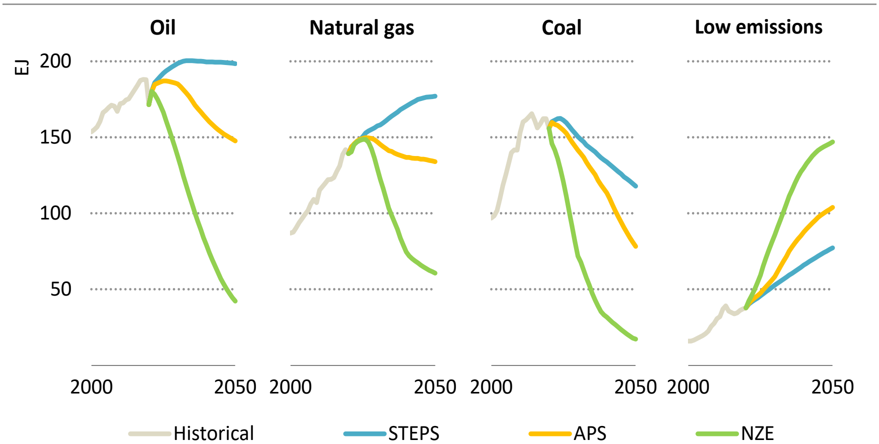
Exploring multiple futures: fuels

Only fuels rush in?

SUMMARY

- For the first time, each of the scenarios examined in this *World Energy Outlook* shows an eventual decline in global oil demand, although the timing and sharpness of the drop vary widely. Today's policy settings, as set out in the Stated Policies Scenario (STEPS), see oil demand level off at 104 million barrels per day (mb/d) in the mid-2030s and then decline very gradually to 2050. In the Announced Pledges Scenario (APS), oil peaks soon after 2025 at 97 mb/d and starts to decline thereafter. Rapid action in the Net Zero Emissions by 2050 Scenario (NZE) to get on track to meet the world's climate goals sees oil demand fall sharply to 72 mb/d in 2030 and continue falling to 24 mb/d by 2050.

Figure 5.1 ▷ Oil, natural gas, coal and low emissions fuel use to 2050



Fuels are an integral part of the energy system in each scenario, but reaching net zero requires a transformation in their production, use and supply chain emissions

Note: Low emissions fuels include low-carbon hydrogen, hydrogen-based fuels and modern bioenergy.

- Natural gas demand increases in each scenario over the next five years, but there are sharp divergences afterwards. Demand in advanced economies declines from the mid-2020s in each scenario, but it falls faster in the APS than in the STEPS and fastest in the NZE. Demand in emerging market and developing economies rises to well above today's level through to 2050 in the APS and still higher in the STEPS, but is kept in check in the NZE. The share of natural gas in the global energy mix remains around 25% to 2050 in the STEPS, while it falls to 20% in the APS and to 11% in the NZE. Around 70% of natural gas use in 2050 in the NZE is equipped with carbon capture, utilisation and storage (CCUS).

- Coal faces structural decline in each of the three scenarios. The main question is how quickly demand falls in emerging market and developing economies, which account for more than 80% of current global demand. In the STEPS, global coal demand rises slightly to 2025, but then starts a slow decline to 2050. In the APS, coal use falls significantly after 2030, notably in China, and global demand in 2050 is half of 2020 levels. In the NZE, global coal demand drops by 90% to 2050 and 80% of coal use in 2050 is equipped with CCUS.
- The drive for net zero naturally has strong implications for fossil fuels, but there are nuances across sectors. By 2030, the NZE shows a fall in the use of coal to generate power in advanced economies (90% decline), a fall in oil use in passenger cars globally (40% decline) and a fall in the use of natural gas in buildings globally (35% decline). Yet there are many areas where fossil fuel use remains resilient. These include: coal use in iron and steel production (20% decline to 2030 in the NZE), oil use in aviation (30% increase), and natural gas use in cement production (40% increase).
- Minimising methane leaks and flaring should be a top priority in the quest to reduce greenhouse gas emissions from fossil fuel operations. On average, we estimate that 8% of natural gas and natural gas liquids entering flares are not combusted and leak into the atmosphere; this is more than double previous estimates. Flaring resulted in more than 500 million tonnes of carbon-dioxide equivalent (Mt CO_2-eq) emissions in 2020, which is more than annual CO_2 emissions from all cars in the European Union.
- Countries with net zero pledges need to introduce policies and measures to close the implementation gap between the STEPS and APS, including to reduce demand for fossil fuels, and stimulate demand and production of low emissions fuels. In the NZE, a rapid rise in low emissions fuels is a key reason why no new oil and gas fields are required beyond those already approved for development.
- Around 2 mb/d of biofuels were used in 2020: volumes approximately double to 2030 in the STEPS, increase two-and-half-times in the APS and triple in the NZE. The use of modern forms of solid bioenergy increases by 30-70% across the scenarios to 2030. In the NZE, biogas provides clean cooking access for 400 million people in 2030, while 2.5 exajoules (EJ) of biomethane is consumed and total biogas demand rises to 5.5 EJ.
- The STEPS sees small increases in the use of low-carbon hydrogen to 2030. In the APS and the NZE, demand rises more rapidly as low-carbon hydrogen replaces the current use of hydrogen in industry, low-carbon hydrogen and hydrogen-based fuels are used to provide flexibility in the power sector and new end-uses emerge. The pipeline of planned low-carbon hydrogen production projects is insufficient to meet the levels of use implied by current pledges (2 EJ in the APS) and far short of the levels required in the NZE (17 EJ in 2030). Shipping and aviation drive large increases in the use of low-carbon hydrogen-based liquid fuels in the APS and NZE after 2030.

5.1 Introduction

A commonly-heard rallying cry for clean energy transitions is to "electrify everything". But not everything can be electrified: only in the Net Zero Emissions by 2050 Scenario (NZE) does electricity approach even an equal share of final energy consumption with fuels. This speaks both to the enduring importance of liquid, gaseous and solid fuels in global energy and to the need to transform their production and use as part of the drive for net zero emissions. In all of the *World Energy Outlook-2021* (*WEO-2021*) scenarios, ensuring adequate supplies of both fossil fuels and low emissions fuels is essential to maintain energy security and reduce price volatility during energy transitions.

Efforts to accelerate clean energy transitions present a new and pervasive set of risks for fossil fuel markets, in particular over the outlook for demand and prices. In the Stated Policies Scenario (STEPS), oil and natural gas demand grow to 2030 while coal demand falls only marginally. In the NZE, demand to 2030 falls by nearly 10% for natural gas, 20% for oil and 55% for coal. These variations in demand are matched by differences in prices. The oil price in 2030 in the NZE (USD 35/barrel) is less than half the level in the STEPS (USD 77/barrel).

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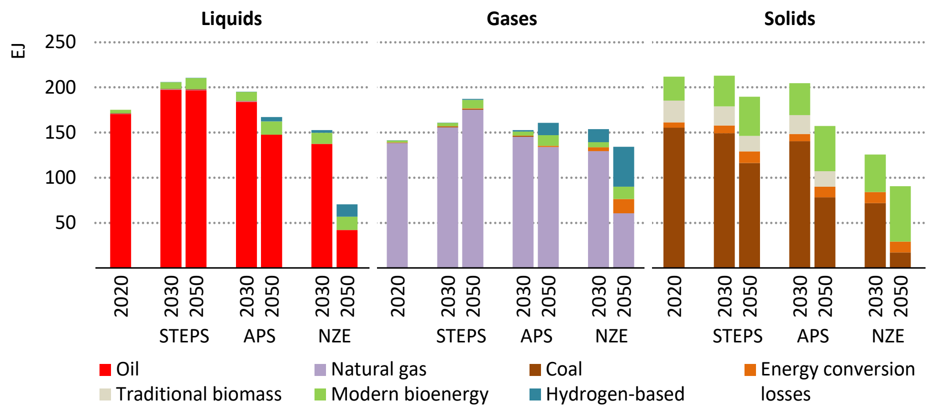
Figure 5.2 ▷ Consumption of liquid, gaseous and solid fuels by scenario



Fuels remain an integral part of the global energy mix to 2050, but there are differences in the outlooks for both fossil and low emissions fuels between scenarios and over time

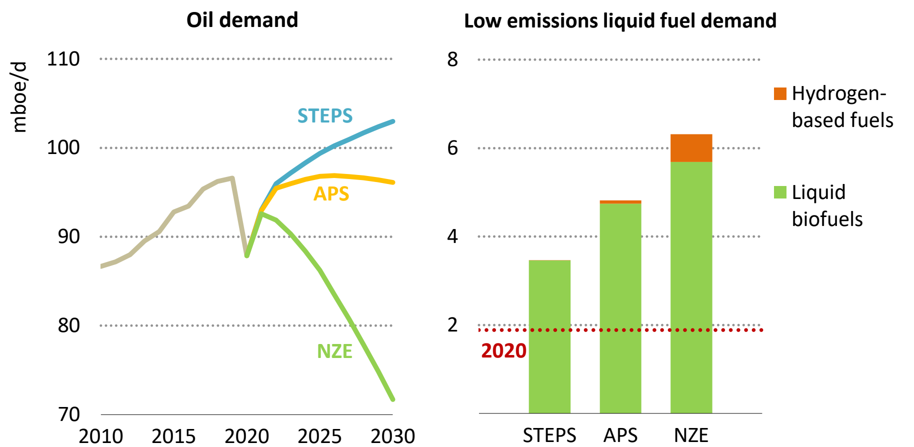
Notes: APS = Announced Pledges Scenario; traditional biomass = traditional use of biomass. Conversion losses = fuel consumed in the transformation process to produce other liquid, gaseous or solid fuels for final consumption.

Yet clean energy transitions also provide new opportunities for fuels, which continue to comprise a large share of total final consumption in each scenario. In the NZE, the share of fossil fuels in final energy consumption drops from 66% in 2020 to just over 20% in 2050, but there is a growing role for alternative low emissions fuels, such as hydrogen-based and modern bioenergy, meaning that the overall drop in fuel demand is much smaller

(Figure 5.2). Policy support for low emissions fuels varies significantly among countries, but they play a key role in the achievement of net zero targets, especially in sectors where direct electrification is most challenging.

5.2 Liquid fuels

Figure 5.3 ▷ Oil demand over time and low emissions fuel demand in 2030



A 31 mboe/d difference in oil demand emerges between the STEPS and NZE by 2030. Biofuels remain the largest low emissions fuel but hydrogen-based fuels increase in the NZE

Note: mboe/d = million barrels of oil equivalent per day.

Activity changes, technology deployment, consumer choices and policy ambition in transport and petrochemicals largely determine the long-term trajectory of global oil demand. In the STEPS, global oil demand exceeds 2019 levels by 2023 before reaching its maximum level of 104 million barrels per day (mb/d) in the mid-2030s and then declining very gradually to 2050 (Figure 5.3). In the APS, global oil demand peaks soon after 2025 and then falls by around 1 mb/d per year to 2050. In the NZE, demand falls by more than 2 mb/d per year between 2020 and 2050.

There has been a strong rebound in oil demand to date in 2021 that has not been matched by a rebound in investment in supply (see Chapter 6). Despite upward pressure on prices, upstream spending in 2021 is set to remain well below 2019 levels. Major international companies are under pressure to diversify spending, while the tight oil industry is demonstrating a new-found commitment to capital discipline, with a number of companies choosing to pay down debt and return money to shareholders. Many national oil companies face severe budgetary constraints and only a handful (including Saudi Aramco and the Abu Dhabi National Oil Company) are in an expansive mode. The differences in demand and price outlooks across our scenarios present a new set of challenges for the industry and will test all of these stances.

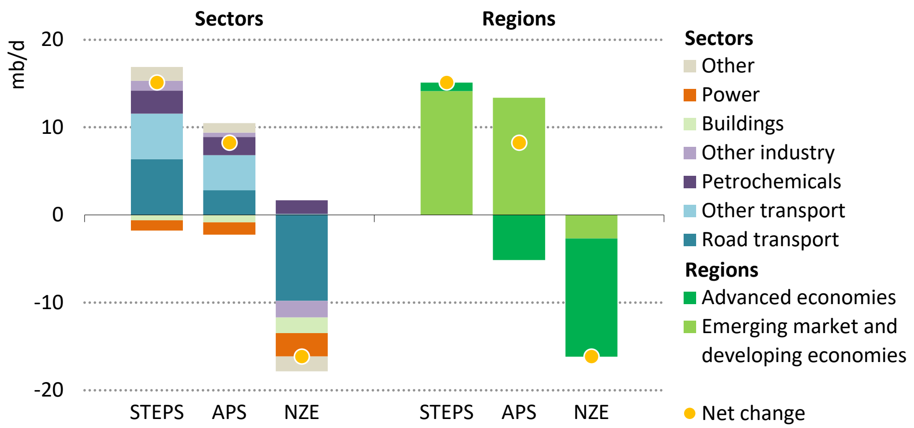
Traditional oil markets could also be challenged by the rise of alternative liquid fuels. Nearly 98% of liquid fuel demand today is met by oil; the remainder is met mainly by conventional liquid biofuels, and by very small quantities of advanced biofuels[1] and hydrogen-based liquid fuels. Biofuel demand increases to 2030 in all scenarios, with a tripling of demand in the NZE. Hydrogen-based fuels are expensive to produce today (e.g. synthetic kerosene costs at least USD 300 per barrel of oil equivalent), and new market frameworks together with major investments in innovation and new large-scale production facilities, will be needed in the 2020s if they are to play a role in the future.

