development, which represent both an opportunity and a challenge. While this reflects a very dynamic industry and opportunities for innovation, it could undermine competitive deployment. A reduced number of commercial SMR designs fosters high levels of standardisation and supply chain consolidation, necessary to drive the economies of series and reduce SMR costs.

The federal government has for objective to stimulate an orderbook of five to ten projects by 2025, which may require additional government effort given the current difficulties to catalyse new nuclear projects. The DOE has identified several measures, which explore greater government support and risk-sharing with the industry during the construction phase:

- **Cost overrun insurance**: A percentage of construction costs over and above a certain amount are covered by the government or private insurer.
- **Tiered grant**: Large grant amount per kW, ramping down over each successive deployment (i.e. second reactor receives less than the first).
- **Government as an owner:** Government commits to build and/or operate reactors to provide pooled demand.
- **Government as an offtaker**: Government signs offtake contract for some or all of generation from an orderbook.

In practice, the implementation of the above measures could take different forms. For example, covering cost overruns could be implemented via partially forgivable loans. Examples of cost overrun coverage for other low-carbon technologies have also been introduced at the state level.[5] Tiered grants may enable milestone-based and performance-based mechanisms to incentivise cost and build-time control, as well as the construction of identical units at the same site to foster standardisation and learning. Such measures should be compatible with existing financing tools and applicable to projects that already receive federal funding under parallel programmes. Building on the existing practice and processes at LPO may also be beneficial.

[5] Dominion Energy Virginia and key stakeholders reached an agreement on how to handle any cost overruns for the USD 9.8 billion, 2.6-GW Coastal Virginia Offshore Wind project. Under the agreement, Dominion’s shareholders would pay half of any costs in the USD 10.3 billion to USD 11.3 billion range and would be responsible for all of any prudently incurred costs from USD 11.3 billion to USD 13.7 billion.

Overall, implementing one or a combination of the above measures could help mitigate construction risks and accelerate new orders. However, specific congressional action may be needed to allow the federal government to take a more active role in the deployment of new nuclear units, in particular to provide cost overrun coverage or engage in long-term PPAs. Having several co-ordinated projects of a limited number of designs, as well as several identical units, will be essential to drive supply chain standardisation and consolidation (with potential negative impacts on competition) and drive costs down.

At the industry level, actions can be taken to derisk and increase the competitiveness of new nuclear projects. For example, an industrial consortium (i.e. buyers group) could be formed allowing risks to be shared across actors and to leverage a "fleet effect" for a given design to reduce deployment risks and costs. GE Hitachi Nuclear Energy (GEH), Tennessee Valley Authority (TVA), Ontario Power Generation (OPG) and Synthos Green Energy have teamed up to advance the global deployment of the GEH BWRX-300 designs. OPG has plans to build a BWRX-300 unit at the Darlington site, with construction permit expected by 2024, and TVA has made public its intention to build the BWRX-300 designs in its Clinch River site. Legislators in South Carolina are encouraging collaboration between utilities such as Dominion and Duke Energy for deployment of new nuclear. Such industrial consortia could also include energy off-takers looking for large amounts of low-carbon electricity available on demand to decarbonise their processes. This is the case with Microsoft, who is exploring the use of SMRs to power its data centres. The company will not own the facilities but rather offer PPAs over existing electricity market prices, which could trigger private investment in SMRs.

Advanced nuclear technologies such as SMRs come with a variety of output temperatures and bring new opportunities for decarbonising hard-to-abate sectors. SMRs can technically provide low-carbon heat between 250°C (current light-water reactor technologies) and almost 1 000°C for the most innovative designs. The United States also has four fully funded demonstration projects of hydrogen production with nuclear power, some of them already operational. Dow Chemical also has selected X-energy's technology to decarbonise its Seadrift site in Texas. These are pioneering projects that would place the United States at the forefront of using nuclear power to decarbonise industrial applications.

Supply chain considerations

The success of new nuclear projects also relies on the availability of a robust supply chain and skilled workforce. "America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition" identifies domestic supply chain gaps for large-scale near net shape components such as reactor pressure vessels, ingots for forging and turbine rotor support pedestals. Recent US nuclear projects have leveraged international supply chains to compensate for these gaps.[6] Transporting large components adds logistical and transportation costs that can make these components more expensive compared to domestic procurement. Once the orders for several new nuclear projects are secured and the manufacturing timelines and delivery schedules fixed, this should provide a clear demand signal for the supply chain to follow and drive the necessary investment to address potential manufacturing and workforce gaps. Forging and casting supply chain capabilities developed for wind and hydropower could also be beneficial for nuclear power, provided these suppliers are qualified to produce nuclear-grade components. Federal government procurement through the Department of Defence represents another option to quick start supply chain capabilities (e.g. Project Pele). The Advanced Materials and Manufacture Technologies Program in the DOE's Office of Nuclear Energy is also supporting innovations in advanced manufacturing and welding that could support the production of domestic large nuclear components in a more competitive manner.

Enabling regulatory frameworks

All US commercial nuclear reactors have been licensed under the two-step process in Title 10 of the Code of Federal Regulations (10 CFR) Part 50, except Vogtle which followed the 10 CFR Part 52 licensing process. The Part 52 process allows for a combined licence, reducing paperwork and enabling referencing standard designs. It is tailored for light-water reactor technologies. The Nuclear Energy Innovation and Modernization Act was signed into effect on 14 January 2019 with the aim of modernising the regulation of nuclear energy. One of the Act's key provisions is the requirement for the NRC to develop a regulatory framework for innovators seeking to deploy advanced nuclear technologies. This resulted in the proposal of a draft 10 CFR Part 53 licensing process which proposes a risk-informed, technology-inclusive regulatory framework, reflecting greater flexibility that could suit a variety of advanced reactor designs in line with the Act.

The nuclear industry association has questioned the NRC's ability to simultaneously handle 13 GW of new projects annually, along with licence renewals. The Nuclear Energy Institute indicates that the NRC's preparations to meet rising nuclear and advanced reactor demand have been incremental and insufficient for the level of ambition. While progress has been made to introduce more enabling regulatory frameworks in line with policy priorities, successfully delivering large-scale nuclear in the United States would likely require additional efforts to build up internal capabilities and ensure that the new regulatory

[6] The reactor pressure vessels for the Vogtle project had been procured by the Korean supplier Doosan Enerbility. This supplier is currently forging the reactor pressure vessels of the first NuScale VOYGR units for the Carbon Free Power Project near Idaho Falls.

processes bring the expected benefits in terms of flexibility without compromising regulatory stability and predictability.

Key recommendations

The US government should:

- Take a holistic, long-term and co-ordinated approach across fragmented US power markets, involving federal agencies and the states in planning and monitoring. Adopt enabling co-ordination and co-operation mechanisms between power market regulators, grid operators and utilities to enable the power transition in an efficient and secure way, including market design, ancillary services and adequate reliability standards and implementation and compliance with them.
- Task out interregional analysis of the future grid needs and system operation dynamics for the anticipated electrification, notably for very high demand from industrial, transportation and building sectors and the needed deployment of clean electricity on the grid.
- Support states' efforts to ensure resource adequacy during the transition to a carbon-free power sector, recognising growing power demand; the need for dispatchable capacity; and the value of smart systems, flexibility and demand-side resources and increasing needs for long-term energy storage.
- Adopt a dedicated federal clean energy strategy with a net zero investment strategy and a policy package, working with the private sector.
- Move quickly to implement the Federal Energy Regulatory Commission's interconnection queue rules, monitor progress towards a carbon-free power sector and take action to overcome any obstacles in partnership with local authorities, supported by federal capacity building and resource programmes. Streamline interconnection processes and network cost allocation to bring new resources online faster to offset plant retirements.
- Prioritise the development of the transmission grid based on a US government grid strategy and consider how to incentivise further action through the Transmission Facilitation Program, the completion of the reform of planning and permitting along with certainty over remuneration.
- With regard to nuclear power, support the long-term operational viability of the existing nuclear fleet, recognising its contribution to low-carbon power generation. Test risk-sharing mechanisms for the construction of new nuclear projects, optimising the use of existing financing tools. Foster scalable projects, supply chain standardisation and consolidation of new designs to improve the cost-competitiveness of nuclear power.
- Strengthen regulatory capabilities, including through international collaboration, and ensure that licensing frameworks support the safe and timely deployment of nuclear power.

2.2 Transport

The federal government set its ambitions and policies out in the US National Blueprint for Transportation Decarbonization, which covers road (light-duty and medium- and heavy-duty), off-road, maritime, aviation and rail transportation, with goals for boosting overall transport sector efficiency and addressing the impacts of land-use planning and community design on transportation accessibility and access. The US transport sector decarbonisation approach focuses on three areas: 1) increasing convenience – walkability and cycling access, co-ordinated land use and transportation system development; 2) enhancing efficiency – public transportation, modal shift for passengers and freight, and improved efficiency of all vehicles; and 3) promoting clean vehicles – zero-emission vehicle fuels and the infrastructure to support them. Under the Blueprint, the federal government targets net zero emissions by 2050. A goal of 50% of US passenger car and light truck sales as zero-emission vehicles, including battery electric, plug-in-hybrid electric or fuel cell electric vehicles, by 2030 is set out in the 2021 Executive Order.

The Blueprint is an interagency framework and the result of the enhanced cross-government co-operation building on the 2022 memorandum of understanding between the Departments of Energy, Transportation, and Housing and Urban Development and the Environment Protection Agency.

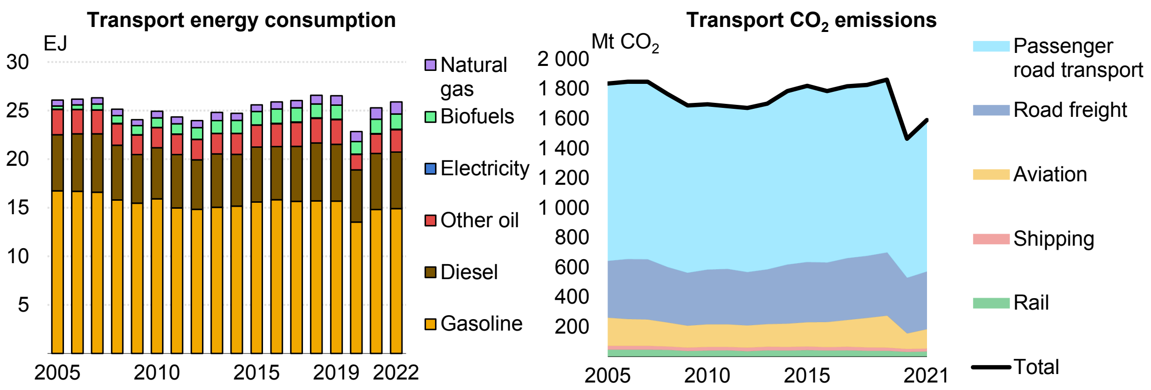
Multiple DOE offices are supporting the Blueprint in different areas, including through the Vehicle Technologies Office, the Hydrogen Fuel Cell Technologies Office and the Bioenergy Technologies Office. The DOE technology offices are also working closely with the national laboratory system on decarbonisation analyses and modelling. Decarbonisation of the transport sector requires a high degree of co-operation from federal, state, regional, local, urban and suburban, rural, and tribal governments; and the non-profit, philanthropy and private sector to create meaningful actions. Stakeholder engagement and interagency collaboration are a cornerstone for implementing the Blueprint's convenient, efficient and clean strategies. Other examples of meaningful stakeholder engagement in the DOE includes the Clean Cities and Communities, with more than 75 clean cities coalitions, representing 84% of the US population.

Key climate and energy trends in the transport sector

In 2022, the US transport sector was the most energy- and emission-intensive sector of the US economy, as transport energy consumption is dominated by oil. However, the share of oil has been decreasing, falling from 96% in 2005 to 89% in 2022, thanks primarily to the increase of biofuels, from 1% to 6% in the same time frame.

Energy consumption from transport dipped in 2020 because of the pandemic, after reaching a peak in 2018. In 2021 and 2022, energy demand from the sector rebounded but did not reach the level of 2018-19 thanks to new fuel economy standards.

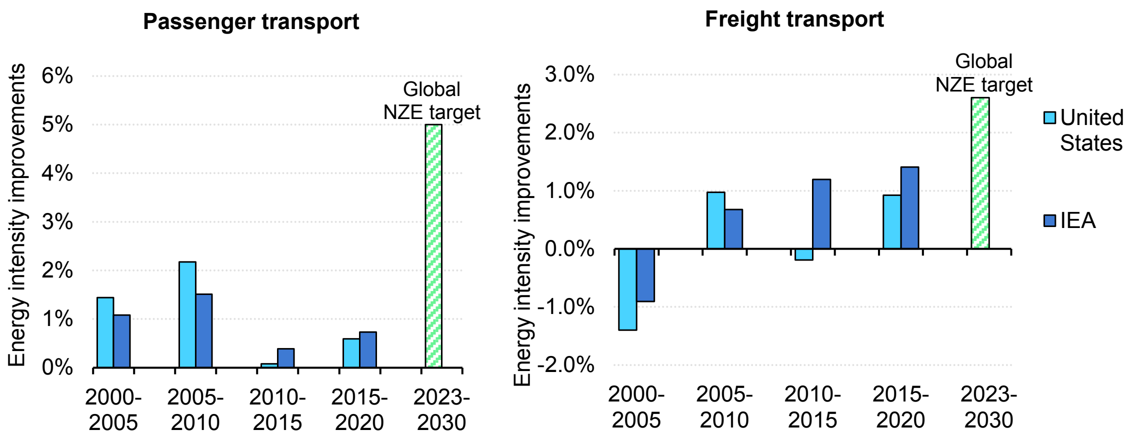
Figure 2.8 Energy consumption and emissions in the transport sector in the United States, 2005-2022



Sources: IEA (2024), World Energy Balances (database); IEA (2023), Greenhouse Gas Emissions from Energy (database).

Following the trend of energy consumption, transport sector emissions have been falling since 2018 and are projected to fall under current policies after a steady rise during the past decade, except for the short decline during the COVID-19 pandemic. Within transport sector emissions, light-duty vehicles account for 50% of emissions and medium- to heavy-duty vehicles for 21%.

Figure 2.9 Passenger and freight transport energy intensity (2005-2030) and average annual energy intensity improvements in transport (2000-2030) in the United States



Notes: pkm = passenger-kilometre; tkm = tonne-kilometre.
Source: IEA (2023), Energy End-Uses and Efficiency Indicators (database).

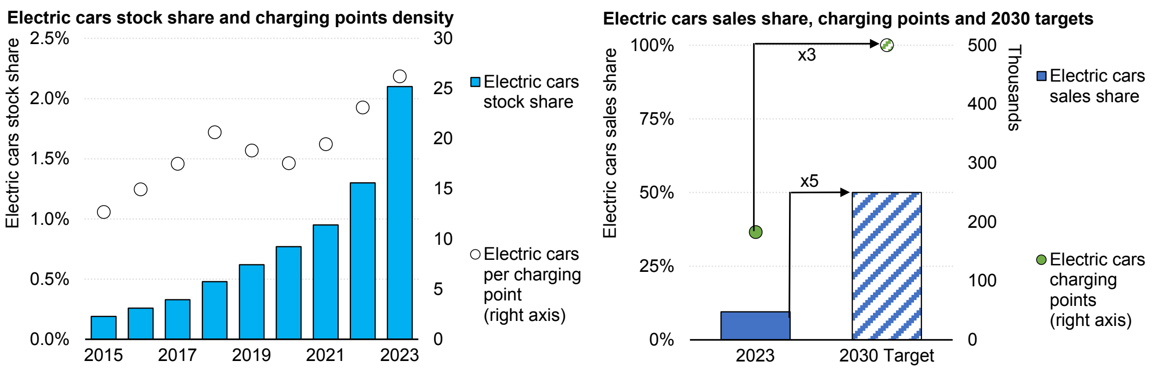
Energy intensity per passenger-kilometre of passenger transport has been decreasing in the United States, though it remains higher than the IEA average. On the other hand, the energy intensity per tonne-kilometre of freight transport has been rather stable and below the IEA average. Average annual energy intensity improvements of the transport sector as a whole have been increasing and between 2015 and 2020 reached over 3%, higher than the IEA average and moving towards the 2020-30 global Net Zero Emission by 2050 Scenario target of 5%. More action is needed on the overall efficiency of the transport system.

The US car fleet is dominated by gasoline light and heavy-duty vehicles. In 2021, the United States had 240.7 million gasoline cars, 7.1 million diesel cars, 1.5 million EVs, 786 800 plug-in hybrid electric vehicles (PHEVs), 11 800 hydrogen vehicles, 7 600 propane and 40 800 compressed natural gas vehicles. The United States had a world-leading "car scrappage scheme" in place until 2009 as part of the fiscal stimulus programme during the global financial and economic crisis. The Car Allowance Rebate System, or "cash for clunker", provided USD 3 billion under a federal scrappage programme which was exhausted after two months, having scrapped 677 081 vehicles. The United States has also a diesel-focused replacement programme in place under the Diesel Emissions Reduction Act (DERA) Program.

In 2023, according to the IEA Global EV Outlook 2024, the United States was the world's third-largest EV market with an electric car market share of 9.5% in total sales. In the same year, the United States had a total electric car stock of 4.8 million – with 1.3 million PHEVs and 3.5 million battery electric vehicles; 2.1% of the total fleet was electric.

The federal government set a target of 50% of new passenger cars and light truck sales to be zero-emission by 2030 (Executive Order on Strengthening American Leadership in Clean Cars and Trucks). The federal government also targets 500 000 charging points by 2030 to start building a national charging network.

Figure 2.10 Share of electric cars in total car stock, charging points density, share of electric cars sales and 2030 targets, United States



Source: IEA (2024), IEA Global EV Data Explorer (database).

Analysis produced by the NREL (2030 National Charging Network) suggests that for a medium-range adoption scenario of 33 million plug-in EVs on the road by 2030, the United States will need 28 million charging points, including 182 000 public fast-charging ports along highways, 1 million public charging points at workplaces, high-density neighbourhoods and retail outlets, and 26 million privately accessible points. As of the end of 2023, 183 000 charging points had been deployed and 1 in 10 cars sold is an EV, according to the IEA global EV data tracker. The trend in the deployment of EV charging points in the United States is diverging from the recommended ten EVs per public charging point, as the number of EVs on the road outpaces the number of public charging points.

The federal government launched the National Electric Vehicle Infrastructure (NEVI) Formula Program, which aims to build a national charging network, with USD 7.5 billion in support from the BIL through the Joint Office of Energy and Transportation. As of May 2024, 36 states have issued solicitations for their first round of funding under the NEVI programme and 22 have additional awards or have agreements in place. In January 2024, the federal government announced the first round of funding from USD 2.5 billion Charging and Fueling Infrastructure Discretionary Grant Program, totalling USD 623 million of grants for 22 states to fund EV chargers for projects including but not limited to apartment blocks in New Jersey, rapid chargers in Oregon and hydrogen fuel chargers for freight trucks in Texas. The funding under the BIL is expected to add 7 500 chargers to the US total in the first round of funding.

There are several IRA tax credits in place, including the Clean Vehicle Credit, Previously-Owned Clean Vehicle Tax Credit, which is the credit for second hand clean vehicles, the Qualified Commercial Clean Vehicles Credit and the Alternative Fuel Vehicle Refuelling Property Credit.

The strategy is to boost US manufacturing through supply chain incentives to manufacture EVs, batteries and chargers, supported by the Advanced Technology Vehicles Manufacturing Loan Program, Domestic Manufacturing Conversion Grant Program, Build America, Buy America requirements for manufactured production, as well as funding of USD 7 billion under the BIL for domestic battery manufacturing and recycling.

The federal government leads efforts with green procurement and direct investment. By 2035, it aims to reach 100% zero-emission vehicle federal fleet acquisitions, with 100% zero-emission light-duty vehicles already by 2027. For instance, the US Postal Service received USD 3 billion to purchase electric delivery vehicles. The EPA Clean Heavy-Duty Vehicles Program offers USD 1 billion in funding. Under the BIL, the Federal Transit Authority’s Low or

No Emission (Low-No) grant programme offers USD 5.5 billion funding to states and local authorities to purchase transit buses and related infrastructure.

The United States is the world's largest producer of biofuels, with 70 billion litres of biofuels per year or 40% of global production. The United States has a suite of policies on biofuels that combine volume obligations under the Renewable Fuels Standard (RFS), long-term tax credits under the IRA, R&D spending, state-level policies and a long-term vision for technology development, notably the SAF Grand Challenge. Under the SAF Grand Challenge, the United States aims to produce 3 billion gallons (or 11.3 billion litres) of SAF by 2030 and by 2050, enough to meet all of the United States' projected jet fuel demand (~35 billion gallons). For this effort, SAF is defined as fuels that achieve at least a 50% reduction in GHGs relative to a petroleum jet fuel baseline on a per-gallon basis. As outlined in the Grand Challenge Roadmap, future growth of SAF depends on six action areas: 1) feedstock innovation; 2) conversion technology innovation; 3) building supply chains; 4) policy and valuation analysis; 5) enabling end use; and 6) communicating progress.

Closing the gap between ambition and current trends

In the outlook to 2030, all IEA World Energy Outlook scenarios see energy demand from transport falling, including under stated energy policies (STEPS). Fuel efficiency is improving, thanks to the IRA financial incentives for electric cars and stronger standards.

The adoption of zero-emission regulations by a number of US states on top of federal GHG and fuel economy standards, and incentives for EV purchases and funding for charging infrastructure, mean that US policies (STEPS) are in line with achieving the announced 50% zero-emission light-duty vehicle sales target (APS) for 2030, according to IEA analysis.

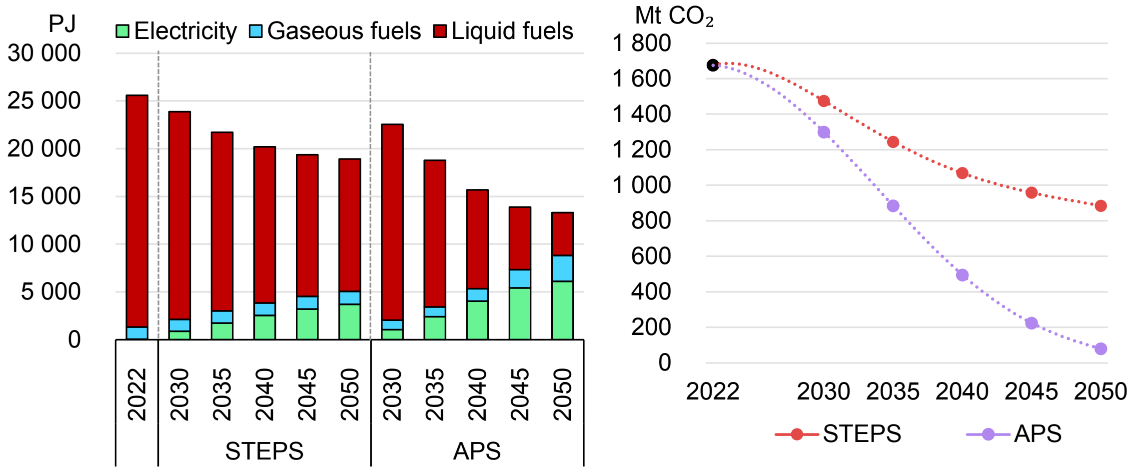
The United States uses GHG emissions standards, regulated by the EPA, and fuel economy or Corporate Average Fuel Economy (CAFE) standards, regulated by the National Highway Traffic Safety Administration.

Enacted fuel economy standards are expected to improve by 8% for model years 2024-25 and by 10% for model year 2026 relative to 2021 levels. In June 2023, the National Highway Traffic Safety Administration proposed increasing fuel efficiency by 2% each year for passenger cars and 4% for light-duty trucks starting in model year 2027. This proposed rule would increase new light-duty vehicle fuel economy by 10 miles per gallon between model year 2027 and 2032. The National Highway Traffic Safety Administration also proposed a 10% annual fuel economy improvement for commercial medium-duty vehicles from model year 2030 through 2035.

New strengthened pollution standards were finalised in March 2024. The EPA presented the final standards for passenger cars, light-duty trucks, and medium-duty vehicles for model years 2027 through 2032 and beyond. These standards limit the amount of pollution year by year which is allowed from vehicle exhaust emissions and include various compliance scenarios. The new rules are projected to cut CO_2 emissions from light-duty vehicles by nearly 50% in 2032 from 2026, to 85 grammes of CO_2 per mile. Besides fully electric vehicles, compliance can be attained by producing a range of “cleaner” cars, including gas-powered cars, hybrid EVs, and plug-in hybrids.

Building upon the Clean Trucks Plan, initiated in 2021, the EPA also issued the final rule (“Phase 3 greenhouse gas”) which revises existing standards and sets stricter greenhouse gas emissions standards for heavy-duty vehicles from model year 2027 through 2032, with a focus on heavy-duty vocational vehicles and tractors. These standards include increased fuel efficiency, higher aerodynamics and weight reduction or emission control systems.

Figure 2.11 Transport sector total final consumption and emissions – outlook for the United States



Note: PJ = petajoule.
Source: IEA (2023), World Energy Outlook 2023.

In 2022, California adopted new zero-emission vehicle standards. They include: a zero-emission and plug-in-hybrid electric vehicles mandate for cars beginning in 2026 and rising to 100% of sales in 2035 (Advanced Clean Cars II). The regulations also boost the deployment of medium- and heavy-duty zero-emission vehicles (Advanced Clean Trucks). Under Article 177 of the Clean Air Act, 17 states and the District of Columbia can adopt these standards. As of January 2024, only a few had done so, according to the California Air Resource Board.

Key recommendations

The US government should:

- Boost diverse clean manufacturing and supply chains at both the domestic and international level for critical minerals, materials, EVs, and refuelling and infrastructure components.
- Prioritise the implementation of the National Electric Vehicle Charging Action Plan, strengthening public charging infrastructure with an objective of at least 500 000 public EV charging points by 2030.
- Expand incentives and policies to increase private sector investment in charging infrastructure, including smart charging and vehicle-to-grid, while promoting open access, standardisation and interoperability.
- Consider additional programmes for vehicle stock renewal, such as scrappage or cash-for-clunker incentives, including for commercial cars and heavy-duty renewal.
- Promote the use of public transportation and its electrification, encouraging states, cities and local governments to work together to reduce emissions. Promote modal shift and the use of compact land-use patterns through co-location of housing, destinations and affordable low-carbon intensity transportation modes including transit, walking and biking.
- Reform the Renewable Fuel Standard with a horizon to 2035 and support the shift to advanced sustainable alternative fuels to meet ambitious sustainable aviation fuel targets, including through targets for differentiated advanced biofuel usage and promoting the commercialisation of new technologies.
- Promote technology innovation in the rail, aviation and shipping sectors.

2.3 Industry

The federal government is committed to decarbonising the industry sector, with a focus on the highest CO_2-emitting sub-sectors, including the chemicals, refining, iron and steel, aluminium, cement, glass, lime, pulp and paper, and food and beverage industries.

The federal government has organised cross-cutting teams to design a new overarching joint strategy framework, building on the 2022 US Industrial Decarbonization Roadmap (which identifies R&D solutions across four key pillars for emissions reductions in the industrial sector) and the Pathways to Commercial Liftoff reports (which focus on market barriers and near-term deployment) as well as relevant Energy Earthshots™, such as the Industrial Heat Shot™, the Carbon Negative Shot™, or the Clean Fuels & Products Shot™.

