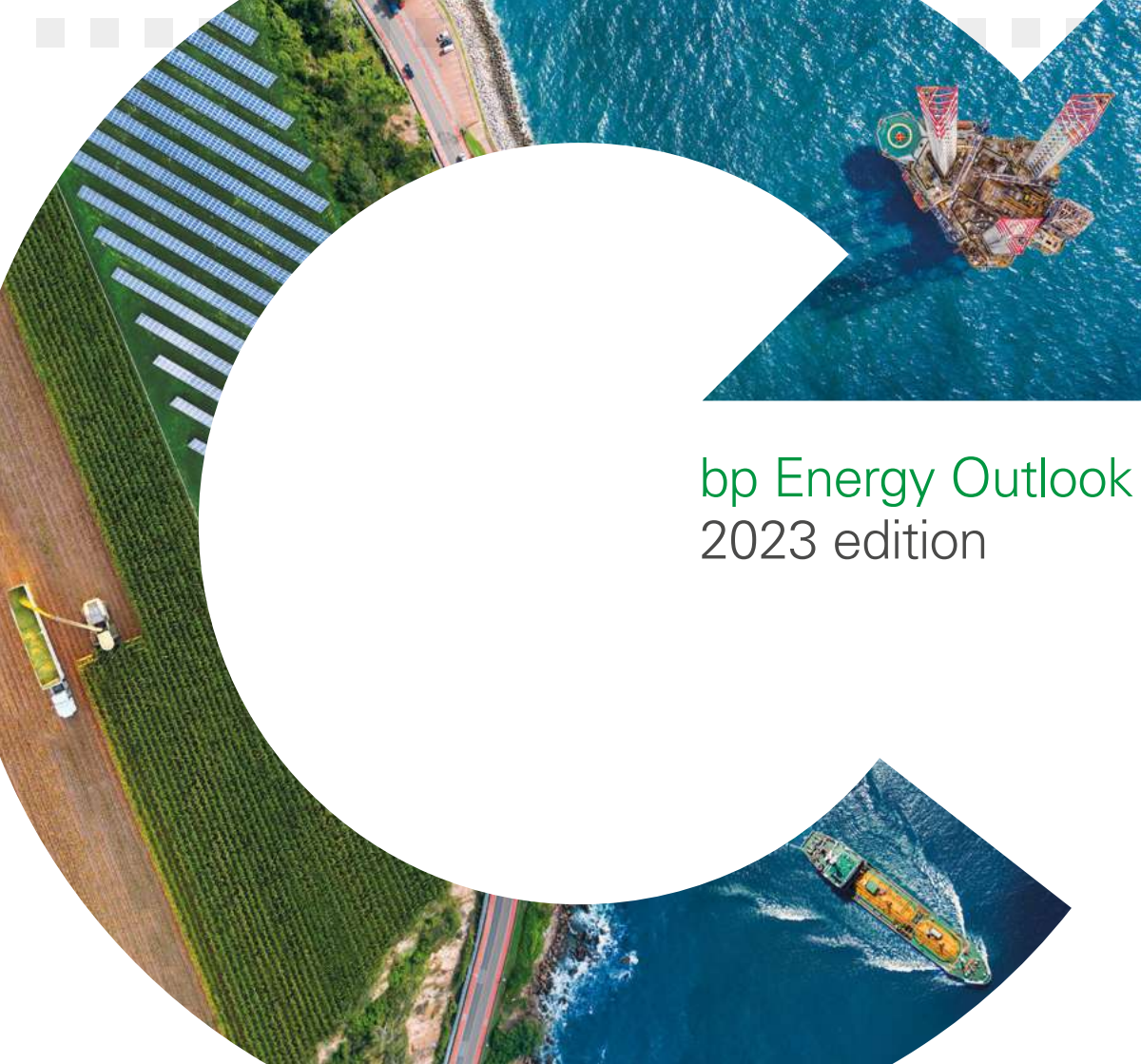




bp Energy Outlook 2023 edition



Energy Outlook 2023 explores the key trends and uncertainties surrounding the energy transition.

Energy Outlook 2023 is focused on three main scenarios: *Accelerated*, *Net Zero* and *New Momentum*. These scenarios are not predictions of what is likely to happen or what bp would like to happen. Rather they explore the possible implications of different judgements and assumptions concerning the nature of the energy transition and the uncertainties around those judgements. The scenarios are based on existing technologies and do not consider the possible impact of entirely new or unknown technologies.

The many uncertainties surrounding the transition of the global energy system mean that the probability of any one of these scenarios materializing exactly as described is negligible. Moreover, the three scenarios do not provide a comprehensive range of possible paths for the transition ahead. They do, however, span a wide range of possible outcomes and so help to illustrate the key uncertainties surrounding energy markets out to 2050.



The scenarios in this year's *Outlook* have been updated to take account of two major developments over the past year: the Russia-Ukraine war and the passing of the Inflation Reduction Act in the US. Aside from updating for those two developments, the scenarios are based largely on the analysis and scenarios in *Energy Outlook 2022*. They do not include a comprehensive assessment of all the changes and developments since *Outlook 2022*.

The *Energy Outlook* is produced to inform bp's strategy and is published as a contribution to the wider debate about the factors shaping the energy transition. But the *Outlook* is only one source among many when considering the future of global energy markets and bp considers a wide range of other external scenarios, analysis and information when forming its long-term strategy.



Welcome to the 2023 edition of bp's *Energy Outlook*.

The past year has been dominated by the terrible consequences of the Russia-Ukraine war and its awful toll on lives and communities. Our thoughts and hopes are with all those affected.

From an energy perspective, the disruptions to Russian energy supplies and the resulting global energy shortages seem likely to have a material and lasting impact on the energy system.

Global energy policies and discussions in recent years have been focused on the importance of decarbonizing the energy system and the transition to net zero. The events of the past year have served as a reminder to us all that this transition also needs to take account of the security and affordability of energy. Together these three dimensions of the energy system – security, affordability, and sustainability – make up the energy trilemma. Any successful and enduring energy transition needs to address all three elements of the trilemma.

Last year's *Energy Outlook* did not include any analysis of the possible implications of the war in Ukraine. The scenarios in *Outlook 2023* have been updated to take account of the war, as well as of the passing of the Inflation Reduction Act in the US.

At the time of writing, the war is continuing with no end in sight. As such, any analysis of its possible implications must be treated as preliminary. However, the experience from the major energy supply shocks of the 1970s suggests that events that heightened energy security concerns can have significant and persistent impacts on energy markets.

Most importantly, the desire of countries to bolster their energy security by reducing their dependency on imported energy – dominated by fossil fuels – and instead have access to more domestically produced energy – much of which is likely to come from renewables and other non-fossil energy sources – suggests that the war is likely to accelerate the pace of the energy transition.

The scale of the economic and social disruptions over the past year associated with the loss of just a fraction of the world's fossil fuels has also highlighted the need for the transition away from hydrocarbons to be orderly, such that the demand for hydrocarbons falls in line with available supplies, avoiding future periods of energy shortages and higher prices.

These issues, together with the broader implications of the energy transition, are explored in this year's *Energy Outlook* using three main scenarios: *Accelerated*, *Net Zero* and *New Momentum*. Together these scenarios span a wide range of the possible outcomes for the global energy system over the next 30 years. Understanding this range of uncertainty helps bp to shape a strategy which is resilient to the different speeds and ways in which the energy system may transition.

The continuing rise in carbon emissions and the increasing frequency of extreme weather events in recent years highlight more clearly than ever the importance of a decisive shift towards a net-zero future. The events of the past year have highlighted the complexity and

interconnectedness of the global energy system and the need to address all three dimensions of the energy trilemma. I hope this year's *Energy Outlook* is useful to everyone trying to navigate this uncertain future and accelerate the transition to global net zero.

As always, any feedback on the *Outlook* and how it can be improved would be most welcome.

Spencer Dale
Chief economist

Core Beliefs

This year's *Outlook* can be used to identify aspects of the energy transition that are common across the main scenarios. These trends help shape core beliefs about how the energy system may evolve over the next 30 years.

- ▶ The carbon budget is running out. Despite the marked increase in government ambitions, CO₂ emissions have increased every year since the Paris COP in 2015 (bar 2020). The longer the delay in taking decisive action to reduce emissions on a sustained basis, the greater are the likely resulting economic and social costs.
- ▶ Government support for the energy transition has increased in a number of countries, including the passing of the Inflation Reduction Act in the US. But the scale of

the decarbonization challenge suggests greater support is required globally, including policies to facilitate quicker permitting and approval of low-carbon energy and infrastructure.

- ▶ The disruption to global energy supplies and associated energy shortages caused by the Russia-Ukraine war increases the importance attached to addressing all three elements of the energy trilemma: security, affordability, and sustainability.
- ▶ The war has long-lasting effects on the global energy system. The heightened focus on energy security increases demand for domestically produced renewables and other non-fossil fuels, helping to accelerate the energy transition.

- ▶ The structure of energy demand changes, with the importance of fossil fuels declining, replaced by a growing share of renewable energy and by increasing electrification. The transition to a low-carbon world requires a range of other energy sources and technologies, including low-carbon hydrogen, modern bioenergy, and carbon capture, use and storage.
- ▶ Oil demand declines over the outlook, driven by falling use in road transport as the efficiency of the vehicle fleet improves and the electrification of road vehicles accelerates. Even so, oil continues to play a major role in the global energy system for the next 15-20 years.

▶ The prospects for natural gas depend on the speed of the energy transition, with increasing demand in emerging economies as they grow and industrialize offset by the transition to lower carbon energy sources, led by the developed world.

- ▶ The recent energy shortages and price spikes highlight the importance of the transition away from hydrocarbons being orderly, such that the demand for hydrocarbons falls in line with available supplies. Natural declines in existing production sources mean there needs to be continuing upstream investment in oil and natural gas over the next 30 years.

▶ The global power system decarbonizes, led by the increasing dominance of wind and solar power. Wind and solar account for all or most of the growth in power generation, aided by continuing cost competitiveness and an increasing ability to integrate high proportions of these variable power sources into power systems. The growth in wind and solar requires a significant acceleration in the financing and building of new capacity.

- ▶ The use of modern bioenergy – modern solid biomass, biofuels and biomethane – grows rapidly, helping to decarbonize hard-to-abate sectors and processes.
- ▶ Low-carbon hydrogen plays a critical role in decarbonizing the energy system, especially in hard-to-abate processes and activities in industry and transport. Low-carbon

hydrogen is dominated by green and blue hydrogen, with green hydrogen growing in importance over time. Hydrogen trade is a mix of regional pipelines transporting pure hydrogen and global seaborne trade in hydrogen derivatives.

- ▶ Carbon capture, use and storage plays a central role in enabling rapid decarbonization trajectories: capturing industrial process emissions, acting as a source of carbon dioxide removal, and abating emissions from the use of fossil fuels.
- ▶ A range of methods for carbon dioxide removal – including bioenergy combined with carbon capture and storage, natural climate solutions, and direct air carbon capture with storage – will be needed for the world to achieve a deep and rapid decarbonization.

Overview



Three scenarios to explore the uncertainties surrounding the speed and shape of the energy transition to 2050

Accelerated and *Net Zero* are broadly in line with 'Paris consistent' IPCC scenarios

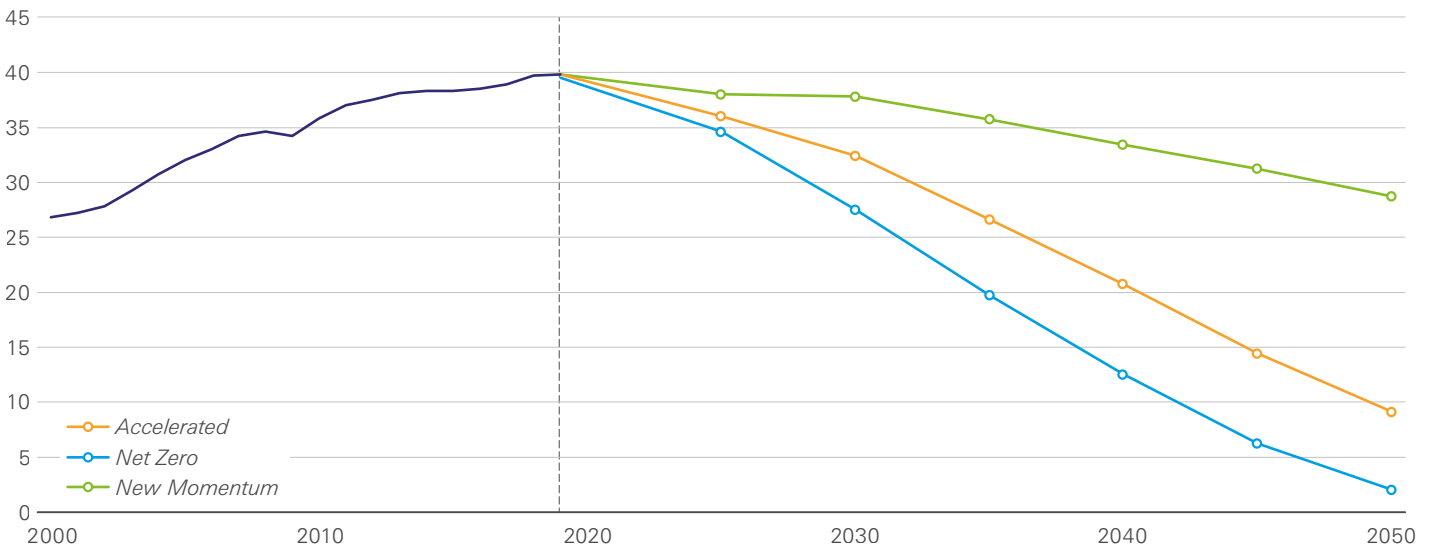
Final energy demand peaks in all three scenarios as gains in energy efficiency accelerate

The future of global energy is dominated by four trends: declining role for hydrocarbons, rapid expansion in renewables, increasing electrification, and growing use of low-carbon hydrogen

Three scenarios to explore the uncertainties surrounding the speed and shape of the energy transition to 2050

Carbon emissions

Gt of CO₂e



Carbon emissions include CO₂ emissions from energy use, industrial processes, natural gas flaring, and methane emissions from energy production.

Key points

bp's *Energy Outlook 2023* uses three scenarios (*Accelerated*, *Net Zero* and *New Momentum*) to consider a range of possible pathways for the global energy system to 2050 and to help shape a resilient strategy for bp.

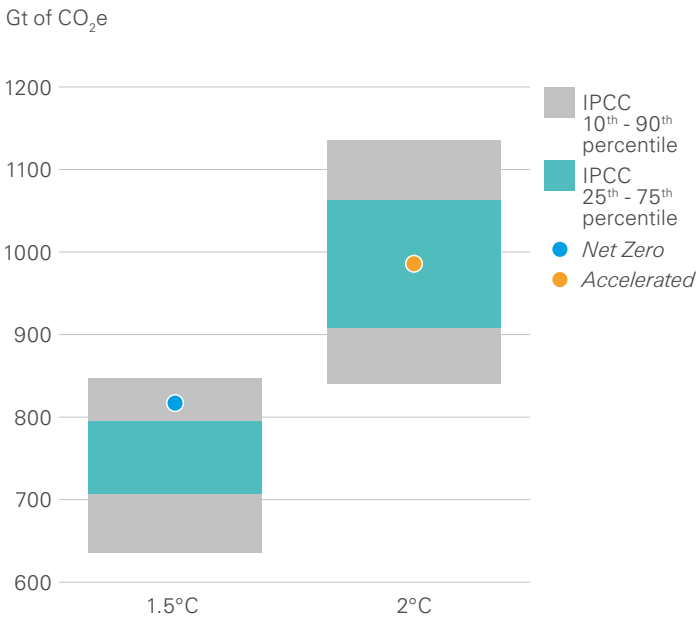
- ▶ The scenarios are not predictions of what is likely to happen or what bp would like to happen. Rather, the scenarios are designed to span a wide range of the outcomes possible out to 2050. In doing so, they inform bp's core beliefs about the energy transition and help shape a strategy that is resilient to the many uncertainties surrounding the speed and nature of the energy transition.
- ▶ The scenarios in this year's *Outlook* have been updated to take account of two major developments over the past year: the Russia-Ukraine war and the passing of the Inflation Reduction Act in the US. Aside from updating for those two developments, the scenarios are largely based on the analysis and scenarios in *Energy Outlook 2022*.

- ▶ The scenarios consider carbon emissions from energy production and use, most non-energy related industrial processes, and natural gas flaring plus methane emissions from the production, transmission, and distribution of fossil fuels (see pages 96-97 of the Annex for more details).
- ▶ *Accelerated* and *Net Zero* explore how different elements of the energy system might change in order to achieve a substantial reduction in carbon emissions. In that sense, they can be viewed as 'what if' scenarios: what elements of the energy system might need to change if the world collectively takes action for CO₂-equivalent emissions (CO₂e) to fall by around 75% by 2050 (relative to 2019 levels) in *Accelerated* and 95% in *Net Zero*. Both scenarios are conditioned on the assumption that there is a significant tightening in climate policies. *Net Zero* also embodies a shift in societal behaviour and preferences, which further supports gains in energy efficiency and the adoption of low-carbon energy.

- ▶ The carbon emissions remaining in *Net Zero* in 2050 could be eliminated by either additional changes to the energy system or by the deployment of carbon dioxide removal (CDR) (see pages 78-79). This will depend on the costs of CDR and of abating greenhouse gases emanating from outside the energy system, neither of which are explicitly considered in the *Outlook*.
- ▶ *New Momentum* is designed to capture the broad trajectory along which the global energy system is currently travelling. It places weight on the marked increase in global ambition for decarbonization in recent years, as well as on the manner and speed of decarbonization seen over the recent past. CO₂e emissions in *New Momentum* peak in the 2020s and by 2050 are around 30% below 2019 levels.

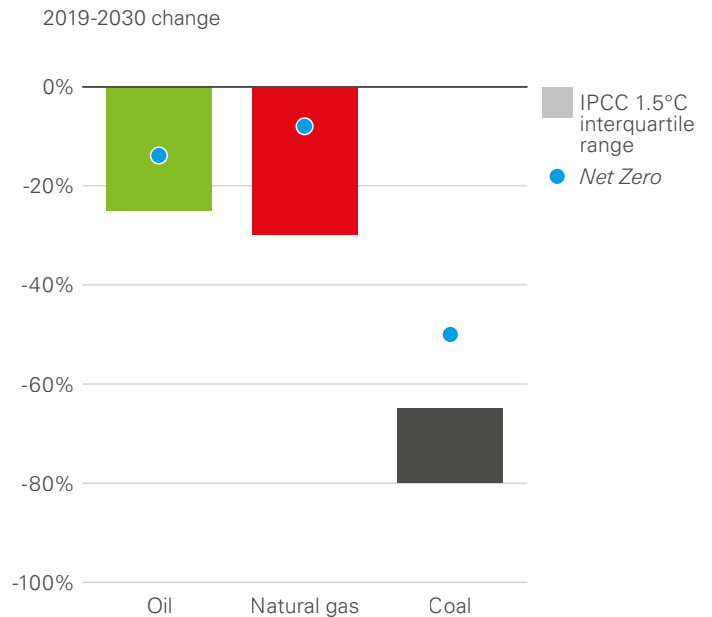
Accelerated and Net Zero are broadly in line with 'Paris consistent' IPCC scenarios

Cumulative CO₂e emissions from energy (2015 - 2050)



Cumulative CO₂e emissions in 2015-2050 are the addition of CO₂ emissions from energy and industrial processes, flaring, and methane emissions

Change in fossil fuels in IPCC 1.5°C scenarios



1.5°C scenarios with no or limited overshoot and 2°C scenarios with immediate action. See Annex for selection of IPCC scenarios

Key points

The pace and extent of decarbonization in *Accelerated* and *Net Zero* are broadly aligned with a range of IPCC scenarios which are consistent with maintaining global average temperature rises well below 2°C and 1.5°C above pre-industrial levels in 2100 respectively (see annex pages 96-97 for more details of IPCC scenarios used).

- ▶ The *Energy Outlook* scenarios extend only to 2050 and do not model all forms of greenhouse gasses or all sectors of the economy. As such, it is not possible to map directly between the scenarios and their implications for the carbon budget and the implied increase in average global temperatures by 2100.
- ▶ However, it is possible to provide an indirect inference by comparing the cumulative carbon emissions in *Accelerated* and *Net Zero* for the energy sector over the period 2015 to 2050 with the ranges of corresponding carbon trajectories taken from the scenarios included in the IPCC Sixth Assessment

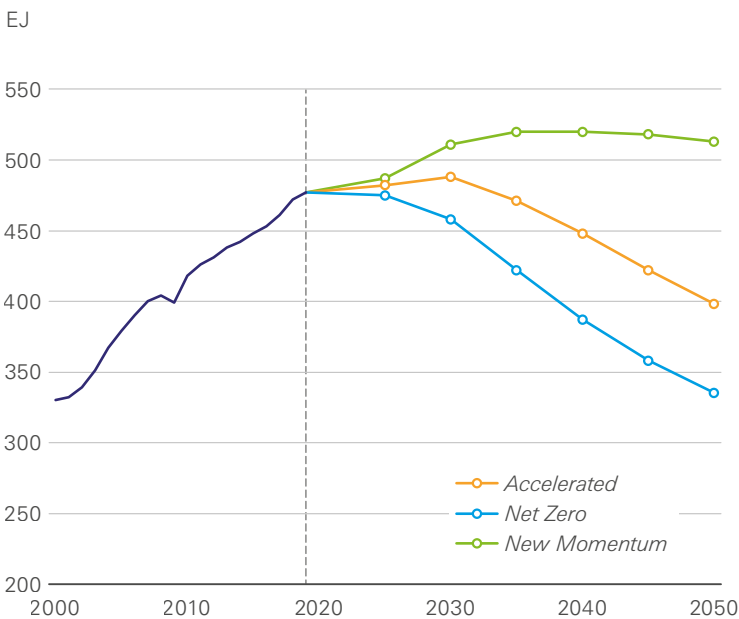
Report – Climate Change 2022: Impacts, Adaptation and Vulnerability.