In the APS, consumption of hydrogen-based fuels reaches material levels in the 2030s in countries with net zero pledges. In the NZE, progress is more rapid and more global. These fuels are particularly important in some of the sectors where emissions reductions are likely to be most challenging. In the NZE, for example, hydrogen-based fuels meet 45% of shipping energy demand and 30% of total aviation fuel demand by 2050.

5.2.1 Oil trends to 2030

Demand

Figure 5.4 ▷ Change in oil demand by scenario between 2020 and 2030



The global oil outlook pivots on changes in road transport. Oil use for petrochemicals grows in all scenarios mainly as a result of large increases in the Middle East, China and India

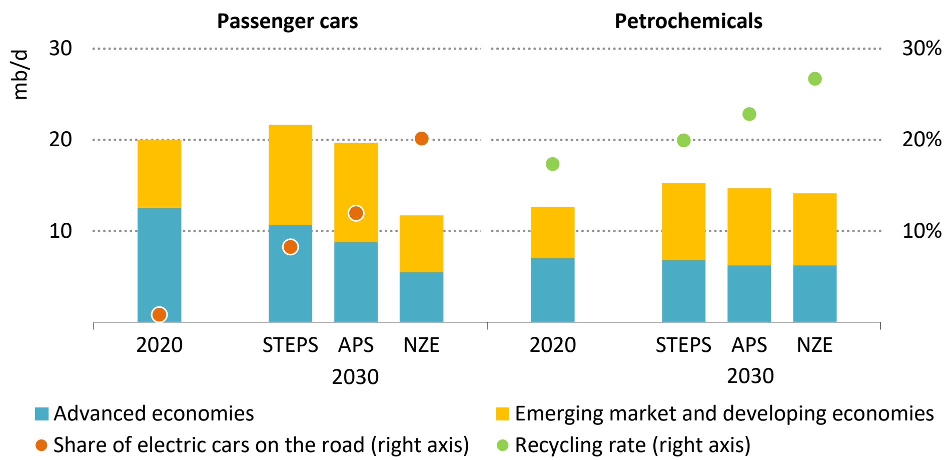
Note: Other includes agriculture and other energy sector.

Passenger cars use the largest volume of oil of any sector today and in 2020 they consumed around 20 mb/d. In the STEPS, demand by passenger cars increases by around 2 mb/d through to 2030, with a particularly sharp rise in 2021 due to the gradual relaxation of

[1] Advanced biofuels are produced from non-food crop feedstocks, result in significantly fewer greenhouse gas emissions than fossil fuels, do not compete with food for agricultural land and do not adversely affect sustainability.

Covid-19 restrictions (Figure 5.4). Around 8% of cars on the road are electric in 2030, but a rise in the number of heavier cars sold – especially sports utility vehicles – offsets some of the reductions in oil use from the rise of electric cars. In the APS, in countries with net zero pledges, more than 15% of passenger cars on the road in 2030 are electric, and the implementation gap between the STEPS and the APS is closed through measures such as specific phase-out plans for internal combustion engine vehicles, strict fuel-economy standards, support for the deployment of alternative fuels infrastructure, and enhanced investment in walking and cycling infrastructure and public transport. Globally, oil use in cars falls by 0.4 mb/d in the APS between 2020 and 2030 (Figure 5.5). In the NZE, major efforts are made across the world to reduce the number of car journeys and to shift passengers towards other modes of transport, and 20% of cars on the road are electric in 2030. As a result, oil demand for passenger cars falls by 8 mb/d to 2030.

Figure 5.5 ▷ Oil use in passenger cars and petrochemicals by scenario between 2020 and 2030



The NZE sees 300 million electric cars on the road in 2030 that displace more than 3.5 mb/d of oil. Plastic recycling rates increase in all scenarios as does oil use in petrochemicals

Heavy trucks (both medium- and heavy-freight trucks) used 10 mb/d of oil in 2020. Electrification and fuel efficiency improvements play a central role in displacing oil use in freight trucking and there is also a potential role for alternative liquid fuels, especially for trips longer than 400 kilometres (km). In the STEPS, electric and fuel cell heavy trucks struggle to gain market share and oil demand increases by around 4 mb/d to 2030. In the APS, 3.5% of heavy trucks on the road in countries with net zero pledges are electric or fuel cell in 2030 and global oil demand for heavy trucks increases by around 3 mb/d to 2030. In the NZE, nearly 10% of heavy trucks on the road globally are electric or fuel cell vehicles by 2030, there is a large uptake in the use of biofuels, and oil demand rises by less than 0.5 mb/d between 2020 and 2030.

Aviation and shipping activity grows markedly in the STEPS, with a strong rebound as restrictions on international travel unwind. Oil demand increases by more than 5 mb/d to 2030 (reaching just over 14 mb/d in 2030). Liquid biofuels are the main alternative fuel choice to 2030, but there are few policies and measures to encourage their use. In the APS, the focus on delivering on domestic net zero pledges means that there are limited efforts to reduce emissions from international aviation and shipping, and global oil demand for aviation and shipping grows by more than 4 mb/d to 2030. In the NZE, the global effort to tackle emissions means that there are widespread efforts to reduce emissions from international aviation and shipping, and total oil use for aviation and shipping in the NZE is flat between 2020 and 2030.

The **petrochemical** sector was the only segment that saw an increase in oil use in 2020. An increasing number of countries have recently announced or introduced policies to scale up recycling and limit single-use plastics, and investment in waste management and recycling featured in a number of stimulus packages.[2] In the STEPS, this translates into a small rise in global average plastic recycling rates from 17% today to 20% in 2030. This is not enough to offset increased consumer demand for packaging and oil use for petrochemicals, and oil demand increases by around 2.5 mb/d between 2020 and 2030 (to 15 mb/d). In the APS, recycling rates increase in countries with net zero pledges to 32% in 2030. Measures to ensure that pledges are achieved include regulatory action to tackle plastic use and the development of an international secondary waste market. However, the absence of significant efforts to boost recycling in countries without net zero pledges means that recycling rates globally only rise to 23% and oil demand increases by just over 2 mb/d to 2030. In the NZE, the global average recycling rate rises to 27% in 2030. Some use is made of bio-based petrochemical feedstocks, but these compete for sustainable feedstock with other sectors and only around 5% of total plastics feedstock in the NZE in 2030 is sourced from bioenergy and oil demand increases by 1.5 mb/d to 2030.

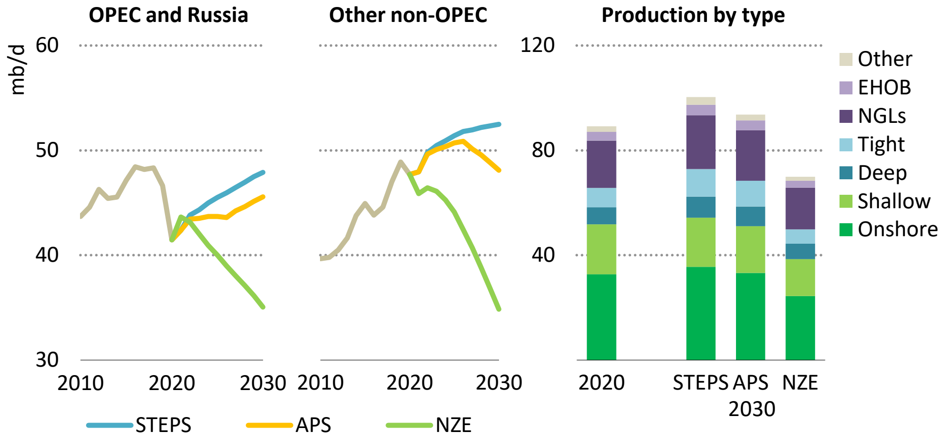
Supply

In the STEPS, tight oil operators choose to prioritise returns over aggressive production growth, even as annual average prices rise to 2030. Tight oil production satisfies around 20% of global oil demand growth between 2020 and 2030 (compared with the 2010-2019 period when it provided 70%). Total oil production in the United States rises by around 3.5 mb/d to 2030 (reaching 20 mb/d in 2030) while Canadian production increases by 0.7 mb/d as long lead time projects approved for development in the mid-2010s start to ramp up (Figure 5.6). Brazil maintains deep water production levels through the 2020s, while emerging producers, including Guyana and Senegal, increase production by around 1 mb/d between 2020 and 2030. Organization of the Petroleum Exporting Countries (OPEC) production increases by around 6 mb/d to 2030, with Iraq, Iran and Kuwait providing over 40% of this growth as new fields come online and production increases at existing fields. OPEC and Russia together

[2] Examples include: a new plastic tax in the European Union, which took effect in January 2021; a law in California in the United States that requires beverage containers to contain a minimum of 15% recycled plastic by 2022: and a ban on some single-use plastics in China.

provide 48% of total oil production in 2030, an increase from 2020, but well below their share during much of the last decade.

Figure 5.6 ▷ Oil supply by scenario



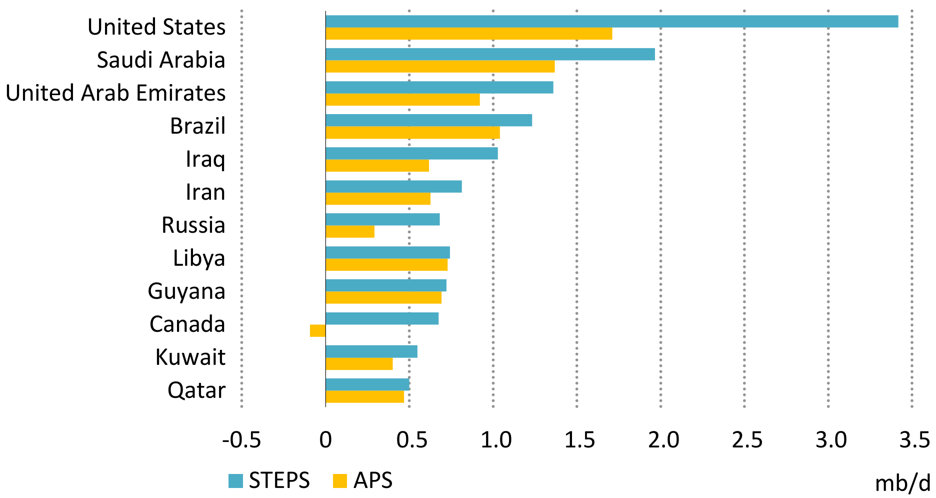
More restrained investment in tight oil means that OPEC and Russia comprise an increasing share of supply to 2030, although this remains below the levels seen in the 2010s

Note: EHOB = extra heavy oil and bitumen; onshore = onshore conventional crude oil; shallow = offshore conventional crude oil from water depths less than 450 metres (m); deep = offshore conventional crude oil from water depths more than 450 m.

In the APS, the peak in global oil demand means that prices are just over USD 65/barrel in 2030. No net zero pledges made by major oil producing countries include explicit targets to curtail production. These countries do however pursue efforts to minimise emissions from oil and gas operations in the APS: this increases their production costs relative to other producers and in many cases also involves additional financing costs. In some of the higher cost producers with net zero pledges, including in Europe and Canada, increased costs and lower prices in the APS mean there are no or very limited investment into new projects from the mid-2020s and production is markedly lower than in the STEPS (Figure 5.7). Projects with lower costs and shorter payback periods that can limit emissions from production and processing activities at low cost are less affected. Demand falls faster than supply in some countries with net zero pledges, allowing them to export more, for example, in 2030 the United States exports 3.5 mb/d in the APS, compared with less than 2.5 mb/d in the STEPS. This puts downward pressure on prices and limits export opportunities for a number of new and emerging producers.

In the NZE, the fall in oil demand and prices does not justify investment in new fields after 2021. Any such investment would be surplus to requirements in the NZE and could struggle to return the capital invested. There is still investment in existing fields to minimise the emissions intensity of production and there are also some low cost extensions of existing fields to maintain or support production. This support includes the use of in-fill drilling and improved management of reservoirs as well as some enhanced oil recovery and tight oil drilling to avoid a sudden near-term drop in supply. Supplies become increasingly concentrated in a small number of low cost producers and the share of Russia and members of OPEC rises to 50% in 2030.