The eight key recommendations from the Roadmap are:

1. advance early-stage research, development and demonstration (RD&D)
2. invest in multiple process strategies
3. scale through demonstrations
4. address process heating efficiency and emissions across all sub-sectors
5. decarbonise electricity sources
6. integrate solutions
7. conduct modelling and system analysis
8. engage communities, develop a thriving workforce.

The recommendations stem from a detailed scoping analysis of the technology pathways required for the industry sector to play its part in achieving the economy-wide goal of net zero GHG emissions by 2050.

The report groups the technologies and strategies under four key pillars: 1) energy efficiency (e.g. energy management systems, system management and optimisation of thermal heat, energy productivity in the manufacturing process through smart and advanced data analytics); 2) industrial electrification (e.g. high-temperature heat pumps, electrification of hydrogen production for industrial process use); 3) low-carbon fuels, feedstocks and energy sources (e.g. clean hydrogen and biofuels); and 4) CCUS (e.g. point source carbon capture on industrial facilities, construction of CO_2 pipelines and CO_2 bioconversion). The Roadmap places a strong emphasis on the innovation needs and opportunities in the industry sector, while the Liftoff reports identify existing technologies that can deployed immediately to reduce emissions and improve the economics of a plant.

Figure 2.12 Industrial decarbonisation pathways

	2020	2025	2030	2040	2050
CCUS	Heat integration Reuse at slipstreams Connection at clusters	CO_2 trunk lines CO_2 use trials CO_2 bioconversion Direct air capture	Pipeline expansion CO_2 utilisation	Hard-to-abate carbon addressed Scale-up	**Net zero**
Low-Carbon Fuels, Feedstocks, & Energy Sources	Clean H_2 blending Clean H_2 ammonia Clean H_2 for process heat Biofuels	Clean H_2 iron or steel Energy or thermal storage and recovery Scale-up clean H_2	New chemistry with 100% no-carbon H_2 Scale-up	Clean H_2 dominates	
Industrial electrification	High temperature heat pumps Trials at clusters Process heat portfolio Intermittent power use Electrolyser efficiency	Hybrid membranes Electrochemistry to chemicals Connection at clusters	Transformative process	Max clean electric	
Energy efficiency	Waste heat to power Strategic energy management Smart manufacturing Materials efficiency Motor systems	Scaled-up use of recycled content Innovative separations Lower embodied carbon	Energy efficiency or transformative technology	Near zero waste	

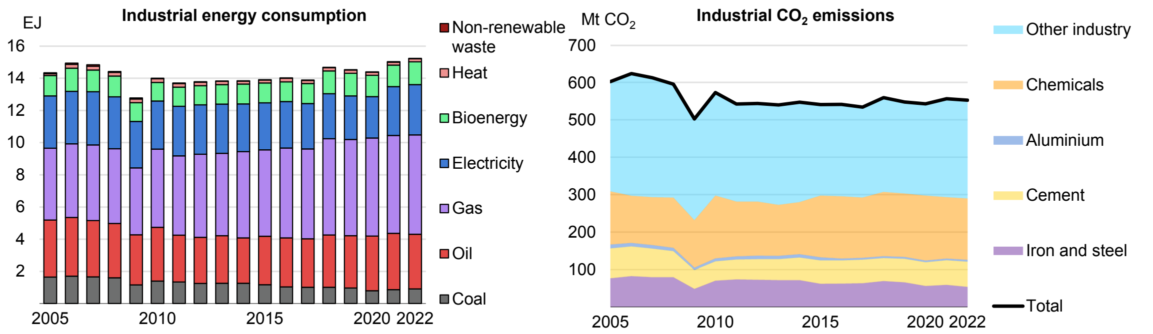
Source: DOE (2022), Industrial Decarbonization Roadmap as modified by the IEA.

Key energy and climate trends in the US industrial sector

Overall, 30% of US primary energy-related CO_2 emissions are linked to the activities of the industrial sector. Around 60% of total industrial carbon dioxide emissions stem from a handful of industrial sub-sectors. This includes chemicals, refining, iron, steel and coal, food and beverage, and cement.

Emissions from the industry sector decreased by 9% from 2005 to 2022, thanks mainly to efficiency and fuel switching from coal to natural gas in these sectors. The fuel mix today varies considerably depending on the sub-sector: coke and refinery industries use mainly oil; the chemical sector relies mostly on natural gas; paper, pulp and print on bioenergy; and iron and steel, glass and cement on coal and natural gas. The share of electricity (20% in 2022) in industrial energy consumption remains lower than the IEA average.

Figure 2.13 Industrial energy consumption and CO_2 emissions in the United States, 2005-2022



Notes: Industrial energy consumption includes final energy consumption in industry together with the energy used in blast furnaces, coke ovens and as chemical feedstocks. Industrial CO_2 emissions include those generated by the fossil fuel and non-renewable waste components of industrial energy consumption, together with industrial process emissions. Indirect CO_2 emissions (e.g. from electricity generation) are not included.

Source: IEA (2023), World Energy Outlook 2023.

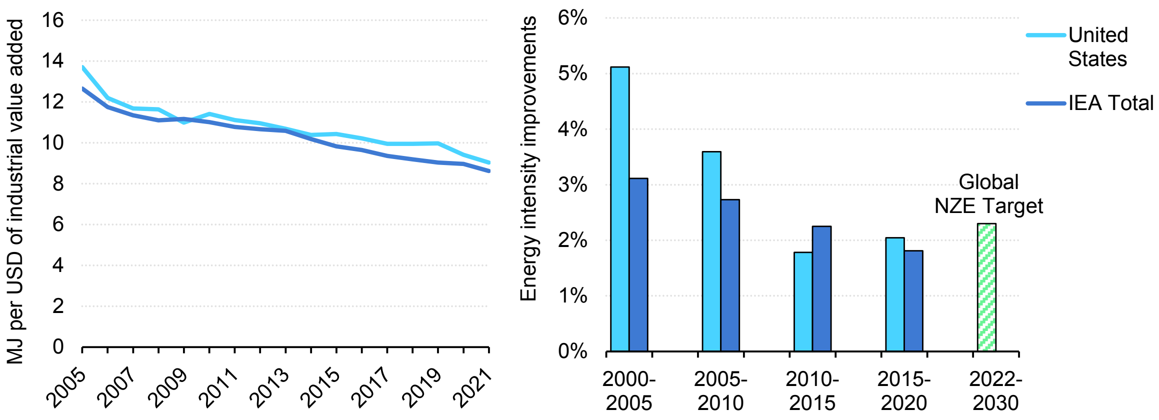
Policies and technologies to reduce industrial greenhouse gas emissions

Since the last IEA review, the United States' federal government has developed a range of programmes to stimulate action across its priorities, with a focus on industrial processing heat (including Industrial Heat Shot™), energy efficiency, material efficiency and sustainable manufacturing.

Industrial energy consumption has remained remarkably stable since 2005, despite a 15% increase in value added by the industry sector over this period. This decoupling reflects efficiency gains and structural changes in the manufacturing base.

In the United States, 90% of manufacturers are small and medium-sized enterprises and are not all certified under ISO 50001. In 2023, the United States had around 30 very large manufacturing companies certified by ISO 50001. The United States has a very strong performance when it comes to industrial efficiency, supported also through the EPA's work with individual manufacturing sectors under the Energy Star Guides for industry. However, in recent years, energy intensity improvements have slowed down. Energy consumption per value added in the manufacturing sector is in line with the IEA average and decreased by 34% from 2005 to 2021. Annual average improvements in energy intensity in the manufacturing sector peaked at 5.1% between 2000 and 2005 and slowed down to 2.0% from 2015 to 2020. On a global level, the IEA estimates that annual average improvement of 2.3% needs to be achieved in the sector to be on track with the net zero emissions scenario.

Figure 2.14 Energy intensity in the manufacturing sector per industrial value added (2005-2021) and energy intensity improvements (2000-2030)



Note: MJ = megajoule; NZE = net zero emissions.
Source: IEA (2023), Energy End-Uses and Efficiency Indicators (database).

One of the most significant driver for industrial decarbonisation is the IRA and its tax credits for CCUS and hydrogen. Under the 45Q Tax Credit, significant support for capture from industrial or power facilities is now available, valued at up to USD 60 per tonne of captured and utilised CO_2 (e.g. for enhanced oil recovery) or USD 85 per tonne if captured permanently stored. 45Q also created a larger credit for direct air capture, awarding USD 130 per tonne for CO_2 captured by direct air capture and utilised, increasing to USD 180 per tonne if permanently stored. All of these values are predicated on specific wage and apprenticeship requirements are being met. The 48C Qualifying Advanced Energy Project Credit can support industrial decarbonisation projects. And the 45V Clean Hydrogen Production Credit will enable production of qualified clean hydrogen, which can, in turn, beused to support the decarbonisation of industrial activities. In addition, grants of USD 9.5 billion will be made available under the BIL for investment in clean hydrogen.

The IRA modified the existing 48C Qualifying Advanced Energy Project Credit, an allocated investment tax credit that can include certain clean energy manufacturing activities, to include a credit for projects that retrofit industrial or manufacturing facilities to reduce GHG emissions by at least 20%. The federal government is promoting expanded partnerships to reduce industrial emissions, with the DOE's Better Plants programme now covering 3 500 facilities representing almost 14% of the US manufacturing footprint. A new Better Plants Low Carbon Pilot has been launched for organisations to share their experiences, successes and challenges in their pursuit of low-carbon emission strategies. The federal government also promotes an advanced clean domestic manufacturing and related trade policy which rewards American manufacturers of clean steel and aluminium. In 2022, the federal government presented the Secure Supply Chain Strategy, a plan to build an energy sector industrial base.

The Clean Fuels and Products Shot™ complements the decarbonisation efforts by aiming to develop the sustainable feedstocks and conversion technologies necessary to produce crucial fuels and carbon-based products in sectors that are difficult to fully decarbonise, and lower GHG emissions at least 85% compared to fossil-based sources by 2035. This specifically aims to have sustainable carbon sources meet 2050 projected demand for 100% of aviation fuel; 50% of maritime, 50% off-road fuel; and 50% of carbon-based chemicals by using sustainable carbon resources.

Demand for low-carbon materials can be stimulated through clean procurement policies and initiatives, spanning both the public and private sectors. On the public sector side, the Buy Clean Task Force incentivises the sourcing of low-carbon construction materials in federal purchasing procedures.

President Biden led the launch of the First Movers Coalition (FMC) at COP26, an initiative supported by 13 partner governments as of late 2023 that brings together 90 companies and counting, representing around USD 16 billion of market demand for critical enabling clean energy technologies with the potential to cut emissions in seven key sectors (aviation, shipping, steel, cement and concrete, aluminium, carbon dioxide removal, and trucking). By 2050, 50% of emissions reductions needed to achieve net zero are expected to come from technologies not yet available at scale.

The FMC catalysed the world's largest private sector clean energy demand signal, which creates an important "pull factor" for the next step of technology innovation for heavy industry. In 2024, the United States views the FMC as being at an inflection point, with the initiative needing to turn to securing procurement contracts for decarbonised goods in order to deliver on its potential. The DOE is engaging more closely with the FMC to link the participating companies with the market-making efforts supported by the BIL and IRA, thereby seeking to put offtake agreements in place by leveraging public funds to mobilise significant private sector financing and commitments. Building on this initiative, the United States is well-placed to lead global efforts on industrial decarbonisation efforts.

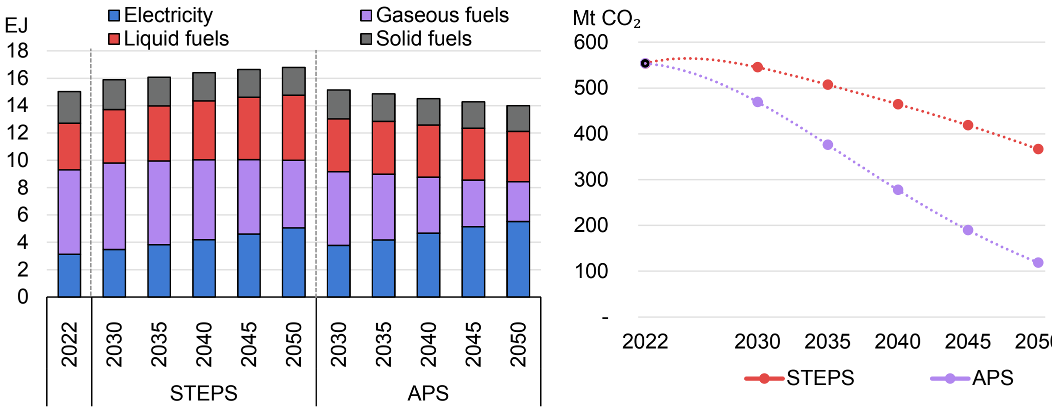
The United States is also an integral member of several other international industrial decarbonisation initiatives, including the IEA Working Party on Industrial Decarbonisation, the Clean Energy Ministerial Industrial Deep Decarbonisation Initiative and the Mission Innovation Net-Zero Industries Mission. Through these multilateral initiatives, the United States seeks to complement its domestic leadership by building the international facing policies and standards harmonisation and technology co-operation needed to decarbonise industrial sectors globally.

Closing the gap between ambition and current trends

In the IEA's modelling of a future scenario for the energy system, the United States is on track to implement its economy-wide pledge of reaching net zero GHG emissions by 2050. In this modelling, emissions from the industry sector will decline by around 15% between 2022 and 2030. However, the outlook for industrial output, particularly in sectors that contribute most to emissions – steel, cement and chemicals production – is projected to be broadly flat over this period, implying a significant reduction in the emissions intensity of production.

The industrial decarbonisation Liftoff reports suggest that rapidly scaling measures for technologies that are deployment-ready and economical today could drive 30-40% emissions reductions if aggressively pursued. R&D remains an essential pillar of additional measures, as around 50% of the industrial technologies needed to achieve a net zero industrial sector are yet to be developed, according to the IEA Net Zero Roadmap 2023.

Figure 2.15 Industry sector total final consumption and emissions - outlook for the United States, 2022-2050



Source: IEA (2023), World Energy Outlook 2023.

Key recommendations

The US government should:

- Further deepen and implement the comprehensive strategy for industrial decarbonisation based on policy packages for domestic industries and leverage international opportunities.
- Incentivise the next level of needed investment by strengthening standards for energy efficiency, circular economy and materials efficiency, using voluntary agreements combined with tax incentives, notably for small and medium-sized enterprises. Encourage and support them to access loan and grant programmes.
- Scale innovation, research, development, demonstration and deployment of critical technologies to achieve deep emissions reductions in the most emissions-intensive industrial sectors.
- Expand global engagement and exchange experience on industrial decarbonisation, including by sharing lessons from the Earth Shots and Pathways to Commercial Liftoff effort, and on demonstration projects through existing platforms such as Mission Innovation.
- Track and analyse where production and investment tax credits are being spent in heavy industries, how underlying production costs are changing and how bankable demand for low-emission industrial products is catalysed.
- Seek to maximise synergies between the new hydrogen hubs supported by BIL funding and opportunities for industrial facilities to accelerate the uptake of clean hydrogen. Leverage the capabilities of national laboratories and universities for economic development via regional and state programmes.

2.4 Buildings

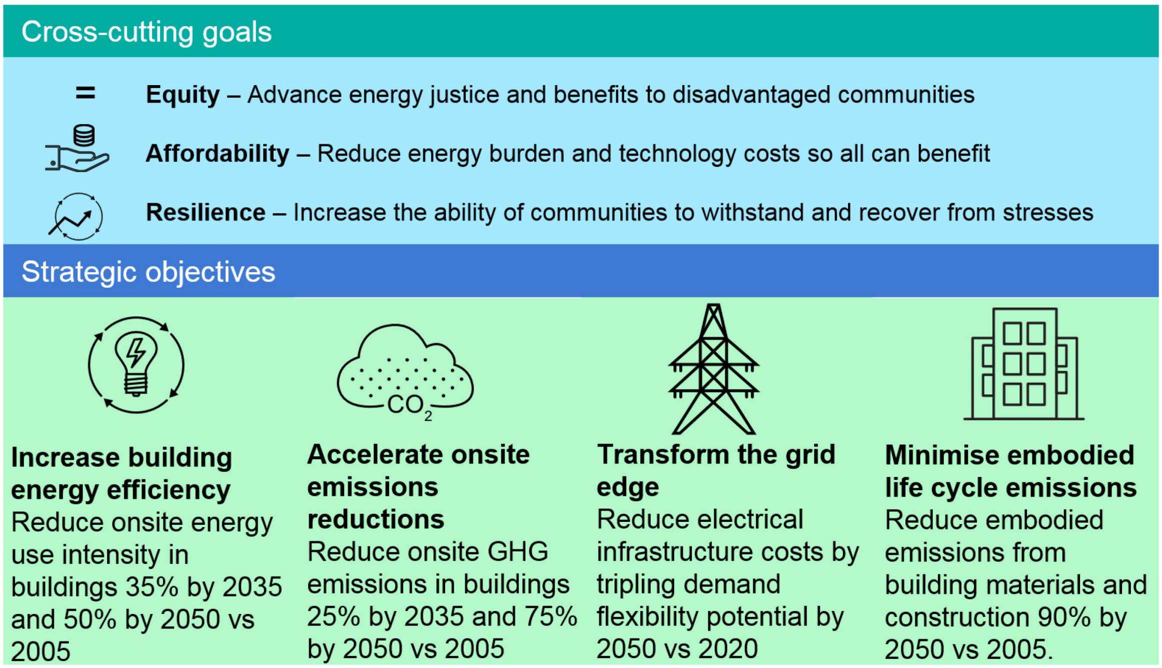
The US has a Blueprint for Decarbonizing Buildings with a targeted reduction in building emissions of 65% by 2035 and 90% by 2050 (from 2005 levels).

The strategy places a cross-cutting focus on equity, affordability and resilience while seeking to increase building energy efficiency, accelerate onsite emissions reductions, increase demand flexibility and minimise building life cycle emissions.

Key energy and climate trends in the buildings sector

Energy consumption (20.6 EJ in 2022) and direct emission levels (551 Mt CO_2 in 2022) in the US buildings sector have been largely stable with some seasonal fluctuations, driving the use of natural gas and electricity, which account for almost half of buildings energy demand each. On the other hand, indirect building emissions from electricity and heat have been declining rapidly, dropping by a third between 2005 and 2022, mostly driven by reductions in the GHG of electricity supply but also due to efficiency offsetting growth in demand.

Figure 2.16 United States' Blueprint for Decarbonizing Buildings

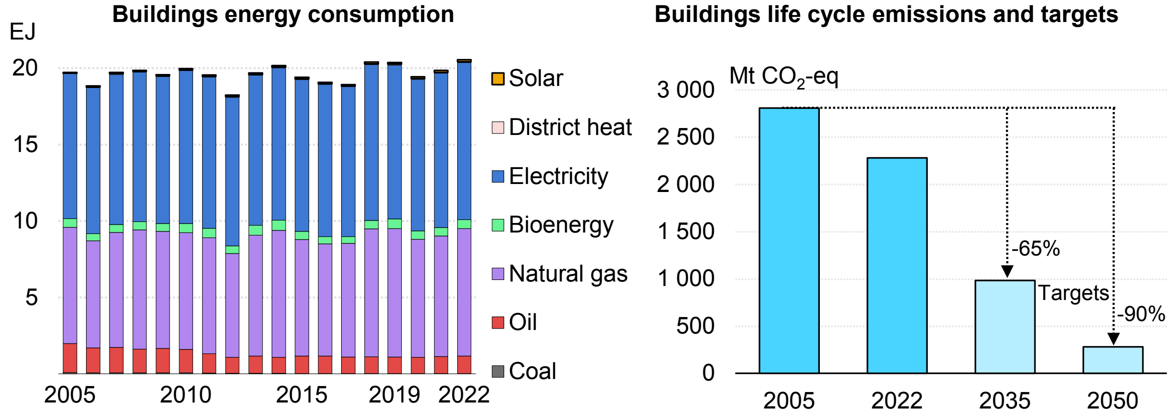


Source: DOE (2024), Decarbonizing the US Economy by 2050: A National Blueprint for the Buildings Sector as modified by the IEA.

In 2020, there were 123.5 million residential dwellings in the United States. Of these, 35% were built after 1990 and 8% after 2010; 62% are single-family homes. There were 5.9 billion service sector buildings, 39% of which were built after 1990 and 9% after 2010. A small portion of service sector buildings (16%) were government-owned. All in all, there are a total of around 130 million commercial and residential buildings combined, 80% of which are 20 years of age and older.

The EIA's residential energy consumption survey found 33.58 million, or one in four, households in "energy insecurity" in 2022, which are mostly low-income households and communities of colour. Around 50 million houses are labelled "affordable housing", single-family, multifamily and manufactured homes occupied by households earning less than 80% of the area median income.

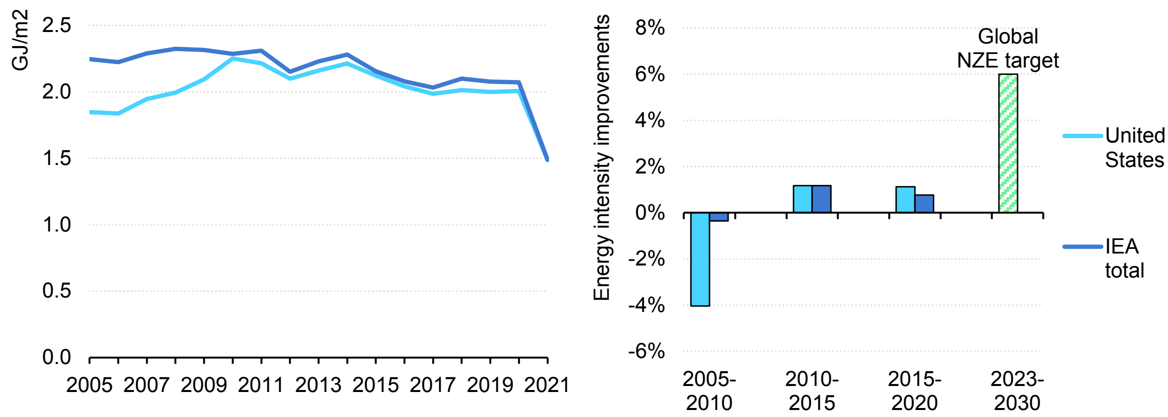
Figure 2.17 Buildings energy consumption and emissions in the United States, 2005-2022



Sources: IEA (2024), World Energy Balances (database); DOE (2024), Decarbonizing the US Economy by 2050: A National Blueprint for the Buildings Sector as modified by the IEA.

Energy intensity per floor area in residential buildings improved by 1.1% between 2015 and 2020, higher than the IEA average of 0.8% but slightly less than the 1.2% witnessed during the previous five-year period (2010-15). Globally, the IEA estimates that improvement rates in residential buildings need to reach 6% over the next ten years.

Figure 2.18 Energy intensity improvements in the buildings sector, 2005-2030



Note: GJ/m² = gigajoules per square metre.
Source: IEA (2024), World Energy Balances (database).

The federal government supports the pathway to net zero emissions buildings under the Blueprint through regulation, incentives and information campaigns to:

Maximise technology performance and affordability

- foundational science
- early-stage R&D funding

- solutions for hard-to-decarbonise segments
- pilot demonstrations

Develop markets and enable deployment

- enabling tools, partnerships and market-facing resources
- contractor/consumer outreach
- workforce development
- technical assistance/validation

Provide direct funding and financing

- point-of-sale rebates
- tax credits and deductions
- facilitate financing

Lock-in cost-effective performance gains

- appliance efficiency standards
- support building energy code development and adoption
- support other state/local regulatory actions.

The DOE's State and Community Energy Programs Office manages USD 16 billion of funding and 28 programmes. The BIL and IRA included historic investments to improve the efficiency and emissions impact of residential and commercial buildings.

Under the BIL, USD 3.5 billion are allocated to the DOE's long-standing and very successful Weatherization Assistance Program, which funds efficiency retrofits for low-income households (since 1976). According to the national evaluation, the programme supports 8 500 jobs and 35 000 homes every year and reaps annual energy savings of around USD 372 or more per household. The programme has increased its scale and capacity in the past five years. The Recovery Act had injected USD 5 billion into it and the income eligibility requirement was adjusted from 150% to 200% of the poverty line and the average insulation cost per site was increased from USD 2 500 to USD 6 500.

The USD 250 million Energy Efficiency Revolving Loan Fund Capitalisation Grant Program offers grants to states to capitalise revolving loan funds for efficiency improvements in commercial and residential buildings.

Created under the American Investment and Recovery Act, the Energy Efficiency and Conservation Block Grant Program offers USD 550 million to assist states, local governments, and tribal communities to implement strategies to reduce energy use and improve energy efficiency.

The IRA includes two Home Energy Rebate programmes, totalling nearly USD 9 billion, to provide point-of-sale rebates for efficiency and electrification improvements to homes. The programmes are targeted at low- and moderate-income households (around 50 million, or 44% of all US households). The Home Efficiency Rebates (HOMES) awards grants to state energy offices to develop and implement a "HOMES" rebate programme that provides rebates to homeowners and aggregators for energy-saving retrofits made for low- and moderate-income households. The Home Electrification and Appliance Rebate awards grants to state energy offices and Indian tribes for qualified electrification project rebates in low- and moderate-income households.

The IRA increased and extended existing tax credits for energy efficiency, electrification and onsite renewable energy investments for households and businesses, including the Energy Efficient Home Improvement Credit, the Residential Clean Energy Credit and, for businesses, the New Energy Efficient Homes Credit and the Energy Efficient Commercial Buildings Deduction.

In the area of regulatory measures, new Energy Building Codes were adopted in 2021 (Standard 90.1-2019) alongside the International Energy Conservation Code for residential buildings. New efficiency standards for appliances and equipment are set by the DOE and implemented through a programme of the Buildings Technologies Office for more than 60 categories, covering 90% of US home energy, 60% of commercial building use and 30% of industrial energy use. In addition, there are state-level standards for energy efficiency. The federal government updated ENERGY STAR standards for heat pump technologies and electric appliances. The DOE will work with states, local governments and industry by providing technical assistance to support code development and implementation on a trajectory towards net zero energy use[7] by 2030 through energy codes. This is also supported by a USD 1 billion technical assistance programme: the State and Community Energy Program.

The DOE's RD&D programmes focus on model building codes, housing programmes, building awards and reducing the cost of renovation packages. For example, the Affordable Home Energy Shot™ targets reductions in the cost of energy-efficient decarbonisation retrofits in affordable homes. It focuses on 60% of multifamily and manufactured homes that face particular decarbonisation and affordability issues, such as a lack of adequate insulation and central air conditioning or which experience other non-energy hazards such as lead and

[7] The DOE's definition of a zero-energy building is one that produces enough renewable energy to meet its own annual energy consumption requirements. A zero-energy building may still have significant emissions from space and water heating.

mould, as these are older buildings and over 58% of low-to-moderate income households are renters. The Energy Earthshot™ aims to reduce the upfront cost of upgrading a home by at least 50% while reducing energy bills by 20% within a decade.

The Appliance and Equipment Standards Program is the single-largest lever to achieve emissions reductions and savings. As a result of these standards, American consumers saved USD 63 billion on their utility bills in 2015 alone. By 2030, cumulative operating cost savings from all standards in effect since 1987 will reach nearly USD 2 trillion. Products covered by standards represent about 90% of home energy use, 60% of commercial building use and 30% of industrial energy use.

The DOE also launched the Initiative for Better Energy, Emissions and Equity, with RDD&D efforts to promote clean heating and cooling systems to support sustainable buildings.

The federal government takes the lead as the country's largest energy consumer and building manager. Targets are set out in the Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, with an overarching ambition of reaching net zero emissions in federal buildings by 2045.