- ▶ Cumulative CO₂e emissions in *Accelerated* are broadly in the middle of the interquartile range of well below 2°C IPCC scenarios. The trajectory for carbon emissions in *Accelerated* lies within the IPCC range over the entire outlook.
- ▶ For *Net Zero*, cumulative CO₂e emissions are within the 10th to 90th percentiles of IPCC scenarios consistent with 1.5°C (with no or limited overshoot), but are a little above the interquartile range. Carbon emissions in *Net Zero* decline more slowly than the range of IPCC 1.5°C scenarios out to 2030, before falling more quickly than the median scenario further out.
- ▶ In the median IPCC scenario consistent with 1.5°C (with no or limited overshoot), net CO₂ emissions decline by 48% by 2030 (relative to 2019 levels). Within this, CO₂ emissions from 'fossil fuels and industrial processes' fall by 40%. This compares with a fall of 30% in *Net Zero*.

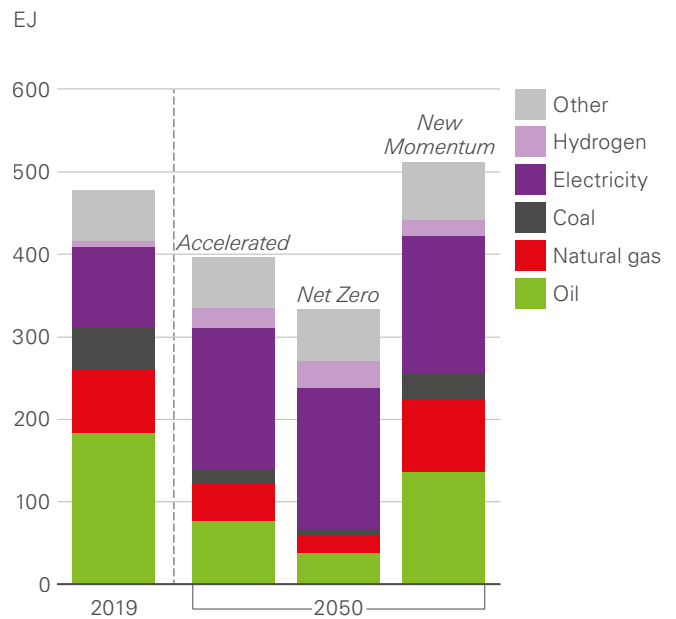
- ▶ The fall in fossil fuels and industrial emissions in the median IPCC scenario is driven largely by a 75% fall in global coal consumption by 2030, with more modest falls of around 10% in oil and natural gas consumption. The falls in oil and natural gas by 2030 in *Net Zero* are consistent with the range of IPCC 1.5°C scenarios, but the fall in coal consumption is significantly smaller. That reflects the continuing importance of coal as an affordable and relatively abundant fuel in many emerging economies where energy demand is expanding rapidly.
- ▶ The time it takes for parts of the energy sector to transition away from fossil fuels highlights the likely importance of carbon dioxide removal (CDR) in helping to reduce net carbon emissions during the transition period while these reforms are undertaken, as well as offsetting any remaining gross emissions in a net zero energy system (see pages 78-79).

Final energy demand peaks in all three scenarios as gains in energy efficiency accelerate

Total final consumption



Total final consumption by fuel



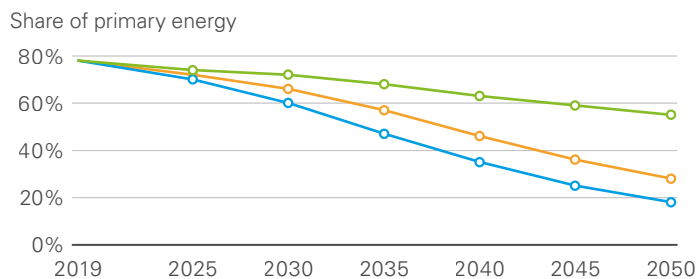
Key points

Global energy demand measured at the final point of use (total final consumption) peaks in all three scenarios as gains in energy efficiency accelerate, more than offsetting the upwards impact of increasing living standards across much of the emerging world.

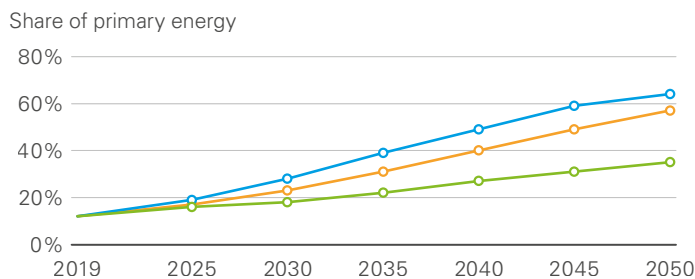
- ▶ Total final consumption (TFC) peaks in the mid-to-late 2020s in *Accelerated* and *Net Zero*, with final energy consumption 15-30% below 2019 levels by 2050. In contrast, TFC increases until around 2040 in *New Momentum*, after which it broadly plateaus with energy consumption in 2050 around 10% above 2019 levels.
- ▶ The main factor driving these differences in final energy consumption is the pace of improvement in energy efficiency. The gains in global energy efficiency over the outlook – measured by comparing growth in final energy demand with economic activity – are much quicker than over the past 20 years in all three scenarios, particularly in *Accelerated* and *Net Zero*. That reflects a number of factors including: the increasing use of electricity at the final point of use, more efficient use of materials through increased recycling and reuse, and a greater focus on energy conservation, given greater impetus by the heightened focus on energy security (see pages 22-23).
- ▶ The assumed increase in the pace of energy efficiency improvements in *Accelerated* and *Net Zero* is a central element in facilitating a rapid reduction in carbon emissions, without which there would need to be even faster growth in low-carbon energy to achieve the same outcome.
- ▶ Final energy demand in emerging markets continues to grow over the coming decade and beyond in *New Momentum* and *Accelerated*, driven by increasing prosperity and improving living standards. In contrast, demand in developed economies peaks in the next few years in all three scenarios.
- ▶ Total final consumption decarbonizes as the direct use of fossil fuels declines, the world electrifies and the power sector is increasingly decarbonized.
- ▶ Within TFC, fossil fuels used at the final point of energy use decline from a share of around 65% in 2019 to 20-50% by 2050 across the three scenarios. Within hydrocarbons, the share of coal falls particularly sharply as the world increasingly shifts to the use of electricity and low-carbon hydrogen in industry, as does the share of oil, driven primarily by the falling use of oil in road transport (see pages 42-43).
- ▶ The role of electricity increases substantially and broadly uniformly across all three scenarios, with electricity consumption increasing by around 75% by 2050.

The future of global energy is dominated by four trends: declining role for hydrocarbons, rapid expansion in renewables, increasing electrification, and growing use of low-carbon hydrogen

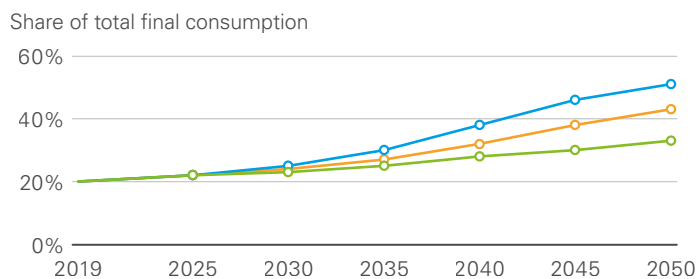
Fossil fuels



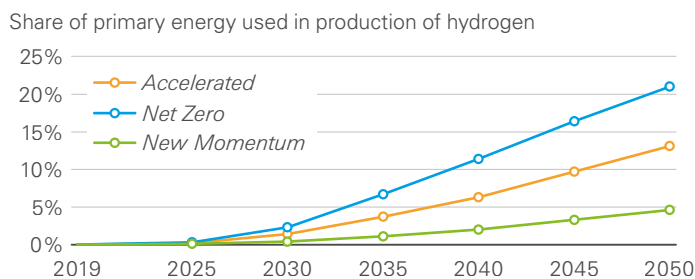
Renewables



Electricity



Low-carbon hydrogen



Key points

The changing composition of energy demand over the outlook is characterized by four trends: a gradual decline in the role of hydrocarbons, rapid growth in renewable energy, and an increasing electrification of the world, supported by low-carbon hydrogen in processes and activities which are hard to electrify.

- ▶ The role of hydrocarbons diminishes as the world transitions to lower carbon energy sources. The share of fossil fuels in primary energy declines from around 80% in 2019 to between 55-20% by 2050.
- ▶ The total consumption of fossil fuels declines in all three scenarios over the outlook. This would be the first time in modern history that there has been a sustained fall in the demand for any fossil fuel.
- ▶ Renewable energy is largely made up of wind and solar power and bioenergy, and also includes geothermal power. Renewables expand rapidly over the outlook, offsetting the declining role of fossil fuels. The share of renewables in global primary energy increases from around 10% in 2019 to between 35-65% by 2050, driven by the improved cost competitiveness of renewables, together with the increasing prevalence of policies encouraging a shift to low-carbon energy.
- ▶ In all three scenarios, the pace at which renewable energy penetrates the global energy system is quicker than any previous fuel in history.
- ▶ The growing importance of renewable energy is underpinned by the continuing electrification of the energy system. The share of electricity in total final energy consumption increases from around a fifth in 2019 to between a third and a half by 2050.
- ▶ The decarbonization of the energy system, especially in *Accelerated* and *Net Zero*, is supported by the growing use of low-carbon hydrogen in hard-to-abate processes which are difficult or costly to electrify. The share of primary energy used in the production of low-carbon hydrogen increases to between 13-21% by 2050 in *Accelerated* and *Net Zero*.

Changes since *Energy Outlook 2022*



The Russia-Ukraine war is likely to have long-lasting effects on the global energy system

The Russia-Ukraine war leads to a downward revision in the outlook for global GDP and energy demand

Increased energy security concerns trigger a shift towards a more local, lower-carbon energy mix

Energy security concerns reduce the role of oil and natural gas imports

The Russia-Ukraine war and the Inflation Reduction Act lower the outlook for carbon emissions

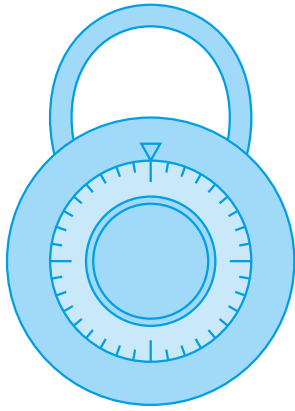
Russian production of oil and natural gas revised down as a result of the war

EU's need for LNG imports in 2030 depends on its success in reducing natural gas demand

The Inflation Reduction Act provides significant support for low-carbon energy and technologies in the US

The Russia-Ukraine war is likely to have long-lasting effects on the global energy system

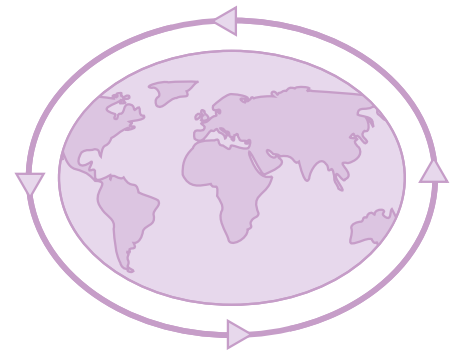
Heightened energy security



Weaker economic growth



Changing mix of global energy supplies



Key points

The Russia-Ukraine war is likely to have a persistent effect on the future path of the global energy system, increasing the focus on energy security, weakening economic growth, and changing the mix of energy supplies.

- ▶ The past year has been dominated by the terrible consequences of the Russia-Ukraine war and its awful toll on lives and communities. Our thoughts and hopes are with all those affected.
- ▶ From an energy perspective, this year's *Outlook* has modelled the impact of the Russia-Ukraine war as operating through three main channels: energy security, economic growth, and composition of global energy supplies. At the time of writing, the war is continuing with no end in sight; as such this analysis should be treated as preliminary and subject to change depending on future developments.

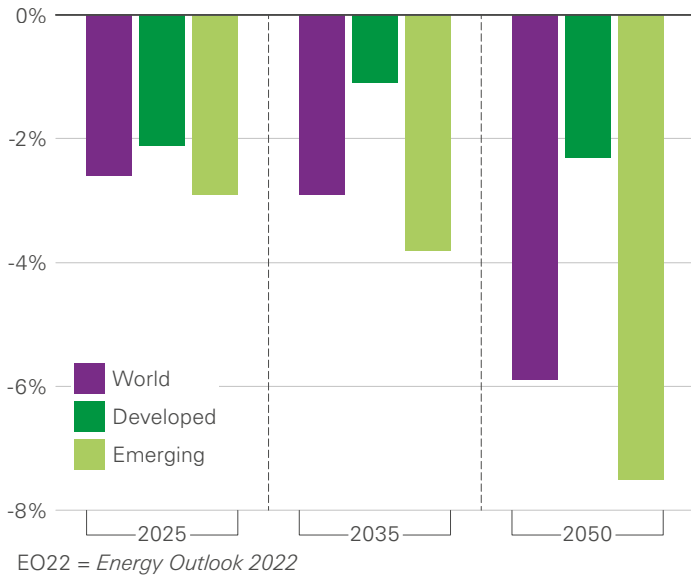
- ▶ *Energy security*: the increased focus on energy security triggered by concerns about energy shortages and vulnerability to geopolitical events is assumed to cause countries and regions to strive to reduce their dependency on imported energy and instead consume more domestically produced energy. It also gives greater incentive to improve energy efficiency, reducing the need for all types of energy.
- ▶ *Economic growth*: the higher food and energy prices associated with the Russia-Ukraine war have contributed to a sharp slowing in global economic growth. The direct economic impact of this commodity price shock is set to persist for the next few years. Further out, the war is assumed to reduce somewhat the pace of global integration and trade, as countries and regions heighten their focus on domestic resilience and reduce their exposures to international shocks. This slower pace of globalization leads to a small reduction in average economic growth over the next 30 years.

- ▶ *Composition of global energy supplies*: the future of Russian energy supplies is uncertain. The scenarios in this year's *Outlook* assume a persistent reduction in Russian exports of hydrocarbons. In the near term, this reflects the impact of voluntary and mandatory sanctions on Russian energy exports. Further out, it stems from the assumption that sanctions affecting Russia's access to foreign investment and technologies ease only gradually.
- ▶ More details on the assumptions used to model the impact of the Russia-Ukraine war can be found in the Annex (pages 90-91).

The Russia-Ukraine war leads to a downward revision in the outlook for global GDP and energy demand

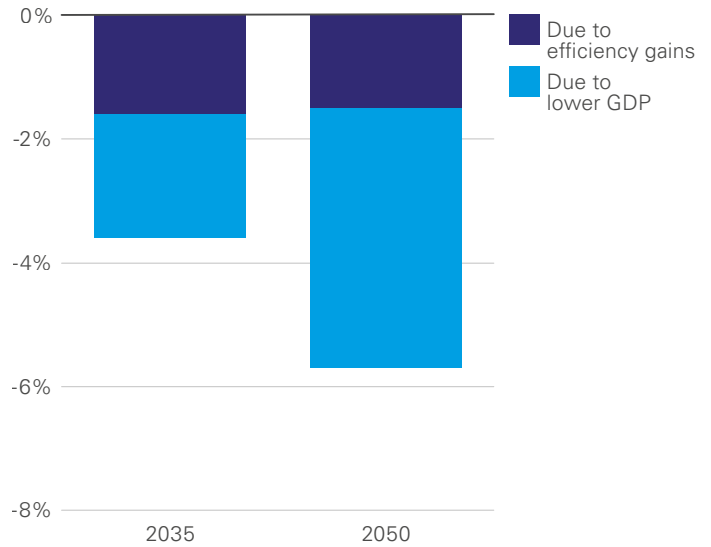
Impact of Russia-Ukraine war on global GDP

Change relative to EO22



Change in total final consumption in *Accelerated*

Change relative to EO22



Key points

The prospects for global GDP and energy demand are weaker than in last year's *Outlook*, reflecting the short- and longer-term impacts of the Russia-Ukraine war.

- ▶ The level of global GDP underlying all three scenarios in this *Outlook* is around 3% lower in 2025 and 2035 than *Energy Outlook 2022* and around 6% lower in 2050.
- ▶ The weaker profile for economic activity over the near term is mostly driven by the commodity price shock associated with the Russia-Ukraine war. The direct impact of the commodity price shock largely fades by 2030, although the war is assumed to have a more persistent scarring effect on the Russian and Ukrainian economies.

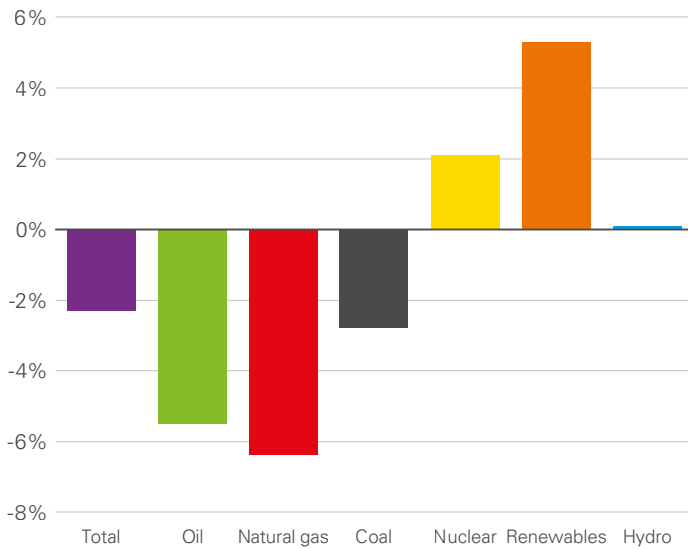
- ▶ Beyond 2030, the lower level of GDP reflects the growing impact of the slower average (or trend) economic growth associated with the lower assumed paths of international trade and interconnectedness. Global GDP growth averages around 2.4% p.a. (on a Purchasing Power Parity basis) over the outlook, compared with 2.6% in *Energy Outlook 2022*.
- ▶ The impact of this reduction in trend economic growth is greatest in those regions that benefit the most from international trade and productivity transfers. In 2050, GDP in China is 7% lower than in last year's *Outlook* and is 12% lower in Africa, but is only 1% lower in the US.

- ▶ As in recent *Energy Outlooks*, the assumed trajectory for global GDP includes an estimate of the impact of climate change on economic growth. This includes the impact of both increasing temperatures on economic activity and the upfront costs of actions to reduce carbon emissions. More details of the approach and its limitations can be found in the Annex (see pages 92-93).
- ▶ The level of total final energy consumption is also weaker than in the previous *Outlook*, down by around 3.5% in 2035 across all the scenarios and by between 5.5%-6% in 2050.
- ▶ In 2035, slightly over half of the downward revision in energy consumption in *Accelerated* reflects the weaker profile for GDP. The remainder is driven by greater gains in energy efficiency reflecting both the heightened focus on energy security and the impact of higher energy prices. By 2050, the lower level of GDP accounts for around three-quarters of the revision to energy consumption.

Increased energy security concerns trigger a shift towards a more local, lower-carbon energy mix

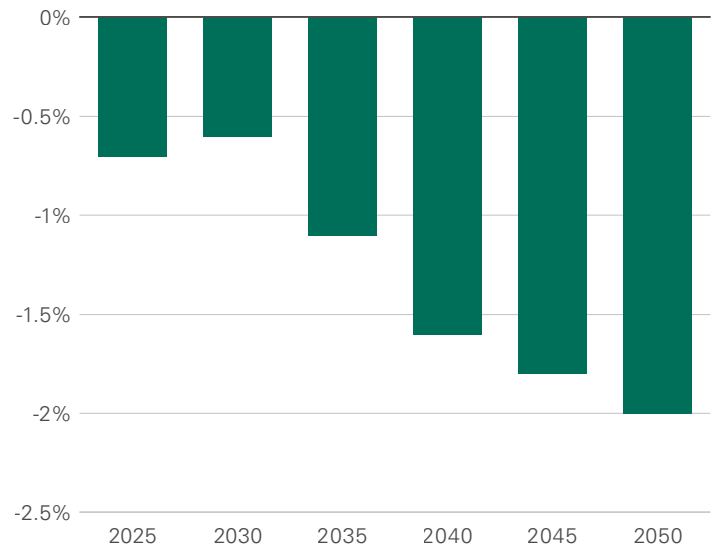
Change in primary energy in *New Momentum*

Change in 2035 relative to EO22



Change in carbon intensity in *New Momentum*

Change relative to EO22



Key points

The increased importance placed on energy security as a result of the Russia-Ukraine war leads over time to a shift away from imported fossil fuels towards locally produced non-fossil fuels, accelerating the energy transition.

▶ Since oil and natural gas are the two most heavily traded fuels internationally, they are most impacted by the increased focus on energy security (see pages 22-23). In *New Momentum*, the 2% lower level of primary energy demand in 2035 relative to *Energy Outlook 2022* is largely accounted for by a 5% downward revision to oil demand and 6% lower natural gas demand. These effects are most concentrated in emerging Asia and the EU, both of which currently have significant reliance on oil and natural gas imports.