Figure 5.7 ⊳ Changes in oil supply in selected countries in the Stated Policies and Announced Pledges scenarios, 2020-2030



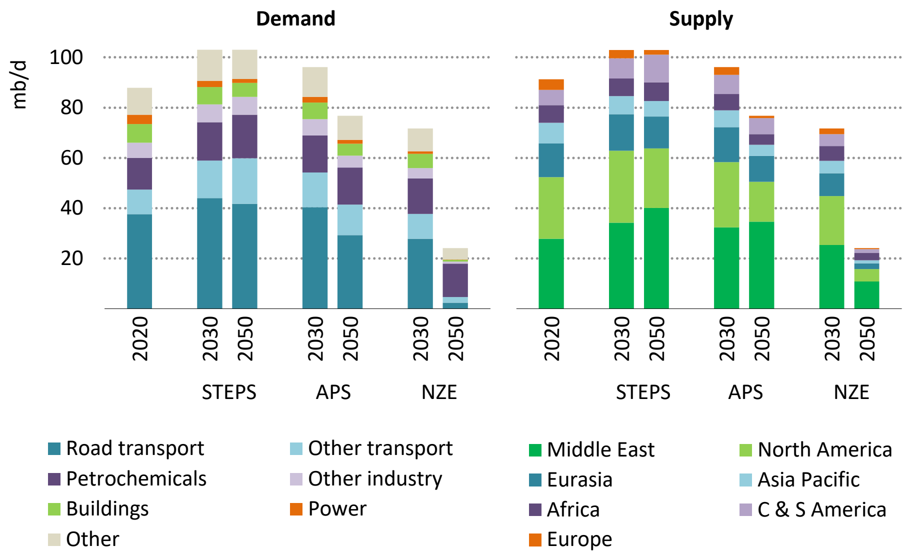
All countries produce less oil in the APS than the STEPS but changes are largest in higher cost countries with net zero pledges as they look to limit emissions from oil activities

The demand trajectories in the APS and the NZE inevitably look challenging from the perspective of the countries and companies that produce oil. High cost assets and those with high emissions intensities would likely struggle to continue producing economically. Efforts will be needed to minimise emissions from traditional operations, including tackling methane emissions. There could also be new opportunities. The skills, competencies and resources of the oil and gas industry could provide it with a competitive advantage when it comes to accelerating innovation and to the deployment of critically important clean energy, such as carbon capture, utilisation and storage (CCUS), hydrogen, bioenergy and offshore wind.

5.2.2 Oil trends after 2030

In the STEPS, oil demand levels off at 104 mb/d in the mid-2030s and then drops very slightly through to 2050. Between 2030 and 2050, oil demand for road transport declines by more than 2 mb/d globally: 30% of passenger cars on the road globally in 2050 are electric and just under 5% of heavy trucks are electric or fuel cell vehicles. Electricity generation and the buildings sector also use less oil. Demand reductions, however, are broadly matched by increases in demand for aviation, shipping and petrochemicals. Non-OPEC (excluding Russia) production declines by close to 6 mb/d between 2030 and 2050 as resource bases become increasingly mature, although production using enhanced oil recovery offsets some of the drop in supply. OPEC and Russia provide 53% of global oil production in 2050, up from 47% in 2020.

Figure 5.8 ▷ Oil demand and supply in 2030 and 2050



Demand in the STEPS levels off in the mid-2030s and falls marginally to 2050; demand falls by 1 mb/d each year from 2030 to 2050 in the APS and by 2.4 mb/d each year in the NZE

Notes: C & S America = Central and South America. Other includes agriculture and other energy sector.

In the APS, demand in countries with net zero pledges falls by nearly 30 mb/d between 2030 and 2050 while it increases by close to 10 mb/d in countries without pledges. By 2050, almost half of the cars on the road globally are electric, and more than one-quarter of heavy trucks are electric or fuel cell vehicles. After 2030, additional costs become necessary to minimise emissions from oil and gas production and there is limited investment in new fields in many countries with net zero pledges (Box 5.1). This means that non-OPEC production takes a smaller market share, and OPEC and Russia provide 58% of global oil production by 2050.

In the NZE, oil demand falls by 48 mb/d between 2030 and 2050 (a 5.3% average annual decline) (Figure 5.8). No new passenger cars with internal combustion engines are sold anywhere after 2035 and the use of oil as a feedstock falls by around 1 mb/d as plastic recycling rates rise globally to more than 50% in 2050 (and to 60% in advanced economies). Production is increasingly concentrated in resource-rich countries due to the large size and slow decline rates of their existing fields. OPEC and Russia account for more than 60% of the global oil market in 2050.

Box 5.1 ▷ Strategies to get the most from existing sources of supply

Investments in existing fields rose from less than half of capital spending on oil between 2010 and 2019 to around 55% in 2021 (IEA, 2021a). Although reductions in demand mean that no new oil fields need to be developed in the NZE after 2021, further investment is required in existing fields to reduce the emissions intensity of operations and to combat natural production declines. In the STEPS and the APS, new fields are needed to meet oil demand levels, but action to get the most from existing operations may still be a pragmatic and cost-effective approach. Such actions could take various forms:

- **Reduce emissions from existing sources of supply.** Oil and gas operations are responsible for around 15% of global energy sector GHG emissions today (IEA, 2020a). Options to reduce these emissions include tackling methane leaks (including intentional methane venting), minimising flaring, switching to low-carbon options to power operations, incorporating energy efficiency improvements across the supply chain and using CCUS for large centralised sources of emissions. All of these play a role in the NZE in reducing the emissions intensity of oil and gas production, which falls from a global average of just over 100 kilogrammes of carbon dioxide equivalent (kg CO_2-eq) per barrel in 2020 to less than 40 kg CO_2-eq/barrel in 2030 (Figure 5.9).

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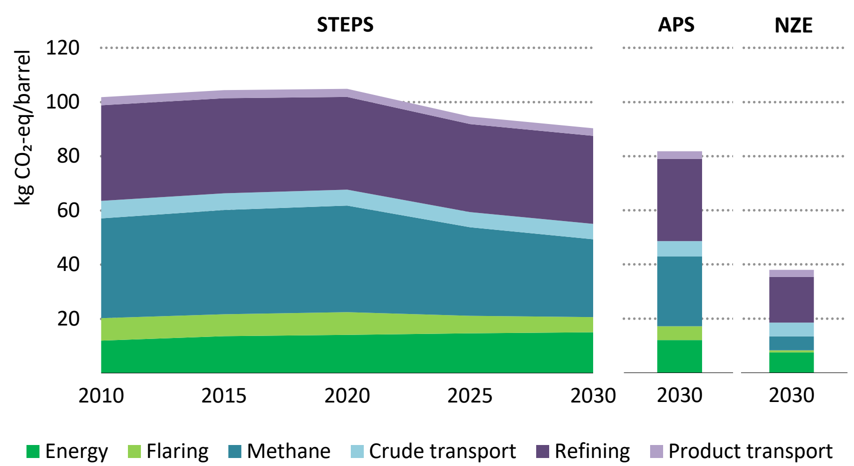
Figure 5.9 ▷ Global average emissions intensity of oil production



Action to minimise supply chain emissions plays an important part in clean energy transitions. In the NZE, the global average emissions intensity falls by 65% to 2030

- **Minimise flaring and methane leakage from flaring.** Around 140 billion cubic metres (bcm) of natural gas was flared worldwide in 2020, which is equivalent to total natural gas use in Central and South America. Flaring is a wasteful practice that causes emissions of CO_2, methane and black soot, and is damaging to health (World Bank, 2021). There should be minimal methane emissions if a flare is designed, maintained and operated correctly, but higher emissions can occur as a result of factors such as weather and changes in production rates (Johnson, 2001; Kostiuk, 2004). Occasionally a flare may be totally extinguished, resulting in direct venting to the atmosphere of gas that should be combusted. Globally, we estimate that flares in 2020 leaked around 8% of the natural gas and natural gas liquids (NGLs) that should have been combusted, more than double previous estimates.[3] This resulted in nearly 8 million tonnes (Mt) of methane emissions which, when combined with CO_2 emissions from combustion, resulted in more than 500 Mt CO_2 equivalent GHG emissions. A rapid reduction in flaring and methane emissions occurs in both the APS and the NZE.
- **Reduce natural production declines.** In the absence of any investment in existing oil fields, supply would fall by around 8-9% per year, which is faster than the rate of decline in oil demand even in the NZE. This rate of decline can be slowed by supporting production from existing fields, for example with improved well reservoir management and in some cases enhanced oil recovery. There are also options to increase production from existing fields through well interventions or workovers, for example by re-perforating existing wells (Kitsios, Shields and Vroemen, 2013). Not all of these opportunities will exist across all fields, but we estimate that adopting these technologies at all applicable conventional oil fields could boost global production by at least 2 mb/d in 2030.
- **Digitalise operations.** Emerging digital technologies could help improve efficiency, reduce costs and reduce the emissions intensity of oil and gas production. They could for example be used to enhance models of the subsurface to identify new production sources (Hafez, et al., 2018), integrate remote surveys and automated robotics to detect and measure emissions levels, and optimise the transport and trade of oil and gas. Digital technologies that optimise fuel usage and reduce emissions for liquefied natural gas (LNG) carriers have been shown to reduce CO_2 emissions by around 7% per cargo delivered (Brown, et al., 2020).

[3] The leakage rate is the proportion of natural gas and NGLs directed into a flare that is not combusted; here it includes volumes not combusted when a flare is operating normally and when it may have been temporarily extinguished. Our estimate is based on a detailed bottom-up assessment of production types, facility and flare design practices, operators, changes in produced volumes over field lifetime, local crosswind variability, and the strength of regulation, oversight and enforcement. In previous *Outlooks*, we estimated that flares released around 3.5% of natural gas and NGLs directed into flares. One tonne of methane is assumed to be equal to 30 tonnes of CO_2 equivalent, based on the 100-year global warming potential (IPCC, 2021).

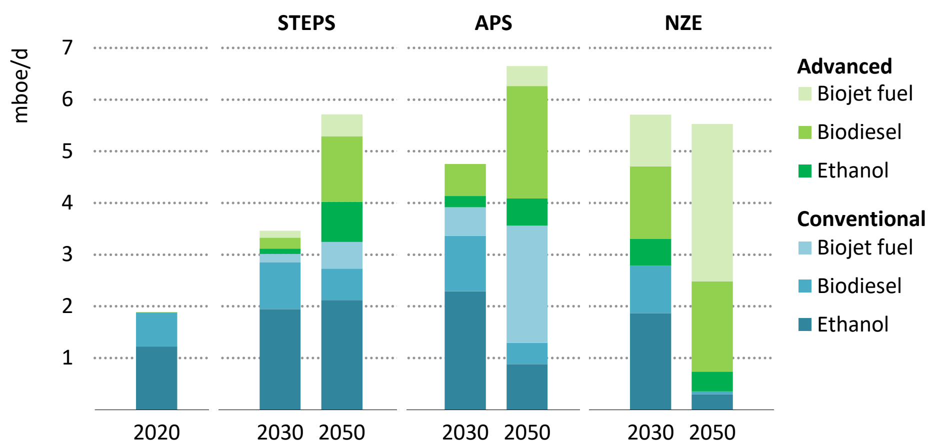
5.2.3 Biofuels and hydrogen-based fuels

Biofuels

A key advantage of biofuels is that they can often be adopted with minimal retrofit costs by end-users. However, biofuels have high costs and there is a limited supply of affordable and sustainable feedstocks. It currently costs USD 70-130 per barrel of oil equivalent (boe) to produce conventional biofuels and USD 85-160/boe to produce advanced biofuels. One major challenge for the future is to mobilise investment to develop multiple new large-scale facilities to lower production costs; another is to develop new sustainable biomass supply chains.

Between 2020 and 2030, biofuel demand increases by nearly 1.5 million barrels of oil equivalent per day (mboe/d) in the STEPS, and conventional ethanol, mostly used in passenger cars, comprises more than half of biofuel consumption in 2030 (Figure 5.10). In the APS, demand increases by more than 2.5 mboe/d to 2030. The implementation gap between the APS and STEPS is closed through blending mandates for biodiesel (mainly in Asia and Latin America) and for biojet fuel (mainly in the United States and China). Existing production facilities are upgraded and retrofitted, and a number of new production facilities are constructed. In the NZE, total biofuel demand increases by more than 3.5 mboe/d to 2030. Conventional biofuels contribute to some of this growth but most of it comes from advanced biofuels, which comprise almost half of total biofuel production in 2030, mainly for use in trucks and for aviation: biojet fuel accounts for 15% of total aviation fuel in 2030 in the NZE.

Figure 5.10 ⊳ Liquid biofuel demand by type and scenario



Production routes and end-uses differ, but biofuels increase strongly in all scenarios to 2030. Advanced biofuels are key to meeting net zero targets, especially for trucks and aviation

Note: mboe/d = million barrels of oil equivalent per day.

In the STEPS, advanced biofuels are responsible for most of the 2.2 mboe/d increase between 2030 and 2050, but conventional ethanol remains the largest single biofuel produced in 2050. In the APS, the electrification of road transport in countries with net zero pledges means ethanol use falls. Biojet fuel and advanced biodiesel increase substantially and total biofuel use rises to 6.5 mboe/d in 2050. In the NZE, biofuel use remains at around 5.5 mboe/d through to 2050 and is increasingly focused on heavy trucks, shipping and aviation. Biojet fuel accounts for around 40% of all aviation fuel in 2050, and advanced biofuels comprise nearly 90% of total biofuel use globally.

Hydrogen-based liquid fuels

Low-carbon hydrogen-based fuels, including ammonia, methanol and other synthetic liquid hydrocarbons made from hydrogen with a very low emissions intensity, offer an alternative to the use of oil.[4] Ammonia, which can be easily stored as a liquid, can also be used for power generation without CO_2 emissions, including via certain fuel cells. However, hydrogen-based fuels will need to overcome a number of hurdles in order to play a major role as liquid fuels. They currently have high costs of production, suffer from limited enabling infrastructure, can involve large energy losses from production to consumption,[5] and, in most cases, must be handled more carefully than traditional liquid fuels.