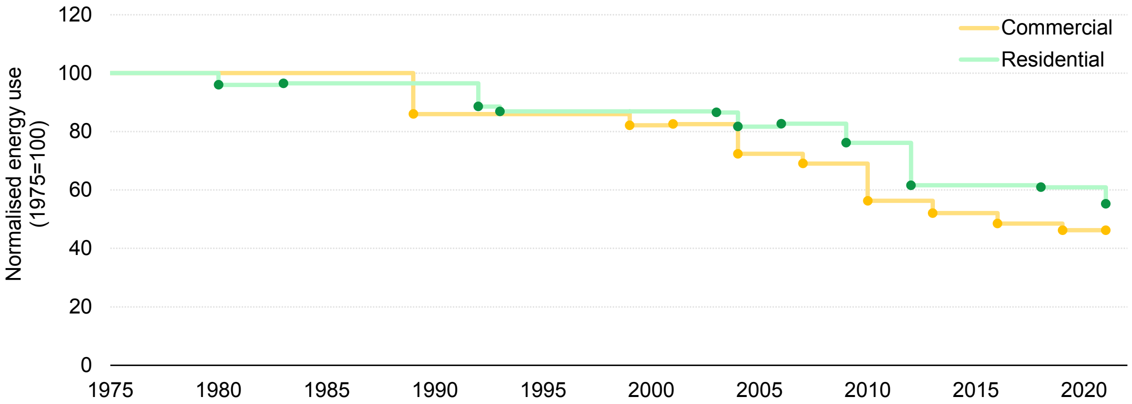
To achieve this overall goal, the federal performance in buildings standard and emissions standard for new federal buildings were announced in 2022. Federal agencies will have to cut energy use and electrify equipment and appliances to achieve zero scope 1 emissions in 30% of building space owned by the federal government. As of 2025, new or newly renovated buildings will be required to reduce emissions associated with energy consumption by 90% (from 2003 levels) and fully decarbonise by 2030.

The federal government will use clean procurement through the Buy Clean policy to promote the use of clean construction materials, with an ambition to meet net zero emissions from federal procurement by 2050 and net zero emissions from overall federal operations by 2050.

Progress in the implementation has been good for commercial buildings, which are applying the latest 90-1 model codes. Following the International Energy Conservation Code building codes, however, residential energy efficiency improvements have largely remained flat since 2010.

To support the implementation of building codes, the federal government launched the Building Performance Standards Coalition of over 30 states and local governments. To expand the efforts of this coalition, the United States can also learn from the experience of the European Union and its major implementation platform, the Concerted Action Energy Performance of Buildings Directive, which supports the exchange of knowledge and best practices in the field of energy efficiency and energy savings.

Figure 2.19 Progress in advancing residential and commercial energy codes in the United States, 1975-2022



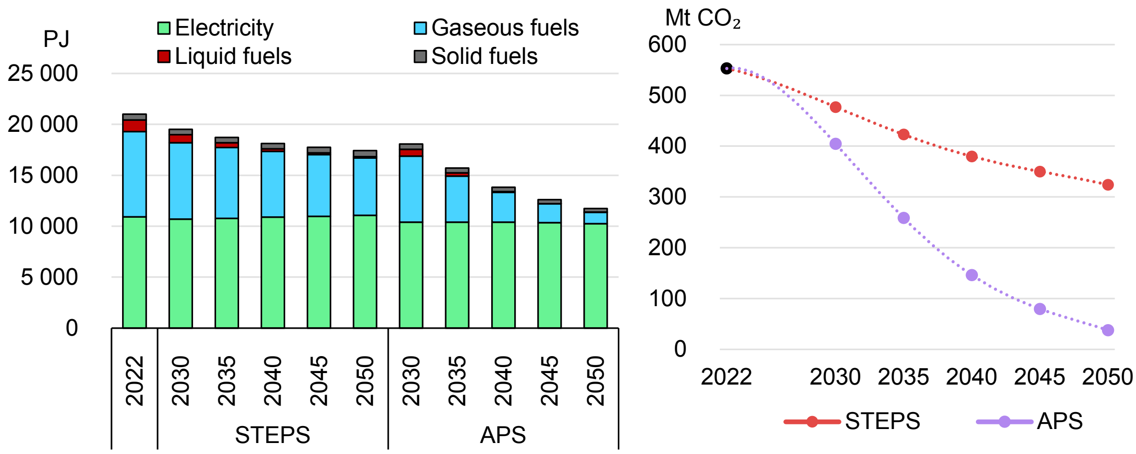
Source: DOE (2022), Building Energy Codes Program as modified by the IEA.

Closing the gap between ambition and current trends

Under current policies (STEPS), the US buildings sector has a significant implementation gap towards its Nationally Determined Contribution already in 2030, which will widen by 2035 if no new policies are implemented. Progress lags behind on the capacity to reach energy efficiency improvements in residential buildings, renovate the existing building stock (70% of which will still be in place in 2050), and address the heating/cooling needs by replacing or complementing natural gas heating and equipment using other delivered fuels with heat pumps. It will also be critical to increase the rate at which existing building envelopes are retrofit to reduce waste from heating and cooling.

Heating is also the largest end-use sector for gas in the United States and electricity connections are often already sized for air conditioners and can usually accommodate the addition of a heat pump. Multiple federal consumer tax credits under the IRA support the deployment of heat pumps, as does the High-Efficiency Electric Home Rebate programme. The United States also is home to around a quarter of global heat pump production.

Figure 2.20 Buildings sector total final consumption and emissions outlook in the United States, 2022-2050



Source: IEA (2023), World Energy Outlook 2023.

Key recommendations

The US government should:

- Embrace the principle of energy efficiency first to reduce energy consumption and related infrastructure, notably for heating/cooling.
- Strengthen standards for new buildings and move towards zero energy or zero energy ready buildings by:
  - supporting the development of codes for large and non-residential new buildings (ASHRAE [American Society of Heating, Refrigerating and Air-Conditioning Engineers]) and for small residential buildings (International Energy Conservation Code)
  - encouraging all states and local governments to implement the latest building codes (ASHRAE and International Energy Conservation Code)
  - supporting the deployment of electric vehicle charging infrastructure in multifamily housing and mixed-use developments.
- Develop packages for the renovation of the existing building stock to help implement tax credits under 179D, for instance by combining subsidy or tax breaks with standards (e.g. ASHRAE 100-2018), information and awareness campaigns, one-stop shops, and guidelines.
- Expand energy efficiency initiatives (such as Energy Star for appliances, and Energy Star homes and DOE Zero Energy Ready homes) that increase the value of existing buildings, products and systems through standards and labelling of buildings and appliances.
- Adapt support mechanisms for building upgrades, efficient electrification and smart controls, using the model of the Affordable Home Energy Earthshot™.

- Support transit-oriented housing stock development, infill and compact development to support the co-location of housing with low energy-intensity transportation options.
- Enable grid decarbonisation by transforming the grid edge to minimise the need for additional grid infrastructure through improved energy efficiency, demand flexibility and controls that integrate building load management with behind-the-meter distributed energy resources.
- Minimise embodied emissions outside the building operational phase, e.g. from production, transport, construction, renovation and disposal of building components/materials.

2.5 Fossil fuel production and transformation

The transition away from fossil fuels in the energy system will need to involve an orderly transition in step with clean energy investment, ensuring resilience and adapting existing infrastructure while scaling up low-carbon alternatives and addressing the risks of slower than expected deployment of low-carbon sources.

The United States has become the largest oil and gas producer in the world today and a net exporter of oil and natural gas and energy overall. This provides substantial benefits in terms of jobs, tax revenues, royalties for mineral rights owners, energy affordability and energy security.

The IEA expects global LNG supply to expand by 25% (or 130 billion cubic metres [bcm] a year) between 2022 and 2026. The United States alone is set to contribute around a half of incremental LNG supply, reinforcing its position as the world's largest LNG exporter. The IEA expects it to retain this position through to 2030.

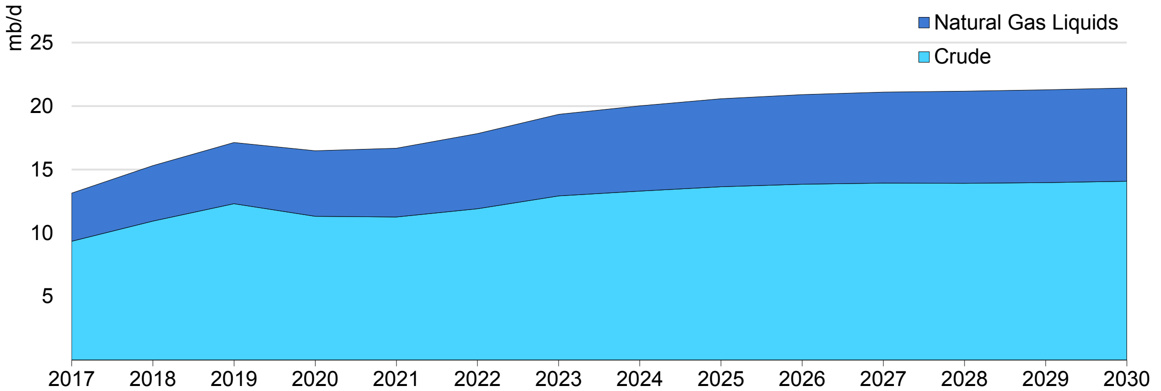
The United States also dominates global oil supply and is the largest source of growth in the medium term. In 2023, it accounted for 75% of the total net global supply increases and made up two-thirds of non-OPEC+ growth. In 2024, it is expected to account for close to half of the anticipated non-OPEC+ increase. At the same time, the United States exports light tight oil and is a large medium and heavy oil importer, as many US refineries are geared to processing heavy crudes.

Key energy and climate trends in the sector

Oil production

In 2023, US oil production amounted to around 19.4 million barrels per day (mb/d). US oil supply growth continues to defy expectations, with output reaching 20 million barrels per day (mb/d) this year, but a slowdown of US oil production growth is expected starting from 2024 onwards. The IEA expects total US oil production to expand to 21.5 mb/d by 2030, driven by natural gas liquids and crude oil (mostly light tight oil) production from the Permian Basin (Texas and New Mexico). US oil majors are increasingly consolidating their positions with new investments through mergers and acquisitions of shale producers.

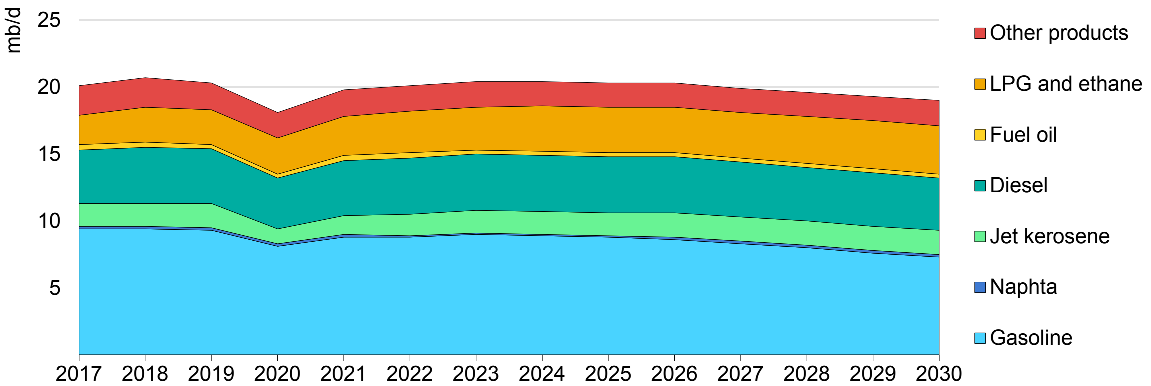
Figure 2.21 United States' oil production and forecast to 2030



Note: kb/d = thousand barrels per day.
Source: IEA (2024), Oil 2024.

In 2023, US oil products consumption stood at 20.4 mb/d, with a large role of gasoline. The demand is expected to remain stable with a decline in the medium term to 18.9 mb/d in 2030.

Figure 2.22 United States' oil product demand and forecast to 2030



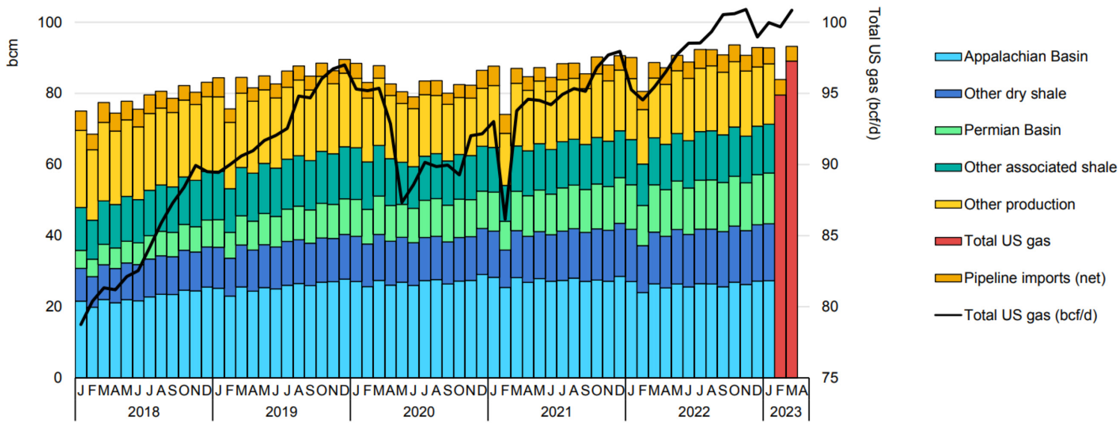
Note: LPG = liquefied petroleum gas.
Source: IEA (2024), Oil 2024.

Natural gas production

The United States' natural gas production has increased over the past five years. It remained close to the record 104 billion cubic feet per day (bcf/d) (or over

1 050 bcm/y) mark during Q1 2023, of which 21 bcf/d (213 bcm/y) was exported. In 2023, the United States had seven large-scale LNG facilities with a baseload capacity of 118 bcm/y.

Figure 2.23 Natural gas supply of the United States, 2018-2023



Source: IEA (2023), Gas Market Report, Q2-2023.

In the coming decade, an additional wave of LNG export projects from the United States will play a critical role to boost gas security of supply worldwide in Europe and Asia, following the fundamental changes in the global gas market as a result of Russia's war in Ukraine.

The United States became the world's largest LNG exporter in 2023 and is expected to further solidify its position in the medium term by nearly doubling export capacity. There is currently over 120 bcm/y of LNG liquefaction capacity under construction. In addition, there is more than 220 bcm/y of LNG liquefaction capacity which completed front-end engineering design and received non-Free Trade Agreement permits but have not yet reached final investment decision. Based on LNG projects currently under construction, export capacity is expected to nearly double from 140 bcm/y and reach close to 260 bcm/y by 2030 when construction is scheduled to be completed.

US LNG supply is sold under a wide range of marketing mechanisms, including tolling and destination-free shipping arrangements, which has boosted and will further increase the liquidity and the flexibility of global LNG trade over the medium term.

In January 2024, the United States announced a temporary pause on reviews of pending applications for exports of LNG to non-Free Trade Agreement countries until the DOE updates the underlying economic and environmental analyses used in regulatory decisions.

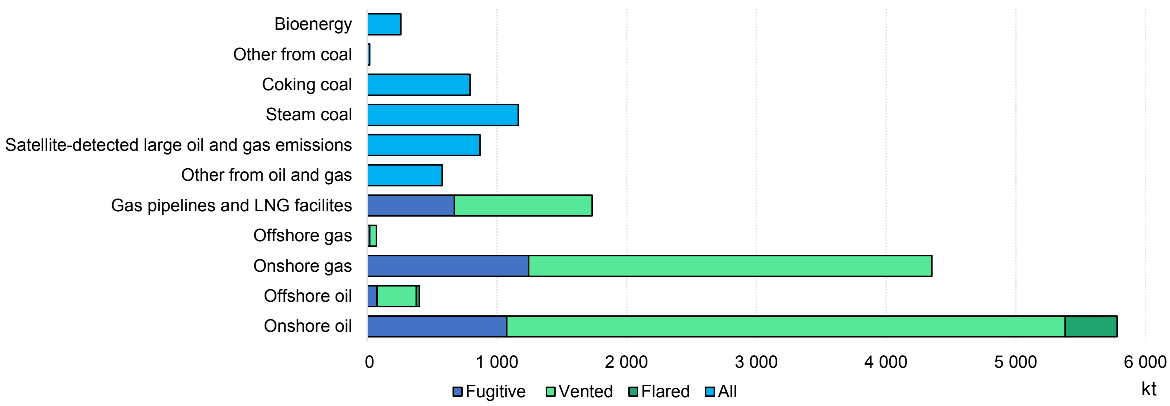
The US government has limited the number of new offshore oil and gas production leases on federal land. In 2023, the Department of the Interior proposed a final programme for offshore lease sales over 2024-29 with three sales, all in the Gulf of Mexico.

Emissions from oil/gas upstream and downstream supply chains

GHG emissions from the upstream sector (including methane emissions) were 519 Mt CO_2-eq in 2021, or 9% of energy-related emissions. In addition, the refinery sector was responsible for 130 Mt CO_2-eq of GHG emissions the same year, or 2.6% of the total.

Around three-quarters of GHG emissions from the upstream sector are methane emissions. According to the IEA Methane Tracker[8] in 2022, the United States was responsible for 9% of global methane emissions and the US energy sector accounted for the lion's share of 53% (followed by agriculture activities). The main sources of energy-sector methane emissions stem from oil and gas operations.

Figure 2.24 Methane emissions in the United States, 2023

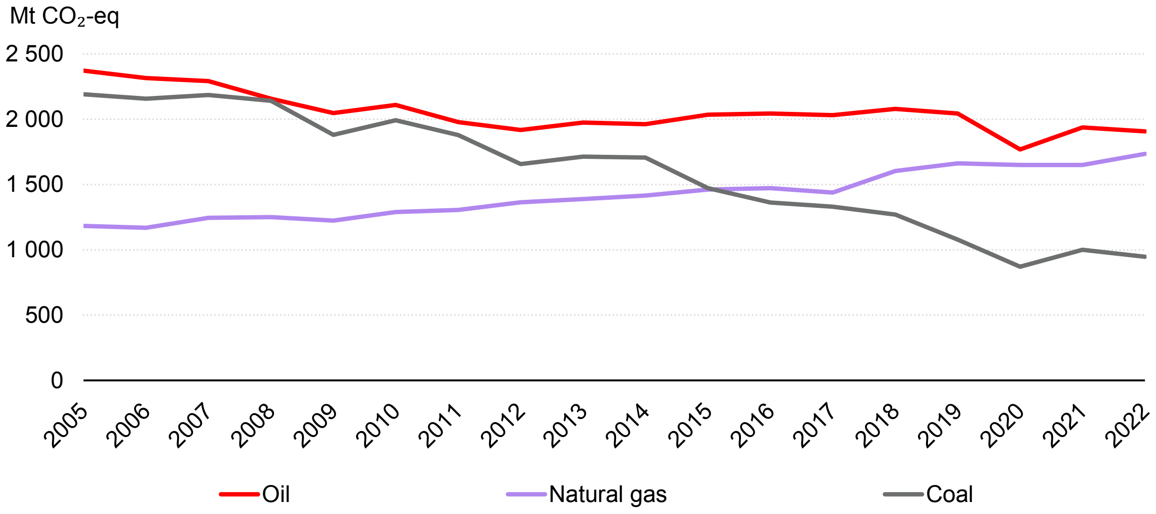


Source: IEA (2024), Methane Tracker.(database).

CO_2 emissions from oil and coal consumption have decreased while gas sector emissions are on the rise. In 2023, coal consumption in the United States was the lowest in history, with major impacts on emissions. Emissions reductions from coal-to-gas switching in the power sector have, however, been partly offset by rising GHG emissions from natural gas consumption.

[8] Methane emissions based on IEA analysis. IEA's methodology uses publicly available information to produce a set of country-level estimates using a consistent methodology.

Figure 2.25 Greenhouse gas emissions from fossil fuel consumption, United States, 2005-2022



Source: IEA (2023), Greenhouse Gas Emissions from Energy (database).

Closing the gap between ambition and current trends

The federal government has put forward a suite of policies for reducing GHG emissions from oil and gas operations (scope 1 and 2 emissions), relying on technologies for the reduction of methane emissions and the scale-up of low-emission fuels and carbon removal technologies, such as CCUS.

The federal government is working towards initiatives for reducing methane emissions from the oil and gas sector (estimated reduction efforts could reach 40-45% by 2025) under the 2021 US Methane Emissions Reduction Action Plan. The Plan originally only targeted orphaned wells, minimising pipeline methane leaks and announced initiatives on methane reduction infrastructure. In 2022, the federal government updated the Plan with a new approach to tackle emissions from ongoing oil/gas operations by directing the EPA, the DOE, and the Pipeline and Hazardous Materials Safety Administration to implement the IRA, Infrastructure and Jobs Act, and the Protecting Our Infrastructure of Pipelines and Enhancing Safety Act 2020.

The federal government uses a carrot and stick approach with incentives and penalties. The DOE's Methane Mitigation Technologies Program supports the quantification, mitigation and technology innovation of methane emissions. As of 2024, the EPA will levy a 900 USD/metric tonnes (30 USD/tonne CO_2) penalty under the IRA, which will increase to 1 200 USD/metric tonnes (40 USD/tonne CO_2) in 2026 and 1 500 USD/metric tonnes (50 USD/tonne CO_2) from 2027 onwards.

Executive Order 13990 directed the EPA to issue regulations under the Clean Air Act to reduce the oil and gas industry's methane emissions. The EPA's supplemental rulemaking of the "super emitter response program" (complimented by subsidies under the IRA) and the waste emissions charge obliges states to address methane emissions from existing sources.

On 2 December 2023, the EPA issued a final rule on the regulation of methane and other harmful pollution in oil and gas operations from new, modified and reconstructed sources (New Source Performance Standards). EPA Emissions Guidelines are for states to follow as they develop plans to limit methane from existing sources.

In terms of publicly announced funding for methane abatement, the BIL provides USD 4.7 billion to plug old oil and gas wells. IRA included funding of USD 1.55 billion for the EPA to provide financial and technical assistance to help accelerate the reduction of methane and other GHG emissions from petroleum and natural gas systems by deploying new equipment (e.g. for detecting, monitoring and measuring GHGs), supporting technological innovation, permanently shutting in and plugging wells, and other activities.

At a global level, the federal government is the co-founder of the Global Methane Pledge, which today includes 155 governments in support of global efforts to cut methane emissions by 30% by 2030, from 2020 levels. Alongside partners in the European Union and Canada, the United States has mobilised major progress towards the goal, including by industry efforts, standards, funding programmes and monitoring tools. Launched by President Biden at the Major Economies Forum, the dedicated Methane Finance Sprint mobilised a total of USD 1 billion of grant funding between COP27 and COP28, much above the targeted USD 200 million.

The federal government is also a co-founder of the Net-Zero Producers Forum, which includes Canada, Norway, Qatar, Saudi Arabia and the United Arab Emirates, representing more than 40% of global oil and natural gas production. The Forum aims to develop pragmatic net zero emission strategies that include methane abatement, deploying clean energy and CCS technologies, diversifying from reliance on hydrocarbon revenues and other measures in line with each country's national circumstances.

Carbon management is a significant pillar of the federal government's international energy outreach. International measures that the United States is taking to advance CCS technology and deployment include both multilateral and bilateral partnerships, as well as funding for the participation of US scientists in major CCS field projects worldwide. The major programmes include the Carbon Management Challenge, the Clean Energy Ministerial (CEM), the CEM CCUS Initiative, the Mission Innovation Global Initiative, and the IEA Greenhouse Gas

R&D Programme. Collectively, these initiatives ensure that carbon management plays an appropriate role in overall climate action and that there is capacity around the world to design and implement robust regulatory frameworks that enable projects to emerge while protecting local communities and the environment.

Federal government measures to decarbonise the oil and gas sector include carbon management, advanced remediation technology, methane mitigation technologies and minerals sustainability measures. There is a strong focus on using regulatory measures to mitigate methane, especially from orphan wells and work on developing a measurement, monitoring, reporting and verification tool to measure methane intensity. These actions are supported by funding programmes under the BIL.

In 2023, US majors also joined the global oil/gas industry efforts under the Oil and Gas Decarbonization Charter, which was launched by the COP28 Presidency in 2023.

There are big opportunities in the United States for the electrification of oil and gas operations thanks to the large potential of wind and solar and the short distance of an electricity connection for oil and gas production sites, according to the IEA report on reducing oil and gas sector emissions. While not all wells have access to electrification opportunities, strategies in collaboration with industry may help identify actions to take electrification efforts forward. At the same time, lessons learnt from the oil and gas sector are very useful for geothermal energy and offshore wind energy as well as critical minerals developments.

Experience from other energy producers such as Australia, Canada, Norway or the United Kingdom confirms that the transition of the oil and gas sector is strongly focused on emissions reductions but less on reducing oil and gas consumption in the domestic energy system. For instance, Canada has adopted a cap on GHG emissions from oil and gas production under its net zero emissions policy with regulations presented for consultation in December 2023 and adoption by mid-2024. Norway has adopted a 50% target for reductions from oil and gas operations by 2030 under the National Climate Action Plan but no plans have yet been set to operationalise this target. In 2023, Australia adopted the revised safeguard mechanism, which covers the largest industrial polluters, including coal mines and oil refineries, to curb their emissions by about 5% each year.

Transition to low-carbon fuels

Low-carbon fuels are part of the decarbonisation pathways for the transport, industry and fossil fuel sectors and a cornerstone of the United States' long-term strategy towards net zero emissions. The federal government could examine the value of adopting a comprehensive low-emission fuels strategy. Based on the IEA 2023 report on the role of e-fuels in decarbonising transport, such a low-carbon fuels strategy could build on five essential elements: 1) strengthened transport GHG reduction targets and regulations (including at the international level for aviation and maritime); 2) support to stimulate sizeable and predictable low-emission fuel demand; 3) early planning and accelerated investment in necessary infrastructure; 4) use of potential synergies with biofuels production and CO_2 infrastructure; and 5) support for RD&D and innovation. The Energy Earthshots™ Initiative has identified advancing extremely low GHG and cost-effective fuels and products as an RDD&D mission area.

Biofuels

The United States is the largest producer of biofuels in the world. National ethanol and biodiesel blending began with the introduction of the RFS in 2005, which obligates fuel distributors to achieve mandated annual renewable volume obligations based on their market share. The federal government has, and continues to, support RFS blending obligations through a mix of tax credits, grants and agricultural policy. Renewable natural gas (biomethane) is also considered a biofuel for transport and accounted for in the RFS, the IRA and the California Low-Carbon Fuel Standard.

The IRA offers production, investment and infrastructure tax credits and grants for biofuels. It supports the extension of the Tax Credits for Biodiesel and Renewable Diesel and of the Tax Credits for Alternative Fuels and Second Generation Biofuel Producers. The Clean Fuel Production Credit and the Sustainable Aviation Fuel Credit also support investment in US biofuels production capacity. State-level policies, such as California’s Low-Carbon Fuel Standard, provide additional biofuel incentives. Most recently, legislation has been put in place in Oregon and Washington, with Washington’s Clean Fuel Standard and Oregon’s Clean Fuels Program.

Several of the existing IRA tax credits for biofuel producers expire in 2027, notably the Clean Fuel Production Credit, which provides limited incentive to construct new biofuel facilities. Given that they will operate for multiple decades, this review suggests the United States consider extending the time horizon to 2035 for the Clean Fuel Production Credit, the Second Generation Biofuel Producer Tax Credit and others to help promote investment in new biofuel facilities.