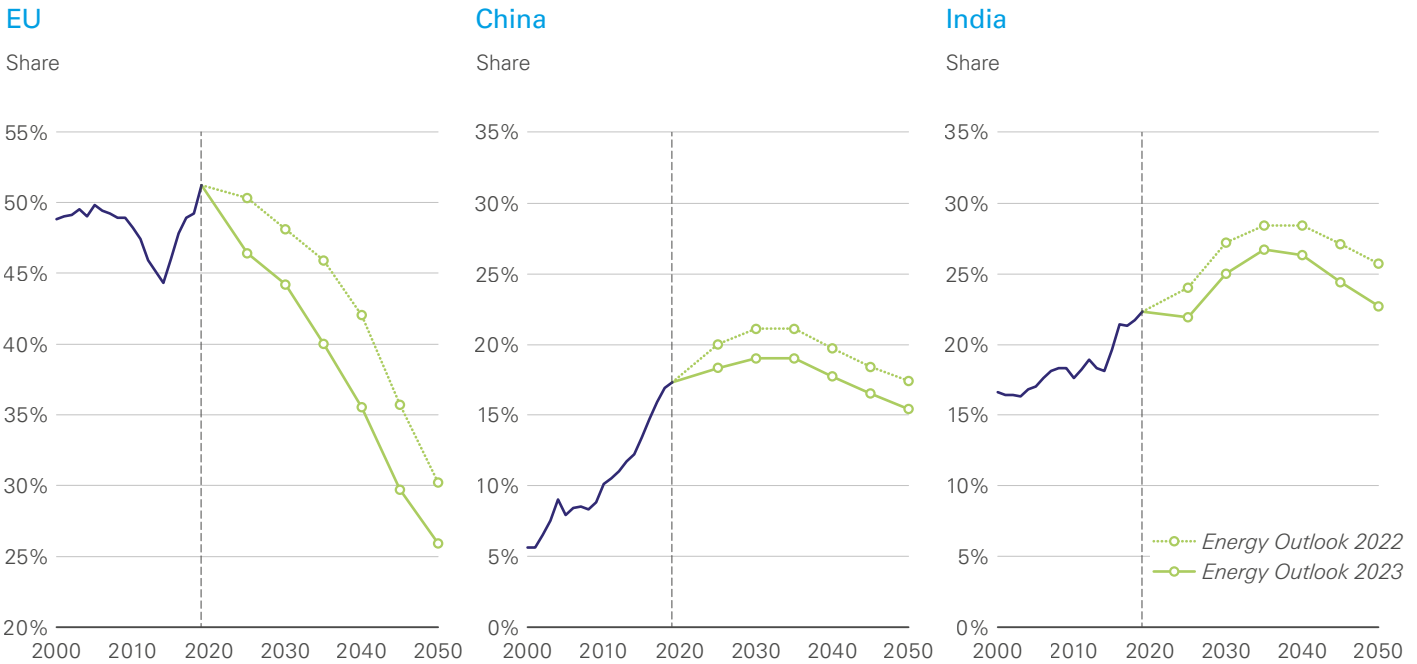
▶ Coal consumption is also lower than in last year's *Energy Outlook*, but the downward revision is smaller than for oil and natural gas. This reflects the continuing heavy use of domestic coal resources in many parts of Asia.

▶ In contrast to the downward pressure on oil and natural gas imports, and despite the lower level of overall energy demand, the consumption of energy that is produced locally is boosted as a result of the heightened energy security concerns. This particularly increases the use of non-fossil fuels as they tend to be produced and consumed locally. The use of renewables and nuclear energy in *New Momentum* in 2035 are higher than in last year's *Outlook*, while hydropower is largely unchanged.

▶ This shift towards locally produced non-fossil fuels at the expense of imported hydrocarbons helps to accelerate the energy transition (see pages 28-29). The carbon-intensity of the fuel mix in *New Momentum* by 2035 in this year's *Outlook* is around one percentage point lower than in *Outlook 2022*, and around two percentage points lower by 2050.

Energy security concerns reduce the role of oil and natural gas imports

Oil & gas imports as a share of primary energy in *New Momentum*



Key points

The increased preference for locally produced energy stemming from heightened energy security concerns reduces imports of oil and natural gas.

- ▶ The impact of increased energy security concerns on energy trade is most pronounced on oil and natural gas, which are the two most heavily traded fuels. This impact is especially marked in China and India, who currently import between 75%-85% of the oil they use and between 40-55% of their natural gas.

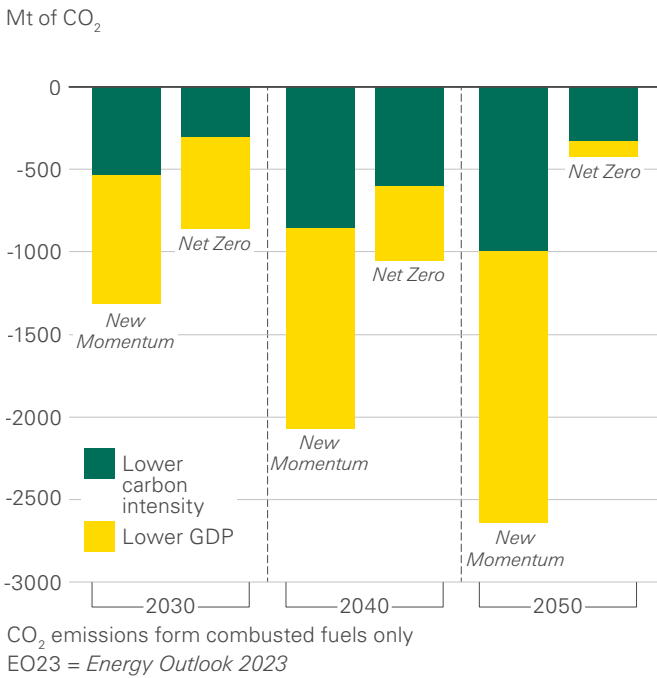
- ▶ The effect of heightened energy security concerns is also particularly evident in the EU given its previous dependence on natural gas imports from Russia, and its heavy dependence on oil and gas imports more generally. Together, the EU, China and India accounted for around 45% of global oil imports and around 50% of natural gas imports in 2021.

- ▶ In all three regions, heightened energy security concerns lead to a permanently lower share of imported oil and gas in primary energy. In 2035, their combined imports of oil and natural gas are over 10% lower in *New Momentum* than in *Outlook 2022*. Similar effects are apparent in *Accelerated* and *Net Zero*.

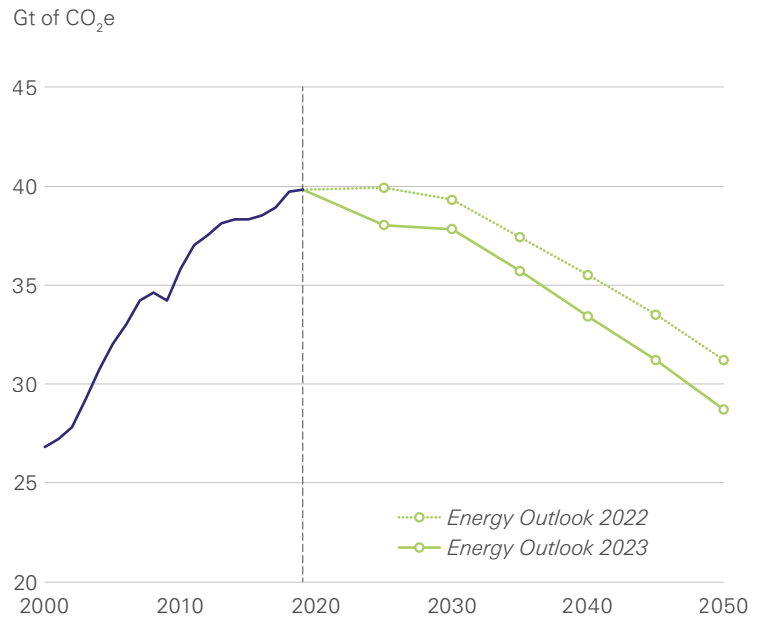
- ▶ The limited scope to increase domestic production of oil and natural gas in these countries and regions means that the reduced share of imported oil and gas in primary energy is offset by greater consumption of domestically produced renewables.

The Russia-Ukraine war and the Inflation Reduction Act lower the outlook for carbon emissions

Change in carbon emissions: EO23 versus EO22



Carbon emissions: EO23 versus EO22 in *New Momentum*



Key points

The impact of the Russia-Ukraine war, together with the policy support provided by the Inflation Reduction Act, reduces carbon emissions over the outlook.

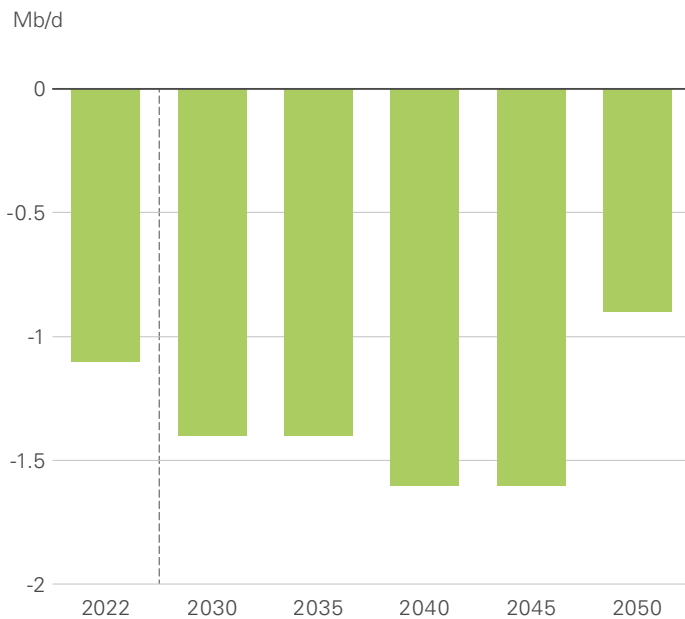
- ▶ Carbon emissions in this year's *New Momentum* are around 1.3 GtCO₂ (3.7%) lower in 2030 than in *Energy Outlook 2022*. This downward revision increases to around 2.0 GtCO₂ (6.4%) in 2040 and 2.6 GtCO₂ (9.3%) in 2050.
- ▶ The lower level of carbon emissions in *New Momentum* is largely driven by the weaker GDP profile caused in the near term by the impact of the war on commodity prices, and further out by the reduction in the pace of growth of global integration and trade. The impact of weaker economic activity increases over the outlook as the effect of the slower trend rate of growth compounds over time.

- ▶ The lower profile for carbon emissions in *New Momentum* also reflects more rapid reductions in the carbon intensity of GDP – the amount of carbon emitted per unit of GDP produced – largely reflecting the shift towards locally produced non-fossil fuels prompted by heightened energy security concerns. The support for low-carbon energy sources and technologies in the US provided by the IRA also contributes to this faster decline in the carbon intensity of GDP (see pages 26-27).
- ▶ The downward revision to carbon emissions in *New Momentum* from 2035 onwards averages around 2.2 GtCO₂e per year – roughly the amount by which global carbon emissions fell in 2020 as a result of COVID lockdowns.

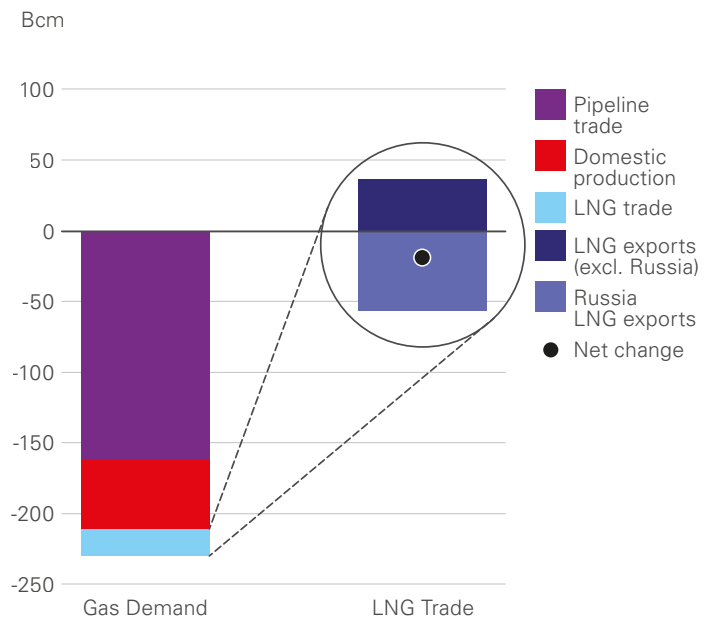
- ▶ The downward revision of carbon emissions in *Net Zero* is less than in *New Momentum*, averaging around 0.8 GtCO₂ per annum over the outlook. This smaller impact reflects the greater level of decarbonization in *Net Zero*, which means that the reduced level of energy demand stemming from the weaker GDP profile leads to a smaller saving in carbon emissions than in *New Momentum*.
- ▶ The reduction in carbon intensity in *Net Zero* by 2050 compared to that in *Outlook 2022* is also less than in *New Momentum*, reflecting the smaller impact of energy security concerns in *Net Zero* as the energy system decarbonizes and becomes increasingly dominated by non-fossil fuels – the majority of which are produced locally.

Russian production of oil and natural gas revised down as a result of the war

Change in Russian oil production: EO23 versus EO22 in *New Momentum*



Changes in natural gas by type of supply and in LNG trade in 2030: EO23 versus EO22 in *New Momentum*



Key points

Prior to the Russia-Ukraine war, Russia was the world's largest energy exporter. The impact of the war reduces Russia's production of both oil and natural gas.

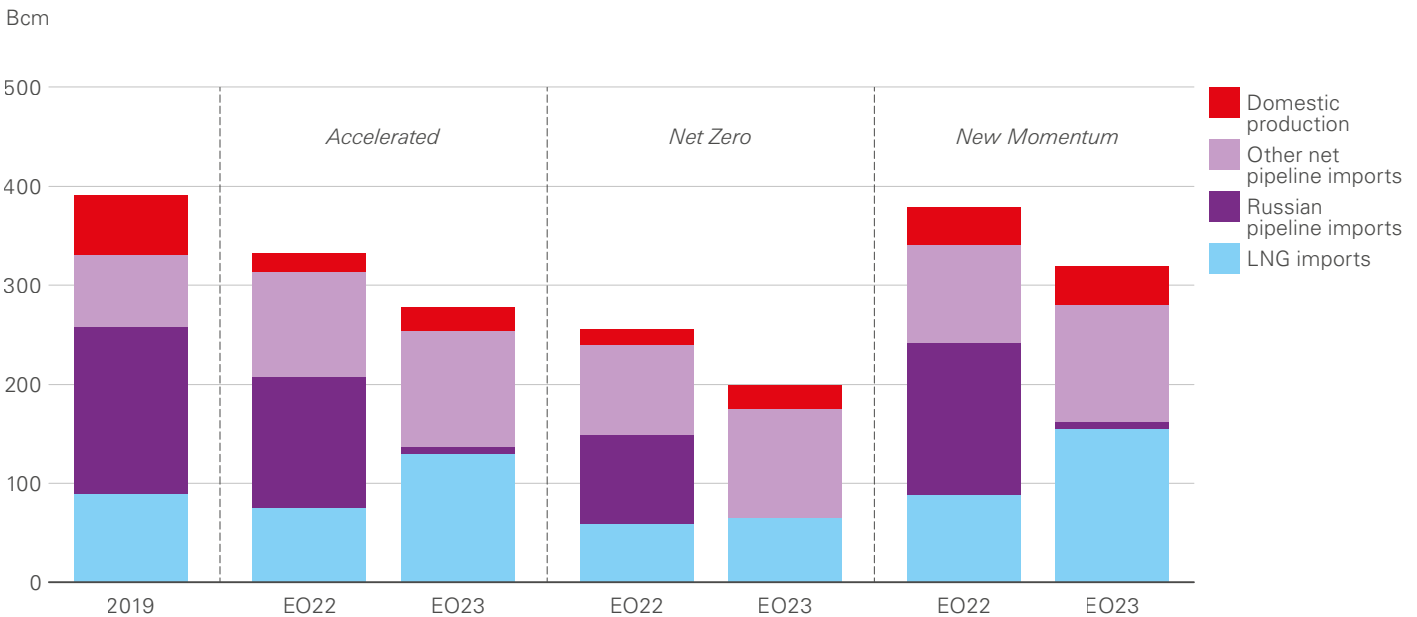
- ▶ **Oil:** The prospects for Russian oil production in the near-term are affected most significantly by the formal and informal sanctions on imports of Russian oil. Further out, the outlook is most heavily influenced by the impact of sanctions on Russia's access to western technology and investment.
- ▶ In *New Momentum*, Russian oil production over much of the outlook is around 1.3 Mb/d (13%) lower than in *Outlook 2022*. This reflects a combination of faster decline rates of existing operating assets and a curtailing of new prospective developments. There are similar-sized downward revisions in *Accelerated* and *Net Zero*. As a result, Russian oil production declines from around 12 Mb/d in 2019 to between 7 and 9 Mb/d in 2035 across the three scenarios.

- ▶ **Natural gas:** The combination of weaker GDP and a reduced preference for imported gas due to energy security concerns means that natural gas demand in the three scenarios in 2030 is between 130-250 Bcm (3.5-5%) lower in this year's *Energy Outlook* than in *Outlook 2022*.
- ▶ Most of this downward revision in gas demand is matched by reduced pipeline gas trade, driven by the almost total elimination of Russian pipeline exports to the EU. Production of gas for domestic use is also slightly lower. Outside of Russia, this fall takes place principally in the US as the shift to the use of alternative lower carbon energies there accelerates.

- ▶ The level of global LNG trade in 2030 in the three scenarios is similar to that in last year's *Outlook*. However, the geographical pattern of that trade is different. Restrictions limiting Russia's access to external finance and technology mean that the significant expansion in Russia's LNG exports envisaged in *Energy Outlook 2022* largely fails to materialize. Offsetting that, the level of non-Russian LNG exports in 2030 in this year's *Outlook* has been revised up by around 25-40 Bcm in *New Momentum* and *Accelerated*, with the US accounting for more than half of those additional exports.

EU's need for LNG imports in 2030 depends on its success in reducing natural gas demand

EU natural gas demand and sources of supply: EO23 compared with EO22



Key points

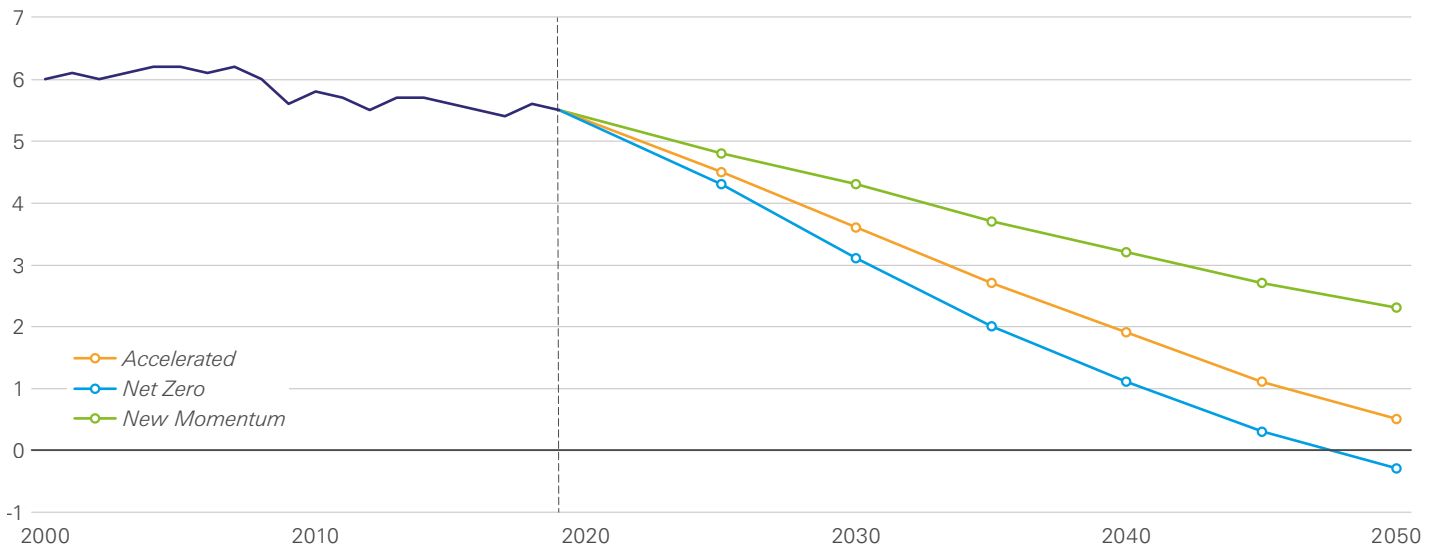
The EU is at the epicentre of the disruptions to global natural gas markets following the reductions in Russian pipeline gas exports. The extent to which the loss of Russian pipeline exports requires the EU to source alternative supplies of gas depends on how successful it is in reducing its demand for natural gas as it decarbonizes its energy system.

- ▶ The EU's desire to reduce its dependency on imported gas given the increased energy security concerns, combined with the weaker GDP profile, means EU natural gas demand in the three scenarios in 2030 is around 50-60 Bcm lower in this year's *Outlook* relative to *Energy Outlook 2022*.
- ▶ In last year's *New Momentum*, EU gas demand in 2030 was only modestly lower than its level in 2019. EU gas demand is lower in this year's *Outlook*. However, the larger fall in Russian exports of pipeline gas means EU's LNG imports in 2030 in *New Momentum* are around 70 Bcm higher than in 2019. The remaining shortfall of natural gas left by the loss of Russian pipeline gas is met by increased pipeline imports from a combination of Norway, Algeria, and Azerbaijan.
- ▶ A similar change in gas demand is seen in *Accelerated*. Although EU consumption of natural gas in 2030 is around 30% lower than 2019 levels, a significant increase in LNG imports (40 Bcm) in 2030 relative to 2019 levels is nonetheless needed to meet demand, in the absence of Russian pipeline gas.
- ▶ In contrast, in *Net Zero*, a combination of faster gains in energy efficiency, rapid growth of wind and solar power and increasing electrification of final energy consumption means EU natural gas demand in 2030 is around 50% (190 Bcm) below 2019 levels. This reduction in demand is greater than the loss of Russian pipeline gas imports, implying that the level of LNG imports needed to meet the EU's domestic gas consumption in 2030 is lower than in 2019.