There are six demonstration projects under construction today that will produce low-carbon liquid synthetic hydrogen-based fuels and a further 38 pilot and demonstration projects are at the planning stage. There are also a large number of projects looking to produce ammonia, mainly for use as a fertiliser but also as a fuel, including some that aim to export the ammonia to overseas markets. A number of countries are exploring options to expand support for hydrogen-based fuels. For example, Germany has a requirement for 2% of fuel use in aviation to be hydrogen-based by 2030 (BMU, 2020); the European Commission has proposed a target for hydrogen and hydrogen-based fuels (derived from renewable energy) to provide 2.6% of energy for transport by 2030 (European Commission, 2021); and Japan has released an interim report on ammonia use in electricity generation and shipping (METI, 2021). Ammonia and methanol-fuelled ships are not commercially available today, although Maersk has ordered eight methanol-powered container ships for delivery in 2024 and around five ammonia-fuelled vessels are in the design phase or have been ordered (Getting to Zero Coalition, 2021). Plans to offer ammonia retrofit packages for existing ships by 2025 have also been announced.

To 2030, in the STEPS, the uptake of hydrogen-based fuels globally is limited because there are few policies supporting their use. In the APS, 0.15 EJ (0.07 mboe/d) of hydrogen-based

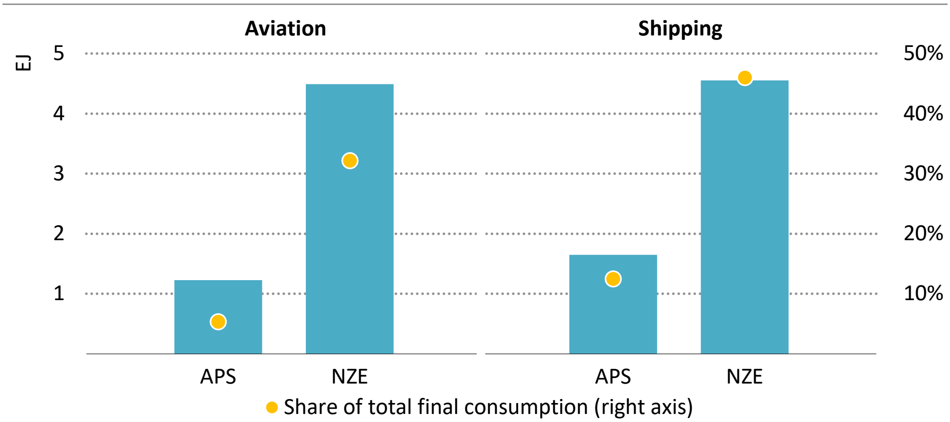
[4] These fuels can replace liquid hydrocarbons in engines and turbines, especially in transport. It is uncertain which specific low-carbon hydrogen-based fuel will be the most cost competitive and attractive to users and so they are generally presented in aggregate in our analysis. The use of low-carbon hydrogen as a gas, including as an input to hydrogen-based fuels, is described in section 5.3.3.

[5] For example, including the energy required to capture CO_2 from the air to provide the carbon inputs for the manufacture of non-fossil synthetic hydrocarbons, well-to-wheel losses could reach over 90% of the initial electricity input. Non-fossil synthetic hydrocarbons can also be made using carbon from biomass where it is available in sufficient quantities.

fuels are consumed globally for transport in 2030, mostly in the form of ammonia in shipping. This is a relatively small amount, but progress to 2030 will be critical to the later success of hydrogen-based fuels. Closing the implementation gap between the STEPS and APS will depend on major investment in innovation to lower the costs of production and transport and to ensure that new end-user equipment and vehicles are readily available on the market. There are likely to be large regional variations in production costs for hydrogen-based fuels; imports could be more economically attractive than domestic production in some countries. International trade will require co-operation on standards to ensure low emissions intensity throughout the value chain. In the NZE, consumption of liquid hydrogen-based fuels in the transport sector increases to 1.3 EJ (0.6 mboe/d) in 2030, most of which is used in shipping (representing just under 10% of total fuel use in shipping at that time).

Beyond 2030, in the STEPS, deployment remains at very low levels. In the APS and NZE, concerted policy and regulatory interventions in the 2020s help bring down production costs and increase use after 2030, with the more global efforts in the NZE having a greater impact than those in the APS. Large production facilities are developed in renewable-rich locations far from electricity demand centres, and hydrogen-based fuels are used in increasing volumes for shipping and aviation (Figure 5.11). They are also used to a lesser extent for heavy trucks, but electrification and the use of gaseous hydrogen in fuel cells are the main mechanisms to reduce emissions from heavy trucks. In shipping, the roll-out of ammonia production facilities and ammonia-fuelled ships increases substantially in the 2030s. Ammonia accounts for almost half of shipping energy demand in the NZE in 2050. In aviation, synthetic kerosene use grows substantially from 2030 and meets about 30% of total aviation fuel demand in 2050 in the NZE.

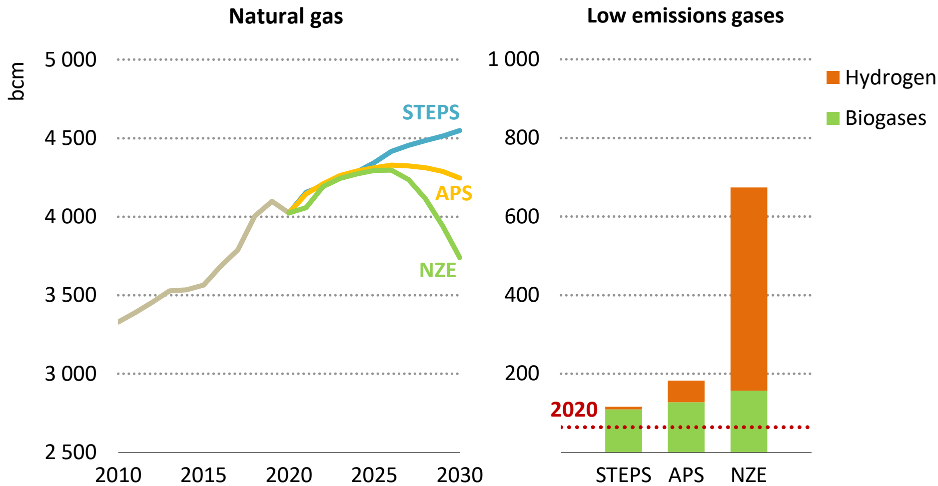
Figure 5.11 ⊳ Low-carbon hydrogen-based fuel consumption in aviation and shipping, 2050



There is limited hydrogen-based fuel use before 2030, but it has a large role in the APS and NZE after 2030. Hydrogen-based fuels provide 45% of fuel use in shipping in the NZE in 2050

5.3 Gaseous fuels

Figure 5.12 ▷ Natural gas use over time and low emissions gas supply in 2030



Natural gas use increases in each scenario to 2025 with sharp divergences thereafter. Biogas use grows rapidly in each scenario. There is a large role for hydrogen in the NZE

Note: Hydrogen gases include low-carbon gaseous hydrogen and synthetic methane with 1 EJ = 29 bcm.

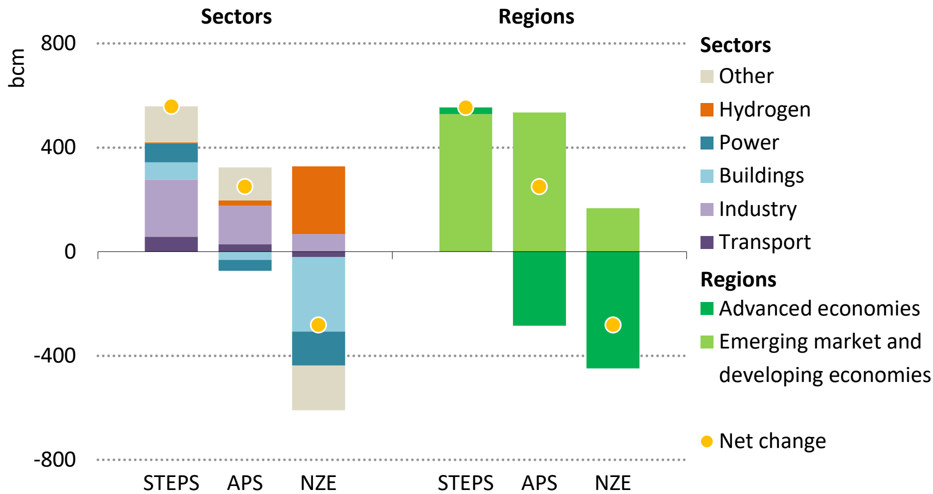
The record highs in spot natural gas prices in 2021 have refocused attention on the role of natural gas, and raised new questions about the extent to which, and for how long, it can retain a place in the energy mix as clean energy transitions accelerate. There is no single storyline. In the power sector, natural gas use could increase in countries with rising electricity demand or declining coal and nuclear capacity or indeed both, but it faces stiff competition from renewables. In industry, natural gas is well suited to provide heat, but it faces a challenge in other areas from electrification. In countries that use natural gas for space heating, building retrofits and other efficiency improvements could lead to large reductions in natural gas use. In emerging market and developing economies, increases in demand are contingent on the affordability of gas, development of new infrastructure, strength of policy measures to improve air quality, and the pace of reductions in coal and oil use in energy-intensive industries. Also looming in the background is the potential role of low emissions gases such as hydrogen, biomethane and synthetic gases.

Natural gas demand increases in all scenarios over the next five years, but there are sharp divergences thereafter (Figure 5.12). In the STEPS, natural gas demand continues to rise after 2025 and demand is around 15% higher in 2030 than in 2020. In the APS, demand reaches its maximum level soon after 2025 and then declines slowly. In the NZE, demand drops sharply after 2025 and falls well below 2020 levels by 2030. The post-2025 drop in natural gas demand in the NZE, however, is partly offset by growth in demand for low emissions gases (including low-carbon hydrogen produced from natural gas with CCUS). Total demand for gases in the NZE in 2030 is around 5% higher than today.

5.3.1 Natural gas trends to 2030

Demand

Figure 5.13 ▷ Changes in natural gas demand between 2020 and 2030



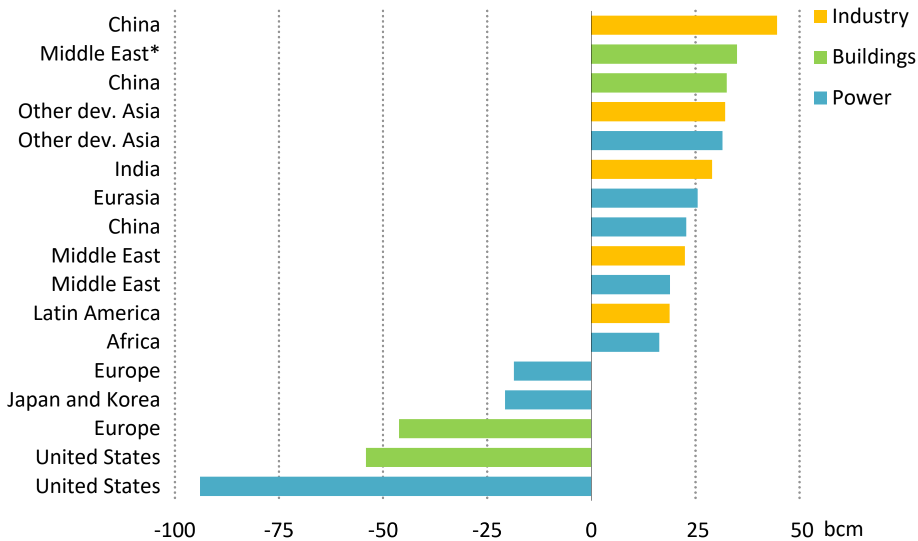
There is not a single storyline for natural gas with large differences across scenarios and sectors

Note: Other includes agriculture and non-energy use.

In the STEPS, nearly all of the 15% global increase in natural gas demand to 2030 comes from emerging market and developing economies (Figure 5.13). Demand in China is 40% higher in 2030 than in 2020. There are declines in a number of established markets, including Japan (down by 25%) and Europe, while North America and Korea see demand peak in the mid-2020s. Industry accounts for nearly 40% of overall demand growth to 2030, led by increases for light manufacturing in China and India, and from the chemical sub-sector in China.

In the APS, the 5% increase in global demand between 2020 and 2030 masks large differences between regions and sectors (Figure 5.14). This includes differences between countries with net zero pledges: in China and Korea, gas consumption increases to 2030 and is used largely to replace more polluting fuels, while in Brazil, Canada, European Union, Japan and United States, demand reduces by 20-35% (though there is considerable variation between various European Union member states). Natural gas demand tends to grow more consistently in countries without net zero pledges.

Figure 5.14 ⊳ Key changes in natural gas demand in the Announced Pledges Scenario, 2020-2030



Most of the growth in natural gas demand is for industry and power in emerging market and developing economies: this is partially offset by declines in advanced economies

* Demand mainly related to desalination.