The RFS currently provides life cycle GHG thresholds that biofuels must meet to be eligible for the programme. However, it does not reward incremental improvements in GHG performance. The federal government may consider modifying the programme to account for incremental improvements following policies such as California’s Low-Carbon Fuel Standard and the existing IRA federal tax credits for biofuels.

The United States has ambitious SAF plans and initiatives. The SAF Grand Challenge, a government-wide approach to work with industry (under the memorandum of understanding between the DOE, the Department of Transportation, the Department of Agriculture and other government agencies), aims to reduce the cost, enhance the sustainability, and expand the production and use of SAF while:

- achieving, on a per-gallon basis, a minimum of a 50% reduction in life cycle GHG emissions compared to conventional fuel
- increasing the production of SAFs to at least 3 billion gallons per year by 2030
- meeting a goal of supplying sufficient SAF to meet 100% of aviation fuel demand by 2050, projected to be 35 billion gallons (132 billion litres) per year.

US biofuel producers nearly tripled volumes between 2005 and 2010. Biofuel policy drove ethanol production to 58 billion litres in 2022, equivalent to almost 7% of gasoline demand on an energy basis.

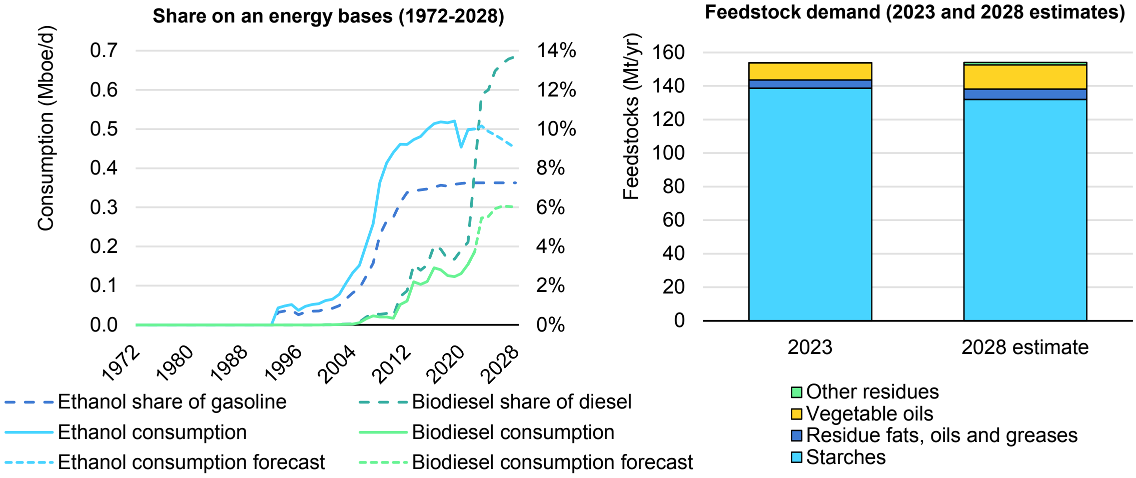
For the biodiesel market, challenges with feedstock availability remain. Biodiesel production mainly comes from vegetable and residue oils, but with tight feedstock availability, the United States needs to shift focus to more advanced biofuels. According to the latest IEA analysis Renewables 2023, fuel providers are on track to meet the RFS obligations.

Expanding biofuel production requires an increase in diverse sustainable feedstock supply and sustainable agriculture production that may include oil seeds produced on marginal land, via cover crops and intercropping.

The United States has set a goal of 11 billion litres (0.2 million barrels of oil equivalent per day [Mboe/d]) of SAF production by 2030 and more than 132 billion litres (2 Mboe/d) by 2050, requiring a significant build-out of facilities to produce these fuels. Additional financial support will be needed to help build facilities and commercialise technologies that can use a wider range of feedstocks, such as waste and residue feedstocks and ethanol-to-jet fuel pathways.

The IEA suggests that differentiated targets, like those contained in the ReFuelEU's aviation sub-targets, could complement existing policies and help secure a market for initial projects. As production scales up and costs become competitive, policies should evolve to performance-based, competitive models to maintain cost-effectiveness and encourage innovation. The United States could provide blending requirements via the RFS for aviation fuels or some other target, and/or extend the IRA credits.

Figure 2.26 Liquid biofuel consumption in the United States



Note: Mt = million tonnes.
Sources: IEA (2024), World Energy Balances, IEA (2023), Renewables 2023.

Renewable natural gas (biomethane/biogas)

Biomethane and biogas are mainly consumed in electricity generation, with over 2 300 sites producing biogas in all 50 states. The latest IEA analysis estimates that the United States has 28% of combined biogas and biomethane use in transport and 59% consumption for heat and power. Biogas for transport, although smaller in scale compared to other biofuels, is a key driver for growth and presents very low-carbon intensity (especially when produced with animal manure).

Biogas use is supported in the transport sector (not for electricity or industrial/residential heat generation) under the US RFS programme and low-carbon fuel standards defined at state levels. The new RFS Set Rule aims to double biomethane supplies in the next three years. Given the obligation volumes proposed, the pipeline of projects under development and California's targets for injected biomethane, biogas and renewable gas supplies combined are expected to more than double in the next five years.

California's Renewable Gas Procurement Program (February 2022) aims to divert organic waste from landfills, with the final goal of reducing the release of methane emissions into the atmosphere.

National clean hydrogen strategy and roadmap

The United States produces 10 million metric tonnes (MMT) of hydrogen per year (compared to roughly 94 MMT per year for total global production), mostly for petroleum refining, ammonia and the chemical industry. One-third of US hydrogen is produced in Texas. The United States has many existing hydrogen pipelines and diverse production sources.

The United States is among the few countries in the world with a small number of hydrogen facilities that capture CO_2. In industry, the United States has projects that capture CO_2 from ammonia plants. In the transport sector, the United States ranks third globally (after China and Korea), with around 18 000 fuel cell cars on the road and an increasing number of fuel cell buses. The stock of hydrogen refilling stations has increased by only 10% since 2019, according to the IEA Global Hydrogen Review 2023. US EPA standards under the Clean Air Act require abatement of fossil fuel use through co-firing with hydrogen. A 38% hydrogen co-firing share was demonstrated in 2023 at a combined-cycle power plant.

As part of the National Clean Hydrogen Strategy and Roadmap, the federal government set targets for the production of clean hydrogen of 10 MMT per year by 2030 (replacing today's production with clean hydrogen), 20 MMT per year by 2040 and 50 MMT per year by 2050. The National Clean Hydrogen Strategy and Roadmap also strongly supports innovation, i.e. through the DOE's Hydrogen Shot™, which sets a cost goal of 1 USD/kg clean hydrogen within a decade.

The IRA provided additional policies and incentives for hydrogen, including the Clean Hydrogen Production Tax Credit (45V), which incentivises the production of clean hydrogen with a production tax credit of up to 3 USD/kg, and BIL/IRA programmes for electrolysers.

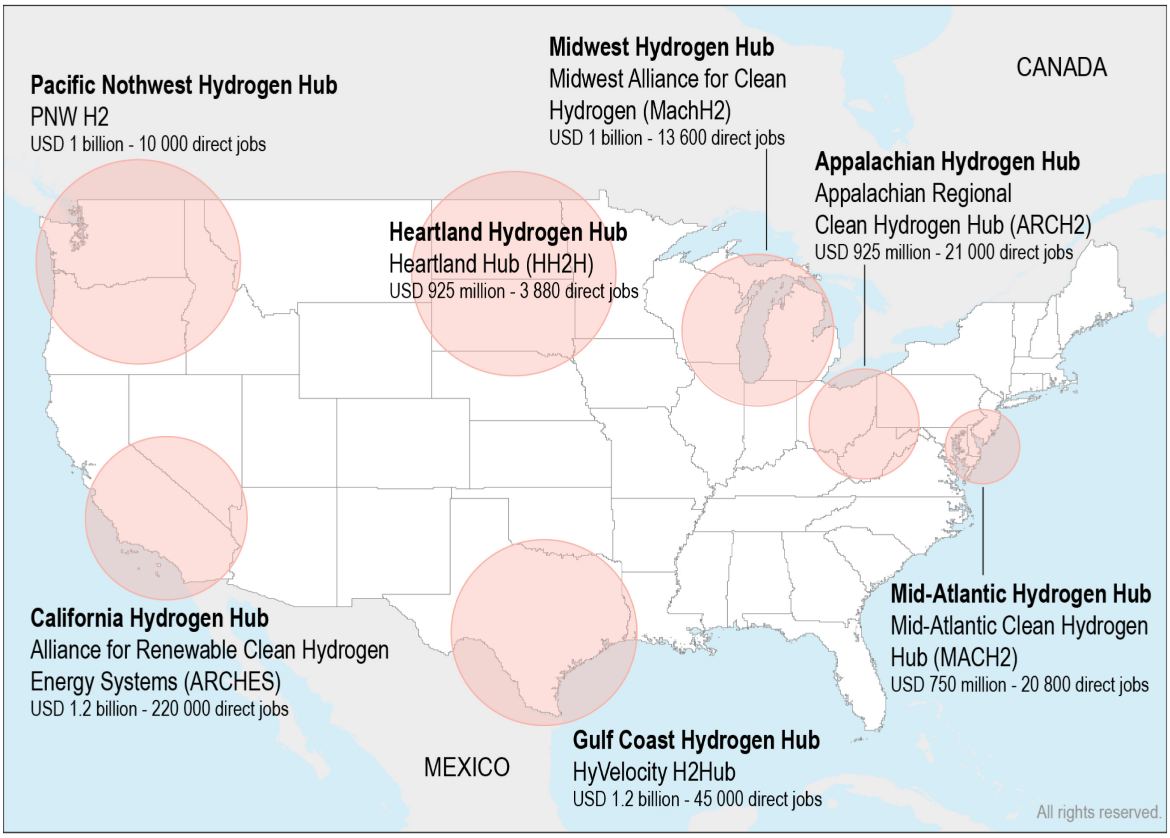
Hydrogen support mechanisms under the BIL (USD 9.5 billion) include large-scale demonstration – the Clean Hydrogen Electrolysis Programme (USD 1 billion) to enable the production of 2 USD/kg clean hydrogen from electrolysis by 2026 – and RDD&D activities under the Clean Hydrogen Manufacturing and Recycling programme (USD 500 million).

The BIL supports the creation of regional clean hydrogen hubs for local industrial development and market promotion. The USD 8 billion programme will enable the demonstration and development of networks of clean hydrogen producers, potential consumers, and connective infrastructure. President Biden and the Secretary of Energy made selections amounting to USD 7 billion for regional hydrogen hubs at the end of October 2023.

Internationally, the DOE also leverages the US expertise and experience with international partners and initiatives, such as the International Partnership for Hydrogen and Fuel Cells in the Economy, the Clean Hydrogen Mission and Hydrogen Breakthrough, among others. On a bilateral level, the United States has launched a Clean Hydrogen Action Committee under the US-Brazil Clean Energy Industry Dialogue with a focus on hydrogen hubs. It also hosted the Hydrogen Americas Summit to draw attention to the opportunities for hydrogen, bringing together thousands from industry and government.

The BIL also mandated the introduction of a clean hydrogen production standard. Finalised guidance sets out a standard of 4 kg of CO_2/kg H_2 based on life cycle emission analysis.

Figure 2.27 Regional hydrogen hubs in the United States (approved in October 2023)



Source: DOE (2024), Regional Clean Hydrogen Hubs Selections for Award Negotiations as modified by the IEA.

Key recommendations

The US government should:

- Work with the oil and gas sector to develop net zero solutions and pathways to reach substantial cuts in scope 1, 2 and 3 emissions by increasing investment in clean energy relative to fossil fuels, as part of an industry investment strategy that commits to achieving net zero scope 3 emissions, recognising the continuing importance of the sector for global and domestic energy security and its influence to develop net zero policies.
- Examine how to use the expertise, workforce and skills in the oil and gas sector to support the development and deployment of clean energy sources, such as next-generation geothermal technologies, advanced biofuels and offshore wind energy.
- Design a National Low-Carbon Fuels Strategy building on a comprehensive evaluation of existing support measures, feedstock availability, and research and development opportunities.

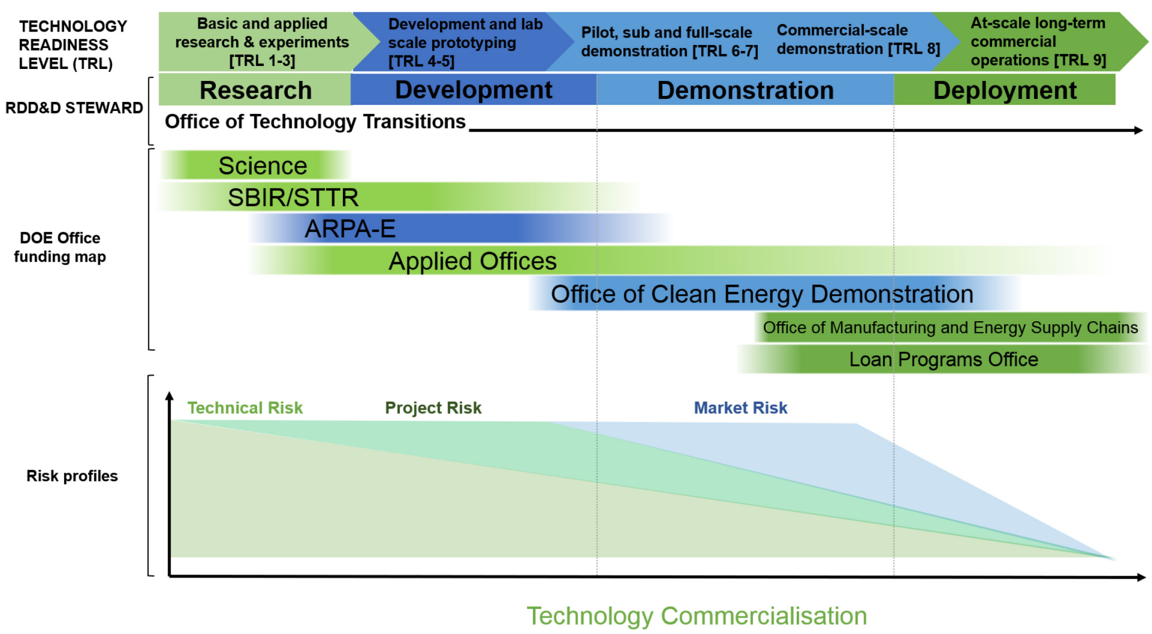
- Adopt and diligently implement proposed new federal rules to reduce emissions from the oil and gas sector in collaboration with states, industry, technology partners and communities.
- Support the industry's electrification of oil and gas operations, including through tax credits for the reduction of scope 2 and 3 emissions.
- Expand the deployment of innovative technologies to ensure that ongoing oil/gas production is delivered to reduce emissions and harmful pollutants across the oil/gas value chain.
- Support, promote and implement emissions-based global standards for reducing methane emissions.
- Work with partners to build an effective international market for zero-emission hydrogen through the IEA and the Hydrogen Trade Forum under the Clean Energy Ministerial.
- Develop an infrastructure transition strategy, working with industry and others, which maps the needs and opportunities for retaining or adapting oil/gas infrastructure, for example to enable the blending of biomethane and hydrogen. Establish standards, certification and safety rules.

3. Clean energy technology and manufacturing

3.1 Energy research, development, demonstration and deployment

With the creation of the DOE almost 50 years ago, the United States has led the global development of energy technology RDD&D and related international collaboration. The consistent investment in energy technology R&D has moved technologies along their technology readiness levels over the years. Thanks to the national laboratories and policy guidance from the DOE, the United States has created the ground for many of the energy transition patents available today. Since the IEA's last review, the DOE has been shifting its organisational structure, governance and strategic focus to deployment, thanks to the IRA/BIL. Understanding the barriers to deployment is becoming a priority area of its work, as the focus shifts from development to deployment.

Figure 3.1 Advancing technology readiness levels through co-ordination across multiple offices and funding streams



Note: SBIR/STTR = Small Business Innovation Research/Small Business Technology Transfer Programs; ARPA-E = Advanced Research Projects Agency-Energy; OCED = Office of Clean Energy Demonstrations; MESC = Office of Manufacturing and Energy Supply Chains.

Source: United States, Department of Energy, 2023, as modified by the IEA.

The United Sates is also the global leader in public and private RDD&D spending. Over the past years, the federal government has significantly stepped up the support to international collaboration efforts on lowering the cost of key clean energy technologies through comprehensive bilateral and multilateral engagement.

The funding and legislative provisions under the IRA (tax incentives) and BIL (grants) are geared towards the massive scale-up of deployment and the roll-out of clean energy technologies. The CHIPS and Science Act complements these efforts in the development of RD&D and investment for future industries. Since the IEA's last review, the DOE has strengthened its institutional governance, creating a strong national energy technology and innovation ecosystem through the new Undersecretary of Science and Innovation and Undersecretary of Infrastructure and related offices, including the Office of Clean Energy Demonstrations, the Loan Programs Office for large-scale infrastructure, and the DOE's ARPA-E and the Office of Technology Transitions (OTT), alongside the 17 national laboratories across the country.

Importantly, the United States has a clear strategy. The National Innovation Pathway of the United States, developed by the White House Office of Science and Technology Policy, the DOE, and the Department of State, highlights the federal government's strategy for accelerating key clean energy technology innovations. It builds on three pillars to drive net zero technology action:

1. invest in R&D for a portfolio of innovations to drive down costs, including long-duration energy storage, carbon removal, hydrogen, enhanced geothermal and floating offshore, industrial heat and clean fuels, and fusion energy
2. demonstrate and support early deployment of emerging technologies, including advanced offshore wind, CCS, direct air capture, hydrogen, advanced nuclear and advanced grid technologies
3. use regulations and financial incentives to accelerate manufacturing, deployment and adoption of existing technologies (solar, wind, batteries, EVs, highly efficient appliances and equipment, expanded transmission).

The strategy has targets for reducing the cost of critical technologies to drive clean energy breakthroughs on advanced technologies for batteries, nuclear, solar, CCUS, carbon removal, shipping fuels, hydrogen, geothermal, fusion energy, industrial decarbonisation, heavy-duty vehicles, methane reduction, long-duration storage, offshore wind and SAF. The DOE's Energy Earthshots™ Initiative contributes to this strategy by setting specific cost and performance targets for technologies across key sectors of the energy economy, for clean hydrogen production, long-duration energy storage, CO_2 removal, enhanced geothermal systems, floating offshore wind, decarbonising industrial process heat, developing alternative feedstocks for clean fuels and products, and decarbonisation retrofits for affordable housing. The eight Energy Earthshots™ are supported by an "all RD&D community" approach across DOE offices to address tough technological challenges and cost hurdles, and rapidly advance solutions. Energy Earthshots™ have established the following cost goals and performance targets:

- **Hydrogen Shot:** 1 USD/kg of clean hydrogen production within 10 years (an 80% cost reduction from the 2021 baseline).
- **Long-Duration Storage Shot:** Reduce the cost of grid-scale energy storage by 90% (relative to 2020 Li-ion baseline) to 5 cents/kWh LCOS (levelised cost of storage) for systems that deliver 10+ hours of duration within the decade.
- **Carbon Negative Shot:** Remove CO_2 from the atmosphere and durably store it at meaningful scales for less than 100 USD/net Mt CO_2-eq within a decade.
- **Enhanced Geothermal Shot:** Reduce the cost of enhanced geothermal systems by 90%, to 45 USD/MWh by 2035.
- **Floating Offshore Wind Shot:** Reduce the cost of floating offshore wind energy by more than 70% by 2035 for deep water sites far from shore. There is a companion national goal of deploying 15 GW of floating offshore wind by that date.
- **Industrial Heat Shot:** Develop cost-competitive industrial heat decarbonisation technologies with at least 85% lower GHG emissions by 2035.
- **Clean Fuels and Products Shot:** Decarbonise the fuel and chemical industry through alternative sources of carbon to advance cost-effective technologies with a minimum of 85% lower GHG emissions by 2035.
- **Affordable Home Energy Shot:** Reduce the cost of energy-efficient retrofits in affordable homes by 50% and decrease residents' energy costs by at least 20% within a decade.

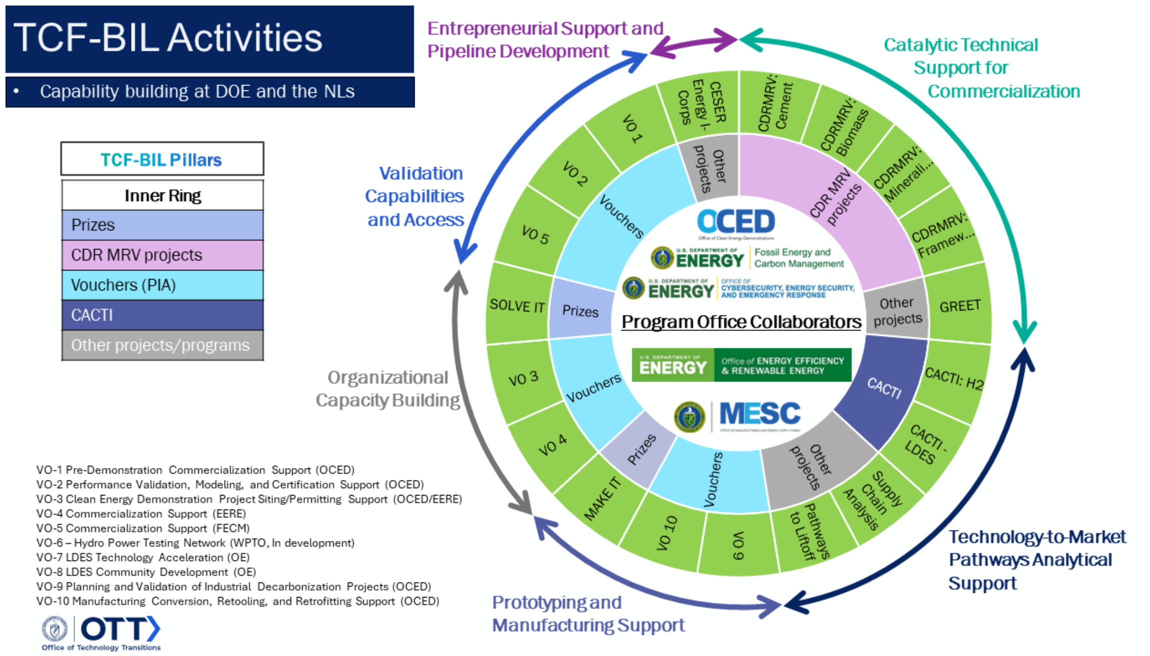
In addition to the Energy Earthshot™ goals, the DOE is pursuing additional clean energy- related targets, including:

- **Advanced batteries (DOE EV Battery Goals)** to reduce the cost of EV batteries to <100 USD/kWh; increase the range of EVs to 300 miles; decrease charge time to 15 minutes or less.
- **Advanced nuclear (DOE Nuclear Strategic Vision)** with two demonstrations in the mid-2020s under the Advanced Reactor Demonstration Program, the demonstration of a microreactor and capabilities for advanced fuel.
- **Advanced solar (DOE SunShot Goals):** Utility-scale solar PV: 0.2 USD/kWh by 2030; commercial solar PV: 0.04 USD/kWh by 2030; residential solar PV: 0.05 USD/kWh by 2030; concentrating solar power: 50 USD/MWh by 2030 for the concentrating solar power system in the Southwest with at least 12 hours of thermal energy storage.

The United States is a leader in clean energy funding efforts at home and globally. Energy-related RDD&D in the United States accounts for 0.04% of GDP, higher than the IEA average. The United States does not report its energy spending RDD&D data to the IEA.

Government expenditure in energy-related RDD&D increased from USD 7.7 billion in 2011 to USD 8.8 billion in 2022, with a peak in 2020 at USD 9.2 billion, according to the latest IEA estimates. Around 30% of the total funding goes to cross-cutting technologies, with spending for energy efficiency technologies and nuclear increasing over recent years.

Figure 3.2 Technology Commercialisation Fund under the Bipartisan Infrastructure Law



Source: United States, Department of Energy, 2023.

New funding under the IRA/BIL adds a large share of funding for the delivery of the DOE's responsibilities on RDD&D. The DOE's latest FY23 budget sets aside more than USD 11.9 billion to support RD&D, which is supplemented by USD 7.5 billion for DOE clean energy innovation programmes in the BIL. At the demonstration and commercialisation end of the spectrum, more than USD 100 billion in funding from the BIL/IRA supports new loan and grant authorities to deploy clean energy technologies, decarbonise industry, strengthen supply chains and more.

The 45Q Tax Credit for Carbon Sequestration in the IRA includes an enhanced credit for direct air capture and point source CCUS facilities. This complements over USD 3 billion in funding for CCUS demonstration projects and USD 3.5 billion for regional clean direct air capture hubs provided in the BIL.

With around USD 400 billion in loan authority, the DOE's LPO supports the transformation of existing energy infrastructure, reviving nuclear construction, scaling utility-scale solar and wind, and expanding domestic manufacturing of EVs. LPO bridges gaps in the private debt markets with USD 100 billion in loans and loan guarantees to help deploy and scale-up innovative clean energy and USD 250 billion to repurpose energy infrastructure for the low-carbon economy.

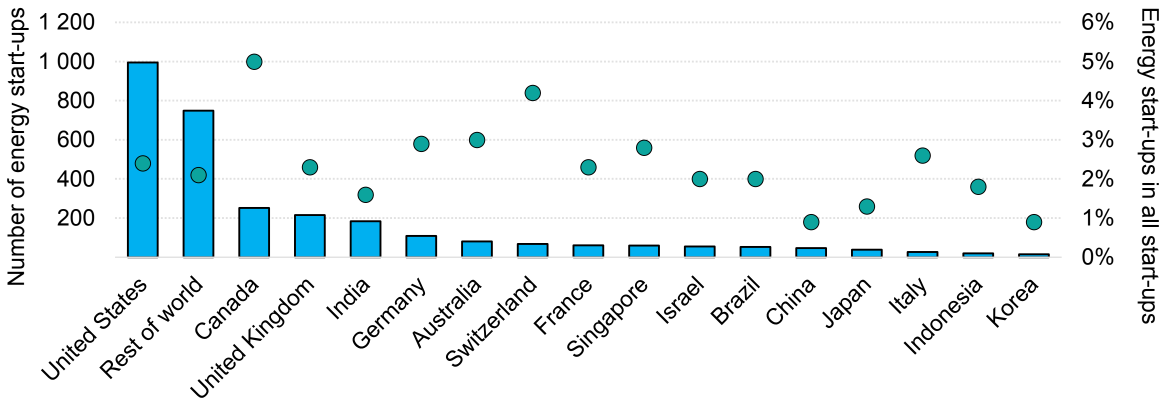
The DOE's commercialisation mission is further bolstered by the OTT and its programmes and activities. The Secretary of Energy established the OTT in 2015 to develop and oversee the delivery of the DOE's strategic vision and goals for technology transfer and commercialisation and engagement with business and industrial sectors. Congress codified the OTT's mission in 2020 to expand the commercial and public impact of the DOE's research investments and to focus on commercialising technologies. The OTT's director is the DOE's chief commercialisation officer, charged to drive private sector uptake of clean energy technologies. The OTT administers the Technology Commercialization Fund (TCF). It is funded by a 0.9% contribution from DOE research, development, demonstration and commercialisation funding. The TCF sub-programme Base Annual Appropriations TCF supports specific commercialisation projects at DOE laboratories. The second TCF sub-programme, the Bipartisan Infrastructure Law TCF, has a portfolio of programmes to provide an effective conduit for BIL funding in support of DOE infrastructure mission objectives (Figure 3.2).