The Inflation Reduction Act provides significant support for low-carbon energy and technologies in the US

US Carbon emissions

Gt of CO₂e



Key points

The US Inflation Reduction Act (IRA), which was signed into law in August 2022, includes a significant package of largely supply-side measures supporting low-carbon energy sources and decarbonization technologies in the US.

- ▶ The modelling of the IRA in this *Outlook* focuses on its potential impact on the US energy system. The possible impacts on other countries and regions are not considered, although in practice the IRA has the potential to have positive spillover effects by helping to reduce global technology costs, expand internationally tradable supplies of some forms of low-carbon energy, and increase the pressure on other countries and regions to offer similar types of incentives.
- ▶ The impact of the IRA depends importantly on the implementation of the incentives by the US authorities, as well as on regulatory reform at a state and federal level. It also hinges on the speed with which the private sector can obtain the various planning and permitting approvals needed to build out low carbon energy sources and technologies. The scenarios in this *Outlook* assume

that there are no material changes in planning and permitting processes other than those directly affected by IRA provisions.

- ▶ The impact of the IRA on the outlook for the US energy system is concentrated in the *New Momentum* scenario. US carbon emissions fall by around 22% by 2030 in *New Momentum* relative to 2019 levels, and by around 60% by 2050. The scale of the policy support already embodied in *Accelerated* and *Net Zero* means the incremental impact of the IRA provisions on these scenarios is relatively limited.

Some of the main impacts of the IRA on *New Momentum* include:

- ▶ Wind and solar power: a substantial acceleration in solar and wind deployment, with capacity increasing more than four-fold by 2030 from 2019 levels. By 2050 solar and wind capacity is more than ten times higher than in 2019, with around 20% of installed capacity used to support green hydrogen production. This increase is underpinned by a corresponding acceleration in other enabling factors, particularly the expansion of the transmission grid.
- ▶ Hydrogen: significant support for low-carbon hydrogen supply, increasing its use to 4 mtpa in 2030 and to 26 mtpa in 2050. The hydrogen incentives are especially supportive of green hydrogen, which accounts for around 60% of US low-carbon hydrogen in 2050, compared with around 25% in *Energy Outlook 2022*.
- ▶ Electric vehicles: the provisions in the IRA that support electric vehicle ownership, combined with new vehicle manufacturer and state-level commitments, increase the size of the US electric vehicle parc by around 15% by the mid-2030s.
- ▶ Biofuels: the additional credits included in the IRA facilitate faster penetration of bioderived sustainable aviation fuel (SAF), such that it reaches around 1300 PJ in *New Momentum* in 2050, more than double the level projected in *Energy Outlook 2022*.
- ▶ Carbon capture, use and storage (CCUS): the increased incentives for CCUS in the IRA support its greater use in the power sector, as well as in industry and to produce blue hydrogen. With the IRA and other incentives, CCUS deployment in the US reaches over 100 mtpa by 2035 and close to 400 mtpa by 2050.

Oil



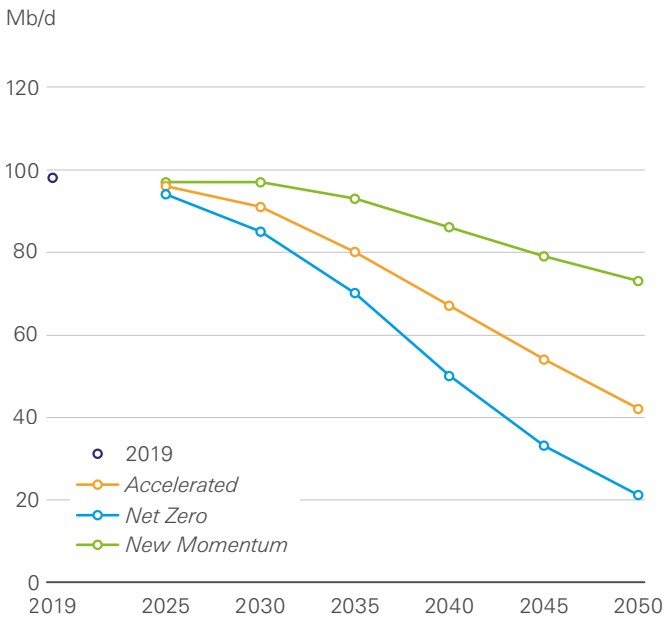
Oil demand falls over the outlook as use in road transportation declines

The role of oil in transport declines as the world switches to lower-carbon alternatives

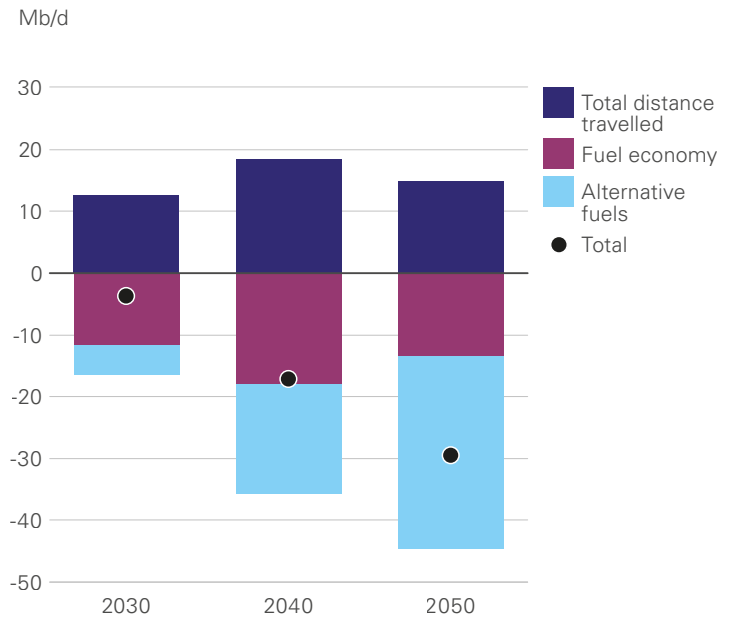
The changing mix of global oil supplies is dominated by trends in US tight oil and OPEC production

Oil demand falls over the outlook as use in road transportation declines

Oil demand



Change in oil demand in road transport versus 2019 in *Accelerated*



Key points

Global oil demand plateaus over the next 10 years or so before declining over the rest of the outlook, driven in part by the falling use of oil in road transport as vehicles become more efficient and are increasingly fuelled by alternative energy sources.

- ▶ Oil continues to play a major role in the global energy system over the first half of the outlook in *Accelerated* and *Net Zero*, with the world consuming between 70-80 Mb/d in 2035. The decline accelerates in the second half of the outlook, with oil demand reaching around 40 Mb/d in *Accelerated* and 20 Mb/d in *Net Zero* in 2050.
- ▶ Oil consumption in *New Momentum* is stronger, remaining close to 100 Mb/d through much of this decade, after which it declines gradually to around 75 Mb/d by 2050.

- ▶ Oil demand in emerging economies is broadly flat or gently rising over much of the first half of the outlook across the three scenarios, but this is offset by the accelerating declines in oil use in the developed world. These contrasting trends are reflected in a gradual shift in the centre of gravity of global oil markets, with emerging economies' share of global oil demand increasing from 55% in 2021 to around 70% in 2050 in all three scenarios.
- ▶ The single biggest factor driving the decline in oil consumption is the falling use of oil within road transport. Rising prosperity and living standards in emerging economies support an increase in both the size of the global vehicle parc and in distances driven, boosting the demand for oil. But this is increasingly offset by a combination of the road vehicle fleet becoming more efficient and the growing switch away from oil to alternative energy sources.

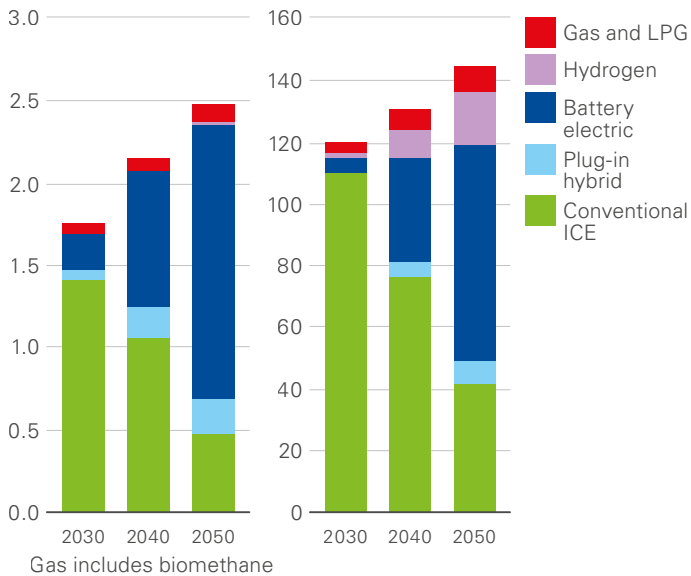
- ▶ Lower demand for oil in road transport accounts for more than half of the reduction in total oil demand in *Accelerated* throughout the outlook. In 2030, this largely reflects the impact of the increasing efficiency of the global vehicle fleet, which is more than twice that of the switch to alternative energy sources. By 2040 these two effects are broadly equal, and by 2050 the switch to alternative energy sources, led by the increasing electrification of vehicles, accounts for more than twice the impact on oil demand than the effects of greater efficiency.

The role of oil in transport declines as the world switches to lower-carbon alternatives

Global vehicle parc in *Accelerated*: Light vehicles Heavy vehicles

Billion vehicles

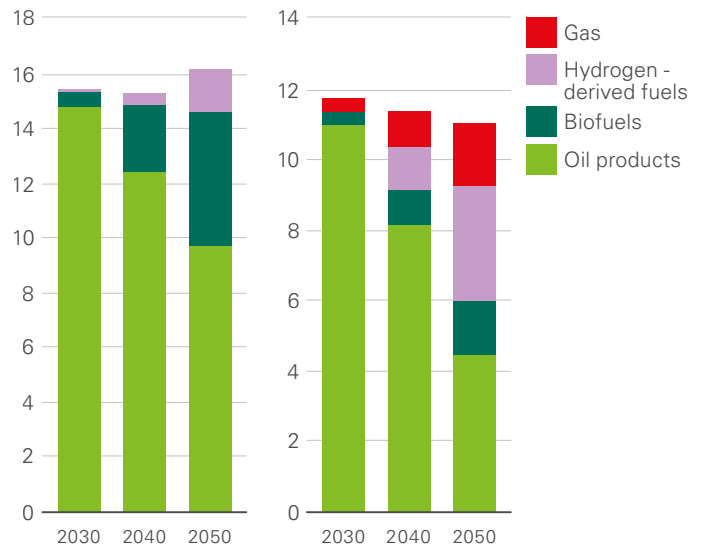
Million vehicles



Total energy usage by fuel in *Accelerated*: Aviation Marine

EJ

EJ



Key points

The role of oil falls across all modes of transport, reflecting a shift to alternative, low-carbon energy sources. That shift is dominated by electrification in road transport and by bio- and hydrogen-derived fuels in aviation and marine.

- ▶ In road transportation, the number of electric (including plug-in hybrid) cars and light-duty trucks increases from around 20 million in 2021 to between 550-700 million (30-35% of that vehicle parc) by 2035 in *Accelerated* and *Net Zero*, and to around 2 billion such vehicles (around 80%) by 2050. Electric passenger cars account for the majority of new car sales by the mid-2030s in *Accelerated* and *Net Zero*, supported by a combination of tighter regulation of vehicle emissions, improving cost and choice competitiveness of electric cars, and growing preference and acceptability among consumers.
- ▶ Although the electrification of cars and light duty trucks is less rapid in *New Momentum*, there are still around 500 million such vehicles by 2035 and 1.4

billion by 2050, with electric passenger cars accounting for around 40% of new car sales in 2035 and 70% in 2050.

- ▶ There is also a switch away from the reliance on diesel in medium- and heavy-duty trucks and buses, with the share of diesel-based trucks in the global parc declining from around 90% in 2021 to between 70-75% in 2035 in *Net Zero* and *Accelerated* and 5-20% in 2050. The main switch is to electrification, but hydrogen-fuelled trucks also play a growing role, especially for heavy-duty, long-distance use cases. The choice between electrification and hydrogen varies across different countries and regions depending on policies affecting the relative price of electricity and low-carbon hydrogen, as well as on regulatory policies and the development of charging and refuelling infrastructures.
- ▶ Electrification of road vehicles is initially dominated by China, Europe and North America, which together account for around 60-75% of the growth of electric road vehicles* to 2035 in the three scenarios and 50-60% of the growth to 2050.

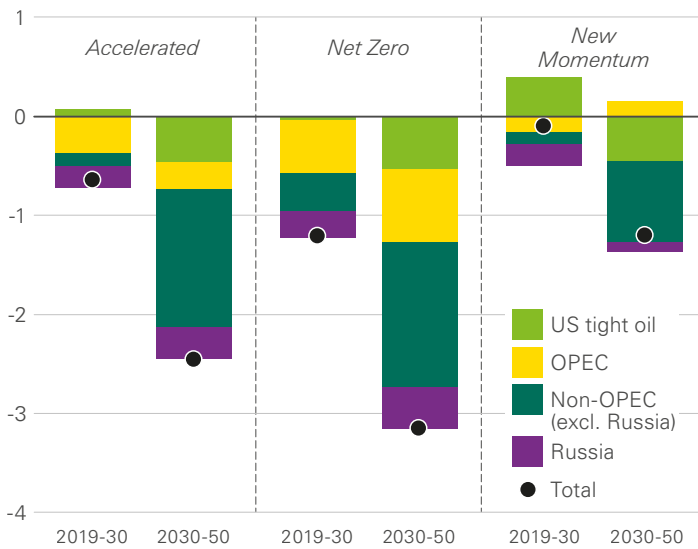
- ▶ Oil continues to dominate the aviation sector over the first half of the outlook, but its share declines to around 60% of energy used in aviation by 2050 in *Accelerated* and 25% in *Net Zero*, offset by the increasing use of sustainable aviation fuel (SAF). In *Accelerated*, the majority of the SAF is derived from bioenergy (biojet). Biojet also provides most of the SAF in *Net Zero*, although by 2050 there is also a greater role for hydrogen-derived fuels (synthetic jet fuel – see pages 70-71).
- ▶ The main alternative to oil-based products in marine use is provided by hydrogen-based fuels (ammonia, methanol and synthetic diesel). The penetration of these fuels is concentrated in the second half of the outlook in *Accelerated* and *Net Zero*, where they account for between 30% and 55% of total energy used in marine by 2050. In contrast, oil continues to account for more than three-quarters of marine energy demand in 2050 in *New Momentum*.

*Excluding e-bicycles

The changing mix of global oil supplies is dominated by trends in US tight oil and OPEC production

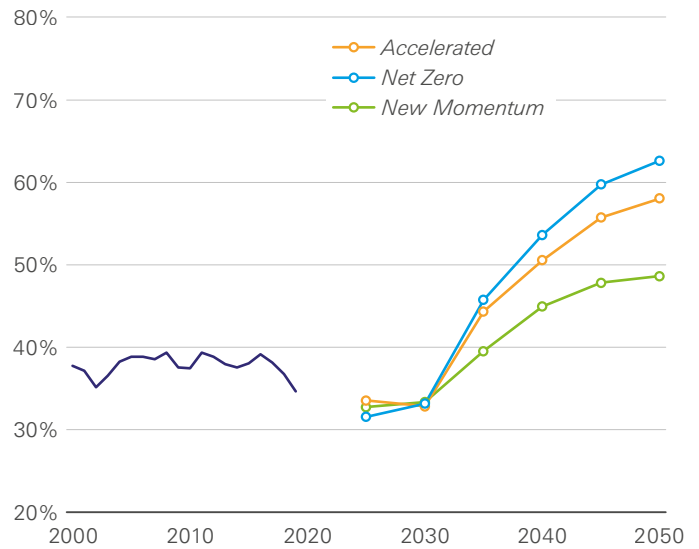
Change in oil supply

Average annual change, Mb/d



OPEC market share of global oil supply

Share of total



Key points

The composition of global oil supplies shifts over time, as US tight oil grows over the rest of this decade after which it declines as the most productive locations are exhausted and OPEC competes to increase its market share. There is a sustained decline in Russian production.

- ▶ US tight oil – including natural gas liquids (NGLs) – grows over the first 10 years or so of the outlook, peaking at between 11-16 Mb/d around the turn of this decade in all three scenarios. Brazilian and Guyana output also increases over the next 10 years or so, reaching around 5 Mb/d and 2 Mb/d respectively by the mid 2030s.
- ▶ US production falls through the 2030s and 40s, as US tight formations mature, and OPEC adopts a more competitive strategy against a backdrop of accelerating declines in oil demand. US tight oil drops to around 2 Mb/d or less in *Accelerated* and *Net Zero* by 2050, and to around 6 Mb/d in *New Momentum*, where the pressures from falling levels of overall demand are less acute.
- ▶ Russian output declines over the entire outlook, falling from around 11.5 Mb/d in 2019 to between 5.5-6.5 Mb/d in 2035 in *Accelerated* and *Net Zero* and to 2.5 Mb/d or less by 2050. The reductions in *New Momentum* are less pronounced, with Russian production falling to around 8.5 Mb/d and 7 Mb/d in 2035 and 2050 respectively.
- ▶ OPEC's production strategy reacts to the changing competitive landscape. OPEC lowers its output over the first decade of the outlook in response to the growth in US and other non-OPEC supplies, accepting a lower market share to mitigate the downward pressure on prices. The fall in OPEC's market share is most pronounced in *Accelerated* and *Net Zero* given the backdrop of falling oil demand from the mid-2020s.
- ▶ As the decline in oil demand gathers pace through the second half of the outlook and the competitiveness of US output wanes, OPEC competes more actively, raising its market share. OPEC's share of global oil production increases to between 45-65% by 2050 in all three scenarios.
- ▶ The higher cost structure of non-OPEC production means between 75-85% of the fall in oil production in *Accelerated* and *Net Zero* by 2050, and virtually all the reduction in *New Momentum*, is borne by non-OPEC suppliers.

Natural gas



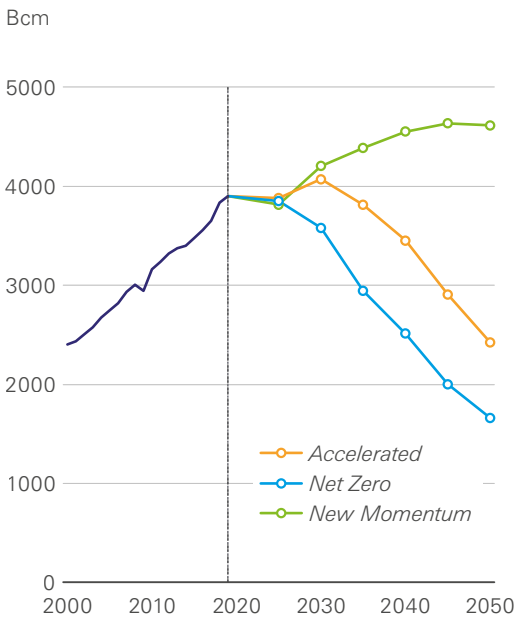
Prospects for natural gas depend on the speed of the energy transition

LNG trade increases in the near term, with the outlook becoming more uncertain post 2030

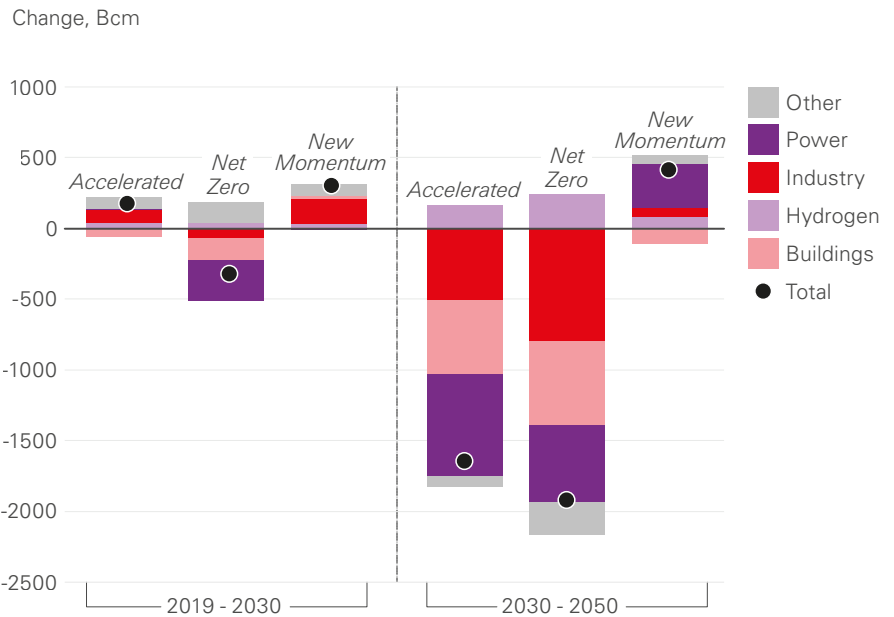
LNG exports are dominated by the US and the Middle East

Prospects for natural gas depend on the speed of the energy transition

Natural gas demand



Change in natural gas demand by sector



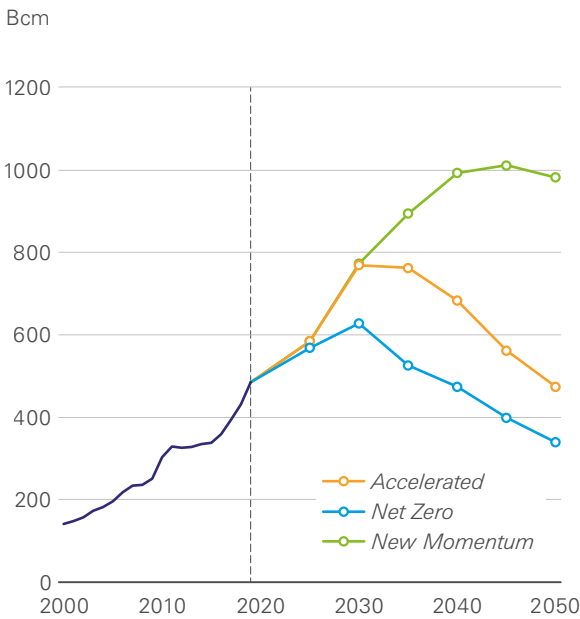
Key points

The prospects for natural gas depend on the outcome of two significant but opposing trends: increasing demand in emerging economies as they grow and industrialize, offset by a shift away from natural gas to lower-carbon energy led by the developed world. The net impact of these opposing trends on global gas demand depends on the pace of the energy transition.