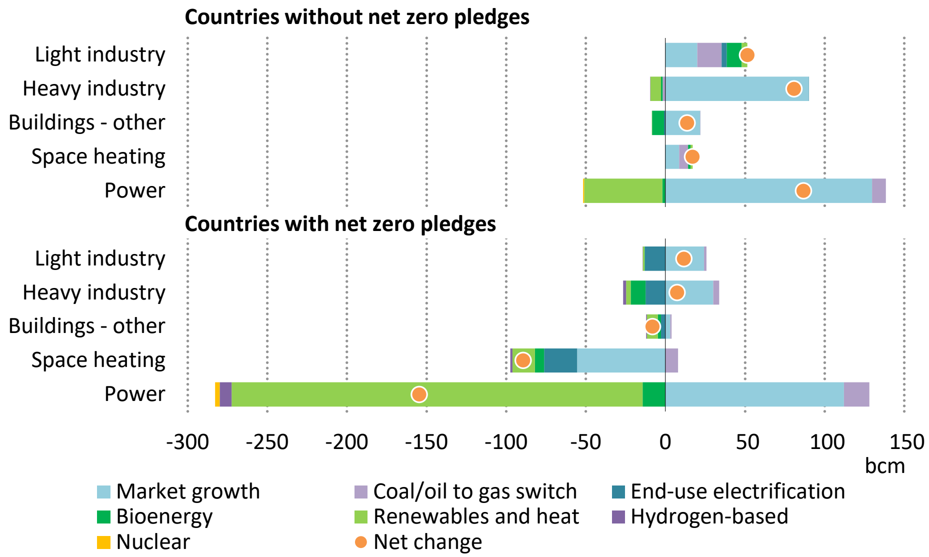
Note: Other dev. Asia = other developing Asia.

In the NZE, natural gas demand falls in nearly all regions, except those that are currently heavily reliant on coal, where it largely displaces coal. There is some upside for natural gas demand in the NZE as a result of its role in scaling up low-carbon hydrogen production: by 2030, around 250 bcm is used in steam methane reformers equipped with CCUS.

The degree of coal-to-gas switching is a key determinant of the outlook for natural gas. Its potential varies between sectors and regions, and depends for a given country on the pace and scale of emissions reductions being sought. Coal-to-gas switching since 2010, primarily in the power sector in the United States and Europe as well as in buildings and industry in China, means that global emissions were around 750 Mt CO_2 lower in 2020 than they otherwise would have been. In the APS, coal-to-gas switching continues in many of these regions. Around 100 bcm of additional gas is used to replace coal in 2030, which avoids around 180 Mt CO_2 of emissions in that year. At a global level, these increases in natural gas demand are partly offset by the drop in demand due to renewables, efficiency and electrification. There is also a modest but important shift away from natural gas to nuclear, modern bioenergy and hydrogen-based fuels, mostly in the United States, Japan and the European Union (Figure 5.15).

In the NZE, additional gas use for switching is even higher at 185 bcm, and oil-to-gas switching becomes an important part of transition strategies, particularly in the power sector in parts of the Middle East and in light industry and manufacturing in emerging market and developing economies in Asia. These increases for gas demand are offset by a switch away from gas to renewables, especially in advanced economies where overall gas demand falls by 20% between 2020 and 2030.

Figure 5.15 ▷ Drivers of change in natural gas demand in selected sectors in the Announced Pledges Scenario between 2020 and 2030



Renewables, electrification and efficiency reduce gas demand in countries with net zero pledges; coal-to-gas switching increases gas demand across the board

Notes: Market growth includes underlying drivers of energy service demand (e.g. population or economic growth or structural variables such as floor area increases), net of efficiency gains. Other includes water heating, cooking, appliances and desalination plants.

Industry in emerging market and developing economies is the key driver of natural gas demand growth in all three scenarios. In the STEPS, the large increase in natural gas demand comes from the manufacturing sector and depends on new grid infrastructure to connect clusters of small- and medium-scale factories and industrial hubs (notably in India, which has ambitious plans to develop city gas distribution networks [IEA, 2021b]). Gas also replaces coal, oil and the use of biomass in a range of industrial applications: around 35 bcm of additional gas use in emerging market and developing economies is related to fuel switching in industry by 2030 in both the STEPS and the APS. In the NZE, natural gas demand remains stable to 2030 as growth in steel and cement production is offset by declines in manufacturing and other light industries. Heavy industry facilities using natural gas also start to be equipped with CCUS.

In the **power** sector, increases in electricity demand and reductions in coal-fired generation mean natural gas use increases in each scenario to 2025. Between 2020 and 2025, natural gas demand increases by 60 bcm in the STEPS, 90 bcm in the APS and 250 bcm in the NZE, although in all cases the increase in generation from renewables is much larger. In the STEPS, demand continues to rise after 2025 as a result of robust increases in emerging market and developing economies which are offset slightly by declines in advanced economies. In both the APS and NZE, the window of opportunity for coal-to-gas switching is short-lived and demand falls below 2020 levels by 2030. Natural gas plays a role in helping to balance variable renewable generation but this is generally not accompanied by a material increase in demand.

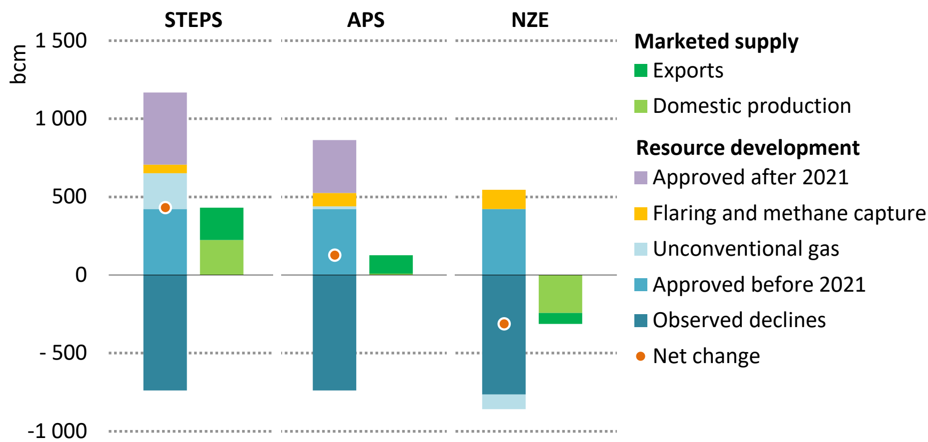
In **buildings**, changes in natural gas demand are closely correlated with the pace and scale of building retrofit rates and of the roll-out of heat pumps, especially in regions where gas plays a seasonal role in heating. In the STEPS, natural gas remains the default option for space heating, the building retrofit rate is less than 1% per year and around 3 million heat pumps are installed every month in buildings around the world in 2030 (compared with 1.5 million today). In the APS, countries with net zero pledges accelerate ambition in both areas, leading to a retrofit rate of around 1.5% per year globally and the installation of 3.5 million heat pumps every month in 2030. The implementation gap between STEPS and APS is closed through measures such as bans on the sale of new gas-fired boilers (except where they are compatible with low-carbon gases) and the introduction of strict performance standards for existing and new buildings together with incentives for retrofits. In the NZE, the global rate of retrofits increases to 2.5% per year and around 5 million heat pumps are installed every month in 2030. Natural gas demand in buildings, which is around 850 bcm today, grows by 70 bcm in the STEPS to 2030, falls by 30 bcm in the APS, and falls by 300 bcm in the NZE.

Supply

In the STEPS, there is a 430 bcm increase in natural gas demand between 2021 and 2030 while existing sources of conventional gas production decline by around 740 bcm (Figure 5.16). Projects that have already been approved add around 420 bcm of production in 2030, and the rest comes from new investment in around 460 bcm per year of new conventional gas projects and 230 bcm of new unconventional gas projects. Around half of the net increase in gas supply is for export. There is a 150 bcm ramp up in annual LNG export capacity, much of it in Qatar, United States, Russia and East Africa.

In the APS, the emissions performance of natural gas produced in countries with net zero pledges, or produced elsewhere for export to them, is subjected to close scrutiny. Countries with net zero pledges experience reductions in domestic demand alongside increases in production costs arising from the need to reduce emissions intensities, and this has knock-on impacts on upstream investment and production levels. In aggregate, production peaks in countries with net zero pledges in the mid-2020s. Countries without net zero pledges see broadly similar levels of production in the STEPS and APS in the period to 2030 as gas demand continues to increase and exports to Asia see similar rates of growth in the two scenarios over the period to 2030. The exception is pipeline exporters to Europe, where exports remain static at 2020 levels in the APS, but increase by 20% in the STEPS by 2030.

Figure 5.16 ▹ Changes in upstream resource development and marketed natural gas supply by scenario between 2021 and 2030



In the STEPS, new gas fields are required; in the APS, this need diminishes; in the NZE, there is no need for any new upstream development

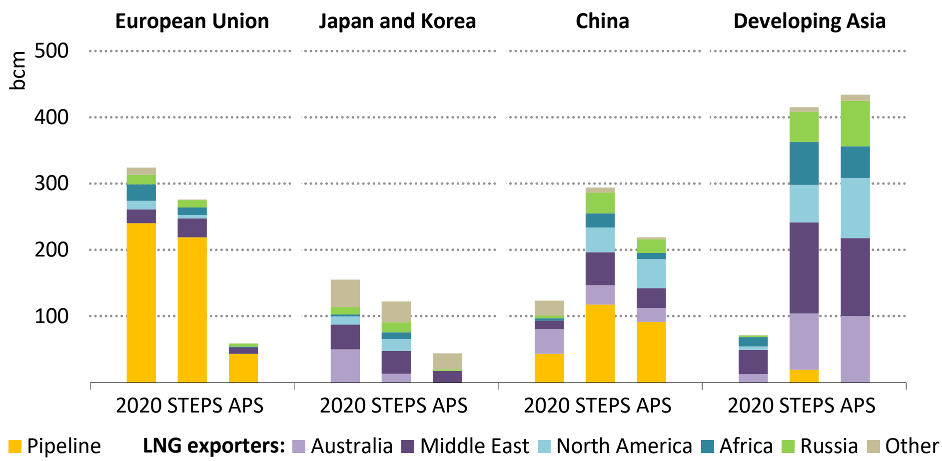
In the NZE, no new gas fields are developed beyond those that have already been approved for development. LNG trade peaks in the mid-2020s at 475 bcm and falls to 2020 levels of 390 bcm by 2030. Around 600 bcm of LNG liquefaction capacity exists today and a further 180 bcm is under construction, implying a reduced rate of utilisation of LNG export capacity globally from the mid-2020s compared with historical utilisation rates (around 85%). Given the low prices of natural gas in the NZE, any LNG projects with a break-even price of more than USD 5 per million British thermal units (MBtu) would be at risk of failing to recoup their investment costs in this scenario.

5.3.2 Natural gas trends after 2030

In the STEPS, natural gas demand continues to increase after 2030, albeit at a slower pace. There is no peak in demand, which reaches 5 100 bcm in 2050, around 30% higher than today. Natural gas demand in industry remains the main engine of growth, but its contribution to overall energy demand growth decreases as emerging market and developing economies transition to more service-oriented economies. Around 70% of the increase in supply between 2020 and 2050 comes from Eurasia and the Middle East, and internationally traded gas volumes increase by 450 bcm over this period. Global LNG trade increasingly takes market share from gas transported by long-distance pipelines, expanding from just over 50% of traded volumes today to 60% in 2050.

In the APS, natural gas demand reaches its maximum level globally soon after 2025 and then declines to 3 830 bcm in 2050. Reductions in advanced economies offset continued growth in emerging market and developing economies. This has important implications for global gas trade, which peaks in the 2030s and falls to 2020 levels by 2050. LNG continues to grow, capturing nearly 70% of traded volumes by 2050: reduced gas demand in Europe leads to an 80% drop in pipeline imports, while LNG supplies the majority of the 430 bcm increase in gas demand in emerging and developing markets in Asia (Figure 5.17). LNG exports from North America are around 130 bcm in 2050, 25% higher than in the STEPS, as reduced demand in the region frees up larger volumes for export.

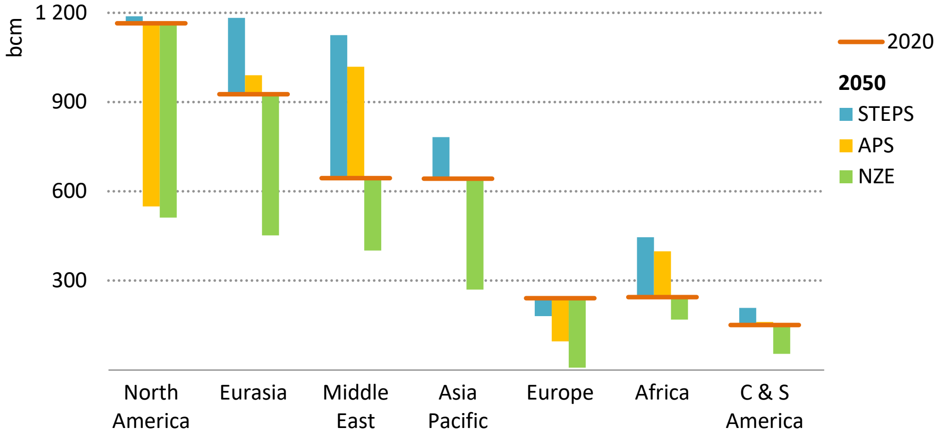
Figure 5.17 ▷ Natural gas imports in selected regions by source in 2020 and by scenario in 2050



In the APS, falling domestic demand frees up additional exports from North America to developing markets in Asia. The European Union sees a sharp drop in pipeline imports

In the NZE, natural gas use in the power sector declines globally by more than 80% in the 2030s. Less than 190 bcm of natural gas is used for power generation in 2050, accounting for around 1% of electricity generation worldwide (compared with almost a quarter today), mostly from facilities equipped with CCUS. Energy demand in buildings also transitions quickly away from natural gas. In 2050, more than 50% of global gas production is used to produce low-carbon hydrogen; a further 15% is used in industry, mainly for cement production and in light industries. Without any need for investment in new upstream projects, production in emerging producers in Africa and elsewhere is constrained, and large existing producers and resource holders increasingly dominate supply. In 2050, more than 40% of global gas is produced in the Middle East and Russia (Figure 5.18). Inter-regional trade of natural gas falls to less than 300 bcm by 2050, around 40% of current levels.