Another relevant piece of legislation is the CHIPS and Science Act of 2022. It authorises USD 170 billion for federal research and innovation to bolster US leadership in R&D and manufacturing capabilities (including nanotechnology, clean energy, quantum computing and artificial intelligence) and create regional innovation hubs and job opportunities in science, technology, engineering and mathematics.

The United States has around 1 000 energy start-ups in the energy sector, accounting for roughly 2.3% of total start-ups in the country. Major success stories from the United States highlight the capacity of the energy sector to innovate:

- **American-Made Challenges:** Run by NREL, it offers a series of prizes for each technology priority identified by the DOE. The first energy technology challenge was in solar manufacturing. Innovators are attracted to the prize format because the entry requirements are lower than for traditional calls for public grants and loans (such as the Small Business Innovation Research Program).
- **Incubatenergy Network:** Connects incubators and others to help energy start-ups progress through the right types of support.
- **Innovation Incubator (IN2):** Helps clean energy hardware start-ups access expertise and precision technology testing and refinement at public laboratories.

Figure 3.3 Number and share of energy start-ups by country, 2016-2020



Source: IEA (2021), Innovative Energy Start-Ups.

Going forward, the federal government needs to ensure the continuity and adequacy of the funding of its 17 national laboratories and DOE RD&D programmes and enhance the innovation focus to maintain global leadership on energy technology innovation, according to the latest review by Energy Futures Initiative Foundation in 2023.

3.2 Global collaboration

The United States will continue to need energy-related imports of various kinds and energy-related trade will continue to play an important role. In the case of critical minerals, the federal government is already looking at how to create more diverse and resilient supply chains, and international partnerships have a potentially valuable role to play here. The DOE is internationalising the Energy Earthshots™; India's collaboration on the Long Duration Energy Earthshot ™ is the first one.

The DOE is also supporting innovation and co-ordination to spur private sector investments for commercialising technologies, for instance through the Pathways to Commercial Liftoff reports, which have been shepherded by the OTT in co-ordination with other DOE programme offices. These reports help the private sector with risk analysis and technology pathways for advanced nuclear, carbon management, clean hydrogen, long-duration energy storage, industrial decarbonisation and virtual power plants, among other technology areas and sectors.

At a global level, the federal and state governments are spearheading global technology collaboration efforts with multilateral partnerships through the Clean Energy Ministerial, Mission Innovation, the First Movers Coalition, Net Zero World and bilateral programmes.

In the CEM, the United States co-leads 13 initiatives and campaigns and is a member of 5 more. As one of the founders and chair of Mission Innovation, the United States co-leads and participates in missions such as Clean Hydrogen, Zero-Emission Shipping, Carbon Dioxide Removal and the Sustainable Aviation Fuel Innovation Community. A major highlight for multilateral co-operation, in 2022, the DOE hosted the ministerial meeting at the first-ever Global Clean Energy Action Forum in Pittsburgh, Pennsylvania, which combined the Mission Innovation and CEM Ministerials. Thanks to US leadership, 16 countries mobilised USD 96 billion for clean energy technology demonstrations in response to President Biden's challenge to mobilise USD 90 billion in public funding by 2026.

The United States also participates in nearly all 38 IEA Technology Collaboration Programmes (TCPs), either through the DOE, its national laboratories, universities or a combination of these entities. Work is now underway to enhance TCP engagement with other international multilateral initiatives to better align TCP activities with the global landscape of energy transition platforms.

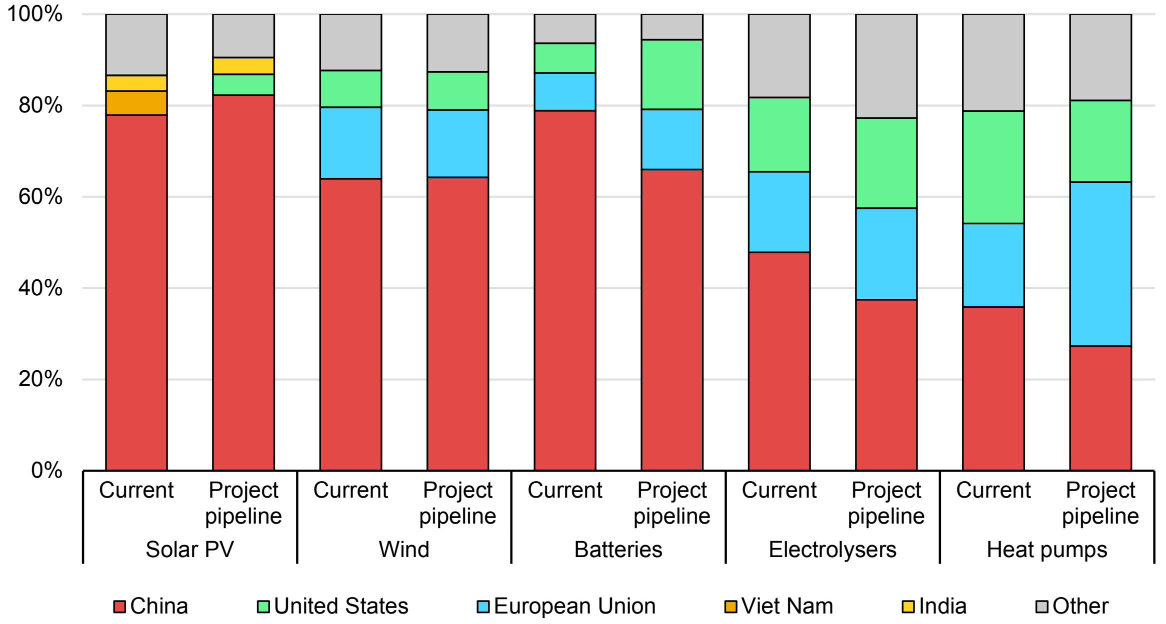
Bilateral programmes include the US-Brazil Energy Forum; the DOE-Natural Resources Canada Memorandum of Understanding on Energy Cooperation; the US-India Strategic Clean Energy Partnership and Renewable Energy Technology Action Platform; the US-Saudi Arabia Energy Cooperation Framework; the US-Australia Compact on Climate, Critical Minerals and Clean Energy Transformation; the US-Poland Strategic Energy Dialogue; the US-United Arab Emirates Partnership for Accelerating Clean Energy; and the US-United Kingdom Strategic Energy Dialogue, among numerous others. Engagement with these parties is essential for expanding markets for world-class energy goods and services. Engagement often also focuses on enhancing advanced energy research, which can increase competitiveness among like-minded parties.

3.3 Clean technology manufacturing

Clean energy technology manufacturing is expanding rapidly, driven by supportive policies, ambitious corporate strategies and consumer demand. The global energy crisis has instilled further impetus to develop manufacturing capacity that can strengthen energy security and diversify the supply chain. Four countries and the European Union account for 80-90% of manufacturing capacity for key clean technologies globally, with China in the lead for all. Concentration at any point along a supply chain makes the entire system vulnerable to unforeseen changes, such as an individual country's policy choices, natural hazards, technical failures or company decisions.

Manufacturing capacity expansions for clean energy technologies tend to have shorter lead times than other steps in the supply chain, such as mining. This means that progress from announcement to operation can be especially dynamic in a supportive environment. If all announced projects for solar PV manufacturing came to fruition, concentration among the top three producing countries would actually increase slightly, relative to today's levels, although the United States would increase its share from 1% to around 5%. For wind technologies, using onshore nacelles as an indicator, concentration among the top three producers would remain broadly flat. For batteries, electrolysers and heat pumps, the realisation of all announced projects would significantly reduce the current levels of concentration at the manufacturing step for these technologies.

Figure 3.4 Geographical concentration of current and announced global manufacturing capacity



Notes: Wind refers to onshore wind nacelles in this analysis. For electrolysers, the analysis only includes projects for which location data were available. Shares are based on manufacturing capacity. "Current" refers to installed capacity data for 2022. "Project pipeline" refers to the sum of current installed capacity and all announced manufacturing capacity additions (as of end Q3 2023) through to 2030. "Other" refers to the aggregate of all capacity outside of the top three countries/regions for each technology and time frame.

Sources: IEA analysis based on data from InfoLink, BNEF, WoodMac, BMI and UN Comtrade.

The United States has displayed global leadership in its policy approach to clean technology supply chains. The federal government has passed landmark legislation and evolved its institutional framework to implement major new areas of policy around supply chain security and resilience in the area of clean technology manufacturing. This topic is addressed here for the first time in an IEA energy policy review. Three key pieces of federal legislation with a bearing on clean technology manufacturing have been enacted in the United States since the last IEA review in 2019: the Inflation Reduction Act, the Bipartisan Infrastructure Law, and the CHIPS and Science Act.

The key institutional development since the IEA's last review is the establishment in 2022 of the MESC, under the remit of the Office of the Undersecretary for Infrastructure at the DOE. This new Office has the responsibility for implementing policy in the area of clean energy technology manufacturing, including relevant components of the IRA, the BIL and the CHIPS and Science Act. The Office administers USD 20 billion of funds to support these aims, including through direct investments in manufacturing capacity. It also conducts analysis to support programmes across the DOE and other departments in the federal government.

Alongside the MESC, several existing DOE offices have also been bolstered to implement several aspects of the recent legislation. For example, the Office of Energy Efficiency & Renewable Energy, which hosts further offices that focus on individual renewable energy technologies, such as the Solar Energy Technologies Office, which oversees the administration of new and expanded tax credits for manufacturing renewable energy equipment comprised in the IRA. These offices work together with the Department of the Treasury and the Internal Revenue Service to register and administer these tax credits.

Inflation Reduction Act

The IRA spans many areas of policy making beyond clean energy technology manufacturing. The manufacturing incentives – notably the expansion of the existing Qualified Advanced Energy Project Credit (administered under the Internal Revenue Code Section 48C) and a new Advanced Manufacturing Production Credit (Section 45X) – are the components of the legislation the most relevant to clean energy technology manufacturing, with specific provisions for individual categories of equipment.

For battery manufacturing, for example, the IRA provides two tax credits to domestic manufacturers of batteries and components thereof. The 45X Production Tax Credit provides 35 USD/kWh for battery cells and a further 10 USD/kWh for the manufacture of the full module. For the cell components, a further 10% Production Cost Tax Credit is provided for the manufacturing of cathodes and anodes, as well as for the processing operations of the critical minerals required. The 48C credit is an allocated credit that is capped at USD 10 billion and can apply to a range of clean energy manufacturing or critical materials processing activities and it can be applied to industrial decarbonisation activities. The 45X and 48C incentives cannot be used in tandem at the same facility.

Bipartisan Infrastructure Law

The majority of the content and funding of the BIL is dedicated to core infrastructure, such as roads, ports and railways, not manufacturing per se. However, there are certain provisions for manufacturing facilities specifically.

The Battery Manufacturing and Recycling Grants, administered by the MESC, are designed to provide direct support for research and demonstration of new technologies, but also for the retooling and new construction of commercial-scale manufacturing facilities. The funding available under the programme amounts to USD 3 billion in grants.

Targeting communities specifically where coal mines and coal power plants have closed, the Advanced Energy Manufacturing and Recycling Grants (also administered by the MESC) provides USD 750 million in grant funding to support manufacturing operations to produce or recycle advanced energy products, such as clean electricity, industrial decarbonisation activities, clean transportation technologies and clean fuel production.

The Clean Hydrogen Manufacturing Recycling Program, administered by the Office of Energy Efficiency & Renewable Energy, provides USD 500 million of mixed funding mechanisms (grants, contracts, co-operative agreements, etc.) for a range of hydrogen-related manufacturing operations, including the development of alternative materials, manufacturing, design and recycling processes for various hydrogen technologies and components thereof.

CHIPS and Science Act

The CHIPS and Science Act authorises USD 170 billion to bolster research, innovation and manufacturing capabilities for semiconductors and the materials used to make them. The key element of the law pertaining to manufacturing operations is the 25% Advanced Manufacturing Investment Tax Credit, which falls under a new Section 48D of the Internal Revenue Code. While semiconductors are used in a host of sectors including nanotechnology, quantum computing and artificial intelligence, they are used extensively for clean energy applications, including EVs; energy monitoring and storage; smart heating and lighting systems; and the innumerable computer systems that are used to design, monitor and manage clean energy production and use.

Other programmes

Authorised by the Independence and Security Act of 2007, the DOE offers loans under its Advanced Technology Vehicles Manufacturing Loan Program to automakers. As noted in the 2019 review, Ford, Nissan and Tesla were among the recipients for projects, such as constructing advanced battery manufacturing plants in the United States or retooling existing plants to produce EVs. With funds from the programme still able to be appropriated, the Advanced Technology Vehicles Manufacturing Loan Program made its first loan since 2010 in 2022, to Ultium Cells, a joint venture between LG Energy Solution and General Motors.

The DOE's Industrial Efficiency & Decarbonization Office hosts an Iron and Steel Manufacturing programme designed to support the development of decarbonisation technologies for iron and steelmaking. These include hydrogen-based technologies, increasing the use of scrap and direct electrification of ironmaking.

Impacts and expected outcomes

The programmes and legislation described above – particularly the provisions comprised in the IRA – have dramatically increased the attractiveness of the United States as a destination for clean technology manufacturing operations. While it is too early to gauge the full impact of these policies, some clear early signs are observable in recent historical data, and many estimates have been made as to the future capacity additions and amount of investments the policies may spur.

According to the Council of Economic Advisors, there has been a sharp increase in US construction of manufacturing facilities, with manufacturing construction spending doubling between the end of 2021 and the beginning of 2023. This rate of increase is significantly above that of other advanced economies.

The Clean Investment Monitor, a joint project of Rhodium Group and the Massachusetts Institute of Technology Center for Energy and Environmental Policy Research, tracks investment in clean technologies and their manufacturing facilities in the United States. Designed to provide real-time tracking of investment trends using a consistent methodology, the Clean Investment Monitor provides publicly available data on thousands of manufacturing facilities, together with millions of EV and heat pumps sales, among other categories of investment. The total quantity of clean energy and manufacturing investment is estimated at USD 213 billion in 2022/23. Investment in clean technology manufacturing facilities specifically – including for renewable energy technologies, batteries, EVs, electrolysers and other GHG-reducing technologies – is the fastest growing segment of investment in the database, increasing from USD 17 billion in 2021/22 to USD 39 billion in 2022/23. The Clean Investment Monitor also tracks project announcements, which have surged since Q3 2021. Over the following year, companies announced USD 73 billion in clean technology manufacturing investment and another USD 64 billion in 2022/23, a fivefold increase over the USD 12 billion annual average over the previous three years.

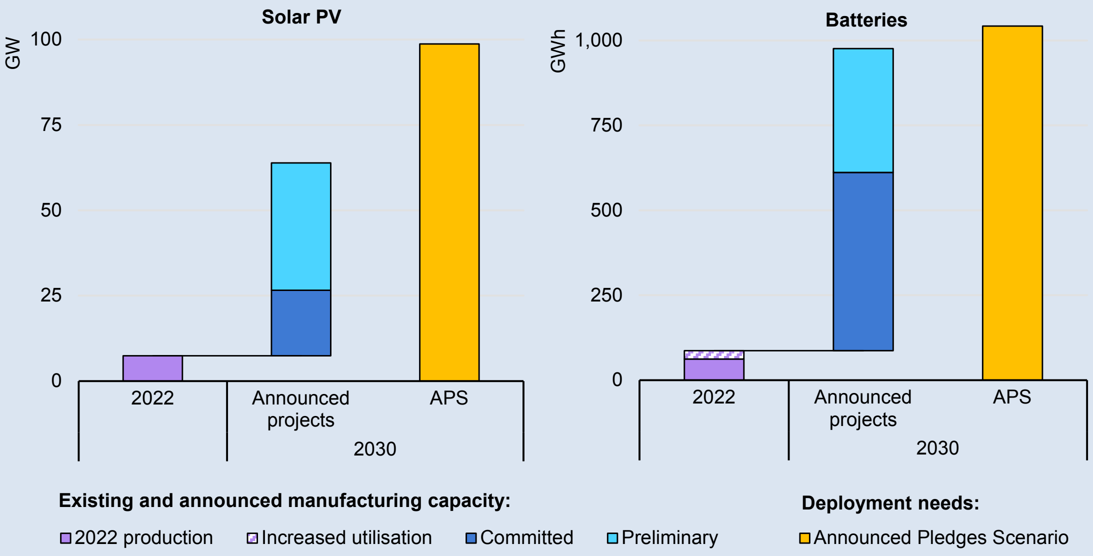
Goldman Sachs estimates that around USD 1.2 trillion of investment incentives will be provided by the IRA through 2032, creating the most supportive regulatory environment in the history of clean energy technology deployment. For battery manufacturing specifically, Ahmed Medhi and Tom Moerenhout of the Center on Global Energy Policy estimate that around 500 gigawatt hours of manufacturing capacity had been announced between the passing the IRA and July 2023. The total cost of the Production Tax Credit for battery manufacturing over the period to 2032 is estimated at USD 150 billion, according to an estimate by Benchmark Minerals Intelligence.

Internationally, some provisions of the legislation received a mixed reaction, especially those of the IRA for clean technology manufacturing. The initial response in Europe centred on concerns about European loss of investment to the United States, with some EU countries asserting World Trade Organization compliance concerns over domestic manufacturing requirements. Recent EU and member states' programmes can be seen as an official response that pave the way for similar forms of support to those provided in the IRA. These include the Net-Zero Industry Act and the Critical Raw Materials Act, which comprise regulatory changes to state aid rules, permitting, strategic projects and standards.

Box 3.1 Tracking progress towards energy and climate goals with manufacturing project announcements

IEA analysis of announced manufacturing projects suggests that the United States is on track to satisfy its deployment needs for electric vehicle batteries almost entirely with domestic production in 2030 in a scenario in which the country is on a pathway to reach its national pledge of achieving net zero greenhouse gas emissions by 2050. This assumes that all project announcements come to fruition. For solar photovoltaic module manufacturing, the announced projects at the time of the analysis (including announcements up to the end of Q3 2023) suggest that nearly two-thirds of the deployment needs can be met by domestic facilities, under the same assumptions.

Figure 3.5 Announced manufacturing projects and domestic production requirements under announced pledges for batteries and solar PV in the United States



Notes: GWh = gigawatt hour. Data based on an assessment of announced projects last updated in November 2023. 2022 production values reflect estimates of actual utilisation rates. Increased utilisation refers to the gap between 2022 production levels and existing capacity being utilised at 85%. A utilisation rate of 85% is used for both existing and announced manufacturing capacity in 2030.

Sources: IEA analysis based on data from InfoLink, Bloomberg New Energy Finance and Benchmark Mineral Intelligence.

3.4 Focus: Nuclear research, development, demonstration and deployment

Innovation is critical for the long-term operation of the existing nuclear fleet and for the cost-competitive deployment of new nuclear power, particularly for advanced designs. The federal government has supported nuclear innovation through its national laboratory network and by fostering co-operation and forging partnerships with industry and academia.

Long-term operation

The Light Water Reactor Sustainability Program was launched to develop solutions to sustain safe and competitive operation of the existing nuclear units. The Program has been successful in providing the necessary technical information to support long-term operations up to 80 years. Ongoing activities currently focus on improving the economics of the existing fleet. Efforts have also been made to develop accident-tolerant fuel for the existing fleet, in particular near-term concepts using coated cladding or doped uranium oxide pellets. The first accident-tolerant fuel rods have been tested in existing reactors, and post-irradiation examination is ongoing in national laboratory facilities.

Hydrogen production with nuclear power demonstration projects

The federal government plans to develop clean hydrogen infrastructure to meet projected demand of around 50 MMT of clean hydrogen by 2050. Current incentives include USD 8 billion to establish at least four regional clean hydrogen hubs, with at least one hub demonstrating hydrogen production using nuclear energy. In addition, Production Tax Credits are available to support qualified clean hydrogen production.

Nuclear-based hydrogen is a viable option to support the United States' hydrogen strategy. The United States has been a first mover in producing hydrogen using nuclear energy. Four pilot projects have already received federal funding, with some being operational[9] or expected to start up in 2024. Existing reactors can also cost-effectively produce hydrogen, with costs estimated at 2-3 USD/kg H_2, comparable to solar PV-based production.

Advanced nuclear power demonstration projects

Efforts have been made at the federal level to accelerate the deployment of advanced nuclear technologies. Activities have focused on the development and qualification of new fuels and the construction of first demonstration projects.

The DOE has invested over USD 400 million in TRiSO (TRi-structural ISOtropic particle fuel) and graphite qualification programmes for several SMRs currently under development (e.g. advanced gas-cooled reactors such as Xe-100 from X-energy). Building on the success on the TRISO programme, the DOE is also working on the qualification and demonstration of innovative metallic and molten salt fuels.

The DOE launched the Advanced Reactor Demonstration Program in 2020 to assist US industry with demonstrating advanced nuclear reactors domestically. In October 2020, the DOE announced USD 160 million in initial funding for TerraPower and X-energy to build two advanced reactors to be operational within seven years, according to the DOE. The BIL provided an additional USD 2.5 billion for these designs.

The Nuclear Energy Innovation Capabilities Act was signed into effect on 28 September 2018. Its primary aim is to accelerate the development of advanced

[9] A low-temperature electrolysis system at the Nine Mile Point nuclear power plant has been generating hydrogen since February 2023.

reactors in the United States. The Act was designed to eliminate some of the financial and technological barriers that have previously hindered nuclear innovation. It authorised the creation of the National Reactor Innovation Center to accelerate advanced nuclear deployment by working on key technologies, risk-sharing with industry and leveraging lab infrastructure as testbeds. For example, the DOME project will modify the EBR-II containment to host microreactor experiments.

The availability of research infrastructure is critical to test and generate the data to qualify materials, fuels and computer codes for advanced nuclear applications. The Versatile Test Reactor is one of the proposed projects to renew the research infrastructure in the United States and support the development of advanced reactors. The project reached the Critical Decision 1 milestone in 2020, but was put on "hold and restart" status pending annual appropriations from Congress.

3.5 Fusion energy

A White House Summit in March 2022 announced the government's Bold Decadal Vision for Commercial Fusion Energy. The vision's objective is to partner with the private sector to realise the first fusion pilot plants (FPPs) and FOAK commercial plants in the 2030s, aiming for aggressive commercial deployment in the 2040s.

The federal government has three different government agencies, all within the DOE, managing R&D of specific fusion applications with differentiated missions (i.e. the National Nuclear Security Administration for stockpile stewardship and the Office of Science and ARPA-E to enable fusion energy). The following government agencies within the US Department of Energy support fusion research activities:

- National Nuclear Security Administration
- Inertial confinement fusion and high-energy density science[10]
- Office of Science – Fusion Energy Sciences
- Fusion energy sciences, with an emphasis on magnetic confinement fusion[11], and plasma science and technologies
- Advanced Research Projects Agency-Energy
- Targeted, high-risk, high-reward translational fusion energy R&D

US fusion R&D activities have achieved significant breakthroughs recently. The Lawrence Livermore National Laboratory National Ignition Facility reported the

[10] This technology uses high-energy laser beams focused on a small pellet or target containing fusion fuel. When hit by the high-energy laser beams, the outer layer of the pellet explodes, compressing and heating the fuel to induce fusion.

[11] This technology uses magnetic fields to confine hot plasma and generate controlled fusion reactions. The tokamak is a type of magnetic confinement employing large toroidal magnetic coils distributed in a doughnut-shaped form. The ITER project is based on the tokamak. Stellarators are another type of magnetic confinement concept, which employs more complex and twisted magnetic fields to confine the hot plasma.

first-ever ignition and "scientific energy gain" in a fusion experiment, meaning that in this case, the experiment produced more fusion energy than the laser energy used to generate it. The National Ignition Facility is based on inertial confinement fusion and supported by the National Nuclear Security Administration as part of its Stockpile Stewardship Program. The private sector ecosystem in fusion energy has also been very active, with dozens of start-up companies developing the next generation of fusion designs based on innovative fusion concepts and technologies.

Box 3.2 Private sector investment in fusion energy in the United States

Private investments in fusion companies have dramatically increased, now exceeding USD 6 billion cumulatively.[1] The United States continues to take the lead with 25 private companies active in fusion energy. Commonwealth Fusion Systems has raised over USD 2 billion to pursue commercial fusion energy. This includes capital to design, construct, commission and operate the SPARC fusion experiment by the mid-2020s, according to Commonwealth Fusion Systems. The SPARC technology is based on the tokamak, a magnetic confinement fusion approach. The company leverages high-temperature superconducting magnet technology to create more compact tokamak systems that can be built faster and at a lower cost. The company Helion Energy is accelerating and merging two plasmoids to form and subsequently compress a field-reversed configuration[2] to achieve fusion. The company has secured over USD 0.5 billion, with an additional USD 1.7 billion of commitments tied to specific milestones. TAE Technologies has secured strategic and institutional investments of USD 1.2 billion. TAE is now constructing Copernicus, TAE's next fusion research experiment. ZAP Energy company was formed from the Advanced Research Projects Agency-Energy's ALPHA programme and uses a sheared-flow-stabilised Z-pinch, a technology developed at the University of Washington. Zap Energy has raised over USD 200 million in funding, including from Chevron Technology Ventures.

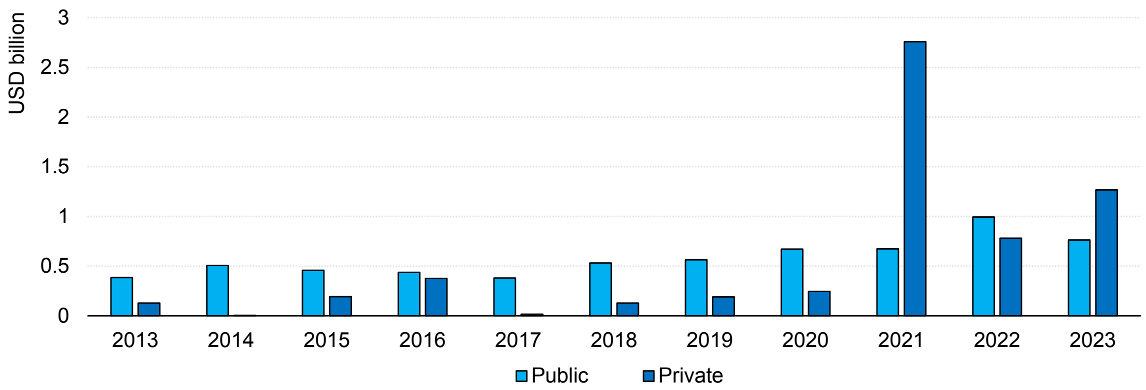
1. See: https://www.fusionindustryassociation.org/news/from-the-fia/#industry-reports

2. A magnetised plasma configuration also with doughnut-shaped closed field lines but without the need for magnets linking the centre of the doughnut.

Recent science and technology breakthroughs, as well as significant private investments indicating market interest, have sparked the need for a renewed federal government strategy on fusion energy RD&D. The DOE's Fusion Energy Sciences' Milestone-Based Fusion Development Program is a centrepiece of the Bold Decadal Vision for realising an operating Fusion Pilot Plant (FPP) in the 2030s. The key programme goals are FPP pre-conceptual designs and technology roadmaps after 18 months and the achievement of FPP preliminary engineering designs for the most aggressive companies after 5 years.

The programme establishes partnerships with the private sector to address and resolve key scientific and technological challenges. In May 2023, the DOE provided USD 46 million to eight fusion companies to develop their concepts. Additional new programmes will aim at securing access for private companies to world-class expertise and research facilities, as well as to develop new research infrastructure.