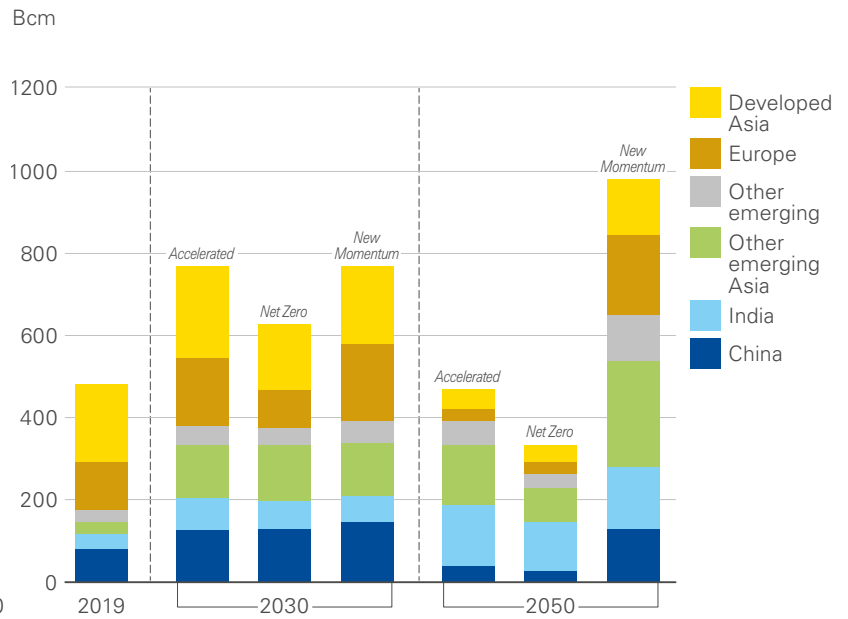
- ▶ Global demand for natural gas rises over the rest of this decade in *New Momentum* and *Accelerated* driven by strong growth in China – underpinned by continued coal-to-gas switching – and also by India and other emerging Asia as they industrialize further.
- ▶ In contrast, natural gas consumption in *Net Zero* peaks in the mid-2020s before then starting to decline. The use of gas within the emerging world grows out to 2030. But this growth is outweighed by falling consumption in the developed world, given the shift towards electrification and lower carbon energy.
- ▶ From the early 2030s onwards, natural gas demand declines in *Accelerated* and *Net Zero* as the sustained decline in its use in the developed world is compounded by falling demand in China and the Middle East, driven by the same patterns of increasing electrification and rapid growth in renewable energy. The decline is only partially offset by the growing use of natural gas to produce blue hydrogen (see pages 72-73). By 2050, natural gas demand is around 40% lower than 2019 levels in *Accelerated* and 55% lower in *Net Zero*.
- ▶ In contrast, global natural gas demand in *New Momentum* continues to grow for much of the period out to 2050, driven by growing use in emerging Asia and Africa. Much of this growth is in the power sector as the share of natural gas consumption in power generation in these regions grows and overall power generation increases robustly. Global natural gas demand in *New Momentum* in 2050 is around 20% above 2019 levels.
- ▶ The range of the difference in global gas demand in 2050 across the three scenarios relative to current levels is greater than for either oil or coal, highlighting the sensitivity of natural gas to the speed of the energy transition.

LNG trade increases in the near term, with the outlook becoming more uncertain post 2030

LNG trade



LNG imports by region



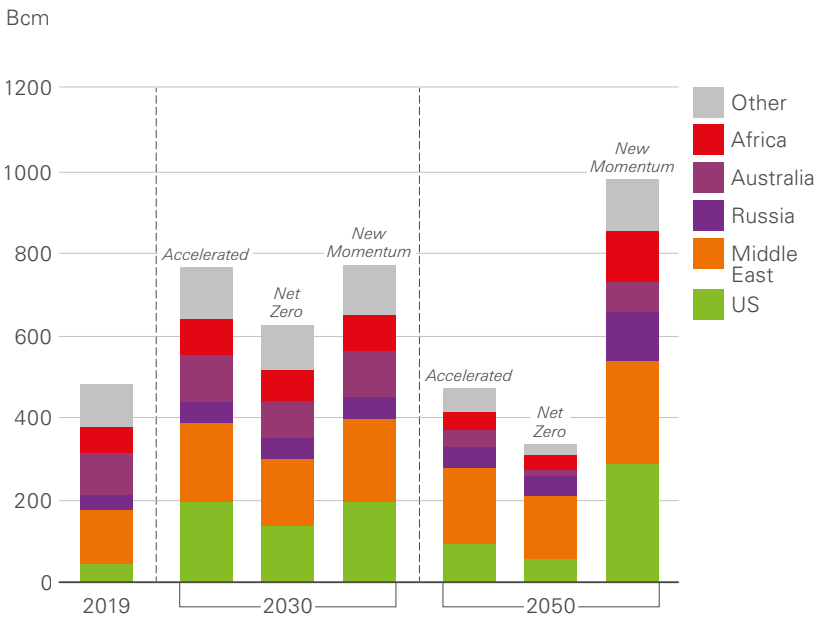
Key points

LNG trade increases robustly in the near term but the range of uncertainty widens post 2030, with continuing demand for LNG in emerging markets as they grow and industrialize, offset by falling import demand in developed markets as they transition to lower carbon energy sources.

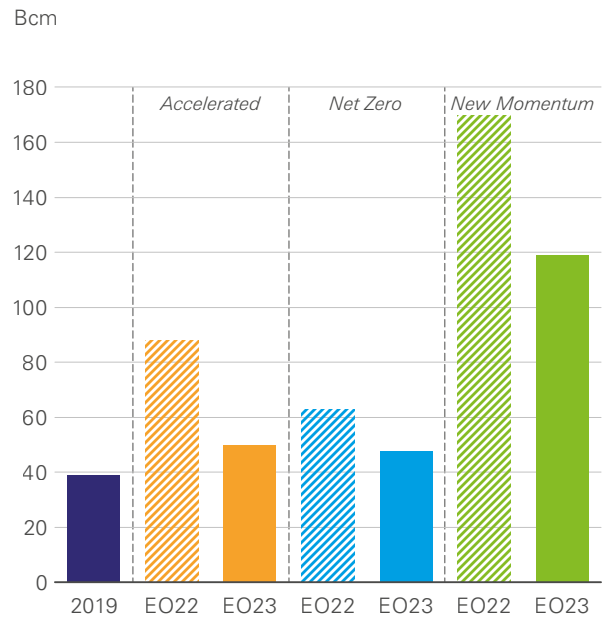
- ▶ LNG trade grows strongly over the first 10 years of the outlook, increasing by around 60% in *New Momentum* and *Accelerated* and by a third in *Net Zero*.
- ▶ Much of this growth is driven by increasing gas demand in emerging Asia (China, India, and other emerging Asia) as these countries switch away from coal and, outside of China, continue to industrialize. LNG imports are the main source for this growing use of natural gas, accounting for 65-75% of the increase in gas consumed in emerging Asia out to 2030 across the three scenarios.
- ▶ European LNG imports also increase materially out to 2030 in *New Momentum* and *Accelerated*, reflecting the fall in Russian pipeline imports and persistent natural gas demand (see pages 34-35).
- ▶ The range of uncertainty in LNG trade increases materially post 2030. Imports of LNG increase by around 30% between 2030 and 2050 in *New Momentum*, whereas they fall by around 40% over the same period in *Accelerated* and *Net Zero*.
- ▶ The growth in LNG demand post-2030 in *New Momentum* is driven by increasing demand from India and other emerging markets, reflecting the increasing use of natural gas in the power and industrial sectors (see pages 48-49). This growth in the emerging world more than offsets declining LNG imports in Europe and developed Asian markets.
- ▶ LNG demand in emerging economies also grows for much of the period post-2030 in *Accelerated* and *Net Zero*, but this is more than offset by sharp falls in LNG imports in developed Asian and European markets and in China, as these regions switch away from natural gas to lower carbon energy sources.
- ▶ The size of the LNG market in 2050 is roughly double its 2019 level in *New Momentum*, broadly unchanged in *Accelerated*, and is around 30% lower in *Net Zero*.

LNG exports are dominated by the US and the Middle East

LNG exports by region



Russia LNG exports in 2050



Key points

The US and Middle East establish themselves as the main global supply hubs for LNG exports, with the prospects for Russian LNG exports scarred by the effects of the Russia-Ukraine war.

▶ The growth in global LNG demand out to 2030 is met by a substantial expansion of exports from the US and Qatar. Growth in US LNG exports account for more than half of the increase in global LNG supplies out to 2030 in *New Momentum* and *Accelerated* and around two-thirds of overall growth in *Net Zero*. Growing exports from the Middle East account for much of the remainder. By 2030, the US and the Middle East together account for around half of global LNG supplies, compared with around a third in 2019.

▶ The fall in LNG exports in the second half of the outlook in *Accelerated* and *Net Zero* is borne disproportionately by the US. US LNG exports fall by more than a half between 2030 and 2050 in these two scenarios, reflecting the increasing competition and the higher transport costs for US supplies to the remaining demand centres in Asia relative to the cost of LNG from the Middle East and Africa.

▶ Australian LNG exports decline post-2030 in all three scenarios reflecting increasing costs and constraints on upstream natural gas production in Australia.

▶ Russian LNG exports out to 2030 are constrained by continuing restrictions on Russia's access to western technology and funding. As such, Russian exports over the first decade of the outlook are broadly flat, with only those projects close to completion before the start of the war assumed to start up.

▶ The constraints on Russia's access to technology and funding are assumed to ease gradually post-2030, allowing Russian LNG exports to more than double by 2050 in *New Momentum*. In contrast, the falls in global LNG demand in the 2030s and 40s in *Accelerated* and *Net Zero* means that Russian LNG exports do not have a chance to recover even as sanctions are eased. Russian LNG exports are between 10-60 Bcm lower in 2035 and 15-50 Bcm lower in 2050 across the three scenarios than in last year's *Energy Outlook* (see pages 32-33).

Renewable energy

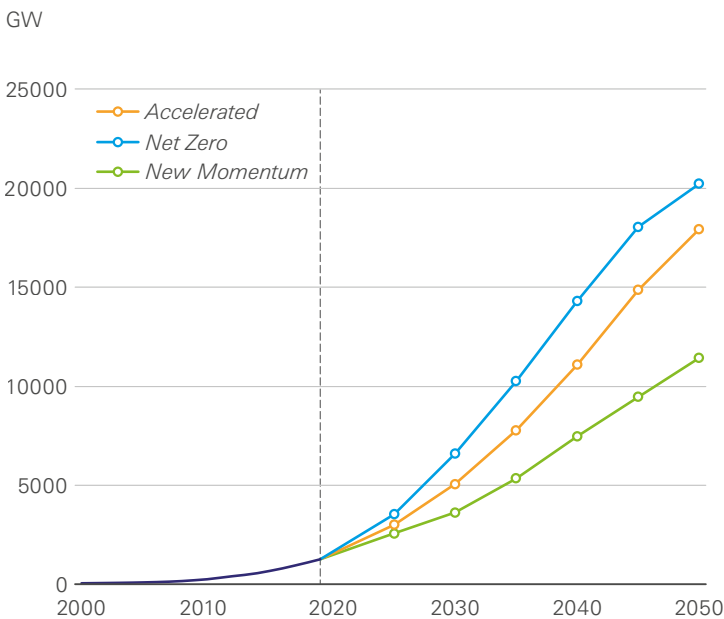


Wind and solar power expands rapidly, requiring significant acceleration in financing and building new capacity

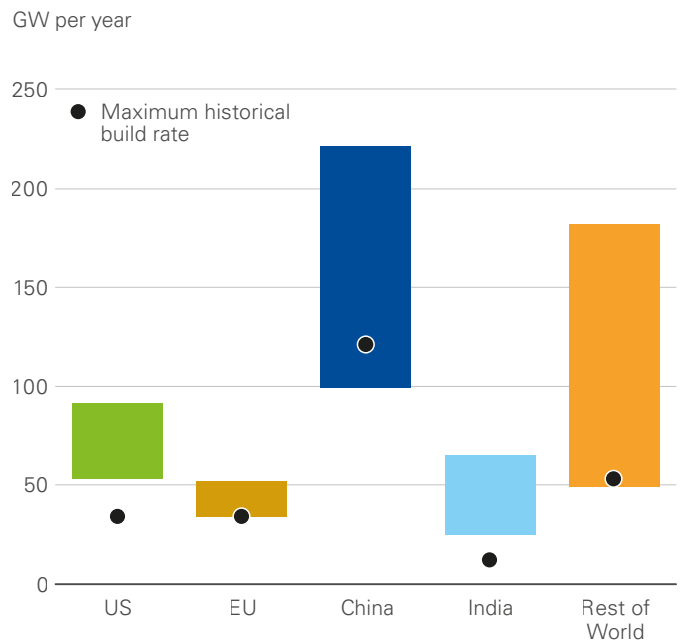
Modern bioenergy expands rapidly, helping to decarbonize hard-to-abate sectors and processes

Wind and solar power expands rapidly, requiring significant acceleration in financing and building new capacity

Installed wind and solar capacity



Range of wind and solar capacity build rates in the three scenarios 2022-2035



Key points

Wind and solar power expands rapidly, driven by increasing cost competitiveness and policies supporting a shift to low-carbon electricity and green hydrogen.

- ▶ Wind and solar installed capacity increases by around 15 fold over the outlook in *Accelerated* and *Net Zero* and 9 fold in *New Momentum*.
- ▶ Most of this capacity provides electricity for final consumption, although around a quarter to a third of the capacity by 2050 in *Accelerated* and *Net Zero* is used to produce green hydrogen.
- ▶ The rapid expansion in wind and solar power is largely underpinned by falls in their costs – which resume after recent short-term inflation pressures, especially over the first 10-15 years of the outlook. Solar and wind technology and production costs fall with growing deployment, supported by increases in module efficiency, load factors and project scales for solar, and by higher load factors of increasingly large turbines and lower operating costs for wind.

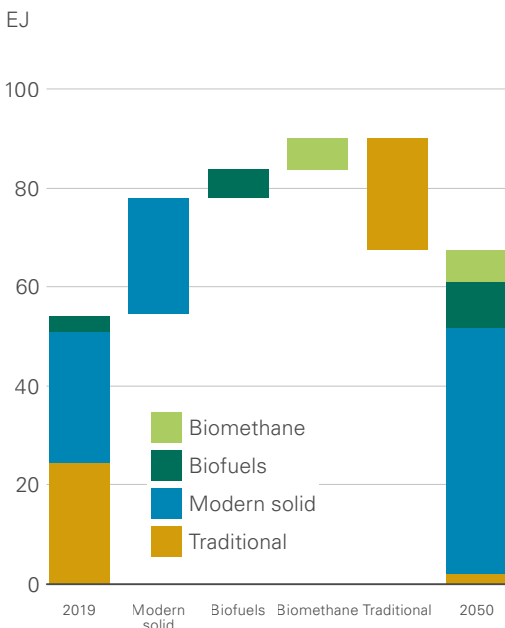
- ▶ The pace of cost reductions slows and eventually plateaus in the final two decades of the outlook as falling generation costs are offset by the growing expense of balancing power systems with increasing shares of variable energy sources. The outlook for costs assumes that the availability of the critical metals used in the manufacturing of photovoltaic modules and wind turbines increases sufficiently to avoid a sustained increase in prices (see pages 84-85). More generally, the scenarios are underpinned by an assumption that supply chains develop and expand so as to avoid excessive dependence on individual countries or regions for key materials, and the challenges around the security of supply of critical materials that might imply.
- ▶ The expansion in installed capacity by 2035 requires a significant acceleration of the pace at which new capacity is financed and built. The average rate of increase in installed capacity in *Accelerated* and *Net Zero* out to 2035 is

450-600 GW per year – around 1.9 to 2.5 times faster than the highest rate of increase seen in the past.

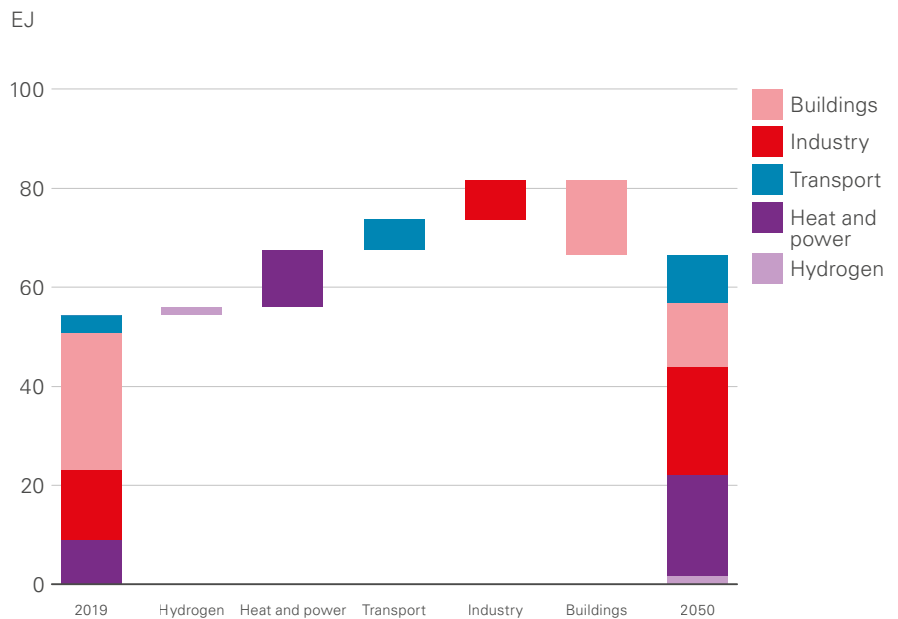
- ▶ In addition to a significant increase in investment (see pages 82-83), this rapid acceleration in the deployment of wind and solar capacity depends on a number of enabling factors scaling at a corresponding pace, including the expansion of transmission and distribution capacity, development of market frameworks to manage intermittency, the speed of planning and permitting, and the availability of route-to-market mechanisms.
- ▶ The growth in installed wind and solar capacity out to 2035 is dominated by China and the developed world, each of which accounts for 30-40% of the overall increase in capacity in all three scenarios. This pattern of growth switches significantly in the second half of the outlook, with emerging economies excluding China accounting for around 75-90% of the growth in the 2040s in *Accelerated* and *Net Zero*.

Modern bioenergy expands rapidly, helping to decarbonize hard-to-abate sectors and processes

Bioenergy supply by type in *Accelerated* (2019-2050)



Bioenergy demand by sector in *Accelerated* (2019-2050)



Key points

The use of modern bioenergy – modern solid biomass (such as wood pellets), biofuels and biomethane – increases significantly, helping to decarbonize hard-to-abate sectors and processes, and displacing the use of traditional biomass – such as waste wood and agricultural residues – for cooking and heating.

- ▶ There is a substantial shift from traditional to modern bioenergy in *Accelerated* and *Net Zero*, with modern bioenergy more than doubling to reach around 65 EJ by 2050, more than offsetting the phasing out of traditional biomass. Growth of modern bioenergy in *New Momentum* is slightly less pronounced, reaching close to 50 EJ by 2050. The expansion in modern bioenergy is achieved without any change in land use, with the vast majority sourced regionally through residues (from agriculture and forestry) and wastes which are accessible without detrimental effect to their ecosystems.
- ▶ The largest growth in demand for modern bioenergy is in solid biomass. Biomass is used mainly in the power sector, with its use in this sector almost

tripling over the outlook in *Accelerated*. Much of the remainder is used to help decarbonize hard-to-abate industrial processes, especially in cement and steel manufacturing. In *Accelerated*, 5 EJ of biomass is used in conjunction with carbon capture and storage (BECCS) by 2050, predominantly in the power and industrial sectors. This use of BECCS in the power sector is concentrated in the developed world. Within emerging economies, biomass in the power sector is used in new biomass cogeneration plants and in co-firing plants with coal. The use of BECCS globally in *Net Zero* is greatest reaching 13 EJ in 2050, around half of which is deployed in the power sector, with much of the remainder used to produce hydrogen.

- ▶ The production of biofuels roughly triples in *Accelerated* and *Net Zero* by 2050 to around 10 EJ, with most of these fuels being used in the aviation sector. By 2050, bio-derived sustainable aviation fuel (biojet) accounts for 30% of total aviation demand in *Accelerated* and 45% in *Net Zero*, with 50-60% of the growth in biojet in the US and Europe, supported by increasing incentives and mandates.