Figure 5.18 ▷ Changes in natural gas production by region and scenario between 2020 and 2050



North America sees a large drop in production between the STEPS and the APS, with smaller reductions in Eurasia and the Middle East. All regions produce much less gas in the NZE

Note: C & S America = Central and South America.

5.3.3 Low-carbon hydrogen and biogas

Low-carbon hydrogen

Close to 11 EJ (90 Mt) of hydrogen was produced worldwide in 2020, mainly for use in the chemicals and refining sub-sectors (IEA, 2021c).[6] Most was produced from natural gas or coal (in China): low-carbon hydrogen comprises less than 1% of current total hydrogen production.[7] Most hydrogen is produced near where it is used: there is little hydrogen pipeline and storage infrastructure today.

Low-carbon hydrogen can reduce GHG emissions by replacing existing sources of hydrogen produced from unabated fossil fuels; by meeting new demand for low emissions fuels and industrial feedstocks; and by converting electricity to a storable fuel to assist with the system integration of renewables. Hydrogen can also be converted to other low-carbon hydrogen-based fuels, including synthetic methane, ammonia and synthetic liquids.

[6] This includes around 2.5 EJ of hydrogen used in a mixture of gases for methanol and steel production without purification of the hydrogen. It does not include hydrogen contained in residual gases from industrial processes that is used for electricity and heat.

[7] Low-carbon hydrogen is hydrogen produced in a way that does not contribute to atmospheric CO_2. Emissions associated with fossil fuel-based hydrogen production must be permanently prevented from reaching the atmosphere and the natural gas supply chain must result in very low levels of methane emissions, or the electricity input to hydrogen produced from water must be from renewable or nuclear sources.

In 2017, Japan was the first country to publish a detailed hydrogen strategy and was followed shortly thereafter by Korea. Today, 17 governments have published low-carbon hydrogen strategies and more than 20 countries are developing them. These strategies generally include targets for hydrogen supply, although attention is increasingly being paid to the policies needed to stimulate low-carbon hydrogen demand.

To 2030 in the STEPS, there is limited demand for low-carbon hydrogen (although recent policy developments mean demand is higher than in previous *World Energy Outlooks)*. Around 0.2 EJ of low-carbon hydrogen is produced globally in 2030, equivalent to 0.05% of final energy consumption. The majority of low-carbon hydrogen in 2030 is produced via electrolysis to take advantage of renewable energy resources near demand centres in China, Europe, Japan and North America. Some cross-border trade also emerges, notably from Australia and the Middle East to demand centres in Asia.

In the APS, total low-carbon hydrogen production rises to around 2 EJ (16 Mt) in 2030. Just over 40% is used in transformation sectors, including to provide flexibility in the power sector (for both inter-seasonal and intra-day storage) and to produce hydrogen-based fuels. The rest is used in gaseous form to decarbonise end-uses. The implementation gap between the STEPS and APS is closed mainly through additional demand policies in Japan, Korea and the European Union. There is also a need to scale up production, which is done in part without the need for new transmission and distribution infrastructure by replacing the hydrogen used today in industry with low-carbon hydrogen and by blending small volumes of low-carbon hydrogen into natural gas grids. In 2030, more than 0.5 EJ low-carbon hydrogen is used in industry and 0.3 EJ is consumed in transport, predominantly for heavy trucks. Low-carbon hydrogen also emerges as an emissions reduction option for some buildings, mainly those in cold climates that are difficult to retrofit or connect to a district heating network, especially if they are close to a source of hydrogen supply. Supplying the low-carbon hydrogen to meet demand in the APS requires many more projects to develop electrolysers and to use CCUS with fossil fuels than are in the current pipeline (Box 5.2).

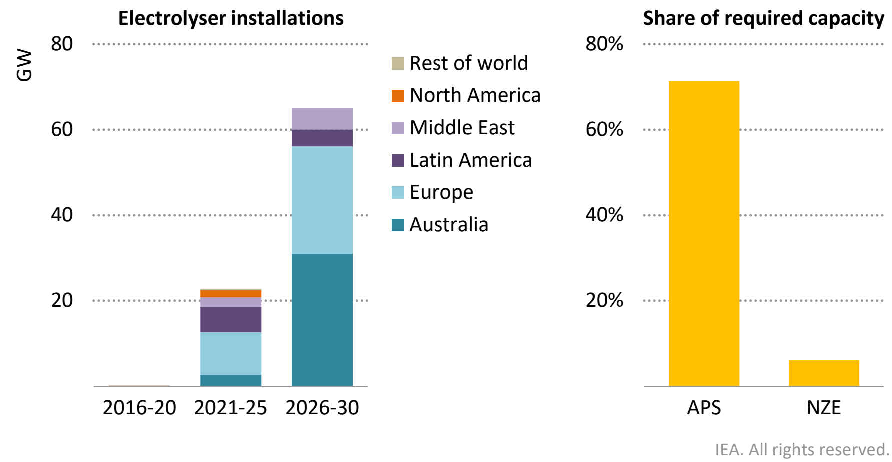
Box 5.2 ▻ Are hydrogen production plans falling short?

The recent upsurge of interest in low-carbon hydrogen production has led to a large pipeline of new production projects. If all planned and announced electrolyser projects were to be completed, we estimate that this would lead to around 90 gigawatts (GW) of capacity installed globally by 2030, producing 1 EJ low-carbon hydrogen (Figure 5.19). This would represent a large increase from the current production level, but this is less than three quarters of the level of low-carbon hydrogen production from electrolysers in 2030 in the APS and less than 10% of projected production in the NZE.

Plans for a number of new facilities producing hydrogen using natural gas with CCUS have also been announced. These include: projects connected to the Porthos CCUS project in the Netherlands, which has been granted government funding; projects in Canada and the Middle East that are targeting exports to Asia; and five industrial clusters in the

United Kingdom that have funding for hydrogen-related engineering studies. Despite these announcements, currently planned projects for low-carbon hydrogen production from fossil fuels also fall far short of deployment levels in the APS and the NZE.

Figure 5.19 ▷ Planned and announced electrolyser installations to 2030 and their proportion of required additions, 2021-2030



The project pipeline for new electrolyser capacity is expanding rapidly, but far more projects are required to keep pace with deployment rates in the APS and NZE

Source: IEA (2021c).

Integrating low-carbon hydrogen in the energy system will require concerted efforts by governments during the 2020s to create market certainty and close the cost gap with incumbent technologies, for example by establishing targets and long-term policy goals, supporting demand creation in industry and other sectors, mitigating investment risks, promoting research and development projects, and harmonising standards to remove barriers. Recent examples include a contracts-for-difference (CfD) system in the Netherlands that provides a guaranteed price for hydrogen production, a proposed auction mechanism in Germany and consultation on a support system based on the CfD model in the United Kingdom. Governments also need to ensure deployment of the new infrastructure required to support longer term increases in low-carbon hydrogen supply and demand, including hydrogen pipelines, port facilities and storage, as well as CO_2 storage.

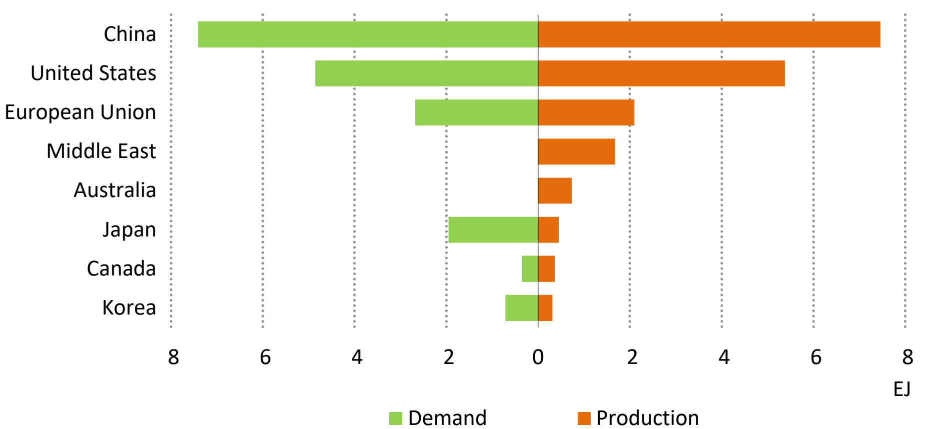
The overall increases in hydrogen demand to 2030 in the APS and NZE may be small compared with increases in electricity and many other clean energy technologies, but they depend on early action by governments and industry.

In the NZE, total low-carbon hydrogen production rises to 17 EJ in 2030. Around one-third is used in the power sector, 25% in industry, and just over 15% is converted into hydrogen-based fuels and the remainder is used in buildings and transport. This uptake of low-carbon hydrogen requires a large increase in the installation of hydrogen end-use equipment and leads to there being more than 15 million hydrogen fuel cell vehicles on the road in 2030, many of which are heavy trucks. Around half of low-carbon hydrogen production in 2030 is from electrolysis and half is from coal and natural gas with CCUS (although this ratio varies considerably between regions).

After 2030, in the STEPS, low-carbon hydrogen production continues to expand and demand in 2050 is equivalent to around 15% of today's total hydrogen use in industrial feedstocks and oil refining. Around 80% of the low-carbon hydrogen produced in 2050 uses electrolysis, reflecting the significant policy support for electrolytic hydrogen in various regions.

In the APS, total low-carbon hydrogen production increases to 20 EJ in 2050 and it plays a key role in displacing oil in transport and coal and natural gas in power generation and industry. Japan, Korea and some countries in Europe develop domestic hydrogen production but rely on imports to meet some of their demand. Many of the largest exporters do not have net zero pledges and there is a need for importing countries to engage with trading partners to encourage and guarantee investments in supply and ensure that hydrogen imports are low-carbon (Figure 5.20) (see Chapter 6).

Figure 5.20 ▷ Low-carbon hydrogen demand and production in selected regions in the Announced Pledges Scenario, 2050



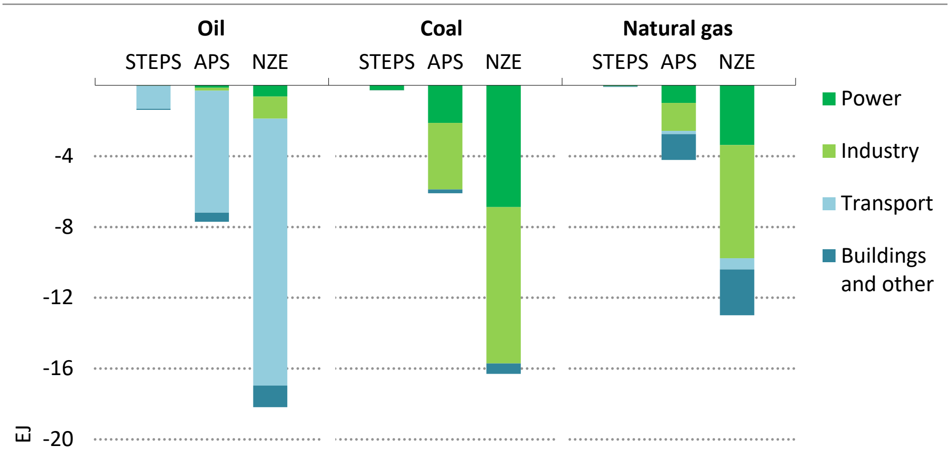
Many countries can satisfy a large share of their hydrogen demand with domestic production, yet multiple hydrogen trade routes emerge

Note: Includes low-carbon hydrogen consumed at the point of end-use as gaseous hydrogen and in hydrogen-based fuels.

In the NZE, total low-carbon hydrogen production increases to 60 EJ in 2050, around one-quarter of which is converted into hydrogen-based fuels. Most of the increase in gaseous hydrogen use after 2030 is in transport, which accounts for one-quarter of total hydrogen use in 2050 (Figure 5.21). Two-thirds of total low-carbon hydrogen produced in 2050 comes from electrolysis and the remainder from natural gas with CCUS. The electricity required for low-carbon hydrogen production in 2050 is more than current electricity demand in China and the United States combined, and the natural gas required accounts for 25% of natural gas supply. The NZE is the only scenario to see any notable rise in synthetic methane, which is produced from low-carbon hydrogen and CO_2 captured from bioenergy or the air. Synthetic methane supply in 2050 in the NZE is 4 EJ, equivalent to 3% of natural gas supply in 2020, and it is used to reduce emissions from applications where it is not cost effective to shift to the use of biomethane, hydrogen or electricity by 2050.