Figure 3.6 Major global fusion energy investment, 2013-2023



Note: Private refers to global equity investments while public refers to Department of Energy Fusion Energy Sciences funding.
Source: IEA as adapted from ARPA-E data.

Delivering on the Bold Decadal Vision will require more co-ordination across federal government agencies and a higher focus on demonstration and deployment rather than on pure scientific and laboratory research. Additional enabling conditions such as regulatory frameworks and fuel availability should be developed in parallel. In 2023, the NRC voted to license/regulate fusion systems under the Byproduct Materials Framework. The DOE has conducted preliminary assessments on fuel supply needs.

At COP28 in Dubai in 2023, the United States announced a new fusion international strategy, which builds on long-standing international partnerships in fusion scientific research while exploring new opportunities to accelerate commercial fusion development and demonstration. The strategy highlights needed new activities to support the eventual commercial deployment of fusion energy, such as growing the future global marketplace, including supply chains, international harmonisation of regulatory frameworks, fostering a diverse global fusion workforce, and improving public education and public engagement in fusion energy.

Key recommendations

The US government should:

- Sustain support for clean energy demonstration and innovation to help develop the future technologies needed for net zero by 2050, expanding Energy Earthshots™ internationally.
- Maximise synergies between the new clean energy hubs (direct air capture/hydrogen) supported by IRA and BIL funding and national laboratories, universities, and regional and state programmes.
- Work with partners and the IEA to promote clean energy technology, innovation and diverse supply chains and expand mineral security partnerships. Establish selection and evaluation criteria for strategic partnerships to procure key supply chain inputs in a manner that reveals mutually beneficial relationships between countries.
- Nuclear fission: Invest in the demonstration of nuclear innovations, particularly technologies that could derisk and accelerate advanced nuclear deployment. Renew research infrastructure for advanced nuclear technology.
- Fusion energy: Adapt existing federal government agency structures and resources to effectively meet the objectives set by the Bold Decadal Vision for Commercial Fusion Energy. Continue to develop enabling conditions for the deployment of fusion energy, such as a regulatory framework and fuel availability, while strengthening co-ordination with the private sector to maximise the value of public investments.

4. Ensuring a people-centred transition

The US climate and energy policy has a strong focus on people-centred energy transitions, aiming at the creation of quality jobs, local social and economic development through infrastructure investment, equity, and inclusion. A reinvigorated Office of Energy Justice and Equity and the Office of Energy Jobs are leading the DOE's implementation of the Justice40 Initiative; diversity, equity, inclusion and accessibility efforts; the creation of quality jobs with workers free and fair chance to join a union; and labour union and community engagement and accountability on energy projects. Conditionality of federal competitive funding is essential for community engagement and, ultimately, project success.

Community Benefits Plans (CBPs) are the DOE's central strategy to advance these goals. The DOE requires that applicants provide CBPs as part of the application for all BIL and IRA funding opportunity announcements and loan applications. In most cases, for grants, these plans are scored at 20% of the technical merit review of proposals. The CBPs use a four-part approach to ensure workers and communities benefit from awarded projects. One part aims to meet or exceed the objectives of the Justice40 Initiative that 40% of the benefits of certain federal investments accrue to disadvantaged communities. Second, the CBPs aim to support diversity, equity, inclusion and accessibility through equitable access to wealth-building opportunities (access to career-track training, quality jobs, business and contracting opportunities). Third, the CBP aims to support high-quality jobs to attract and retain skilled workers. High-quality jobs include above-average wages and benefits, investments in training, workplace health and safety, and support for worker organising, collective bargaining and the free and fair chance of workers to join a union. Fourth, the CBPs prioritise engaging communities and labour organisations throughout the life of the project. The federal government suggests that applicants sign formal negotiated agreements with community and labour organisations to ensure accountability and enforcement of the CBPs.

The DOE has implemented a framework for reviewing applicants' CBPs. If a project is selected, voluntary commitments in CBPs become contractual obligations with the DOE. The recipient will be required to implement its proposed CBP. The DOE will evaluate the recipient's progress, including as part of the Go/No-Go review process.

To further ensure the implementation of a people-centred transition, and in alignment with Executive Orders 13985 and 14091, the DOE published its second Equity Action Plan in 2023, which highlights the top five new priority strategies to advance equity. These include: 1) establishing a DOE-wide CBP framework; 2) updating the Merit Review Program to facilitate equitable outcomes; 3) increasing access to procurement opportunities for new entrants and disadvantaged businesses; 4) integrating justice considerations into R&D programmes; and 5) developing an agency-wide framework to work with tribal and disadvantaged communities.

The IEA high-level Global Commission on People-Centred Transitions provided a set of recommendations on how to ensure people are at the centre of the global energy transition (Figure 4.1). The four priorities of the CBP are well-aligned with the IEA principles.

Figure 4.1 IEA principles for just energy transitions

DECENT JOBS AND WORKER PROTECTION

1 Design transitions to maximise the creation of decent jobs

2 Develop tailored government support for communities and workers as well as focus on skills and training

3 Use social dialogue, robust stakeholder and policy co-ordination to deliver better outcomes

SOCIAL AND ECONOMIC DEVELOPMENT

4 Ensure that policies enhance social and economic development, and improve quality of life for all

5 Prioritise universal clean energy access and the elimination of energy poverty

6 Maintain and enhance energy security, affordability and resilience

EQUITY, SOCIAL INCLUSION AND FAIRNESS

7 Incorporate gender, equality and social inclusion considerations in all policies

8 Ensure fair distribution of clean energy benefits and avoid the risk of disproportionate negative impacts on vulnerable populations

9 Integrate the voices of younger generations in decision making

PEOPLE AS ACTIVE PARTICIPANTS

10 Involve the public through participation and communication

11 Use insights from behavioural science to design effective behaviour change policies

12 Enhance impact through international collaboration and exchange best practice

Source: IEA (2021), Recommendations of the Global Commission on People-Centred Clean Energy Transitions.

4.1 Jobs and skills

Supporting quality jobs and developing a skilled energy workforce are at the heart of the United States' just and inclusive energy transition policy and the success of the DOE's plan for manufacturing and supply chains. The federal government has taken significant steps to ensure that clean energy policy implementation is accompanied by measures to support quality jobs, both in the BIL and the IRA. The federal government's job data collection, the United States Energy and Employment Report (USEER), is a world-leading data tracker for employment in the energy sector.

According to the USEER report published in 2023, in 2022 the US energy sector employed around 8.1 million people, or 5% of the total workforce (the total number of all people who were employed amounted to about 163 million). In 2022, there were 3.1 million clean energy jobs meeting the net zero aligned definition.[12] This represents an increase of more than 114 000 since 2021, or growth of 3.9%. These jobs made up more than 40% of total energy jobs in 2022.

Table 4.1 Change in energy jobs by industry, United States, 2021-2022

	Electric power generation	Transmission, distribution, and storage	Fuels	Energy efficiency	Motor vehicles	Industry total
Agriculture and forestry	0	0	82	0	0	82
Mining and extraction	0	0	107 029	0	0	107 029
Utility	5 142	5 866	0	0	0	11 008
Construction	6 660	13 989	885	23 729	0	45 263
Manufacturing	2 193	2 862	4 266	6 022	16 354	31 697
Wholesale trade, distribution and transport	2 276	2 069	3 362	8 213	19 489	35 409
Pipeline transportation	0	-181	0	0	0	-181
Professional and business services	8 015	5 047	7 689	11 504	1 092	33 347
Other services	1 397	284	64	1 049	27 938	30 732
Total change from 2021	**25 683**	**29 936**	**123 377**	**50 517**	**64 873**	**294 386**

Source: DOE (2023), United States Energy & Employment Report 2023.

[12] Clean energy jobs include jobs in the technologies that align with this "net zero" future, including those related to renewable energy; grid technologies and storage; traditional electricity transmission and distribution for electricity; nuclear energy; a subset of energy efficiency that does not involve fossil fuel burning equipment; biofuels; and plug-in hybrid, battery electric, and hydrogen fuel cell vehicles and components.

President Biden's Invest in America agenda strongly supports the creation of high-quality union jobs. High labour standards are statutory levers to address job quality, including the Davis Beacon Act on BIL-funded projects and IRA enhanced tax credits conditioned on prevailing wages and the use of registered apprentices. In addition, Executive Orders detailing the government's use of collective bargaining agreements on large construction projects and other efforts on worker empowerment further strengthen the US commitment to good jobs. DOE assesses private sector commitments to quality jobs, worker organising and collective bargaining and labour union engagement as part of its scoring of proposals, as described in the CBP.

Union representation in the energy workforce (11%) exceeded the private sector average (7%) by over 50%, with significant geographic variation. The transmission, distribution and storage sector had a higher representation (18%) compared to the overall energy workforce. Among all energy technologies, nuclear power generation had the highest unionisation rate in 2022 (19%). Greater unionisation can be seen in a positive light, due to the fact that union employers often report less difficulty finding workers than non-union employers. According to USEER, 29% of union and 48% of non-union firms reported that it was very difficult to find workers. This is most noticeable within the construction industry. Additionally, "unionized employers report less difficulty in having skilled workers and are more than twice as likely to have formal diversity, equity, inclusion, and access programmes." The concentration of workers represented by a union or covered under a project labour or collective bargaining agreement (11%) was higher than the national private sector average (7%).

USEER does not forecast/model future workforce needs. The next step in the federal government's efforts is a detailed workforce modelling and mapping of the future demand for an energy workforce, the expected supply, existing gaps and recommended actions. The forward-looking companion report is expected to be completed by the end of Q3 2024. The federal government initiated the 21st Century Energy Workforce Advisory Board that is comprised of industry, education, labour and workforce experts. The Board is tasked with developing a strategy and recommendations to prepare the energy workforce for the changing security, resilience, reliability and decarbonisation challenges of 21st century energy system.

Across many clean energy tax credits, the IRA rules create incentives for newly created jobs to be good paying. A project or facility can earn five times higher tax credits if it meets prevailing wage and registered apprenticeship requirements.[13]

[13] These requirements include three components – a labour hours requirement, a ratio requirement and a participation requirement. See also: https://www.apprenticeship.gov/inflation-reduction-act-apprenticeship-resources.

Through the BIL and the IRA, the DOE allocates several grants to train a qualified and diverse clean energy workforce across several technology sectors. The DOE's Office of State and Community Energy Programs was appropriated USD 260 million for Workforce Development and Business Owner Training Programs that will help states, non-government organisations and industry prepare workers and businesses to deliver the energy efficiency and electrification projects that will decarbonise buildings.

President Biden issued several Executive Orders in 2021 to boost jobs and skills:

- **Executive Order 14008:** Tackling the Climate Crisis at Home and Abroad – Calls for an all-of-government approach to "create well-paying union jobs to build a modern and sustainable infrastructure, deliver an equitable, clean energy future, and put the United States on a path to achieve net zero emissions, economy-wide, by no later than 2050."
- **Executive Order 14005:** Ensuring the Future Is Made in All of America – Increases domestic content requirements on federal procurement, driving domestic job creation.
- **Executive Order 14063:** Use of Project Labor Agreements for Federal Construction Projects – Requires project labour agreements on large federally contracted construction projects.
- **Executive Order 14025:** Worker Organizing and Empowerment – Established the Task Force on Worker Organizing and Empowerment to identify ways the federal government could fully use its authority to encourage worker organising and collective bargaining. The Task Force released its report in 2022, detailing nearly 70 recommendations for revising labour laws and regulations.
- **Executive Order 14052:** Implementation of the BIL – Emphasises the importance of high labour standards, including prevailing wages, and the free and fair chance to join a union in the implementation of the Infrastructure Investment and Jobs Act.

4.2 Infrastructure and economic revitalisation

The federal government's historic commitment to environmental justice is articulated in Executive Order 14008. The White House Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization works on initiatives to support cities, counties, economic developers, employees and communities with strong coal, oil and gas, and power plant presence.

Through the BIL, the IRA and the Justice40 Initiative, the federal government is committed to deliver 40% of overall benefits from certain federal investments to disadvantaged communities that are marginalised, underserved and overburdened by pollution. Such investments include climate change mitigation and resilience, clean energy and energy efficiency, clean transit, affordable and sustainable housing, training and workforce development, remediation and reduction of legacy pollution, and the development of critical clean water and wastewater infrastructure.

The federal government provides significant support for communities that currently host fossil energy infrastructure, such as retired coal plants, through bonus credits and other programmes providing financial support to reinvest in or replace fossil fuel-powered plants. The Interagency Working Group on Coal and Power Plant Communities and Economic Revitalisation ensures that these historic coal and power plant communities benefit from job creation, pollution cleanup and other opportunities provided by the growing clean energy economy.

The IRA also provides targeted support for energy communities, which include areas that have been economically reliant on the extraction, processing, transport or storage of coal, oil or natural gas but now face higher-than-average unemployment. The IRA's Production and Investment Tax Credits for clean electricity offer bonus credits for projects located in an energy community, and at least USD 4 billion of the total USD 10 billion of Section 48C Advanced Energy Project Credit allocations are reserved for areas that have experienced the closure of a coal mine or coal plant. The United States, among others, is promoting the development of CCUS through tax credits as a decarbonisation pathway for its fossil fuel-dependent industries to help preserve jobs in these sectors. The BIL in 2021 and the IRA in 2022 amended the 2005 Energy Policy Act and its Title 17 Clean Energy Financing Program through the DOE Loan Programs Office (LPO). LPO can provide federal financing for projects located in the United States that support clean energy deployment and energy infrastructure reinvestment to reduce GHG emissions and air pollution, through guarantees and loans for projects that "retool, repurpose or replace energy infrastructure that ceased operations".

Box 4.1 Working with philanthropy on just and inclusive energy transitions

The Inflation Reduction Act, the Bipartisan Infrastructure Law, and the CHIPS and Science Act support a private sector-led government-enabled energy transition which builds on the substantive involvement of the private sector, notably to avoid disproportionate impacts and support technical assistance and capacity building at the level of state, urban, local and tribal communities.

The Department of Energy (DOE) supports people-centred transitions, notably in workforce development and engagement with unions, social acceptance of energy infrastructure and sectoral energy transitions in transport and buildings sectors, be it home rebates, renovation or decentralised energy programmes. Key programmes include the National Energy Technology Laboratory's regional workforce initiative and DOE's Battery Workforce Initiative.

Other countries around the world work through climate partnerships with local communities, for instance the industry-specific climate partnerships in Denmark. Denmark has also deployed a cross-government implementation taskforce, NEKST, to focus on lifting the barriers on concrete areas of buildings, transport and power sector transitions (e.g. heat network planning). Such initiatives often require substantial communication, community engagement and local capacity building as well as co-ordination. Philanthropies can play an important role in this regard to help the implementation of the energy transition for the people.

Focus: Coal transitions

Jobs in the coal sector are linked to mining, processing and power generation. Working across all levels of government, the United States supports the transition of coal, oil, gas and power plant regions, pulling together experts and using considerable investments from the BIL and the IRA. In particular, the BIL provided the Department of the Interior with USD 16 billion to address legacy pollution, including USD 11.3 billion to clean up abandoned mine lands in coal communities. Several offices in DOE support the coal transition efforts: the Office of Energy Justice and Equity, Office of Energy Jobs, Office of Indian Energy, LPO, FECM and OCED, among others. In 2021, the White House Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization was created and identified 25 priority communities across the country that will be the hardest hit by coal mine and power plant closures and delivered recommendations. It also evaluates new economic opportunities through outreach events for coal regions, such as critical minerals, manufacturing, geothermal and CCUS investment. The Working Group presented a national roadmap to partner with local communities.

Box 4.2 The case of repowering coal with nuclear power

The smaller size of small modular reactors (SMRs) also enables siting at locations not adapted for large nuclear plants, such as existing coal sites in the United States. A 2022 report from Idaho National Laboratory identified hundreds of coal plants in the United States that could potentially host SMRs.

Deploying SMRs on existing coal infrastructure supports decarbonisation goals while enabling a just transition and reducing nuclear deployment costs.

Capital expenditure reductions up to 20% for new nuclear are possible by reusing existing buildings, grid connections and heat sinks infrastructure at coal sites.

Note: A significant portion of the existing workforce could also transition from coal to nuclear operations with limited training, while maintaining tax revenue to support local community development.

Focus: Nuclear transitions

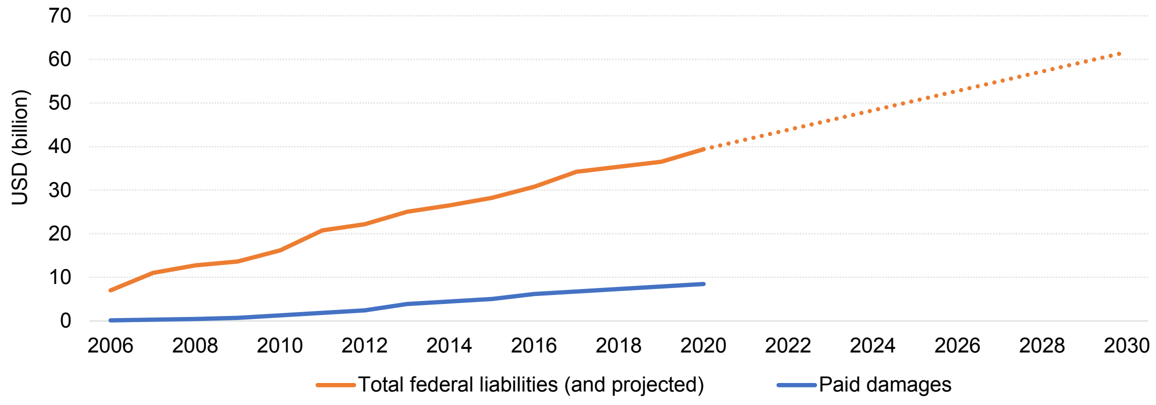
Community engagement on nuclear is positive in the United States, as the sector is a significant driver of jobs and employment and local economic benefits. Decommissioning and nuclear waste management aim to build trust in nuclear power applications.

In the United States, the decommissioning liabilities are separated from liabilities for disposal of spent nuclear fuel (SNF).

Over the years, nuclear operators have set aside provisions to finance their decommissioning liabilities. As of December 2018, provisions for decommissioning amounted to USD 65 billion. According to the Nuclear Waste Policy Act of 1982, as amended, the DOE is responsible for the final disposal of SNF. As of the end of 2021, approximately 89 000 metric tonnes of this fuel were stored onsite at 75 operating or shut down nuclear power plants across 33 states, according to the DOE's latest data. This amount increases by about 2 000 metric tonnes annually. The absence of centralisation also hinders the ability to leverage economies of scale, which could reduce storage costs.

The Nuclear Waste Policy Act also specifies that the only site that may be considered for the permanent disposal of commercial SNF is a geologic repository at Yucca Mountain, Nevada. However, in 2010, the DOE terminated its efforts to license a repository at Yucca Mountain and Congress subsequently halted funding activities related to the site.

Figure 4.2 Department of Energy's commercial spent nuclear fuel total liability estimate and paid damages, 2006-2030



Source: IEA analysis based on GAO (2021), Commercial spent nuclear fuel.

Additionally, a per-kWh fee sold by existing reactors to contribute to the Nuclear Waste Fund was set at zero in 2014.[14] Since then, policy makers have been at an impasse on fulfilling the federal disposal obligation, leading to significant financial implications for taxpayers. As of 30 September 2023, more than USD 10 billion had been paid out in combined settlements and judgements. On average, about USD 740 million has been paid out each year over the past ten years. Payments from the Judgement Fund (taxpayer money) began in fiscal year 2004 following litigation by fuel owners (utilities) against the DOE for a partial breach of contract (the Standard Contract in the Nuclear Waste Policy Act of 1982, as amended). These costs will continue to grow until the federal government develops and approves a consolidated interim storage facility or permanent disposal repository and assumes responsibility for the fuel. The outstanding liabilities for storing and disposing SNF are estimated to be USD 30.6 billion.

The Government Accountability Office suggests that the costs might be underestimated. In a 2021 report, it recommended:

- amending the Nuclear Waste Policy Act to authorise a new consent-based siting process
- restructuring the Nuclear Waste Fund to ensure adequate funding
- directing the DOE to develop and implement an integrated nuclear waste management strategy.

More recently, through the Consolidated Appropriations Acts of 2021, 2022 and 2023, the DOE was directed by Congress to work toward identifying a site for federal consolidated interim storage for SNF using a consent-based siting

[14] On 19 November 2013, the US Court of Appeals for the District of Columbia Circuit sustained a challenge to the DOE's determination of the adequacy of the Nuclear Waste Fund fee and directed the DOE to transmit a proposal to Congress to reduce the fee to zero. The DOE complied and, after a congressional review period, its proposal became effective on 16 May 2014.

process. In 2021, the DOE issued a request for information concerning the use of consent-based siting approach for identifying potential sites for federal interim storage of SNF. In 2023, the DOE released an updated Consent-Based Siting for Federal Consolidated Interim Storage of Spent Nuclear Fuel process document that incorporated public input.

The consent-based siting process consists of three main stages:

1. **Planning and capacity building:** Build relationships, encourage mutual learning and develop a common understanding of nuclear waste management-related topics.
2. **Site screening and assessment:** Share screening and assessment criteria; issue a national call for volunteers; draft preliminary and detailed site assessments in collaboration with volunteer communities.
3. **Negotiation and implementation:** Negotiate agreements with willing and informed host communities with licensing, construction and operation activities to follow.

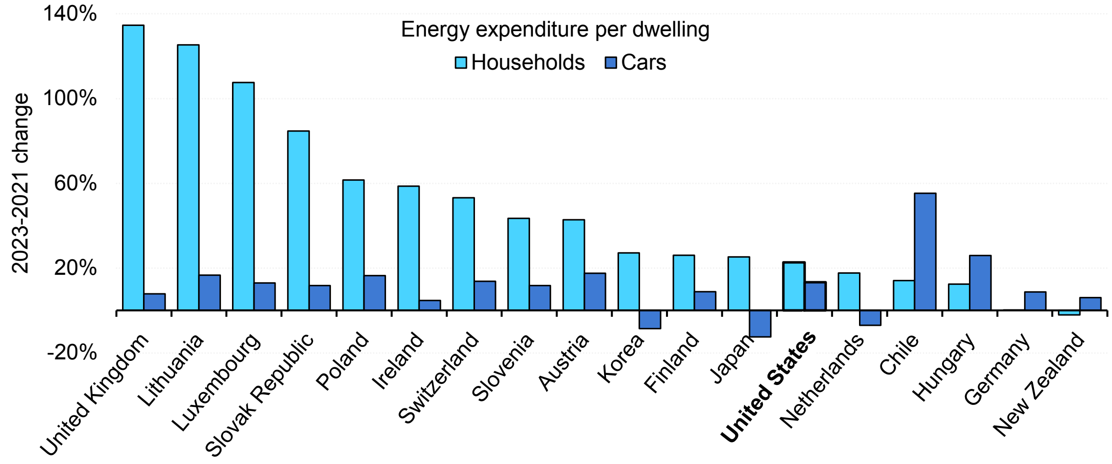
The DOE's consent-based process for interim storage of SNF is currently in Stage 1 with an estimated remaining duration of two to three years, depending on programme resourcing. Stage 2 has an anticipated duration of four to seven years. The DOE has spent the last ten years designing, fabricating and extensively testing purpose-built railcar equipment for future transport of SNF and high-level radioactive waste. It is also developing preliminary plans for a full-sized rail cask package performance demonstration, including the NRC and public participation. Although federal consolidated interim storage does not address the ultimate waste disposal challenge and an integrated long-term waste management strategy still lacks, it offers a means to gain experience with consent-based approaches, foster trust and begin fulfilling the DOE's obligations concerning SNF.

SNF final disposal is a long-standing issue in the United States which remains unresolved. This situation contrasts with countries like Finland, France and Sweden, which have long-term waste management plans and advanced deep geological repository projects. For instance, the first SNF is expected to be disposed at the Onkalo site in Finland by 2025. Previous reviews to propose solutions to this issue, including the 2012 Blue Ribbon Commission on America's Nuclear Future, have concluded the need of creating a new, independent, single-purpose nuclear waste management organisation with a new funding strategy. Critical steps to designing this new organisation may include the organisation's relationship to the President and Congress; its source of funding; and other organisational attributes, such as how it will engage stakeholders and be treated by federal and state regulatory agencies. As highlighted by the Government Accountability Office in 2021, congressional action is needed to break the current impasse and advance the development of a permanent disposal solution in the United States.

4.3 Affordability and distributional equity

By international comparison among IEA countries, the United States' annual household energy expenditure (households and cars) has been stable and was shielded of the impact of the global energy crisis of 2022, unlike Europe or Asia.

Figure 4.3 Change in households' annual energy expenditure (households and cars), selected countries, 2021-2023

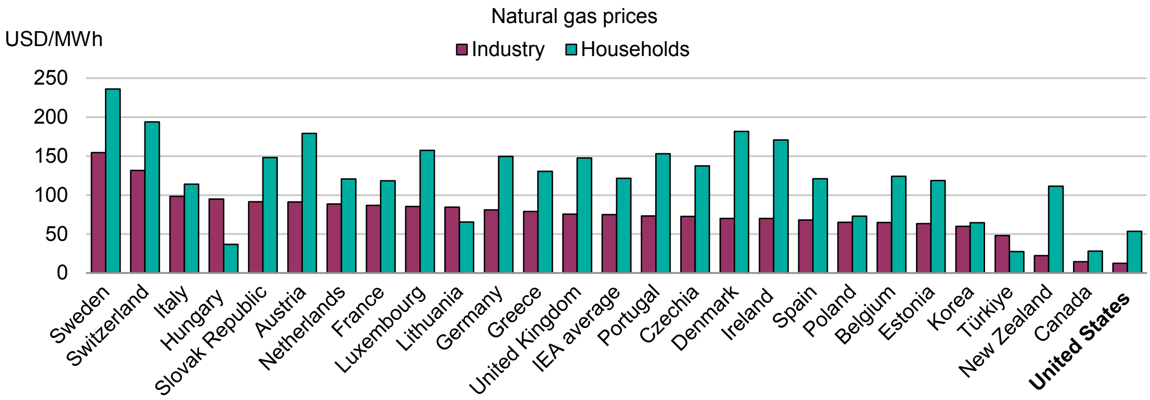


Source: Estimates based on IEA (2024), Energy Prices, IEA (2023), Energy End-uses and Efficiency Indicators and IEA (2024), World Energy Balances (datasets).

Price trends remained above 2021 levels and follow international transport fuel prices (as the United States imports oil products to satisfy its demand), going up in 2022 but decreasing in 2023.