- ▶ Biomethane grows significantly in all scenarios, from less than 0.2 EJ in 2019 to between 6-7 EJ in *Accelerated* and *Net Zero* by 2050 and 4.3 EJ in *New Momentum*. Biomethane is blended into the natural gas grid as a direct substitute for natural gas and is shared broadly equally across industry, buildings, and transport.
- ▶ In contrast to modern bioenergy, the role of traditional biomass is largely phased out by 2050 in *Accelerated* and *Net Zero*. That largely reflects its current use in buildings in emerging economies disappearing as access to electricity and clean-cooking fuels increases. The use of traditional biomass is more persistent in *New Momentum* reflecting the slower electrification of energy systems in emerging economies.
- ▶ The growth of modern bioenergy in all three scenarios is dominated by emerging economies, which account for around three quarters of the growth to 2050 in all three scenarios.

Electricity



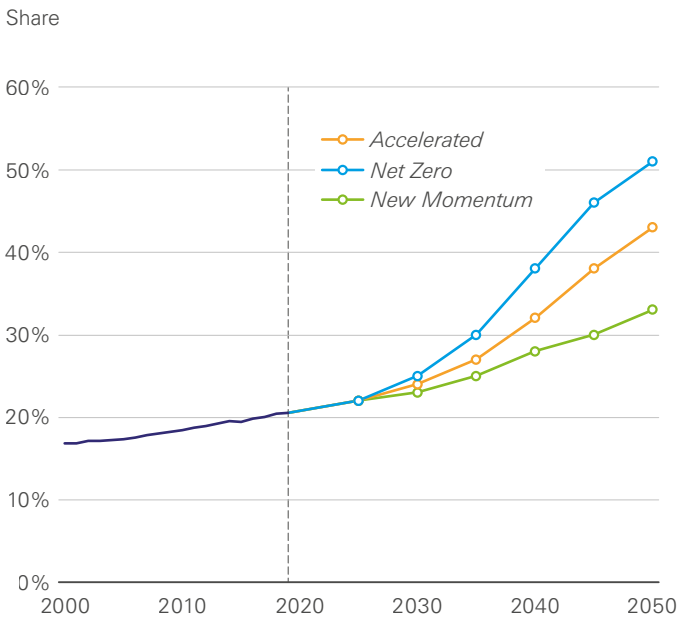
Electricity demand expands significantly as prosperity in emerging economies grows and the world increasingly electrifies

The global power system decarbonizes, led by the increasing dominance of wind and solar power

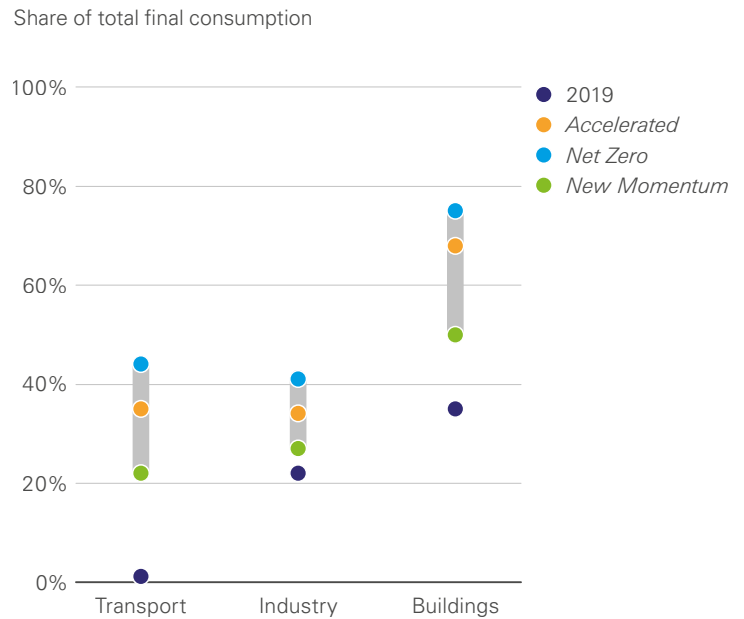
The mix of power generation differs between developed and emerging economies

Electricity demand expands significantly as prosperity in emerging economies grows and the world increasingly electrifies

Electricity as a share of total final consumption



Range of electrification across end-use sectors in 2050



Key points

Electricity demand grows robustly over the outlook, driven by growing prosperity in emerging economies and increasing electrification of the global energy system.

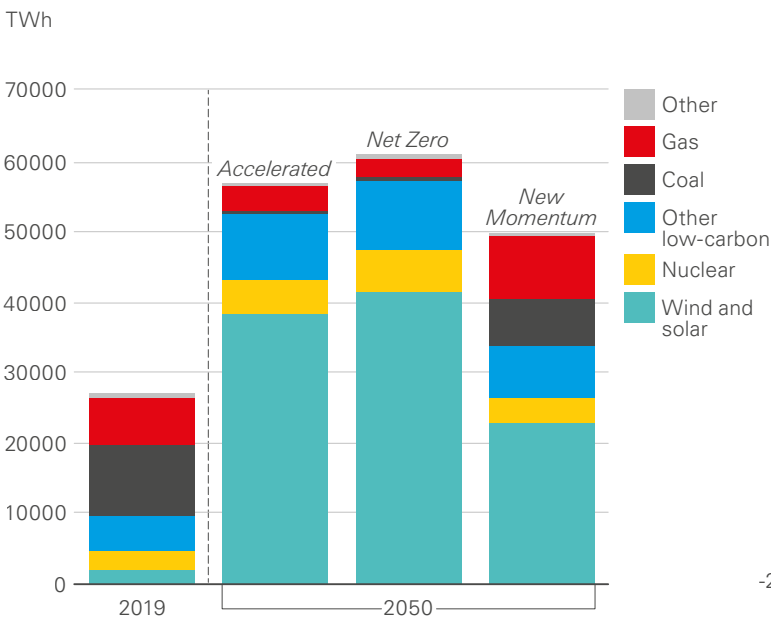
- ▶ Final electricity demand increases by around 75% by 2050 in all three scenarios. The vast majority of this growth (around 90%) is accounted for by emerging economies as rising prosperity and living standards support a rapid expansion in the use of electricity.
- ▶ In developed markets, the increasing electrification of end energy uses underpins some growth in electricity consumption. But this growth is very modest compared with that in emerging economies.

- ▶ Electricity demand in India grows by between 250-280% over the outlook across the three scenarios, compared with 10-30% in the EU. Even so, electricity consumption per capita in the EU in 2050 is still around double that in India.
- ▶ The increasing electrification of the energy system is most pronounced in *Accelerated* and *Net Zero*, with the share of electricity in total final consumption (TFC) increasing from 20% in 2019 to between 40-50% by 2050. Despite the slower pace of decarbonization, the share of electricity in TFC in *New Momentum* still increases to over 30% by the end of the outlook.

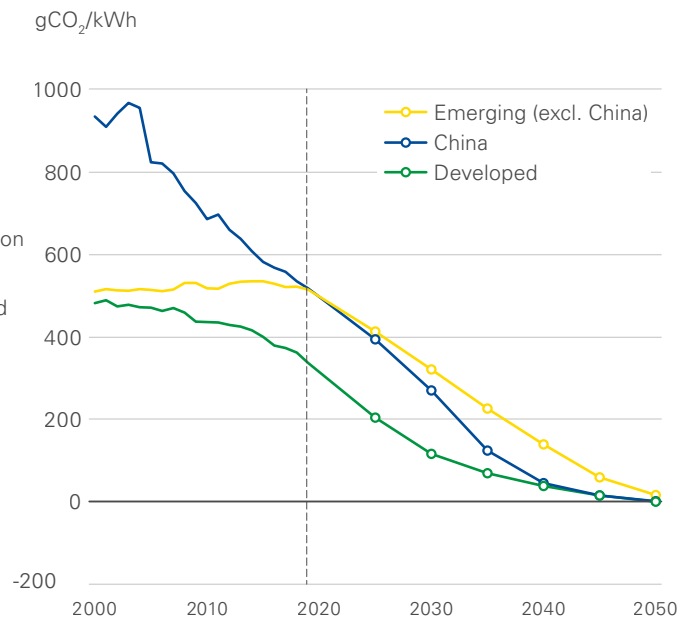
- ▶ The increase in electrification is apparent across all-end-use sectors. The greatest scope for electrification is in buildings, where at least half of final energy demand is electrified by 2050 in all three scenarios. The higher degree of electrification of buildings' energy demand in *Accelerated* and *Net Zero* is largely driven by the greater adoption of heat pumps.
- ▶ The transport sector has the largest increase in the share of electrification relative to its current low level, largely reflecting the electrification of road transport (see pages 42-43).
- ▶ Compared with the other sectors, the scope for significant increases in the electrification of final energy use in industry is more limited, particularly for processes requiring high temperatures (>200°C).

The global power system decarbonizes, led by the increasing dominance of wind and solar power

Electricity generation by fuel



Carbon intensity of power generation in *Accelerated*



Key points

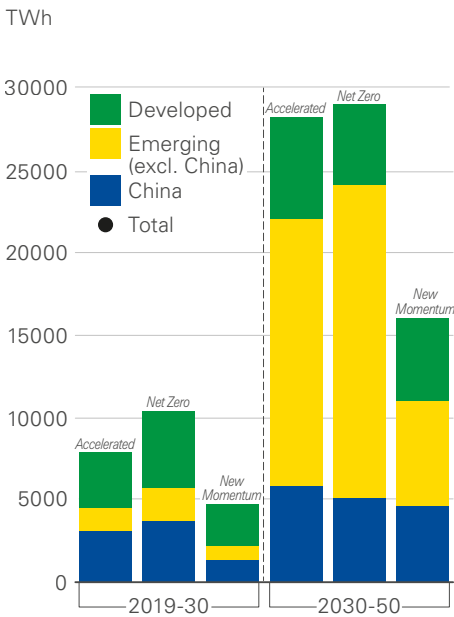
Global power generation decarbonizes, enabled by rapid growth in wind and solar power which accounts for all or most of the increase in power generation over the outlook.

- ▶ By 2050, wind and solar power account for around two-thirds of global power generation – and closer to 75% in the most advantaged regions – in *Accelerated* and *Net Zero*. That share is around a half by 2050 in *New Momentum*.
- ▶ Although direct electricity consumption is similar across the three scenarios (see pages 18-19), total power generation is higher in *Accelerated* and *Net Zero*, with an additional 15-20% of total generation by 2050 used to produce green hydrogen (see pages 72-73).
- ▶ Other sources of low-carbon power generation (nuclear, hydro, bioenergy and geothermal) continue to play a significant role, accounting for around 25% of global power generation in 2050 in *Accelerated* and *Net Zero*, similar to their share in 2019.
- ▶ Within that, nuclear power generation increases by around 80% by 2050 in *Accelerated* and more than doubles in *Net Zero*. Investment in new nuclear capacity is concentrated in China – which accounts for 50-65% of the growth in nuclear power in *Accelerated* and *Net Zero* – supported by new capacity in other emerging economies and an extension of lifetimes and restarting of existing plants in some developed economies.
- ▶ Coal is the fuel that loses most ground to the increasing dominance of low-carbon power, as its share in global power generation falls from close to 40% in 2019 to a little over 10% in *New Momentum* by 2050 and close to zero in *Accelerated* and *Net Zero*.
- ▶ The role of natural gas in global power generation is relatively stable over the first part of the outlook in *Accelerated* and *New Momentum*, given its continuing importance in the emerging world. But its use declines sharply in the second half of the outlook in *Accelerated* and *Net Zero* as the expansion of wind and solar power gathers pace. In 2050, 60-95% of the remaining gas-fired power generation in *Accelerated* and *Net Zero* is used in conjunction with carbon capture, use and storage (CCUS, see pages 76-77).
- ▶ In the second half the outlook, low-carbon hydrogen also emerges as a fuel in the power sector: although its overall share of generation is very small, it plays an important role as dispatchable low-carbon power in electricity systems with a high share of solar and wind.
- ▶ The increasing dominance of low-carbon energy, together with the use of CCUS, cause carbon emissions from power generation in *Accelerated* to fall by around 55% by 2035 and to be virtually eliminated by 2050. The reduction in the carbon intensity of global power generation over the first part of the outlook is led by the developed world and China, with emerging economies catching up over the second half of the period. Similar trends are also apparent in *Net Zero*, where the greater use of bioenergy combined with CCUS results in the power sector being a source of negative emissions by 2050.

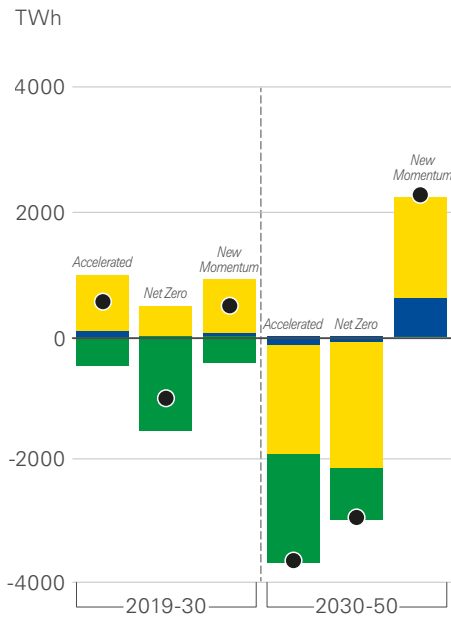
The mix of power generation differs between developed and emerging economies

Change in generation by source and region

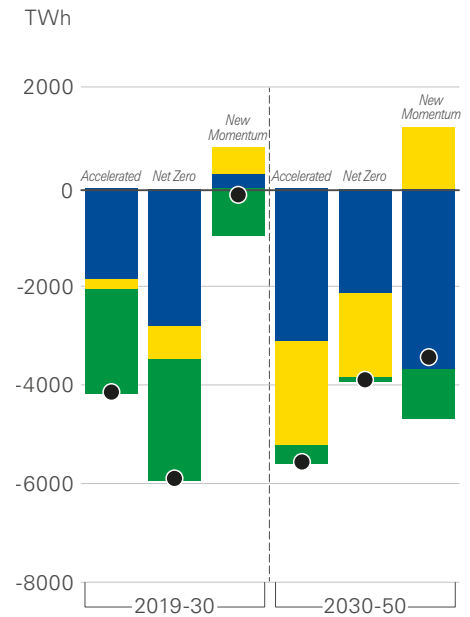
Wind and solar



Gas power



Coal power



Key points

The energy sources used to fuel the growth in power generation vary across developed and emerging economies, reflecting differences in their stages of development and in the maturity and size of power generation markets.

- ▶ Growth in wind and solar generation over the rest of this decade is dominated by China and the developed world, which together account for 80-85% of the growth in wind and solar power out to 2030 in the three scenarios.
- ▶ This share declines to 35-60% in the period after 2030 as the growth in renewable power generation in emerging economies (excluding China) rises sharply, underpinned by strong growth in power demand and the increasing ability of these markets to support a rapid build out of wind and solar capacity.

- ▶ The growth in gas-fired power generation over the rest of the current decade is concentrated in emerging economies. In *Accelerated* and *Net Zero*, the increase in gas-fired power generation and the rapid expansion in wind and solar power facilitate a modest reduction in coal generation by 2030 in emerging economies. That higher level of gas-fired power generation is relatively short-lived in *Accelerated* and *Net Zero*, as the push to decarbonize the power sector, led by a sharp acceleration in wind and solar power generation, triggers a reduction in both gas- and coal-fired generation after 2030.

- ▶ In contrast, the slower growth in power demand in developed economies, together with robust increases in renewable power generation, cause gas-fired generation in the developed world to plateau in the next few years in *Net Zero* and *Accelerated* before declining thereafter.

- ▶ The move to decarbonize the power sector causes coal-fired generation to decrease markedly in all regions in *Accelerated* and *Net Zero*. The use of coal is more persistent in *New Momentum*, with a small increase in coal generation in China and other emerging economies over the rest of this decade. But that rise is more than reversed by a sharp fall in Chinese coal generation in the final 20 years of the outlook. At a global level, the fall in total coal-fired generation is dominated by China, which explains around half of the total decline in *Accelerated* and *Net Zero* and more than the total in *New Momentum*.

Low-carbon hydrogen

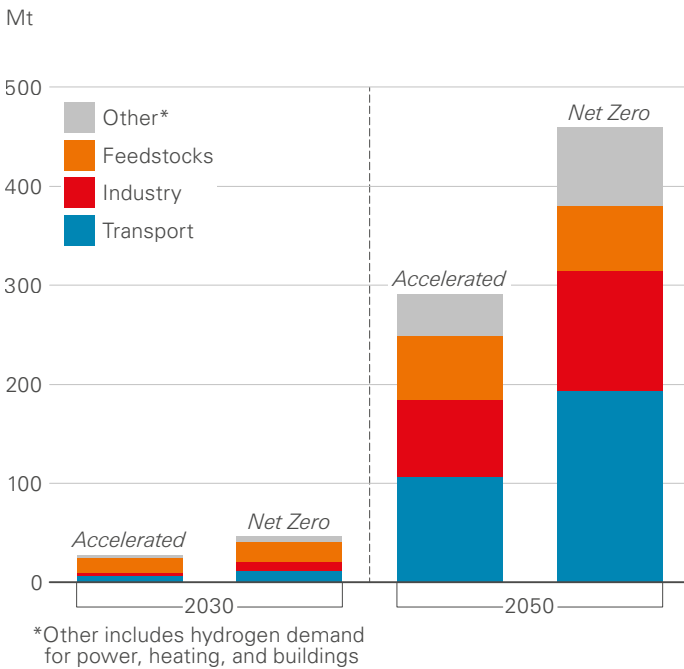


Low-carbon hydrogen plays a critical role in helping the energy system to decarbonize

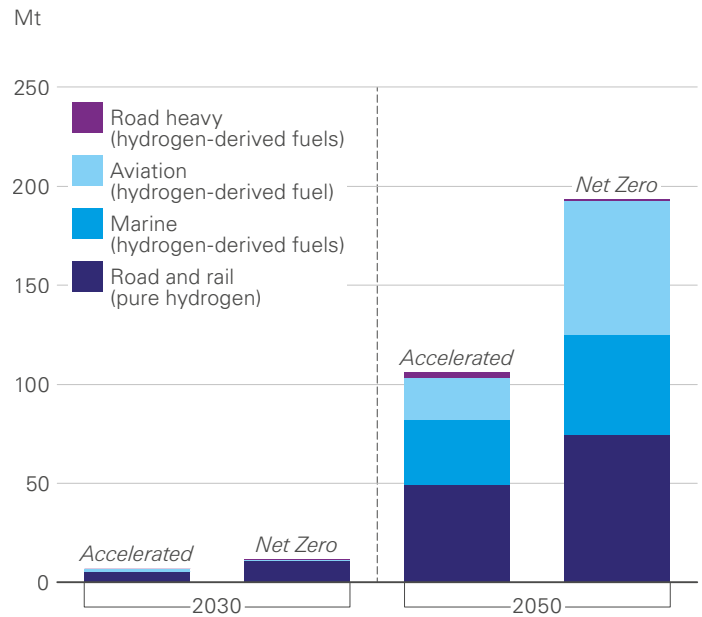
Low-carbon hydrogen is dominated by green and blue hydrogen, with trade in hydrogen a mix of regional pipelines and global shipping

Low-carbon hydrogen plays a critical role in helping the energy system to decarbonize

Low-carbon hydrogen demand



Low-carbon hydrogen demand in transport



Key points

The use of low-carbon hydrogen grows as the world transitions to a more sustainable energy system, helping to decarbonize hard-to-abate processes and activities in industry and transport.

- ▶ The use of low-carbon hydrogen is most pronounced in *Accelerated* and *Net Zero*, complementing growing electrification of the energy system by acting as a carrier of low-carbon energy for activities that are difficult to electrify. The lower degree of decarbonization in *New Momentum* means low-carbon hydrogen plays a relatively limited role.
- ▶ The growth of low-carbon hydrogen during the first decade or so of the outlook is relatively slow, reflecting both the long lead times to establish low-carbon hydrogen projects and the need for considerable policy support to incentivize its use in place of lower-cost alternatives. The demand for low-carbon hydrogen by 2030 is between 30-50 Mtpa in *Accelerated* and *Net Zero*, the majority of which is used as a lower carbon alternative to the existing

unabated gas- and coal-based hydrogen used as an industrial feedstock in refining and the production of ammonia and methanol.

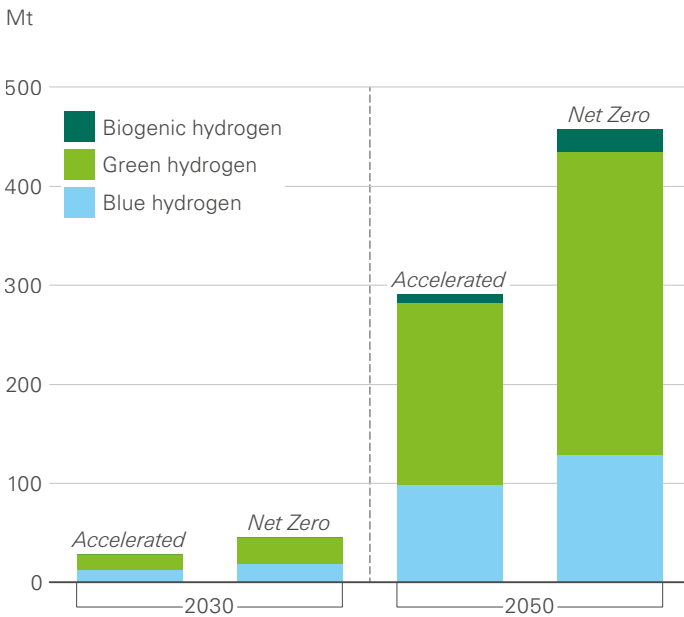
- ▶ The pace of growth accelerates in the 2030s and 2040s as falling costs of production and tightening carbon emissions policies allow low-carbon hydrogen to compete against incumbent fuels in hard-to-abate processes and activities, especially within industry and transport. Demand for low-carbon hydrogen rises by a factor of 10 between 2030 and 2050 in *Accelerated* and *Net Zero*, reaching close to 300 and 460 Mtpa (35-55 EJ) respectively.
- ▶ The use of low-carbon hydrogen in iron and steel production accounts for around 40% of total industrial hydrogen demand by 2050 in *Accelerated* and *Net Zero*, where it acts as an alternative to coal and natural gas as both a reducing agent and a source of energy. The remaining industrial use of hydrogen is in other parts of heavy industry, such as chemicals and cement production, which also require high-temperature heat processes. By

2050, low-carbon hydrogen accounts for around 5-10% of total final energy used in industry in *Accelerated* and *Net Zero*.