5

Figure 5.21 ▷ Fuel substitution of oil, coal and natural gas by low-carbon gaseous hydrogen and synthetic methane, 2050



Direct use of hydrogen displaces oil in trucks, as well as coal and gas in power and industry

Biogas

Every part of the world has significant scope to produce biogases – biogas and biomethane – but these have not enjoyed as much recent policy support as hydrogen.[8] Biogas can provide access to clean cooking, but the relatively high upfront cost of biodigesters and the challenges of continuous maintenance of dispersed and small-scale units has slowed its deployment. Biomethane faces challenges of costs and availability and a number of non-economic barriers need to be overcome, including sourcing adequate volumes of feedstocks of consistent quality. Nonetheless, the global potential is significant.

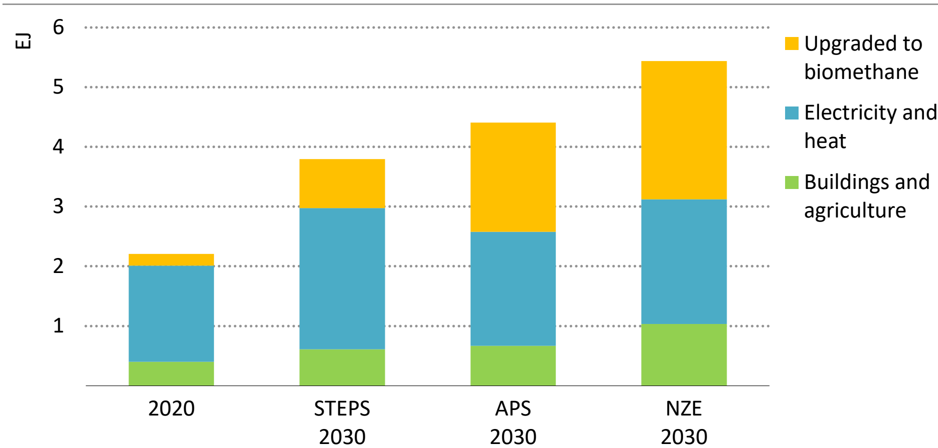
[8] Biogases includes both biogas and biomethane. Biogas is a mixture of methane, CO_2 and small quantities of other gases; biomethane is a near-pure source of methane.

Our bottom-up assessment of sustainable feedstocks indicates that around 25 EJ of biomethane could be developed globally and a further 7 EJ of biomethane could be produced from biomass gasification. With today's high prices for natural gas, around quarter of the global sustainable potential is cost competitive.

Around 70% of biogas developed today is used for power and heat, 20% is for cooking purposes and the other 10% is upgraded to biomethane. More than half of biogas production today takes place in Asia, which also has the largest growth potential given the availability of significant volumes of organic feedstocks such as crop residues and rising levels of municipal solid waste. Well managed biogas projects not only help to reduce emissions but also provide co-benefits such as rural development and local job creation.

Some potential biogas feedstocks would produce methane emissions if left untreated, so converting them to biogas can prevent such emissions.[9] If methane leaks occur during biogas production, however, they would add to overall GHG emissions and presently there is some uncertainty about the extent to which this happens (Bakkaloglu, et al., 2021; Scheutz and Fredenslund, 2019). Many factors affect leakage levels, including the type of facility, whether biogas production is a primary or secondary activity, and whether operators use open or closed storage tanks. The industry needs to anticipate – and should support – more robust methane measurement, reporting and verification, and should move swiftly to put in place plans to detect and repair potential leaks.

Figure 5.22 ▷ Biogas production by use and scenario in 2020 and 2030



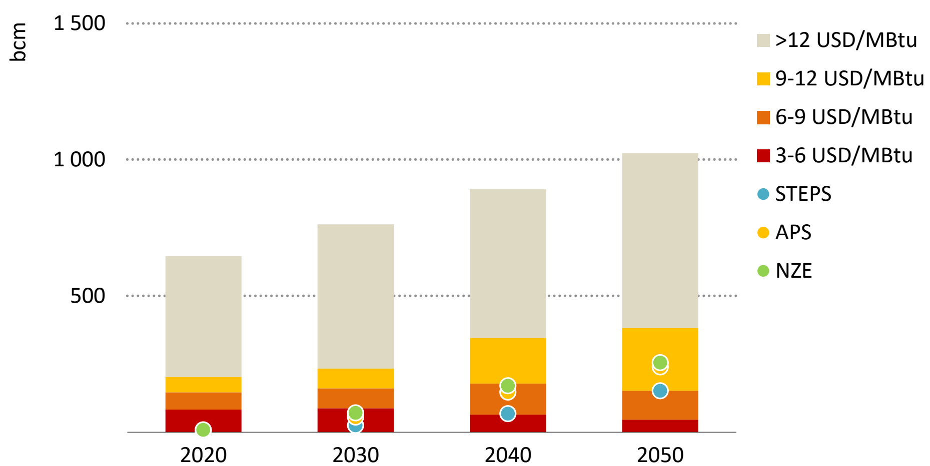
Biogas production sees strong growth, yet accounts for a small share of gas demand in 2030. In the NZE, biomethane meets 2% of gas demand in 2030

[9] Feedstocks such as animal manure and the organic fraction of municipal solid waste can produce methane emissions. Crop residues which decompose in the presence of oxygen generally do not produce methane emissions.

To 2030, policy support for biogas development in the STEPS, especially in China, Europe, India and United States, sees production nearly double by 2030 (Figure 5.22). Around 20% of biogas production in 2030 is upgraded to biomethane, which is mostly used in industry and transport. In the APS, the consumption of biogas rises to 4 EJ in 2030 as countries with net zero targets expand subsidies and implement more robust blending mandates. Closing the implementation gap between the STEPS and the APS depends on improving the cost competitiveness of biomethane, developing low-carbon gas certification schemes and blending mandates, and ensuring preferential access to gas infrastructure. For biogas, a more concerted push to overcome financing barriers, through low cost loans or grant funding, could help to scale up adoption by low income households (IEA, 2020b). In the NZE, the need to ensure universal access to clean cooking by 2030 gives a boost to biogas in emerging market and developing economies.

After 2030, in the STEPS, biomethane consumption continues to grow (reaching 5 EJ in 2050) and volumes blended into gas grids account for 3% of global gas demand by 2050. In the APS, around 8 EJ of biomethane is consumed globally in 2050 and blending into gas grids accounts for more than 5% of global gas demand. In Europe, the use of biomethane expands to heavy industry where emissions reductions are likely to be particularly challenging. In the NZE, biomethane captures a bigger share of remaining gas demand, with a number of regions seeing blending rates of 20-40%. Yet, just one-quarter of the total sustainable potential is tapped; a significant portion remains too costly to develop, and biogas and biomethane have to compete for support with other forms of bioenergy (Figure 5.23).

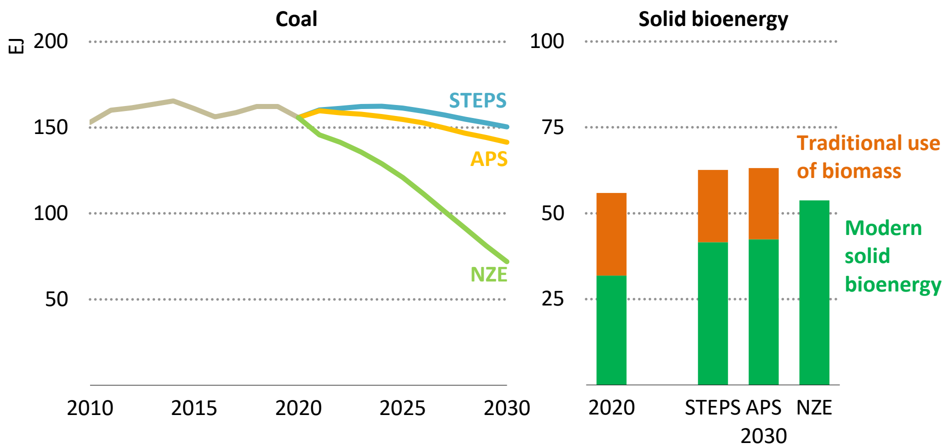
Figure 5.23 ▷ Cost ranges for global development potential and volumes of sustainable biomethane by scenario



Biomethane use grows strongly in each scenario, reaching 230 bcm by 2050 in the NZE. This is only 5% of global gas demand today and one-quarter of the total potential

5.4 Solid fuels

Figure 5.24 ▷ Coal and solid bioenergy demand by scenario



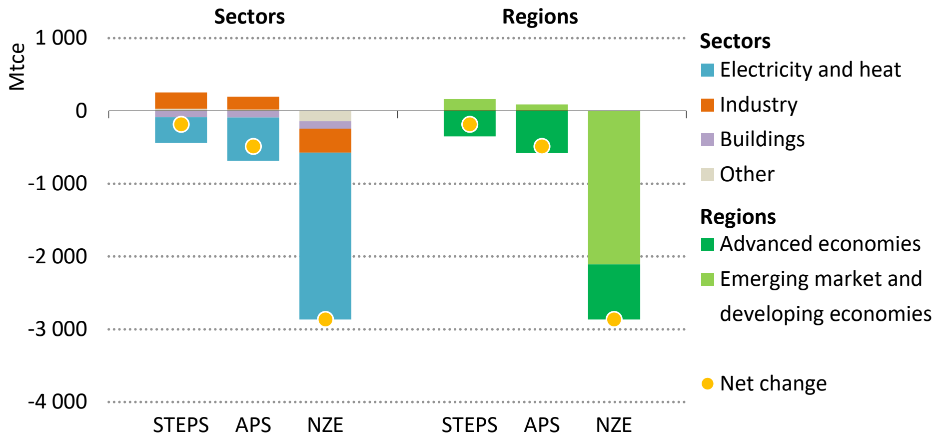
Coal demand declines by 55% to 2030 in the NZE, far below levels in the other scenarios. Modern bioenergy increases in each scenario; traditional uses are phased out in the NZE

Since the 1990s, around 60% of coal consumed has been used to generate electricity and most of the rest was coking coal used in steel production. Coal's role in the power sector is increasingly under pressure from climate policies and the rapid growth in renewables. The key question for the global coal outlook is whether increased demand from developing economies in Asia will offset the pace of decline in advanced economies. In the STEPS, global coal demand peaks in the mid-2020s and falls to 2020 levels in 2030 (Figure 5.24). In the APS, total demand falls by around 10% between 2020 and 2030 as coal is phased out of the power sector in countries with net zero pledges. In the NZE, coal use is hit hard in all markets and falls by 55% globally through to 2030.

Solid bioenergy is the largest single fuel type consumed today after fossil fuels. Around 40% is used in traditional methods for cooking. This use of solid bioenergy drops marginally in the STEPS and APS, and is entirely eliminated in the NZE through the push to achieve universal access to clean cooking by 2030. Modern forms of solid bioenergy increase in all scenarios: some of it is used for electricity generation, some as feedstock to produce liquid and gaseous biofuels, and some is consumed directly in end-use sectors. Growth is contingent on supportive policies as well as sufficient availability of biomass from sustainable sources; there is uncertainty on both accounts.

5.4.1 Coal trends to 2030

Figure 5.25 ⊳ Change in coal demand by scenario between 2020 and 2030



The 55% drop in coal demand in the NZE stems mainly from large reductions in coal use in power generation around the world; coal use in industry varies across the scenarios

Note: Mtce = million tonnes of coal equivalent.

In the STEPS, coal use rises slightly in the early-2020s, mainly as a result of increased demand in China's industry and power sectors (Figure 5.25). Between 2025 and 2030, total coal demand in China falls and there are large reductions in coal use in North America (a 45% reduction between 2020 and 2030), Europe (40%) and Japan (25%), mainly as a result of lower demand in the power sector. Coal use in industry also falls in these regions, but at a much slower rate. However, coal use expands in many emerging market and developing economies, mainly in Asia, and this offsets some of the reductions.

In the APS, advanced economies see a more rapid phasing out of coal across the power and industry sectors than in the STEPS, with demand declining by around 40% in aggregate to 2030. However, more than 80% of coal demand today comes from countries that do not have net zero pledges or aim only to reduce emissions after 2030, and their demand increases through to 2030. As a result, global coal demand in 2030 is only 6% lower than in the STEPS. Closing the implementation gap between the STEPS and the APS requires stronger policies to promote the deployment of renewables as well as more stringent efficiency and emissions standards to reduce the use of inefficient power plants.

In the NZE, global coal demand falls by around 55% to 2030, with a 65% reduction in the power sector and a 20% decline in industry. Just under 10% of coal use in the power sector is equipped with CCUS in 2030, as is 3% of coal use in industry. Retrofitting coal-fired power plants with CCUS or co-firing low emissions fuels such as bioenergy or ammonia allows emissions to come down without widespread retirement of existing plants.

China is both the consumer and producer of more than half of the world's coal today; it holds the key to future global coal trends. More than 90% of coal demand in China is supplied with domestic production, but imports play an important role in setting prices through arbitrage, especially in coastal regions, and in filling some gaps. There have been major efforts to restructure the coal supply industry in China in recent years (Box 5.3). In the STEPS, domestic coal production moves broadly in line with changes in demand; imports fall slightly to 180 million tonnes of coal equivalent (Mtce) in 2030.