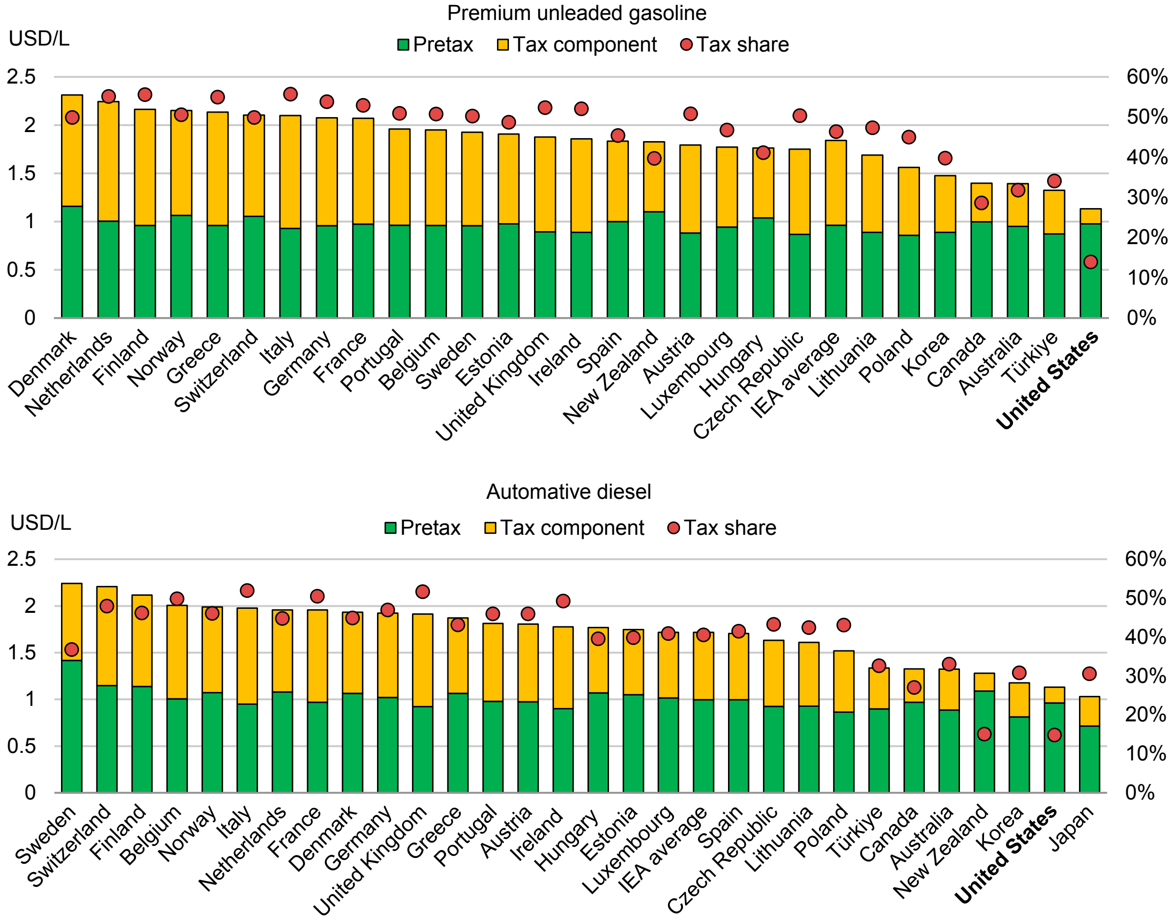
In 2023, the United States' natural gas prices for industry and households had the lowest levels among IEA countries. In 2023, it also had the second-lowest levels of retail prices for diesel and the lowest premium unleaded gasoline.

Figure 4.4 Natural gas prices for industry and households in selected IEA countries, 2Q 2023



Source: IEA (2023), OECD Energy Prices and Taxes quarterly (database).

Figure 4.5 Fuel prices in the United States and in selected IEA countries, 2Q 2023

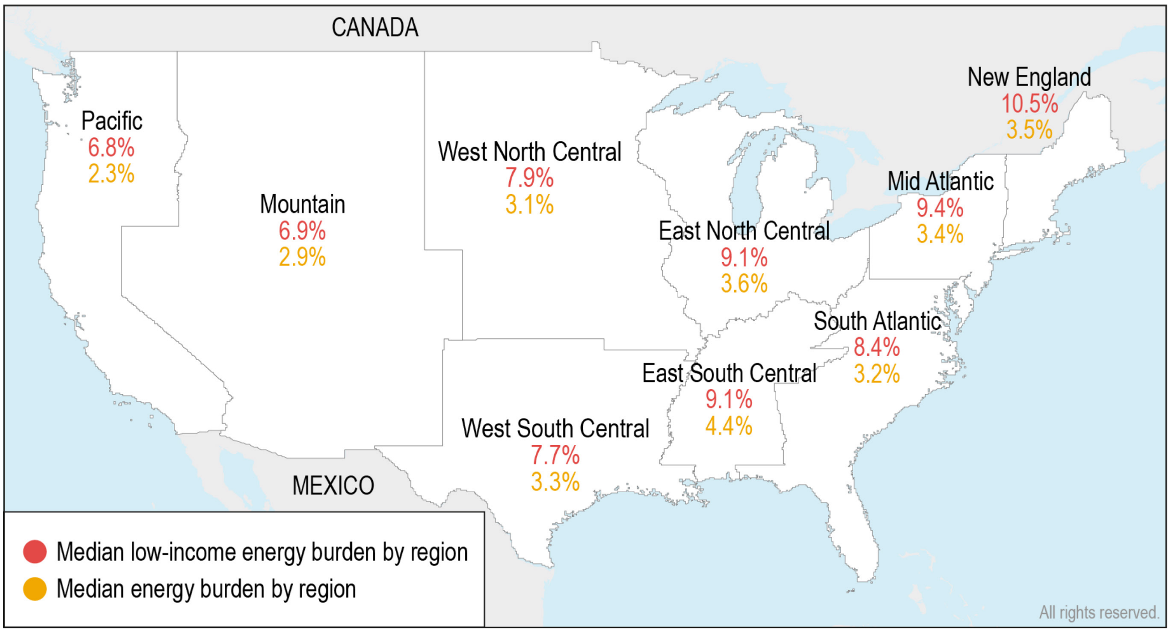


Source: IEA (2024) OECD Energy Prices and Taxes quarterly (database).

The median energy burden[15] of low-income households is 3.5 times higher than that of non-low-income households (the national average energy burden for low-income households is 8.6% while non-low-income households are estimated at 3%). The median energy burden of Black households is 45% higher than that of non-Hispanic white households. The regional distribution of the energy burden varies widely. EIA 2020 and 2015 survey results include rates of energy insecurity, defined as the inability to adequately meet household energy needs. Survey results can be used to determine which households are energy-poor based on the percentage of income spent on fuel. 52% of Black households and 47% of Latinx households in the US report energy insecurity. Further, energy insecurity is higher for people over the age of 60, families with children and low-income households.

[15] Energy burden is defined as the percentage of gross household income spent on energy costs. It is measured through the DOE's Low-Income Energy Affordability Data Tool. A value above 6% is considered a high energy burden in the United States.

Figure 4.6 Regional disparities in energy burden in the United States, 2020



Source: American Council for an Energy-Efficient Economy (2020), How High Are Household Energy Burdens? as modified by the IEA.

The federal government deploys measures that specifically target support to low-income households, for example through energy efficiency grants, such as the long-standing Weatherization Assistance Program, the Low Income Home Energy Assistance Program, the Energy Efficiency and Conservation Block Grants, or the Home Energy Rebates.

The IRA authorises and the Internal Revenue Service administers a new credit monetisation provision, elective pay. This allows applicable entities, including tax-exempt and governmental entities that would otherwise be unable to claim certain credits because they do not owe federal income tax, to benefit from some clean energy tax credits. By choosing this election, the amount of the credit is treated as a payment of tax and any overpayment will result in a refund.

Another important driver of energy efficiency is consumer-driven action. To raise consumer awareness, the federal government is supporting initiatives providing easily accessible and easily understandable data on consumption. The United States has also shown positive results on energy savings from home energy consumption when comparing consumption with similar households in a neighbourhood.

Table 4.2 Federal government affordability programmes under the Bipartisan Infrastructure Law and the Inflation Reduction Act

Bipartisan Infrastructure Law	Inflation Reduction Act
USD 3.5 billion for the Weatherization Assistance Program	USD 11.7 billion for the Department of Energy's Loan Programs Office
USD 500 million in Energy Efficiency and Conservation Block Grants	Home Energy Rebates (formula) – USD 9 billion (retrofits and appliances)
USD 500 million for the State Energy Program	USD 1 billion for advanced building energy codes
USD 1 billion in Energy Improvements in Rural or Remote Areas	USD 27 billion Greenhouse Gas Reduction Fund (USD 14 billion for the National Clean Investment Fund, USD 6 billion for the Clean Communities Investment Accelerator and USD 7 billion for Solar for All)
USD 200 million for State Home Energy Efficiency Contractor Training Grant Programs (workforce)	
Connecting local governments, utilities, community-based groups – Clean Energy to Communities	

4.4 Citizen engagement and inclusion

Pooling local resources through active and early engagement by citizens in clean energy projects, including renewable energy projects, can promote local acceptance, as well as access to capital, consumer choice and local economic opportunities. Several countries have promoted community models, including the United States. The strong focus on inclusion and early citizen engagement is reflected in the promotion of local energy communities in the United States, including through the CBPs.

The DOE runs programmes under its States and Community Energy Programs (part of the Office of the Undersecretary for Infrastructure). The IRA bonus tax incentivises investment in energy communities, including for coal regions.

The federal government has initiated the American Climate Corps initiative, which engages young people on climate issues and opportunities to train young people and provide pathways into career-track training and employment in a large range of areas of the transition: clean energy, conservation, and climate resilience related skills, including restoring coastal wetlands to protect communities from storm surges and flooding, deploying clean energy, managing forests to improve health and prevent catastrophic wildfires, implementing energy efficient solutions to cut energy bills for hardworking families, and more. Under the ACC initiative the White House has a partnership with several federal agencies to co-ordinate recruitment across federal programmes, streamline pathways into civil service and leverage tribal, state and local governments.

In the spring of 2023, the DOE launched its Energy Justice to the People Roadshow. The series of workshops and community listening sessions in the Rio Grande Valley and Cancer Alley brought key stakeholders and government officials together to learn about the DOE's available initiatives and funding to support disadvantaged frontline communities and advance US energy security in a just and equitable way.

In the spring of 2024, DOE launched its Regional Energy Democracy Initiative (REDI) pilot in the Gulf South of the United States, designed to provide capacity building and technical assistance for communities in the region to maximise the benefits derived from the significant clean energy investments made by DOE. REDI will fund consortia to support local communities in the implementation of CBPs, ensuring benefits from BIL and IRA investments are successfully delivered.

In the spring of 2024, DOE launched its Community Workforce Readiness Accelerator (RAMP) pilot, a place-based initiative to help connect local and disadvantaged workers to construction and operations jobs on large energy projects supported by the Invest in America agenda (BIL and IRA-funded projects).

The DOE's Clean Energy to Communities Program is the key plank of the DOE's Community Opportunities Program, which provides a platform for charities and voluntary organisations to promote their services.

The DOE provides grid resilience funding for states, utilities and industry players (State and Tribal Formula Grants, Grid Resilience Utility and Industry Grants).

Key recommendations

The US government should:

- Ensure that equity is firmly embedded in US energy policy, taking into account work streams on good jobs and skills training, revitalisation, affordability/distributional equity, community/citizen engagement and impact on communities when permitting infrastructure.
- Support the implementation of the Department of Energy's community benefits plans and its requirements through further engagement with labour unions, youth, tribal nations and disadvantaged communities. Link up with other funding programmes for greater impact, including philanthropies.
- Ramp up capacity in energy communities to ensure marginalised communities, including disadvantaged, energy and rural and tribal communities, can better access opportunities under the Justice40 Initiative, the Bipartisan Infrastructure Law, the Inflation Reduction Act and other programmes.

- Expand data tracking and modelling of community benefits, building on the United States Energy and Employment Report, to better quantify economic benefits, distributional impacts and workforce needs. Expand energy workforce data collection to include projections of net zero aligned employment needs at a more granular geographic level and gender diversity and future projections.
- Invest in targeted (re-)training, technical assistance and workforce development in collaboration with relevant stakeholders to foster economic prosperity and community improvements. Work with the private sector to ensure the creation of employment opportunities and advancement opportunities to attract, train and retain a skilled and stable workforce.

5. Managing energy security in the transition

Managing energy security in the transition requires a broad and structured approach, going beyond traditional fuel security, such as oil and gas security. Governments need to synchronise supply and demand-side investment in producer and importing countries using energy efficiency as the first fuel while promoting clean energy investment as they reduce fossil fuel consumption.

A focus on affordability and vulnerable communities is necessary alongside an orderly transition of the oil and gas sectors, with a focus on managing the retirement, reuse and repurposing of existing infrastructure and guiding the transition of producer economies. Chapter 4 reviewed and presented the United States' approach on people-centred transitions.

Last but not least, governments need to take the lead in managing cost-effective transitions, using competitive energy markets and flexible investment frameworks as the basis for achieving investment for meeting climate and energy goals.

In the context of clean transitions in general and on the pathway to net zero emissions in particular, governments need to address future fuels security, notably electricity security, flexibility and grid resilience; emerging energy security concerns, such as resilience against extreme weather events and cybersecurity; and support diversified critical minerals and supply chains needed for the clean energy technologies of the future.

This chapter provides a snapshot of the key emerging energy security issues for the US energy transition and recommendations for the design of the next policy reforms.

5.1 Critical Minerals security

Critical minerals essential for a range of clean energy technologies have risen up the policy and business agenda in recent years, to a great extent also in the United States. Rapid growth in demand is providing new opportunities for the industry, but a combination of volatile price movements, supply chain bottlenecks and geopolitical concerns has created a potent mix of risks for the security of clean energy transitions. This has triggered an array of new policy actions in different jurisdictions to enhance the diversity and reliability of critical mineral supplies.

Even though minerals still play a significant role in the US economy and are essential to economic prosperity and national security, the United States' market share in the global mineral market has been slowly declining since the end of the

Cold War. Indeed, domestic production essential for war purposes decreased to leave place to economic efficiency and has slowly been relocated to other countries. The relocation also generated losses in workforce and skills, creating tensions and risks across the supply chain that are hard to control.

To respond to the tension over recent years in the international critical minerals scene and the almost monopoly of some countries on some parts of the supply chains, the United States has taken action. The US government is stepping up on critical minerals' work to ensure security and diversity of critical mineral supply chains. A large number of US government bodies are currently dedicating part of their activity to critical minerals: data collection; analysis; policy guidance; international collaboration for production; consumption; recycling; secondary and unconventional supply; imports/exports; RD&D; innovation; workforce; manufacturing; environmental, social and governance; and security.

The Energy Act of 2020 aims at modernising US energy policies to encourage innovation across technologies essential to energy and national security and environment protection. It has a provision dedicated to critical minerals (Title VII) which:

- Defines critical minerals and materials for the Department of the Interior (DOI) and the DOE
- Directs the US Geological Survey (USGS) to produce an annual critical minerals outlook
- Requests the Department of Labor (DOL) and the DOI to assess the existing workforce that is essential for the domestic critical minerals supply chains
- Orders the implementation of several programmes, including R&D training programmes

In March 2021, Executive Order 14017: America's Supply Chains asked federal agencies to prepare supply chains deep-dive assessment reports. Following this command, the Department of Defense worked on the Review of Critical Minerals and Materials of the 100-Day Reviews under EO 14017. This review reflects the current status of critical materials necessary for defence purposes, but also provides risk assessments and recommendations. The DOE responded to Executive Order 14017 with America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition. The Strategy lays out a supply chain assessment and strategy for the energy sector industrial base.[16]

In November 2021, the US Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law, provided USD 7 billion to strengthen the US battery supply chain, which includes producing and recycling critical minerals

[16] Defined by the DOE as the energy sector and associated supply chains that include all industries, companies and stakeholders directly and indirectly involved in the energy sector.

without new extraction, mining and sourcing materials for domestic manufacturing. Out of the USD 7 billion, over USD 510 million were invested in the United States Geological Survey to map critical mineral potential, study the potential of critical minerals in mine waste and more generally gain a better understanding of critical minerals on domestic soil.

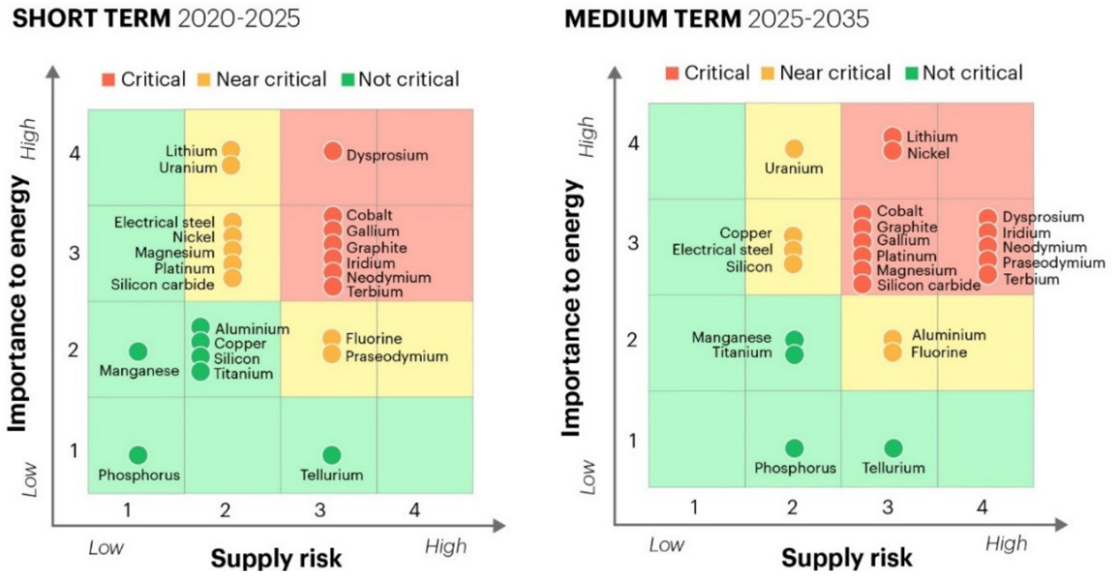
In February 2022, the Biden-Harris administration published the "Fundamental Principles for Domestic Mining Reform". The 11-point plan recognised the need to modernise the legal framework surrounding mining on federal public lands by addressing modern challenges and concerns, such as the need for responsible mining standards, prioritising recycling and the efficient use of critical minerals, and engaging with communities.

The CHIPS & Science Act, enacted in August 2022, aims at boosting the US semiconductor industry. The United States represents 10% of the world's production (and not the most modern generation of chips) while East Asia represents 75% of production. To respond to this dominance, the CHIPS and Science Act invested USD 52.7 billion for semiconductors R&D, manufacturing, and workforce development.

The IRA, enacted in August 2022, is key to accelerating the implementation of the United States' climate agenda, including the clean energy transition. To achieve its emissions reduction goal of 50-52% below 2005 levels by 2030, clean energy technology investment needs to grow to achieve emissions reductions across all sectors of the economy. The IRA altered the eligibility requirements for clean vehicles purchased after 16 August 2022, allowing for up to a USD 7 500 tax credit only under strict conditions related to critical minerals and battery components sourcing. With respect to electric vehicle supply chains, the IRA has encouraged a domestic EV supply chain to diversify the sourcing of battery components and cells by offering tax credits for companies that manufacture battery cells and modules in the United States. The IRA also incentivises domestic processing and recycling of critical minerals and materials.

In 2023, the Department of Energy published its Critical Materials Assessment. The Assessment defined minerals criticality based on national and global priorities, technology advancement, and technology adoption trends (see figure below). The analysis identified seven materials as critical in the short term. The importance and supply risk scores for certain materials shifts in the medium term as minerals essential for batteries, vehicle lightweighting, solar energy technologies, and global electrification become critical or near critical.

Figure 5.1 Short-term and medium-term minerals criticality matrix



Source: DOE (2023), What Are Critical Materials and Critical Minerals?

Domestic initiatives will certainly be essential, ranging from permitting improvements to strong social and environmental standards. These initiatives can help the United States contribute to limiting global critical mineral shortfalls and reducing exposure to supply chain risks. However, addressing the international dimensions of critical minerals, specifically trade with economic and regional allies, is essential for the United States.

An approach to critical mineral security needs to cast its net widely to also encompass niche minerals. While the focus has understandably been on battery metals and copper, recent events, such as the export curbs on Chinese gallium and germanium in July 2023 and graphite in October 2023, have highlighted the significance of a lesser-known group of critical minerals, often characterised by small volumes but high levels of supply concentration. These illustrate how relatively niche minerals such as magnesium, high-purity manganese, high-purity phosphorus, and silicon may disrupt supply chains due to high reliance on a small group of suppliers. A broad and bold federal strategy is needed that brings together investment, innovation, recycling, rigorous sustainability standards and well-designed safety nets.[17]

5.2 Nuclear fuel security

The United States possesses domestic uranium resources. However, it imports nearly 100% of its uranium supplies, which amounted to around

[17] In parallel to this Energy Policy Review of the United States, the IEA also conducted a separate Critical Minerals Review, with a detailed assessment of US policies in the field of critical minerals.

40.5 million pounds of U3O8e (equivalent) in 2022. Most of the uranium consumed in the United States came from Canada (27%), Kazakhstan (25%), Russia (12%) and Uzbekistan (11%). Almost 50% of the United States' uranium needs are sourced from Russia and its satellite countries, according to EIA data.

Russia's war on Ukraine sparked policy debate around nuclear fuel diversification and the need to increase domestic uranium supply. In 2022, US uranium mines produced 194 000 pounds of U3O8e (covering 0.5% of domestic needs). This was a significant rise from the 21 000 pounds produced in 2021, thanks to resumed operations at the White Mesa Mill in Utah. In December 2023, the Nuclear Fuel Security Act of 2023 was enacted as part of the National Defense Authorization Act of 2024, establishing a Nuclear Fuel Security Program to boost domestic production and ensure a consistent supply of domestically produced, converted and enriched uranium. One objective is to boost the domestic production of high-assay low-enriched uranium (HALEU), which requires enrichment levels up to 20%, compared to the 5% levels required for light water reactors.

The production of HALEU is critical, especially since Russia holds a global monopoly, which could directly influence the deployment of advanced nuclear technologies in the United States. More than 50% of the SMRs being developed in the United States are expected to be powered with HALEU, and the same applies to many other designs under development globally, according to the Nuclear Energy Agency. The United States can produce HALEU by recovering and downblending existing high-enriched uranium stockpiles, but this approach has its limitations. This is how Oklo secured its fuel for the Aurora concept. On the other hand, Terrapower has stated that its project will face at least a two-year delay due to the HALEU shortage.

The IRA has allocated USD 700 million to promote research, transportation and production of HALEU within the United States. USD 500 million of this amount are specifically allocated for the government procurement of HALEU and deconversion services. Nonetheless, further efforts might be necessary to establish commercial-scale, domestic production capabilities for HALEU. The DOE has a programme with Centrus to produce 0.9 million tonnes of HALEU per year for up to around 8 million tonnes of uranium (MTU) if all option years are exercised but projected demand by 2030 is around 40 MTU. While producing HALEU does not face technical challenges, significant investment is needed to add enrichment capability and comply with safeguards and security regulations, particularly beyond 10% of enrichment. This will require a clear and strong demand signal to stimulate investments necessary to scale up production.

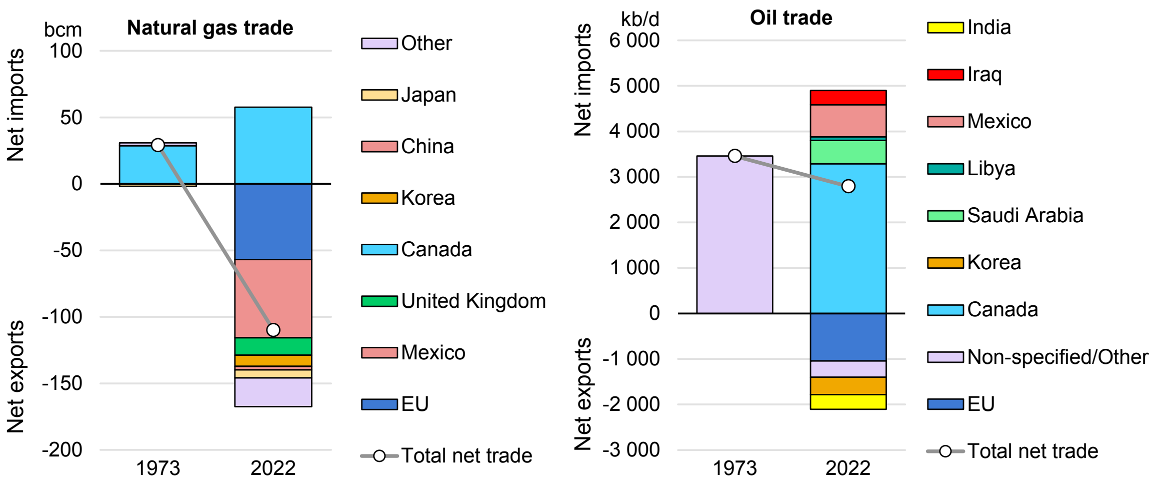
5.3 Oil security

The enormous increase in US crude oil production that has occurred since the early 2010s has significantly bolstered oil security both domestically and internationally. IEA analysis expects oil demand in transport to decrease in the United States, as new fuel economy and GHG emissions vehicle standards are being implemented and the US EV market is expanding.

US crude oil production has increased dramatically as a consequence of growth in non-conventional shale oil production. As a result, the United States has become a major crude oil exporter, even though it remains a net importer of crude (while a large quantity of domestic crude production is exported, heavier grades are typically imported for processing in US refineries). As shale oil production has grown, the surplus of liquefied petroleum gas and natural gas liquids has also increased, boosting the United States' net export position in oil products. Besides crude oil, the United States is a significant net exporter of oil products. It is a net exporter of diesel but remains a net importer of gasoline, largely as a result of import requirements in the north-east.

The United States is less dependent today on imports from OPEC (Organization of the Petroleum Exporting Countries) countries than it was almost 50 years ago. In 1977, OPEC countries were the main source of crude oil imports (85%); in 2021, this share had dropped to 13%, according to the DOE.

Figure 5.2 Natural gas and crude oil trade, United States, 1973 and 2022

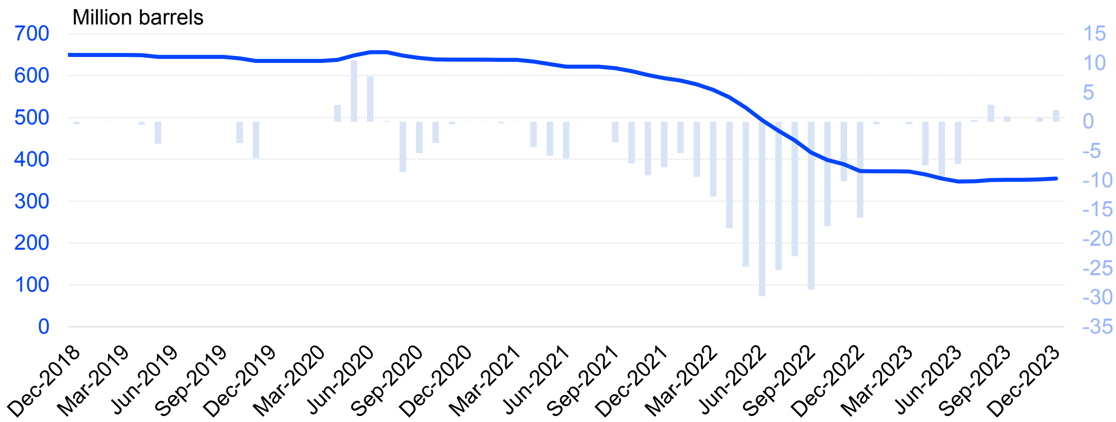


Sources: IEA (2023), Natural Gas Information (database); IEA (2023), Oil Information (database).

Nevertheless, as a major oil consumer, the United States remains vulnerable to global and domestic supply tightness in oil markets. The east coast market is particularly vulnerable to tightness in distillate markets due to its high level of heating oil consumption and its reliance on foreign imports and pipeline supply from the Gulf Coast. This reliance has grown as a result of the closure of a large amount of refining capacity in the north-east in the past 15 years. This is a particular concern given the dependence of some disadvantaged communities on oil products for home heating. Ultimately, however, it is recognised that vulnerability to distillate market tightness in east coast markets will fall with increased electrification of heating, as well as efforts to blend biofuels in heating oil.