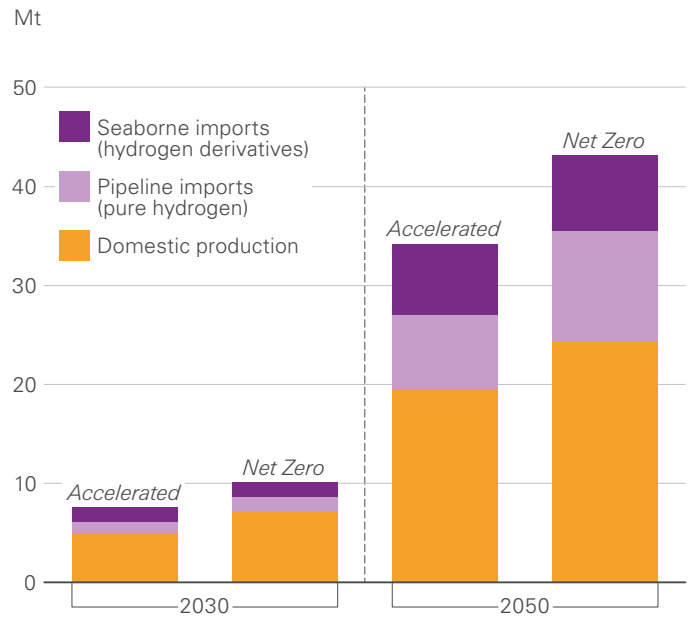
- ▶ The use of hydrogen within transport is heavily concentrated in the production of hydrogen-derived fuels used to decarbonize long-distance transportation in marine (in the form of ammonia, methanol, and synthetic diesel) and in aviation (in the form of synthetic jet fuel). These hydrogen-derived fuels account for between 10-30% of final aviation energy demand by 2050 and 30-55% of final energy use in the marine sector in *Accelerated* and *Net Zero*. Most of the remainder is used directly in heavy duty road transport. By 2050, low-carbon hydrogen and hydrogen-derived fuels account for between 10-20% of total final energy used by the transport sector in *Accelerated* and *Net Zero*.
- ▶ The production of some hydrogen derived fuels requires sources of carbon-neutral feedstocks. These can be derived from either biogenic sources or from direct air capture (see pages 78-79).

Low-carbon hydrogen is dominated by green and blue hydrogen, with trade in hydrogen a mix of regional pipelines and global shipping

Global low-carbon hydrogen supply



Sources of EU low-carbon hydrogen



Key points

Low-carbon hydrogen is dominated by a combination of green hydrogen, made via electrolysis using renewable power, and blue hydrogen, made from natural gas (or coal) with the associated carbon emissions captured and stored. Hydrogen trade occurs via regional pipelines or global shipping depending on the form in which the hydrogen is used.

- ▶ At present, the cost of producing blue hydrogen is generally lower than for green hydrogen in most parts of the world. However, the combination of recent policy initiatives (such as the Inflation Reduction Act in the US – see pages 36-37) and higher natural gas prices in Europe and Asia as a result of the Russia-Ukraine war (see pages 34-35) has reduced this cost advantage in some countries and regions. This cost differential is further eroded over the outlook as improvements in technology and manufacturing efficiency lower the price of both renewable power and electrolyzers.
- ▶ As a result, green hydrogen accounts for around 60% of low-carbon hydrogen in 2030 in *Accelerated* and *Net Zero*, with that share increasing to around 65% by 2050. Most of the remaining hydrogen is provided by blue hydrogen, with a small amount produced from bioenergy combined with carbon capture and storage (BECCS). Blue hydrogen acts as an important complement to green hydrogen providing, a lower-cost alternative in some regions as well as providing a source of firm (non-variable) low-carbon hydrogen supply. The growth of blue hydrogen also reduces the extent to which renewable energy is diverted from decarbonizing electricity that is consumed directly.
- ▶ The nature of hydrogen trade is likely to vary depending on its final use. For activities and processes that require hydrogen in its pure form – such as for high temperature heat processes in industry or for use in road transport – the gas is likely to be imported via pipelines from regional markets, reflecting the high cost of shipping pure hydrogen. In contrast, for activities that can use hydrogen derivatives, such as ammonia and methanol in marine or hydrogen-derived hot briquetted iron (HBI) in iron and steel manufacturing, the lower cost of shipping these derivatives allows imports from the most cost-advantaged locations globally.
- ▶ For example, the EU produces around 70% of the low-carbon hydrogen it uses in 2030 in *Accelerated* and *Net Zero*, with that share falling to around 60% by 2050. Of the low-carbon hydrogen it imports, around half is transported as pure hydrogen via pipeline from North Africa and other European countries (Norway and the UK); and the other half is imported by sea in the form of hydrogen derivatives from global markets.

Carbon mitigation and removals

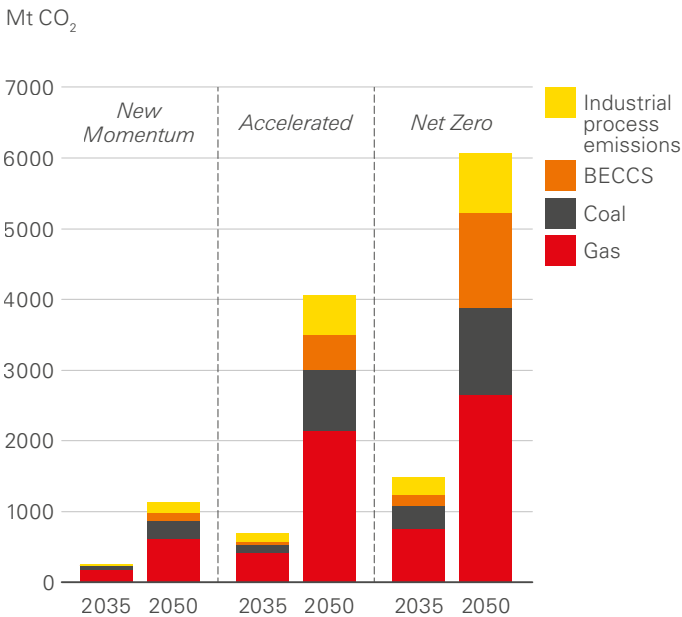


Carbon capture, use and storage plays a central role in enabling deep decarbonization pathways

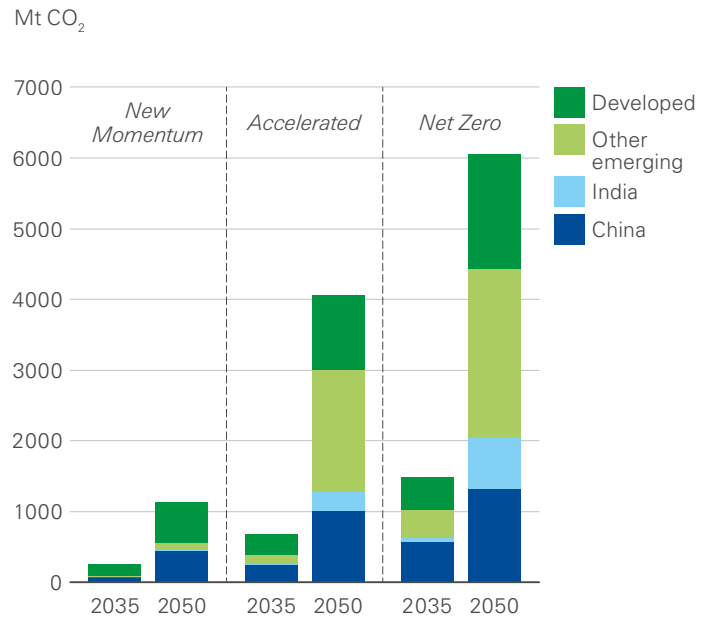
Carbon dioxide removal is necessary to achieve the Paris climate goals

Carbon capture, use and storage plays a central role in enabling deep decarbonization pathways

Carbon capture, use and storage by emissions source



Carbon capture, use and storage by region



Key points

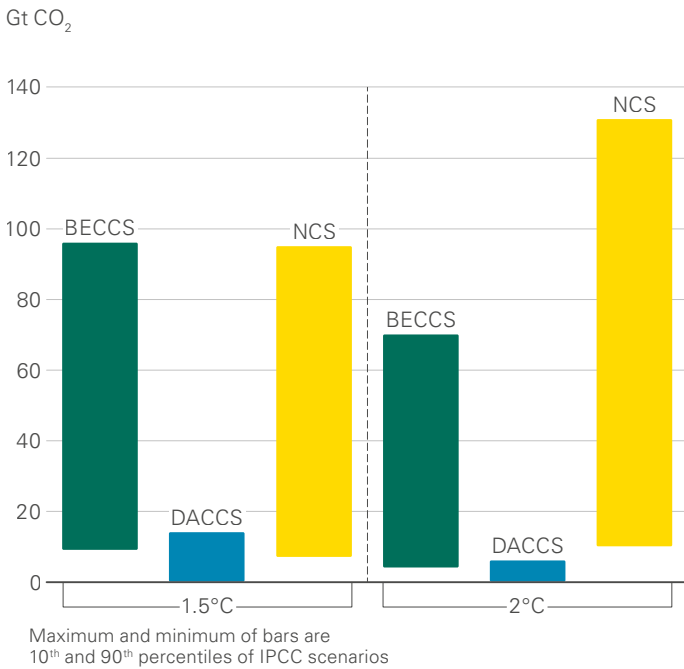
Carbon capture, use and storage plays a central role in supporting the transition to a low-carbon energy system: capturing industrial process emissions, acting as a source of carbon dioxide removal, and abating emissions from the use of fossil fuels.

- ▶ Carbon capture, use and storage (CCUS) reaches between 4-6 GtCO₂ by 2050 in *Accelerated* and *Net Zero*, compared with 1 GtCO₂ in *New Momentum*. The long lead times associated with developing storage sites and their related transport infrastructure means that most of this capacity is completed in the second half of the *Outlook*.
- ▶ In all the scenarios, around 15% of the CCUS operating in 2050 is used to capture and store non-energy process emissions from cement production, which has limited decarbonization alternatives.
- ▶ The use of CCUS with bioenergy (BECCS) provides both a source of energy and a form of carbon dioxide removal (see pages 78-79). BECCS accounts for around 10% of CCUS in *New Momentum* and *Accelerated* in 2050 and around 20% in *Net Zero*.
- ▶ The remaining CCUS is utilized to abate emissions from the use of natural gas and coal.
- ▶ In *Accelerated* and *Net Zero*, the deployment of CCUS with natural gas is spread broadly equally across the use of natural gas to produce blue hydrogen (see pages 72-73), to abate emissions in the power sector and to capture emissions from the combustion of gas in industry. The greatest use of CCUS with natural gas occurs in the US, followed by the Middle East, Russia, and China – which combined account for around two-thirds of CCUS deployed with natural gas in 2050 in *Accelerated* and *Net Zero*.
- ▶ The vast majority of CCUS with coal is used in regions with relatively new coal-based assets in the power and steel sectors, largely in emerging Asia, led by China.
- ▶ In *Accelerated* and *Net Zero*, over 70% of the global deployment of CCUS in 2050 is in emerging economies, led by China and India. This requires a very rapid scale-up of CCUS in these countries relative to their historical levels of oil and gas production, which can be used as an indicator of the geological suitability and engineering capability to develop industrial scale CCUS facilities*.

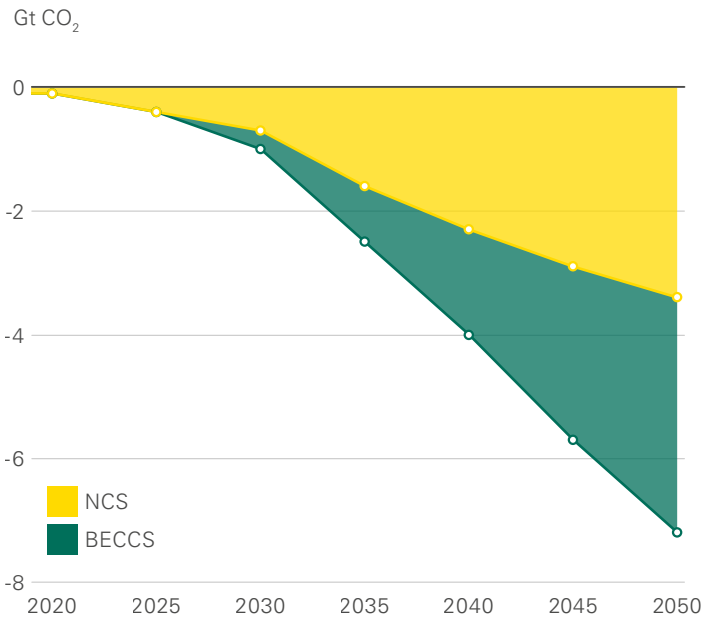
* Lane et al. (2021): Uncertain storage prospects create a conundrum for carbon capture and storage ambitions

Carbon dioxide removal is necessary to achieve the Paris climate goals

Cumulative carbon dioxide removal in IPCC scenarios: 2015-2050



Annual carbon dioxide removal in median IPCC 1.5°C scenario



Key points

The IPCC, in its Sixth Assessment Report, stated that carbon dioxide removal (CDR) is necessary to counteract hard-to-abate emissions and achieve the Paris climate goals. This includes bioenergy combined with CCUS, natural climate solutions, and direct air carbon capture with storage.

- ▶ Bioenergy combined with CCUS (BECCS) has the benefit that it generates useful energy as well as negative carbon emissions. However, the extent to which it can be scaled is limited by the need to ensure the sustainability of the biomass used and by the competition with other priority uses for that biomass.
- ▶ Natural climate solutions (NCS) conserve, restore or manage forests, wetlands, grasslands and agricultural lands to increase carbon storage or avoid greenhouse gas emissions. In doing so, NCS can either reduce CO₂ emissions or remove CO₂ already in the atmosphere. NCS can have important co-benefits, such as promoting biodiversity, but can face challenges in ensuring and monitoring their effectiveness and permanence.
- ▶ Direct air carbon capture with storage (DACCS) is a process of capturing CO₂ directly from ambient air and then storing it. DACCS has the advantage that it has the potential to be scaled materially, located in the most advantaged regions, and provide considerable certainty on permanence and additionality. However, the current costs of DACCS are high relative to other forms of CDR, reflecting both its relatively low technological maturity and its inherent high energy requirements.
- ▶ The uncertainties associated with all forms of CDR means that the IPCC scenarios included in the Sixth Assessment Report include a range of outcomes for the different types of CDR. But all highlight the need for tens to hundreds of gigatons cumulatively out to 2050.
- ▶ The median IPCC 1.5°C scenario includes a rapid scale-up of both NCS and BECCS, reaching over 7 GtCO₂ per annum by 2050. The pace at which these forms of CDR grow means they help to accelerate the pace of decarbonization over coming decades, as well as offset hard-to-abate emissions in a net zero system.
- ▶ Although few of the modelled pathways included in the IPCC's Sixth Assessment Report embody a material role for DACCS, more recent analysis by the IEA and the Energy Transitions Commission* envisage a larger role for it.

Synthetic fuel CO₂ feedstock requirement

- ▶ The production of some hydrogen-derived fuels - primarily synthetic jet fuel, but also synthetic diesel and methanol (see pages 42-43) – require a carbon-neutral feedstock. This can be sourced from either bioenergy with carbon capture or direct air capture. Although the source is not explicitly modelled in the *Outlook*, the CO₂ requirement for hydrogen-derived fuels by 2050 is around 200 and 500 Mtpa for *Accelerated* and *Net Zero*, respectively.

*International Energy Agency, World Energy Outlook 2022; Energy Transitions Commission, Mind the Gap: How Carbon Dioxide Removals Must Complement Deep Decarbonization to Keep 1.5°C Alive, March 2022

Investment and critical minerals

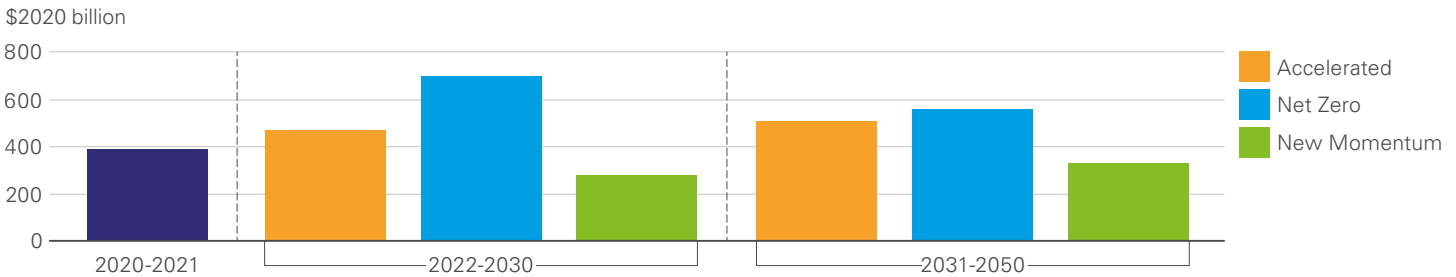


Investment in wind and solar capacity increases sharply and continues in oil and natural gas

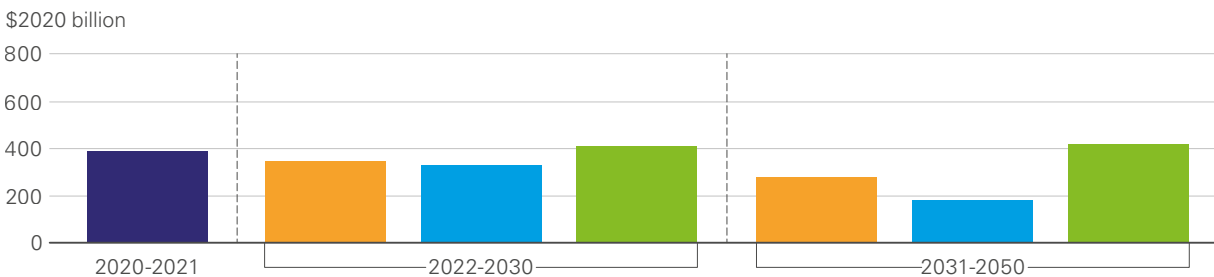
The energy transition leads to a significant increase in the demand for critical minerals

Investment in wind and solar capacity increases sharply and continues in oil and natural gas

Average annual investment in wind and solar



Average annual investment in upstream oil and gas



Key points

The energy transition requires substantial levels of investment across a wide range of energy value chains. The implied level of investment in wind and solar capacity accelerates markedly from recent levels. Despite declining levels of demand, continuing investment in upstream oil and natural gas is also required.

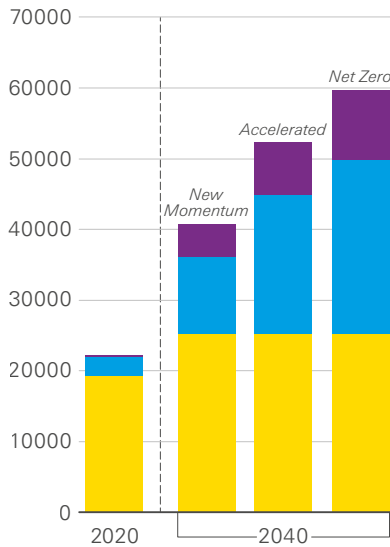
- ▶ The investment estimates considered here refer to investments in wind and solar capacity and in upstream oil and gas production. The assumptions underlying the implied investment requirements, and the associated uncertainties, are described in the Annex (see pages 94-95).
- ▶ The energy pathways envisaged by the three scenarios also require substantial investment in other types of assets not included in these estimates, such as electricity distribution and transmission networks, pipelines for transporting low-carbon hydrogen and CO₂, and new facilities for producing bio- and hydrogen-based fuels.
- ▶ The central role that wind and solar energy play in the production of low-carbon electricity requires a substantial acceleration in the investment in new capacity. In *Accelerated* and *Net Zero*, the average level of annual investment over the rest of this decade is between 20-80% higher than recent levels. The falling cost of wind and solar energy (see pages 56-57) means that investment expenditure in *New Momentum* out to 2030 is lower than recent levels whilst maintaining a similar pace of increase in new capacity deployed; investment spending scales up in the second half of the outlook as deployment accelerates.
- ▶ In *Accelerated* and *Net Zero*, around 70% of the investment in new wind and solar capacity over the outlook occurs in emerging economies. This underlines the importance that renewable developers in these economies have good access to capital and finance.
- ▶ Although the demand for oil and gas falls in all three scenarios, natural base decline in existing production means that continuing investment in upstream oil and natural gas assets is required in all three scenarios to meet future demand. This includes investment across a range of different types of supply (brownfield, greenfield, and tight oil and natural gas). The uncertainty surrounding the prospects for future oil and natural gas demand means shorter-cycle and phased production opportunities with greater optionality become increasingly important over time.
- ▶ The implied rates of investment in upstream oil and gas in the second half of the outlook, especially in *Accelerated* and *Net Zero*, are lower than levels in the recent past and significantly less than the required investment in wind and solar capacity.
- ▶ The average annual investment in upstream oil and natural gas over the rest of this decade in the three scenarios is between \$325-\$405 billion, compared with \$395 billion in the recent past*.

*Upstream oil and gas investment includes capital expenditures on wells construction, facilities and exploration. It does not include operational expenditures.