Oil and natural gas imports are set to grow rapidly in China. Plans are underway to convert coal to gas and oil products to reduce import dependence. Coal can be converted to chemicals, natural gas and oil products, but such facilities are capital intensive, require large quantities of water and lead to high levels of CO_2 emissions. These technologies have gained some attention in coal-rich countries outside of China, notably in India, but planned production levels elsewhere are dwarfed by those in China. In the STEPS, around 3.5 EJ (120 Mtce) of coal worldwide is converted to chemicals, liquids and gases in 2030, of which China accounts for 70%. In the APS, the need to reduce emissions sharply in China after 2030 means that any investments in coal conversion plants prior to 2030 are at risk of becoming stranded assets. Equipping facilities with CCUS could limit this risk. Coal conversion plants produce a concentrated stream of CO_2, which would reduce the overall costs of CO_2 capture. But this would still require an additional level of capital expenditure, and facilities may not be suitable for retrofitting with CCUS unless specifically designed with it in mind.

India has seen increasing thermal coal imports in recent years. This reflects domestic production and quality constraints, and significant distances between its coal deposits and demand centres. Imports currently account for around 30% of total coal demand, though there is a strong policy push to reduce imports as much as possible. The coal industry, led by state-owned Coal India Limited, is charged with raising output. But ambitious volumetric targets have run up against major uncertainties about the demand trajectory as well as challenges associated with the low quality of large portions of domestic coal production. In the STEPS, coal demand in India grows by around 30% to 2030, mainly as a result of a 70% increase in demand in industry. Coal use in the power sector increases by around 20% to the mid-2020s but starts to decline slowly as wind and solar photovoltaics (PV) meet the vast majority of electricity demand growth. Domestic coal production expands broadly in line with the increase in demand to 2030 and so it continues to import around 200 Mtce of coal in 2030 (similar to current levels), mainly in the form of coking coal for use in blast furnaces and high quality thermal coal for use in some coastal power plants.

Coal exporters have to contend with a variety of different possible futures. Producers from Colombia and the United States face strong competition from Russian producers in the Atlantic market, while Australian exports often compete with Indonesian exports in the Pacific market. In the STEPS, Australia remains the world's largest exporter of coal but exports fall by 5% to 340 Mtce in 2030 as demand falls in Japan and Korea, which have historically been important markets for Australian coal. Coking coal exports increase slightly and Australia displaces some Indonesian exports of steam coal, which fall by more than 10%

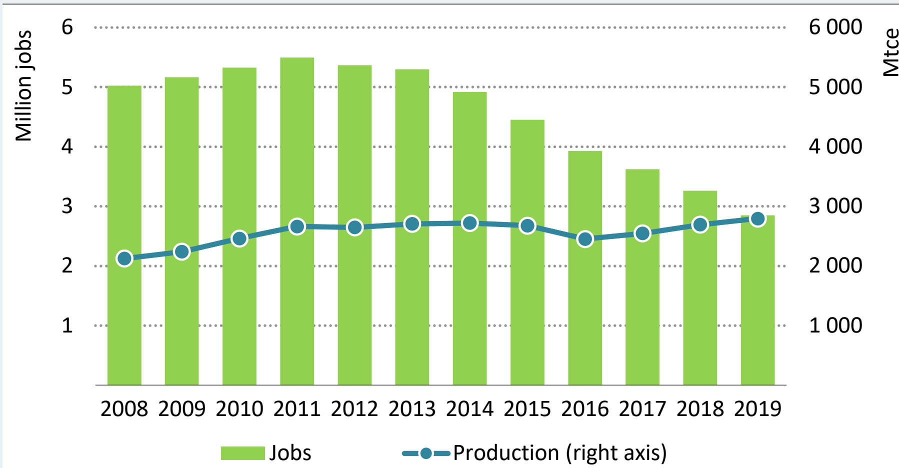
to 2030. Russian exports remain flat through to 2030. In the APS, exports from Russia fall by around 15% to 2030 while Australian exports fall by 25%. In the NZE, global coal trade drops by more than 50% to 2030 and production in all exporting countries falls sharply.

Box 5.3 ▹ Impacts of coal reforms on production and workers in China

One of the priorities of China's 13th Five-year Plan was to eliminate excess coal production capacity to achieve a better match between demand and supply. As part of this process, more than half of Chinese coal mines – the least productive and unsafe ones – have been closed, which has led to an 80% decline in coal mining deaths and a 10% reduction in average mining costs.

The reforms eliminated 2.5 million coal mining jobs (a near 50% reduction) between 2013 and 2019 without significantly affecting production (Figure 5.26). Production is now more geographically concentrated with 70% of output in 2019 from just three regions (Inner Mongolia, Shanxi and Shaanxi). A number of measures were introduced to support redundant workers in the hardest hit areas, including resettlement, early retirement and the creation of alternative jobs, still, job losses have had a profound impact on local communities. The financial system was also affected by the coal supply reforms as public authorities had to assume the debts and environmental liabilities of closed mines and failed companies.

Figure 5.26 ▹ Coal mining jobs and production in China, 2008-2019



Coal production in China was relatively stable over the decade though with a large decrease in coal jobs reflecting closure of less productive mines

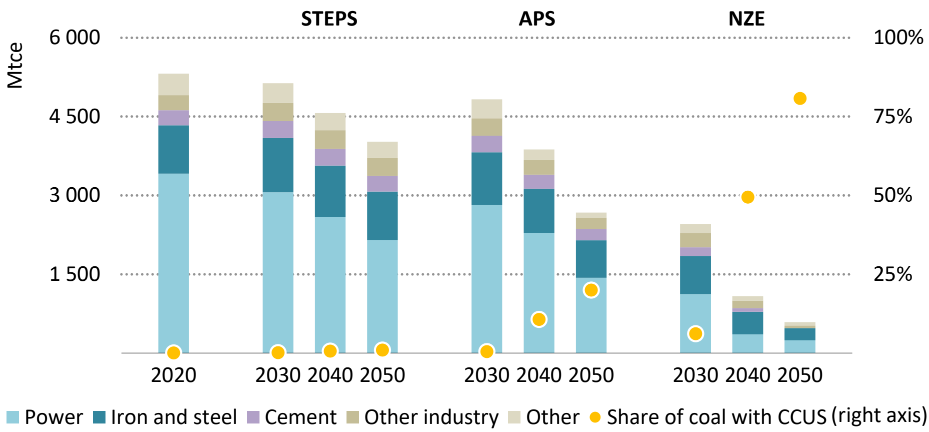
Note: IEA analysis based on NBS (2018).

5

Coal reforms are not yet complete. Efforts continue to focus coal production in the most productive areas, integrate advanced mining technologies to boost productivity and safety, and foster merger and acquisitions to create companies with more capacity to invest and improve technology. There is also a continuing focus on reducing the environmental impacts of mining, including through reclamation of old mines, improved processing of mine water, and reducing coal waste and methane emissions from operations.

5.4.2 Coal trends after 2030

Figure 5.27 ▻ Global coal demand by sector to 2050



Coal use in the power sector falls to the largest extent in the STEPS and APS. Coal use is much lower in the NZE across all sectors and 80% of coal use in 2050 is paired with CCUS

In the STEPS, there is a steady reduction in coal demand between 2030 and 2050 to around 4 000 Mtce in 2050 (25% less than in 2020) (Figure 5.27). This stems mostly from a 30% decline in the power sector over this period as wind and solar provide an increasing share of electricity generation, while coal use in industry falls by around 10% between 2030 and 2050. In China, there is a 30-35% reduction in coal use in both its electricity and industry sectors between 2030 and 2050. In India, coal demand peaks in the mid-2030s, though still above 2020 levels in 2050. Coal use in India for electricity generation declines by around 35% between 2030 and 2050, but most of the reduction is offset by increases in the industry sector. China continues to focus on domestic supply and it imports around 100 Mtce in 2050. The import dependency of India increases and imports rise to 240 Mtce in 2050. Russia and Australia both see a small increase in coal exports after 2030, most of which is coking coal.

In the APS, coal demand declines much faster to 2 650 Mtce in 2050 (half of 2020 levels). To achieve net zero pledges, countries in Europe and North America rapidly phase out coal use in industry and electricity and by 2040 almost all coal power plants still in use have been retrofitted. Coal use in China falls by close to 70% between 2030 and 2050 and its share of global coal demand drops to 30% in 2050 (from 55% in 2020). This decline comes about because China electrifies many industrial processes (e.g. by switching iron and steel production to electric arc furnaces) and significantly reduces coal use in the power sector. China has 800 GW of coal-fired power plants remaining in 2050 (down from more than 1 000 GW today), 20% of which are equipped with CCUS. The annual average utilisation of unabated coal-fired power plant capacity in China drops to less than 10% in 2050, down from more than 50% today.

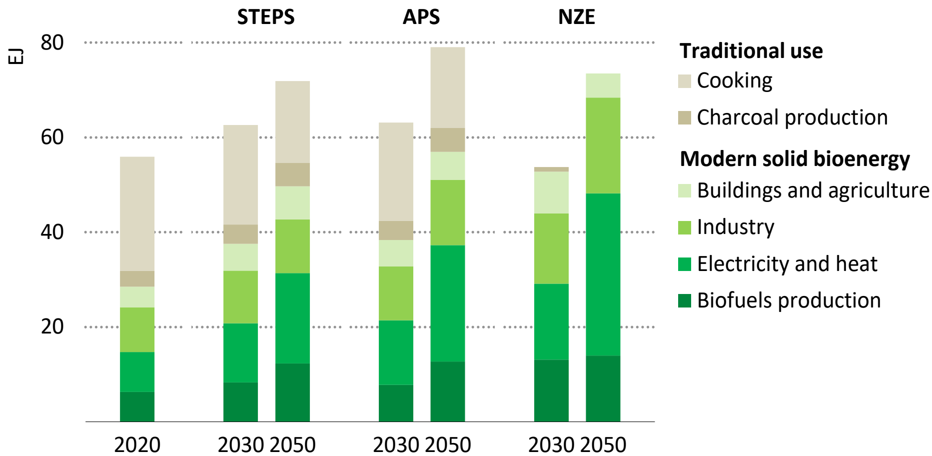
In NZE, global coal use drops by 90% from 2020 to 2050, and around 80% of remaining coal use is in facilities equipped with CCUS by 2050. All new coal industrial facilities built after 2030 are near zero emissions and most facilities built before then are retrofitted to use CCUS or to enable co-firing with bioenergy or hydrogen-based fuels. The majority of remaining coal use in 2050 is in the chemical, iron and steel industries.

5.4.3 Solid bioenergy

Around 55 EJ of solid bioenergy is consumed worldwide today. Almost half is in the form of solid biomass used in traditional methods for cooking and charcoal production, which is a major cause of household air pollution and premature deaths. Modern solid bioenergy, which accounts for the remainder, is used to produce liquid and gaseous biofuels or electricity and heat or is consumed directly in end-use sectors. There is a high degree of uncertainty over the precise levels of the world's sustainable bioenergy supply potential; it has been assessed as being at least 100 EJ (Creutzig et al., 2015) and could be as much as 150-170 EJ (Frank, 2021; Wu, 2019). Sustainable bioenergy could come from energy crops, organic by-products and residues from agriculture, forestry, municipal solid waste and wastewater.

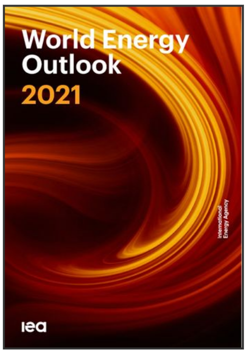
To 2030, the largest difference between the STEPS and APS on the one hand and the NZE on the other is related to the phase-out of the traditional use of solid biomass. In the STEPS and APS, 1.9 billion people still rely on traditional use of biomass for cooking in 2030 and its use declines by only 15% to 2030. In the NZE, universal access to clean cooking is achieved by 2030 and traditional use of biomass is fully phased out (Figure 5.28). There are smaller differences in the rate of increase in modern solid bioenergy over the period to 2030. In the STEPS and the APS, the supply of modern solid bioenergy increases by 10 EJ to 2030. Power is the fastest growing sector in these scenarios, accounting for half of the increase in demand to 2030. In the NZE, modern solid bioenergy is around 12 EJ higher than in the STEPS and APS in 2030, with higher demand as a feedstock for biofuels production, in industry and buildings, and for electricity and heat.

Figure 5.28 ▷ Solid bioenergy supply by scenario



Modern bioenergy plays a key role in meeting net zero pledges. Traditional uses of biomass continue in the STEPS and APS, but not in the NZE

After 2030, the use of modern solid bioenergy continues to rise steadily in the STEPS while the traditional use of solid biomass falls slightly. In the APS, traditional use of biomass continues at much the same level as in the STEPS, but countries with net zero pledges make greater use of modern solid bioenergy, especially for electricity and heat and in industry. As a result, solid bioenergy demand reaches 80 EJ in 2050, the highest level in any scenario. In the NZE, the supply of modern solid bioenergy expands to 75 EJ in 2050, of which around 45% comes from forestry by-products and residues, 25% from energy crops, and the remainder from agricultural residues and municipal solid waste.



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