The US Strategic Petroleum Reserve (SPR) remains of fundamental importance to global and domestic oil security and is a key pillar of the IEA's oil stockholding system. The decisive action taken by the United States in March and April 2022 to release large volumes of oil from its SPR, as part of two IEA Collective Actions, undoubtedly played a significant role in alleviating supply tightness at a time of considerable market uncertainty following Russia's invasion of Ukraine. However, as a result of these releases, in addition to independent sales directed by the President and other congressionally mandated sales, the volume of oil held in the SPR has declined markedly in the past two years, falling to a 34-year low of 351 mb in September 2023, compared to 619 mb in September 2021. As of early 2024, SPR reserves had risen to 361 mb following replenishment efforts.

Figure 5.3 US Strategic Petroleum Reserve weekly ending stocks, 1983-2023



Source: IEA analysis based on EIA (2023), Petroleum and Other Liquids.

While Congress took the prudent decision to cancel 140 mb of previously announced sales from the SPR, almost 100 mb is still scheduled to be released between 2026 and 2031 as a result of further congressionally mandated sales. These cancellations have resulted in significant progress toward replenishment. In addition, the DOE has purchased or solicited the purchase of around 30 mb. In the absence of major replenishment, significant depletion of SPR, beyond what is planned, could potentially undermine market confidence in the United States' ability to effectively respond to worst-case scenario oil supply disruptions.

To head off such concerns, the United States has initiated a three-part SPR replenishment strategy: 1) direct purchases with revenues from emergency sales; 2) "exchange returns", or the return of loaned out barrels that include a premium of oil above the volume lent out; and 3) working with Congress to avoid unnecessary sales unrelated to supply disruptions.

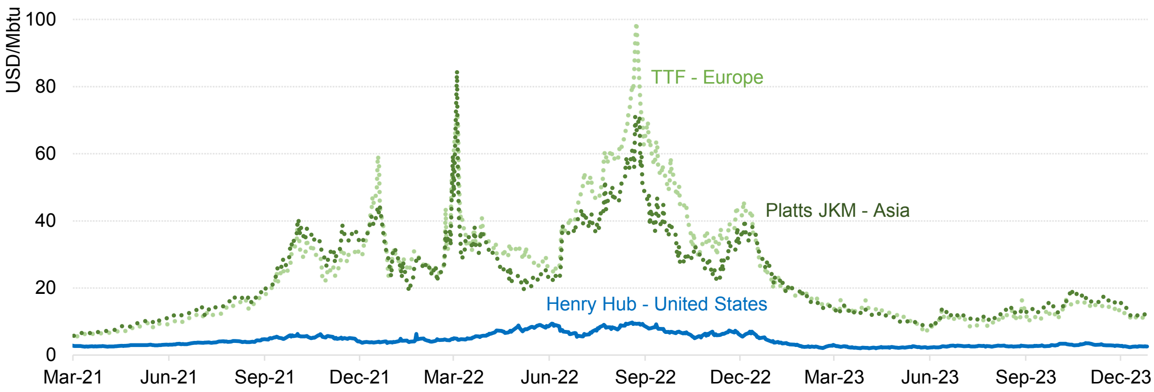
5.4 Natural gas security

Just as with crude oil, a sustained increase in natural gas production in the United States in the past decade has significantly enhanced the security of gas supply, both domestically and globally.

In 2022, the United States became the largest exporter of LNG (by export capacity), overtaking Qatar and Australia, and the main supplier of LNG to the European Union, as the continent seeks to end reliance on Russian energy sources. In 2022, the European Union was the prime market for US LNG, with France, Spain, the Netherlands and the United Kingdom accounting for a combined 74% of total US LNG exports to Europe.

US wholesale gas prices at Henry Hub have largely remained stable over the past years, while other regions, notably the European Union and Asia, experienced major price spikes following Russia's invasion of Ukraine.

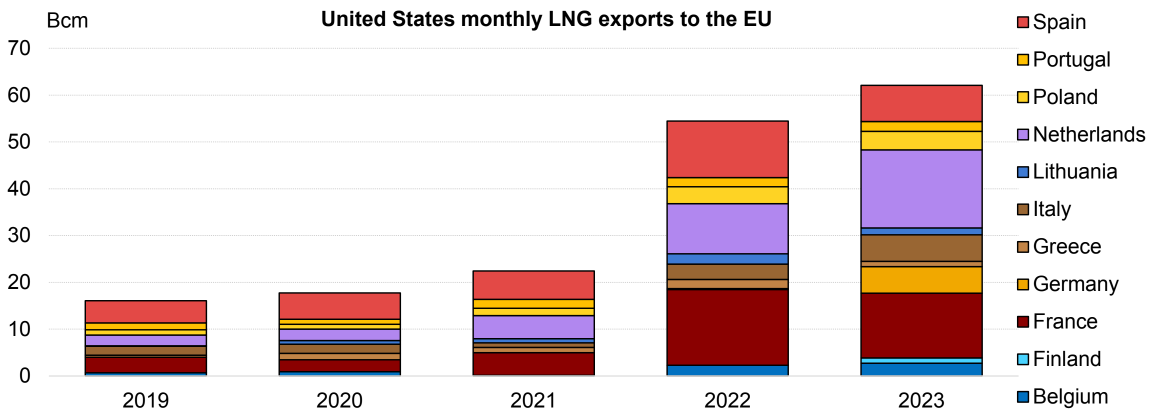
Figure 5.4 Wholesale natural gas prices in the United States compared to other regional price markets



Source: IEA (2023), Gas Market Report, Q2-2023.

US LNG has played a substantial role in filling supply gaps that emerged in many markets following Russia's invasion of Ukraine and is playing a key role in enhancing global gas security as LNG exports from the United States continue to grow.

Figure 5.5 LNG exports from the United States to the European Union, 2019-2023



Source: IEA (2024), Monthly Gas Statistics (database).

US natural gas production is serving global energy security in a carbon-constrained world. The IEA's *World Energy Outlook 2023* confirms that natural gas demand in advanced economies is expected to decline in the STEPS scenario by 2030, notably in heating. However, by 2030, the decline is expected to be less than demand growth in emerging market and developing economies, where natural gas demand is shifting to industrial uses.

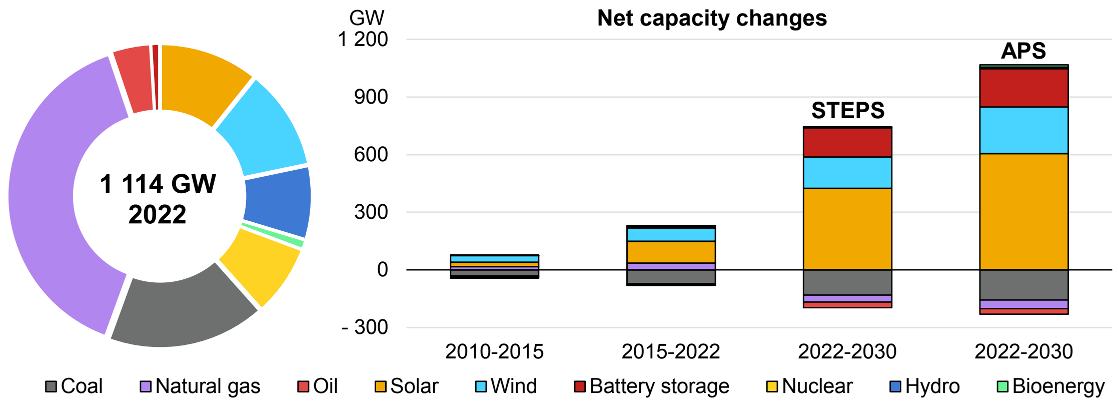
Domestic natural gas consumption has been on an upward trend in the United States in recent years, largely driven by increased usage in power generation as new gas generators have partially compensated for retiring coal generators. In 2022, domestic natural gas consumption in the United States hit an historic record, reaching approximately 900 bcm/y for the first time, as natural gas increased in power generation, amid coal retirements. Concerns have been raised around the security of natural gas supply to some regions in the domestic market. Notably, attention should be given to closely monitoring whether natural gas transmission and storage capacity remains sufficient. For instance, the future security of gas supply to the north-east, which relies on LNG imports from abroad for some of its supply, is a particular concern.

The key role of natural gas in power generation keeps natural gas demand strong, notably during summer months to meet record air conditioning needs. Natural gas consumption now has two peak periods to cover winter heating and summer air conditioning demand. Natural gas is expected to support system integration of renewable energy in the United States. Gas demand is expected to see stronger peaks, particularly during periods when production from variable renewables falls, and when electricity demand is high. It is crucial to ensure that natural gas infrastructure remains adequate to meet peak demand periods throughout the transition to cleaner energy, even as total natural gas demand declines.

5.5 Electricity security

The federal government's aspirational goal to achieve 100% carbon-free electricity by 2035 also entails new emerging risks to electricity supply that are a direct result of rapidly evolving energy markets. The retirement of some fossil fuel generation resources will be necessary if this goal is to be achieved.

Figure 5.6 Electricity installed capacity in the United States, 2022 and outlook to 2030



Sources: IEA (2024) World Energy Balances (database); IEA (2023) World Energy Outlook 2023.

Uncertainty exits around the pace of entry for new generation resources for a variety of reasons, including permitting issues, as described in Chapter 1. Over the past decade, the US power system has experienced a fast pace of retirements in coal while adding new natural gas plants and renewables. The pace of retirements announced of around 60 GW, 40% retired by 2030, may outpace the deployment of renewables. Only 5% of variable renewables in the connection queue has been put into commercial operation over the past decade. If impediments to ramping up clean energy generation are not removed, and existing dispatchable generation capacity is rapidly retired, this could increase the potential for supply disruptions and emergency events, and deteriorate power system reliability.

While resource adequacy is ultimately the responsibility of individual states, the federal government is encouraged to continue to work alongside states to facilitate the removal of any impediments to ramping up clean energy supply, and to ensure that there is sufficient and timely supply to meet growing demand throughout the transition to cleaner generation.

The federal government can play a substantial role in supporting market designs for resource efficiency that are co-ordinated across the ISO/RTOs. For instance, ISO/RTOs and FERC have recently moved towards phasing out the minimum offer price rules in electricity capacity markets and this will support greater resource efficiency, reliability, and the alignment of states' policies and federal market rules. Due to minimum offer price rules, some states had considered dropping out of RTO capacity markets.

New lessons come from across regional markets on how to remunerate the value of each type of technology to meet electricity security targets. Important in this regard is FERC Order No. 841 on the participation of storage in energy, capacity and ancillary services markets. Prompted in part by FERC's approval of this rule, the effective load carrying capability is an approach used by PJM and other ISO/RTOs, which offers a more detailed calculation of the contribution, but values fluctuate based on time and location. PJM also uses shortage (scarcity) pricing to provide incentives for firm and flexible technologies.

FERC's recent steps in convening a variety of stakeholders to discuss how to improve interregional planning are positive, as is the consideration that is being given to mandating a minimum amount of power transfer capability between regions. The IEA highly encourages the United States to continue its efforts to pursue co-ordinated, interregional planning to ensure that electricity can be transferred to where it is most needed when supply is tight to mitigate the consequences of unplanned power outages.

A lack of interregional transmission capacity also played a major role in exacerbating recent electricity supply emergencies, notably the 2021 winter Storm Uri. A relatively small amount of interregional transfer capability may have prevented the blackouts that occurred as a result of Storm Uri. Power transmission from one region to another is often limited in the United States due to a lack of interregional transmission capacity, stemming in part from a long-standing lack of sufficient co-ordinated, interregional infrastructure planning.

Box 5.1 Coal power retirements in the United States

As of 2022, coal power represented 20% of the total electricity generation and is besides nuclear and hydropower a key pillar of dispatchable generation in the United States.

The peak of the United States' coal capacity and generation was reached in 2011, with approximately 318 GW producing 43% of the country's total electricity. By 2021, the operational coal capacity had declined to 228 GW, contributing to 22% of the national electricity generation. Within a decade, the United States has thus retired about 90 GW, averaging close to 10 GW annually. In 2022 alone, an additional 13.5 GW was taken offline. Long-term forecasts indicate additional closures of approximately 60 GW by 2035, averaging 6-5 GW annually, according to the Energy Information Administration (EIA)The typical operating coal unit in the

United States is, on average, around 45 years old. While there is no mandated retirement age for coal plants in the United States, most closures predominantly affect older units. Nevertheless, not all units slated for retirement are the oldest. For instance, the 600 MW Sandow Unit 5 was retired after less than a decade in service. On average, plants that have been or are set to be retired in the United States are around 50 years old, according to the EIA.

In fact, beyond age considerations, retirements of coal plants in the United States are primarily driven by a combination of dwindling competitiveness compared to natural gas and variable renewables, strengthened environmental regulations and enhanced climate policies. Data from the EIA reveal that, since 2008, the availability or capacity factor for coal plants in the United States has declined from 75% to 54% in 2017. Additionally, the EPA introduced new regulations in 2015 related to mercury and hazardous air pollutants[18] that triggered a wave of retirements, culminating in a record 15 GW of closures in that same year. The new greenhouse gas standards and guidelines for fossil fuel-fired power plants, proposed by the EPA in May 2023, could have the same impact on existing coal assets as previous regulations. This may accelerate coal plant retirements, raising possible risks to capacity adequacy and grid reliability if no efforts are pursued to ensure investment in low-carbon dispatchable capacity at the same pace.

The US power system has to withstand a rising number of extreme weather events, including floods, cold spells, storms, hurricanes and heatwaves. Besides, the power sector is experiencing a fast shift in resources and evolving cyber and physical threats on the system. The strong dependence of the US power sector on natural gas supply (an average of 40%) and related infrastructure (production, transmission, storage) requires a much stronger approach to intersectoral resilience and links between gas and electricity security plans, as natural gas plays an outsized role in the US electricity generation.

The devastation that can be caused by extreme weather events, and consequential power outages, was evidenced by two historic winter storms in 2021 and 2022 (Storm Uri and Storm Elliott), both of which caused outages leaving millions of customers without power for extended periods during low temperatures. The impacts of Storm Uri and Storm Elliott could have been mitigated, at least to some degree, by improved weatherisation of energy infrastructure.

[18] In 2015, the EPA issued National Emission Standards for Hazardous Air Pollutants for Coal- and Oil-Fired Electric Utility Steam Generating Units (EGUs), also known as the Mercury and Air Toxics Standards or MATS. EPA set technology-based emissions standards for mercury and other hazardous air pollutants (HAP) emitted by units with a capacity of more than 25 MWs.

Recent actions taken by NERC and FERC are welcomed. In February 2023 and 2024, FERC approved cold-weather reliability standards. In June 2023, FERC directed NERC to develop a reliability standard to ensure transmission system performance during extreme heat and cold. The federal government and relevant federal agencies are encouraged to compel owners of all critical energy infrastructure to implement weatherisation measures, including power line owners. While there has been an understandable recent focus on cold weather preparedness, extreme heat and wildfires have also contributed to emergency situations in recent years; reliability standards should, therefore, focus on all forms of extreme weather.

A recent illustration are the Texas 2021 blackouts during winter Storm Uri, which caused the worst energy infrastructure failure in Texas' state history and led to shortages of water, food and heat. ERCOT ordered 20 000 MW of rolling blackouts to prevent grid collapse, the largest manually controlled load shedding event in US history. More than 4.5 million people in Texas lost power – some for as long as 4 days, causing over 200 deaths in Texas.

Recent evaluations of the event showed that the blackouts were the result of failures across all types of power generation technologies, caused by inadequate weatherisation of power generators and the freezing and failure of critical natural gas infrastructure. A net exporter for 4-6 bcm/d, the Texas gas system came under severe stress during the storm and was no longer able to deliver natural gas by pipeline to many of its customers.

The Joint FERC/NERC report of December 2021 evaluated the effects of winter Storm Uri on the electric system and made 28 recommendations. The combination of freezing and fuel issues caused the majority of the unplanned generating unit outages, derates and failures to start. FERC and NERC recommended enhanced winterisation standards for generator operators and called on federal and state policy makers to require natural gas system cold weather preparedness. In 2023, FERC also directed NERC to develop new reliability standards in three areas: 1) cybersecurity; 2) extreme weather; 3) inverter-based resources.

In November 2023, a FERC/NERC report reviewed the response actions during winter Storm Elliott and called for greater co-ordination between gas and electricity sector stakeholders and congressional and state legislation or regulation to establish reliability rules for natural gas infrastructure (during cold weather).

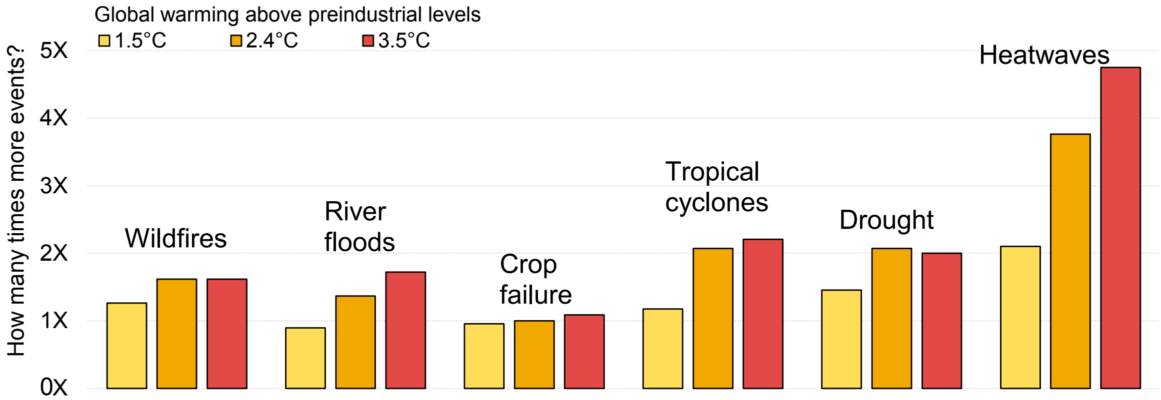
5.6 Climate resilience and security

The National Oceanic and Atmospheric Administration's National Centres for Environmental Information (NCEI) analysis of extreme weather and climate events in the United States illustrates the economic and societal impacts of such events.

Based on quarterly data from the NCEI (1980-2021), the United States has sustained 323 separate weather and climate disasters, with overall estimated damages/costs above USD 1 billion per disaster and total direct costs over more than USD 2 trillion (consumer price index or inflation adjusted to 2022). The three main impacted states are Texas, Louisiana and Florida. Impacts are concentrated in the south, central and south-east regions, but also occur in California, New Jersey, New York and other states.

Mandated by the Congress, the Fifth National Climate Assessment was presented in November 2023, a major update from the 2018 assessment. The report analyses the rising impacts of climate change on various sectors, including on the energy sector. The report highlighted the need for increased resilience of the energy infrastructure to climate change impacts, notably grids, to be taken into account in energy planning.

Figure 5.7. Climate change risks in the United States



Source: IEA based on data from U.S. Global Change Research Program (2023), Fifth National Climate Assessment.

For the first time, the assessment also recognised the critical and positive role of energy sector mitigation actions for climate resilience and security, including renewable energy deployment, technology innovation, energy efficiency and demand-side management in reducing energy demand and addressing climate change.

Building on Executive Order 14008 and the EPA's first Climate Change Adaptation Plan in 2014 and its update in 2021, today each agency is mandated to develop its own climate resilience and adaptation plan. By end of 2023, 23 federal agencies had released climate adaptation and resilience plans to outline steps to ensure their facilities and operations adapt to climate change impacts. The DOE also has a Climate Adaptation and Resilience Plan, presented in 2021, which sets out a set of principles and strategic objectives without specific targets. Building on the first plans, the federal government needs to promote the institutionalisation of climate adaptation and resilience plans and create a collaborative framework across sectors and states to ensure continuous implementation over time. Overall principles and guidance in this context were established at the federal level in September 2023 through the National Climate Resilience Framework to guide the cross-agency collaboration.

Energy sector resilience against climate disasters is a prerequisite for the implementation of adaptation measures in other sectors (e.g. education, health, housing and urban development, and transportation, among others).

The DOE has also developed tools and frameworks for assessing and raising awareness of climate vulnerability in the energy sector and has been implementing disaster response and recovery plans under the Federal Emergency Management Agency and related activities of the Office of Cybersecurity, Energy Security and Emergency Response. The IEA considers the DOE’s resilience toolkit a best practice. The DOE has also been actively working on public-private partnerships for climate resilience, encouraging the private sector to consider climate impacts. One notable progress since the previous review is the launch of the 2021 Climate Adaptation and Resilience Plan and its following progress report. This established a monitoring cycle, which is essential for continuous improvement of the Climate Adaptation and Resilience Plan.

Intersectoral collaboration is particularly essential to protect vulnerable groups (e.g. indigenous communities, gender minorities, elderly, children), who are the first to be deprived of basic services by climate disasters. Good co-operation was obtained for the agriculture sector with the creation of the Drought Resilience Interagency Working Group. A framework to create synergies among the relevant agencies could be helpful, including through an interagency climate resilience working group.

The implications of changing climate and extreme weather are increasingly being integrated into long-term energy planning in the United States as part of a broader effort to mitigate and adapt to the effects of climate change. Long-term energy plans increasingly focus on building more resilient infrastructure that can withstand extreme events, such as burying power lines, strengthening substations and using more durable materials. Long-term energy plans are also incorporating energy storage technologies, such as batteries and pumped hydro, to help ensure a reliable and resilient energy supply during extreme weather events. Some long-term energy plans now include climate risk assessments, which evaluate the potential impacts of climate change and extreme weather on energy infrastructure and operations.

In 2022, the Government Accountability Office recommended an improved DOE response to power outages caused by natural disasters. US government agencies have acted since to address this recommendation.

After the February 2021 winter freeze, FERC and NERC and NERC's regional entities issued a 300-page analysis on the impact of the freeze and subsequent recommendations, including a revision of the reliability standards, mandatory inspections, winterisation efforts and maintenance.

NERC's 2023 Summer Reliability Assessment warned of the possibility of energy shortages during extreme operating conditions caused by elements such as heat, wildfires and other grid disturbances. It is important to highlight, however, that under normal conditions, all regions in North America possess adequate generation capacity to satisfy summer demand and reserve requirements. Additionally, NERC highlighted factors such as the decommissioning of generation facilities in the face of the increasing integration of variable energy resources, heightened demand across various locations, project delays or generator maintenance as aspects which could potentially intensify reliability risks. This demonstrates the importance of climate resilience in maintaining reliable energy supply amid changing environmental conditions.

Winter Storm Elliott resulted in a call to strengthen the resilience standards not only for electricity but also for gas infrastructure.

Key recommendations

The US government should:

- Develop a federal strategy for critical minerals with national security of supply objectives based on projections of supply and demand. Strengthen the co-ordination of critical minerals policies across all levels of government, including on environmental, social and governance standards; and permitting and data, while increasing community and international engagement.
- Foster nuclear fuel security by developing domestic high-assay low-enriched uranium production, expanding international co-ordination on securing nuclear fuel value chains and facilitating US investment in nuclear projects globally.
- Advance the development of a deep geological repository while intensifying efforts to accelerate the consent-based siting process of a federal consolidated interim storage facility for spent nuclear fuel. Enhance international collaboration to learn from best practices in other countries.
- Introduce more rigorous reliability standards for electricity and new reliability standards for natural gas infrastructure and systems and enhance the resilience of critical electricity infrastructure to disruptive events, including extreme weather.
- Continue efforts to accelerate interregional network planning and strongly consider mandating minimum power transfer requirements to avoid or mitigate the impacts of unplanned power outages.

- Ensure that Strategic Petroleum Reserve stocks are always held at a level that enables the United States to contribute its share to a "worst-case scenario" IEA Collective Action.
- Implement the federal climate resilience framework and design programmes of action on climate resilience and adaptation, taking a whole-of-government approach.
- Prioritise investment in weatherisation, winterisation and cooling and expand support for disadvantaged communities for investment in adaptation to increase local communities' resilience to climate change impacts.
- Deepen the co-operation of the Federal Emergency Management Agency with other federal agencies on the annual monitoring and evaluation of climate resilience and adaptation, including through the Office of Cybersecurity, Energy Security and Emergency Response and the State Energy Security Plans.
- Strengthen the institutionalisation of planning, monitoring and reporting cycles for federal climate resilience and adaptation plans. Promote further collaboration and interaction among agencies and across sectors by creating a framework for implementation consistent with the Disaster Resilience Planning Act.

Annexes

Acknowledgements

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Acronyms and abbreviations

APS	Announced Pledges Scenario
ARPA-E	Advanced Research Projects Agency-Energy
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIL	Bipartisan Infrastructure Law
CBP	community benefits plan
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CEM	Clean Energy Ministerial
CHIPS	CHIPS and Science
CO_2	carbon dioxide
DER	distributed energy resource
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EU	European Union
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
FMC	First Movers Coalition
FOAK	first-of-a-kind
FPA	Federal Power Act
FPP	fusion pilot plant
GDP	gross domestic product
GHG	greenhouse gas
HALEU	High-Assay Low-Enriched Uranium
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IRA	Inflation Reduction Act
ISO	independent system operator
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LPO	Loan Programs Office
LTS	Long-Term Strategy
MESC	manufacturing and energy supply chains
NCEI	National Centres for Environmental Information
NEPA	National Environmental Policy Act
NERC	North American Electric Reliability Corporation
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
OPEC	Organization of the Petroleum Exporting Countries
OTT	Office of Technology Transitions
PHEV	plug-in hybrid electric vehicle
PPA	power purchase agreement
PV	photovoltaic
R&D	research and development

RD&D	research, development and demonstration
RDD&D	research, development, demonstration and deployment
RFS	Renewable Fuels Standard
RTO	regional transmission organisation
SAF	sustainable aviation fuel
SMR	small modular reactor
SNF	spent nuclear fuel
SPR	Strategic Petroleum Reserve
STEPS	Stated Energy Policy Scenario
TCF	Technology Commercialization Fund
TCP	Technology Collaboration Programme
TES	total energy supply
TFC	total final consumption
US	United States
USD	United States dollar (currency)
USEER	United States Energy and Employment Report
VPP	virtual power plant

Units of measurement

bcf/d	billion cubic feet per day
bcm	billion cubic metres
EJ	exajoule
GW	gigawatt
kb/d	thousand barrels per day
kg	kilogramme
kWe	kilowatt electrical
kWh	kilowatt hour
mb/d	million barrels per day
Mboe/d	million barrels of oil equivalent per day
MMT	megatonne
Mt CO_2	million tonnes carbon dioxide
Mt CO_2-eq	million tonnes carbon dioxide equivalent
MTU	million tonnes of uranium
MW	megawatt
TWh	terawatt hour

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Energy Policy Review

Government action plays a pivotal role in ensuring secure and sustainable energy transitions and combatting the climate crisis. Energy policy is critical not just for the energy sector but also for meeting environmental, economic and social goals. Governments need to respond to their country's specific needs, adapt to regional contexts and help address global challenges. In this context, the International Energy Agency (IEA) conducts Energy Policy Reviews to support governments in developing more impactful energy and climate policies.

This *Energy Policy Review* was prepared in partnership between the Government of the United States and the IEA. It draws on the IEA's extensive knowledge and the inputs of expert peers from IEA member countries to assess the United States' most pressing energy sector challenges and provide recommendations on how to address them, backed by international best practices. The report also highlights areas where United States' leadership can serve as an example in promoting secure clean energy transitions. It also promotes the exchange of best practices among countries to foster learning, build consensus and strengthen political will for a sustainable and affordable clean energy future.