The energy transition leads to a significant increase in the demand for critical minerals

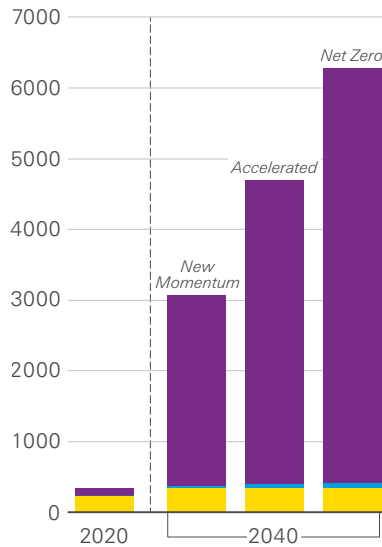
Copper demand

kt



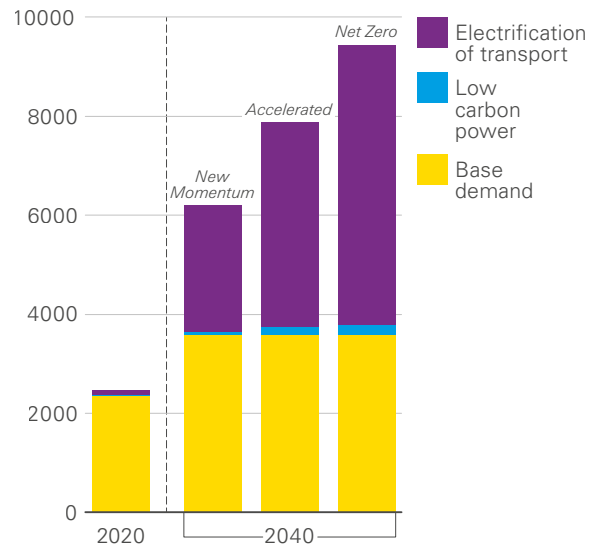
Lithium demand

kt, Lithium carbonate equivalent



Nickel demand

kt



Key points

The shift to a low-carbon energy system requires a substantial increase in the use of a range of minerals critical for the infrastructure and equipment supporting this transition.

- ▶ The increasing demands for minerals and materials associated with the energy transition come from across the low-carbon energy system, including the construction of wind and solar facilities, batteries, hydrogen and CO₂ pipelines, and new storage facilities. Two particularly important sources of demand in this year's *Outlook* stem from:
 - ▶ Growth in low-carbon power requiring a substantial expansion in the grid and distribution systems used to connect renewable assets and deliver electricity to its end use.
 - ▶ Electrification of road transport leading to a global car parc of between 1-2 billion electric vehicles by 2050, implying an increased demand for annual battery capacity within road transport of between 10-20 TWh.

- ▶ The growing requirements associated with the energy transition, along with the broader economic expansion envisaged over the outlook, have important implications for a range of minerals critical for the transition. Below we look at just three: copper, lithium, and nickel.

- ▶ **Copper:** The future growth of copper is dominated by its use in the construction of new electricity networks for low-carbon power, which increases between four- and seven-fold out to 2040 in the three scenarios. Total copper demand grows between two and three times over this period: 65-85% of the growth is due to the increasing demand for copper to support the transmission of low-carbon power and the electrification of transport. As a result, the use of copper within low-carbon energy activities and electrification of transport accounts for around a half of total copper demand in 2040 in *Accelerated* and *Net Zero* compared with around 15% in 2020.
- ▶ **Lithium:** The growing demand for lithium over the outlook is driven by its use in

electric vehicles, which grows by a factor of between 25 and 60 out to 2040 across the three scenarios. This use accounts for 85-95% of the aggregate demand for lithium in 2040, compared with 30% in 2020.

- ▶ **Nickel:** Increasing demand for nickel is also driven by its role in the electrification of transport. Total nickel demand increases between 2.5-4 times out to 2040 across the three scenarios – 65-80% of that growth is due to the increasing use of lithium-ion batteries in electric vehicles.
- ▶ The scenarios assume that the supply of critical minerals scales to meet these increasing demands. This requires a significant increase in investment and resources within the critical minerals mining sector, as well as an acceleration in planning and permitting lead times. The challenge associated with this scaling up is compounded by the need to maintain close scrutiny on the sustainability of new and existing mining activity.

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Data tables

	2019	Level in 2050*			Change 2019-2050 (p.a.)			Share of primary energy in 2050		
		Acc	Net Zero	NMS	Acc	Net Zero	NMS	Acc	Net Zero	NMS
Primary energy by fuel										
Total	627	666	630	733	0.2%	0.0%	0.5%	100%	100%	100%
Oil	193	78	39	140	-2.9%	-5.0%	-1.0%	12%	6%	19%
Natural gas	140	87	60	166	-1.5%	-2.7%	0.5%	13%	9%	23%
Coal	158	23	17	96	-6.0%	-7.0%	-1.6%	4%	3%	13%
Nuclear	25	40	47	28	1.5%	2.1%	0.4%	6%	7%	4%
Hydro	38	61	65	48	1.6%	1.8%	0.8%	9%	10%	7%
Renewables (incl. bioenergy)	74	377	403	256	5.4%	5.6%	4.1%	57%	64%	35%
Native units										
Oil (Mb/d)	98	42	21	73						
Natural gas (Bcm)	3900	2422	1658	4616						
Primary energy by region										
Developed	234	171	162	199	-1.0%	-1.2%	-0.5%	26%	26%	27%
US	97	76	74	89	-0.8%	-0.9%	-0.3%	11%	12%	12%
EU	65	45	42	51	-1.2%	-1.4%	-0.8%	7%	7%	7%
Emerging	393	495	468	534	0.8%	0.6%	1.0%	74%	74%	73%
China	147	149	138	160	0.0%	-0.2%	0.3%	22%	22%	22%
India	42	88	88	94	2.5%	2.4%	2.6%	13%	14%	13%
Middle East	37	47	45	48	0.7%	0.6%	0.8%	7%	7%	7%
Russia	30	30	26	32	-0.1%	-0.4%	0.1%	4%	4%	4%
Brazil	16	17	15	18	0.2%	-0.1%	0.5%	2%	2%	3%

	2019	Level in 2050*			Change 2019-2050 (p.a.)			Share of total final consumption in 2050		
		Acc	Net Zero	NMS	Acc	Net Zero	NMS	Acc	Net Zero	NMS
Total final consumption by sector										
Total	477	398	335	513	-0.6%	-1.1%	0.2%	100%	100%	100%
Transport	119	100	90	114	-0.6%	-0.9%	-0.1%	25%	27%	22%
Industry	188	153	128	203	-0.7%	-1.3%	0.2%	38%	38%	40%
Feedstocks	38	36	27	45	-0.2%	-1.0%	0.6%	9%	8%	9%
Buildings	132	110	90	151	-0.6%	-1.2%	0.4%	28%	27%	29%
Generation by carrier										
Electricity ('000 TWh)	27	57	61	50	2.4%	2.7%	2.0%	52%	66%	35%
Hydrogen (Mt)	66	301	460	165	5.0%	6.4%	3.0%	9%	17%	4%
Production										
Oil (Mb/d)	98	42	21	73	-2.7%	-4.8%	-0.9%			
Natural gas (Bcm)	3976	2422	1658	4616	-1.6%	-2.8%	0.5%			
Coal (EJ)	168	27	15	92	-5.7%	-7.4%	-1.9%			
Emissions										
Net emissions from energy and industry (Gt of CO ₂ e)	39.8	9.1	2.0	28.7	-4.7%	-9.1%	-1.1%			
Carbon capture use & storage (Gt)	0.0	4.1	6.1	1.1	56%	58%	49%			
Macro										
GDP (trillion US\$ PPP)	128	266	266	266	2.4%	2.4%	2.4%			
Energy intensity (MJ of TFC per US\$ of GDP)	3.7	1.5	1.3	1.9	-2.9%	-3.5%	-2.1%			

*Exajoules (EJ) unless otherwise stated

Modelling the impact of the Russia-Ukraine war on the global energy system

The impact of the Russia-Ukraine war was modelled by capturing three types of economic shock associated with the war: near-term commodity price (stagflation) shock, heightened energy security concerns, and a reduced pace of globalization.

Commodity price shock

This shock is modelled as a sharp but transitory increase in fossil fuel prices, combined with significantly lower global GDP. Real interest rates are also higher as central banks tighten monetary policy to control inflation, which increase the levelized costs of different energy sources, affecting the relative prices of alternative technologies. The shock dissipates by 2030, by which time prices and, in almost all cases, GDP levels have returned to their long-term trend. The exception to this is the level of GDP in Russia and Ukraine, where the war is

assumed to have a persistent negative impact on GDP.

Heightened energy security concerns

The Russia-Ukraine war is assumed to cause governments to implement policies to reduce their dependency on imported energy. The shock is modelled by adding a c.30% 'security' premium to the price of the energy imported into each region or country. This premium is increased to roughly 60% for energy imported by the EU given its particular exposure to war-related disruption and the need to reduce imports from Russia rapidly. The security premium imposed on imported energy increases the competitiveness of domestically produced energy, including renewables, nuclear and hydro power.

Reduced pace of globalization

The war in Ukraine is assumed to reduce the pace of globalization, as countries and regions heighten their focus on domestic resilience and reduce their exposure to international shocks. The lower profile for international trade and openness has a small but negative impact on global economic growth. Although the effect is small on a yearly basis – reducing average annual growth by around 0.1 percentage point – the impact on the level of GDP compounds over time, reducing the level of global GDP by around 4% in 2050.

The impact from this reduced pace of globalization is assumed to have different effects in different countries and regions: with those economies whose future economic growth is particularly dependent on international trade and on the sharing of ideas and productivity the most heavily impacted. For example, the shock has a much larger impact on emerging Asian economies than on the United States. The methodology used to calibrate the deglobalization shock is based on the trade growth literature, including studies by the World Bank (2017) and Alcalá and Ciccone (2004).

Although these three shocks are assumed to take effect immediately, their peak effects occur over different time frames. In the short term (up until around 2025), the commodity price shock is the most impactful. In the medium term (around 2030-2035), the impact from heightened energy security concerns has the largest impact on the energy system. In the longer term, the lower level of global activity caused by reduced pace of globalization is preeminent.

Sources:

World Bank (2017) 'The Global Costs of Protectionism'. Policy Research working paper, no. WP 8277.

Alcalá, F. and Ciccone, A. (2004) 'Trade and Productivity'. *The Quarterly Journal of Economics*, 119 (2), pp. 613-646.

The economic impact of climate change

The GDP profiles used in the *Energy Outlook* come from Oxford Economics (OE). These long-term forecasts incorporate estimates of the economic impact of climate change. These estimates draw on the latest research in the scientific literature and follow a similar methodology to that used in *Energy Outlook 2020* and *Energy Outlook 2022*.

OE updated and extended the estimation approach developed by Burke, Hsiang and Miguel (2015), which suggests a non-linear relationship between productivity and temperature, in which per capita income growth rises to an average (population weighted) temperature of just under 15°C ((Burke et al.'s initial assessment was 13°C). This temperature curve suggests that 'cold country' income growth increases with annual temperatures. However, at annual temperatures above 15°C, per capita

income growth is increasingly adversely affected by higher temperatures.

The OE emissions forecasts are broadly in line with the IEA STEPS scenario and assume average global temperatures will reach 2°C above pre-industrial levels by 2050. The results suggest that in 2050 global GDP is around 2% lower than in a counterfactual scenario where the temperature change remained at the current level. The regional impacts are distributed according to the evolution of their temperatures relative to the concave function estimated by OE. While OE's approach captures channels associated with average temperatures, these estimates remain uncertain and incomplete; they do not, for example, explicitly include impact from migration or extensive coastal flooding.

The mitigation costs of actions to decarbonize the energy system are also uncertain, with significant variations across different external estimates. Most estimates, however, suggest that the upfront costs increase with the stringency of the mitigation effort, suggesting that they are likely to be bigger in *Accelerated* and *Net Zero* than in *New Momentum*. Estimates published by the IPCC (AR5 – Chapter 6) suggest that for scenarios consistent with keeping global temperature increases to well below 2°C, median estimates of mitigation costs range between 2-6% of global consumption by 2050.

Given the huge range of uncertainty surrounding estimates of the economic impact of both climate changes and mitigation, and the fact that all three of the main scenarios include both types of costs to a greater or lesser extent, the GDP profiles used in the *Outlook* are based on the illustrative assumption that these effects reduce GDP in 2050 by around 2% in all three scenarios, relative to the counterfactual in which temperatures are held constant at recent average levels.

Sources:

Burke, M., Hsiang, S. & Miguel, E. Global non-linear effect of temperature on economic production. *Nature* 527, 235–239 (2015) <https://www.nature.com/articles/nature15725>

The global aggregate mitigation cost estimates in terms of GDP losses are taken from IPCC AR5 – Chapter 6: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter6.pdf

Investment methodology

Oil and gas upstream

Implied levels of oil and gas investment are derived from the production levels in each scenario. Upstream oil and natural gas capital expenditure includes well capex (costs related to well construction, well completion, well stimulation, steel costs and materials), facility capex (costs to develop, install, maintain, and modify surface installations and infrastructure) and exploration capex (costs incurred to find and prove hydrocarbons). It excludes operating costs and midstream capex such as capex associated with developing LNG liquefaction capacity.

Asset level production profiles are aggregated by geography, supply segment (onshore, offshore, shale and oil sands), supply type (crude, condensates, NGLs, natural gas) and developmental stage, i.e., classified by whether the asset is currently producing, under development, or non-producing and unsanctioned. As production from producing and sanctioned assets declines, incremental production from infill drilling and new, unsanctioned assets is called on to meet the oil and gas demand shortfalls. The investment required to bring this volume online is then added to any capital costs associated with maintaining

producing and sanctioned projects. The average 2022-2050 decline rate for assets currently producing and under development is around 4.5% p.a. for both oil and for natural gas, although this varies widely by segment and hydrocarbon type. All estimates are derived using asset-level assessments from Rystad Energy.

Wind and solar

Wind and solar energy investment requirements are based on the capital expenditure costs associated with the deployment profiles of each technology in each scenario.

Wind and solar deployment profiles include both renewable power capacity for end-use and for green hydrogen production. The deployment profiles also consider the potential impact of curtailment.

Capital expenditure costs are assigned to each scenario based on their historical values and estimated future evolution. They are differentiated by technology, region and scenario using a combination of internal bp estimates and external benchmarking. The capital expenditure figures do not include the incremental wider system integration costs associated with wind and solar deployment.

Carbon emissions definitions and sources

Unless otherwise stated, carbon emissions refer to CO₂ emissions from:

- ▶ energy use (i.e. the production and use of energy in the three final end-use sectors: industry, transport and buildings),
- ▶ most non-energy related industrial processes,
- ▶ natural gas flaring,
- ▶ methane emissions associated with the production, transmission and distribution of fossil fuels, expressed in CO₂ equivalent terms.

CO₂ emissions from industrial processes refer only to non-energy emissions from cement production. CO₂ emissions associated with the production of hydrogen feedstock for ammonia and methanol are included under hydrogen sector emissions.

Historical data for natural gas flaring data is taken from VIIRS Nightfire (VNF) data and produced by the Earth Observation Group (EOG), Payne Institute for Public Policy, Colorado School of Mines. The profiles for natural gas flaring in the scenarios assume that flaring moves in line with wellhead upstream output.

Historical data on methane emissions associated with the production, transportation and distribution of fossil fuels are sourced from IEA estimates of greenhouse gas emissions. The profiles for future methane emissions assumed in the scenarios are based on fossil fuel production and take account of recent policy initiatives such as the Global Methane Pledge. The net change in methane emissions is the aggregation of future changes to fossil fuel production and methane intensity.

There is a wide range of uncertainty with respect to both current estimates of methane emissions and the

global warming potential of methane emissions. The methane to CO₂e factor used in the scenarios is a 100-year Global Warming Potential (GWP) of 25, recommended by the IPCC in AR4. This conversion factor is used to ensure alignment with financial and government reporting standards, and to ensure consistency across all bp corporate reporting. In particular, this is the same factor to be used in the bp Annual Report, also published in Q1 2023.

IPCC scenarios and emissions methodology

We use scenarios that are in the database corresponding to the Sixth Assessment Report published in 2022. This database is hosted by the International Institute for Applied Systems Analysis (IIASA) as part of a cooperation agreement with Working Group III of the IPCC.

The scenarios used in the analysis are those labelled as:

Scenarios C1: these scenarios are referred to as scenarios that limit warming to 1.5°C (>50%) with no or limited overshoot.

Scenarios C3a: these scenarios are referred to as scenarios that limit warming to 2°C (>67%) with immediate action.

Cumulative CO₂e emissions in 2015-2050 are the addition of CO₂ emissions from energy and industrial processes and methane emissions from energy supply transformed into CO₂e using a factor Global Warming Potential of 25. The AR6 Scenarios Database report

data for every five years. For the missing intermediate years, a linear interpolation is used.

Sources

Andrew, R.M., 2019. Global CO₂ emissions from cement production, 1928–2018. *Earth System Science Data* 11, 1675–1710, (updated dataset July 2021)

IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).

VIIRS Nightfire (VNF) produced by the Earth Observation Group (EOG), Payne Institute for Public Policy, Colorado School of Mines.

IEA (2021), Greenhouse Gas Emissions from Energy Data Explorer, IEA, Paris
IPCC Fourth Assessment Report: Climate Change 2007.

IPCC Sixth Assessment Report – Climate Change 2022: Impacts, Adaptation and Vulnerability

IEA (2021), Methane Tracker 2021, IEA, Paris

Sustainability Reporting Guidance for the Oil and Gas Industry, 4th Edition, 2020. IPIECA/API/IOGP.

Edward Byers, Volker Krey, Elmar Kriegler, Keywan Riahi, Roberto Schaeffer, Jarmo Kikstra, Robin Lamboll, Zebedee Nicholls, Marit Sanstad, Chris Smith, Kaj-Ivar van der Wijst, Alaa Al Khourdajie, Franck Lecocq, Joana Portugal-Pereira, Yamina Saheb, Anders Strømman, Harald Winkler, Cornelia Auer, Elina Brutschin, Matthew Gidden, Philip Hackstock, Mathijs Harmsen, Daniel Huppmann, Peter Kolp, Claire Lepault, Jared Lewis, Giacomo Marangoni, Eduardo Müller-Casseres, Ragnhild Skeie, Michaela Werning, Katherine Calvin, Piers Forster, Celine Guivarch, Tomoko Hasegawa, Malte Meinshausen, Glen Peters, Joeri Rogelj, Bjorn Samset, Julia Steinberger, Massimo Tavoni, Detlef van Vuuren. AR6 Scenarios Database hosted by IIASA International Institute for Applied Systems Analysis, 2022.

Other data definitions and sources

Data definitions are based on the bp Statistical Review of World Energy, unless otherwise noted. Data used for comparisons, unless otherwise noted, are rebased to be consistent with the bp Statistical Review.

Primary energy, unless otherwise noted, comprises commercially traded fuels and traditional biomass. In this Outlook, primary energy is derived using:

- ▶ the substitution method - which grosses up energy derived from non-fossil power by the equivalent amount of fossil fuel required to generate the same volume of electricity in a thermal power station. The grossing up assumption is time varying, with the simplified assumption that efficiency will increase linearly from 40% today to 45% by 2050

Gross Domestic Product (GDP) is expressed in terms of real Purchasing Power Parity (PPP) at 2015 prices.

Sectors

Transport includes energy used in heavy road, light road, marine, rail and aviation. Electric vehicles include all four wheeled vehicles capable of plug-in electric charging. Industry includes energy used in commodity and goods manufacturing, construction, mining, the energy industry including pipeline transport, and for transformation processes outside of power, heat and hydrogen generation. Feedstocks includes non-combusted fuel that is used as a feedstock to create materials such as petrochemicals, lubricant and bitumen. Buildings includes energy used in residential and commercial buildings, agriculture, forestry, and fishing.

Regions

Developed is approximated as North America plus Europe plus Developed Asia. Emerging refers to all other countries and regions not in Developed. China refers to the Chinese Mainland. Developed Asia includes OECD Asia plus other high income Asian countries and regions. Emerging Asia includes all countries and regions in Asia excluding mainland China, India and Developed Asia.

Fuels, energy carriers, carbon and materials

Oil, unless otherwise noted, includes crude (including shale oil and oil sands), natural gas liquids (NGLs), gas-to-liquids (GTLs), coal-to-liquids (CTLs), condensates, and refinery gains. Hydrogen-derived fuels are all fuels derived from low-carbon hydrogen, including ammonia, methanol, and other synthetic hydrocarbons.

Renewables, unless otherwise noted, includes wind, solar, geothermal, biomass, biomethane, and biofuels and exclude large-scale hydro. Non-fossils include renewables, nuclear and hydro. Traditional biomass refers to solid biomass (typically not traded) used with basic technologies e.g. for cooking.

Hydrogen demand includes its direct consumption in transport, industry, buildings, power and heat, as well as feedstock demand for the production of hydrogen-derived fuels and for conventional refining and petrochemical feedstock demand.

Low-carbon hydrogen includes green hydrogen, and hydrogen produced from biomass with CCUS, gas with CCUS, and coal with CCUS. CCUS options include CO₂ capture rates of 93-98% over the *Outlook*. The global average methane emissions rate for the gas or coal consumed to produce blue hydrogen is between 1.4-0.7% over the *Outlook*.

Key data sources

BP p.l.c., bp Statistical Review of World Energy, London, United Kingdom, June 2021

International Energy Agency, World Energy Statistics, September 2021

International Energy Agency, World Energy Balances, July 2021

Oxford Economics, Global GDP Forecasts, 2022

United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. Rev. 1

IEA (2021), Methane Tracker 2021, IEA, Paris

Sustainability Reporting Guidance for the Oil and Gas Industry, 4th Edition, 2020. IPIECA/API/IOGP.

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